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SIGNATURE AND APPROVALS ON ORIGINAL

PREPARED: E. TACCHINO / M. FONTANA

CHECKED : M. MONTABONE / S. OTTAVIANO

APPROVED: A. SFERLAZZO

AUTHORIZED: P. MARCHESE

APPROVALS:

PRODUCT ASSURANCE N. D'AMICO

CONFIGURATION CONTROL M. MARCHI

SUBSYSTEM ENGINEER F. BANDINI

PROGRAM MANAGER S. BRONDOLO

DATA MANAGEMENT: 13/5/96

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TABLE OF CONTENTS

1 INTRODUCTION 6

2 DOCUMENTS 7

2.1 APPLICABLE DOCUMENTS 7

2.2 REFERENCE DOCUMENTS 9

3 WELDING PROCESS SUMMARY 10

3.1 GENERAL DESCRIPTION 10

3.2 PLASMA WELDING DEVELOPMENT PLAN 10

3.2.1 V.P.P.A Pilot Plant 11

3.2.2 Production Plant 13

3.3 EXPERIMENTAL ACTIVITY 15

3.3.1 Welding Samples 15

3.3.2 Automatic Repair Welding Procedure 16

3.3.3 Manual Repair Welding 16

3.4 TEST RESULTS EVALUATION 17

3.4.1 Tensile Results 17

3.4.1.1
Automatic Welding 17

3.4.1.2
Repair Welding 29

3.4.1.3
Tensile Test Comparison between Longitudinal and Circumferential Configuration 42

3.4.2
Microhardness Results 46

3.4.3
Bead Geometry 55

3.4.4
Micro/Macro Examination 79

3.4.5
Susceptibility to Stress Corrosion Cracking 81

3.4.5.1
Test Results 81

3.4.5.1.1
Tensile Tests 81

3.4.5.1.2
Macroscopic Examination 84

3.4.5.1.3
Microscopic Examination 89

3.4.6
Fracture Toughness Results 98

3.4.7
Residual Strength Evaluation for Through Crack Defects 107

3.4.8
Residual Strength Evaluation for Surface Crack Defects 110

3.4.9
Fatigue Crack Growth and Threshold Results 113

3.4.10
Leak before Burst Test 121

3.4.11
Stress Corrosion Cracking Tests 123

4
CONCLUSIONS 128

1 INTRODUCTION

This document is the final issue of the welding qualification tests report that includes all the results obtained according to the Qualification Test Plan, Ref. A.D.[1]. This report also includes the test results reported in the previous issue of this document, R.D.[1].
Welding qualification activity has been performed utilizing samples welded in longitudinal configuration after the verification that the same qualified welding parameters could be applied to the circumferential configuration.
Additional tests have been performed on welds between one forged ring and one plate in order to simulate the welding between the ring and the panel in the primary structure of the module.
Qualification testing has included the following characterization :

- Mechanical tests (tensile)
- Fracture mechanics tests (Kc, threshold, crack propagation, leak before burst, susceptibility to stress corrosion cracking)
- Metallurgical examination and hardness tests

This qualification program has been applied for the following welds :

- Automatic welding
- Automatic welding at minimum energy
- Automatic welding at maximum energy
- Automatic welding + automatic repair welding (single)
- Automatic welding + manual repair welding (single)
- Automatic welding + manual repair welding (double)
- Automatic welding with mismatch
- Automatic welding with peaking

2 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

[1] MLM-PL-AI-0012
"Test Plan for the Characterization of the MPLM Primary Structure VPPA Welding"

[2] MLM-PL-AI-0052
"Plasma Welding Development Plan"

[3] QQ-A-250/30
"Aluminum Alloy 2219, Plate and Sheet"

[4] SG-SP-AI-0096
"Procurement Requirement for 2219-T851/2 Aluminum Alloy Hand Forging and Rolled Rings"

[5] ANSI/AWS A 5.10
"Specification for Aluminum and Aluminum Bare Welding Rods and Electrodes"

[6] RDF-IF-006-93 Manufacturing Procedure
"Saldatura V.P.P.A. Provette Al Aly 2219-T851 su Impianto di Produzione"

[7] RDF-IF-012-94 Manufacturing Procedure
"Saldatura Provette per Qualifica Processo di Riparazione Automatica in V.P.P.A."

[8] RDF-IF-007-94
"Saldatura Provette per Qualifica Processo di Riparazione Manuale Singola e Doppia mediante T.I.G.-DCEN"

[9] MLM-SP-AI-0012 Alenia Spazio Specification
"Welding of 2219 Aluminum Alloy for MPLM"

[10] RPS Nr. 256
"Test Report for Qualification of VPPA Automatic Welding Process : Tensile Tests, Metallographic Examination and Microhardness Tests" - ALENIA SPAZIO LABORATORIO

[11] RPS Nr. 472
"Test Report for Qualification of VPPA Welding Process followed by Automatic Repair and Manual Repai : Tensile Tests, Metallographic Examination and Microhardness Measurements"

[12] 61/RP/T851B/930136
"Verifica del Trasferimento dei Parametri Longitudinali alla Configurazione Circonferenziale su Impianto Pilota"

[13] ESA PSS-01-737 Sept. 1981
"Determination of the Susceptibility of Metals to Stress Corrosion Cracking"

[14] DDIA 96-1
"Prove di Susceptibility to Stress Corrosion su Provette di Alluminio 2219-T8 Saldate al Plasma" - DIPARTIMENTO DI INGEGNERIA AEROSPAZIALE UNIVERSITA' DEGLI STUDI DI PISA

[15] ASTM-E-561
"Standard Practice for R-Curve Determination"

[16] ASTM-E-740
"Standard Practice for Fracture Testing with Surface-Crack Tension Specimens"

[17] RPS Nr. 247
"Test Report for Characterization of V.P.P.A. Automatic Welding : Crack Growth Rate Test and R-Curve Determination" - ALENIA SPAZIO LABORATORIO

[18] RPS Nr. 471
"Test Report for Characterization of V.P.P.A. Welding and Repair : R-Curve Determination and Crack Growth Rate" - ALENIA SPAZIO LABORATORIO

[19] ASTM-E-647
"Standard Test Method for Measurement of Fatigue Crack Growth Rates"

2.2 REFERENCE DOCUMENTS

[1] MLM-RP-AI-0126
"Welding Qualification Tests Report" - Issue 1 - Nov. 94

[2] ANSI/AWS B 4.0
"Standard Method for Mechanical Testing of Welding"

[3] NASA TM-86482
"The Variable Polarity Plasma Arc Welding Process " Its Application to the Space Shuttle External Tank-First Interim Report"

[4] NASA TM-86482
"The Variable Polarity Plasma Arc Welding Process : Its Application to the Space Shuttle External Tank-Second Interim Report"

3 WELDING PROCESS SUMMARY

3.1 GENERAL DESCRIPTION

A plasma welding development plan, A.D.[2], has been defined in order to optimize and qualify the welding parameters.
This plan included several technological phases oriented to develop a reliable welding process in terms of mechanical-metallurgical properties and quality of welded joints.
Main characteristics of this process may be so listed :

- Base material	2219-T851 Aluminum Alloy (Procurement Specification : A.D.[3], A.D.[4])
- Filler metal	2319 Aluminum Alloy (Procurement Specification : A.D.[5])
- Welding thickness	7 mm
- Automatic welding process	V.P.P.A. (Variable Polarity Plasma Arc) KEY-HOLE (Manufacturing Procedure : A.D.[6])
- Plasma gas	Argon
- Shielding gas	Helium
- Automatic repair welding	V.P.P.A MELT IN (Manufacturing Procedure : A.D.[7])
- Manual repair welding (single and double)	T.I.G. (Tungsten Inert Gas) D.C.E.N. (Direct Current Electrode Negative) (Manufacturing Procedure : A.D. [8])

3.2 PLASMA WELDING DEVELOPMENT PLAN

The plasma welding development plan has been defined following this philosophy :

- Development of the automatic process on pilot plant in longitudinal configuration (vertical-up)

- Verification that the longitudinal welding parametrs are applicable to the circumferential welding (confirmed by mechanical and metallurgical characterization of welded joints).
  The application of the same welding parameters is justified because tooling and fixture are the same for both configurations (heat dissipation, clamping device, joint preparation etc)

- Qualification of the welding process in longitudinal configuration (vertical-up), in order to have flat samples with significant weld length (250 mm) for mechanic and fracture mechanics tests.

- Transfer of the qualified process on production plant verifying mechanical properties (tensile tests), metallurgical characteristics (micro/macro examination) and bead geometry of the welded joints.

3.2.1 V.P.P.A Pilot Plant

A schematic view of the pilot plant is shown in Fig. 3.2.1-1.
Main characteristics of this plant are listed below :

- welding source model HOBART VP 300S

- torch type HOBART Mod. MPW-400C

- computerized system for continuous welding parameters control and monitoring

1) Tilting table dia. 1500 mm for radial and circumferential weldings

2) Manipulator with rotating arm holder welding head from 0 deg. to 90 deg.
Arm vertical translation 1500 mm
Head horizontal translation 1500 mm

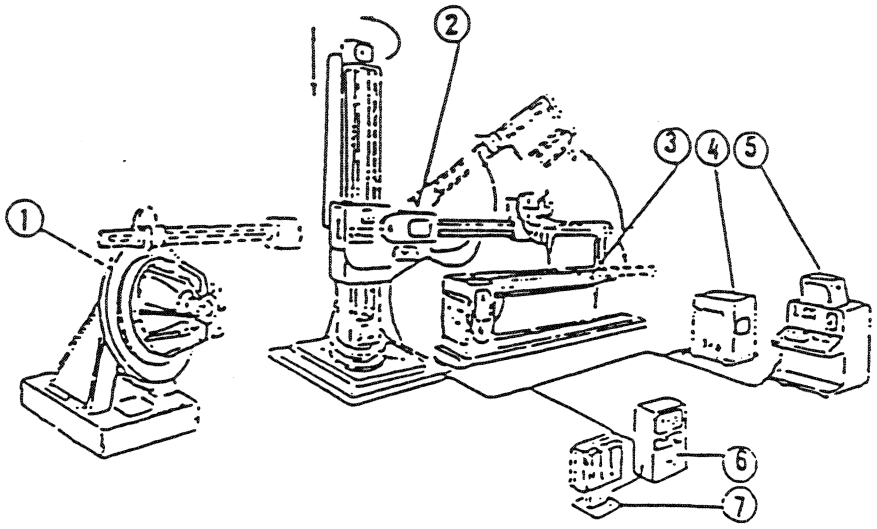
3) Longitudinal positioner SIAD IBL-1100 P working length 1100 mm

4) Welding source

5) Electronics rack for servomechanism control

6) Computerized control unit

7) Data recorder I, V, torch speed, etc



1) Tilting table dia. 1500 mm for radial and circumferential weldings

2) Manipulator with rotating arm holder welding head from 0 deg. to 90 deg.
Arm vertical translation 1500 mm
Head horizontal translation 1500 mm

3) Longitudinal positioner SIAD IBL-1100 P working length 1100 mm

4) Welding source

5) Electronics rack for servomechanism control

6) Computerized control unit

7) Data recorder I, V, torch speed, etc

Fig. 3.2.1-1 - Welding Pilot Plant Scheme

Experimental activity performed on this equipment included :

- Material, tooling and welding machine inspection
- Development and optimization of the continuous (seal pass) tack welding process by V.P.P.A. melt-in technique
- Development of the welding process in longitudinal configuration (vertical-up) optimizing the main welding parameters (Voltage, Current, Travel Torch, Filler Wire Speed)
- Development and optimization of the key-hole closure process in longitudinal configuration, including welding start
- Definition of the welding parameters tolerances for the main parameters
- Development and optimization of manual and automatic repair welding in longitudinal configuration
- Transfer of the longitudinal welding parameters (optimized in the above phases) on the cylinder and cone circumferential configuration

For each step of this activity a mechanical and metallurgical characterization of the welded joints was performed in terms of :

- Dimensional measurements
- X-ray control
- Dye penetrant inspection
- Tensile tests
- Microhardness
- Micro/macro examination

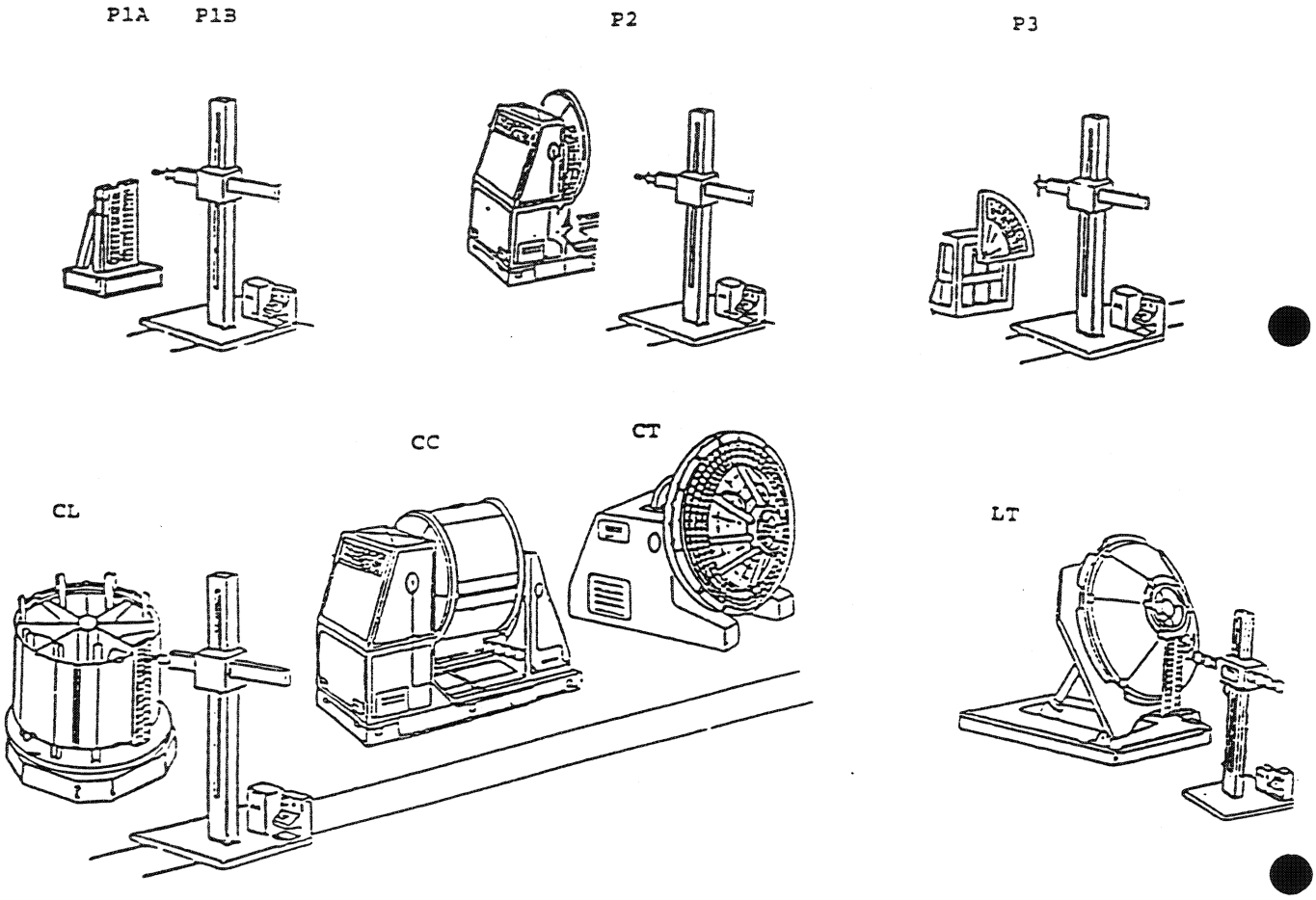
3.2.2 Production Plant

Preproduction and production welding tools are shown in Fig. 3.2.2-1 and are equipped with two welding stations composed by :

- Arc welding generator : HOBART VP 300S
- Welding torch : HOBART 400 WP
- Manipulator : SIAD
- Positioner : SIAD
- Computer : HOBART HAWCS equipped with a printer type OKIDATA MICROLINE 321
- Numeric control equipment : TPA IC 286

As previously mentioned, production plant is pratically identical to the pilot plant, only difference is the radius of the circumferential configuration.

PREPRODUCTION WELDING TOOLS **PRODUCTION WELDING TOOLS**



P1A, P1B = Longitudinal
P2 = Circumferential Cylinder
P3 = Circumferential Cone

LT = Longitudinal Cone
CL = Longitudinal Cylinder
CC = Circumferential Cylinder
CT = Circumferential Cone

Fig. 3.2.2-1 - Production Welding Plant

The activity performed on this plant included :

- Transfer of optimized welding parameters on production plant in all the configurations (cone longitudinal and circumferential, cylinder longitudinal and circumferential)

- Verification by geometrical measurements and X-ray control, mechanical and metallurgical characterization of welded joints that the transfer was completed with successful results.

- Production of welded qualification samples to be submitted to the qualification tests according to A.D.[1], whose results are partially reported in this document

3.3 EXPERIMENTAL ACTIVITY

3.3.1 Welding Samples

Welded samples have been manufactured joining together pairs of sheets having the following dimensions:

- 790 x 150 mm

- 890 x 275 mm (to be utilized for fracture mechanics characterization)

Welding configuration was longitudinal in vertical-up position.
Additional weldings have been performed between plates and forged parts in circumferential configuration to simulate the welding between panels and ring.
All the welds have been performed according to Alenia Manufacturing Procedure A.D.[6] monitoring and recording the welding parameters.
Every qualification welded samples has been submitted to :

a) Geometrical measurements

b) Bead shaving

c) X-ray inspection

d) Dye penetrant inspection

After these controls and activities, samples have been machined to obtain specimens for the material characterization according to A.D.[1].

3.3.2 Automatic Repair Welding Procedure

The automatic repair welding procedure is described in the Doc. in Ref., A.D.[7], in detail.
This type of repair welding is applicable when defects like undercut and lack of fill are detected for a significant length.
The procedure foresees the following steps :

- Automatic welding of test sample
- Visual and geometrical examination
- Shaving of bead at torch and root side by a dedicated tool until to obtain a crown reinforcement of +0.2/-0 mm
- X-ray control
- Dye penetrant inspection
- Automatic welding by V.P.P.A. MELT IN process in one pass applying the welding parameters reported in the Repair Welding Procedure, A.D.[7].

3.3.3 Manual Repair Welding

The manual repair welding procedure (single and double) is described in the A.D.[8] in detail.
This type of repair welding is applicable when welding defects like pores, inclusions etc are localized in small areas and in short length.
The procedure foresees the following steps :

Single Repair Welding

- Automatic welding of tests samples
- Visual and geometrical inspection
- Shaving of bead at torch and root side by a dedicated tool until to obtain a crown reinforcement of +0.2/-0 mm
- X-ray control
- Dye penetrant inspection
- Bead material removing by a circular mil (120 mm dia.) : 5.6 + 0.2 mm depth x 8 + 0.2 mm width with a through hole of 4 + 0.2 mm width
- Manual welding by T.I.G. process in 3 passes as a maximum applying the welding parameters reported in the Repair Welding Procedure, A.D.[8]

Double Repair Welding

- Same procedure as per Single Repair Welding at the first 7 steps
- Visual and geometrical inspection
- Shaving of bead at torch and root side by a dedicated tool until to obtain a crown reinforcement of +0.2/-0 mm
- X-ray control
- Bead material removing by a circular mill (120 mm dia.) : 4.2 + 0.2 mm depth x 8 + 0.2 mm width, on previously repaired areas (If samples are affected by deformation after the first repair welding, a straightening process is allowed applying a dedicated procedure followed by X-ray control).

3.4 TEST RESULTS EVALUATION

3.4.1 Tensile Results

Tensile tests have been performed on:

- Specimens welded with nominal parameters (abbr. : Nomin.)
- Specimens welded at the extreme tolerance welding parameters (abbr. : H.E. = High Energy; abbr. : L.E. = Low Energy)
- Specimens welded with peaking at the maximum value (5°) allowed by A.D.[9] (Abbr. : Peak.)
- Specimens welded with mismatch at the maximum value (0.7 mm equal to 10% of weld thickness) allowed by A.D.[9] (Abbr. : Mism.)
- Specimens welded and automatic repair welded (identification mark : "B")
- Specimens welded and manual single repair welded (identification mark : "C")
- Specimens welded and manual double repair welded (identification mark : "D")

3.4.1.1 Automatic Welding

Specimens derived from samples welded with mismatch and peaking have been tested applying two different gauge lengths : 10 mm and 50 mm.
Furthermore from samples welded with nominal parameters, tensile specimens have been obtained with the bead transversal to the axis of the specimen and other specimens (cylindrical) entirely taken inside the bead. This second typology has been chosen in order to evaluate the real mechanical strength of the bead without the influence of the H.A.Z. (Heat Affected Zone) and the parent material according to R.D.[2].
Tensile test results are listed in Tab. 3.4.1.1-1 and Tab. 3.4.1.1-2. Ultimate tensile strength values (average and minimum) are higher than tensile requirements (σultim. = 253 MPa average, σultim. = 249 MPa minimum) reported in A.D.[9] (para 3.1.3.1).

The average values are comparable with the results of the activity performed by NASA in the V.P.P.A. application to the Space Shuttle External Tank (R.D.[3] and R.D.[4]).
Specimens affected by peaking and mismatch do not show particular differences in the mechanical properties with respect to the welds wituout defects.
Graphic representations of the tensile results are shown from Fig. 3.4.1.1-1 to Fig. 3.4.1.1-5.
Synthesis of elongation values are summarized from Fig. 3.4.1.1-6 to Fig. 3.4.1.1-9.
More detailed technical description is reported in Annex 1 - Alenia Spazio Laboratorio Test Report, A.D.[10].

TENSILE PROPERTIES OF VIRGIN WELD WITHOUT DEFECTS					
ALL-WELD METAL SPECIMENS					
Nominal Parameters					
Sample Number	Specimen Number	Gauge Length (mm)	σu (MPa)	σ0.2 (MPa)	Elong. (%)
LAX002	A018	16	262.19	127.43	20.1
	A019	16	263.71	132.67	19.9
	A020	16	261.57	126.92	20.9
	A021	16	266.26	125.39	20.6
	A022	16	260.07	129.02	17.4
	A023	16	260.71	130.87	15.2
LAX006	A030	16	259.78	134.03	18.5
	A031	16	263.31	131.96	20.4
	A032	16	259.87	129.32	20.1
LAX008	A024	16	260.88	123.45	19.6
	A025	16	261.20	130.30	18.6
	A026	16	259.38	135.50	18.9
	A027	16	258.52	130.99	18.1
	A028	16	260.27	134.39	18.3
	A029	16	260.68	124.97	19.2
AVG			261.23	129.81	19.05
STD			1.97	3.64	1.47
MIN			258.52	123.45	15.20
MAX			266.26	135.50	20.90
Allowable			254.28	117.02	13.86

TENSILE PROPERTIES OF VIRGIN WELD WITHOUT DEFECTS			
SPECIMENS TRANSVERSE TO THE CENTERLINE OF WELD			
Nominal Parameters			
Sample Number	Specimen Number	Gauge Length (mm)	σu (MPa)
LAX001	A001	50	262.06
	A002	50	261.46
	A003	50	260.32
	A004	50	261.14
	A005	50	261.88
	A006	50	259.67
	A007	50	260.66
	A008	50	259.88
	A009	50	261.14
	A010	50	261.82
AVG			261.00
STD			0.84
MIN			259.67
MAX			262.06
Allowable			257.64
LAX001	A011	10	260.63
	A012	10	261.88
	A013	10	260.52
	A014	10	260.82
	A015	10	262.35
AVG			261.24
STD			0.82
MIN			260.52
MAX			262.35

Tab. 3.4.1.1-1 - Tensile Properties on Virgin Weld without Defects

TENSILE PROPERTIES OF VIRGIN WELD WITH MISMATCH			
SPECIMENS TRANSVERSE TO THE CENTERLINE OF WELD			
Nominal Parameters			
Sample Number	Specimen Number	Gauge Length (mm)	σu (MPa)
LEX001	A001	50	271.79
	A002	50	269.54
	A003	50	269.62
	A004	50	267.88
	A005	50	268.94
	A006	50	262.55
	A007	50	264.46
	A008	50	266.28
	A009	50	270.48
	A010	50	268.85
AVG			268.04
STD			2.83
MIN			262.55
MAX			271.79
Allowable			258.06
LEX001	A011	10	262.53
	A012	10	268.28
	A013	10	266.97
	A014	10	269.85
	A015	10	263.79
AVG			266.28
STD			3.06
MIN			262.53
MAX			269.85

TENSILE PROPERTIES OF VIRGIN WELD WITH PEAKING			
SPECIMENS TRANSVERSE TO THE CENTERLINE OF WELD			
Nominal Parameters			
Sample Number	Specimen Number	Gauge Length (mm)	σu (MPa)
LFX001	A001	50	277.94
	A002	50	271.06
	A003	50	281.12
	A004	50	27[illegible].01
	A005	50	278.33
	A006	50	272.08
	A007	50	281.58
	A008	50	280.08
	A009	50	276.19
	A010	50	278.24
AVG			277.36
STD			3.50
MIN			271.06
MAX			281.58
Allowable			265.03
LFX001	A011	10	279.63
	A012	10	279.13
	A013	10	278.64
	A014	10	279.40
	A015	10	281.42
AVG			279.64
STD			1.06
MIN			278.64
MAX			281.42

Tab. 3.4.1.1-2 - Tensile Properties on Virgin Weld with Defects

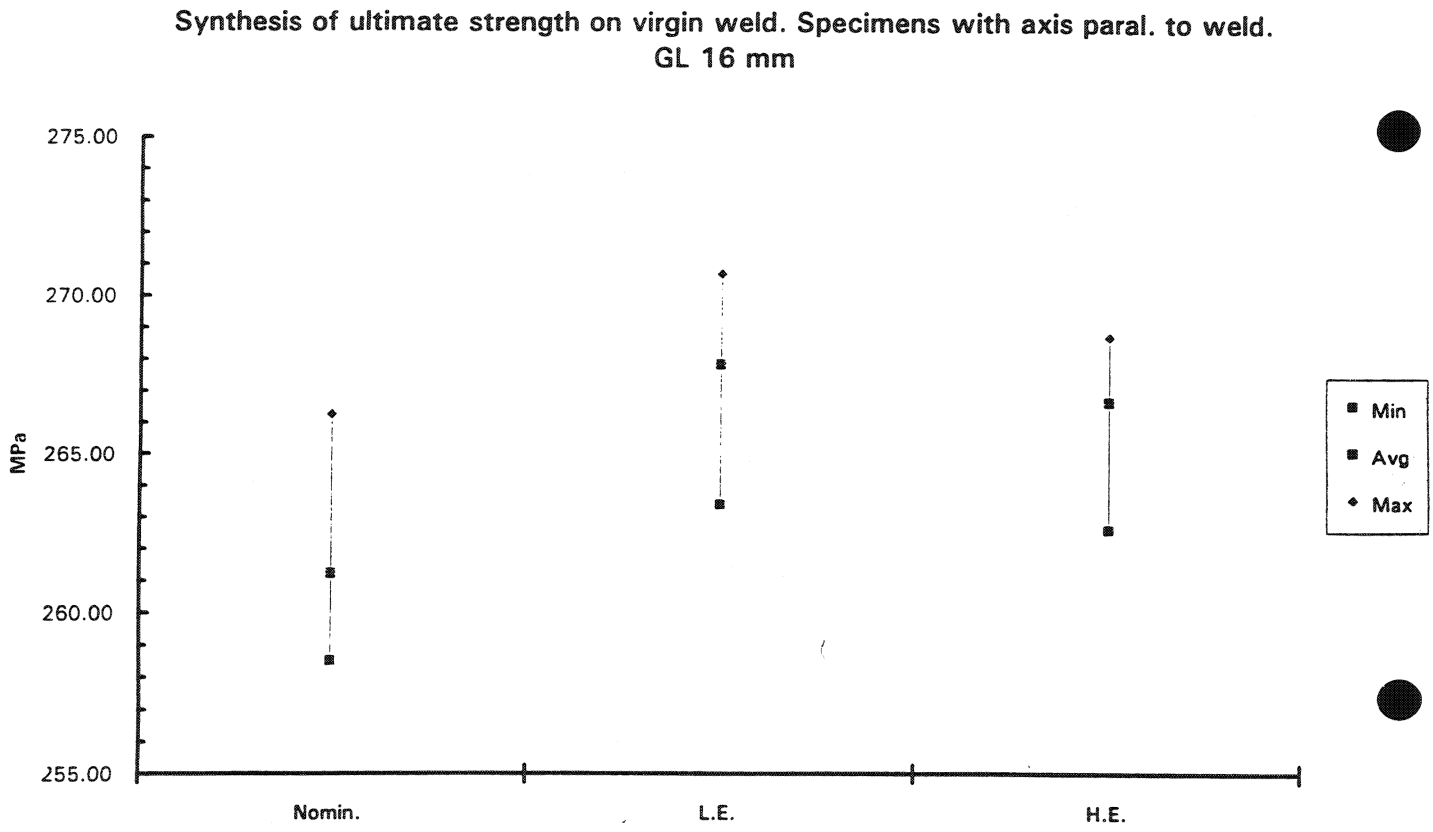


Fig. 3.4.1.1-1 - Synthesis of Ultimate Strength on Virgin Weld. Specimens with Axis Parallel to Weld. GL 16 mm

Synthesis of Ultimate strength on virgin weld. Specimens with axis trans. to weld. GL 50 mm

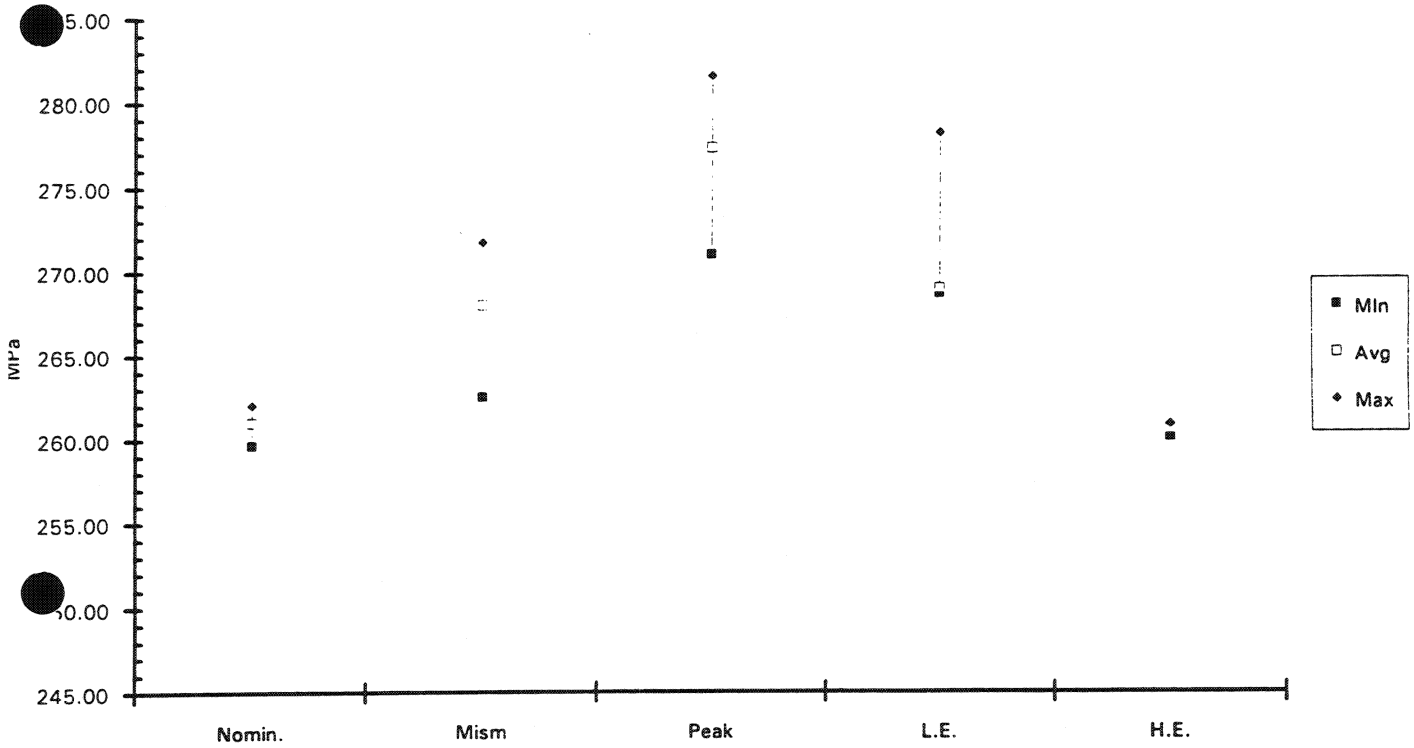


Fig. 3.4.1.1-2 - Synthesis of Ultimate Strength. Specimens with Axis Transversal to Weld. GL 50 mm

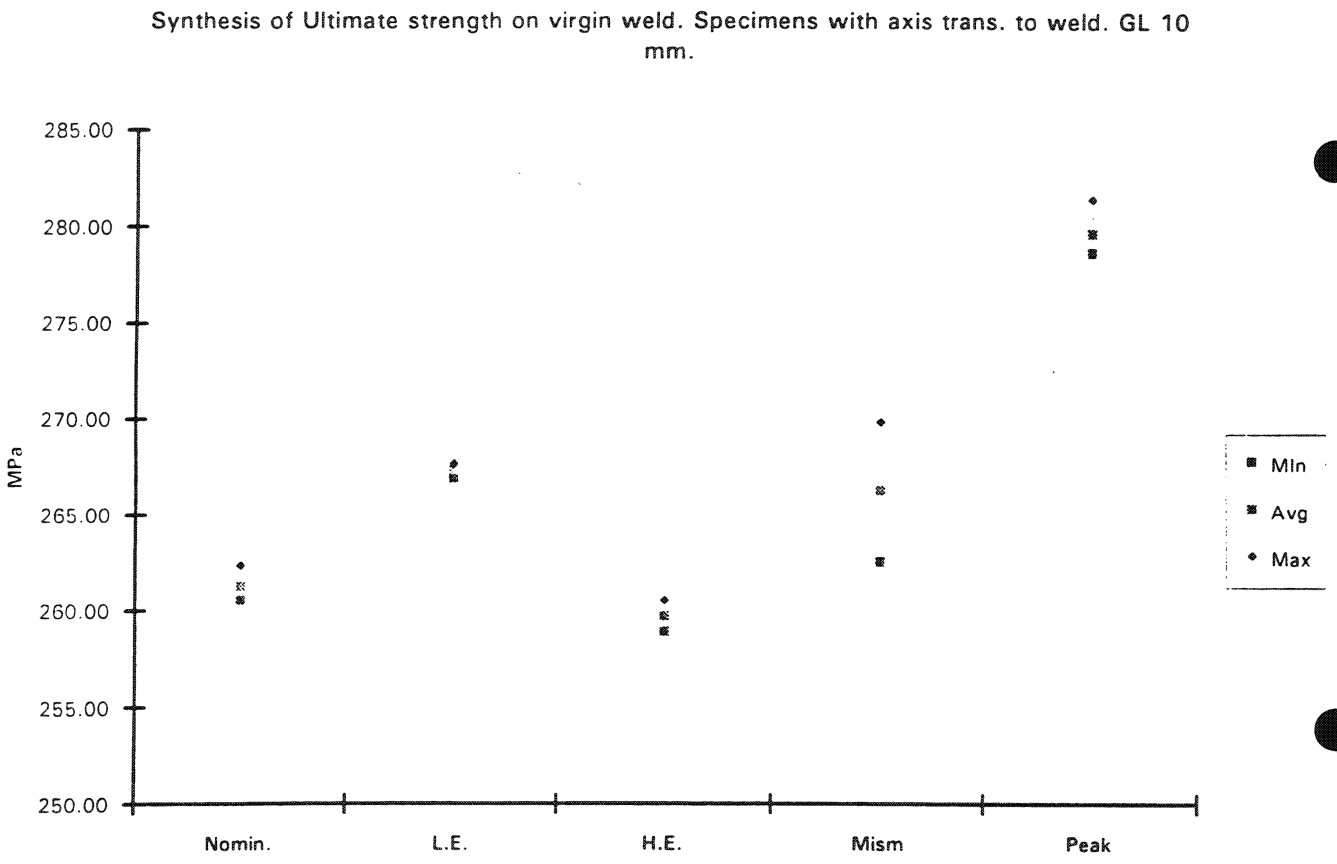


Fig. 3.4.1.1-3 - Synthesis of Ultimate Strength. Specimens with Axis Transversal to Weld. GL 10 mm

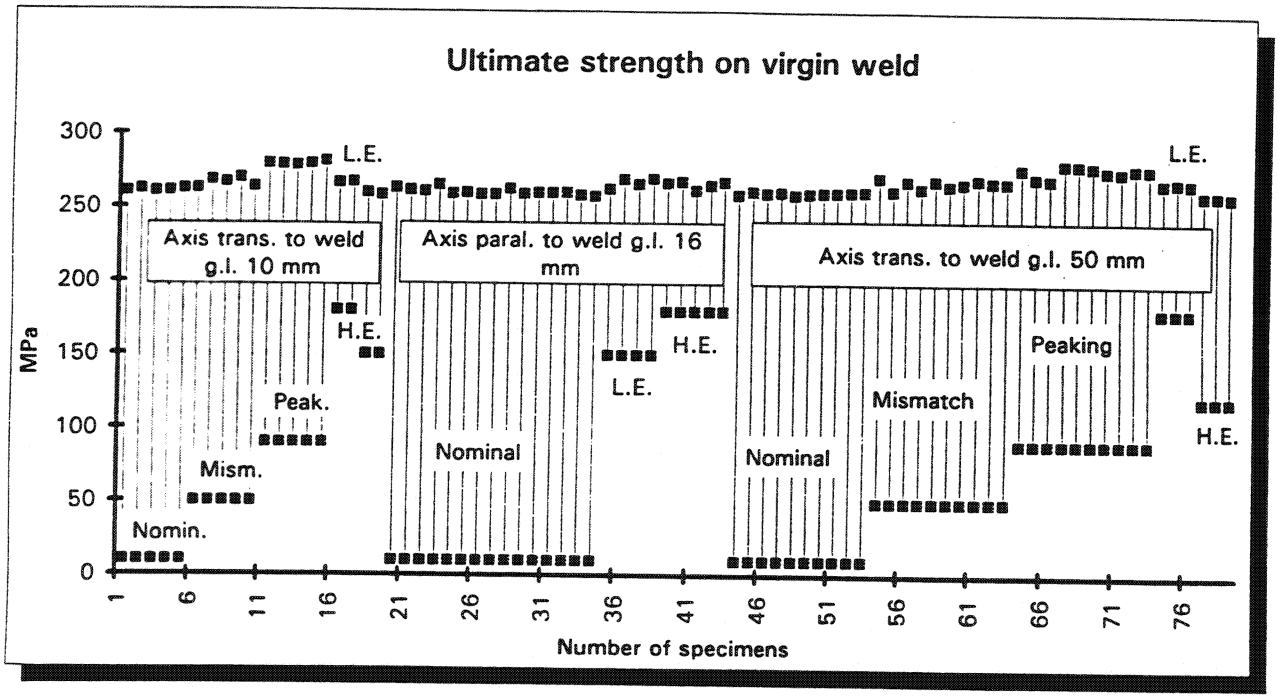


Fig. 3.4.1.1-4 - Ultimate Strength on Virgin Weld

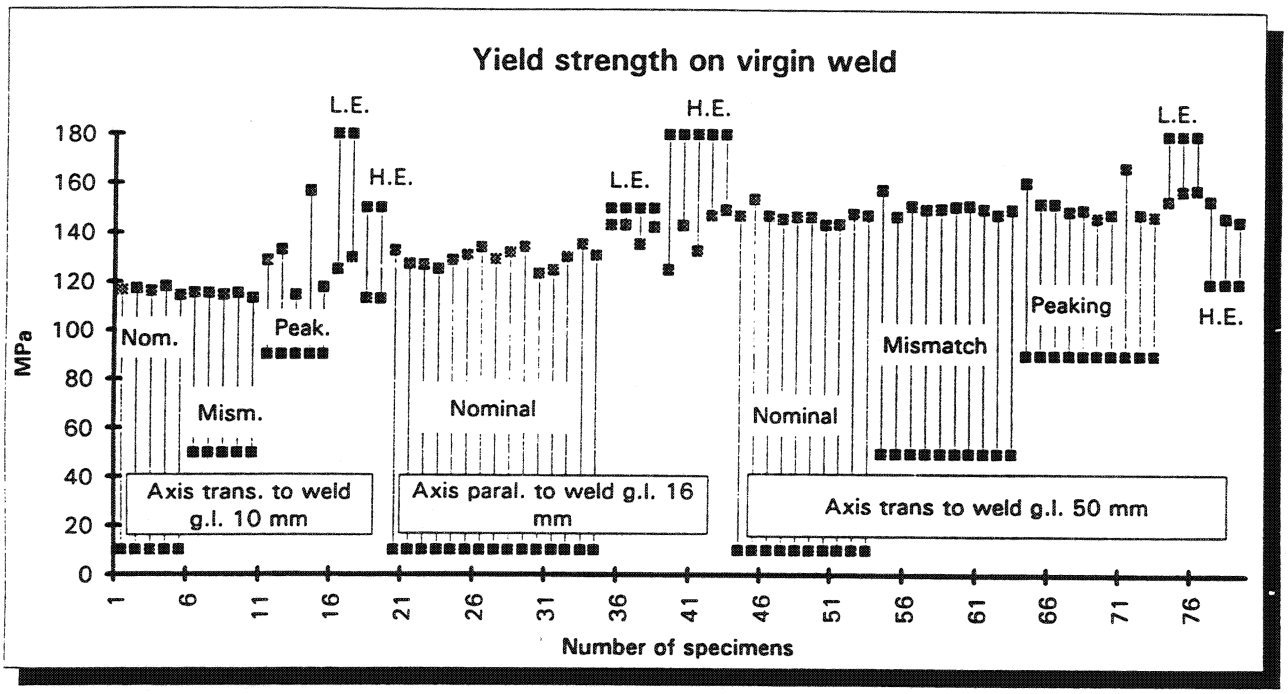


Fig. 3.4.1.1-5 - Yield Strength on Virgin Weld

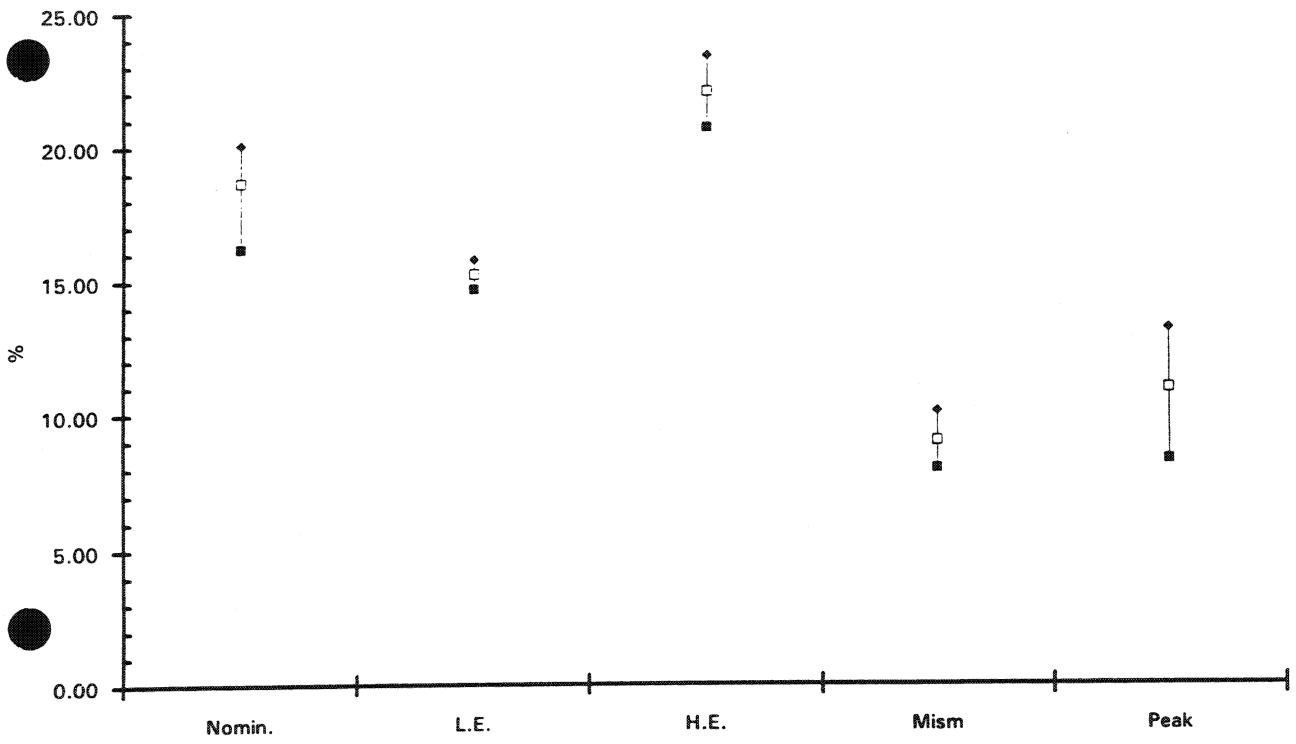


Fig. 3.4.1.1-6 - Synthesis of Elongation on Virgin Weld. Specimens with Axis Transversal to Weld. GL 10 mm

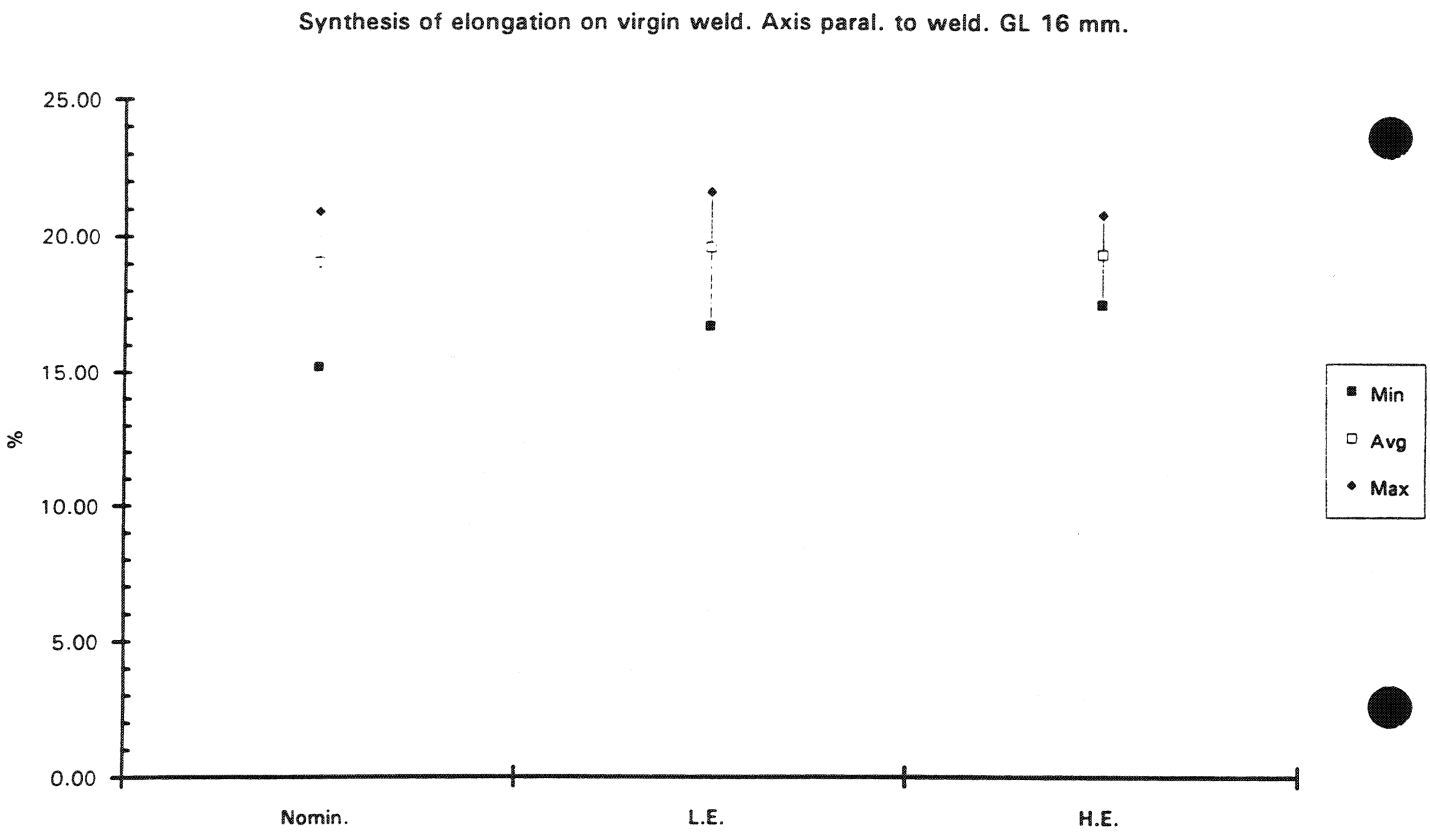


Fig. 3.4.1.1-7 - Synthesis of Elongation on Virgin Weld. Specimens with Axis Parallel to Weld. GL 16 mm

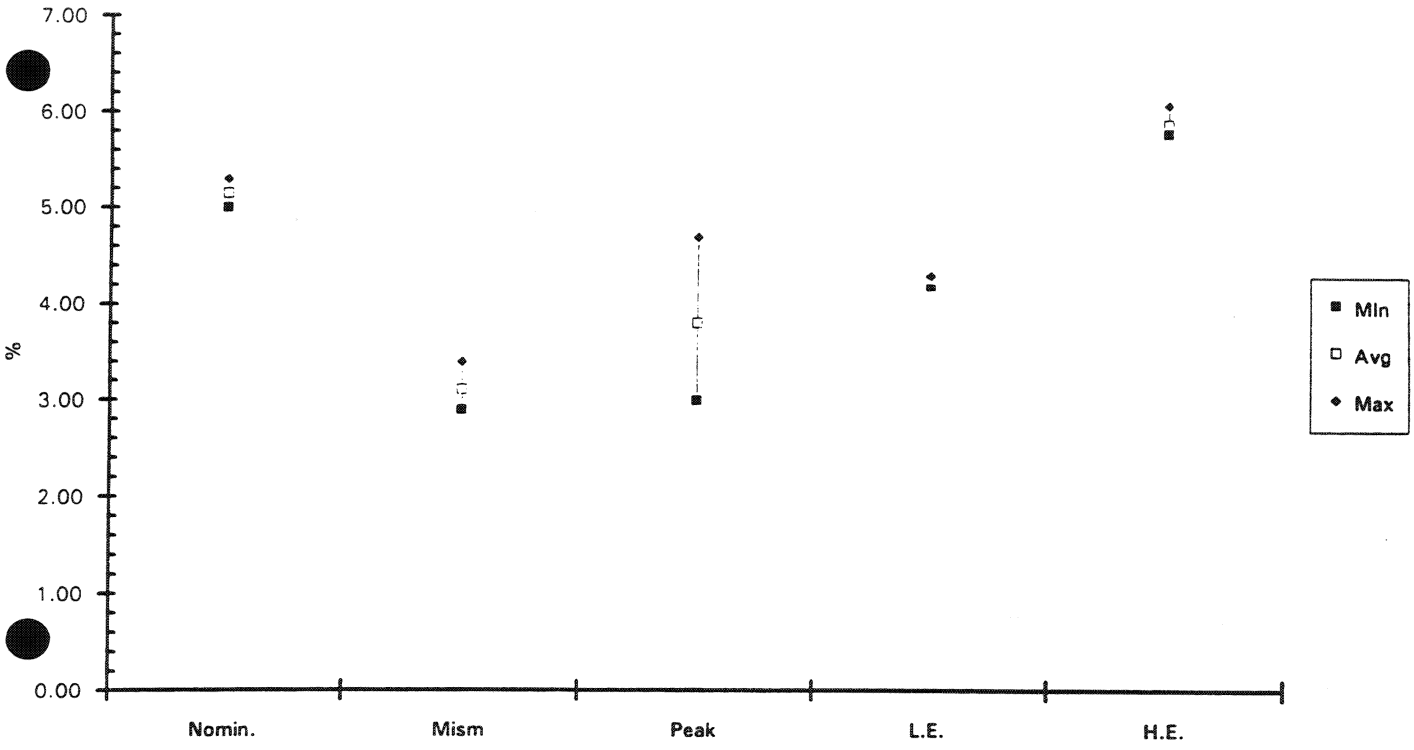


Fig. 3.4 1 1-8 - Synthesis of Elongation on Virgin Weld. Specimens with Axis Transversal to Weld. GL 50 mm

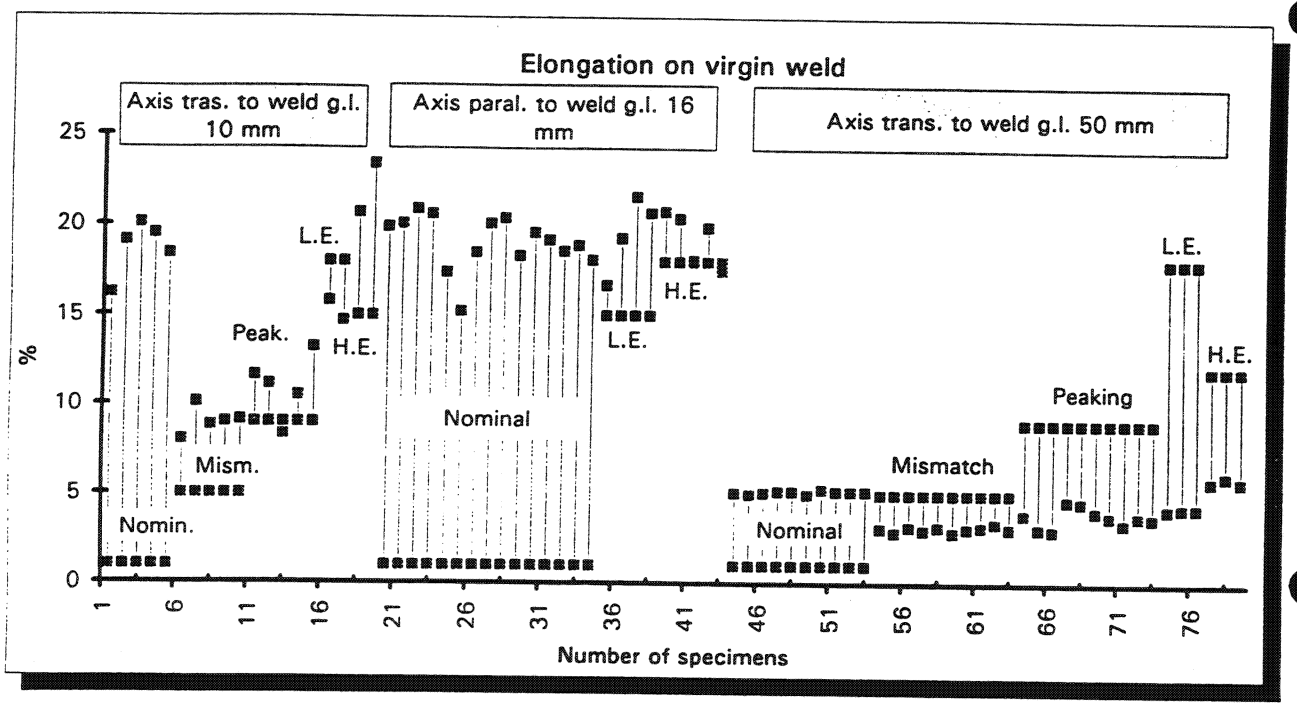


Fig. 3.4.1.1-9 - Elongation on Virgin Weld

3.4.1.2

Repair Welding

Tensile tests results are described in detail in the A.D.[11] attached to this document as Annex 2.
All the results of ultimate strength are in compliance with the requirement reported in the Welding Specification (A.D.[9] : 253 N/mm2 (average value), 249 N/mm2 (minimum value).
The graphic representations of the above results are shown from Fig. 3.4.1.2-1 to Fig. 3.4.1.2-3.
Each graphic put in comparison the automatic virgin welding with the repair welding (automatic and manual). The allowable values have been also calculated for ultimate and yield strength according to MIL-HDBK-5E A- Basis.
The first two figures indicate an increase of ultimate and yield strength in the repaired beads.
The highest values have been found in manual repaired beads by T.I.G. process.
No significant variation of elongation has been found between the different welding processes (Fig. 3.4.1.2.-3). Another series of graphics has been derived (from Fig. 3.4.1.2-4 to Fig. 3.4.1.2-12) correlating, for each type of repair welding, results obtained from the following tensile specimens :

- Longitudinal axis of tensile specimen parallel to weld (gauge length : 16 mm)
- Longitudinal axis of tensile specimen transverse to weld (gauge length : 10 mm)
- Longitudinal axis of tensile specimen transverse to weld (gauge length : 50 mm)

In terms of ultimate strength, test values are equivalent for the three test and repair typologies (Figg. 3.4.1.2-4, 3.4.1.2-5, 3.4.1.2-6).
Higher yield strength values have been found in specimens tested with a gauge length of 50 mm (Figg. 3.4.1.2-7, 3.4.1.2-8, 3.4.1.2-9) as a logical consequence of the fact that a significant quantity of base material has been interested during the test execution.
The opposite behaviour has been noted for the elongation, where higher values have been found in the test executions performed with the shortest gauge length. (Figg. 3.4.1.2-10, 3.4.1.2-11, 3.4.1.2-12).
This is reasonable because the shortest gauge only measures the material deformation in correspondence of the bead without the influence of the base material. The thermal status of the bead is close to "0" temper, more ductile than -T851 of the base material, and consequently with an higher elongation value.

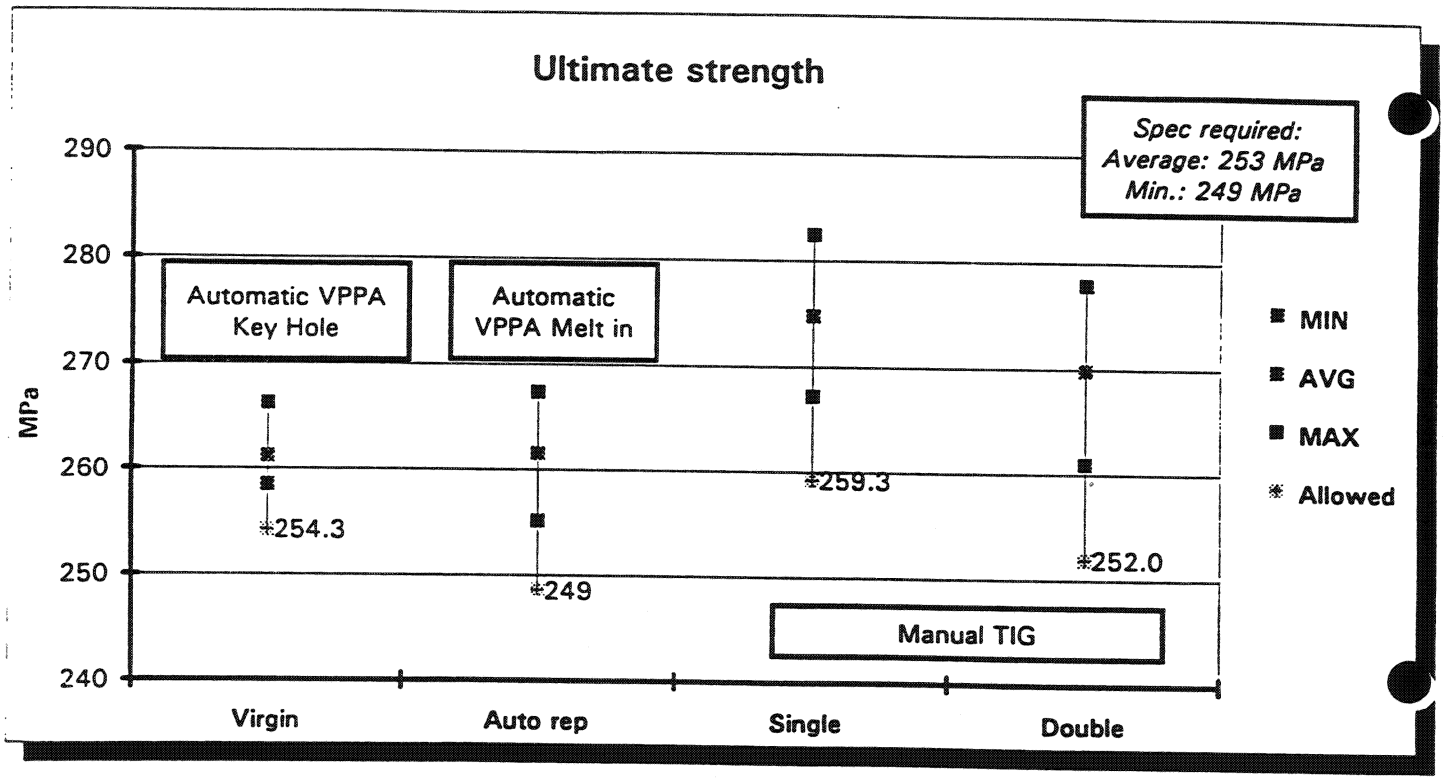


Fig. 3.4.1.2-1 - Comparison between Ultimate Strength Results of Virgin and Repair Welding

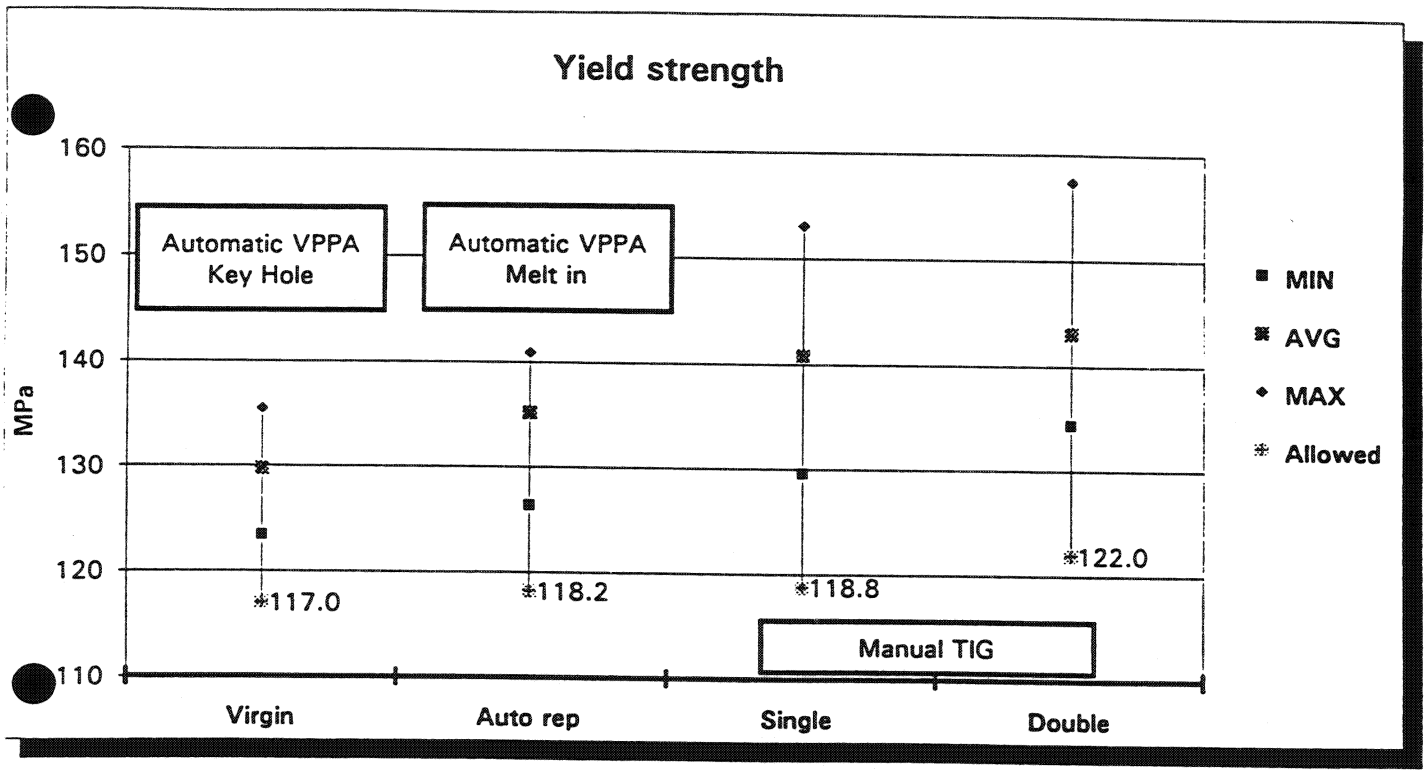


Fig. 3.4.1.2-2 - Comparison between Yield Strength Results of Virgin and Repair Welding

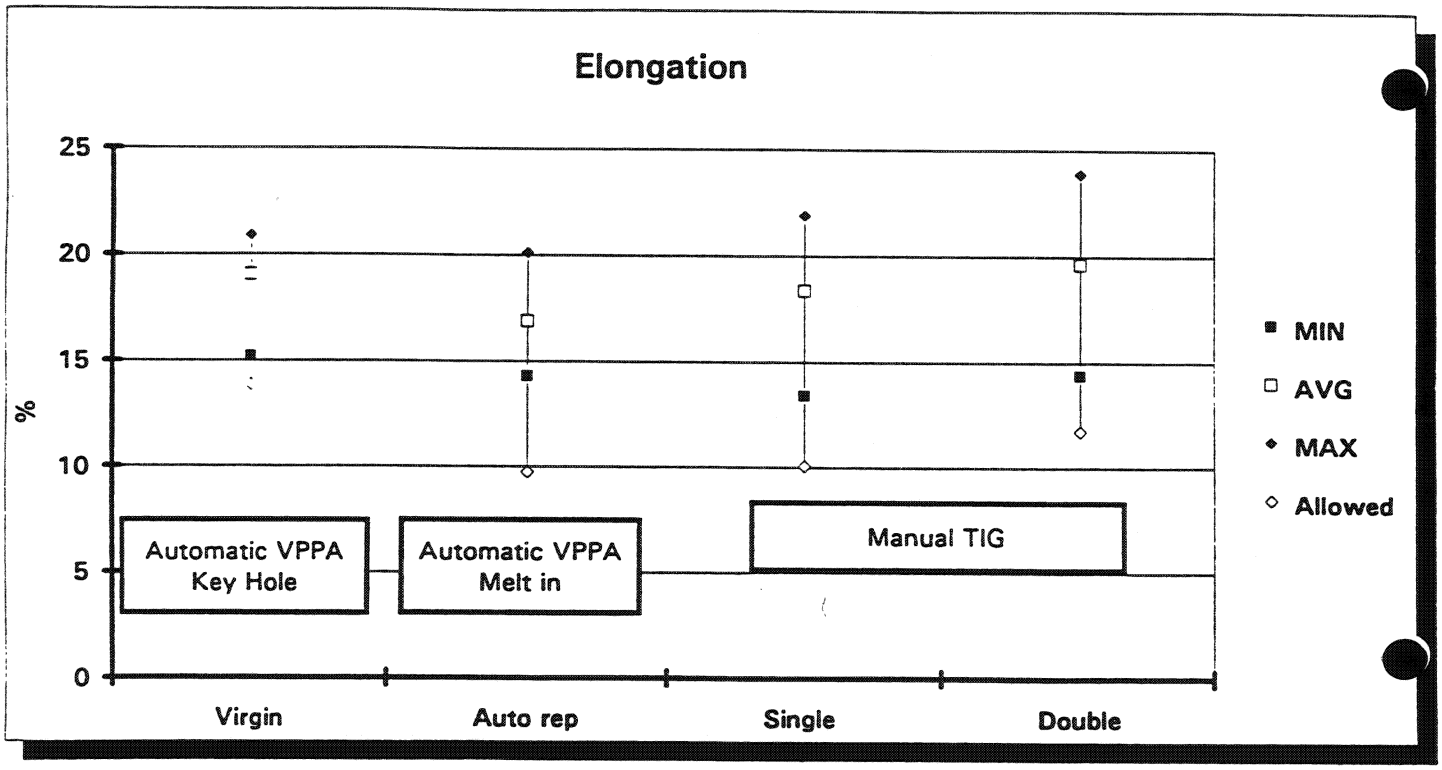


Fig. 3.4.1.2-3 - Comparison between Elongation Results of Virgin and Repair Welding

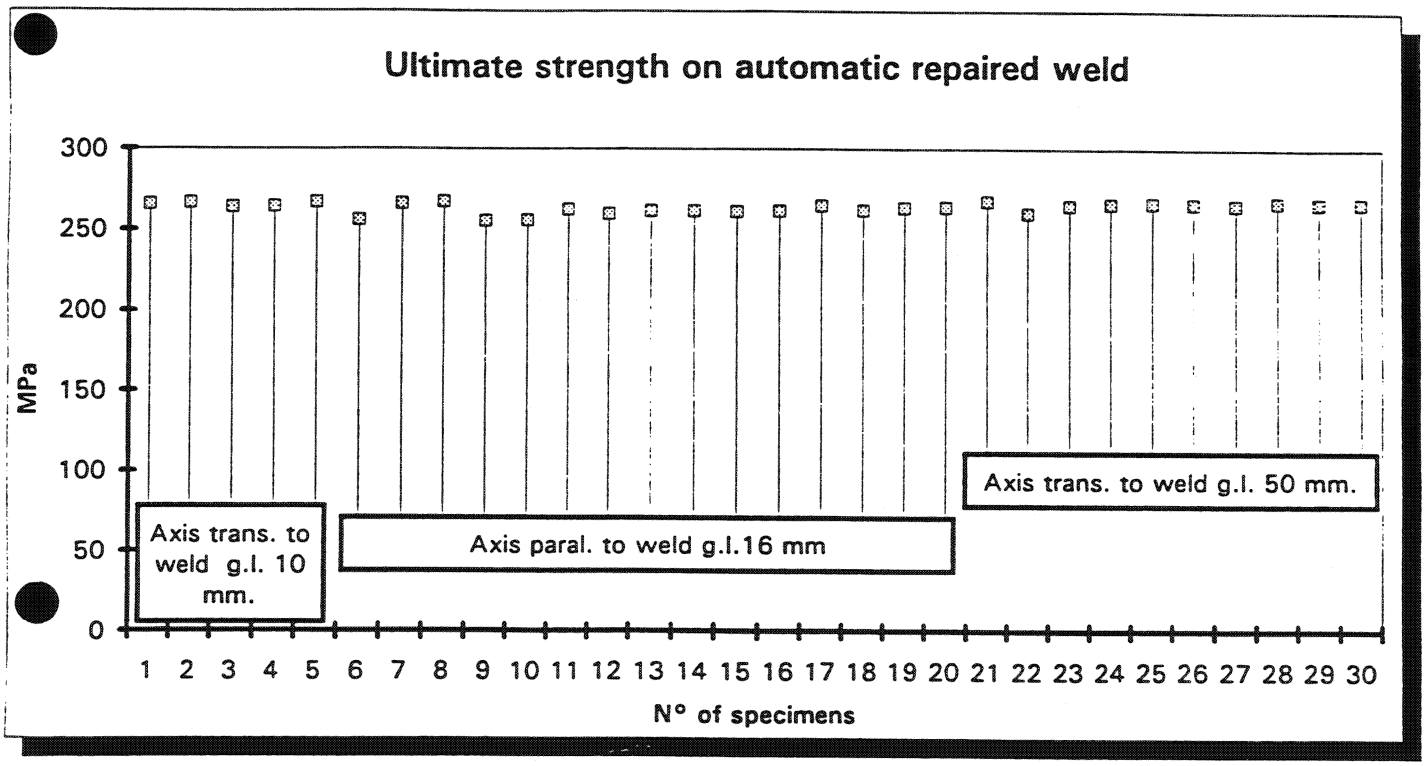


Fig. 3.4.1.2-4 - Ultimate Strength of Automatic Repair Welding

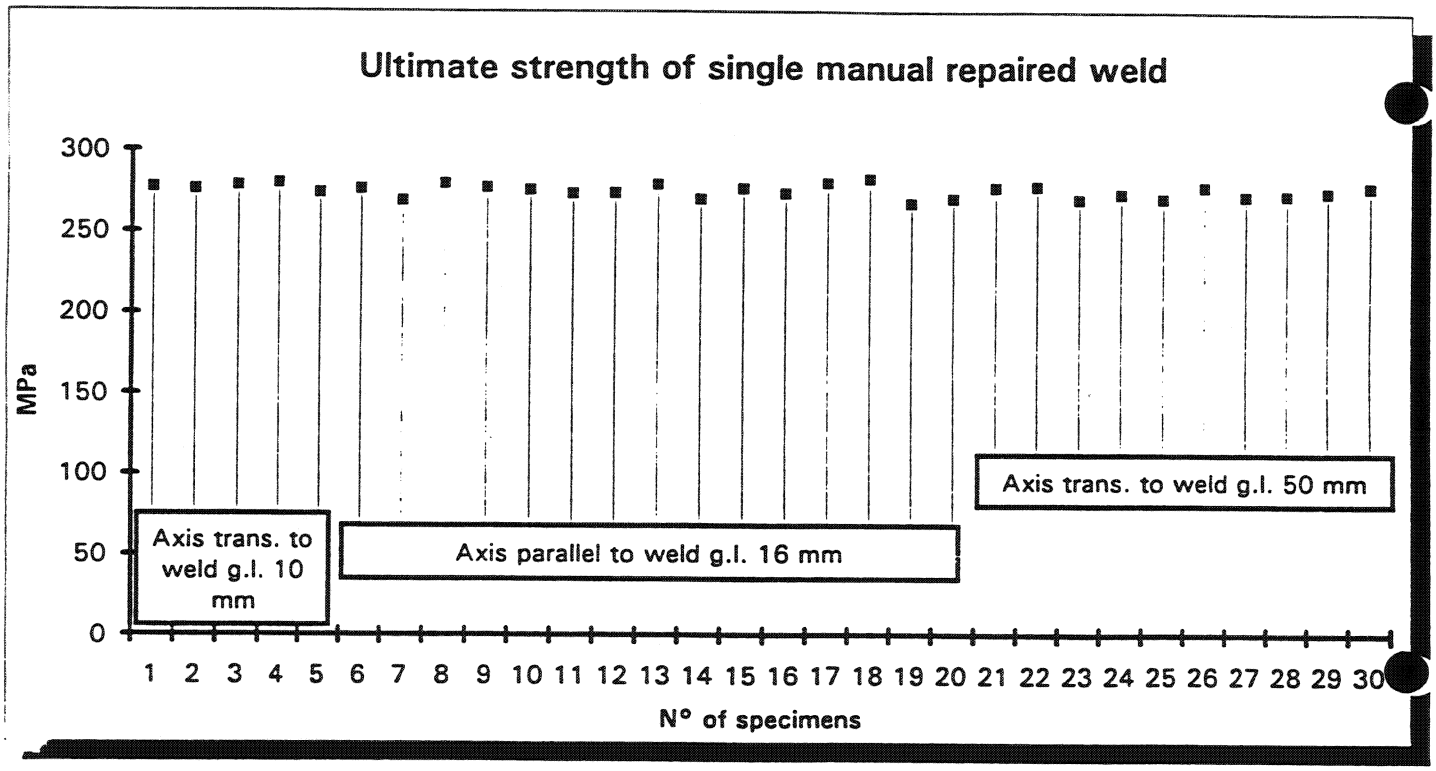


Fig. 3.4.1.2-5 - Ultimate Strength of Single Manual Repair Welding

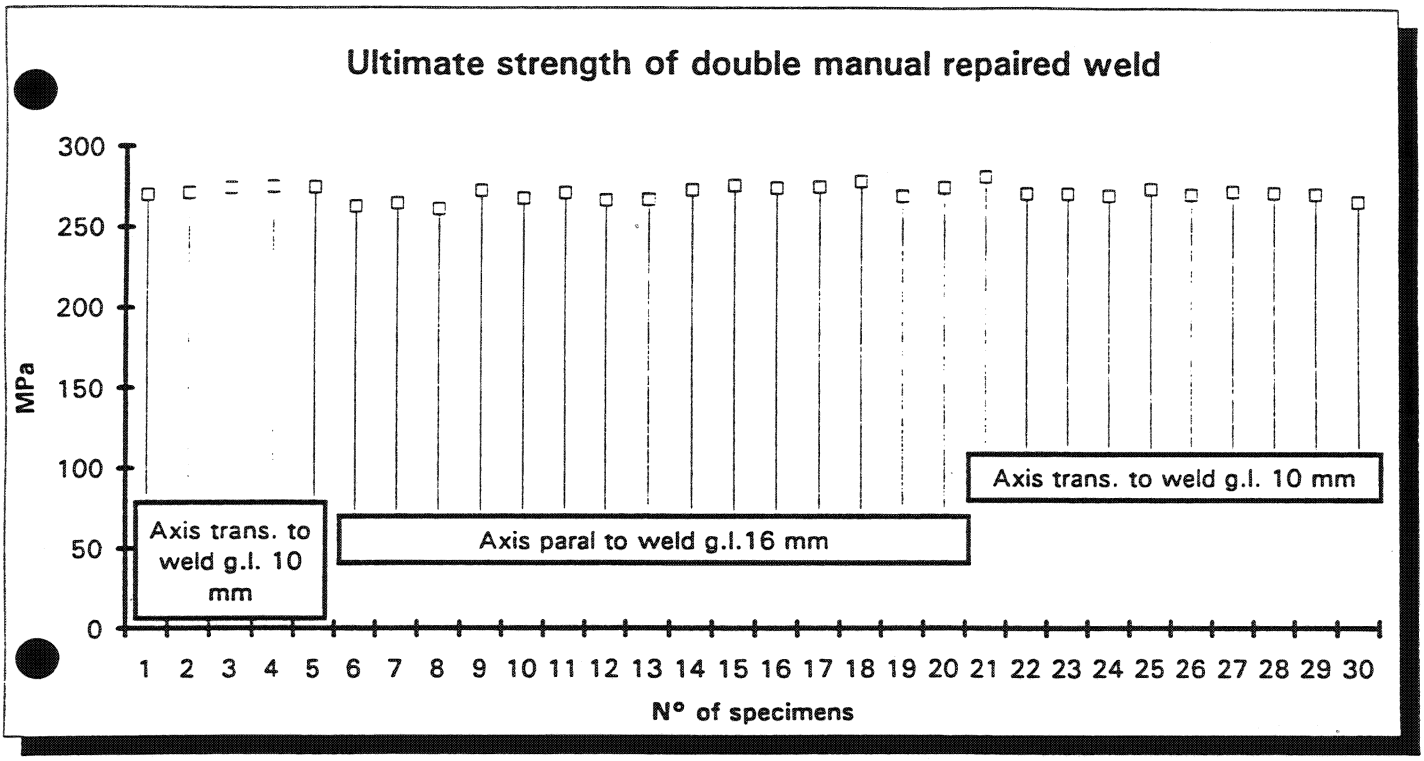


Fig. 3.4.1.2-6 - Ultimate Strength of Double Manual Repair Welding

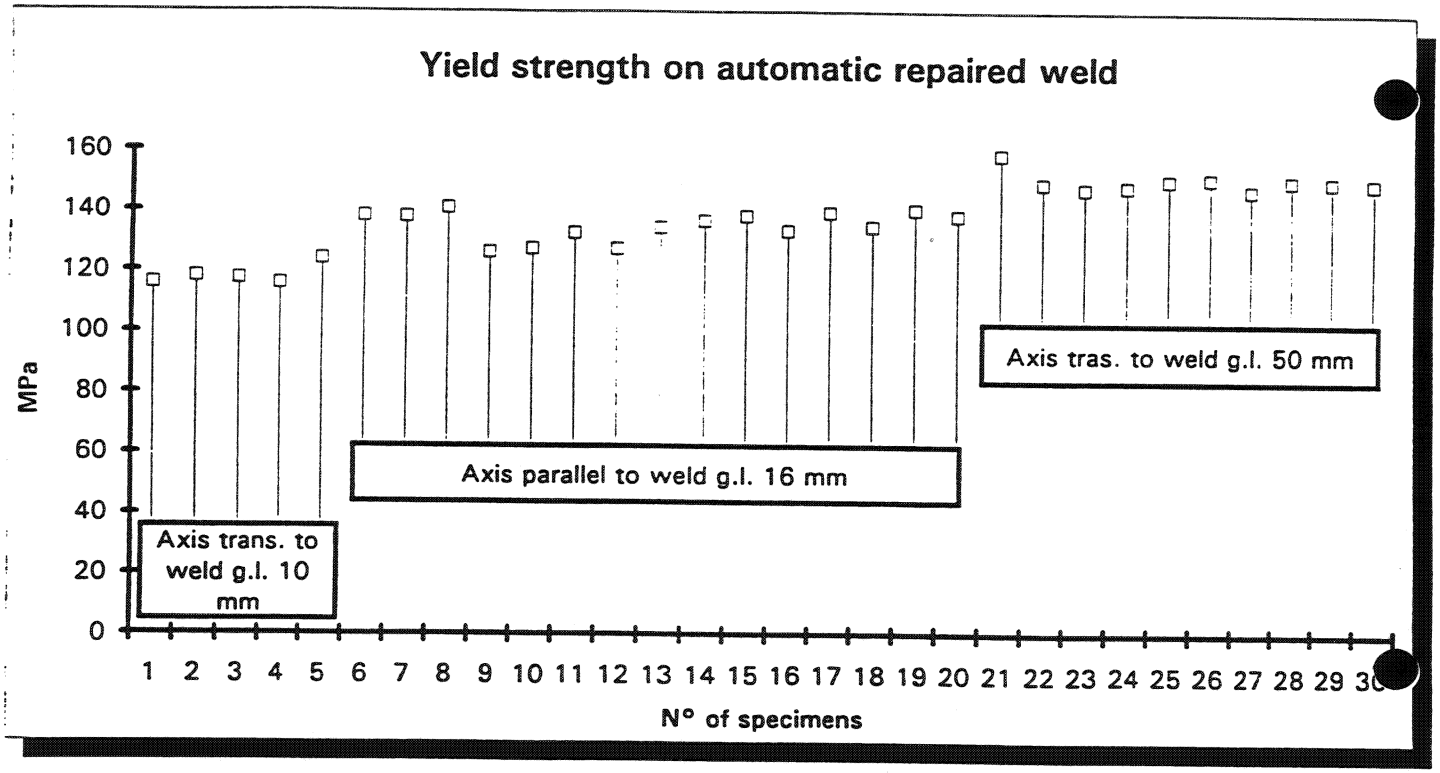


Fig. 3.4.1.2-7 - Yield Strength of Automatic Repair Welding

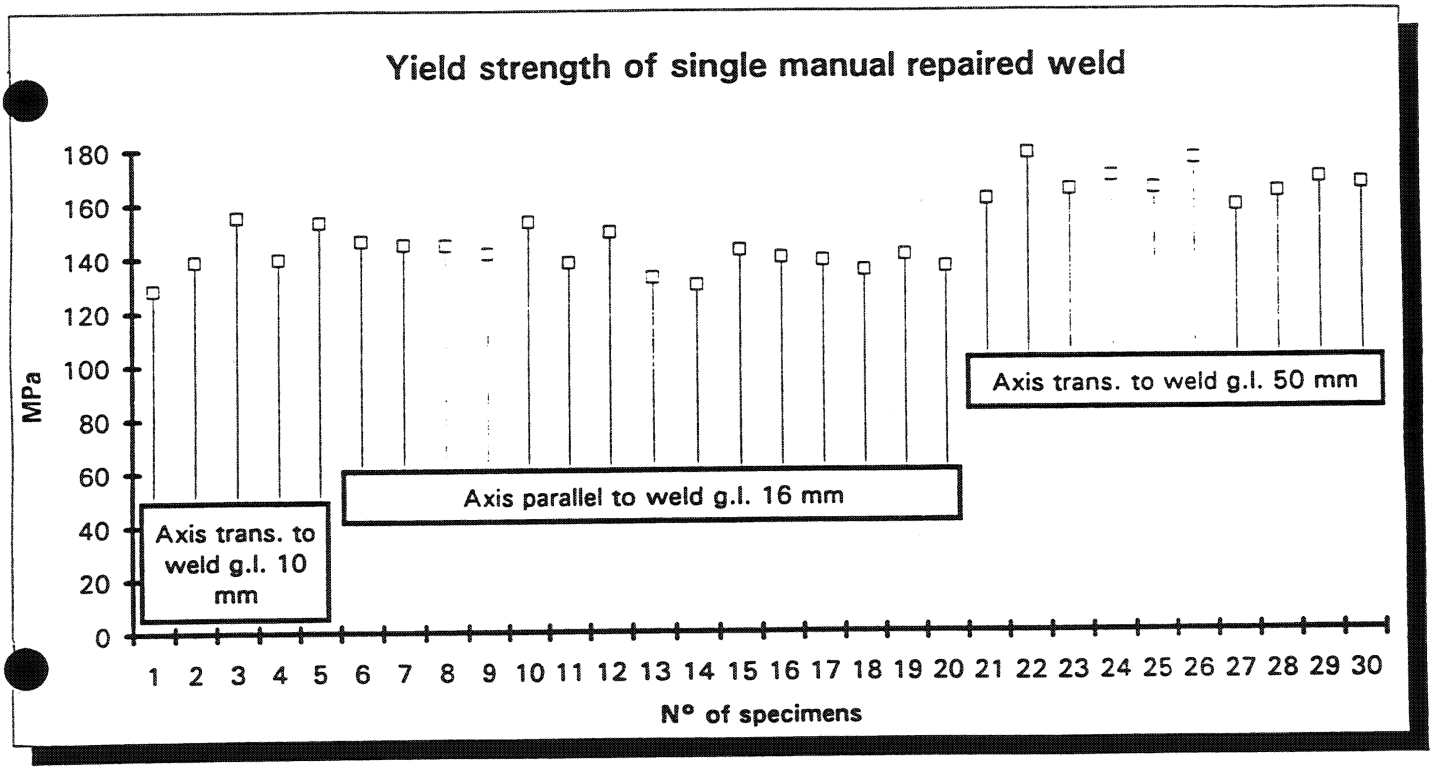


Fig. 3.4.1.2-8 - Yield Strength of Single Manual Repair Welding

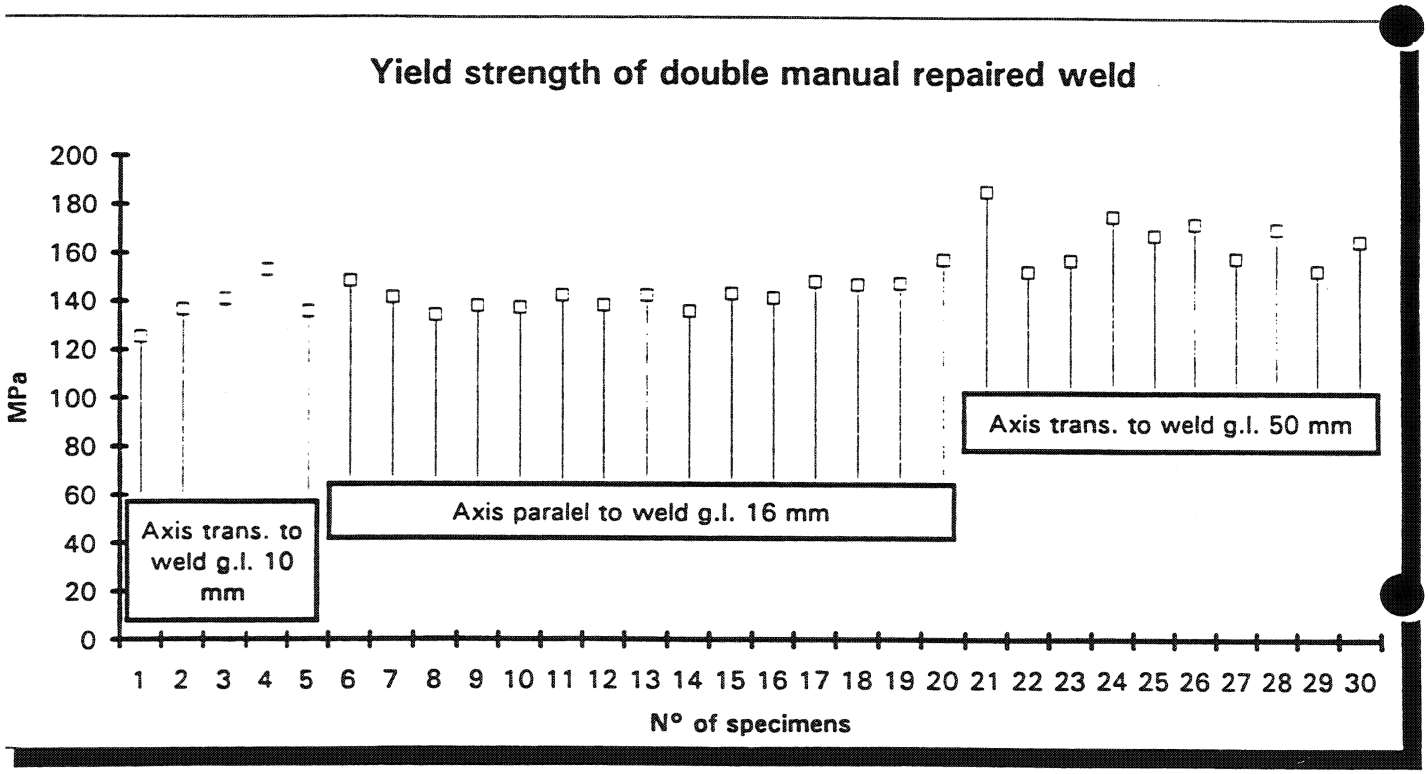


Fig. 3.4.1.2-9 - Yield Strength of Double Repair Welding

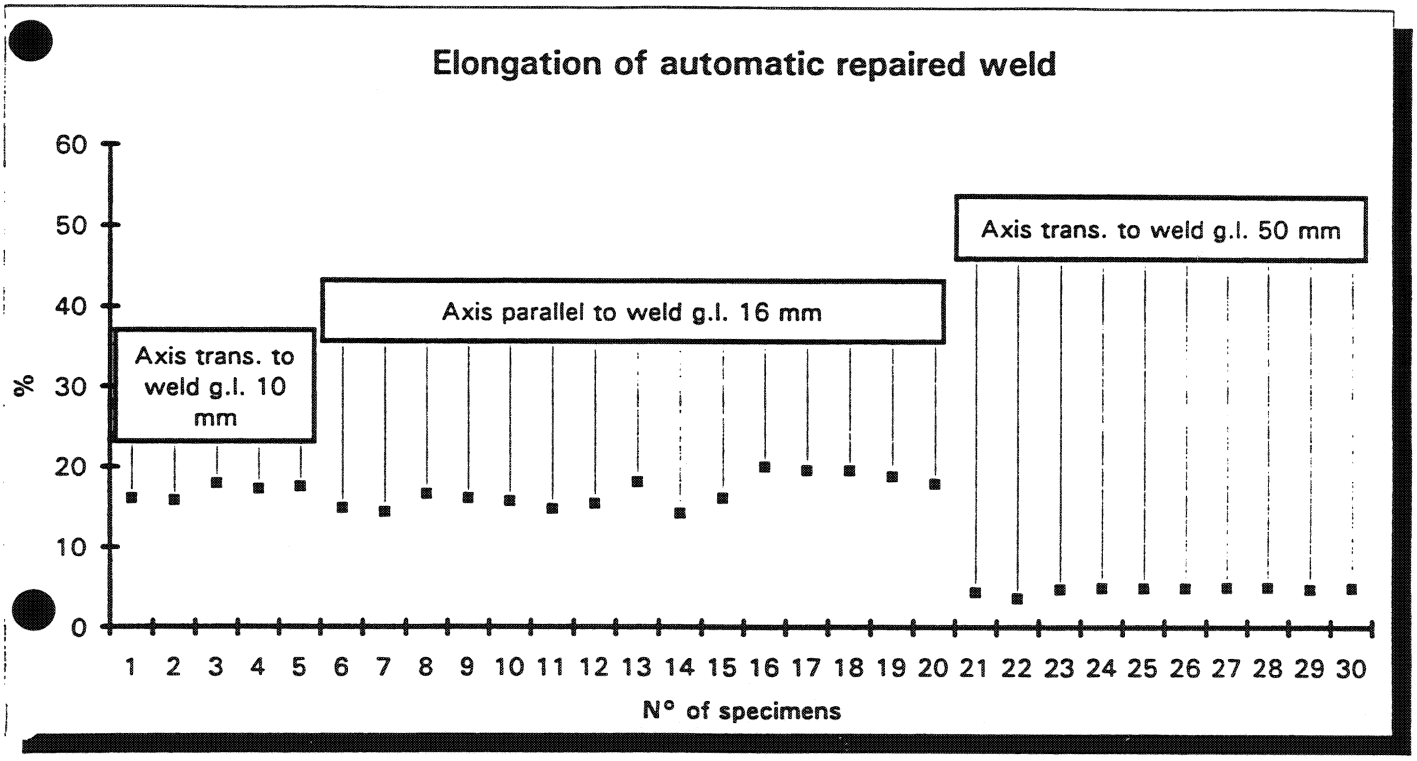


Fig. 3.4.1.2-10 - Elongation of Automatic Repair Welding

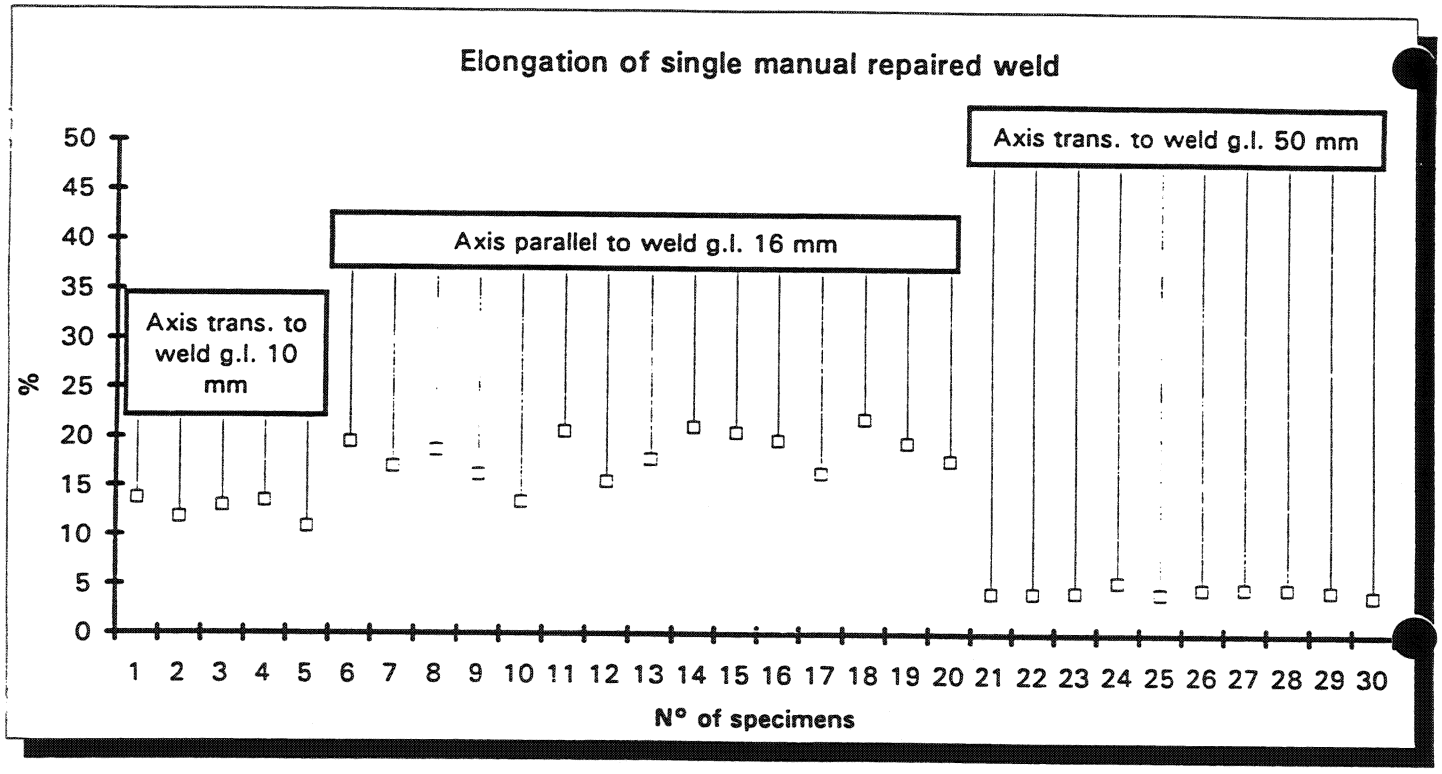


Fig. 3.4.1.2-11 - Elongation of Single Manual Repair Welding

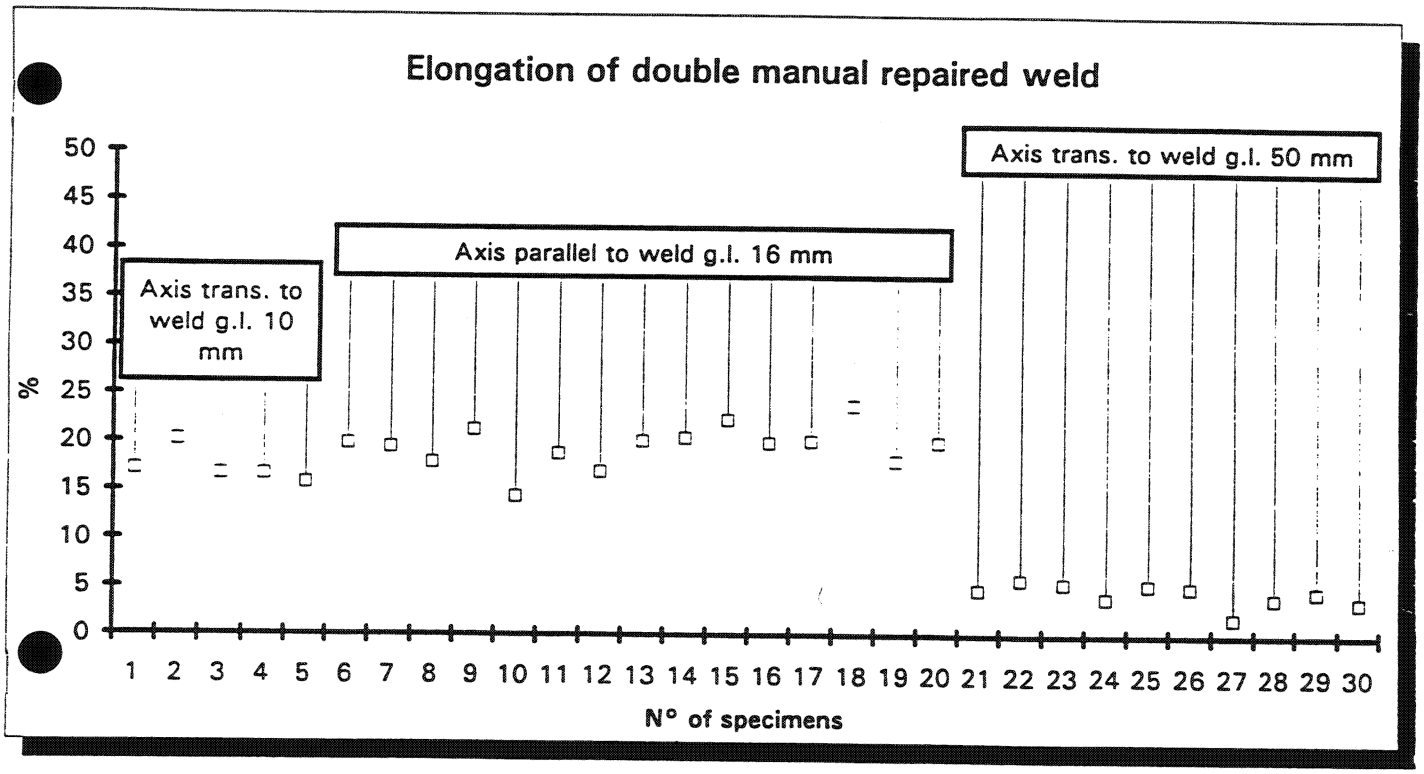


Fig. 3.4.1.2-12 - Elongation of Double Manual Repair Welding

3.4.1.3

Tensile Test Comparison between Longitudinal and Circumferential Configuration

As previously specified (Para 1), a certain number of weldings has been performed in circumferential configuration and then tensile tested in order to demonstrate that both the welding configurations give results according to the requirements reported in the welding specification (A.D.[9]). This goal has been achieved applying the welding parameters within the qualified range and adopting the same tooling concept for both the configurations.
Test results are summarized in Figg. 3.4.1.3-1, 3.4.1.3-2 and 3.4.1.3-3. Ultimate strength values are higher than 253 MPa, as required by welding specification.
More detailed technical description is reported in A.D.[12].

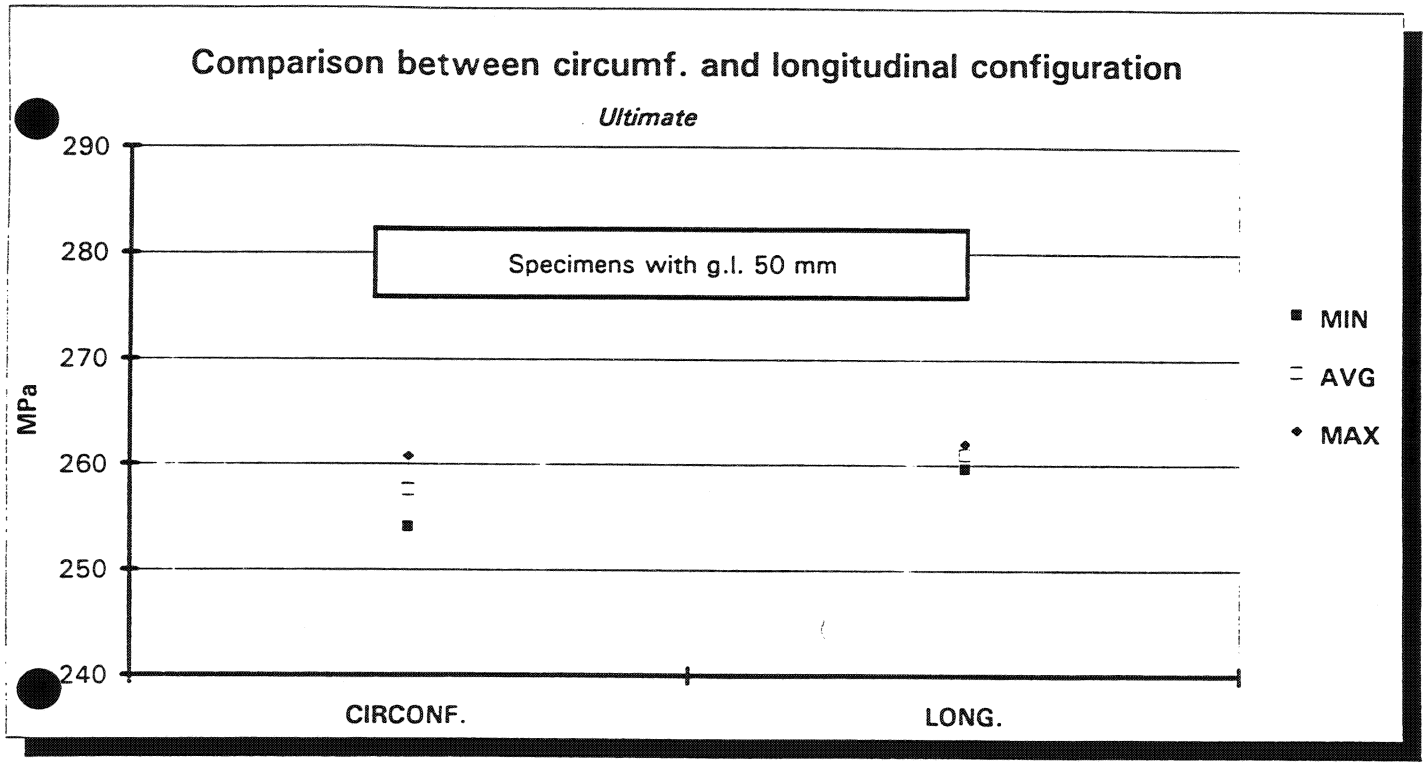


Fig. 3.4.1.3-1 - Tensile Test Results in Circumferential and Longitudinal Welding Configuration

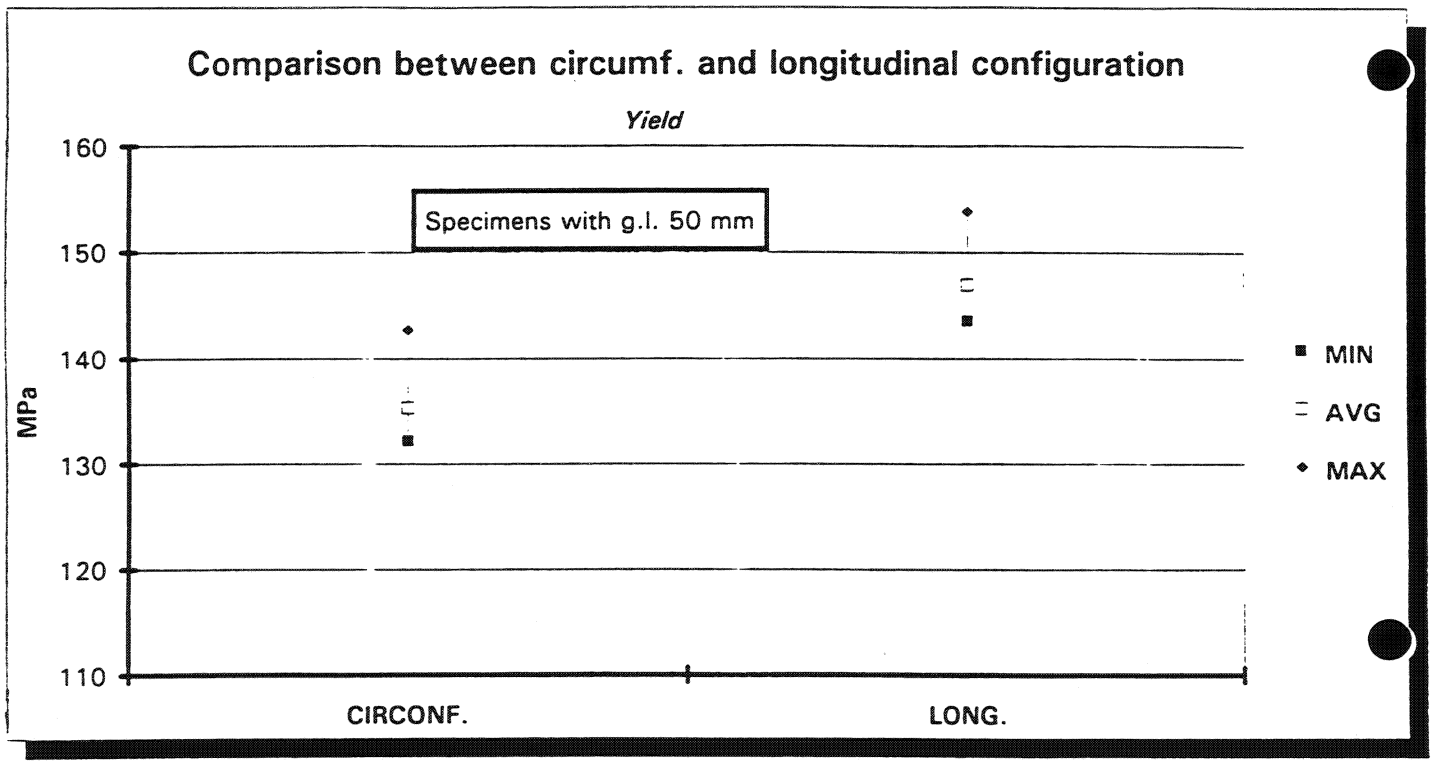


Fig. 3.4.1.3-2 - Tensile Test Results in Circumferential and Longitudinal Welding Configuration

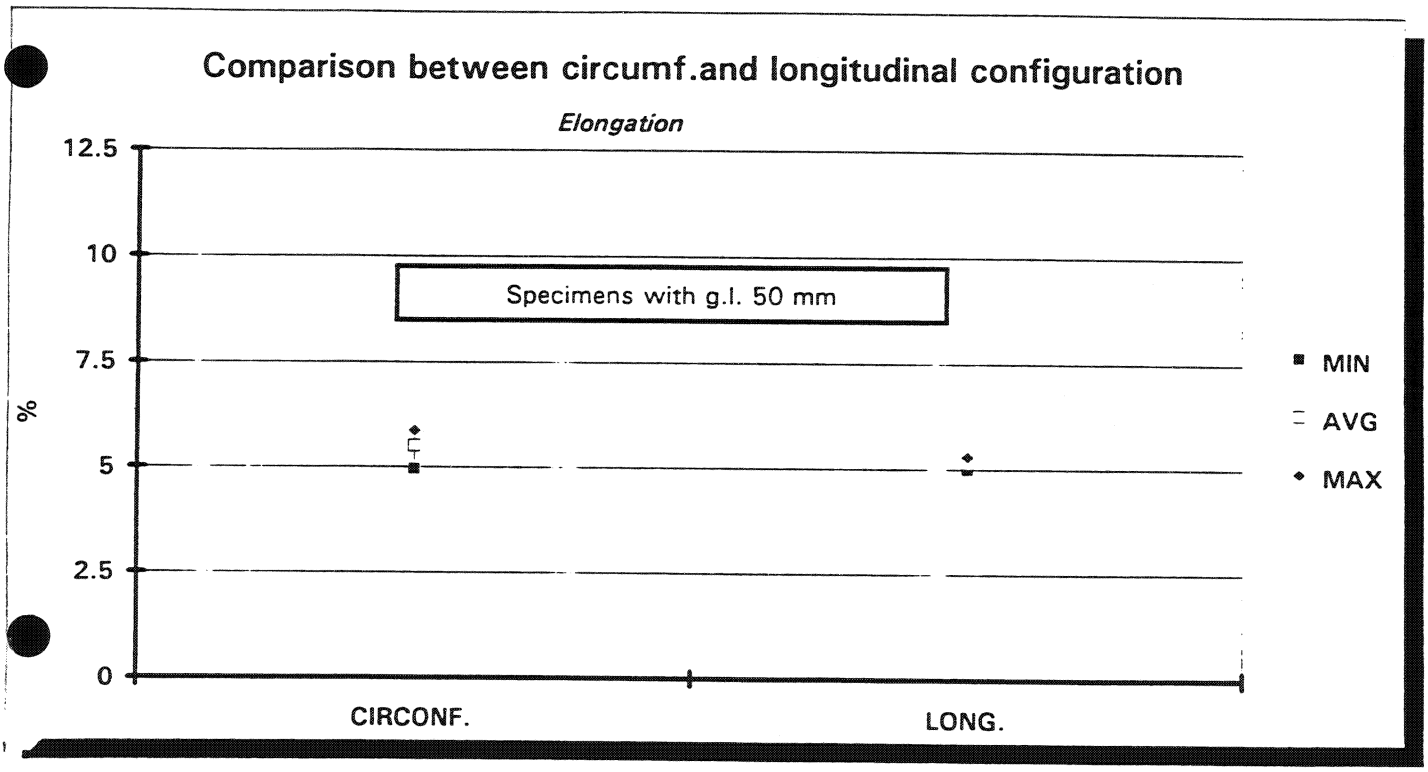


Fig. 3.4.1.3-3 - Tensile Test Results in Circumferential and Longitudinal Welding Configuration

3.4.2

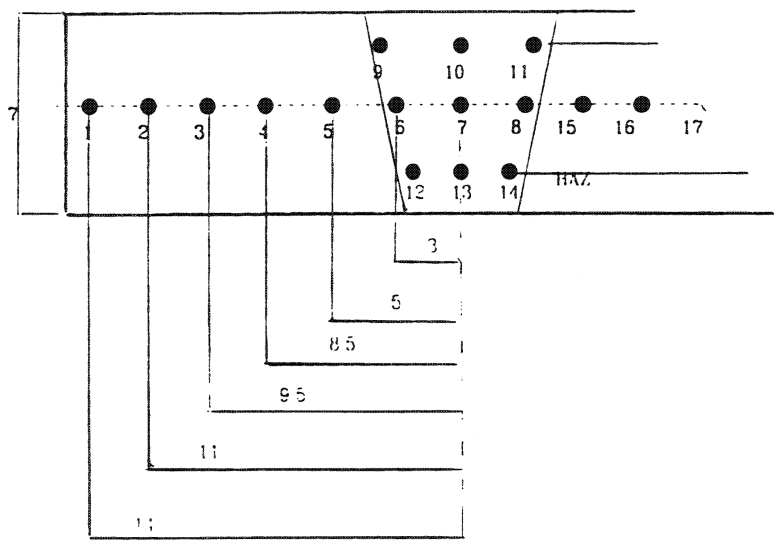
Microhardness Results

Microhardness tests were performed on :

- virgin weld
- virgin weld with peaking and mismatch
- virgin weld at minimum and at maximum of energy
- automatic repair welding
- manual repair welding (single and double)

For each type of welding, 19 measurements points were tested as per map below:

Map of measures



Graphic representations are shown from Fig. 3.4.2-1 to 3.4.2-8.
As foreseen, microhardness values are correlated to the tested areas. The lowest values are within the weld zone and increase in the H.A.Z. (Heat Affected Zone) until to reach the typical values of 2219 Al in the base material.
Comparing the different graphs, higher values have been found in the welds conducted at the minimum energy of the tolerance field. The low energy input from the torch to the workpiece has less influence on the decreasing of the mechanical properties of the welded joint, in the H.A.Z. particularly.
Welds performed with peaking and mismatch seem to have the same hardness behaviour like the virgin welds.
Concerning the repair welding, the behaviour of the hardness values along the cross section of the bead is similar to that one relevant to the automatic virgin welding.

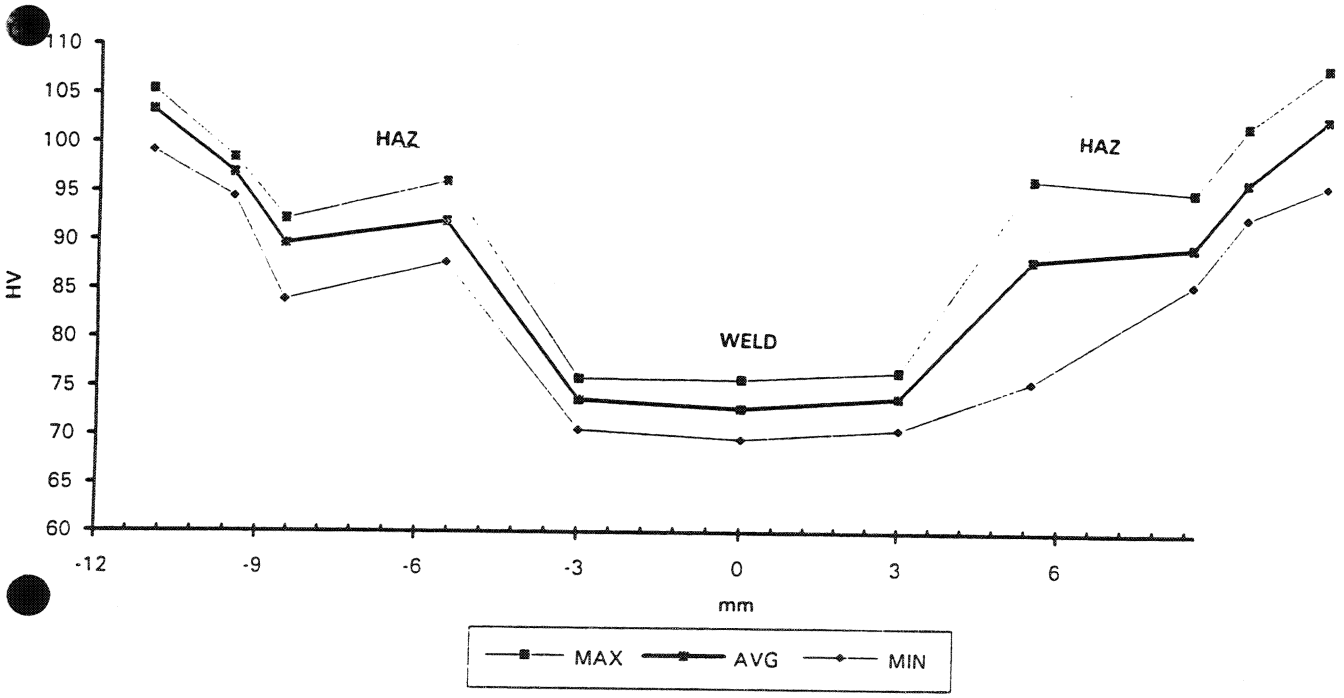


Fig. 3.4.2-1 - Hardness Values of Virgin Weld

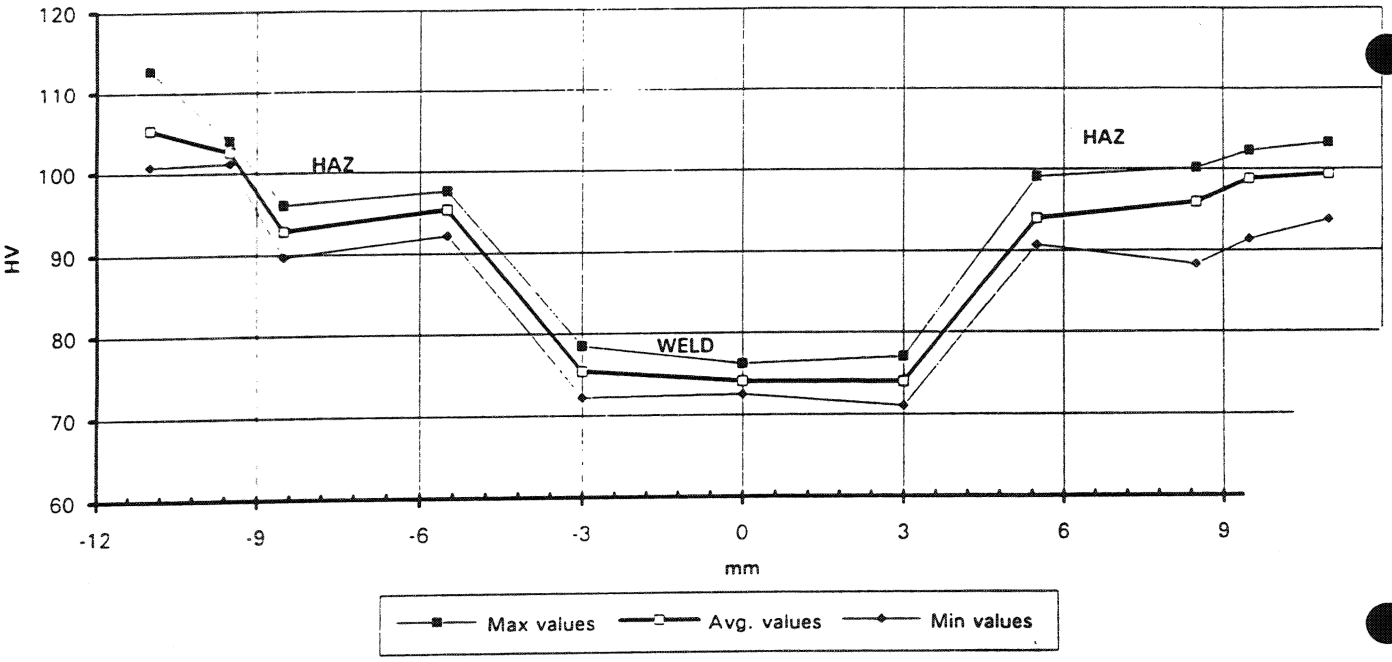


Fig. 3.4.2-2 - Hardness Values of Welded Samples with Peaking

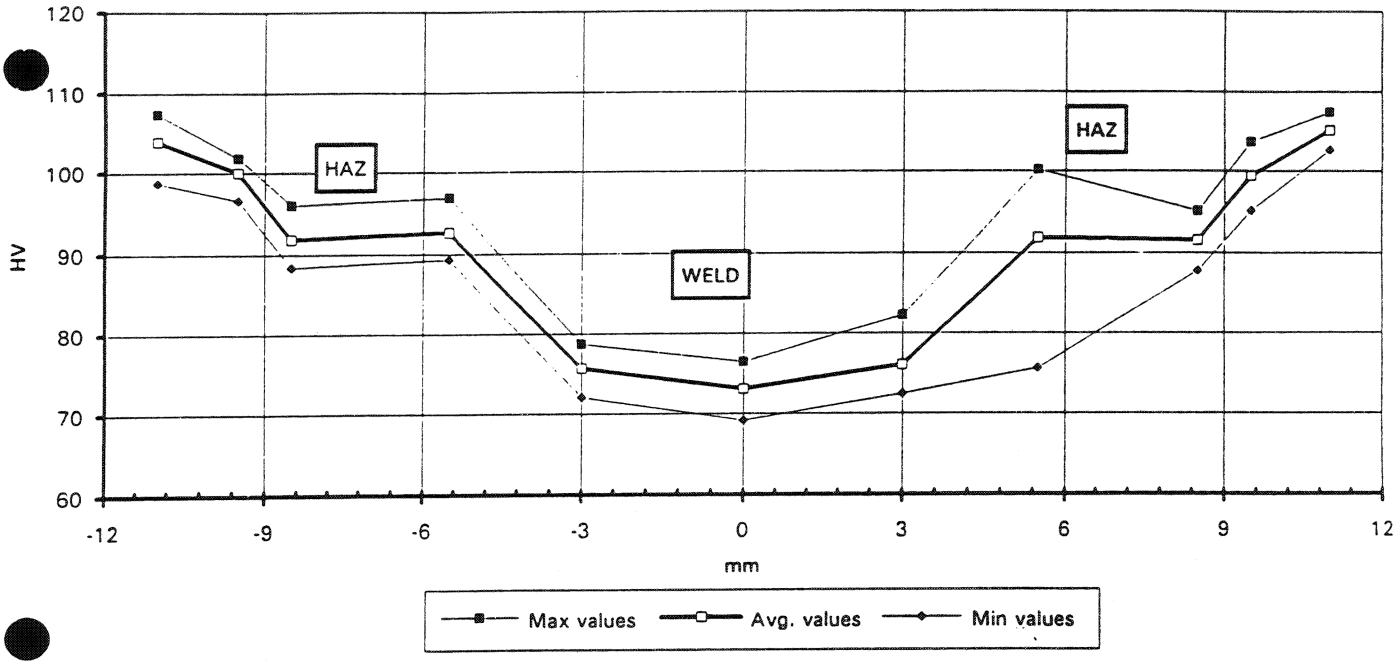


Fig. 3.4.2-3 - Hardness Values of Welded Samples with Mismatch

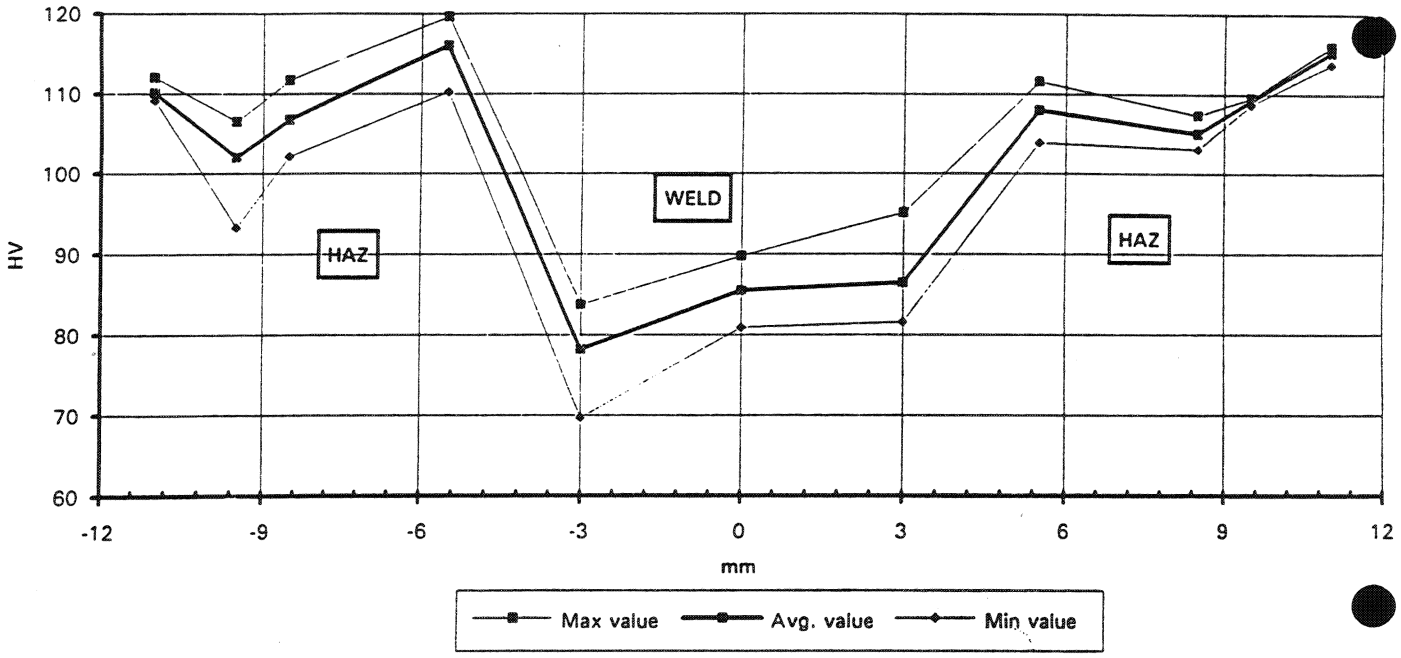


Fig. 3.4.2-4 - Hardness Values of Welded Samples at min. Energy

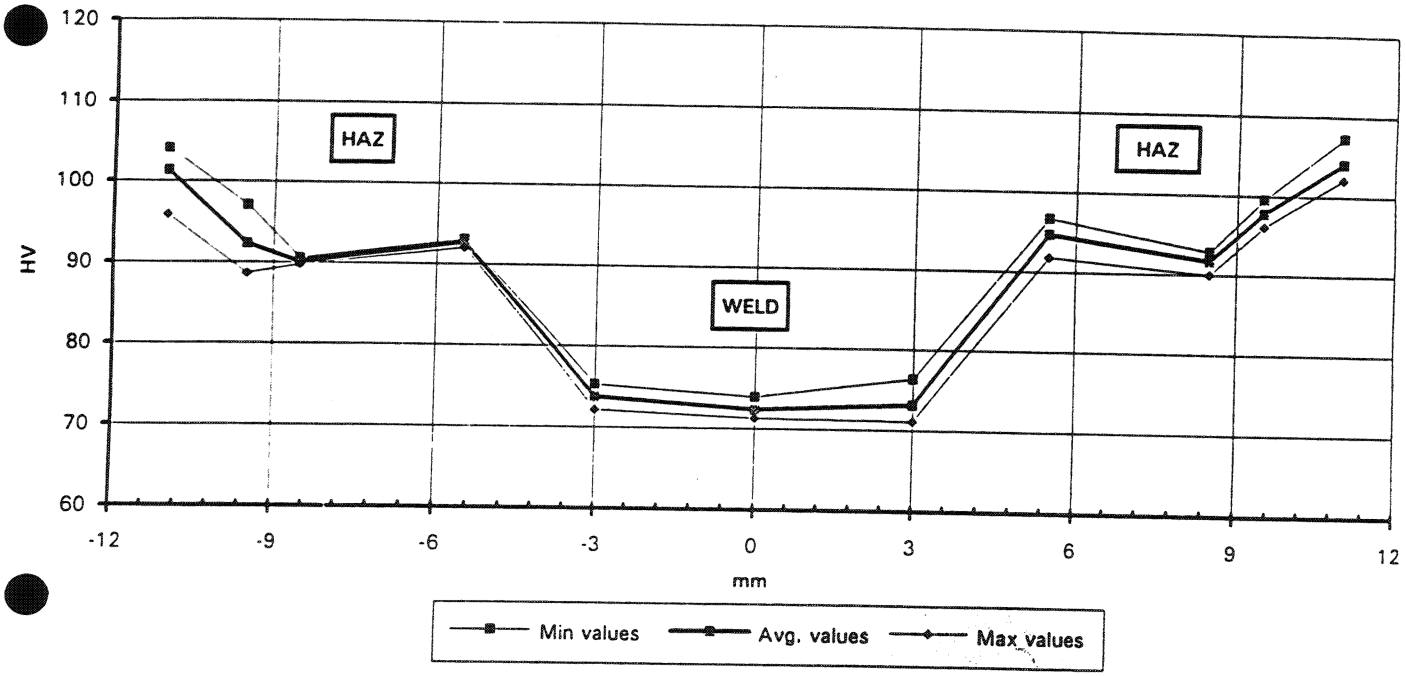


Fig. 3.4.2-5 - Hardness Values of Samples Welded at max. Energy

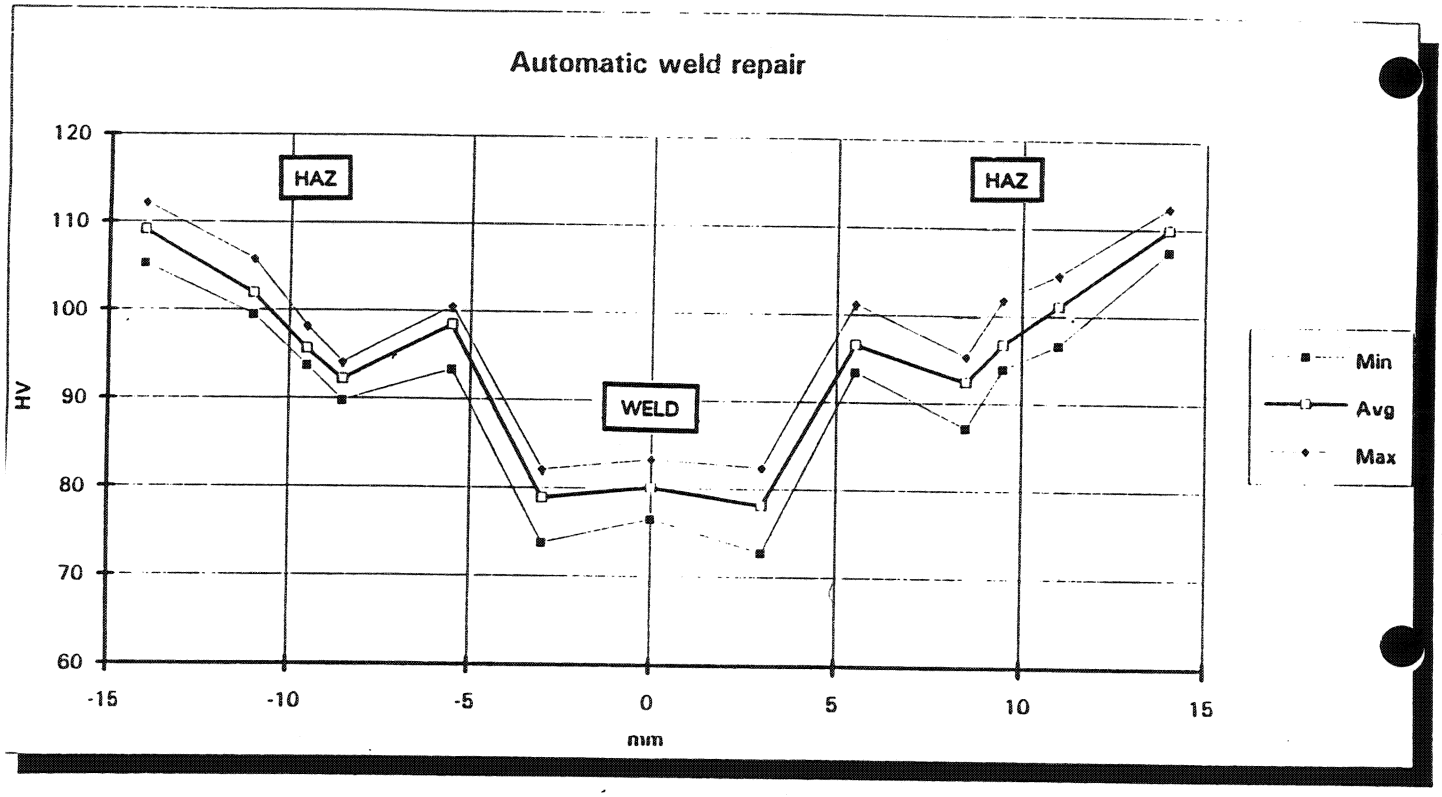


Fig. 3.4.2-6 - Hardness Values of Automatic Repaired Samples

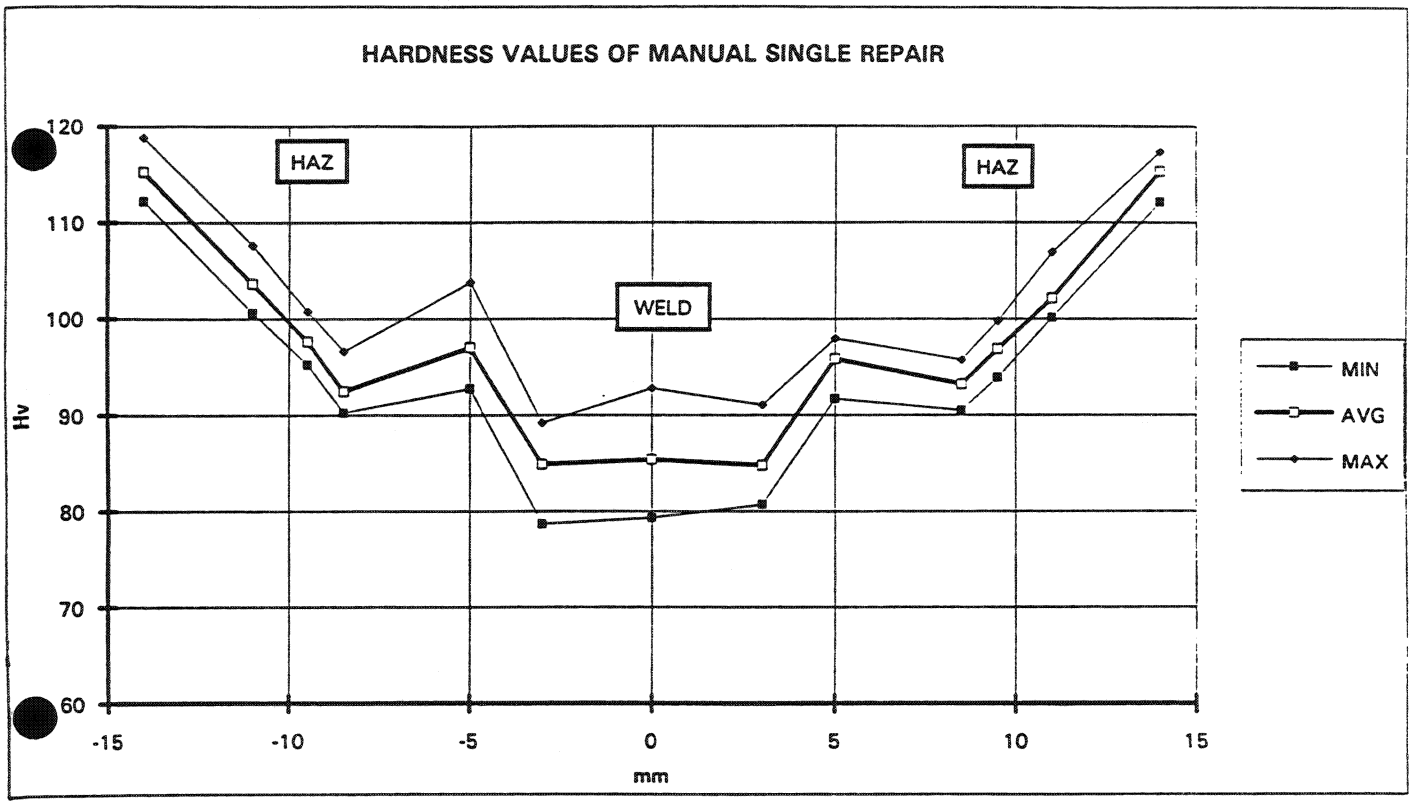


Fig. 3.4.2-7 - Hardness Values of Manual Repaired Samples (Single Repair)

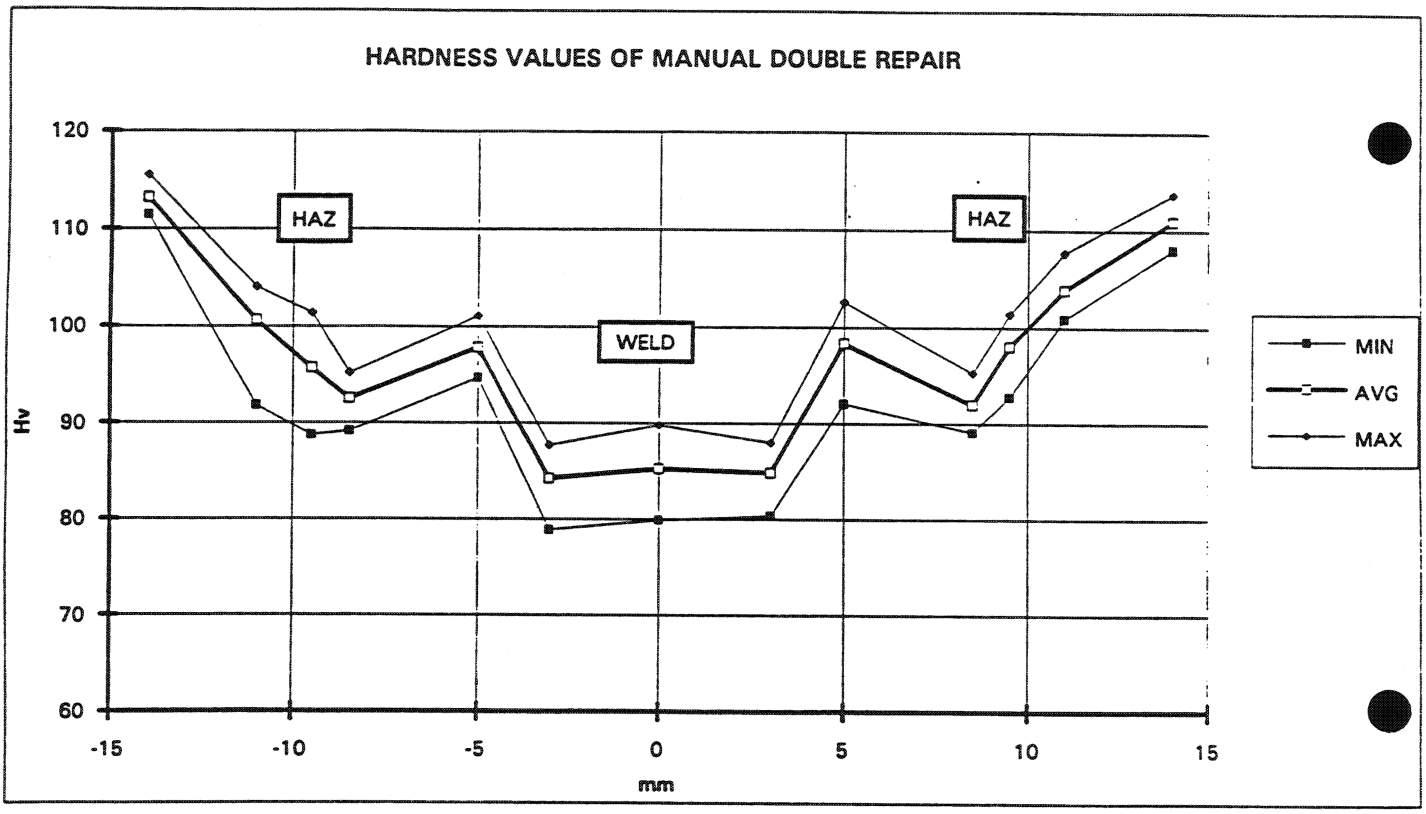


Fig. 3.4.2-8 - Hardness Values of Manual Repaired Samples (Double Repair)

3.4.3 Bead Geometry

The summary of the geometrical measurements of the welded joints is reported from Tab. 3.4.3-1 to Tab. 3.4.3-8.
Measured values show a good repeatability of the bead shape in the welds.
Values ranges are within the tolerances reported in the welding specification A.D.[9].

NOMINAL WELDING PARAMETERS (WITHOUT PEAKING AND MISMATCH					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
LAX001	1	9.8	2.1	7.3	1.4
	2	10.1	2	7.2	1.5
	3	10.1	2.2	7.2	1.4
	4	10.2	2.1	7.3	1.3
	5	10.2	1.9	7.2	1.3
LAX002	1	9.9	2.1	7	1.2
	2	10.2	2.1	7.1	1.3
	3	10.2	2.2	7.1	1.2
	4	10.4	2.1	7.3	1.2
	5	10.1	1.9	7.3	1.3
LAX003	1	10	2.15	7.4	1.3
	2	9.8	2.1	7.2	1.2
	3	10.1	2.1	7.2	1.2
	4	10.1	2.1	7.1	1.3
	5	10.2	2	7.3	1.4
LAX004	1	10	2	7.2	1.3
	2	9.7	2.1	7.2	1.4
	3	10.3	2.3	7.3	1.3
	4	10.3	2.15	7.1	1.3
	5	10.4	2	7.2	1.4
LAX005	1	10	2.1	7.4	1.2
	2	10.1	2.2	7.3	1.1
	3	10.1	2.3	7.1	1
	4	10	2.3	7.1	1.2
	5	9.8	2.1	7.3	1.1
LAX006	1	10	2	7.3	1.4
	2	10.1	2.1	7.2	1.4
	3	10.3	2.1	7.2	1.3
	4	10.4	2.2	7.1	1.4
	5	10.4	2.2	7.3	1.3
LAX008	1	10	2.1	7.2	1.4
	2	10.1	2.1	7.2	1.4
	3	10.1	2.1	7.2	1.4
	4	10.1	2.1	7.2	1.4
	5	10.1	2.1	7.2	1.4

Tab. 3.4.3-1 - Geometrical Examination Results of Beads

NOMINAL WELDING PARAMETERS (WITHOUT PEAKING AND MISMATCH)					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
LAX009	1	10.3	2	7.5	1.3
	2	10.1	2	7.4	1.2
	3	10.2	1.9	7.4	1.4
	4	10.4	2	7.5	1.4
	5	10.3	2	7.3	1.3
LAX010	1	10.1	2	7.3	1.2
	2	10	1.9	6.9	1.1
	3	10.2	2	7	1.3
	4	10.3	1.8	7.5	1.4
	5	9.8	1.6	7.2	1.2
LAX011	1	9.8	1.8	7.5	1.3
	2	9.8	2	7.6	1.4
	3	9.7	2	7.5	1.1
	4	9.7	1.9	7.6	1.4
	5	10	1.9	7.4	1.35
LAY001	1	9.6	2	7.2	1.4
	2	9.9	2.1	7.1	1.4
	3	9.8	2	7.3	1.3
	4	9.8	2.1	7.2	1.5
	5	9.6	1.9	7.2	1.4
LAY002	1	9.8	1.9	7.4	1.5
	2	10	2	7.4	1.4
	3	10.3	2	7.1	1.2
	4	9.5	2	7.2	1.4
	5	9.8	1.9	7.4	1.4
LAY003	1	9.8	2	7.2	1.4
	2	9.7	1.9	7.1	1.3
	3	9.8	2.1	7.2	1.4
	4	9.8	2.1	7.3	1.5
	5	9.9	1.9	7.3	1.3
LAY004	1	9.7	1.9	7.2	1.6
	2	10	2	7.1	1.4
	3	9.8	1.9	7.2	1.5
	4	9.7	2	7	1.4
	5	9.7	1.9	7.2	1.3

Tab. 3.4.3-1 (Cont'd) - Geometrical Examination Results of Beads

NOMINAL WELDING PARAMETERS (WITHOUT PEAKING AND MISMATCH)					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
LAY005	1	10.1	1.9	7.4	1.2
	2	10.1	2.1	7.3	1.3
	3	9.8	2	7.3	1.3
	4	10	2	7.1	1.4
	5	10.2	2	7.4	1.4
LAY006	1	10.1	2	7.3	1.4
	2	10.1	2.1	7.3	1.4
	3	10.1	2	7.2	1.3
	4	10.1	2.1	7.3	1.2
	5	10.1	2	7.4	1.3
LAY007	1	9.9	2	7.4	1.4
	2	10	2.1	7.3	1.4
	3	9.8	2.1	7.2	1.3
	4	9.8	2	7.3	1.4
	5	9.7	2	7.5	1.5
LAY008	1	9.6	2	7.3	1.5
	2	9.8	2.1	7.2	1.4
	3	9.7	2.1	7.1	1.5
	4	9.8	2	7.2	1.3
	5	9.8	1.9	7.2	1.4
LAY009	1	9.7	2	7.2	1.3
	2	10	2	7.1	1.6
	3	10	2	7.2	1.4
	4	10.1	2	7.1	1.3
	5	9.8	1.9	7.3	1.4
LAY010	1	9.9	1.8	7.1	1.3
	2	10.2	1.9	7.2	1.5
	3	10.3	2	7.3	1.5
	4	10	1.9	7.3	1.5
	5	9.8	1.9	7.4	1.5
LAY011	1	10.1	2	7.2	1.2
	2	10.2	2	7.1	1.2
	3	10	2.1	7.1	1.2
	4	10.3	2	7.2	1.3
	5	10.3	2	7.4	1.4

Tab. 3.4.3-1 (Cont'd) - Geometrical Examination Results of Beads

NOMINAL WELDING PARAMETERS (WITHOUT PEAKING AND MISMATCH)					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
LAY012	1	10.5	2	7.3	1.5
	2	9.8	2	7.2	1.6
	3	10.2	2	7.4	1.4
	4	9.8	2.1	7.2	1.5
	5	10	1.9	7.3	1.3
LAY013	1	10.1	2.1	7.2	1.4
	2	10.2	2	7.3	1.4
	3	9.8	1.9	7.2	1.3
	4	10.6	2	7.3	1.5
	5	9.8	1.9	7.4	1.4
LAY014	1	9.6	1.9	7.4	1.3
	2	9.8	2	7.3	1.4
	3	10.1	2	7.3	1.3
	4	9.8	1.9	7.4	1.3
	5	9.6	1.9	7.4	1.4
LAY015	1	10.2	1.9	7.2	1.4
	2	10	1.8	7.2	1.3
	3	9.8	1.9	7.3	1.4
	4	10.2	2	7.4	1.2
	5	10	1.9	7.2	1.4
LAY016	1	9.7	2.1	7.1	1.3
	2	10.1	2.1	7.3	1.4
	3	10.2	2.1	7.2	1.3
	4	9.8	2	7.2	1.3
	5	10	1.9	7.3	1.4
LAY017	1	9.8	1.9	7.1	1.2
	2	9.8	2	7.3	1.3
	3	10	2.1	7.2	1.3
	4	9.8	2	7.1	1.3
	5	9.7	2	7.3	1.3
LAY018	1	10.3	2	7	1.5
	2	9.8	2.1	7.3	1.3
	3	9.8	2	7.1	1.2
	4	9.8	2.1	7.1	1.4
	5	9.7	1.9	7.3	1.3

Tab. 3.4.3-1 (Cont'd) - Geometrical Examination Results of Beads

NOMINAL WELDING PARAMETERS (WITHOUT PEAKING AND MISMATCH)					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
LAY019	1	10	1.9	7.3	1.7
	2	10	1.95	7.3	1.7
	3	10.3	1.95	7.3	1.7
	4	10	1.95	7.3	1.7
	5	10	1.82	7.4	1.8
LAY020	1	9.7	1.7	7.3	1.6
	2	9.8	1.95	7.3	1.6
	3	9.8	2	7.2	1.7
	4	8.6	1.35	7.4	1.4
	5	10.4	1.8	7.3	1.7

Tab. 3.4.3-1 (Cont'd) - Geometrical Examination Results of Beads

NOMINAL WELDING PARAMETERS (WITH MISMATCH)					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
LEX001	1	9.9	2	7.1	1.25
	2	10	2.1	7.3	1.3
	3	10.3	2	7.3	1.3
	4	9.6	2	7.2	1.3
	5	10.3	1.9	7.3	1.35
LEX002	1	9.9	1.9	7.3	1.2
	2	10	2	7.5	1.3
	3	10.1	2	7.5	1.3
	4	10	1.9	7.6	1.4
	5	9.7	1.8	7.7	1.3

Tab. 3.4.3-2 - Geometrical Examination Results of Beads

NOMINAL WELDING PARAMETERS (WITH PEAKING)					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
LFX001	1	9.5	2	7.3	1.5
	2	9.5	2.1	7.2	1.45
	3	10	2.1	7.4	1.5
	4	9.5	2	7	1.4
	5	9.6	1.9	7.2	1.35
LFX002	1	9.6	2	7.5	1.1
	2	9	2	7	1.1
	3	9.5	2	7.2	1.2
	4	9.5	2.1	7.2	1.3
	5	9.7	2.1	7.2	1.1

Tab. 3.4.3-3 - Geometrical Examination Results of Beads

WELDS PERFORMED AT MINIMUM ENERGY					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
LGX003	1	9.1	2.45	5.5	0.8
	2	8.9	2.5	5.4	0.8
	3	9.2	2.5	5.7	0.6
	4	9.4	2.55	5.6	0.7
	5	9.3	2.4	6.2	0.8
LGX004	1	8.9	2.5	5.3	0.6
	2	9.2	2.5	5.5	0.7
	3	9.1	2.6	5.6	0.8
	4	9.4	2.5	5.5	0.7
	5	9.1	2.3	5.5	0.9

Tab. 3.4.3-4 - Geometrical Examination Results of Beads

WELDS PERFORMED AT MAXIMUM ENERGY					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
LHX001	1	9.3	1.8	8.6	1.8
	2	10.2	1.3	8.8	2
	3	10	1.6	8.2	2
	4	10	1.5	8.5	1.8
	5	10.2	1.5	9	1.6
LHX002	1	9.7	1.5	8.5	1.7
	2	9.75	1.6	8.8	1.7
	3	9.9	1.6	8.8	1.8
	4	9.8	1.5	8.4	1.8
	5	10	1.5	8.8	1

Tab. 3.4.3-5 - Geometrical Examination Results of Beads

AUTOMATIC CIRCUMFERENTIAL WELDING					
Serial Number	Point of Measurement	a (mm)	b (mm)	c (mm)	d (mm)
CAY001	1	10.1	1.9	1.7	7.1
	2	10.3	1.9	1.7	7
	3	10.1	2	1.7	7.2
CAY002	1	10.2	1.9	1.7	7.1
	2	9.7	1.9	1.8	7.3
	3	10.1	2.1	1.8	7
CAY003	1	9.9	1.8	1.6	7.2
	2	10.2	1.7	1.6	7.3
	3	10.4	1.9	1.7	7.2
CAY004	1	9.6	1.8	1.6	6.9
	2	9.8	1.8	1.7	7.2
	3	10.2	2.1	1.9	7.5
CAY005	1	10	1.8	1.7	7.2
	2	10.1	1.8	1.6	7.3
	3	10.1	1.7	1.7	7.2
CAY006	1	10.3	1.8	1.7	7.1
	2	10.1	1.8	1.7	7.4
	3	10.1	1.9	1.7	7.2
CAY007	1	9.8	1.9	1.6	7.2
	2	10.1	2	1.7	7.4
	3	10.2	1.9	1.7	6.9
CAY008	1	10.4	1.9	1.7	7.1
	2	9.9	1.7	1.6	7
	3	10.2	1.8	1.7	7.4
CAY009	1	10.2	1.9	1.7	7.2
	2	10.1	1.9	1.7	7.1
	3	9.8	1.8	1.7	7.1

Tab. 3.4.3-6 - Geometrical Examination Results of Beads

AUTOMATIC REPAIR WELDING							
		VIRGIN WELD				AFTER REPAIR	
Serial Number	Point of Measure	a (mm)	b (mm)	c (mm)	d (mm)	a (mm)	b (mm)
LBX007	1	10.5	2	1.7	7.5	13.2	1.8
	2	10.5	2	1.7	7.6	13.3	1.6
	3	10.7	2	1.6	7.3	13.2	1.7
	4	10.3	2	1.5	7.5	13.3	1.9
	5	10.2	2	1.7	7.5	13.3	1.8
LBX009	1	10.2	1.9	1.4	7.2	13.8	1.6
	2	10	1.7	1.6	7.2	13.4	1.8
	3	9.9	1.9	1.5	7.3	13.8	1.8
	4	10.5	1.8	1.5	7.2	13.7	1.9
	5	10.2	1.9	1.6	7.1	13.5	1.8
LBX010	1	10.1	1.9	1.6	7.2	13.4	1.5
	2	10.3	1.9	1.5	7.3	13.2	1.5
	3	10.2	1.9	1.4	7.4	13.6	1.6
	4	10.3	1.9	1.5	7.2	13.4	1.5
	5	10.2	1.9	1.5	7.3	13.4	1.7
LBX011	1	10.3	1.9	1.6	7.2	13.3	1.6
	2	10.4	2	1.6	7.3	13.7	1.5
	3	10.2	1.9	1.5	7.5	13.6	1.6
	4	10.2	1.8	1.6	7.2	13.8	1.6
	5	10.3	1.9	1.4	7.3	13.5	1.5
LBX012	1	9.8	1.9	1.6	7.4	11.3	2.3
	2	9.9	2.1	1.5	7.3	10.9	2.2
	3	9.8	2.1	1.5	7.4	11.1	2.1
	4	10.1	2	1.7	7.4	11.3	2.1
	5	10	1.9	1.6	7.6	11.3	2.2
LBX013	1	9.7	2	1.6	7.4	12.8	1.8
	2	9.9	1.9	1.7	7.3	12.9	1.8
	3	10.1	1.9	1.7	7.5	12.5	1.8
	4	9.9	2	1.6	7.7	12.7	1.9
	5	10.2	2.1	1.6	7.3	13.1	1.7

Tab. 3.4.3-7 - Geometrical Examination Results of Beads

AUTOMATIC REPAIR WELDING							
		VIRGIN WELD				AFTER REPAIR	
Serial Number	Point of Measure	a (mm)	b (mm)	c (mm)	d (mm)	a (mm)	b (mm)
LBX014	1	9.9	2	1.7	7.5	12.2	2
	2	9.9	2	1.6	7.4	12.7	2
	3	10.2	2.1	1.5	7.5	12.5	1.9
	4	10.3	2	1.5	7.6	12.8	2
	5	10.2	2	1.7	7.5	12	2.1
LBX015	1	9.8	1.9	1.6	7.4	12.1	1.9
	2	10.3	1.9	1.5	7.6	12.6	1.8
	3	10.3	2	1.6	7.5	12.2	1.9
	4	10.1	1.9	1.6	7.3	12.4	2
	5	10	2	1.7	7.3	12.5	1.9
LBY001	1	10.5	2	1.6	7.5	11.2	2.1
	2	10.4	2.2	1.6	7.7	11.4	2.2
	3	10.4	2.1	1.5	7.6	11.7	2.1
	4	10.7	2.1	1.6	7.7	11.3	2.1
	5	10.6	2.5	1.5	7.6	11.9	2.1
LBY002	1	9.8	1.9	1.7	7.6	12	1.9
	2	10.4	2	1.8	7.7	12.2	2
	3	10.3	2	1.7	7.9	11.9	1.9
	4	10	2	1.8	7.9	12.2	1.9
	5	10.2	1.9	1.8	7.7	12.3	1.9
LBY003	1	10.1	1.9	1.7	7.8	12.2	1.9
	2	10.5	2	1.8	7.8	11.9	1.7
	3	10.5	2.1	1.8	7.7	12	1.8
	4	10.4	2	1.8	7.8	12.3	1.8
	5	10	1.8	1.6	7.6	12.5	1.7
LBY004	1	10.1	2	1.6	7.3	11.8	2
	2	9.8	2	1.6	7.5	12.3	1.8
	3	10.3	2.1	1.7	7.7	12.5	1.7
	4	10.2	2.1	1.5	7.5	12.6	1.7
	5	9.6	2.2	1.6	7.5	12.4	1.8

Tab. 3.4.3-7 (Cont'd) - Geometrical Examination Results of Beads

AUTOMATIC REPAIR WELDING							
		VIRGIN WELD				AFTER REPAIR	
Serial Number	Point of Measure	a (mm)	b (mm)	c (mm)	d (mm)	a (mm)	b (mm)
LBY005	1	10.1	2	1.6	7.4	11.5	2
	2	10.2	2.1	1.7	7.6	11.5	2
	3	10.2	2	1.9	7.7	11.5	2
	4	10.3	2	1.7	7.6	11.5	2
	5	10.2	2	1.7	7.5	11.5	2
LBY006	1	10.3	2.1	1.7	7.5	11.9	2
	2	10.2	2	1.9	7.7	12.1	1.8
	3	10.1	2.1	1.7	7.6	12.3	1.9
	4	10.3	2.1	1.7	7.6	12.6	1.8
	5	10.2	1.9	1.8	7.5	12.5	1.8
LBY007	1	10.2	2.1	1.4	7.2	12	1.9
	2	10	2	1.6	7.5	12.2	1.9
	3	10.2	2.1	1.6	7.7	12.3	2
	4	10.1	2	1.6	7.6	12.5	1.8
	5	10	1.9	1.5	7.5	12.5	1.9
LBY008	1	10.3	2.1	1.6	7.4	11.2	2.1
	2	10.2	2.1	1.5	7.2	11.3	2
	3	10.2	2.2	1.3	7.4	11.3	1.9
	4	10.3	2	1.5	7.5	11.8	2
	5	10	1.9	1.6	7.5	12	2
LBY009	1	9.5	1.9	1.4	7.4	12.3	2
	2	10.1	2	1.6	7.3	12.5	1.8
	3	9.6	1.9	1.8	7.6	11.7	2
	4	10	1.9	1.7	7.5	12.4	1.7
	5	9.8	1.8	1.6	7.6	12.2	1.9
LBY010	1	9.9	1.9	1.7	7.5	12.1	1.8
	2	9.9	1.9	1.8	7.6	12.3	1.7
	3	9.8	2	1.7	7.4	11.9	1.8
	4	10	1.9	1.6	7.4	12.5	1.8
	5	10	2	1.7	7.5	12.2	1.7

Tab. 3.4.3-7 (Cont'd) - Geometrical Examination Results of Beads

AUTOMATIC REPAIR WELDING							
		VIRGIN WELDING				AFTER REPAIR	
Serial Number	Point of Measure	a (mm)	b (mm)	c (mm)	d (mm)	a (mm)	b (mm)
LBY012	1	10	1.8	1.5	7.5	11.8	1.8
	2	10.3	1.9	1.7	7.3	12.1	1.8
	3	10	2	1.4	7.5	12.1	1.9
	4	10	1.8	1.6	7.5	11.9	1.9
	5	9.5	1.7	1.5	7.4	12	1.8
LBY020	1	9.8	1.9	1.6	7.2	11.5	2.1
	2	9.6	1.8	1.5	7.3	11.8	1.9
	3	9.8	1.8	1.4	7.3	11.9	2
	4	9.7	1.9	1.5	7.4	12	2
	5	9.8	2	1.5	7.3	11.9	2
LBY023	1	9.7	2	1.6	7.3	12.1	1.9
	2	9.7	2	1.5	7.2	11.7	1.9
	3	9.8	1.9	1.7	7.2	12.3	1.7
	4	9.6	2	1.6	7.1	12	1.9
	5	9.9	1.9	1.7	7.2	11.8	1.8
LBY025	1	9.8	1.9	1.5	7.1	12.7	1.9
	2	9.9	2	1.7	7.2	12.5	1.8
	3	10.1	2	1.5	7	12.3	1.8
	4	9.7	1.8	1.5	7	12.6	1.9
	5	9.4	1.9	1.4	7.2	12.5	1.8

Tab. 3.4.3-7 (Cont'd) - Geometrical Examination Results of Beads

MANUAL SINGLE REPAIR					
Serial Number		a (mm)	b (mm)	c (mm)	d (mm)
LCX014	MIN	9.24	0.94	1.41	7.39
	AVG	10.64	1.60	1.61	12.61
	MAX	12.04	2.26	1.81	17.84
LCX016	MIN	9.30	0.96	1.36	7.37
	AVG	10.63	1.66	1.60	7.60
	MAX	11.96	2.36	1.84	7.83
LCX017	MIN	9.21	0.97	1.36	7.37
	AVG	10.56	1.66	1.61	7.61
	MAX	11.91	2.34	1.86	7.84
LCX018	MIN	9.23	0.93	1.36	7.33
	AVG	10.62	1.64	1.60	7.56
	MAX	12.01	2.36	1.84	7.80
LCX019	MIN	9.30	0.97	1.37	7.37
	AVG	10.70	1.67	1.62	7.62
	MAX	12.10	2.37	1.87	7.87
LCX020	MIN	9.30	0.97	1.37	7.37
	AVG	10.67	1.67	1.60	7.62
	MAX	12.03	2.37	1.83	7.87

Tab. 3.4.3-8 - Geometrical Examination Results of Beads

MANUAL SINGLE REPAIR					
Serial Number		a (mm)	b (mm)	c (mm)	d (mm)
LCX021	MIN	9.27	0.97	1.37	7.37
	AVG	10.60	1.67	1.62	7.62
	MAX	11.93	2.37	1.87	7.87
LCX022	MIN	9.23	0.97	1.37	7.33
	AVG	10.62	1.67	1.60	7.58
	MAX	12.00	2.37	1.83	7.83
LCX023	MIN	9.30	0.97	1.33	7.37
	AVG	10.63	1.67	1.58	7.62
	MAX	11.97	2.37	1.83	7.87
LCX024	MIN	9.30	0.97	1.33	7.33
	AVG	10.62	1.65	1.58	7.60
	MAX	11.93	2.33	1.83	7.87
LCY013	MIN	9.20	0.97	1.20	7.33
	AVG	10.63	1.67	1.50	7.57
	MAX	12.07	2.37	1.80	7.80
LCY014	MIN	9.30	1.00	1.23	7.30
	AVG	10.62	1.68	1.55	7.57
	MAX	11.93	2.37	1.87	7.83

Tab. 3.4.3-8 (Cont'd) - Geometrical Examination Results of Beads

MANUAL SINGLE REPAIR					
Serial Number		a (mm)	b (mm)	c (mm)	d (mm)
LCY019	MIN	9.43	0.87	1.33	7.37
	AVG	10.68	1.65	1.58	7.60
	MAX	11.93	2.43	1.83	7.83
LCY020	MIN	9.20	0.97	1.37	7.37
	AVG	10.63	1.65	1.60	7.60
	MAX	12.07	2.33	1.83	7.83
LCY021	MIN	9.30	1.00	1.33	7.37
	AVG	10.62	1.65	1.58	7.60
	MAX	11.93	2.30	1.83	7.83
LCY022	MIN	9.13	0.97	1.33	7.33
	AVG	10.57	1.65	1.58	7.57
	MAX	12.00	2.33	1.83	7.80
LCY023	MIN	9.17	0.97	1.43	7.37
	AVG	10.57	1.67	1.63	7.63
	MAX	11.97	2.37	1.83	7.90
LCY024	MIN	9.23	0.97	1.43	7.37
	AVG	10.60	1.67	1.63	7.60
	MAX	11.97	2.37	1.83	7.83

Tab. 3.4.3-8 (Cont'd) - Geometrical Examination Results of Beads

MANUAL SINGLE REPAIR					
Serial Number		a (mm)	b (mm)	c (mm)	d (mm)
LCY025	MIN	9.30	0.97	1.43	7.30
	AVG	10.65	1.63	1.65	7.58
	MAX	12.00	2.30	1.87	7.87
LCY026	MIN	9.17	0.97	1.37	7.43
	AVG	10.53	1.68	1.62	7.62
	MAX	11.90	2.40	1.87	7.80
LCY027	MIN	9.07	0.93	1.37	7.37
	AVG	10.53	1.65	1.62	7.60
	MAX	12.00	2.37	1.87	7.83
LCY028	MIN	9.20	0.93	1.30	7.37
	AVG	10.48	1.65	1.57	7.60
	MAX	11.77	2.37	1.83	7.83
LCY029	MIN	9.23	1.00	1.37	7.37
	AVG	10.63	1.63	1.60	7.62
	MAX	12.03	2.27	1.83	7.87
LCY030	MIN	9.13	0.97	1.40	7.37
	AVG	10.55	1.67	1.62	7.60
	MAX	11.97	2.37	1.83	7.83

Tab. 3.4.3-8 (Cont'd) - Geometrical Examination Results of Beads

MANUAL SINGLE REPAIR					
Serial Number		a (mm)	b (mm)	c (mm)	d (mm)
LCY031	MIN	9.07	0.60	1.67	7.00
	AVG	9.40	0.80	1.83	7.47
	MAX	9.73	1.00	2.00	7.93
LCY032	MIN	9.00	0.57	1.70	6.90
	AVG	9.48	0.82	1.87	7.60
	MAX	9.97	1.07	2.03	8.30
LCY033	MIN	9.20	0.77	1.73	7.10
	AVG	9.83	1.03	1.93	7.70
	MAX	10.47	1.30	2.13	8.30

Tab. 3.4.3-8 (Cont'd) - Geometrical Examination Results of Beads

MANUAL DOUBLE REPAIR						
Serial Number	Repair Number		a (mm)	b (mm)	c (mm)	d (mm)
LDX001	1 st	MIN	9.34	0.77	1.29	7.26
		AVG	10.54	1.55	1.54	7.52
		MAX	11.74	2.33	1.79	7.79
	2 nd	MIN	9.27	0.87	1.37	7.33
		AVG	10.60	1.61	1.61	7.57
		MAX	11.93	2.34	1.84	7.81
LDX002	1 st	MIN	9.39	0.81	1.26	7.23
		AVG	10.56	1.59	1.52	7.47
		MAX	11.74	2.36	1.79	7.71
	2 nd	MIN	9.29	0.96	1.34	7.43
		AVG	10.63	1.67	1.59	7.64
		MAX	11.97	2.39	1.84	7.84
LDX003	1 st	MIN	9.33	0.77	1.30	7.30
		AVG	10.50	1.53	1.55	7.54
		MAX	11.67	2.29	1.80	7.79
	2 nd	MIN	9.27	0.93	1.34	7.30
		AVG	10.61	1.64	1.58	7.56
		MAX	11.96	2.36	1.81	7.83
LDX004	1 st	MIN	9.37	0.74	1.30	7.33
		AVG	10.49	1.53	1.52	7.55
		MAX	11.61	2.31	1.74	7.77
	2 nd	MIN	9.27	0.94	1.34	7.33
		AVG	10.62	1.66	1.60	7.59
		MAX	11.97	2.39	1.86	7.84

Tab. 3.4.3-9 - Geometrical Examination Results of Beads

MANUAL DOUBLE REPAIR						
Serial Number	Repair Number		a (mm)	b (mm)	c (mm)	d (mm)
LDX005	1 st	MIN	9.30	0.77	1.26	7.26
		AVG	10.51	1.54	1.51	7.52
		MAX	11.71	2.31	1.76	7.79
	2 nd	MIN	9.30	0.96	1.43	7.33
		AVG	10.61	1.66	1.64	7.57
		MAX	11.93	2.36	1.86	7.81
LDX006	1 st	MIN	10.43	1.03	1.27	7.23
		AVG	11.33	1.65	1.57	7.47
		MAX	12.23	2.27	1.87	7.71
	2 nd	MIN	9.37	0.87	1.37	7.43
		AVG	10.55	1.62	1.60	7.64
		MAX	11.73	2.37	1.83	7.84
LDX007	1 st	MIN	10.07	0.90	1.27	7.30
		AVG	10.87	1.60	1.55	7.54
		MAX	11.67	2.30	1.83	7.79
	2 nd	MIN	9.37	0.93	1.40	7.30
		AVG	10.63	1.68	1.63	7.56
		MAX	11.90	2.43	1.87	7.83
LDX008	1 st	MIN	9.70	0.83	1.87	7.33
		AVG	10.45	1.57	3.15	7.55
		MAX	11.20	2.30	4.43	7.77
	2 nd	MIN	9.40	0.97	1.33	7.33
		AVG	10.62	1.65	1.60	7.59
		MAX	11.83	2.33	1.87	7.84

Tab. 3.4.3-9 (Cont'd) - Geometrical Examination Results of Beads

MANUAL DOUBLE REPAIR						
Serial Number	Repair Number		a (mm)	b (mm)	c (mm)	d (mm)
LDX009	1 st	MIN	9.87	0.73	1.20	7.30
		AVG	10.68	1.48	1.48	7.58
		MAX	11.50	2.23	1.77	7.87
	2 nd	MIN	9.37	0.97	1.43	7.40
		AVG	10.68	1.68	1.63	7.62
		MAX	12.00	2.40	1.83	7.83
LDX010	1 st	MIN	9.53	0.83	1.17	7.43
		AVG	10.57	1.58	1.50	7.65
		MAX	11.60	2.33	1.83	7.87
	2 nd	MIN	9.20	0.87	1.37	7.43
		AVG	10.65	1.63	1.62	7.65
		MAX	12.10	2.40	1.87	7.87
LDX011	1 st	MIN	9.27	0.83	1.23	7.33
		AVG	10.52	1.55	1.53	7.58
		MAX	11.77	2.27	1.83	7.87
	2 nd	MIN	9.77	0.93	1.37	7.30
		AVG	10.83	1.65	1.58	7.58
		MAX	11.90	2.37	1.80	7.87
LDY001	1 st	MIN	9.33	0.87	1.23	7.23
		AVG	10.53	1.62	1.50	7.50
		MAX	11.73	2.37	1.77	7.77
	2 nd	MIN	9.33	0.97	1.37	7.40
		AVG	10.63	1.65	1.58	7.62
		MAX	11.93	2.33	1.80	7.83

Tab. 3.4.3-9 (Cont'd) - Geometrical Examination Results of Beads

MANUAL DOUBLE REPAIR						
Serial Number	Repair Number		a (mm)	b (mm)	c (mm)	d (mm)
LDY002	1 st	MIN	9.27	0.87	1.17	7.23
		AVG	10.43	1.62	1.47	7.48
		MAX	11.60	2.37	1.77	7.73
	2 nd	MIN	9.27	0.93	1.37	7.37
		AVG	10.58	1.67	1.60	7.60
		MAX	11.90	2.40	1.83	7.83
LDY003	1 st	MIN	9.30	0.87	1.23	7.33
		AVG	10.57	1.58	1.48	7.53
		MAX	11.83	2.30	1.73	7.73
	2 nd	MIN	9.13	0.93	1.43	7.37
		AVG	10.53	1.67	1.65	7.58
		MAX	11.93	2.40	1.87	7.80
LDY004	1 st	MIN	9.37	0.97	1.13	7.30
		AVG	10.65	1.67	1.48	7.53
		MAX	11.93	2.37	1.83	7.77
	2 nd	MIN	9.40	0.87	1.37	7.37
		AVG	10.65	1.62	1.58	7.62
		MAX	11.90	2.37	1.80	7.87
LDY005	1 st	MIN	9.47	1.03	1.27	7.37
		AVG	10.72	1.70	1.55	7.58
		MAX	11.97	2.37	1.83	7.80
	2 nd	MIN	9.30	0.83	1.43	7.33
		AVG	10.63	1.60	1.63	7.58
		MAX	11.97	2.37	1.83	7.83

Tab. 3.4.3-9 (Cont'd) - Geometrical Examination Results of Beads

MANUAL DOUBLE REPAIR						
Serial Number	Repair Number		a (mm)	b (mm)	c (mm)	d (mm)
LDY006	1 st	MIN	9.23	0.93	1.23	7.37
		AVG	10.68	1.62	1.52	7.57
		MAX	12.13	2.30	1.80	7.77
	2 nd	MIN	9.23	0.93	1.43	7.37
		AVG	10.57	1.65	1.65	7.60
		MAX	11.90	2.37	1.87	7.83
LDY007	1 st	MIN	9.40	1.00	1.23	7.17
		AVG	10.73	1.68	1.50	7.50
		MAX	12.07	2.37	1.77	7.83
	2 nd	MIN	9.27	0.97	1.37	7.37
		AVG	10.60	1.67	1.62	7.60
		MAX	11.93	2.37	1.87	7.83
LDY008	1 st	MIN	9.20	0.97	1.23	7.33
		AVG	10.53	1.67	1.52	7.57
		MAX	11.87	2.37	1.80	7.80
	2 nd	MIN	9.30	0.97	1.33	7.37
		AVG	10.60	1.67	1.58	7.60
		MAX	11.90	2.37	1.83	7.83
LDY009	1 st	MIN	9.40	1.03	1.30	7.23
		AVG	10.70	1.68	1.57	7.55
		MAX	12.00	2.33	1.83	7.87
	2 nd	MIN	9.47	0.87	1.43	7.37
		AVG	10.72	1.62	1.63	7.57
		MAX	11.97	2.37	1.83	7.77

Tab. 3.4.3-9 (Cont'd) - Geometrical Examination Results of Beads

MANUAL DOUBLE REPAIR					
Serial Number	Repair Number	a (mm)	b (mm)	c (mm)	d (mm)
LDY010	1 st MIN	9.73	0.90	1.27	7.33
	1 st AVG	10.78	1.63	1.52	7.57
	1 st MAX	11.83	2.37	1.77	7.80
	2 nd MIN	9.33	0.97	1.33	7.37
	2 nd AVG	10.65	1.67	1.60	7.62
	2 nd MAX	11.97	2.37	1.87	7.87
LDY011	1 st MIN	9.77	0.73	1.37	7.27
	1 st AVG	10.77	1.52	1.55	7.55
	1 st MAX	11.77	2.30	1.73	7.83
	2 nd MIN	9.27	0.97	1.27	7.37
	2 nd AVG	10.62	1.67	1.57	7.60
	2 nd MAX	11.97	2.37	1.87	7.83
LDY012	1 st MIN	9.70	0.80	1.37	7.33
	1 st AVG	10.83	1.60	1.57	7.60
	1 st MAX	11.97	2.40	1.77	7.87
	2 nd MIN	9.20	0.97	1.40	7.30
	2 nd AVG	10.57	1.67	1.63	7.57
	2 nd MAX	11.93	2.37	1.87	7.83
LDY013	1 st MIN	9.63	0.87	1.40	7.37
	1 st AVG	10.70	1.58	1.62	7.62
	1 st MAX	11.77	2.30	1.83	7.87
	2 nd MIN	9.23	0.93	1.37	7.27
	2 nd AVG	10.57	1.67	1.60	7.57
	2 nd MAX	11.90	2.40	1.83	7.87
LDY014	1 st MIN	9.67	0.83	1.47	7.37
	1 st AVG	10.82	1.60	1.65	7.62
	1 st MAX	11.97	2.37	1.83	7.87
	2 nd MIN	9.30	0.90	1.37	7.37
	2 nd AVG	10.63	1.65	1.60	7.58
	2 nd MAX	11.97	2.40	1.83	7.80

Tab. 3.4.3-9 (Cont'd) - Geometrical Examination Results of Beads

3.4.4

Micro/Macro Examination

Automatic Welding

Macroexamination : Regular bead showing a width ratio torch side/root side of approx. 1.4.

Microexamination : Dendritic microstructure typical of high cooling rates without any dicontinuity.
No significant modification in H.A.Z. (Heat Affected Zone) feature was observed.
No appreciable internal defects were detected.
All the documentation is reported in Annex 1 of this document - Alenia Spazio Laboratorio Test Report, A.D.[10].

Automatic Welding with Mismatch

Macroexamination : Regular bead affected by imposed mismatch

Microexamination : Evaluation comparable to virgin weld.
All the documentation is reported in Annex 1 of this document - Alenia Spazio Laboratorio Test Report, A.D.[10].

Automatic Welding with Peaking

Macroexamination : Regular bead affected by imposed peaking

Microexamination : Evaluation comparable to virgin weld.
All the documentation is reported in Annex 1 of this document - Alenia Spazio Laboratorio Test Report, A.D.[10].

Automatic Welding at Minimum Energy

Macroexamination : Regular bead showing a width ratio torch side/root side of approx. 1.8 demonstrating a bead restriction at root side with respect to normal condition due to welding energy reduction.

Microexamination : Dendritic microstructure without metallurgical discontinuities associated to high cooling rates typical of plasma welding.
No relevant modification in H.A.Z. feature was observed.
Few isolated micropores lower than 0.1 mm in size were found in the melted material, mainly in torch side position.
All the documentation is reported in Annex 1 of this document - Alenia Spazio Laboratorio Test Report, A.D.[10].

Automatic Welding at Maximum Energy

Macroexamination : Regular bead showing a width ratio torch side/root side of approx. 1.3 demonstrating a bead tendency to a rectangular shape due to energy increase.

Microexamination : Dendritic microstructure without metallurgical discontinuities associated to high cooling rates typical of plasma welding.
Very slight modifications of grain boundary feature were observed in H.A.Z.
All the documentation is reported in Annex 1 of this document - Alenia Spazio Laboratorio Test Report, A.D.[10].

Automatic Welding followed by Manual Single Repair

Macroexamination : Regular bead showing a width ratio torch side/root side of approx. 1.3.

Microexamination : Dendritic microstructure without metallurgical discontinuities typical of high cooling rate.
No significative modifications in H.A.Z. feature were noted.
No appreciable internal defects were observed.
All the documentation is reported in Annex 2 of this document - Alenia Spazio Laboratorio Test Report, A.D.[11].

Automatic Welding followed by Manual Double Repair

Macroexamination : Satisfactory bead geometry even after manual double repair.
No appreciable defects are present.
The width ratio between torch side and root side varies between 0.8 and 1.07.

Microexamination : Regular dendritic microstructure in the fused zone and typical microstructure in the H.A.Z.
No appreciable internal defects are present.
All the documentation is reported in Annex 2 of this document - Alenia Spazio Laboratorio Test Report, A.D.[11].

Automatic Welding followed by Automatic Repair

Macroexamination : Satisfactory bead geometry even after automatic repair.
No appreciable internal defects are present.
The width ratio between torch side and root side varies between 1.87 and 2.28.

Microexamination : Regular dendritic microstructure in the fused zone and typical microstructure in the H.A.Z.
No appreciable internal defects are present.
All the documentation is reported in Annex 2 of this document - Alenia Spazio Laboratorio Test Report, A.D.[11].

3.4.5 Susceptibility to Stress Corrosion Cracking

Test of the susceptibility to stress corrosion cracking were carried out according to ESA specification PSS-01-737, A.D.[13].
Nine tensile specimens, "Dogbone type", were tested in the following conditions :

- N.3 control specimens (un-stressed and un-corroded)
- N.3 stressed specimens (at 75% of yield strength) exposed for thirty days to corrosive environment
- N.3 un-stressed specimens exposed for thirthy days to the same corrosive environment

for each type of welding configuration as described below.

The corrosive environment was a 3.5% sodium chloride solution, where the specimens were alternative exposed for thirty days, ten minutes in each hour.
A sketch of the equipment is shown in Fig. 3.4.5-1.
The specimens were tested in the following conditions :

- Automatic welded - Specimen Identification : LAX
- Automatic welded and automatic repaired welded - Specimen Identification : LBX
- Automatic welded and manual repaired welded (single repair) - Specimen Identification : LCX
- Automatic welded and manual repaired welded (double repair) - Specimen Identification : LDX

Specimens have been cut from welded samples (size : 600x1000 mm).

3.4.5.1 Test Results

3.4.5.1.1 Tensile Tests

No specimen failure was observed during the tests.
Test results, ultimate strength (σu), yield strength (σy) and elongation, are reported in Tab. 3.4.5.1-1.
Ultimate strength is not affected by the repair welding (either automatic or manual) and by the corrosive environment exposure.
Yield strength decreases after automatic repair welding, while is constant after manual repair welding (single and double). Same behaviour for elongation.
More detailed documentation is reported in Annex 3 of this document - Aerospace Engineering Department of PISA UNIVERSITY, A.D.[14].

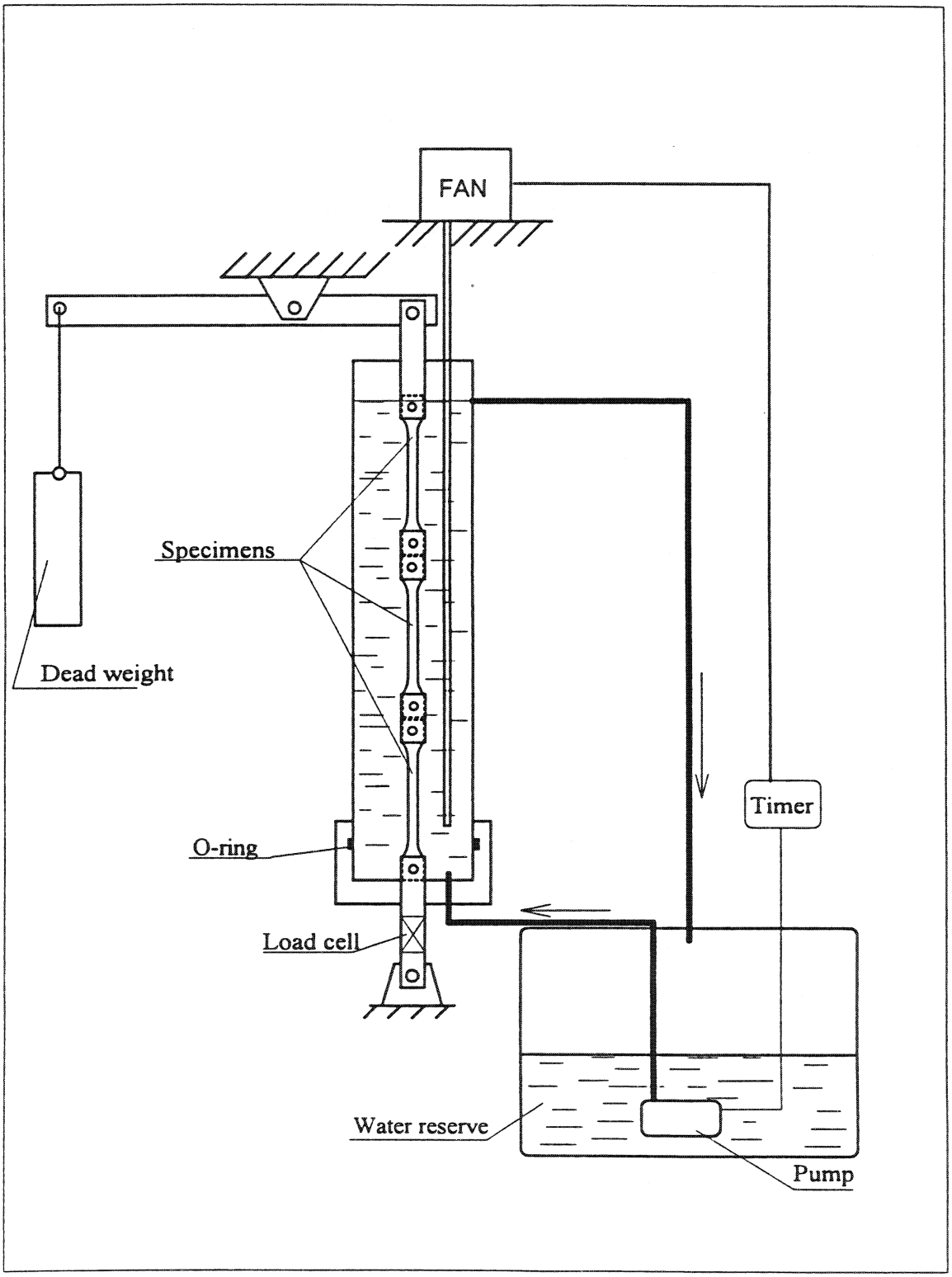
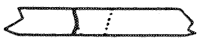
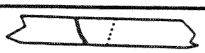
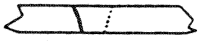
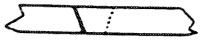
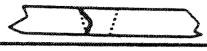
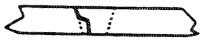
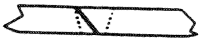
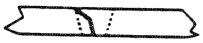
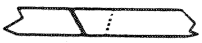
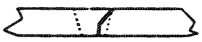
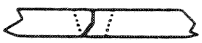
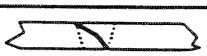
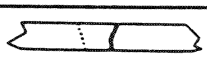
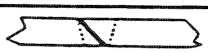
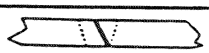


Fig. 3.4.5-1 - Scheme of the Test Equipment

Specimen Status	Specimen Identification	σy (MPa)	σu (MPa)	Elong. (%)	Failure Mode
Stressed and corroded	LAX-011-L001	168	261	3.8	
	LAX-011-L002	168	264	4.8	
Un-stressed and corroded	LAX-011-L004	178	264	2.4	
	LAX-011-L005	162	252	3.6	
Un-stressed and un-corroded	LAX-011-L007	164	269	5.9	
	LAX-011-L009	165	276	5.9	
Stressed and corroded	LBX-012-L001	129	266	4.1	
	LBX-012-L002	126	256	3.8	
Un-stressed and corroded	LBX-012-L004	126	259	4.1	
	LBX-012-L005	131	245	3.7	
Un-stressed and un-corroded	LBX-012-L007	132	273	5.4	
	LBX-012-L008	130	276	5.3	
Stressed and corroded	LCX-016-L001	182	275	4.0	
	LCX-016-L002	168	265	3.9	
Un-stressed and corroded	LCX-016-L004	175	270	4.2	
	LCX-016-L005	179	269	3.6	
Un-stressed and un-corroded	LCX-016-L008	177	277	4.4	
	LCX-016-L009	178	278	4.1	
Stressed and corroded	LDX-005-L001	172	263	5.4	
	LDX-005-L002	164	265	4.9	
Un-stressed and corroded	LDX-005-L004	161	266	5.4	
	LDX-005-L005	175	269	4.6	
Un-stressed and un-corroded	LDX-005-L007	173	272	4.6	
	LDX-005-L008	179	273	4.0	
	LDX-005-L009	178	263	5.2	

Tab. 3.4.5.1.1-1 - Static Test Results

3.4.5.1.2

Macroscopic Examination

Pitting and exfoliation were observed, either in stressed or in un-stressed condition, in the H.A.Z. (Heat Affected Zone) particularly (Fig. 3.4.5.1.2-1).
This phenomenon is diffused in virgin welded specimens, scattered in automatic and manual (single) repaired specimens and pratically absent in manual (double) repaired specimens.
As shown in Tab. 3.4.5.1.1-1, failure mode is always in the bead, due to lower strength properties of the bead with respect to the parent material.
The corrosive environment exposure has determined the type of the failure.
Stressed virgin welded specimens show many cracks in the bead and in the H.A.Z. (Heat Affected Zone) (see Fig. 3.4.5.1.2-2) after corrosive environment exposure.
Un-stressed virgin welded specimens show few cracks after corrosive environment exposure (see Fig. 3.4.5.1.2-3) and, as usual, not exposed specimens have the typical failure after tension testing (see Fig. 3.4.5.1.2-4).
Failure of un-corroded specimens is always in the bead, while it is in the H.A.Z. in corroded specimens (see Tab. 3.4.5.1.1-1 Failure Mode). This means that the Heat Affected Zone is more susceptible to the corrosion environment with respect to the bead.
More detailed documentation is reported in Annex 3 of this document - Aerospace Engineering Department of PISA UNIVERSITY, A.D.[14].

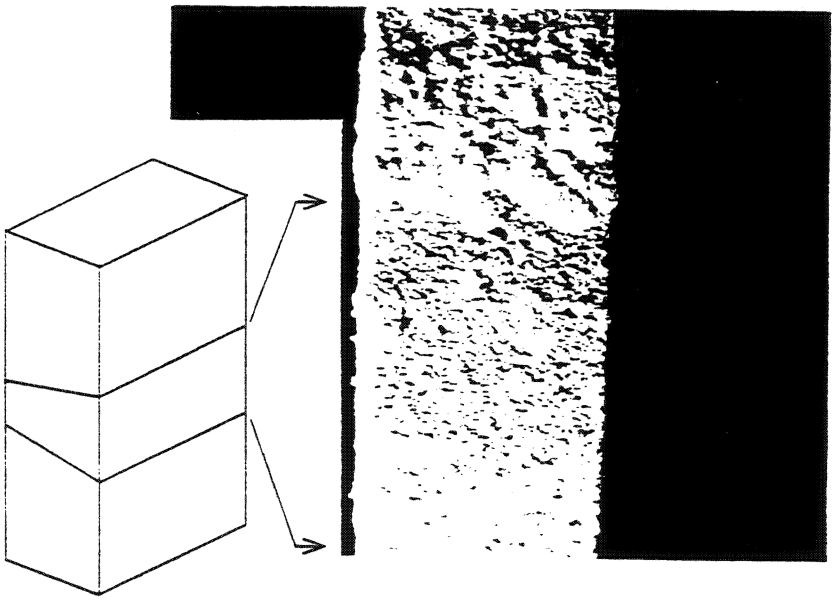
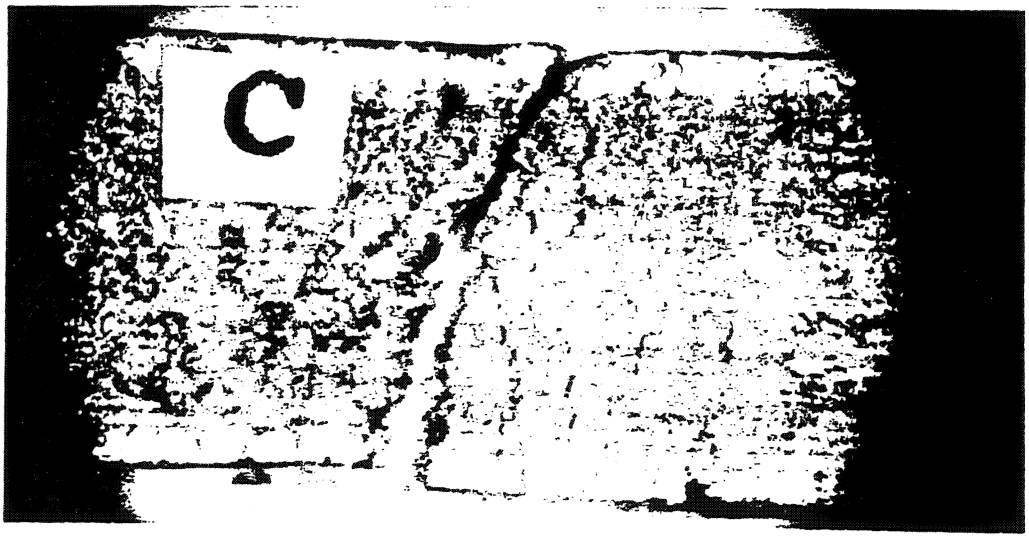


Fig. 3.4.5.1.2-1 - Macrographic Examination of Welded Specimen after Corrosive Environment Exposure

LAX

Fig. 3.4.5.1.2-2 - Failure Mode of Stressed-Corroded Welded Specimens after Tension Testing



LAX

Fig. 3.4.5.1.2-3 - Failure Mode of Corroded Welded Specimen after Tension Testing

3.4.5.1.3

Microscopic Examination

Virgin welded specimens show intergranular corrosion after corrosive environment exposure (see Fig. 3.4.5.1.3-1 and 3.4.5.1.3-2). Microstructure of the base material is shown in Fig. 3.4.5.1.3-3.
Automatic repaired specimens are more susceptible to the intergranular corrosion, as shown in Fig. 3.4.5.1.3-4 and Fig. 3.4.5.1.3-5 and this phenomenon increases in the single manual repaired specimens (see Fig. 3.4.5.1.3-6 and Fig. 3.4.5.1.3-7).
The intergranular corrosion disappears in double manual repaired specimens, where very little corrosion pits are present (Fig. 3.4.5.1.3-8).
The further heat input given to the material by the second repair welding seems to have a good effect about the stress corrosion resistance of the material.
More detailed documentation is reported in the Annex 3 of this document - Aerospace Engineering Department of PISA UNIVERSITY, A.D.[14].

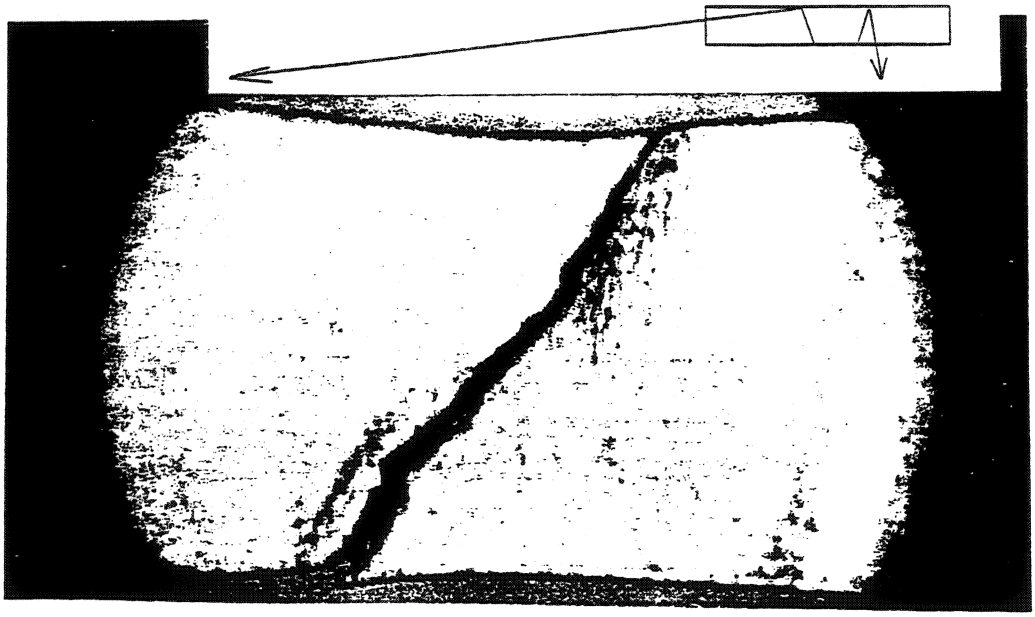


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Fig. 3.4.5.1.2-4 - Failure Mode of Un-Stressed and Un-Corroded Welded Specimen after Tension Testing

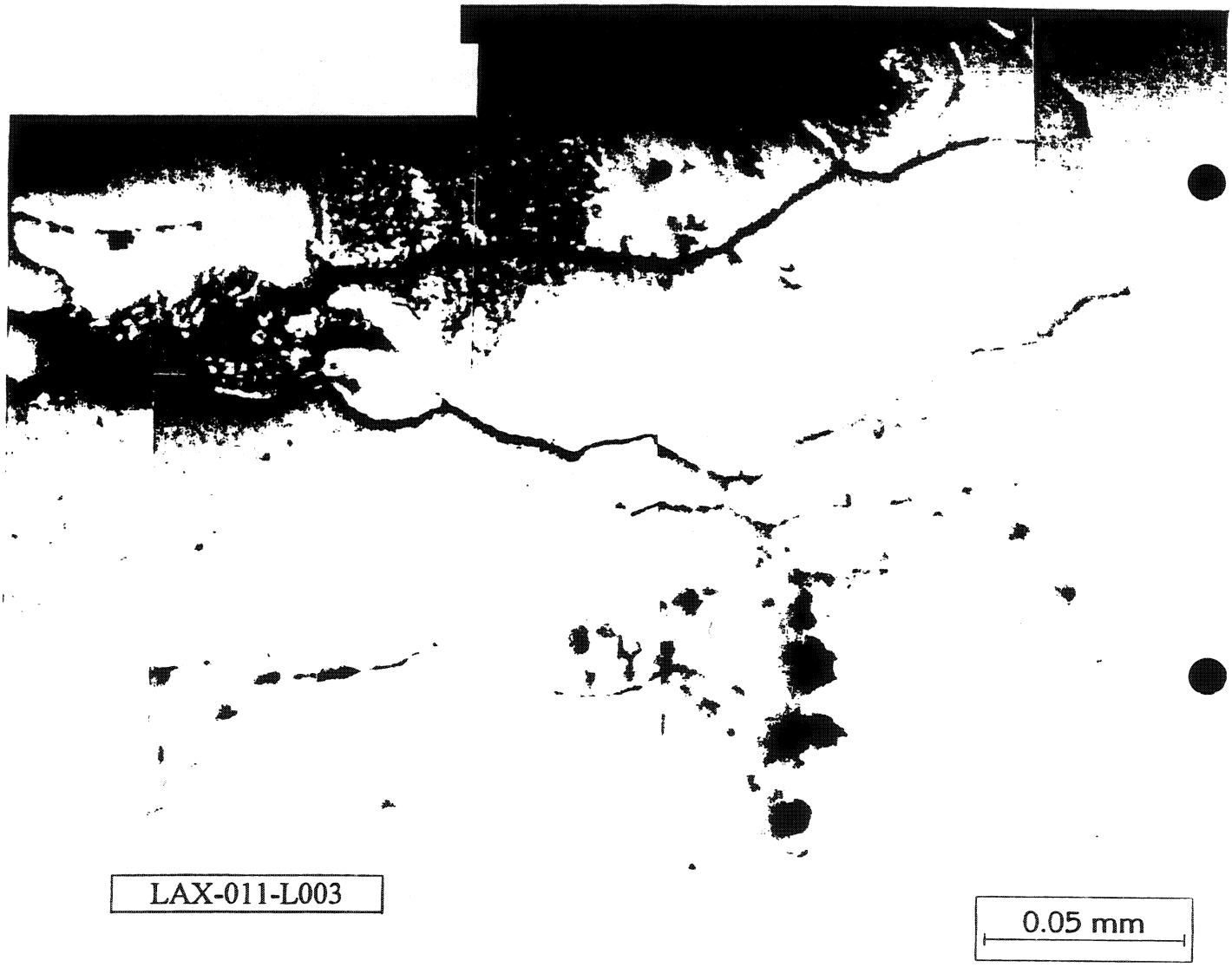


Fig. 3.4.5.1.3-1 - Microstructure of Stressed-Corroded Specimen (Virgin Welded)

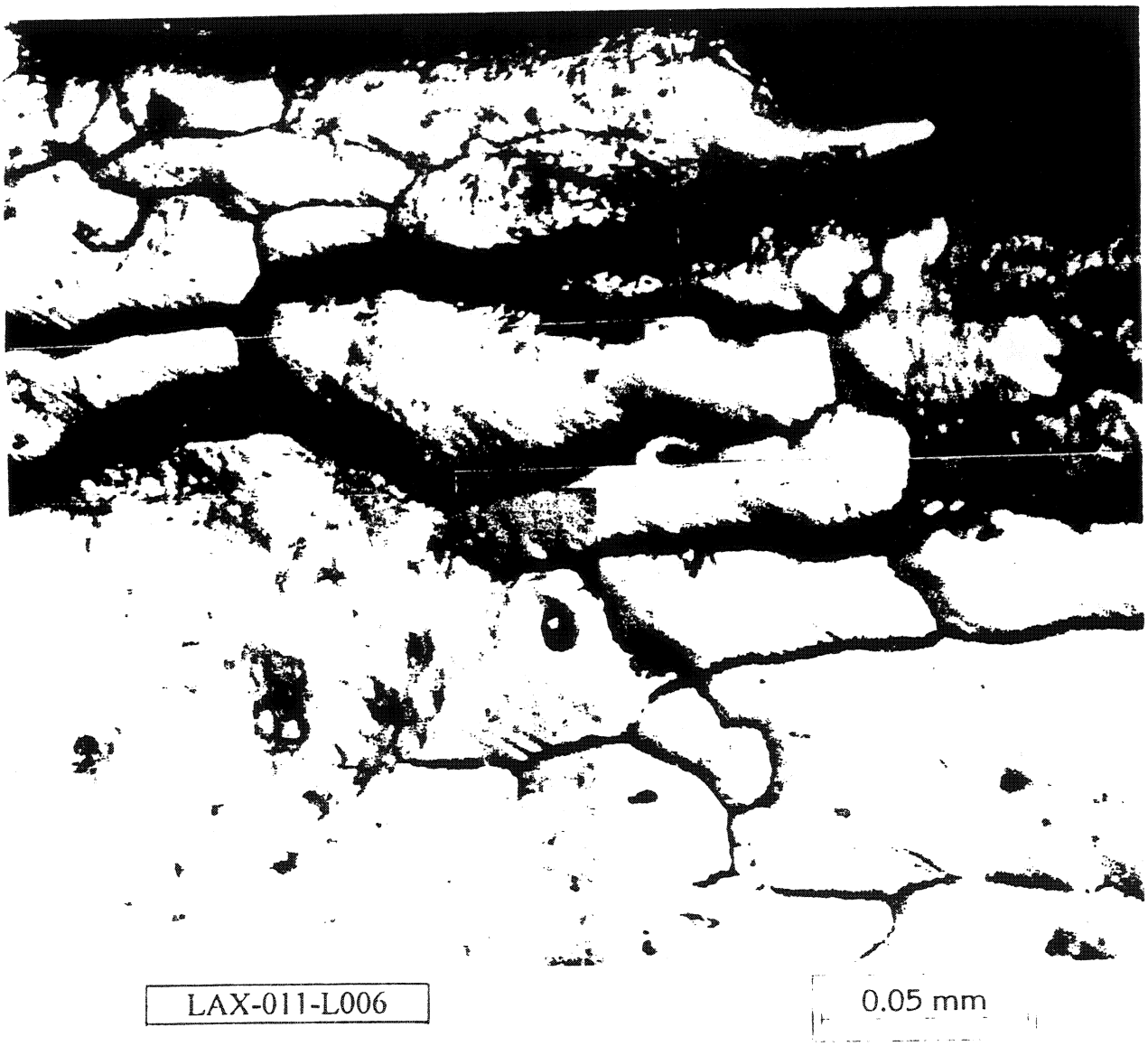


Fig. 3.4.5.1.3-2 - Microstructure of Corroded Specimen (Virgin Welded)

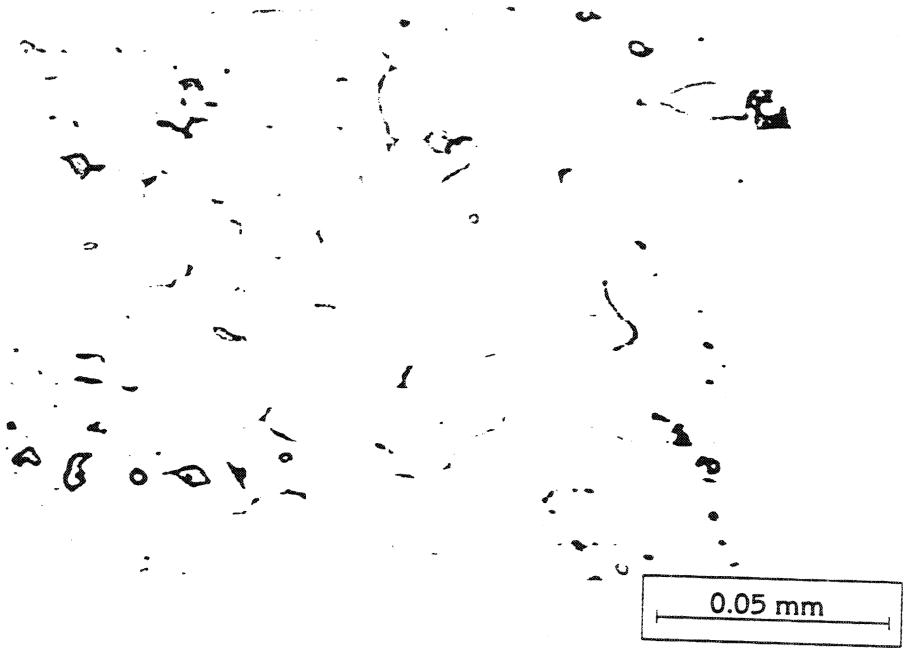


Fig. 3.4.5.1.3-3 - Microstructure of Base Material

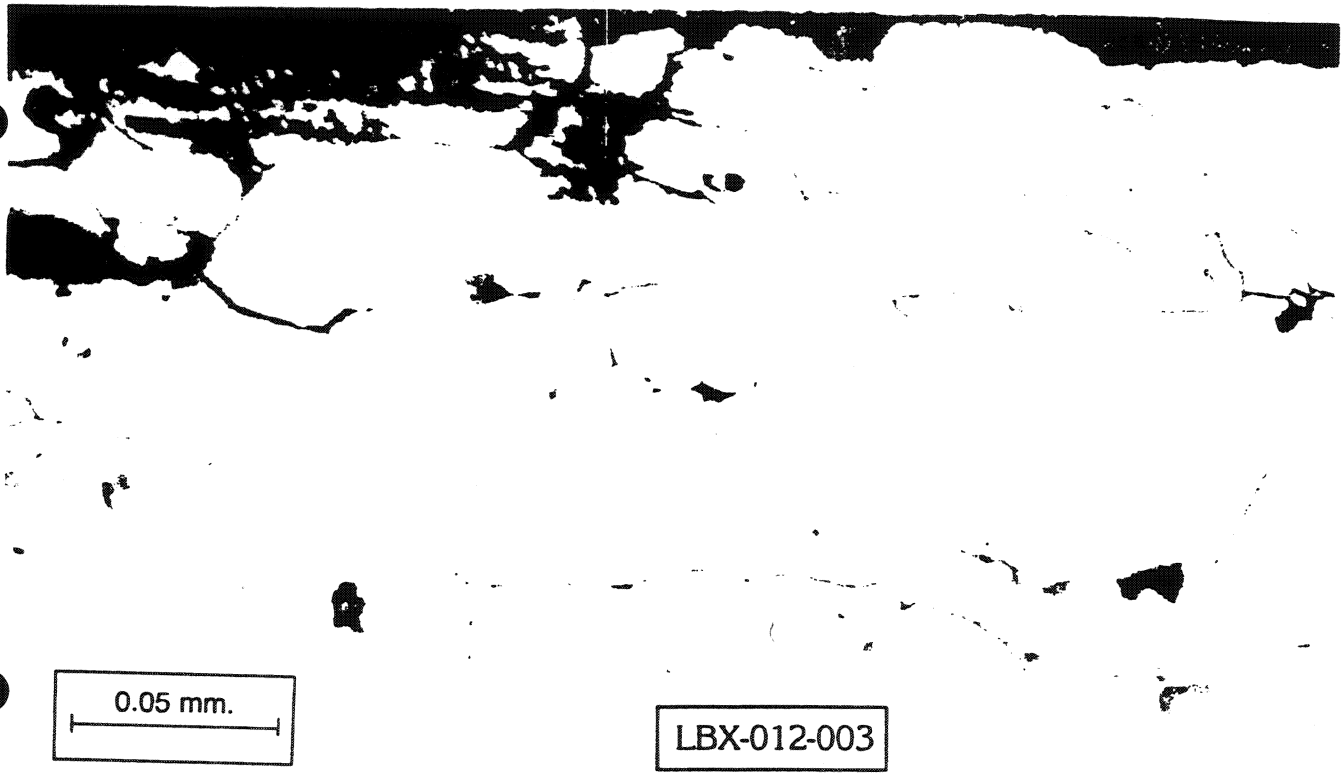


Fig. 3.4.5.1.3-4 - Microstructure of Stressed-Corroded Specimen (Automatic Repair Welded)

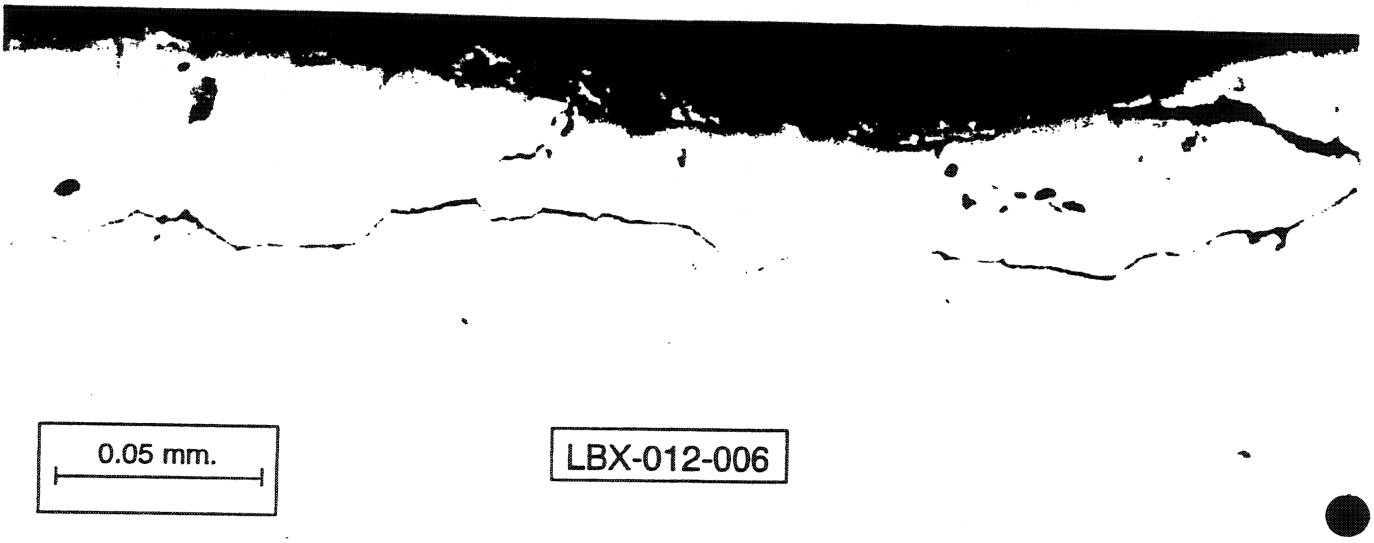


Fig. 3.4.5.1.3-5 - Microstructure of Corroded Specimen (Automatic Repair Welded)

Fig. 3.4.5.1.3-6 - Microstructure of Stressed-Corroded Specimen (Single Manual Repair Welded)

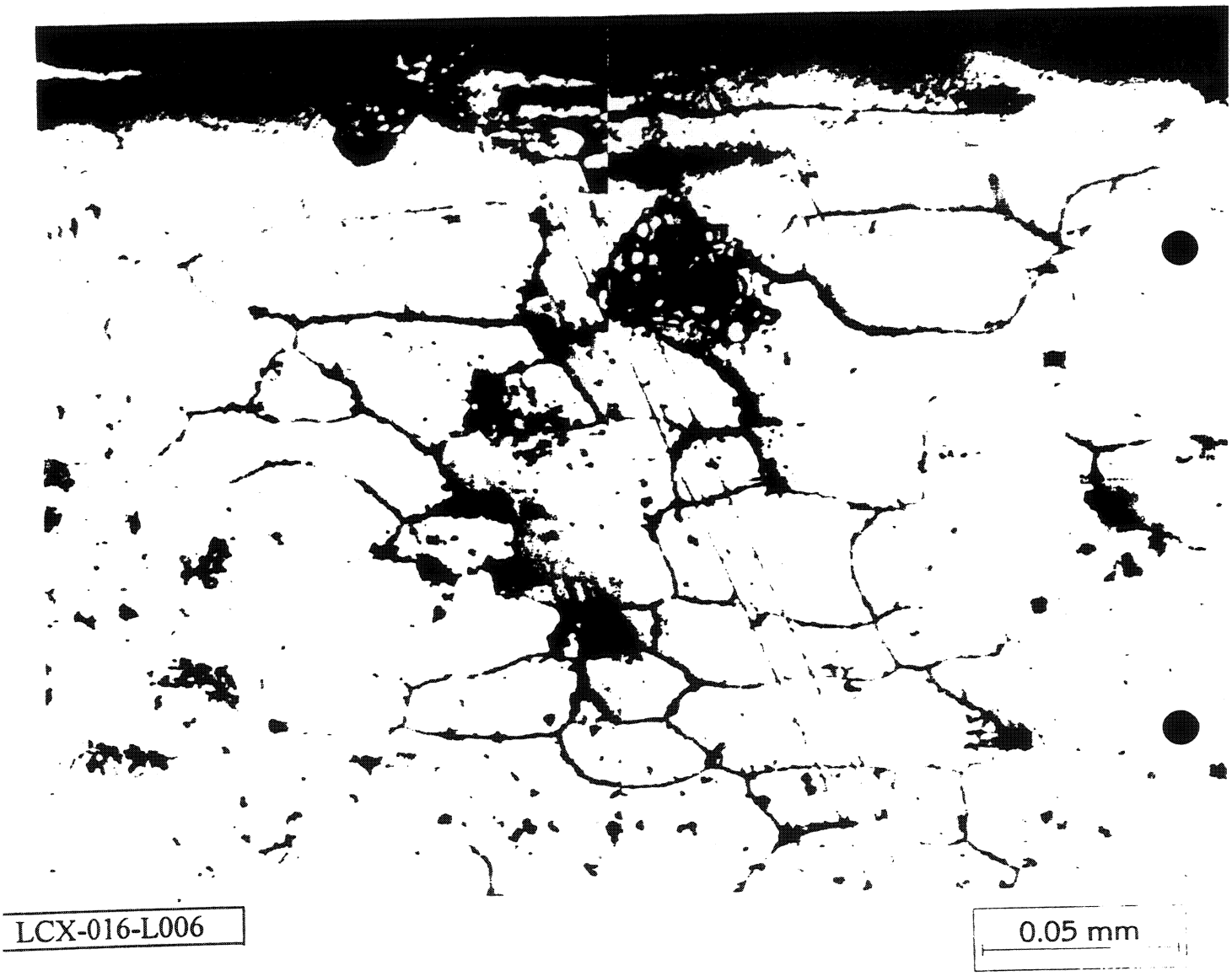


Fig. 3.4.5.1.3-7 - Microstructure of Corroded Specimen (Single Manual Repair Welded)

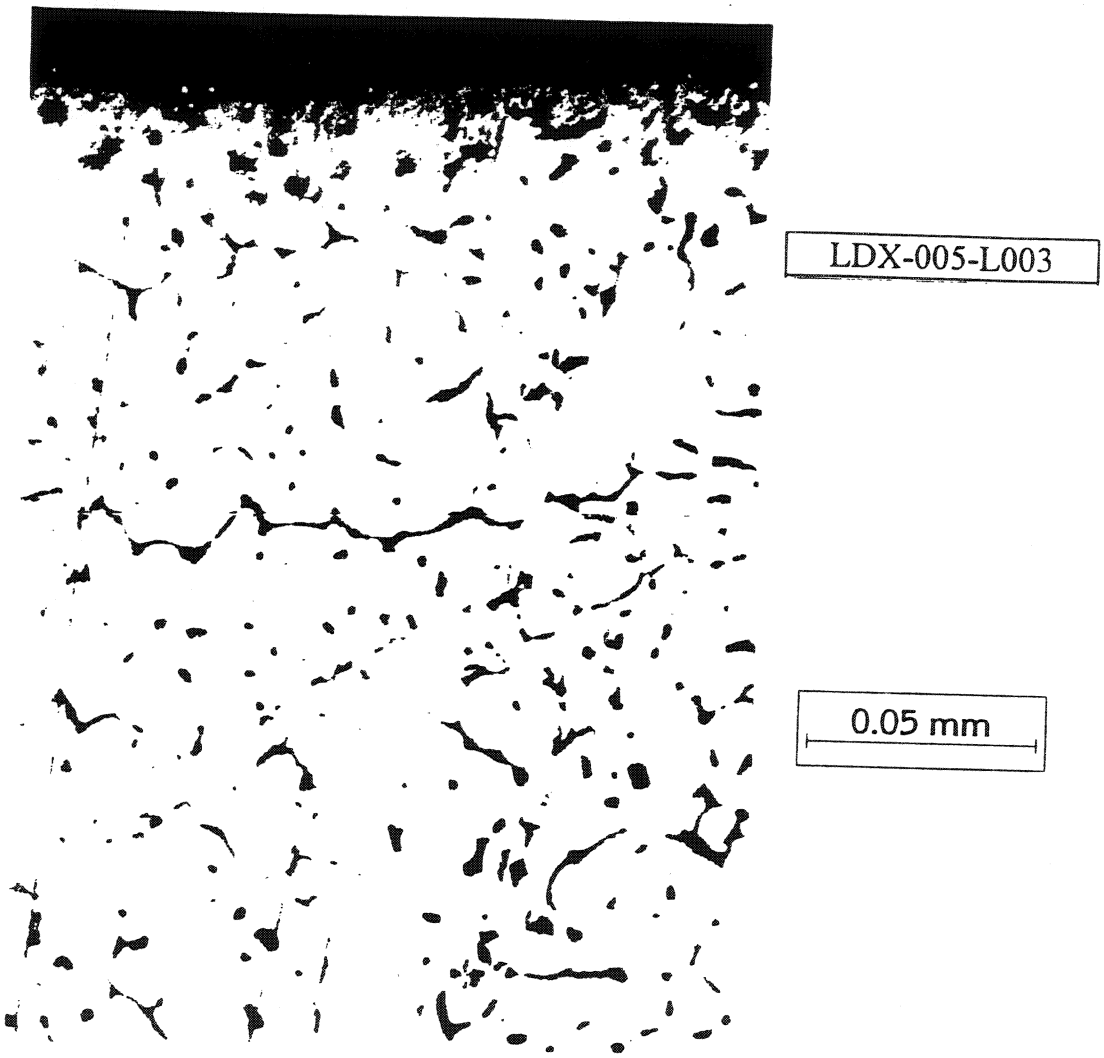


Fig. 3.4.5.1.3-8 - Microstructure of Stressed-Corroded Specimen (Double Manual Repair Welded)

3.4.6 Fracture Toughness Results

Plane Stress Fracture Toughness tests have been carried out for 2219-T851 weld material. The tests have been performed on 150 and 200 mm wide panels having a thickness of 7 mm. The standards used are the ASTM-E-561 (R-curve) [A.D. 15] for the through crack configuration (200 mm wide panels) and ASTM-E-740 [A.D. 16] for surface crack configuration (150 mm wide panels). The location of cracks is parallel to weld line both in weld material and in the heat affected zone (H.A.Z.).

The tests have been carried out on four series of specimens, the first series was welded using the automatic process (see A.D.[17]), the second series was welded using the automatic process followed by the automatic repair, the third series was welded adopting the automatic process followed by the manual repair, the last one was welded using an automatic process followed by two manual repairs (see A.D. [18]). The Tables 3.4.6-1, 3.4.6-3, 3.4.6-5, 3.4.6-7 reports the main results obtained from all the specimens containing the through crack, while the Tables 3.4.6-2, 3.4.6-4, 3.4.6-6, 3.4.6-8 reports the main results obtained from the tests of the specimens with the surface defect and the surface defects. For through crack defects, the nominal toughness reported in this table is obtained using the following stress intensity factor formulation :

$$Kcn = \sigma * \sqrt{\pi * ao * \sec\left(\pi * \frac{ao}{W}\right)}$$

Where ao is the initial crack length and σ is the gross stress at rupture.

For surface defects the SIF solution used is obtained from the ESACRACK data base : SC-02 model, but results are not significant for fracture analysis and therefore they are not been reported. In spite of relatively large panels used, due to the low Yield strength of the weld metal, all specimens failed to meet the plane stress value according to the ASTM limitations for the minimum panel width, therefore an effective Kc value cannot be determined. This data are however useful for an evaluation of residual strength of the weld junction and can be subsequently applied for fracture mechanics analysis.

The main result from these tests is that the weld bead is less resistant than the Heat Affected Zone. The second results is that the influence of the repair methods is negligible.

FRACTURE TOUGHNESS RESULTS : AUTOMATIC WELDING (Through Crack)

TEST N.	CRACK LOC.	PANEL WIDTH [mm]	THICK. [mm]	MAX LOAD [KN]	GROSS STRESS GROSS [MPa]	INITIAL CRACK LENGTH [mm]	NET STRESS NET [MPa]	NOMINAL FRACTURE TOUGHNESS MPasqr(mm)
LAY-001-D001	BEAD	200	7.2	165	114.58	40.4	192.25	1438
LAY-001-D002	BEAD	200	7.2	165	114.58	40.1	191.29	1431
LAY-001-D003	BEAD	200	7.2	170	118.06	39.1	193.85	1447
LAY-002-D-004	BEAD	200	7.2	175	121.53	38.9	198.90	1484
LAY-002-D-005	BEAD	200	7.2	165	114.58	40.4	192.25	1438
LAY-002-D-006	BEAD	200	7.2	170	118.06	40.5	198.41	1485
LAY-003-D-007	HAZ	200	7.2	200	138.89	38.5	225.84	1684
LAY-003-D-008	HAZ	200	7.2	205	142.36	40.5	239.26	1790
LAY-003-D-009	HAZ	200	7.2	205	142.36	40.4	238.86	1787
LAY-004-D-010	HAZ	200	7.2	195	135.42	40.4	227.21	1700
LAY-004-D-011	HAZ	200	7.2	200	138.89	40.1	231.87	1734
LAY-004-D-012	HAZ	200	7.2	195	135.42	40.2	226.45	1694
CAY-009-D001	HAZ*	200	7.08	190	134.18	39.59	222.12	1660
CAY-009-D003	HAZ*	200	7.08	160	112.99	38.81	184.66	1378

* : Crack in forged side.

Tab. 3.4.6-1 - Fracture Toughness Results for the Automatic Process (through crack in bead and H.A.Z.)

FRACTURE TOUGHNESS RESULTS : AUTOMATIC WELDING (Surface crack a/C = 0.2)

TEST N.	CRACK LOC	PANEL WIDTH [mm]	THICK. [mm]	MAX LOAD [N]	GROSS STRESS [MPa]	INITIAL CRACK a :DEPTH [mm]	INITIAL CRACK 2C:LENGTH [mm]	NET STRESS [MPa]	FRACTURE TOUGHNESS MPasqr(mm) K(a)
LAY-008-D013	BEAD	150	7.2	252600	233.89	1.40	14	244	Not valid
LAY-008-D015	BEAD	150	7.2	220725	204.38	2.80	28	222	Not valid
LAY-009-D017	BEAD	150	7.2	183938	170.31	4.20	42	201	Not valid
LAY-010-D019	BEAD	150	7.2	156960	145.33	5.60	56	196	Not valid
LAY-008-D014	HAZ	150	7.2	(1)		1.4	14		
LAY-009-D016	HAZ	150	7.2	(1)		2.8	28		
LAY-009-D018	HAZ	150	7.2	225630	208.92	4.2	42	246	Not valid
LAY-010-D020	HAZ	150	7.2	186390	172.58	5.6	56	233	Not valid
LAY-010-D021	HAZ	150	7.2	296753	274.77	1,4	14	286	Not valid
LAY-011-D022	HAZ	150	7.2	264870	245.25	2.8	28	266	Not valid
CAY-007-D004	HAZ(2)	150	7,2	164317	152.15	5.6	56	205	Not valid
CAY-008-D005	HAZ(2)	150	7.2	132435	122.63	5.6	56	165	Not valid

(1) Clip gauge pulled off before rupture: Maximum load not recorded

(2) Crack in HAZ forged side

Tab. 3.4.6-2 - Fracture Toughness Results for the Automatic Process (surface crack in bead and H.A.Z.)

FRACTURE TOUGHNESS RESULTS : AUTOMATIC REPAIR (Through Crack)

TEST N.	CRACK LOC.	PANEL WIDTH [mm]	THICK. [mm]	MAX LOAD [KN]	GROSS STRESS [MPa]	INITIAL CRACK LENGTH [mm]	NET STRESS [MPa]	NOMINAL TOUGHNESS MPasqr(mm)
LBY-001-D001	BEAD	200	7.1	170.0	119.72	40.53	201.31	1507
LBY-001-D002	BEAD	200	7.1	200.0	140.85	28.19	196.14	1394
LBY-001-D003	BEAD	200	7	190.0	135.71	29.88	193.55	1392
LBY-005-D004	HAZ	200	7	230.0	164.29	28.25	228.97	1629
LBY-005-D005	HAZ	200	7	240.9	172.04	27.82	238.34	1690
LBY-005-D006	HAZ	200	7.1	210.0	147.89	37.67	237.27	1766

Tab. 3.4.6-3 - Fracture Toughness Results for the Automatic Repair (through crack in bead and H.A.Z.)

FRACTURE TOUGHNESS RESULTS : AUTOMATIC REPAIR (Surface crack a/C = 0.2)

TEST N.	CRACK LOC.	PANEL WIDTH [mm]	THICK. [mm]	MAX LOAD [N]	GROSS STRESS [MPa]	INITIAL CRACK a :DEPTH [mm]	INITIAL CRACK 2C:LENGTH [mm]	NET STRESS [MPa]	FRACTURE TOUGHNESS MPasqr(mm) K(a)
LBY-006-D008	BEAD	150	7.2	181485	168.04	4.20	42	198	Not valid
LBY-006-D009	BEAD	150	7.2	154507	143.06	5.60	56	222	Not valid
LBY-006-D010	BEAD	150	7.2	143471	132.84	5.60	56	179	Not valid
LBY-007-D011	HAZ	150	7.2	215820	199.83	4.2	42	236	Not valid
LBY-007-D012	HAZ	150	7.2	171675	158.96	5.6	56	214	Not valid
LBY-007-D013	HAZ	150	7.2	174127	161.23	5.6	56	217	Not valid

Tab.3.4.6-4 - Fracture Toughness Results for the Automatic Repair (surface crack in bead and H.A.Z.)

FRACTURE TOUGHNESS RESULTS : MANUAL REPAIR (Through Crack)

TEST N.	CRACK LOC.	PANEL WIDTH [mm]	THICK. [mm]	MAX LOAD [KN]	GROSS STRESS [MPa]	INITIAL CRACK LENGTH [mm]	NET STRESS [MPa]	NOMINAL TOUGHNESS MPasqr(mm)
LCY-016-D001	BEAD	200	7.1	175.1	123.31	39.75	204.66	1530
LCY-016-D002	BEAD	200	7.1	210.0	147.89	29.85	210.82	1516
LCY-016-D003	BEAD	200	7.1	220.0	154.93	28.59	216.96	1547
LCY-019-D004	HAZ	200	7.1	190.0	133.80	38.12	216.21	1611
LCY-019-D005	HAZ	200	7.1	210.0	147.89	28.11	205.71	1462
LCY-019-D006	HAZ	200	7.1	230.0	161.97	27.50	223.41	1580

Tab.3.4.6-5 - Fracture Toughness Results for the Manual Repair (through crack in bead and H.A.Z.)

FRACTURE TOUGHNESS RESULTS : MANUAL REPAIR (Surface Crack a/C = 0.2)

TEST N.	CRACK LOC.	PANEL WIDTH [mm]	THICK. [mm]	MAX LOAD [KN]	GROSS STRESS [MPa]	INITIAL CRACK a :DEPTH [mm]	INITIAL CRACK 2C:LENGTH [mm]	NET STRESS [MPa]	FRACTURE TOUGHNESS MPasqr(mm) K(a)
LCY-020-D008	BEAD	150	7.2	196200	181.67	4.20	42	214	Not valid
LCY-020-D009	BEAD	150	7.2	161865	149.88	5.60	56	202	Not valid
LCY-021-D010	BEAD	150	7.2	166770	154.42	5.60	56	208	Not valid
LCY-021-D011	HAZ	150	7.2	215820	199.83	4.2	42	236	Not valid
LCY-D21-D012	HAZ	150	7.2	174127	161.23	5.6	56	217	Not valid
LCY-022-D013	HAZ	150	7.2	213056	197.27	5.6	56	223	Not valid

Tab.3.4.6-6 - Fracture Toughness Results for the Manual Repair (surface crack in bead and H.A.Z.)

FRACTURE TOUGHNESS RESULTS : DOUBLE MANUAL REPAIR

TEST N.	CRACK LOC.	PANEL WIDTH [mm]	THICK. [mm]	MAX LOAD [KN]	GROSS STRESS [MPa]	INITIAL CRACK LENGTH [mm]	NET STRESS [MPa]	NOMINAL TOUGHNESS MPasqr(mm)
LDY-001-D001	BEAD	200	7.08	200.0	141.24	28.84	198.49	1418
LDY-001-D002	BEAD	200	7.17	200.0	139.47	28.19	194.22	1381
LDY-001-D003	BEAD	200	7.09	170.0	119.89	39.12	196.92	1470
LDY-018-D004	HAZ	200	7.09	200.0	141.04	37.31	224.99	1673
LDY-018-D005	HAZ	200	7.1	220.0	154.93	29.78	220.63	1586
LDY-018-D006	HAZ	200	7.09	220.0	155.15	28.22	216.14	1537

Tab.3.4.6-7 - Fracture Toughness Results for the Double Manual Repair (through crack in bead and H.A.Z.)

FRACTURE TOUGHNESS RESULTS : DOUBLE MANUAL REPAIR (Surface Crack a/C = 0.2)

TEST N.	CRACK LOC.	PANEL WIDTH [mm]	THICK. [mm]	MAX LOAD [N]	GROSS STRESS [MPa]	INITIAL CRACK a :DEPTH [mm]	INITIAL CRACK 2C :LENGTH [mm]	NET STRESS [MPa]	FRACTURE TOUGHNESS MPasqr(mm) K(a)
LDY-006-D009	BEAD	150	7.2	188842	174.85	4.20	42	206	Not valid
LDY-006-D010	BEAD	150	7.2	158186	146.47	5.60	56	197	Not valid
LDY-006-D011	BEAD	150	7.2	160638	148.74	5.60	56	200	Not valid
LDY-002-D008	HAZ	150	7.2	203557	188.48	4.2	42	222	Not valid
LDY-013-D012	HAZ	150	7.2	152055	140.79	5.6	56	190	Not valid
LDY-013-D013	HAZ	150	7.2	176580	163.50	5.6	56	220	Not valid

Tab.3.4.6-8 - Fracture Toughness Results for the Double Manual Repair (surface crack in bead and H.A.Z.)

3.4.7 Residual Strength Evaluation for Through Crack Defects

The figures reported in this paragraph represent the residual strength diagram, in which the gross stress is plotted as a function of the crack length.
Data have been reported for the automatic process and for the automatic repair, the manual repair and the double repair.
The dotted lines represent the net section yielding and the plastic rupture respectively. The theoretical value of K for an 200 mm wide panel is also reported for comparison and will be adopted for fracture analysis of welded parts.
The figure 3.4.7-1 shows the results for the crack in weld bead while the figure 3.4.7-2 for crack in HAZ.
For larger panel it can be expected an augmentation of the Kc value, however this is impractical to obtain.

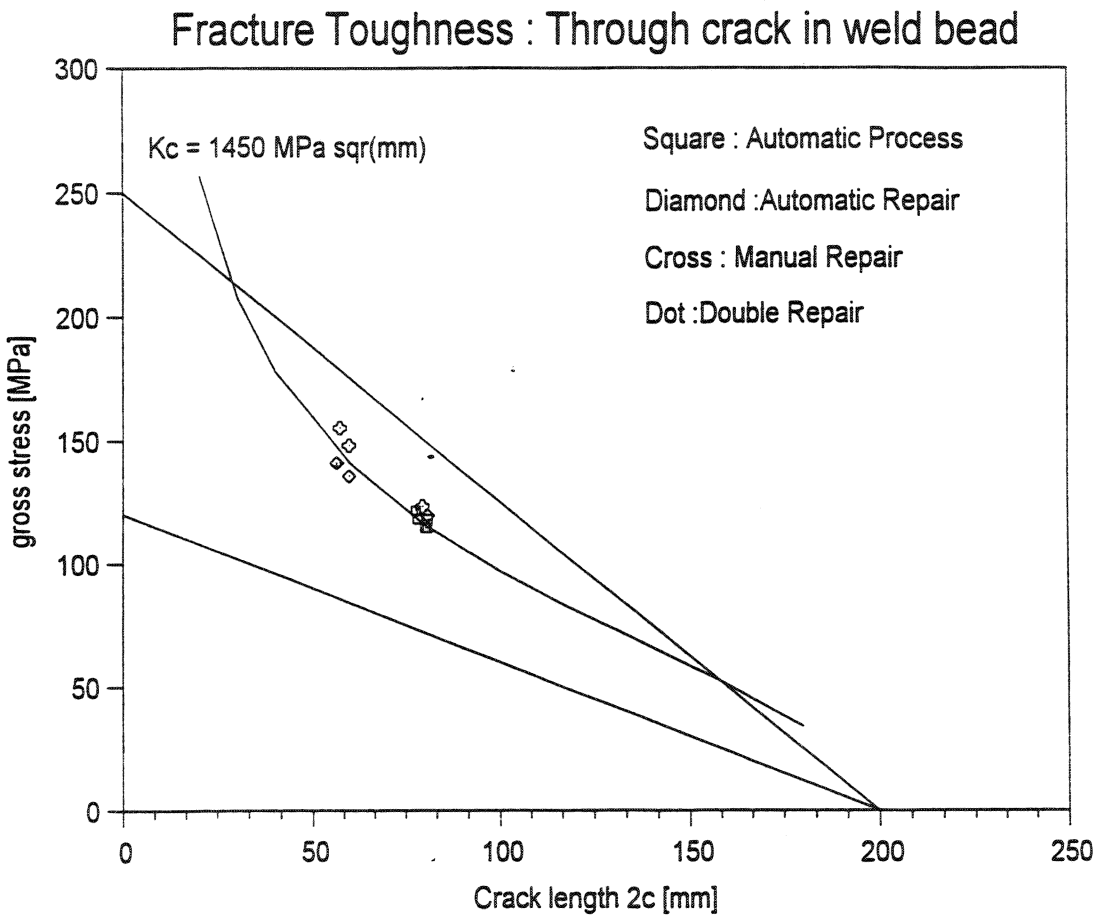


Fig. 3.4.7-1 - Residual Strength Diagram for Crack in Weld Bead (through crack)

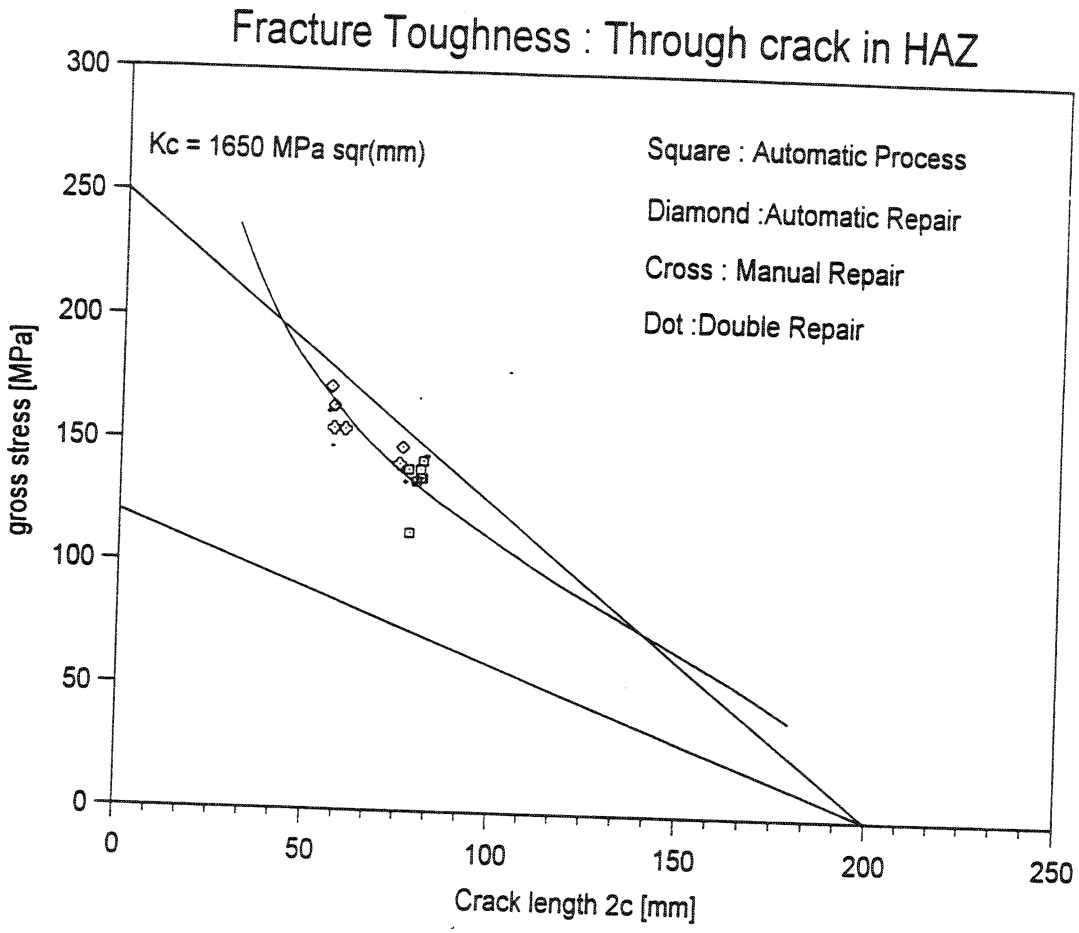


Fig. 3.4.7-2 - Residual Strength Diagram for Crack in H.A.Z. (through crack)

3.4.8

Residual Strength Evaluation for Surface Crack Defects

The two diagrams here represent the gross stress at fracture as a function of the crack depth (a/C=0.2). Data are available for all weld configuration crack in weld bead and heat affected zone (H.A.Z.): Automatic weld, Automatic repair, Manual repair and Double repair.
The calculation of a valid fracture toughness is not possible because the gross stress range well above the yield strength.
The curves in Fig 3.4.8-1,3.4.8-2 shown that the gross stress decrease when the crack depth increase and the weld bead is less resistant than the H.A.Z .

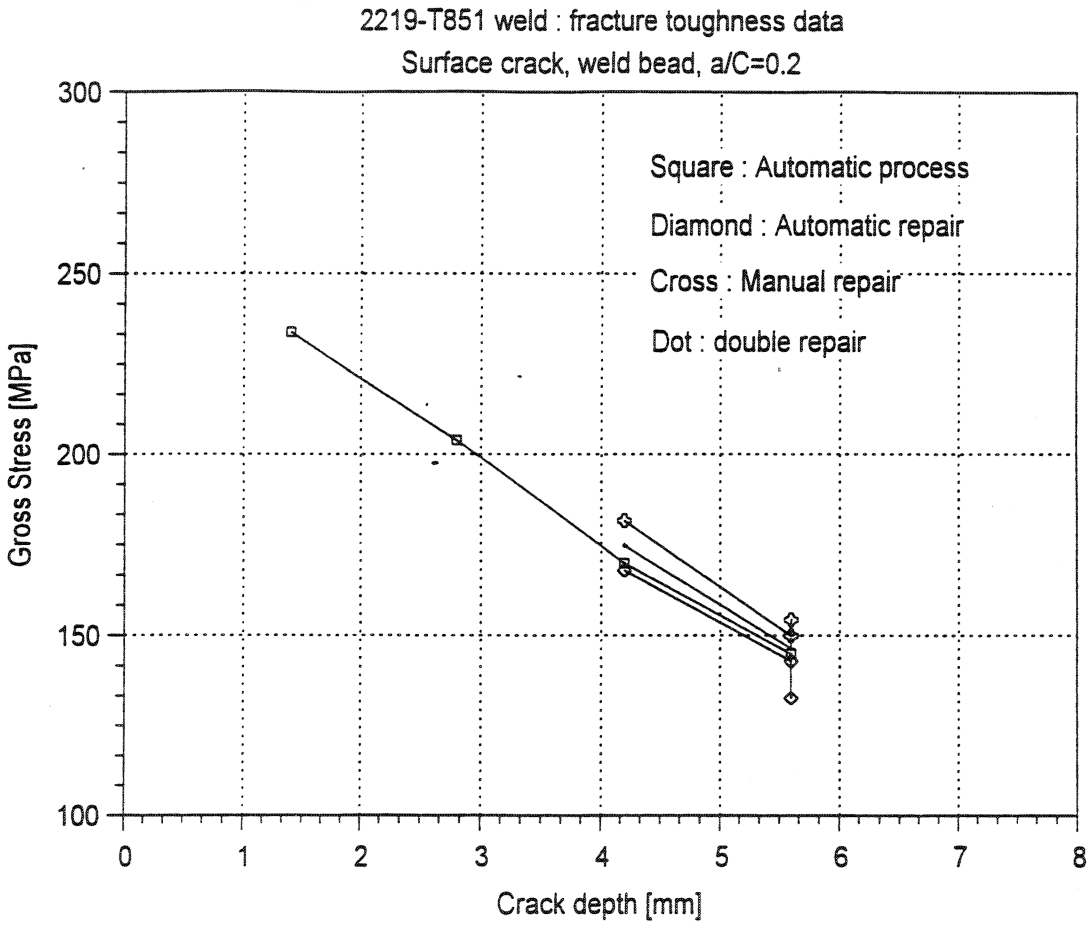


Fig. 3.4.8-1 - Residual Strength Diagram for Crack in Weld Bead (surface crack)

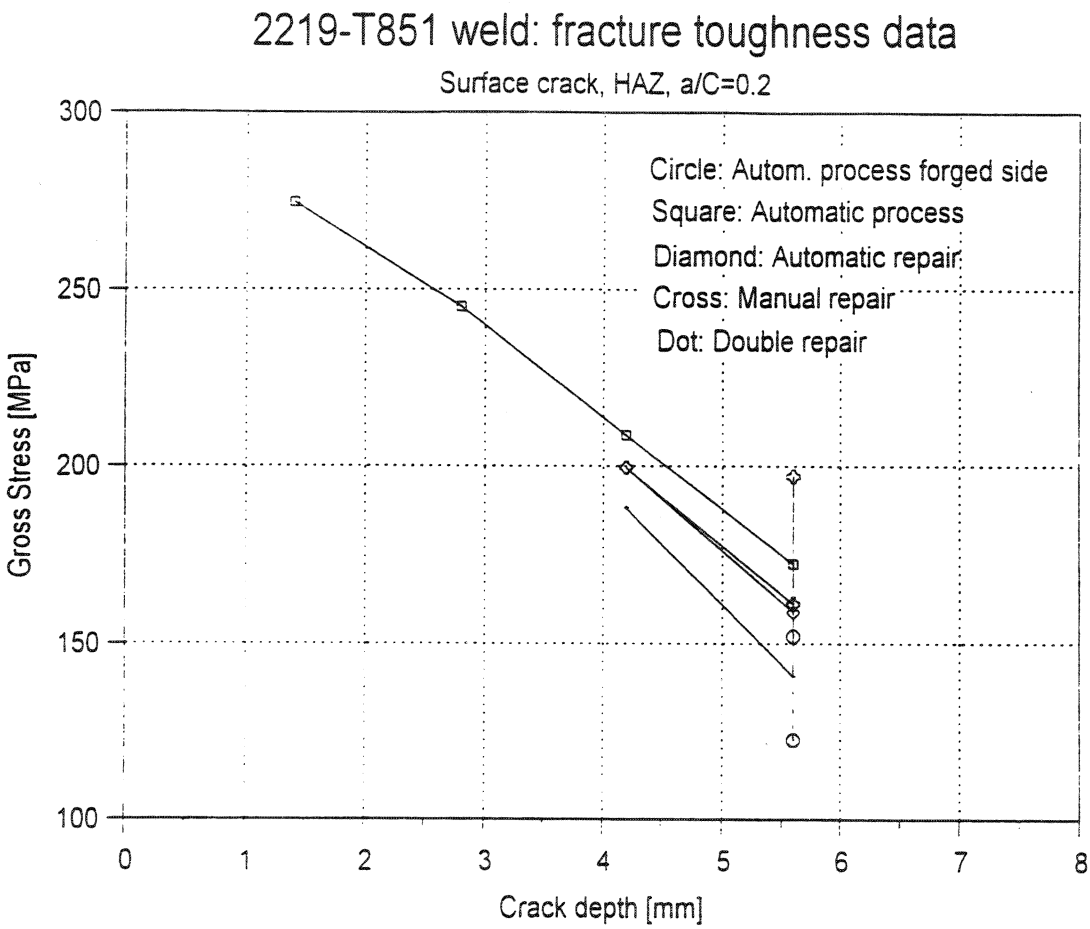


Fig. 3.4.8-2 - Residual Strength Diagram for Crack in H.A.Z. (surface crack)

3.4.9

Fatigue Crack Growth and Threshold Results

Fatigue crack growth tests have been performed according to ASTM-E-647, A.D.[19], results are available for crack in weld bead and H.A.Z. at stress ratios R = 0.1/0.5 (see Annex 4, A.D.[17] and Annex 5, A.D.[18]).

Curve fit and experimental data are reported from Fig. 3.4.9-1 to 3.4.9-8.

The material constants (Forman equation) are evaluated using the ESACRACK (NASGRO) dedicated routine with the "closure" option.
The curve fit agreed well in the linear part of the data while is not so good at high K values.
This is due to the not complete validation of the experimental data obtained for the M(t) specimen in this part of the graphic due to the net section yielding.
Threshold data are plotted in the same diagram and the DKo value was taken equal to 100 MPa√mm.

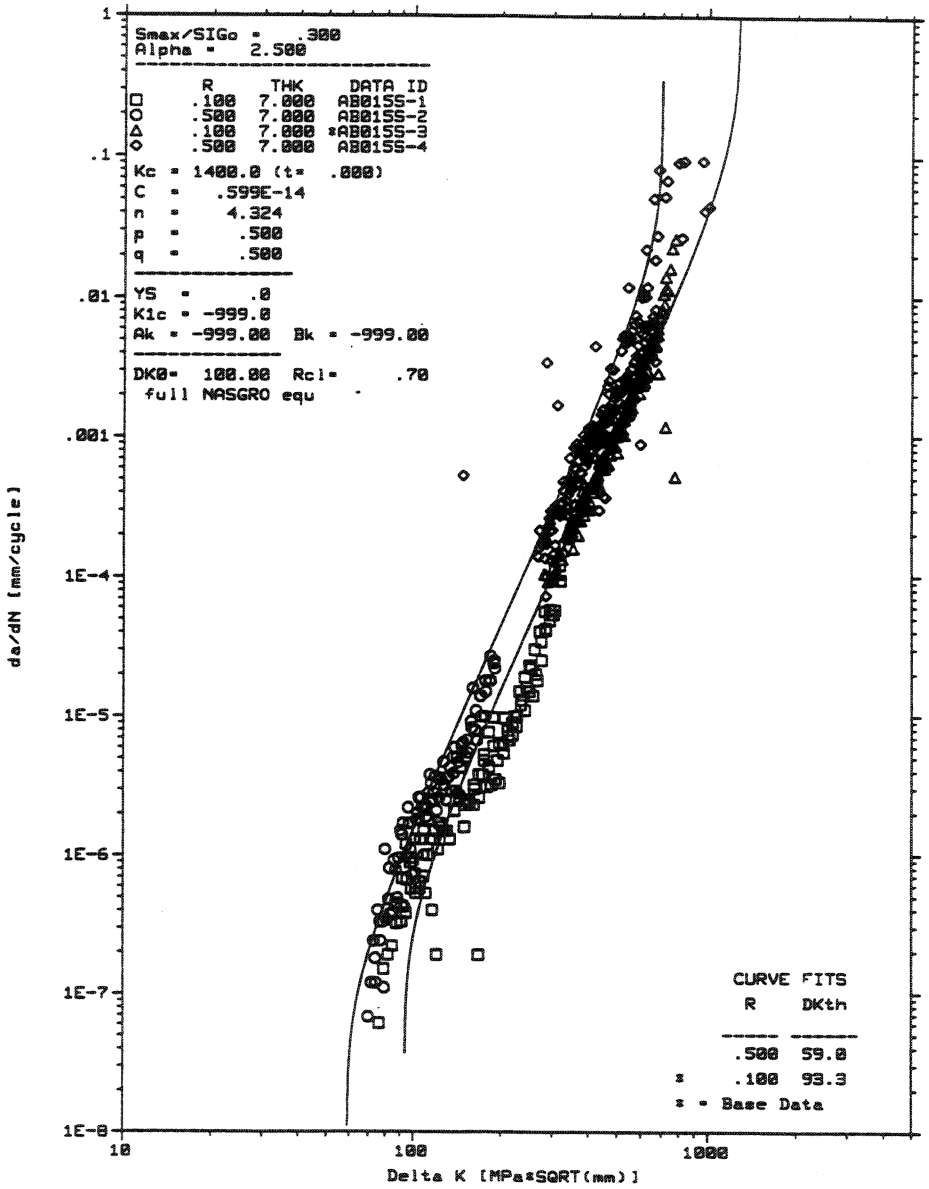


Fig. 3.4.9-1 - Crack Propagation Data for Automatic Weld Process (crack in weld bead)

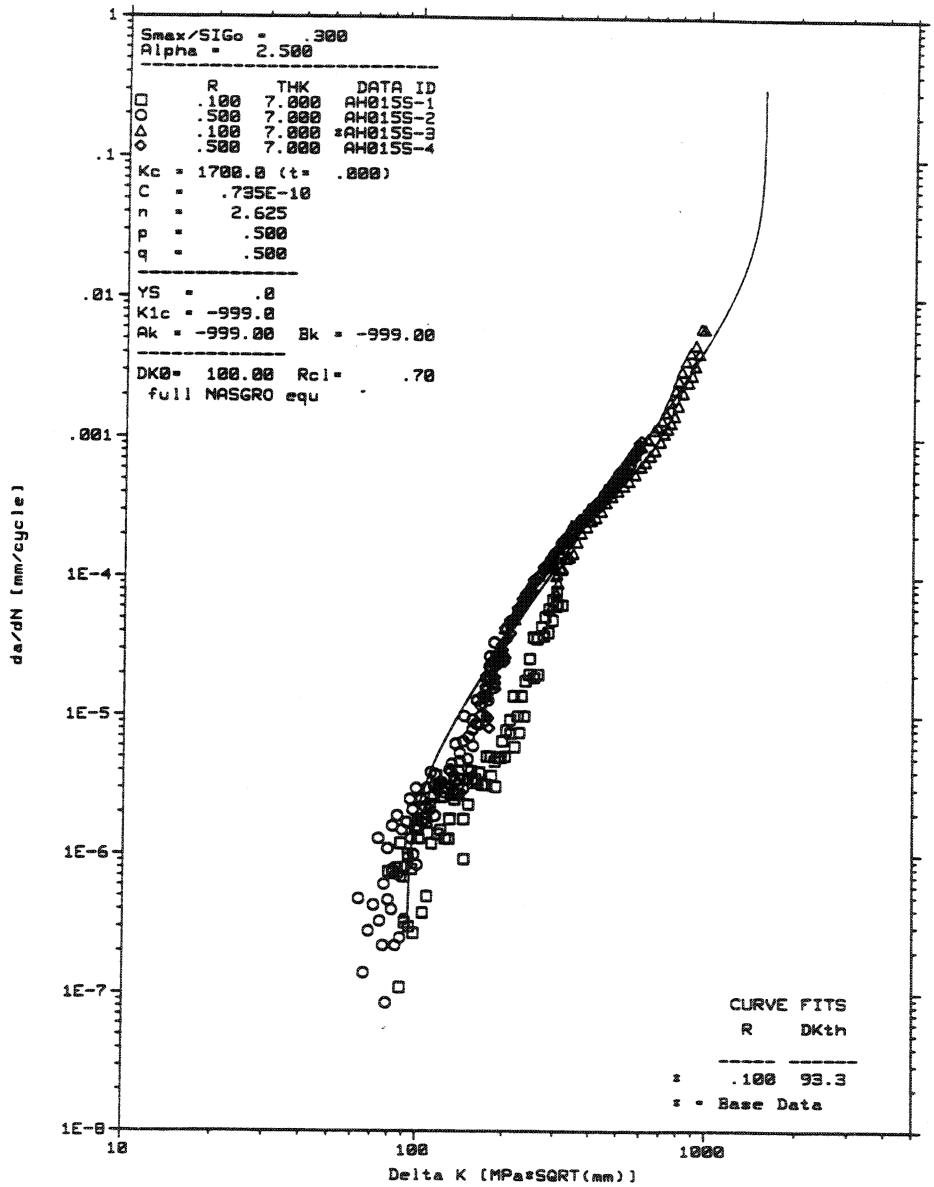


Fig. 3.4.9-2 - Crack Propagation Data for Automatic Weld Process (crack in H.A.Z.)

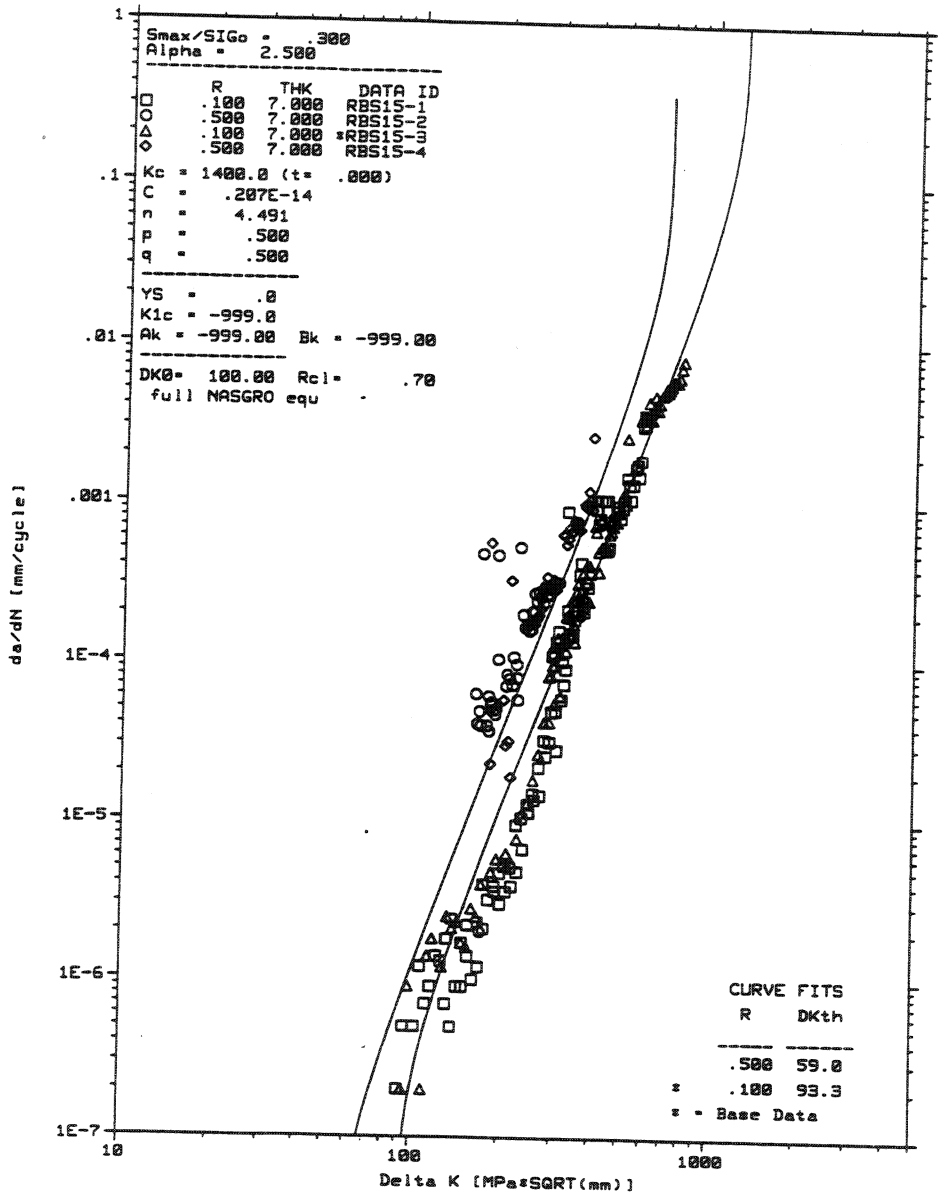


Fig. 3.4.9-3 - Crack Propagation Data for Automatic Repair Process (crack in Bead)

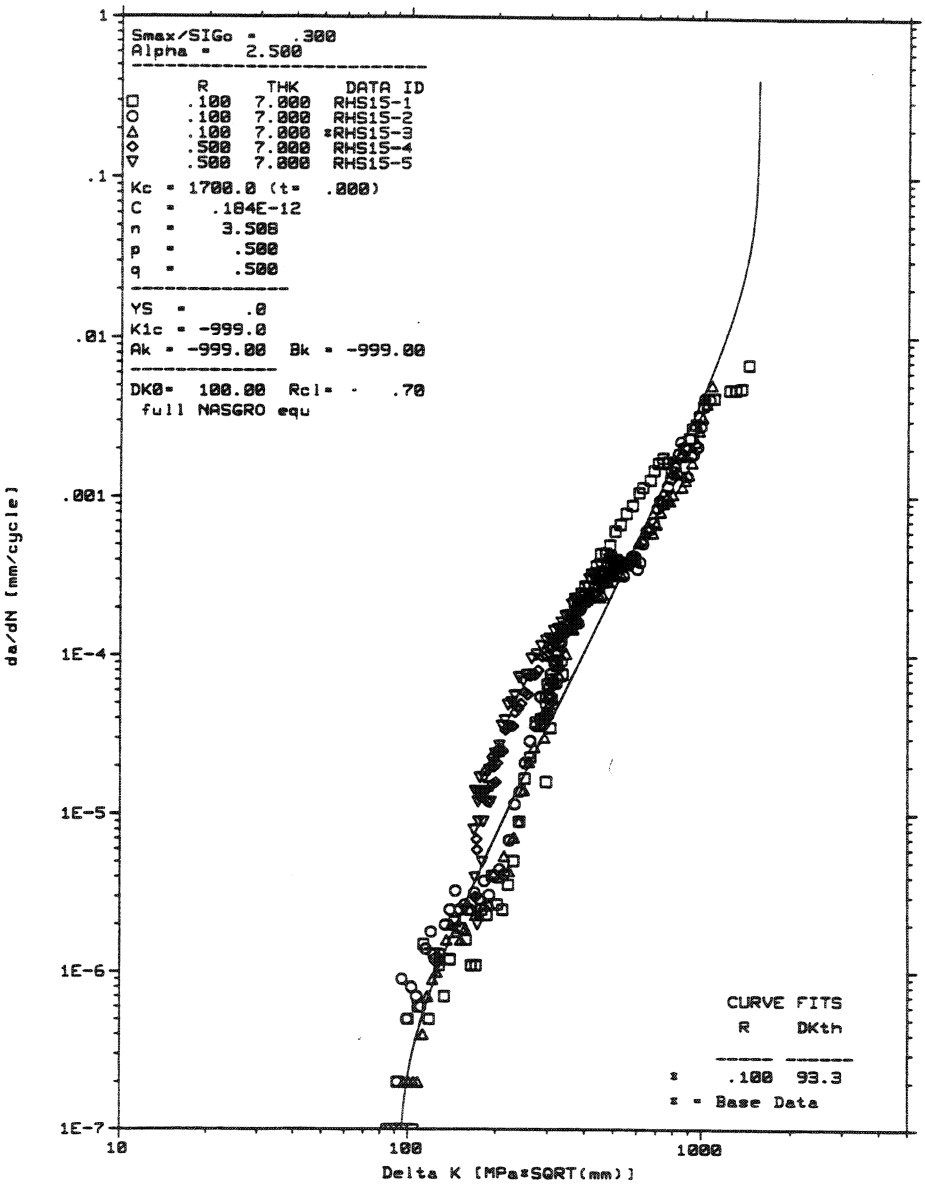


Fig. 3.4.9-4 - Crack Propagation Data for Automatic Repair Process (crack in H.A.Z.)

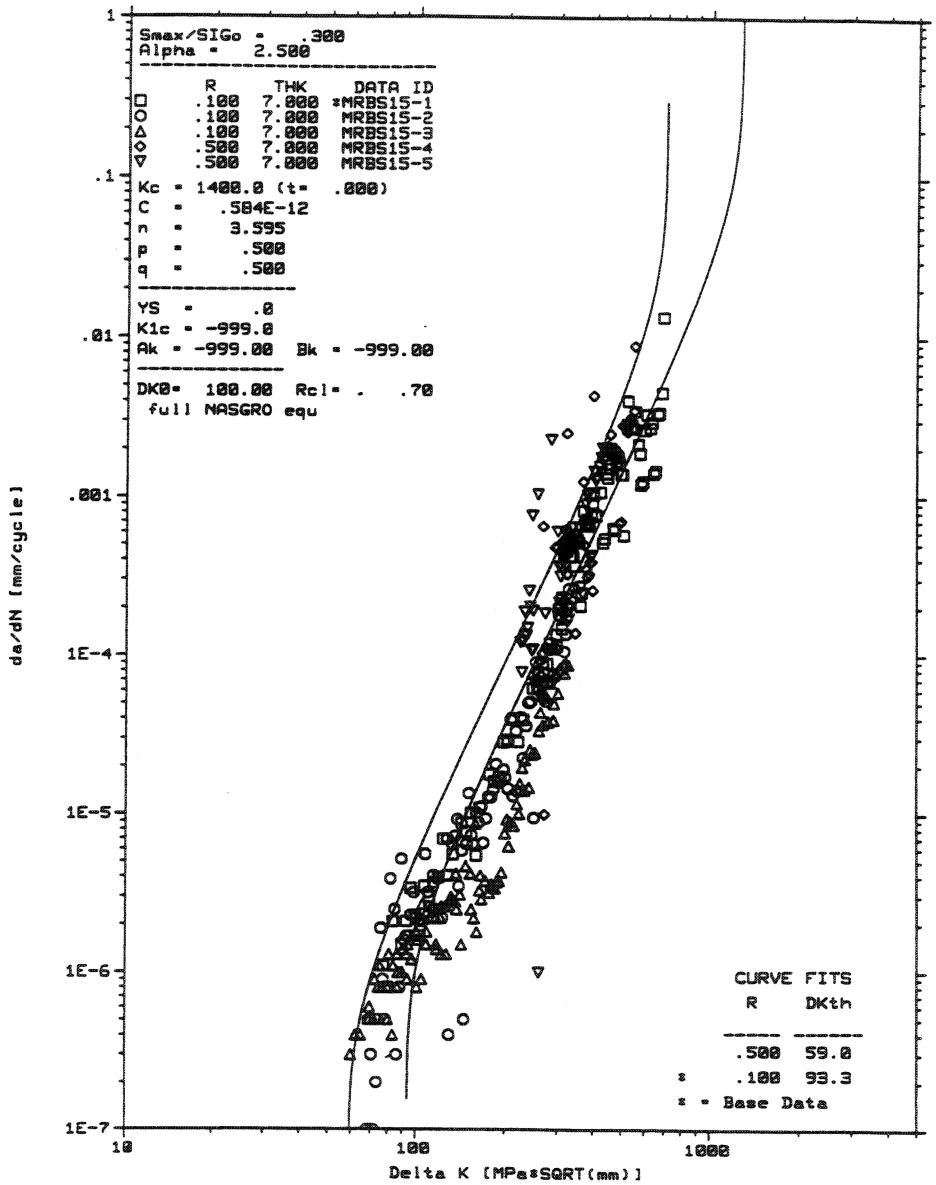


Fig. 3.4.9-5 - Crack Propagation Data for Manual Repair Process (crack in Bead)

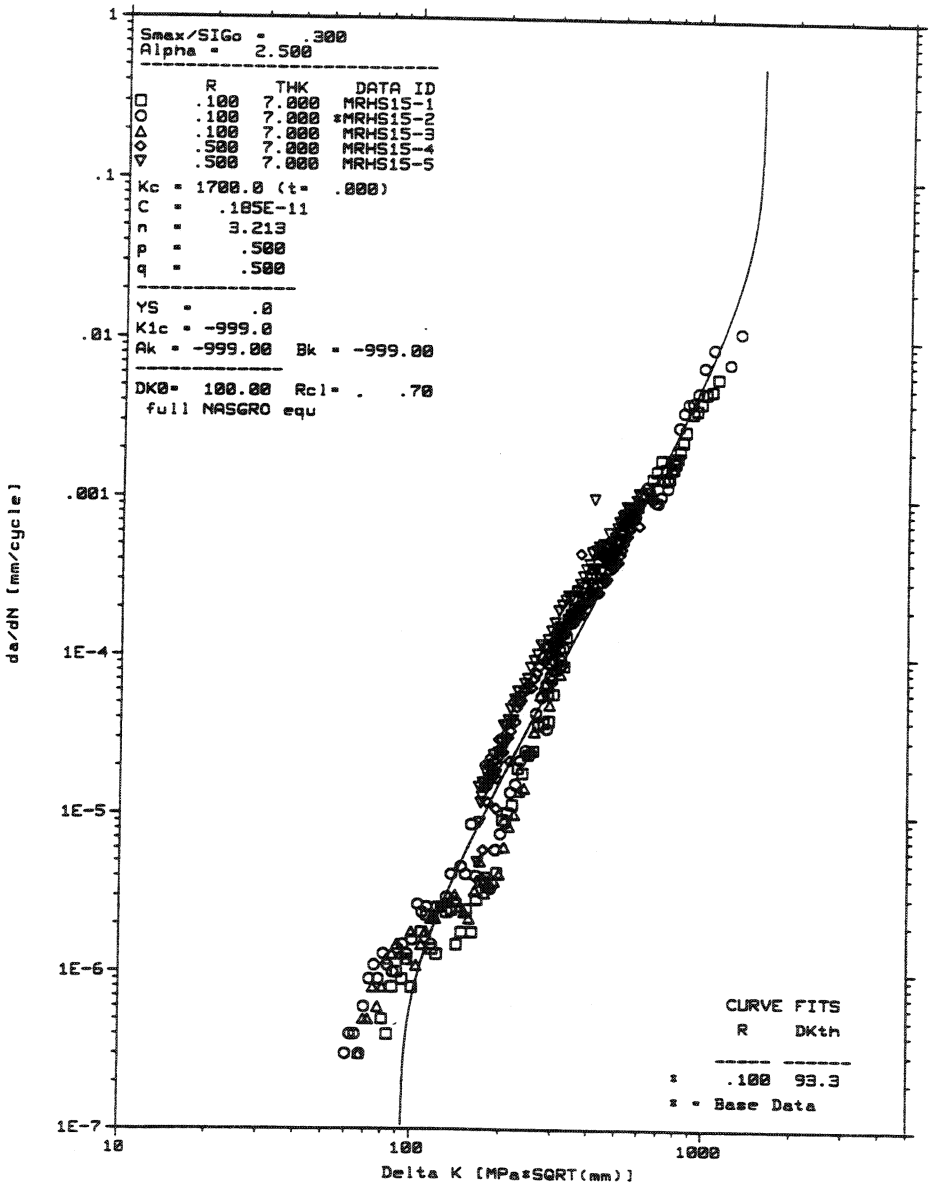


Fig. 3.4.9-6 - Crack Propagation Data for Manual Repair Process (crack in H.A.Z.)

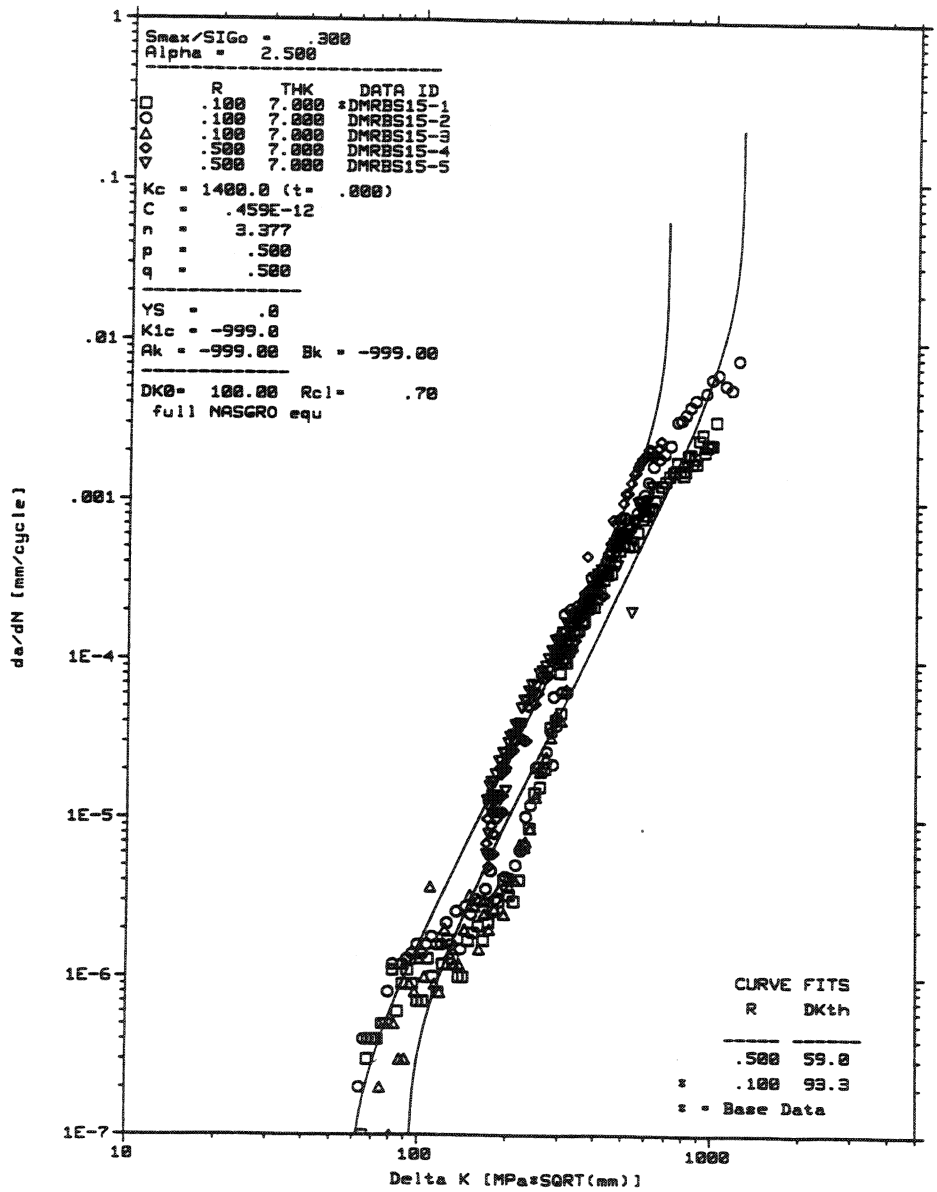


Fig. 3.4.9-7 - Crack Propagation Data for Double Manual Repair Process (crack in Bead)

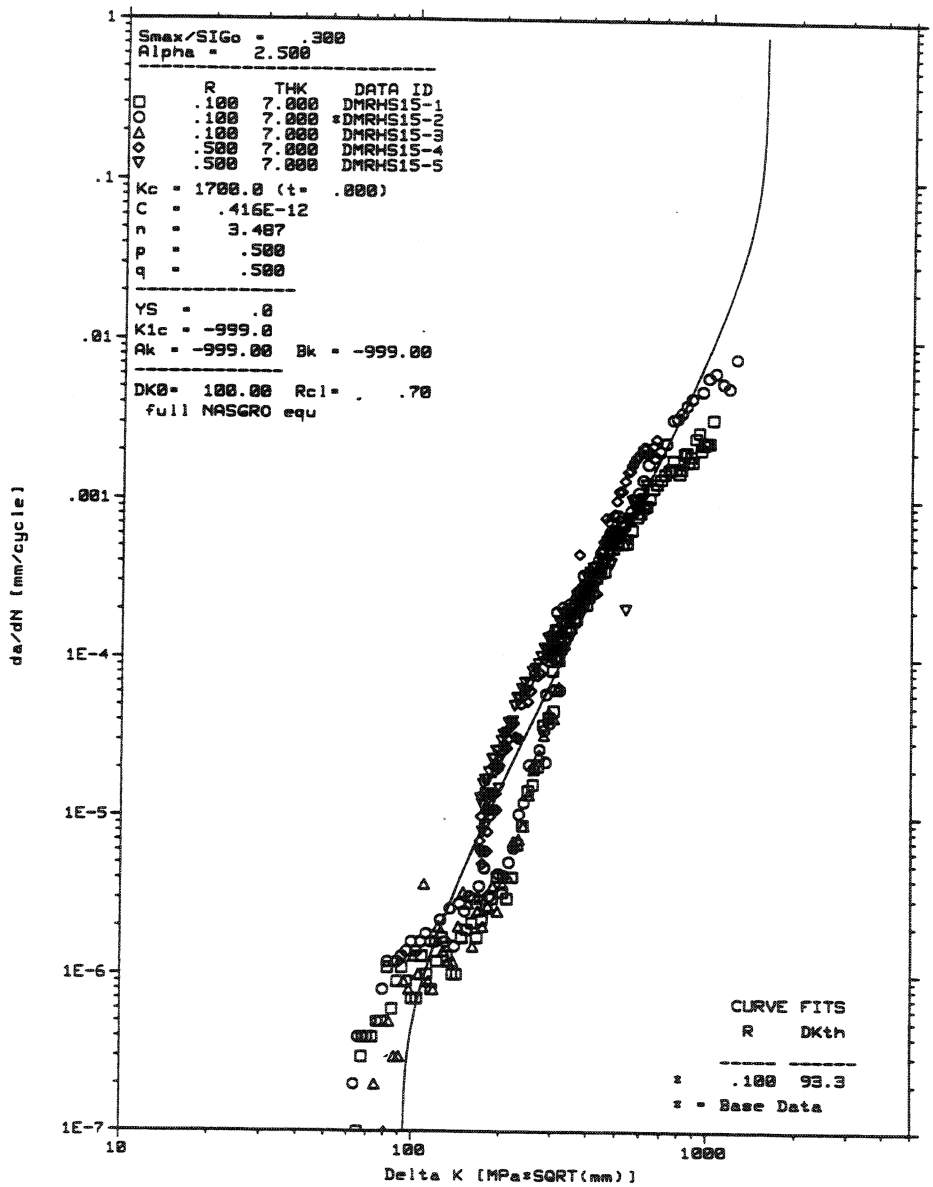


Fig. 3.4.9-8 - Crack Propagation Data for Double Manual Repair Process (crack in H.A.Z.)

3.4.10

Leak before Burst Test

The leak before burst test has been performed on 7 mm thick and 200 mm wide panels where artificial defects were introduced in the centre of each specimen, both in weld bead and in the heat affected zone (H.A.Z.). The artificial defect size was : crack depth = 3 mm crack length = 6 mm.
These defects were sharpened using cyclic loads (Smax = 90 MPa R=0.1) and subsequently during crack propagation. Crack length measures were recorded during crack propagation until crack breaks through. Data are available for all the welding configurations and are here reported in the Annex 2 (TEST DATA FOR LEAK BEFORE BURST).
The specimens have been identified as follows :
- LAY = Automatic Virgin Weld
- LBY = Automatic Repair Weld
- LCY = Single Manual Repair Weld
- LDY = Double Manual Repair Weld

A summary of tests results is reported in the Tab. 3.4.10-1, no specimen failed during crack transition. Test data show that the crack grows more rapidly in the bead than in the H.A.Z. and for each configuration the crack grows in the repair weld more than in the virgin weld.
In one test, specimen LAY-018-F004, the number of cycles to leakage is very low, compared with the other LAY specimens. This seems due to the effect of the previous cyclic loads performed on this specimen, at lower stress level.
In another specimen, LCY-029-F003, the number of cycles to leakage was very high with respect to the other LCY specimen. In this case another test specimen, LAY-030-F005, was tested and the results confirmed that the LCY-029-F003 was anomalous.

Crack in weld bead

SPECIMEN NUMB.	CYCLE TO LEAKAGE	CRACK LENGTH [mm]	ASPECT RATIO a/c
LAY-018-F001	132270		
LAY-018-F002	124350		
LAY-018-F003	135030		
LBY-016-F001	126700	18.4	0.78
LBY-017-F005	121400	19.7	0.71
LCY-029-F001	81940	19.9	0.72
LCY-029-F002	95390	17.8	0.8
LDY-007-F001	79830	22	0.65
LDY-007-F002	73300	20.7	0.69

Crack in HAZ

SPECIMEN NUMB.	CYCLE TO LEAKAGE	CRACK LENGTH [mm]	ASPECT RATIO a/c
LAY-018-F005	196980		
LAY-018-F006	197210		
LAY-018-F004(*)	93950	-	-
LBY-017-F003	205750	19.1	0.75
LBY-017-F004	208900	18.2	0.79
LCY-029-F003(#)	230640	15.7	0.91
LCY-029-F004	115900	17.2	0.83
LCY-030-F005	136400	18.8	0.75
LDY-007-F003	112860	21.8	0.66
LDY-007-F004	139500	16.3	0.88

LAY : Automatic weld process
LBY : Automatic weld repair
LCY : Manual weld repair
LDY : Double repair

Initial crack size :
depth a = 3 mm
legth 2C= 6 mm
Aspect ratio a/C = 1
(*) Specimen damaged
(#) Anomalous, substituted by LCY-030-005

Tab. 3.4.10-1 - Leak before burst test results summary (crack in bead and HAZ)

3.4.11

Stress Corrosion Cracking Tests

The Kscc tests has been performed on Compact tension specimens 7 mm thick and 140 mm wide.
The crack length was always set around 70 mm, the position was in the weld bead or in the HAZ.
The environment adopted, Humid air at 90% and 21 Celsius of temperature, simulate the ambient in the module in orbit.
All the tests has been performed applying a constant load for 30 days, which level produce a stress intensity factor on the crack tip equal to 90% of the nominal fracture toughness.
Two specimens, LCX-021-G006 (Manual repair, crack in HAZ) and LDX-009-G008 (Double manual repair, Crack in HAZ) failed during the application of the sustained loads.
All the other specimens survived to the 30 days sustained loads with a little stable crack propagation in the order of 1 mm maximum.
At the end of the test, the specimens were loaded to failure. The results are summarized in the tables 3.4.11-1and 3.4.11-2 in which the nominal Kmax is reported for comparison.

STRESS CORROSION CRACKING TESTS

SPECIMEN	DEFECT	INITIAL CRACK [mm]	FINAL CRACK [mm]	Pmax [N]	Kmax [MPasqr(mm)]
LAX-004-G002	BEAD	70.44	70.84	13851	1607
LAX-004-G003	BEAD	70.4	70.55	13920	1615
LAX-004-G004	BEAD	70.6	70.84	14224	1650
LAX-005-G005	BEAD	71	71.08	14038	1628
LAX-005-G006	BEAD	70.8	70.94	14097	1635
LBX-013-G001	BEAD	69.5	70.33	13980	1622
LBX-013-G002	BEAD	70	70.12	13852	1607
LBX-013-G003	BEAD	70	70.18	13734	1593
LCX-020-G001	BEAD	70.05	70.4	15813	1834
LCX-020-G002	BEAD	69.7	70.37	15019	1742
LCX-020-G003	BEAD	69.94	70.27	15264	1771
LDX-006-G001	BEAD	70.11	71.02	13979	1622
LDX-006-G002	BEAD	69.93	70.13	15941	1849
LDX-006-G003	BEAD	70.05	70.87	15147	1757

Tab.3.4.11-1 - Stress Corrosion Cracking Test Results Summary (crack in bead)

STRESS CORROSION CRACKING TESTS

SPECIMEN	DEFECT	INITIAL CRACK [mm]	FINAL CRACK [mm]	Pmax [N]	Kmax [MPasqr(mm)]
LAX-009-G007	HAZ	70.39	70.75	17040	1977
LAX-009-G008	HAZ	70.08	70.53	16795	1948
LAX-009-G009	HAZ	70.15	70.62	17413	2020
LAX-010-G010	HAZ	70.08	70.56	16795	1948
LAX-010-G011	HAZ	70.38	70.83	17167	1991
LBX-014-G004	HAZ	70	70.49	16550	1920
LBX-014-G005	HAZ	70	70.68	16677	1935
LBX-014-G006	HAZ	71.1	71.63	16432	1906
LCX-021-G004	HAZ	70.28	70.55	17530	2033
LCX-021-G005	HAZ	70.43	71.12	16060	1863
LCX-021-G006	HAZ	70	Failed	13351	1549
LDX-007-G005	HAZ	69.8	70.14	15696	1821
LDX-008-G006	HAZ	69.1	69.44	18090	2098
LDX-009-G008	HAZ	70	Failed	13145	1525

Tab.3.4.11-2 - Stress Corrosion Cracking Test Results Summary (crack in H.A.Z.)

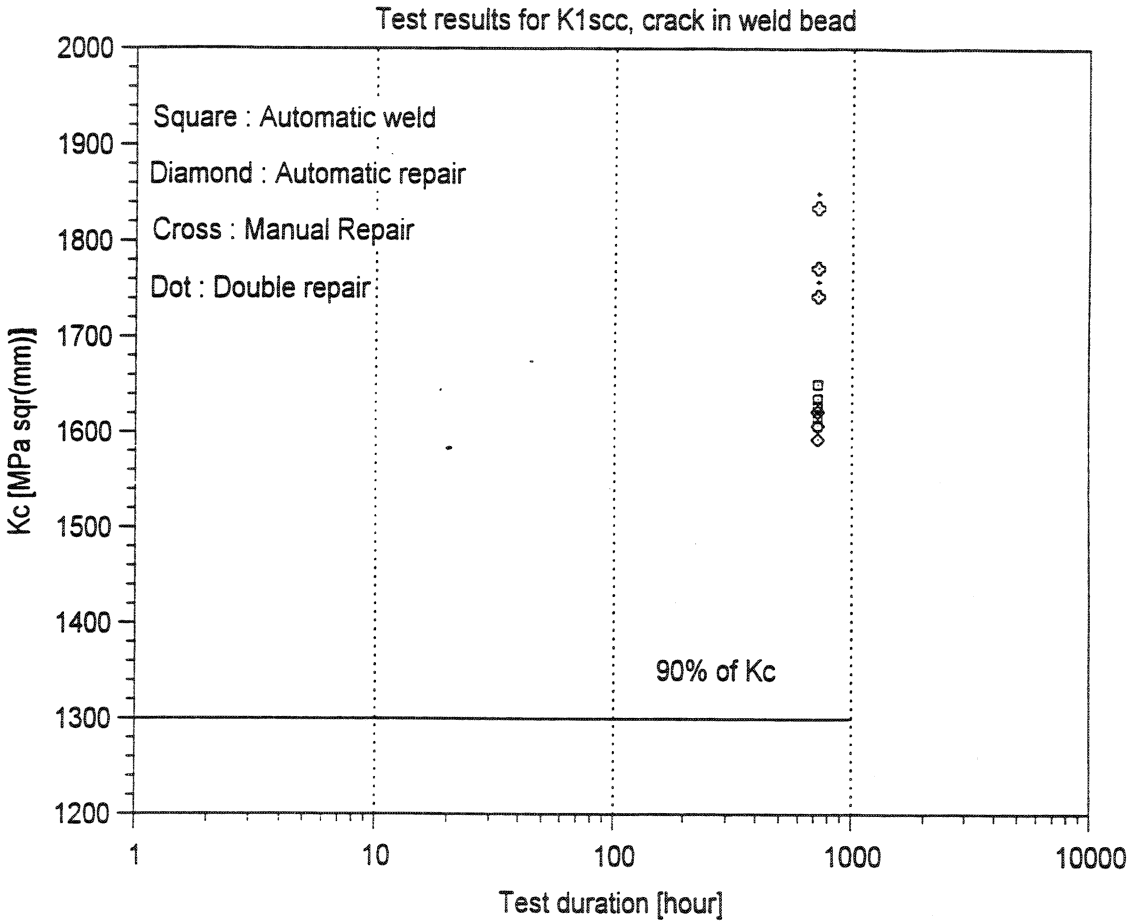


Fig. 3.4.11-1 - Stress Corrosion Cracking Test Results Summary (crack in bead)

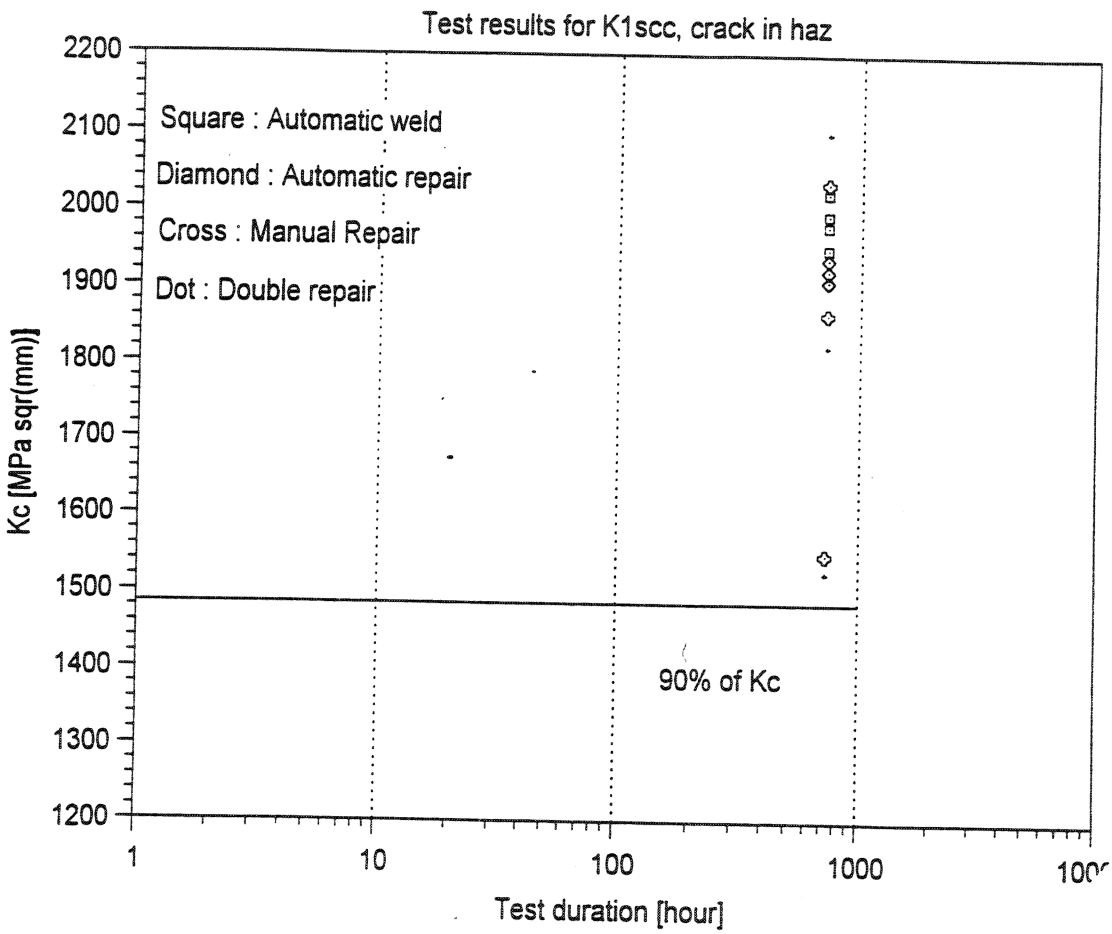


Fig. 3.4.11-2 - Stress Corrosion Cracking Test Results Summary (crack in H.A.Z.)

4 CONCLUSIONS

On the basis of the test results obtained in the qualification and mechanical-metallurgical characterization campaign, ALENIA SPAZIO confirm that automatic V.P.P.A. (Variable Polarity Plasma Arc) welding process, automatic and manual repair welding can be considered qualified and can be used for MPLM module construction.
The above characterization has been carried out on virgin weldings, automatic and manual (single and double) repair weldings.
All the results meet the requirements reported in Alenia Spazio Welding Specification, A.D.[9], in terms of :

- Mechanical properties of the welded joint
- Welded joint geometry
- Welded joint internal quality
- Welded joint surface quality after shaving

The mechanical-metallurgical characterization of the welded joints, performed according to Alenia Spazio Test Plan, A.D.[1], has confirmed the joint goodness concerning :

- Fracture Toughness
- Residual Strength Evaluation for Through Crack Defects
- Fatigue Crack Growth and Threshold
- Leak before Burst
- Stress Corrosion Cracking
- Susceptibility to Stress Corrosion Cracking

ANNEX 1

RPS Nr. 256

"TEST REPORT FOR QUALIFICATION OF V.P.P.A. AUTOMATIC WELDING PROCESS : TENSILE TESTS, METALLOGRAPHIC EXAMINATION AND MICROHARDNESS TESTS"

ALENIA SPAZIO LABORATORIO

TEST REPORT

PROGRAM : MPLM

TITLE : TEST REPORT FOR QUALIFICATION OF VPPA AUTOMATIC WELDING PROCESS: TENSILE TESTS, METALLOGRAPHIC EXAMINATION AND MICROHARDNESS TESTS.

SUMMARY

Tensile tests were carried out on joints welded by automatic VPPA process. The values of tensile strength are always higher than the minimum spec. requirement.
Metallographic examination exhibits good results in terms of bead geometry as well as microstructural features of the weld material and Heat Affected Zone.
Microhardness profiles appeared in the normal trend behaviour associated to Al 2219 weldments.

TEST SHEET : 298

LABORATORY AREA : Mechanical tests, Chemical and Physical Analysis

PREPARED : B. Birolo,
: F. Giuggioli

CHECKED : E. Bonadero
A. Ferri

APPROVED : A. Belmondo

TABLE OF CONTENTS

1.0 INTRODUCTION

2.0 MECHANICAL TESTS

2.1 Reference documents
2.2 Test specimens
2.3 Testing machine
2.4 Test results

3.0 METALLOGRAPHIC EXAMINATION

3.1 Reference documents
3.2 Automatic virgin welding
3.3 Automatic virgin welding with mismatch
3.4 Automatic virgin welding with peaking
3.5 Automatic virgin welding at minimun energy
3.6 Automatic virgin welding at maximum energy

4.0 MICROHARDNESS TESTS

4.1 Reference documents

ANNEX 1
ANNEX 2
ANNEX 3
ANNEX 4
ANNEX 5
ANNEX 6

1.0 INTRODUCTION

The aim of the qualification phase of Plasma Welding technique was to verify mechanical and metallurgical properties of joints made of 2219 - T851 Alluminum Alloy welded by this process.

This report contains the results of tests campaign performed to qualify the process:

- tensile tests
- metallurgical examination
- microhardness tests

on specimens automatic welded in longitudinal configuration and according to the following types:

- automatic virgin welding
- automatic virgin welding containing mismatch
- automatic virgin welding containing peaking
- automatic virgin welding at minimun energy
- automatic virgin welding at maximum energy

2.0 MECHANICAL TESTING

Tensile tests were performed on rectangular specimens with weld position perpendicular to the longitudinal axis and on cylindrical specimens obtained from all-weld metal in order to evaluate the properties of welded joint.

Tensile strength requirements of plasma welded joints are given in document [2.1.02] para 3.1.3.1.

2.1 Reference documents

[2.1.01] - MLM-PL-AI-0012
"Test plan for the characterization of the MPLM primary structure VPPA welding"

[2.1.02] - MLM-SP-AI-0012
"Welding of 2219 alluminum Alloy for MPLM (Mini Pressurized Logistic Module)"

[2.1.03] - ASTM E 8
"Standard test method of tension testing of metallic materials"

[2.1.04] - ANSI-B4.0-92 AWS
"Standard method for mechanical testing of welds"

[2.1.05] - PRS 014
"Procedura di utilizzo in automatico della macchina Zwick per prove meccaniche a trazione su provini rettangolari e cilindrici"

2.2 Test specimens

Test specimens were machined, from welded samples, according to the following configurations:

1) rectangular specimens (fig.2.2-1) for tensile tests on automatic welded joints without and with geometrical defects (mismatch and peaking) and automatic process at minimum and maximum energy welding parameter.

2) round specimens (fig.2.2-2) for tensile tests on automatic welding without defects and automatic welding at minimum and maximum energy welding parameter.

Specimens identification is reported in document [2.1.01] para 6.6 : each specimen reproduces identification mark of the sample, letter - A - to specify tensile test and a sequential number.

2.3 Testing machine

Tensile tests were performed using a mechanical testing machine UTM Zwick 1475, controlled by Zwick software "7005", with two different configurations:

a) load cell = 100 kN
gage length of extensometer = 50 and 10 mm
for rectangular specimens (see para.2.3 point a))

test set up was:

test temperature	: room temperature
control mode	: Stroke
speed of testing	: 5 mm/min
configuration level	: TRAZSALD

b) load cell = 10 kN
gage length of extensometer = 16 mm
for round specimens (see para 2.3 point b))

test set up was:

test temperature	: room temperature
control mode	: Stroke
speed of testing	: 3 mm/min
configuration level	: TRAZSALD

2.4 Tests results

Tests results are summarized in the following tables for each homogeneous group of specimens:

Tab. 2.4-1a Tab. 2.4-1b Tab. 2.4-1c Tab. 2.4-1d	AUTOMATIC VIRGIN WELDING
Tab. 2.4-2	AUTOMATIC WELDING CONTAINING MISMATCH
Tab. 2.4-3	AUTOMATIC WELDING CONTAINING PEAKING
Tab. 2.4-4a Tab. 2.4-4b	AUTOMATIC WELDING AT MINUMUM ENERGY
Tab. 2.4-5a Tab. 2.4-5b	AUTOMATIC WELDING AT MAXIMUM ENERGY

Tab.2.4-1a: **AUTOMATIC VIRGIN WELDING**

SAMPLE LAX - 001 : rectangular test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]
A001	50	262.06
A002	50	261.46
A003	50	260.32
A004	50	261.14
A005	50	261.88
A006	50	259.67
A007	50	260.66
A008	50	259.88
A009	50	261.14
A010	50	261.82
A011	10	260.63
A012	10	261.88
A013	10	260.52
A014	10	260.82
A015	10	262.35

Tab.2.4-1b: **AUTOMATIC VIRGING WELDING - BEAD -**

SAMPLE LAX - 002 - round test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]	Yield Strength [MPa]	Elongation [%]
A018	16	263.71	132.67	19.9
A019	16	261.57	126.92	20.9
A020	16	266.26	125.39	20.6
A021	16	260.07	129.02	17.4
A022	16	260.71	130.87	15.2
A023	16	262.19	127.43	20.1

Tab.2.4-1c: **AUTOMATIC VIRGIN WELDING - BEAD -**

SAMPLE LAX - 008 - round test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]	Yield Strength [MPa]	Elongation [%]
A024	16	260.88	123.45	19.6
A025	16	261.20	130.3	18.6
A026	16	259.38	135.5	18.9
A027	16	258.52	130.99	18.1
A028	16	260.27	134.39	18.3
A029	16	260.68	124.97	19.2

Tab.2.4-1d: **AUTOMATIC VIRGIN WELDING - BEAD -**

SAMPLE LAX - 006 - round test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]	Yield Strength [MPa]	Elongation [%]
A030	16	259.78	134.03	18.5
A031	16	263.31	131.96	20.4
A032	16	259.87	129.32	20.1

Tab.2.4-2 : **AUTOMATIC WELDING CONTAINING MISMATCH**

SAMPLE LEX - 001 - rectangular test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]
A001	50	271.79
A002	50	269.54
A003	50	269.62
A004	50	267.88
A005	50	268.94
A006	50	262.55
A007	50	264.46
A008	50	266.28
A009	50	270.48
A010	50	268.85
A011	10	262.53
A012	10	268.28
A013	10	266.97
A014	10	269.85
A015	10	263.79

Tab.2.4-3 : **AUTOMATIC WELDING CONTAINING PEAKING**

SAMPLE LFX - 001 - rectangular test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]
A001	50	277.94
A002	50	271.06
A003	50	281.12
A004	50	277.01
A005	50	278.33
A006	50	272.08
A007	50	281.58
A008	50	280.08
A009	50	276.19
A010	50	278.24
A011	10	279.62
A012	10	279.13
A013	10	278.64
A014	10	279.40
A015	10	281.42

Tab.2.4-4a : **AUTOMATIC WELDING AT MINIMUM ENERGY**

SAMPLE LGX - 003 - rectangular test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]
A001	50	268.8
A002	50	269.5
A003	50	268.7

SAMPLE LGX - 004 - rectangular test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]
A004	10	266.9
A005	10	267.7

Tab.2.4-4b : **AUTOMATIC WELDING AT MINIMUM ENERGY - BEAD -**

SAMPLE LGX - 003 - round test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]	Yield Strength [MPa]	Elongation [%]
A007	16	263.4	143.4	16.7
A008	16	270.3	143.4	19.3

SAMPLE LGX - 004 - round test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]	Yield Strength [MPa]	Elongation [%]
A009	16	266.9	135.5	21.6
A010	16	270.7	142.5	20.7

Tab.2.4-5b : **AUTOMATIC WELDING AT MAXIMUM ENERGY**

SAMPLE LHX - 001 - rectangular test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]
A001	50	260.87
A002	50	260.74
A003	50	260.1
A004	10	260.53
A005	10	258.9

Tab.2.4-5b : **AUTOMATIC WELDING AT MAXIMUM ENERGY - BEAD -**

SAMPLE LHX - 001 - round test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]	Yield Strength [MPa]	Elongation [%]
A007	16	267.5	125.2	20.8
A008	16	268.7	143.0	20.4

SAMPLE LHX - 002 - round test specimen

SPECIMEN IDENTIFICATION	Gage length [mm]	Tensile strength [MPa]	Yield Strength [MPa]	Elongation [%]
A009	16	262.6	132.7	18.1
A010	16	265.9	147.1	19.9
A011	16	268.5	149.4	17.5

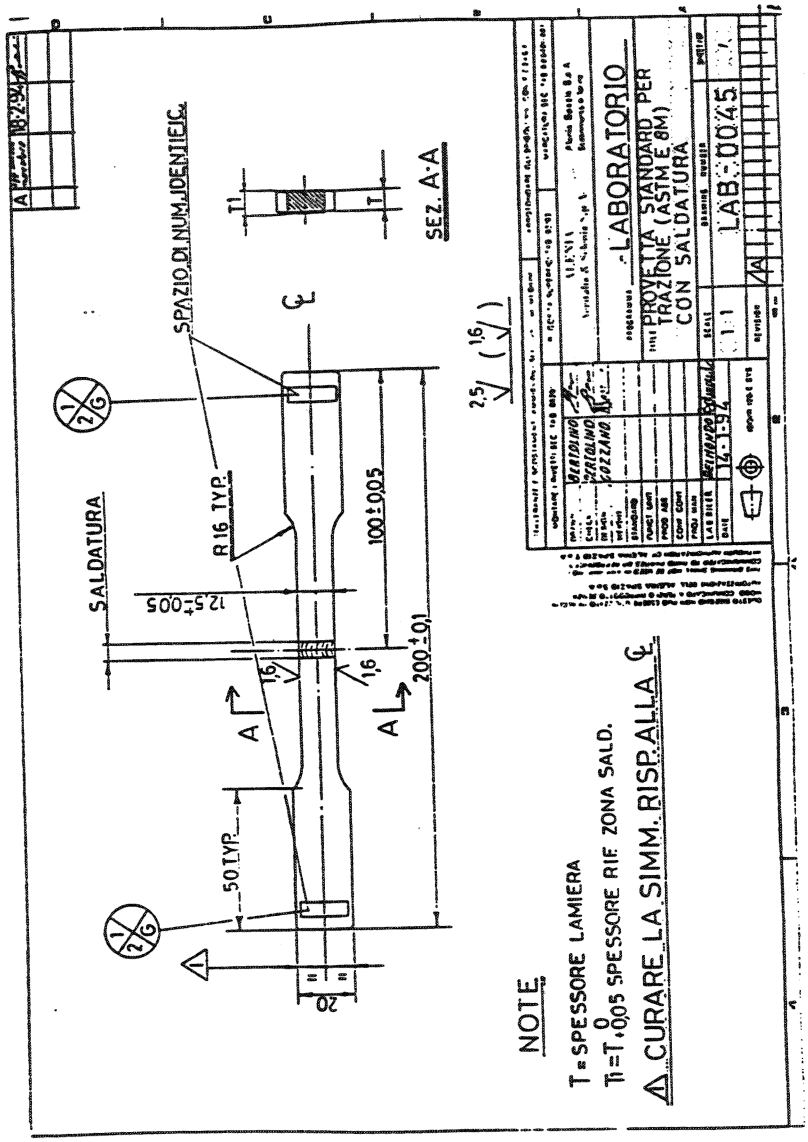


Fig. 2.2-1: rectangular tensile test specimen

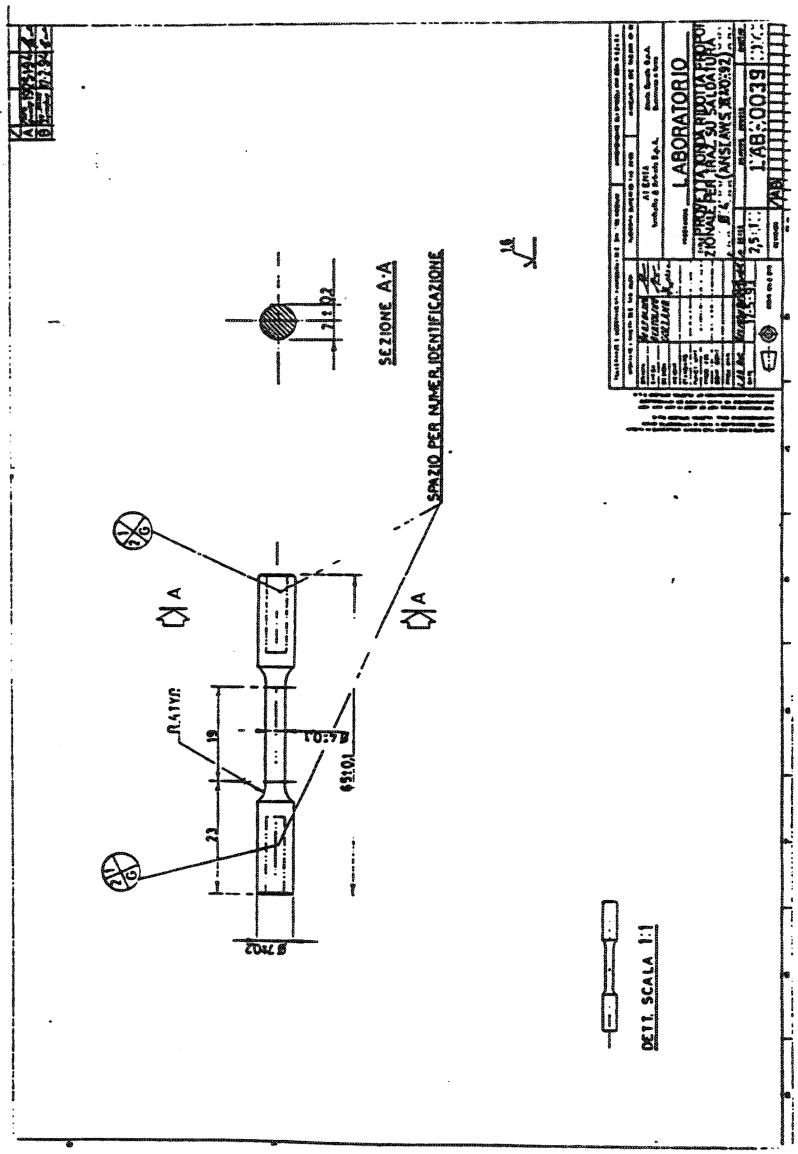


Fig. 2.2-2: cylindrical tensile test specimen

3.0 METALLOGRAPHIC EXAMINATION

Metallographic examinations have been carried out on each group of homogeneous specimens.

Cross sections of the welding beads cutted in different welding positions have been investigated by using Keller's reagent to reveal microstructural features.
The entire area have been carefully examinated and the following observations heve been documented:

a) macroexamination of the joint (7 X)
b) microexamination of the welded material (100 X)
c) microexamination of the transition welded material-HAZ.

Specific comments and evaluationa are contained in the related paragraphs, showing the results of each type of welding following presented.

3.1 Reference documents

[3.1.01] - MLM-PL-AI-0012
"Test plan for the characterization of the MPLM primary structure VPPA welding"

[3.1.02] - ASTM E 3
"Standard method of preparation of metallographic specimens"

3.2 Automatic virgin welding

Details and remarks are reported in Annex 1.

3.3 Automatic welding with mismatch

Details and remarks are reported in Annex 2.

3.4 Automatic welding with peaking

Details and remarks are reported in Annex 3.

3.5 Automatic welding at minimum energy

Details and remarks are reported in Annex 4.

3.6 Automatic welding at maximum energy

Details and remarks are reported in Annex 5.

A N N E X 1

AUTOMATIC VIRGIN WELDING

RESULTS OF: AUTOMATIC VIRGIN WELDING
Risultati di

RESULTS SUMMARY:
Risultati complessivi

Macroexamination: a regular weld bead is evident showing a width ratio torch side / back side of approx. 1.4.

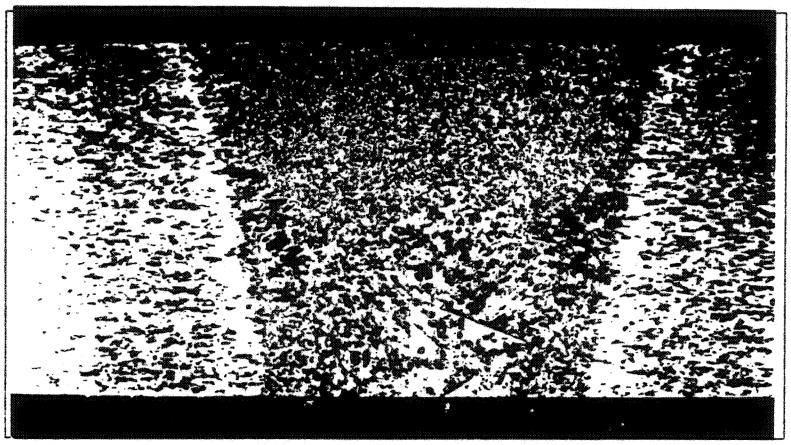
Microexamination: dendritic microstructure without any discontinuities typical of high cooling rates. No significative modifications in HAZ feature are evinced. No appreciable internal defects have been observed.

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° / *Provino N°* LAX-006/I 001

VIRGIN WELD



MACRO OF WELD

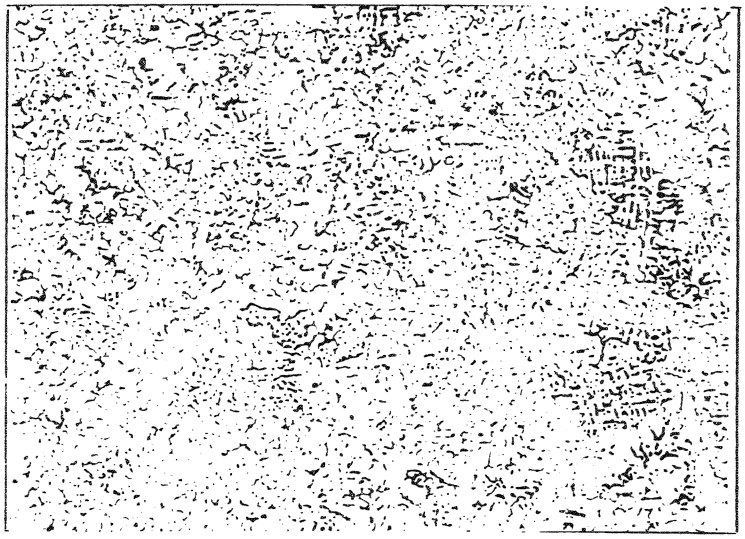
PHOTO N°: / *Foto* 719

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: / *Foto* 719 A

x: 100



MICRO
CENTER WELD DETAIL

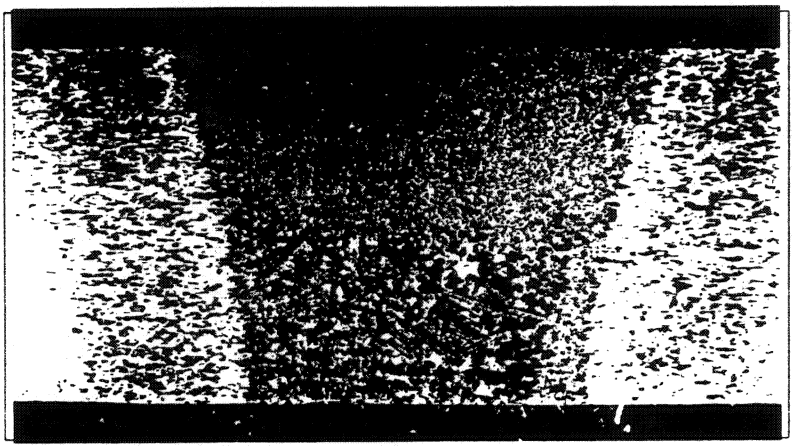
PHOTO N°: / *Foto* 719 B

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 3 of 7 *Pag. di*

SAMPLE N° / *Provino N°* LAX-006/I002

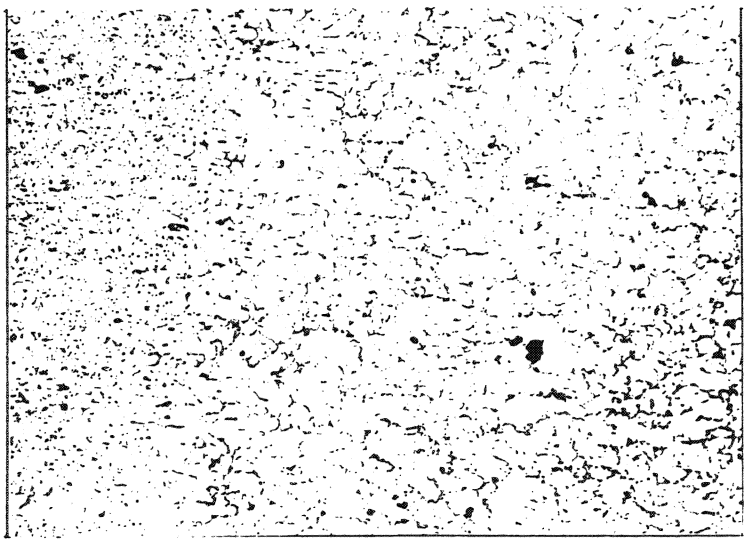
VIRGIN WELD



MACRO OF WELD

PHOTO N°: / *Foto* 720

x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: / *Foto* 720 A

x: 100

MICRO
CENTER WELD DETAIL

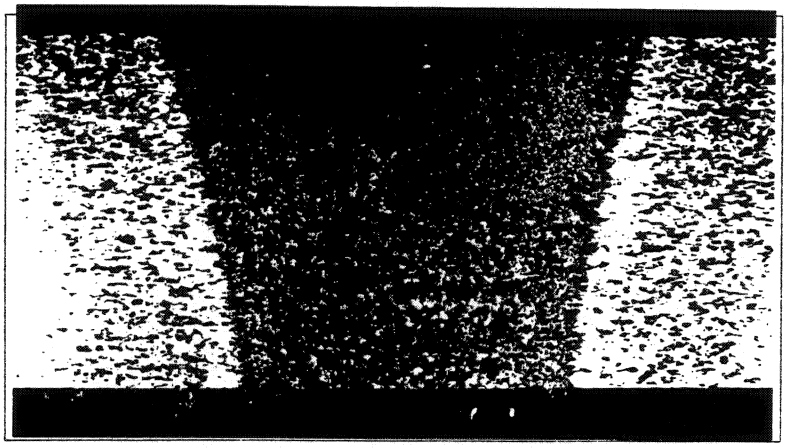
PHOTO N°: / *Foto* 720 B

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 4 of 7 *Pag. di*

SAMPLE N°
Provino N° LAX-006/I003

VIRGIN WELD



MACRO OF WELD

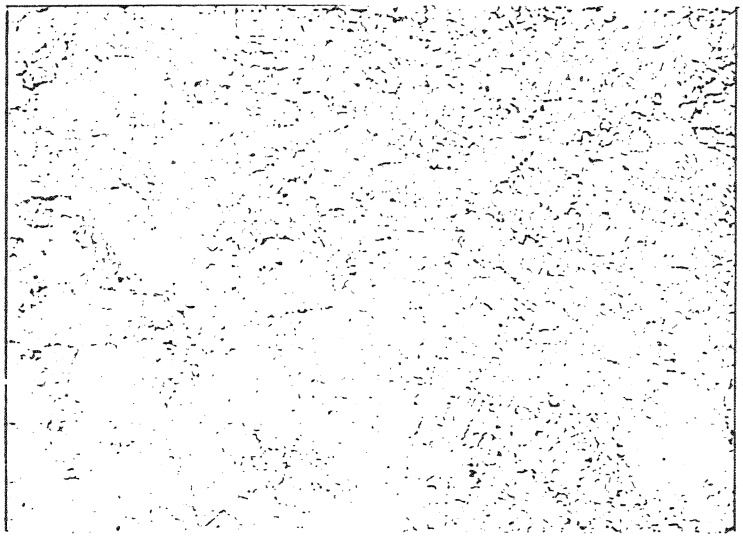
PHOTO N°: 721
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 721 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

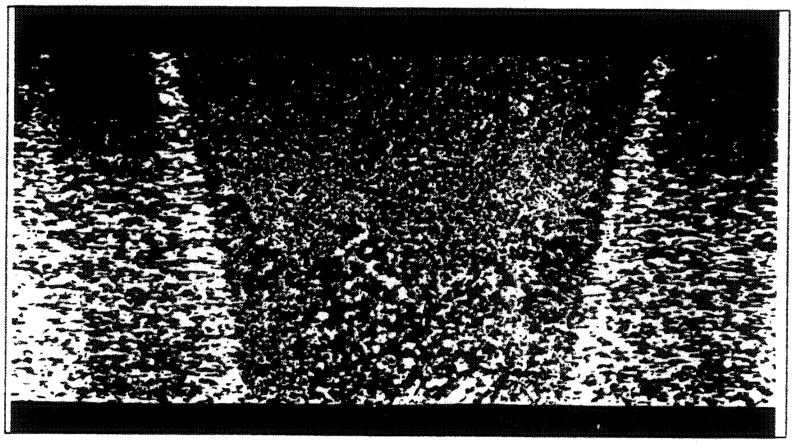
PHOTO N°: 721 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 5 of 7 *Pag. di*

SAMPLE N°
Provino N° LAX-006/I004

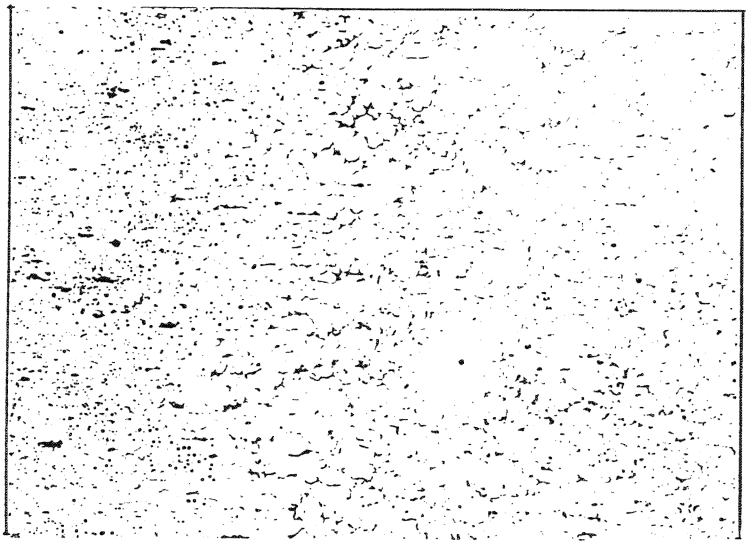
VIRGIN WELD



MACRO OF WELD

PHOTO N°: 722
Foto

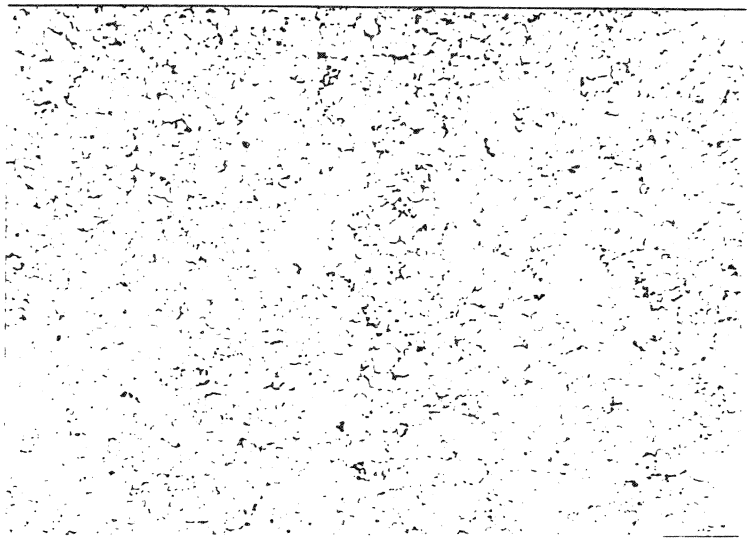
x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 722 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

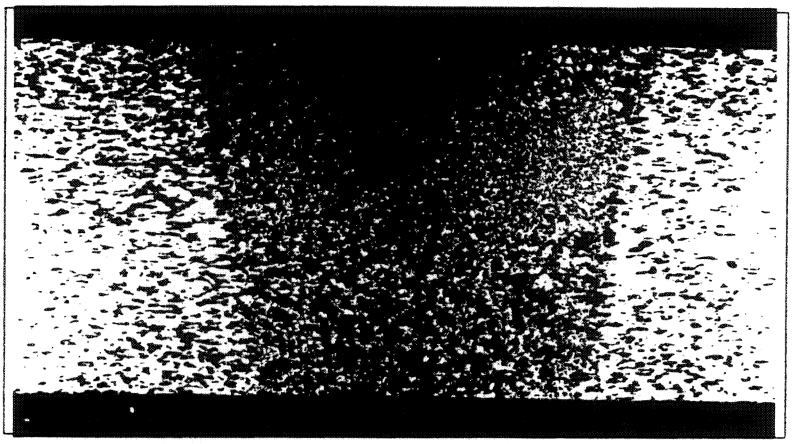
PHOTO N°: 722 B
Foto

x: 100

MICRO - MACRO EXAMINATION RESULTS
Risultati esami micro - macrografici

SAMPLE N° LAX-003/I005
Provino N°

VIRGIN WELD



MACRO OF WELD

PHOTO N°: 723
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 723 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

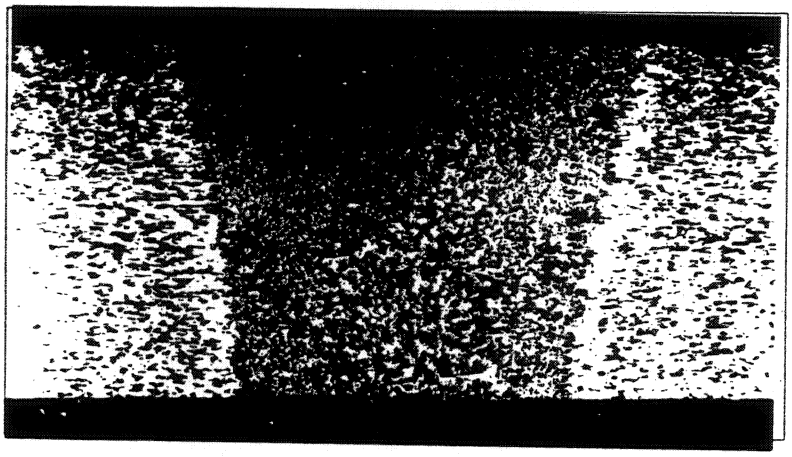
PHOTO N°: 723 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 7 of 7 *Pag. di*

SAMPLE N°
Provino N° LAX-003/I006

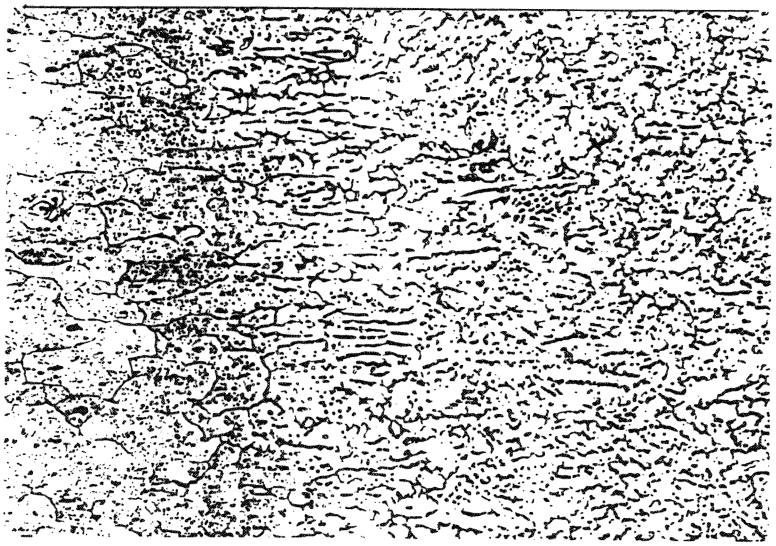
VIRGIN WELD



MACRO OF WELD

PHOTO N°: 724
Foto

x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 724 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 724 B
Foto

x: 100

RESULTS OF: AUTOMATIC WELDING WITH MISMATCH
Risultati di

RESULTS SUMMARY:
Risultati complessivi

Macroexamination: a regular bead is evident affected by imposed mismatch.

Microexamination: evaluation comparable to virgin weld

A N N E X 2

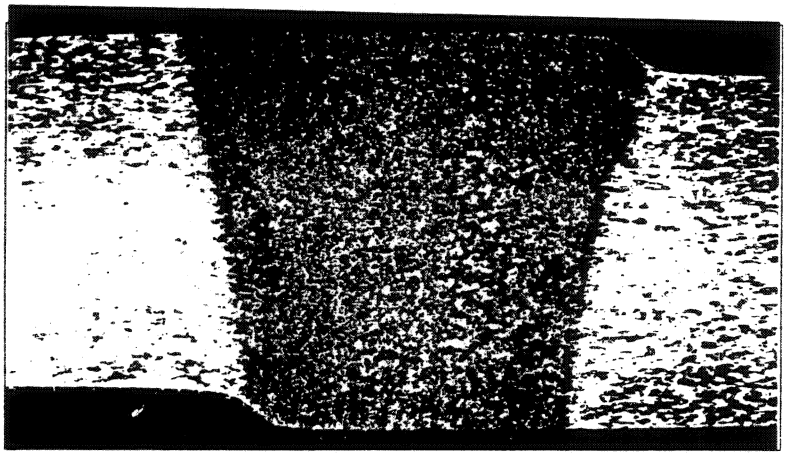
AUTOMATIC WELDING WITH MISMATCH

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° / *Provino N°* LEX - 002/I001

WELDED WITH MISMATCH



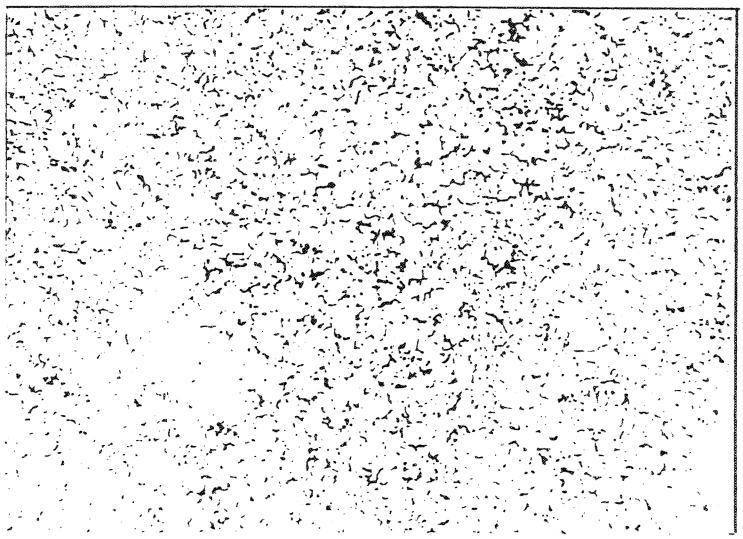
MACRO OF WELD

PHOTO N°: 740 / *Foto* x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 740 A / *Foto*

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 740 B / *Foto*

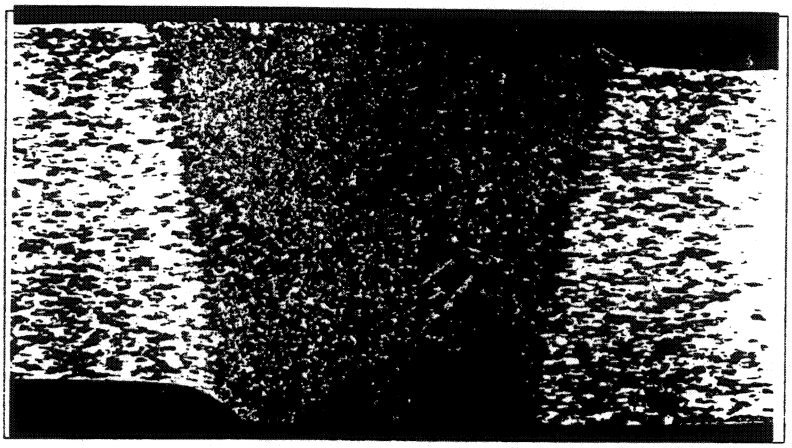
x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

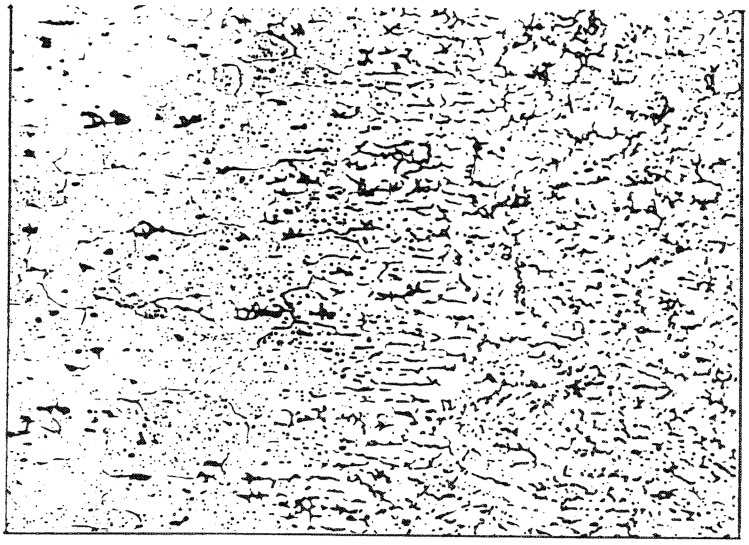
SAMPLE N° / *Provino N°* LEX - 002 / I 002

WELDED WITH MISMATCH



MACRO OF WELD

PHOTO N°: 741 x: 7
Foto



MICRO
HAZ WELD DETAIL

PHOTO N°: 741 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

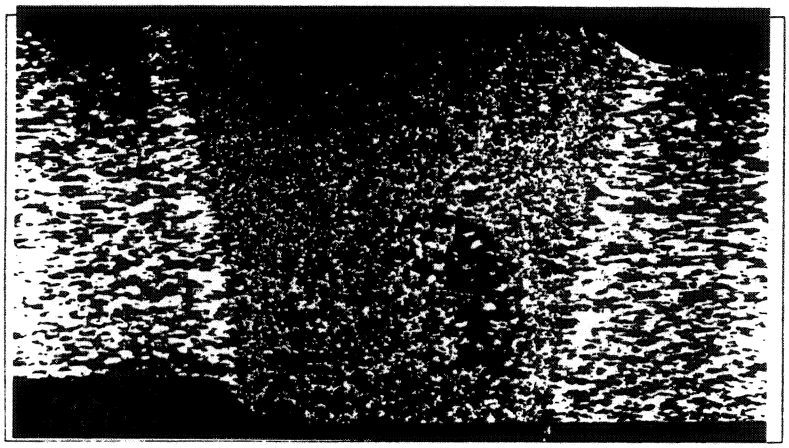
PHOTO N°: 741 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 4 of 7 *Pag. di*

SAMPLE N°
Provino N° LEX-002/003

WELDED WITH MISMATCH



MACRO OF WELD

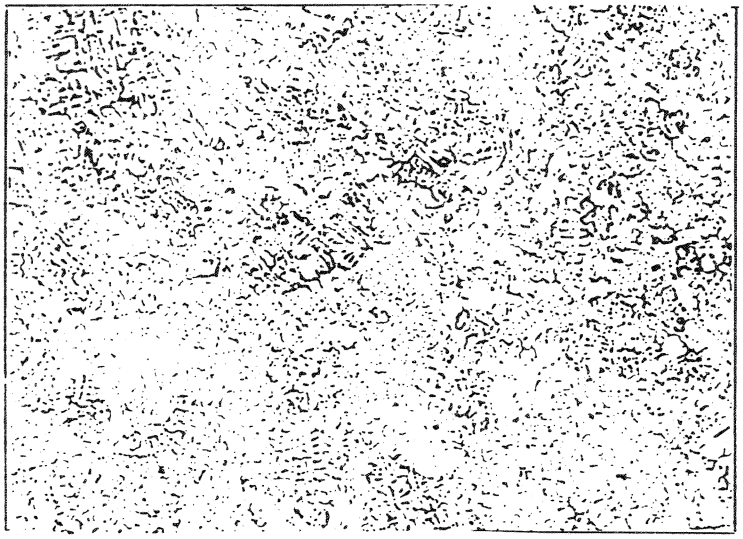
PHOTO N°: 742
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 742 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 742 B
Foto

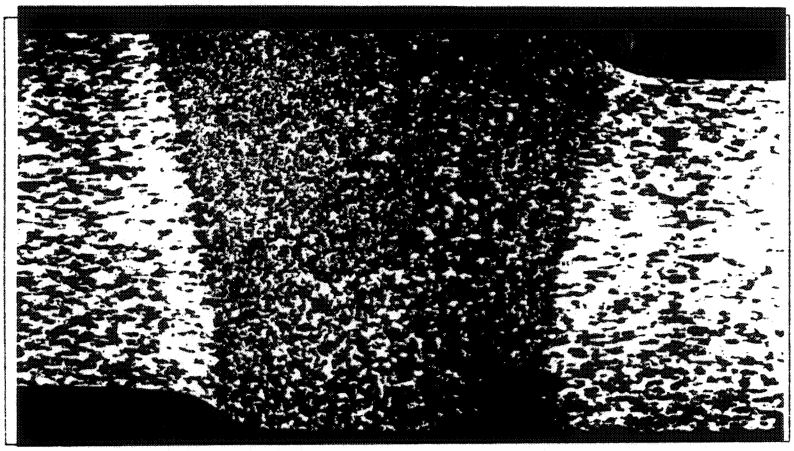
x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° LEX-002/I004
Provino N°

WELDED WITH MISMATCH



MACRO OF WELD

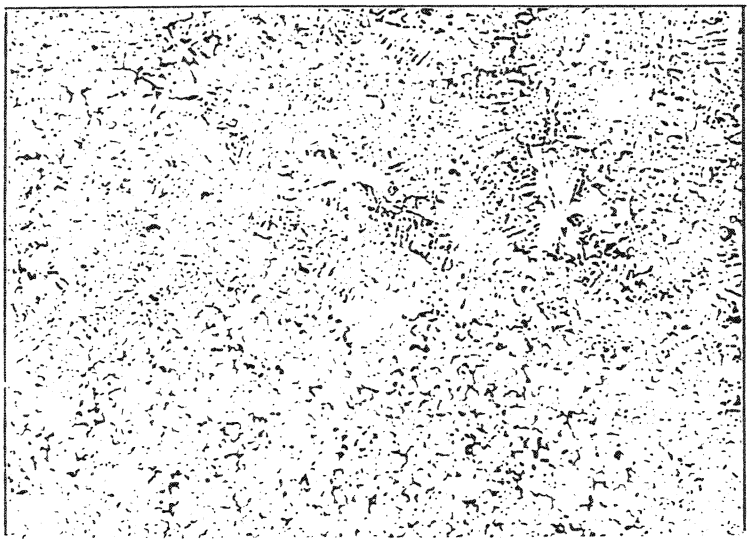
PHOTO N°: 743
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 743 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 743 B
Foto

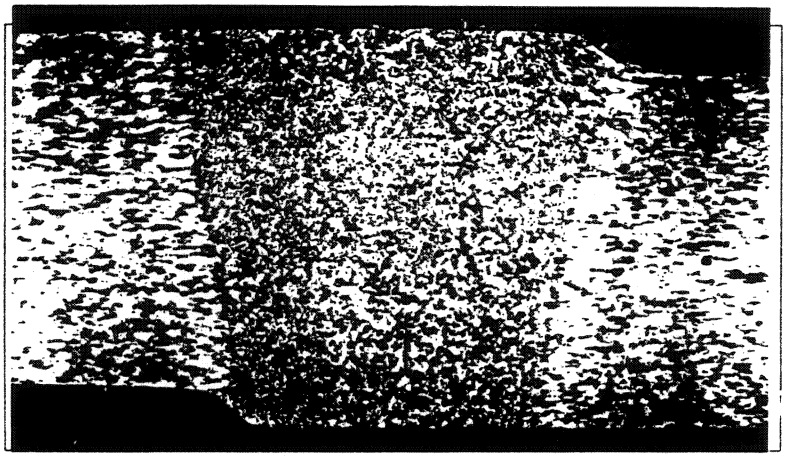
x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

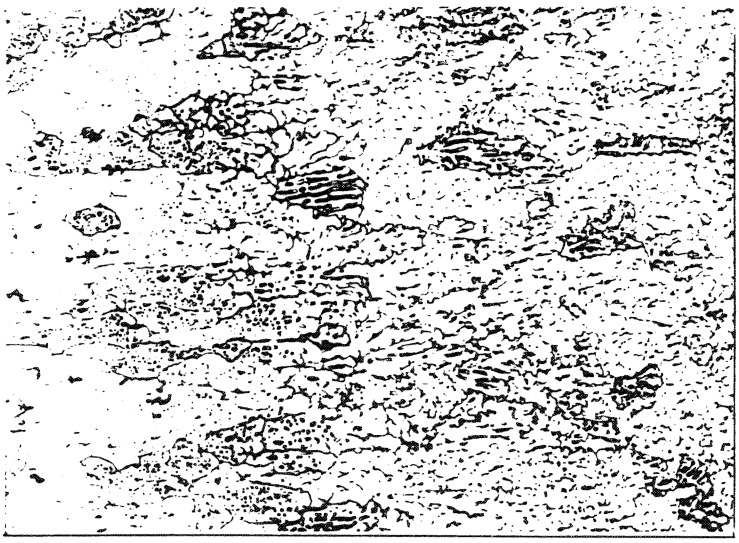
SAMPLE N° / *Provino N°* LEX-002/I005

WELDED WITH MISMATCH



MACRO OF WELD

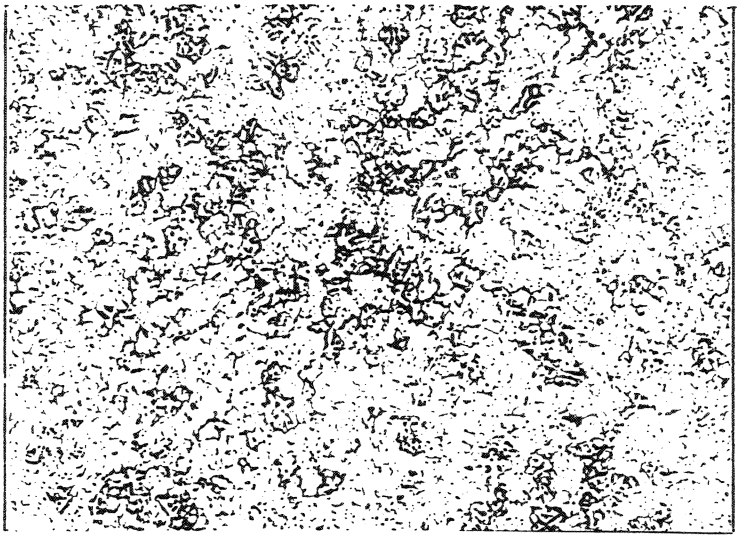
PHOTO N°: 744 / *Foto* x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 744 A / *Foto*

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 744 B / *Foto*

x: 100

RESULTS OF: AUTOMATIC WELDING WITH PEAKING
Risultati di

RESULTS SUMMARY:
Risultati complessivi

Macroexamination: a regular weld bead is evident affected by imposed peaking.

Microexamination: evaluation comparable to virgin weld.

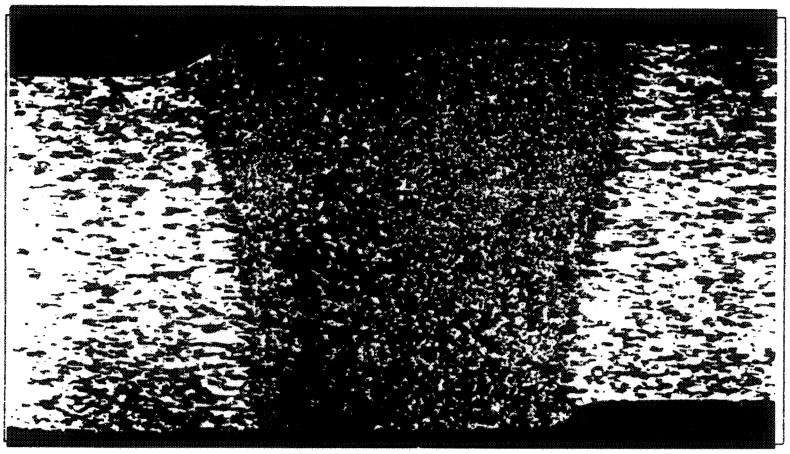
A N N E X 3

AUTOMATIC WELDING WITH PEAKING

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 7 of 7 *Pag. di*

SAMPLE N°
Provino N° LEX – 002/I006

WELDED WITH MISMATCH



MACRO OF WELD

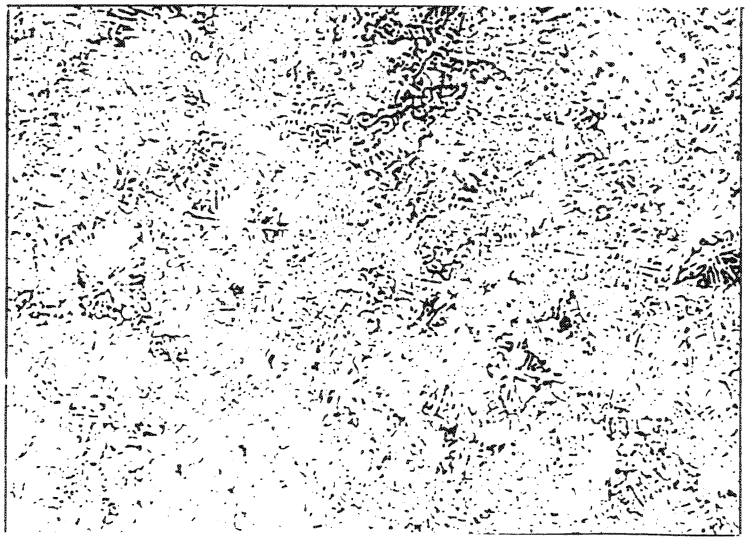
PHOTO N°: 745
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 745 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

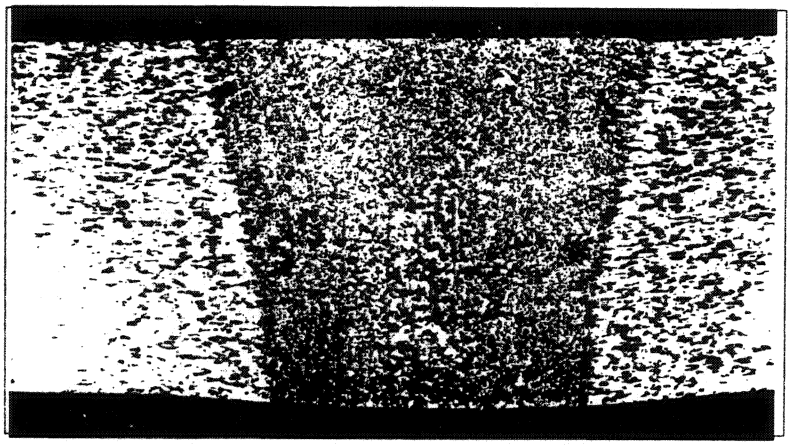
PHOTO N°: 745 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 2 of 7 *Pag. di*

SAMPLE N°
Provino N° LFX-002/I001

WELDED WITH PEAKING



MACRO OF WELD

PHOTO N°: 752
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 752 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 752 B
Foto

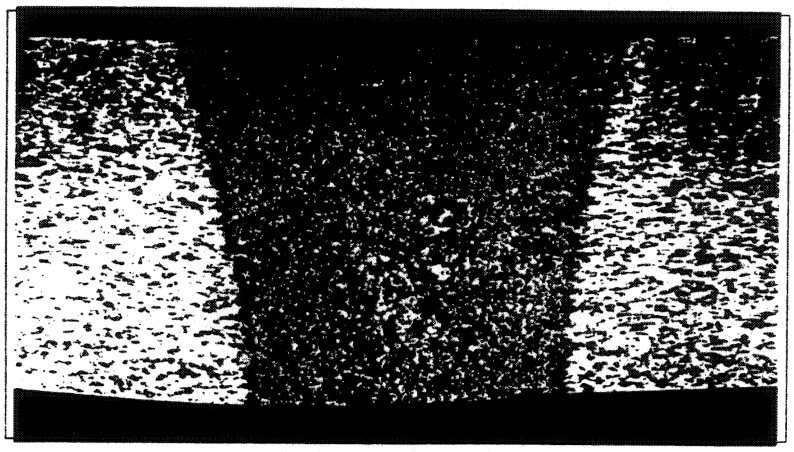
x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

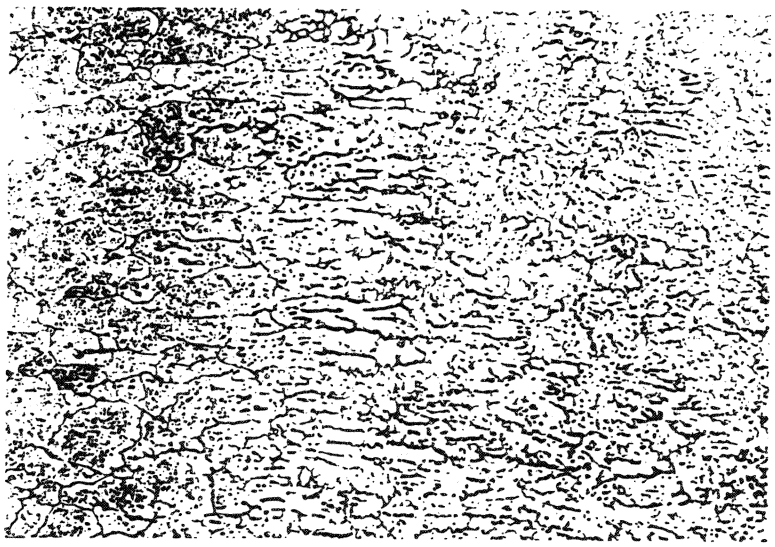
SAMPLE N° / *Provino N°* LFX - 002/I002

WELDED WITH PEAKING



MACRO OF WELD

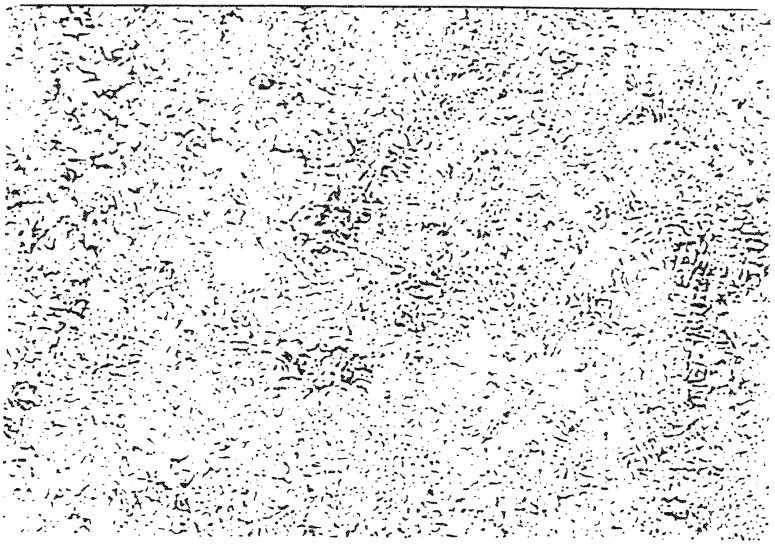
PHOTO N°: 753 / *Foto* x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 753 A / *Foto*

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 753 B / *Foto*

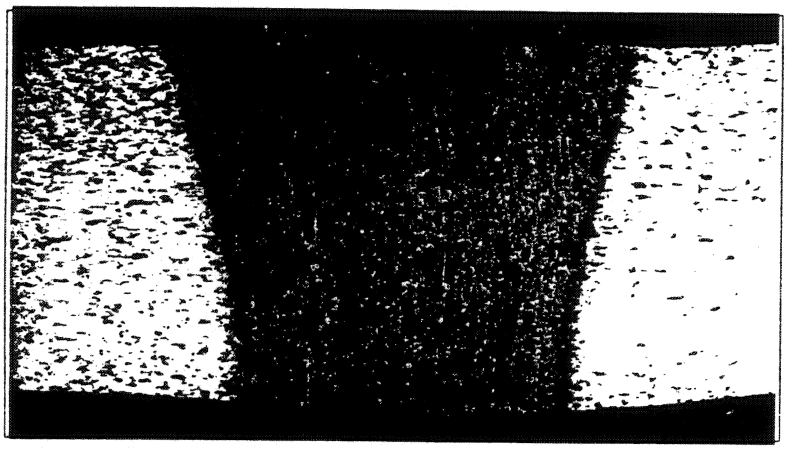
x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

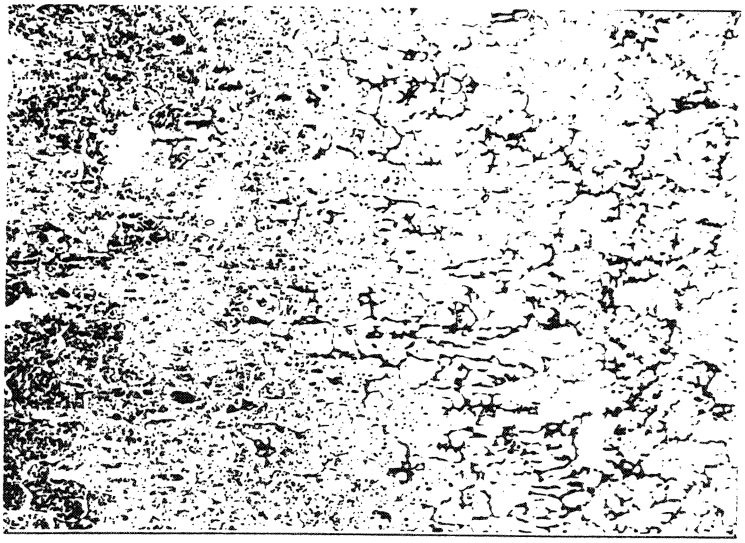
SAMPLE N° / *Provino N°* L FX - 002 / I 003

WELDED WITH PEAKING



MACRO OF WELD

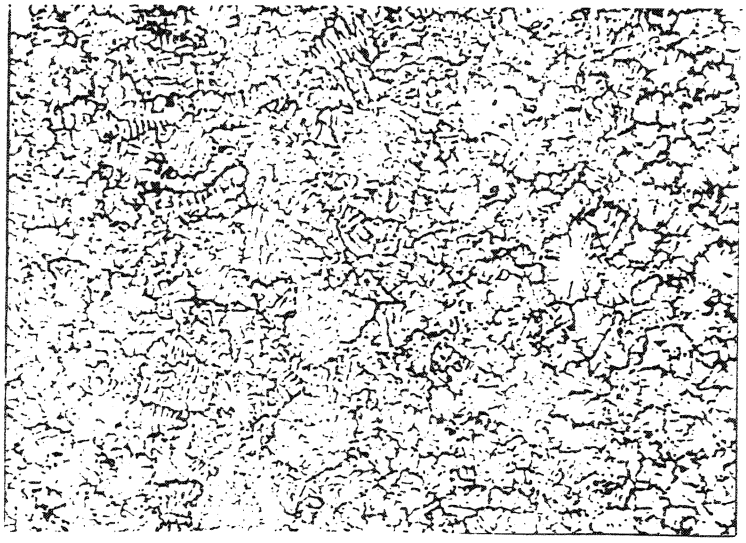
PHOTO N°: / *Foto* 754 x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: / *Foto* 754 A

x: 100



MICRO
CENTER WELD DETAIL

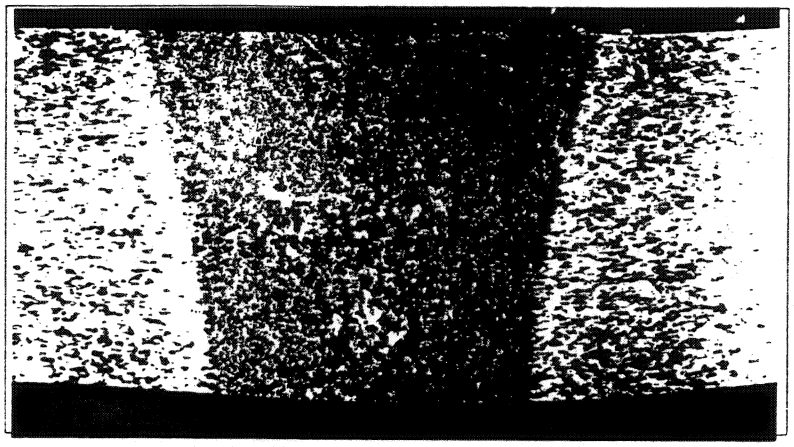
PHOTO N°: / *Foto* 754 B

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 5 of 7 *Pag. di*

SAMPLE N°
Provino N° LFX-002/I004

WELDED WITH PEAKING



MACRO OF WELD

PHOTO N°: 755
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 755 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 755 B
Foto

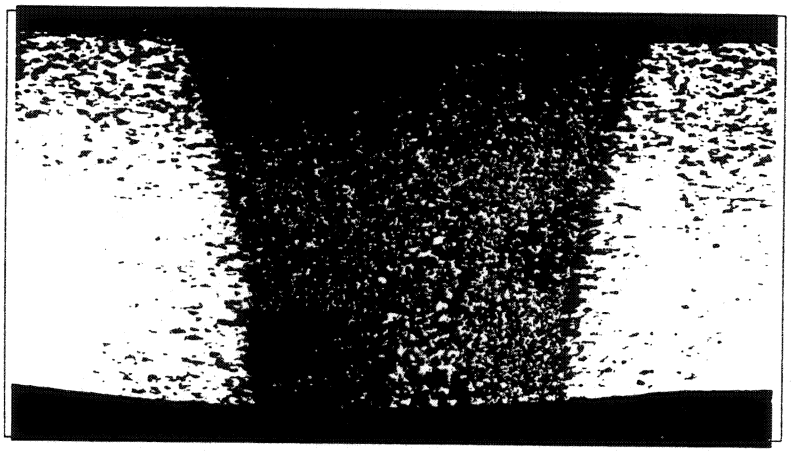
x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N°
Provino N° LFX-002/I 005

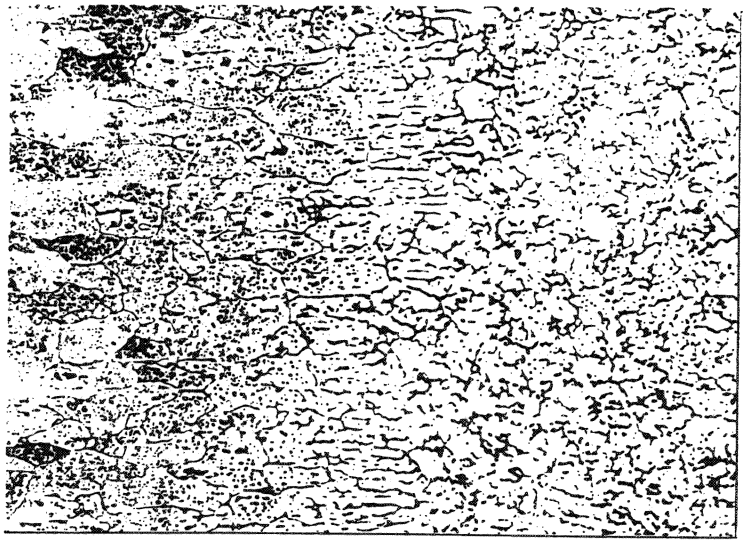
WELDED WITH PEAKING



MACRO OF WELD

PHOTO N°: 756
Foto

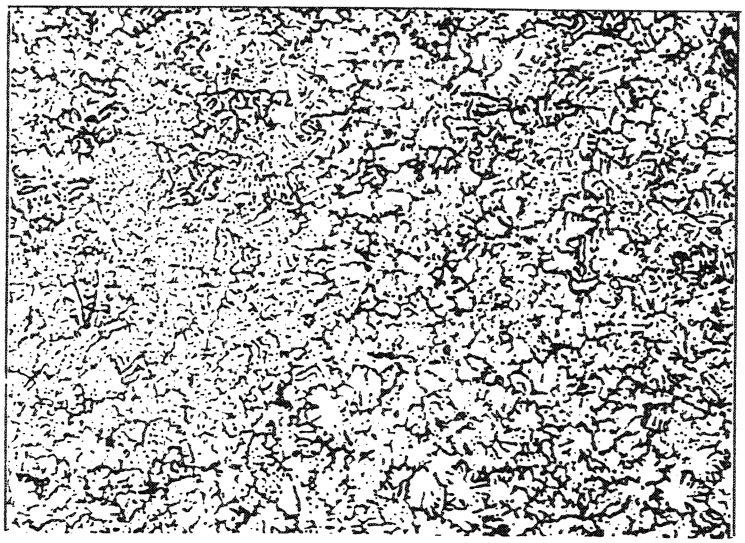
x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 756 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 756 B
Foto

x: 100

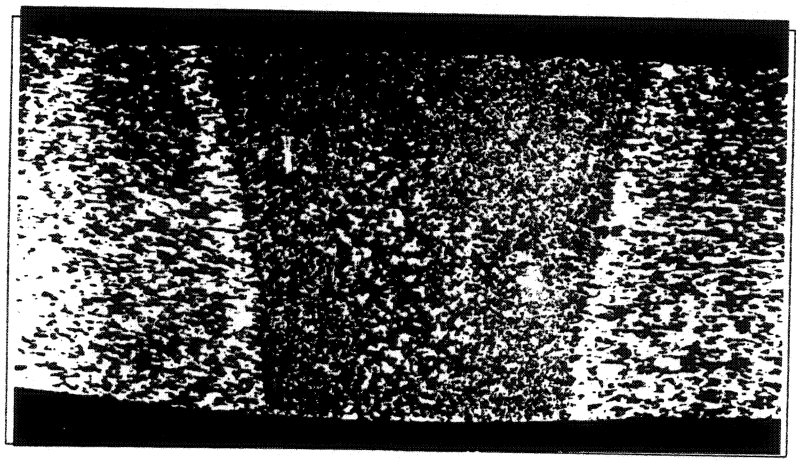
Alenia
Alenia Spazio S.p.A.

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N°
Provino N° LFX-002/I006

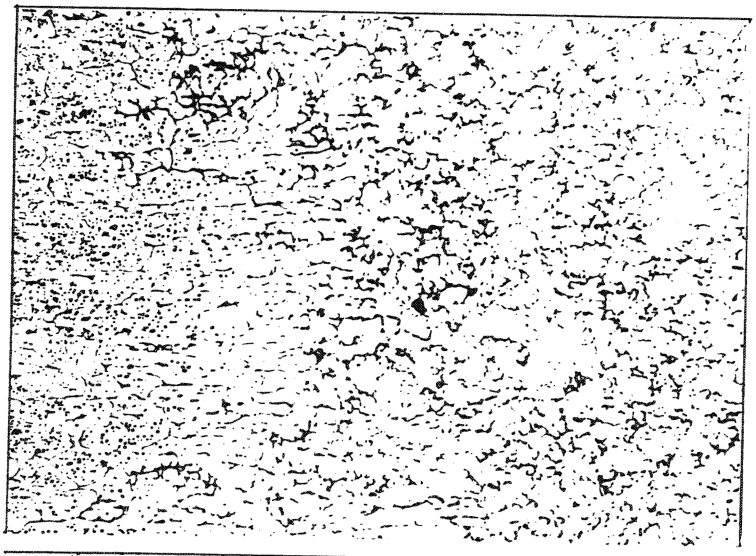
WELDED WITH PEAKING



MACRO OF WELD

PHOTO N°: 757
Foto

x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 757 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 757 B
Foto

x: 100

RESULTS OF: AUTOMATIC WELDING AT MINIMUM ENERGY
Risultati di

RESULTS SUMMARY:
Risultati complessivi

Macroexamination: a regular weld bead is evident showing a width ratio torch side / back side of approx.1.8 demonstrating a bead restriction back side in respect to normal conditions according to the welding energy reduction.

Microexamination: dendritic microstructure without metallurgical discontinuities associated to high cooling rates typical of plasma welding.
No relevant modifications in HAZ feature are evident.
Few isolated micropores lower than 0.1 mm in size were found in the melted material mainly in torch side position.

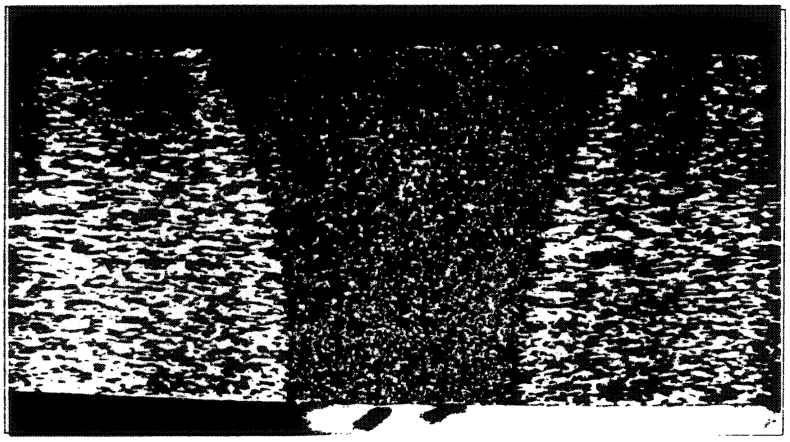
A N N E X 4

AUTOMATIC WELDING AT MINIMUM ENERGY

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 2 of 4 *Pag. di*

SAMPLE N°
Provino N° LGX-003/I004

WELDED AT MIN. ENERGY



MACRO OF WELD

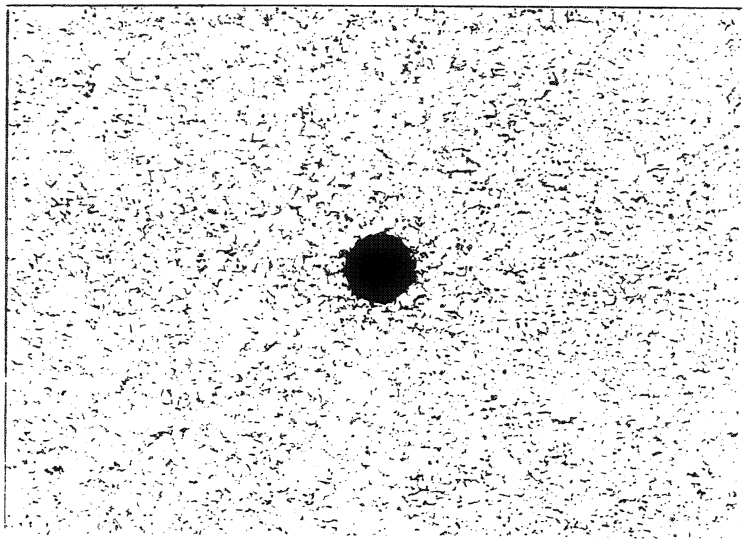
PHOTO N°: 818
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 818 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

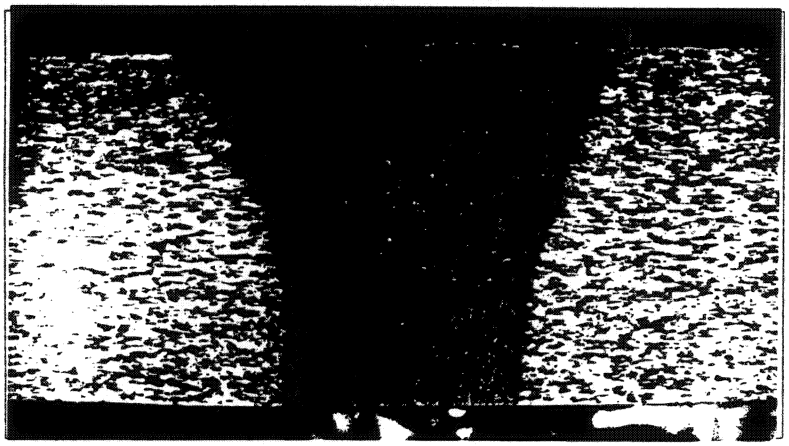
PHOTO N°: 818 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 3 of 4 *Pag. di*

SAMPLE N°
Provino N° LGX-003/T005

WELDED AT MIN. ENERGY



MACRO OF WELD

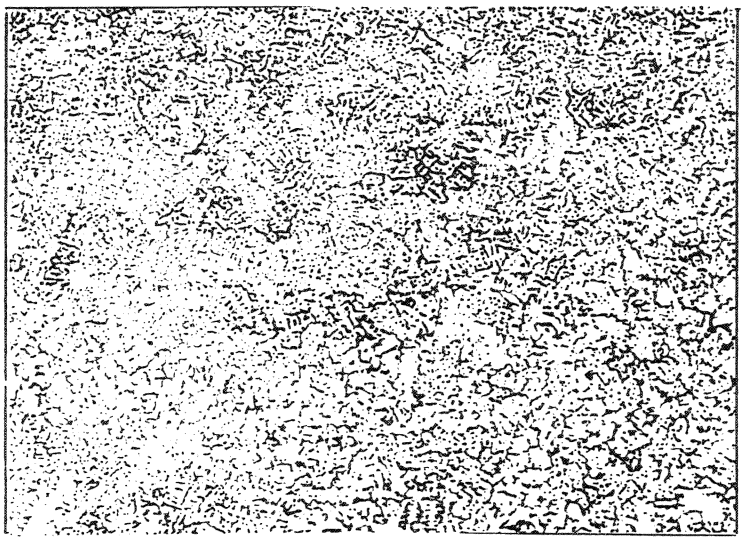
PHOTO N°: 819
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 819 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 819 B
Foto

x: 100

RESULTS OF: AUTOMATIC WELDING AT MAXIMUM ENERGY
Risultati di

RESULTS SUMMARY:
Risultati complessivi

Macroexamination: a regular weld bead is evident showing a width ratio torch side / back side of approx.1.3 demonstrating a bead tendency to a rectangular shape according to energy increase.

Microexamination: dendritic microstructure without any metallurgical discontinuities associated to high cooling rates typical of plasma welding.
Very sligth modification of grain boundary feature were found in HAZ.

A N N E X 5

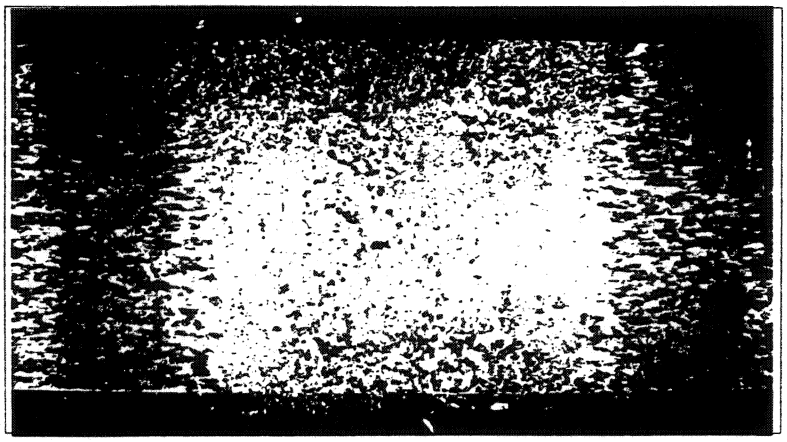
AUTOMATIC WELDING AT MAXIMUM ENERGY

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° LHX-001/I002
Provino N°

WELDED AT MAX. ENERGY



MACRO OF WELD

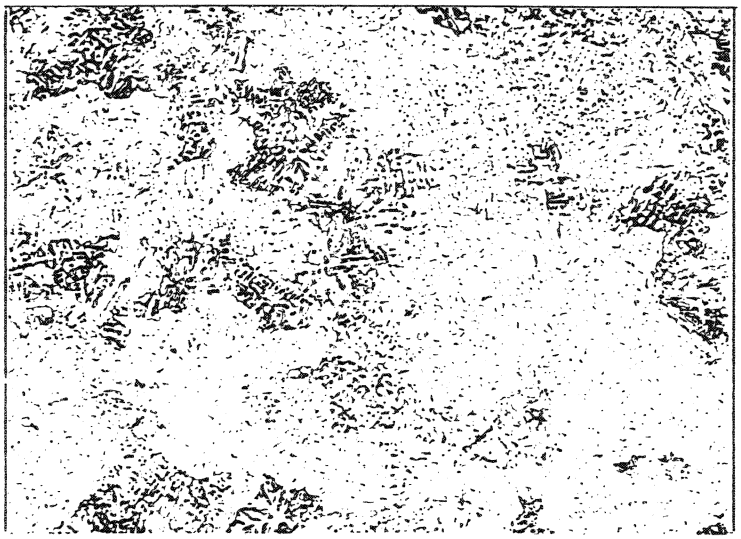
PHOTO N°: 766
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 766 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 766 B
Foto

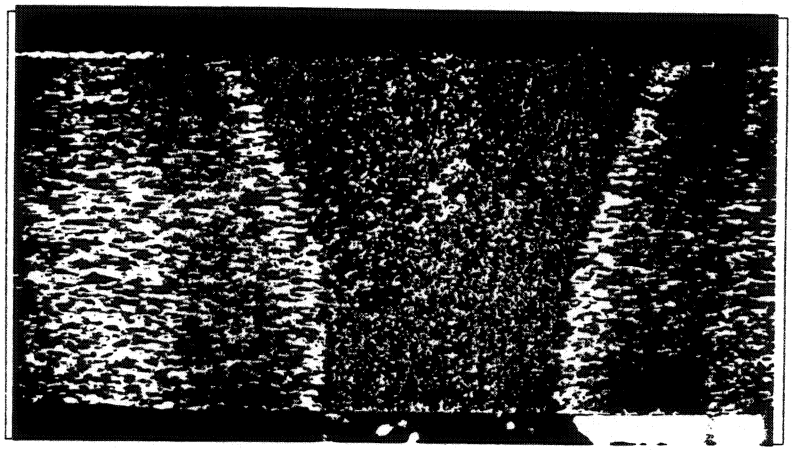
x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N°
Provino N° LGX-003/006

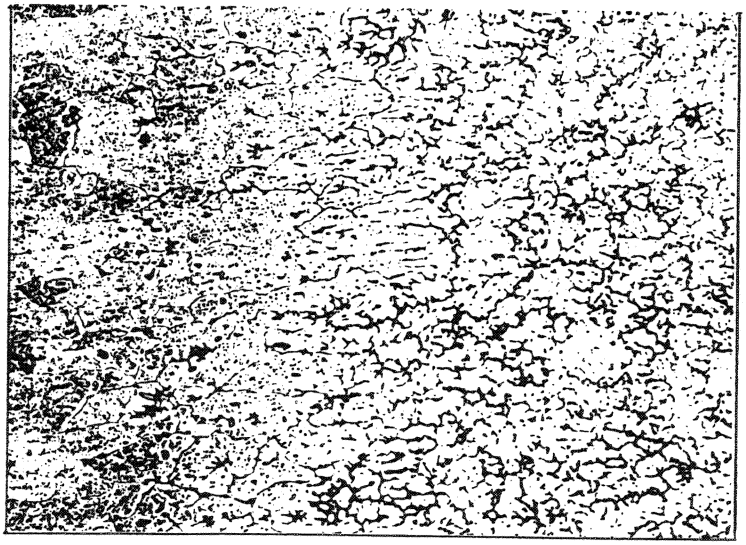
WELDED AT MIN. ENERGY



MACRO OF WELD

PHOTO N°: 820
Foto

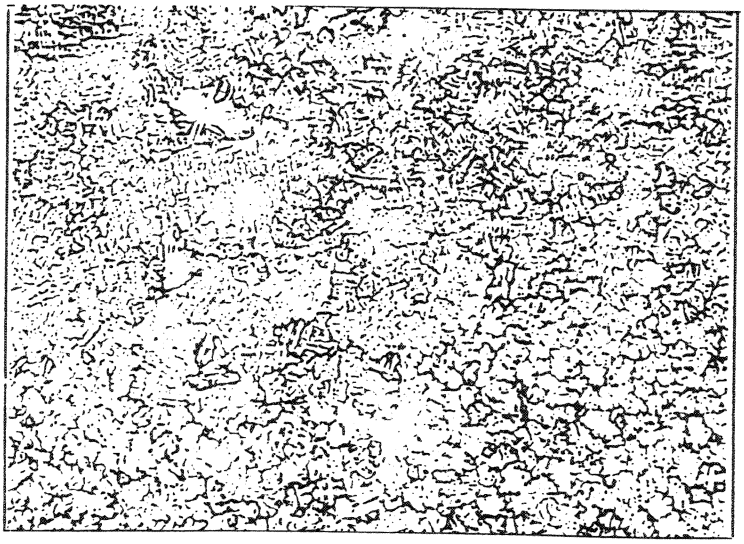
x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 820 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 820 B
Foto

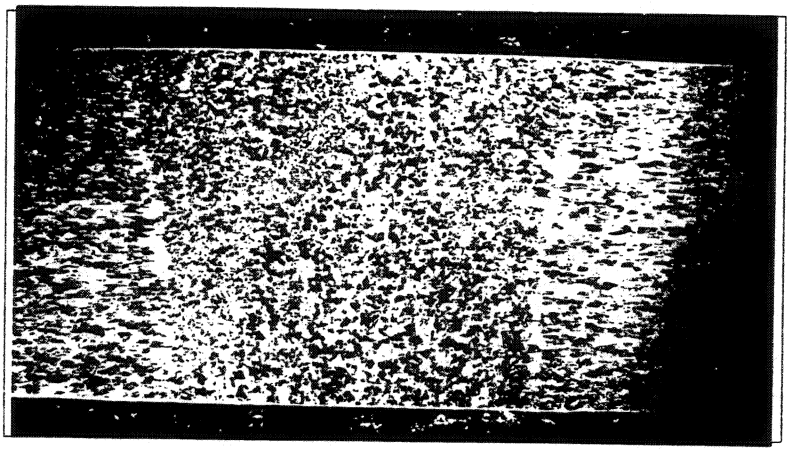
x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N°
Provino N° LHX-001/I001

WELDED AT MAX. ENERGY



MACRO OF WELD

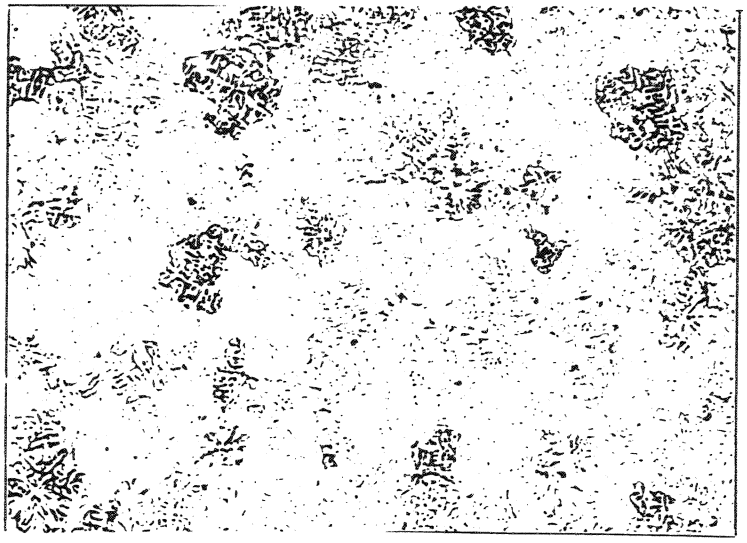
PHOTO N°: 765
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 765 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

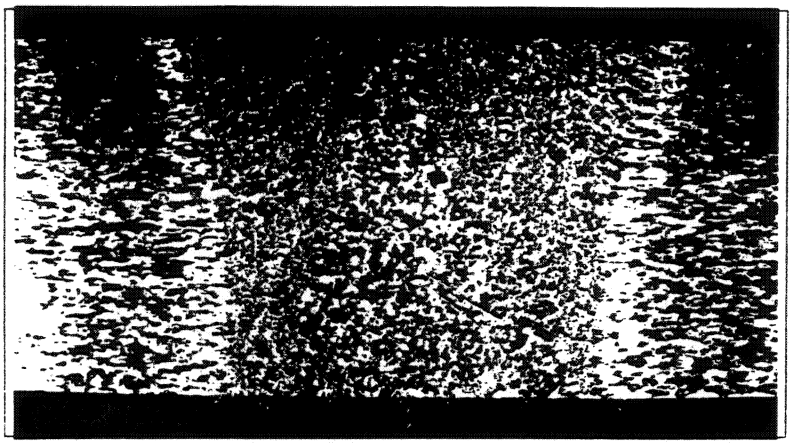
PHOTO N°: 765 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 4 of 4 *Pag. di*

SAMPLE N°
Provino N° LHX-001/I003

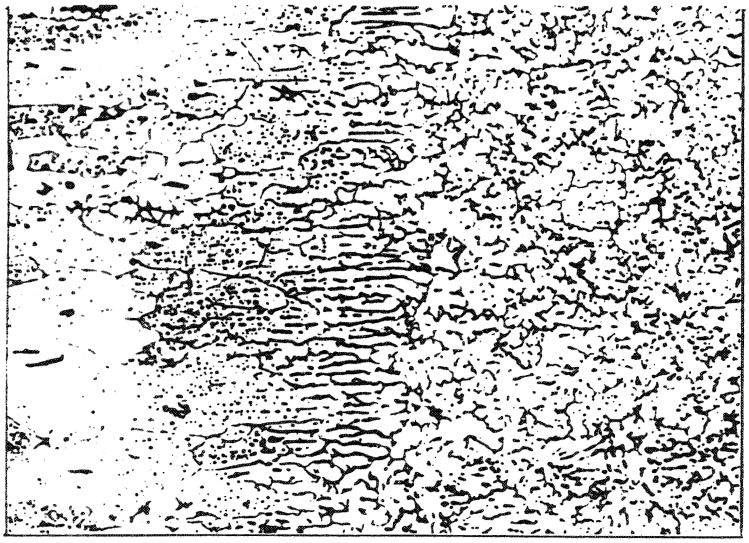
WELDED AT MAX. ENERGY



MACRO OF WELD

PHOTO N°: 767
Foto

x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 767 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 767 B
Foto

x: 100

A N N E X 6

MICROHARDNESS TEST RESULTS

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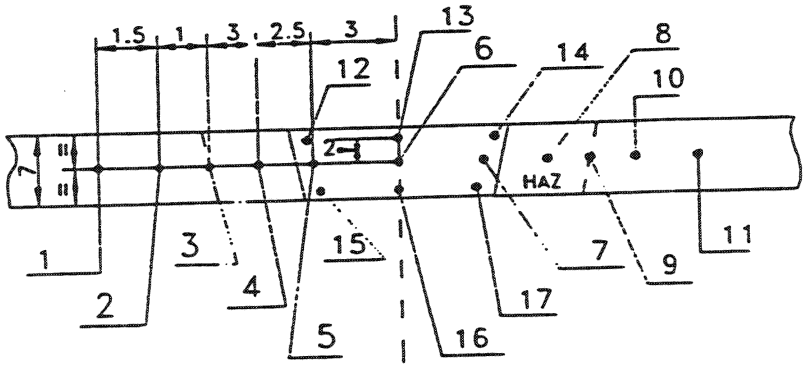
Alenia Spazio S.p.A.

MICROHARDNESS RESULTS
Risultati microdurezza

SAMPLE N° / *Provettone N°*: LAX-003 FORCE: / *Carico*: 5 N TYPE: / *Tipo*: HV

Point of measure



AUTOMATIC WELDING

Specimens N°	H001	H002	H003	H004	H005	H006
Lab. identif.	*725*	*726*	*727*	*728*	*729*	*730*
Point of meas.	HV					
1	104.58	105.05	99.22	104.98	101.13	105.44
2	98.42	95.82	94.52	98.49	96.24	98.28
3	88.66	92.20	83.90	92.26	92.14	89.23
4	96.17	88.43	95.06	87.81	93.86	91.11
5	72.82	76.03	68.51	74.36	75.07	72.92
6	68.84	73.42	70.77	75.98	77.51	68.55
7	74.55	75.41	72.37	77.51	69.46	74.64
8	91.17	89.78	86.33	89.65	75.60	96.51
9	95.34	87.10	85.80	88.18	89.41	92.20
10	102.25	92.86	97.56	97.34	92.92	95.95
11	108.37	104.58	102.21	104.58	96.23	102.38
12	71.30	73.66	72.06	73.52	69.52	72.92
13	69.14	73.24	71.61	71.88	72.87	73.52
14	74.08	71.08	75.22	73.89	72.78	72.11
15	78.08	74.36	71.46	76.62	77.17	73.84
16	74.87	71.47	73.66	75.64	76.38	71.21
17	75.36	72.24	74.79	77.07	76.38	71.52

WELD zone: HAZ:

NOTE: / *Note*

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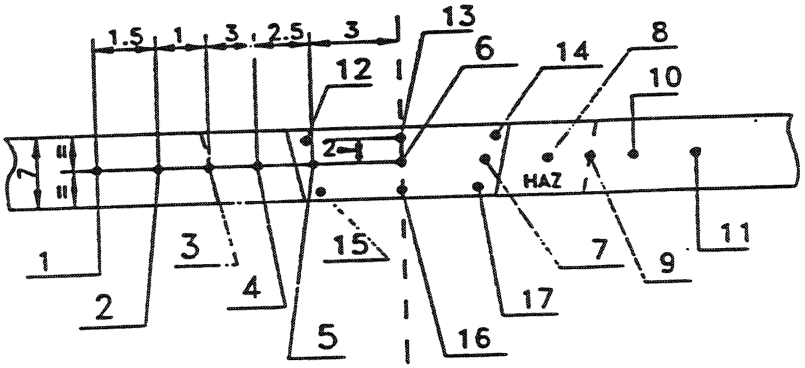
MICROHARDNESS RESULTS
Risultati microdurezza

SAMPLE N° / *Provettone N°*: LEX-002

FORCE: / *Carico*: 5 N

TYPE: / *Tipo*: HV

Point of measure



AUTOMATIC WELDING WITH MISMATCH

Specimens N°	H001	H002	H003	H004	H005	H006
Lab. Identif.	*746*	*747*	*748*	*749*	*750*	*751*
Point of meas.	HV					
1	98.71	107.38	105.29	105.52	103.25	103.02
2	96.58	100.53	100.68	99.72	101.80	100.46
3	90.73	95.95	88.42	89.78	93.85	92.21
4	89.34	91.75	91.17	93.78	92.79	96.79
5	75.26	79.15	74.31	72.33	77.72	76.43
6	66.51	73.01	73.52	72.42	75.50	74.22
7	70.29	73.52	74.69	72.64	80.51	75.16
8	90.34	91.94	95.54	75.60	97.42	100.17
9	92.47	92.21	90.34	87.82	95.07	91.11
10	100.68	99.66	103.64	95.13	99.65	97.49
11	105.28	105.29	107.38	102.63	103.32	106.32
12	74.45	77.87	70.03	75.23	78.99	74.93
13	71.75	71.97	72.97	75.65	77.72	70.73
14	73.56	76.47	75.07	76.38	82.51	76.67
15	74.83	73.94	76.72	78.02	76.33	74.08
16	70.12	73.75	73.99	71.66	76.18	73.15
17	73.84	77.07	78.33	73.43	83.74	74.17

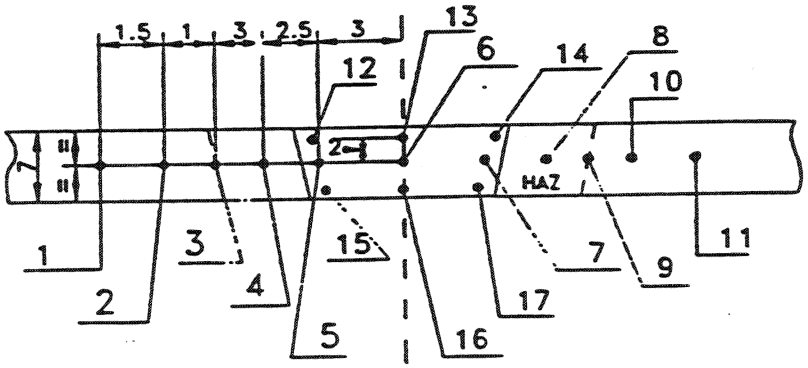
WELD HAZ

NOTE: / *Note*

MICROHARDNESS RESULTS
Risultati microdurezza

SAMPLE N° / *Provettone N°* LFX-0002 FORCE: / *Carico* 5 N TYPE: / *Tipo* HV

Point of measure



AUTOMATIC WELDING WITH PEAKING

Specimen N°	H001	H002	H003	H004	H005	H006
Lab. identif.	*758*	*759*	*760*	*761*	*762*	*763*
Point of meas.	HV					
1	102.56	101.06	105.20	112.71	109.54	100.75
2	101.12	103.17	103.95	102.95	101.95	101.95
3	96.03	89.66	92.21	92.60	92.87	93.59
4	97.63	93.25	93.98	92.20	97.46	97.63
5	71.93	76.52	78.94	77.66	75.84	75.26
6	74.36	77.61	75.31	72.55	72.11	73.80
7	71.48	74.83	73.89	71.75	72.79	73.28
8	91.30	99.06	90.73	91.05	93.52	97.85
9	88.30	99.72	100.10	97.08	95.14	95.26
10	91.37	100.99	102.26	101.21	100.68	96.03
11	93.78	100.68	103.25	100.24	98.64	99.32
12	73.06	78.58	78.47	76.43	72.55	75.79
13	72.97	74.74	74.03	73.61	73.19	73.85
14	70.04	75.26	76.43	78.89	74.45	74.17
15	74.07	77.98	73.33	72.70	72.11	75.46
16	73.24	75.94	76.28	72.37	73.98	73.10
17	73.89	77.22	72.88	75.60	71.56	72.79

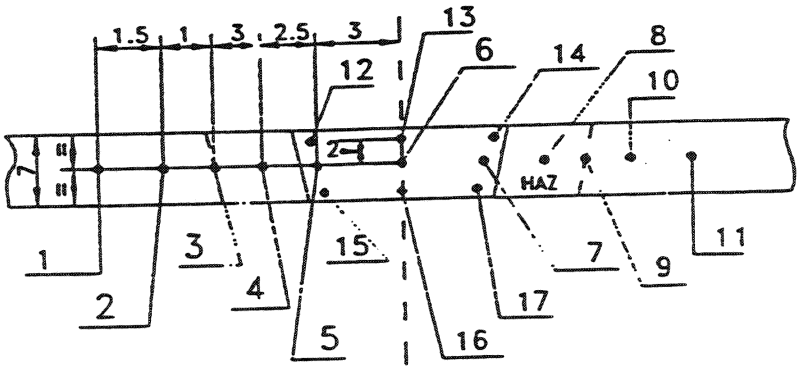
WELD zone: HAZ:

NOTE:
Note

MICROHARDNESS RESULTS
Risultati microdurezza

SAMPLE N° / *Provettone N°*: LGX-004 FORCE: / *Carico*: 5 N TYPE: / *Tipo*: HV

Point of measure



AUTOMATIC WELDING PERFORMED AT MINIMUM ENERGY

Specimens N°	H004	H005	H006
Lab. identif.	*771*	*772*	*773*
Point of meas.	HV		
1	109.11	109.21	112.02
2	106.24	93.25	106.48
3	106.57	111.66	102.11
4	118.28	119.62	110.21
5	81.15	83.06	50.63
6	87.69	93.12	81.96
7	77.97	109.87	78.12
8	103.87	108.45	111.58
9	103.11	107.38	104.58
10	109.54	109.36	108.7
11	113.69	115.77	115.95
12	77.56	81.42	77.17
13	79.77	89.23	83.40
14	82.62	87.51	81.63
15	84.64	86.73	81.37
16	80.93	86.97	85.92
17	87.89	86.62	85.05

WELD zone HAZ

NOTE: / *Note*: * Not valid value. Replaced by 76.57 and 80.46 measured as near as possible to the previous one.

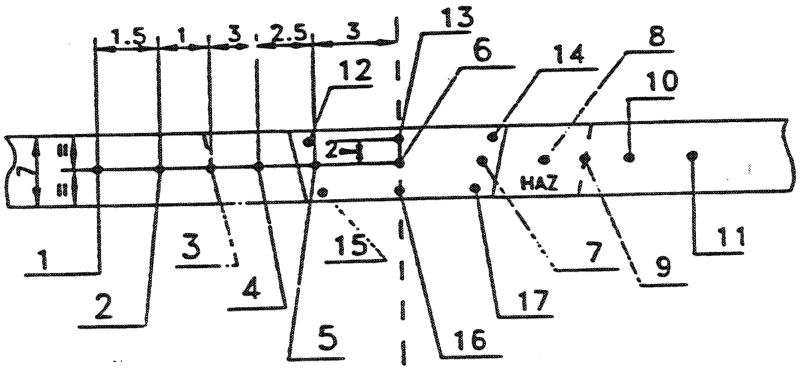
MICROHARDNESS RESULTS
Risultati microdurezza

SAMPLE N° / *Provettone N°*: LHX-002

FORCE: / *Carico*: 5 N

TYPE: / *Tipo*: HV

Point of measure



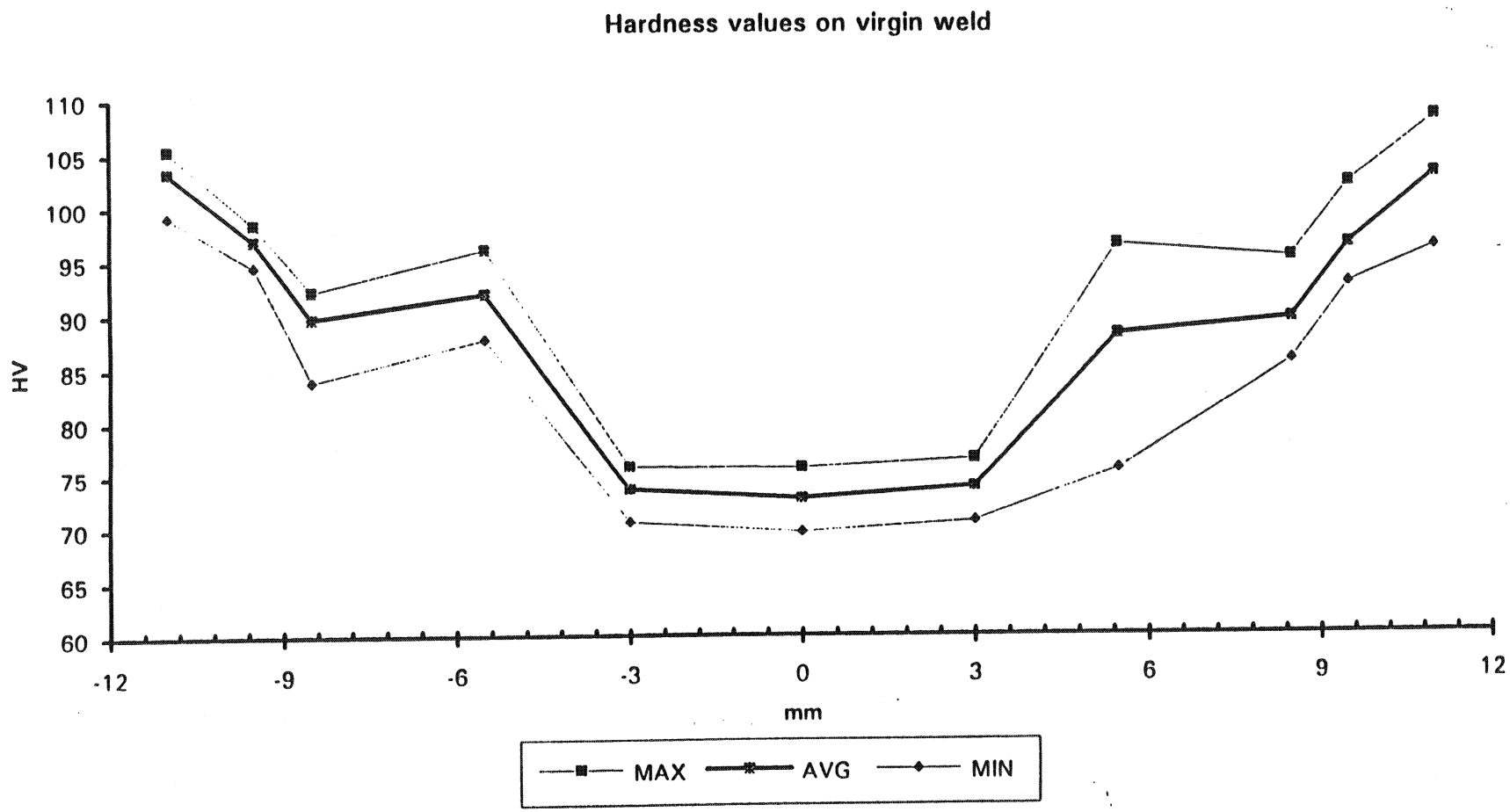
AUTOMATIC WELDING PERFORMED AT MAXIMUM ENERGY

Specimens N°	H001	H002	H003
Lab.identif.	*768*	*769*	*770*
Point of meas.	HV		
1	104.10	95.82	104.06
2	91.18	97.08	88.67
3	89.72	90.54	89.91
4	92.01	92.86	93.06
5	73.10	70.73	75.17
6	70.21	74.12	70.78
7	73.43	73.47	77.02
8	91.82	96.72	95.54
9	89.97	92.20	92.86
10	99.58	97.49	96.10
11	107.30	102.11	102.79
12	77.61	76.96	74.55
13	70.90	72.61	71.61
14	71.26	76.87	70.17
15	71.03	72.87	71.21
16	72.74	73.01	74.87
17	70.81	75.16	69.65

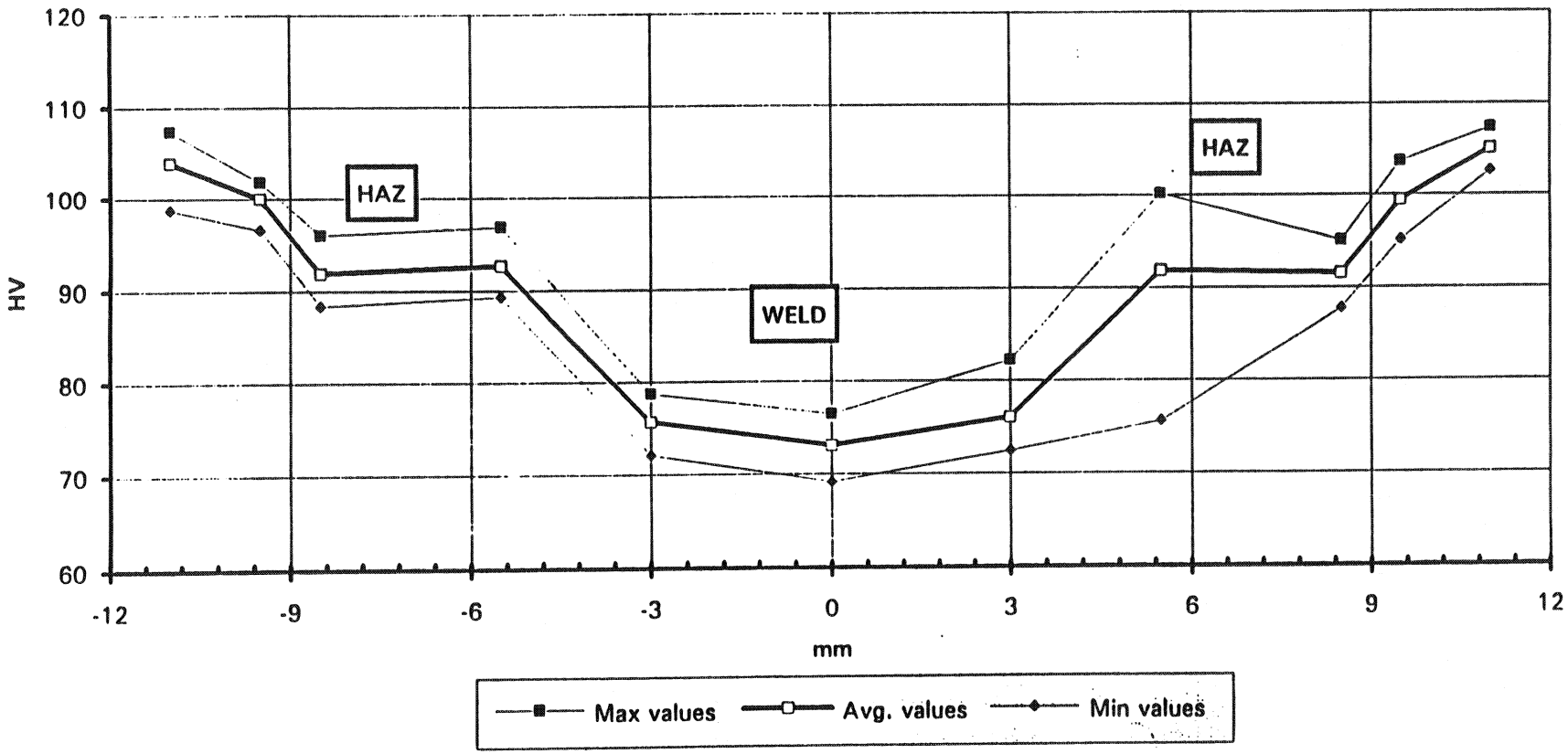
WELD zone

HAZ:

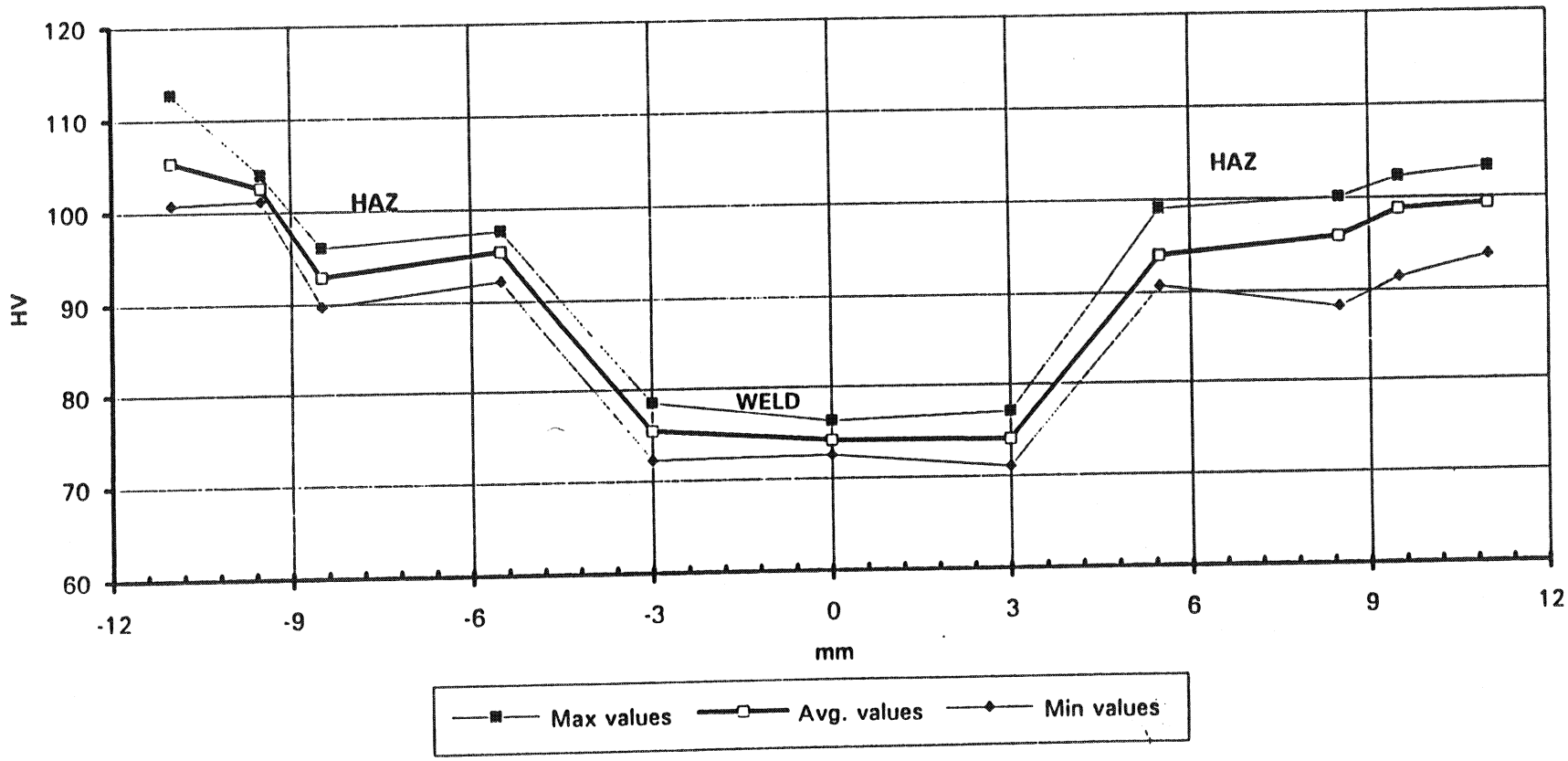
NOTE:
Note

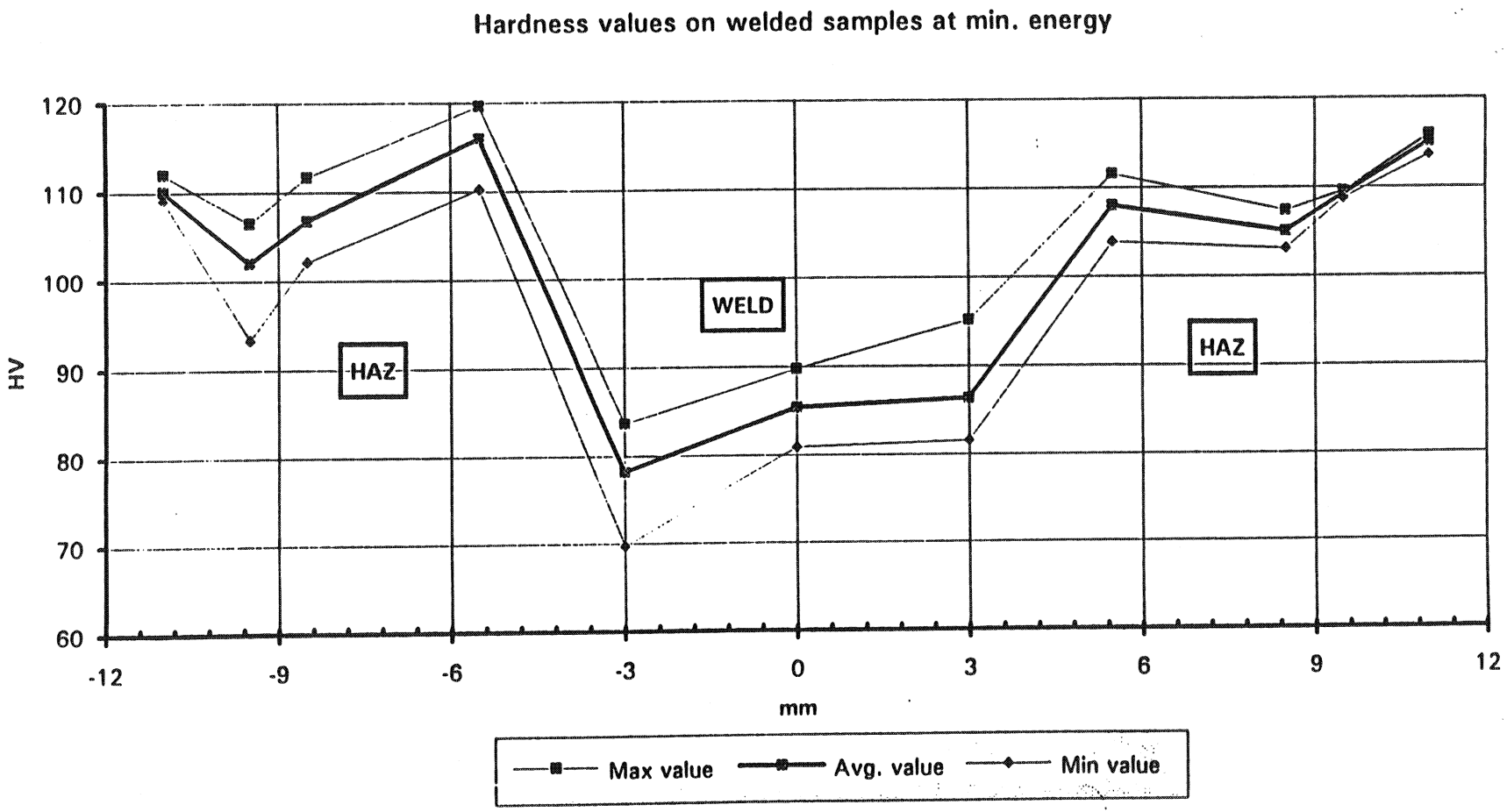

Hardness values on virgin weld
HV
110
105
100
95
90
85
80
75
70
65
60
-12
-9
-6
-3
0
3
6
9
12
mm
MAX
AVG
MIN

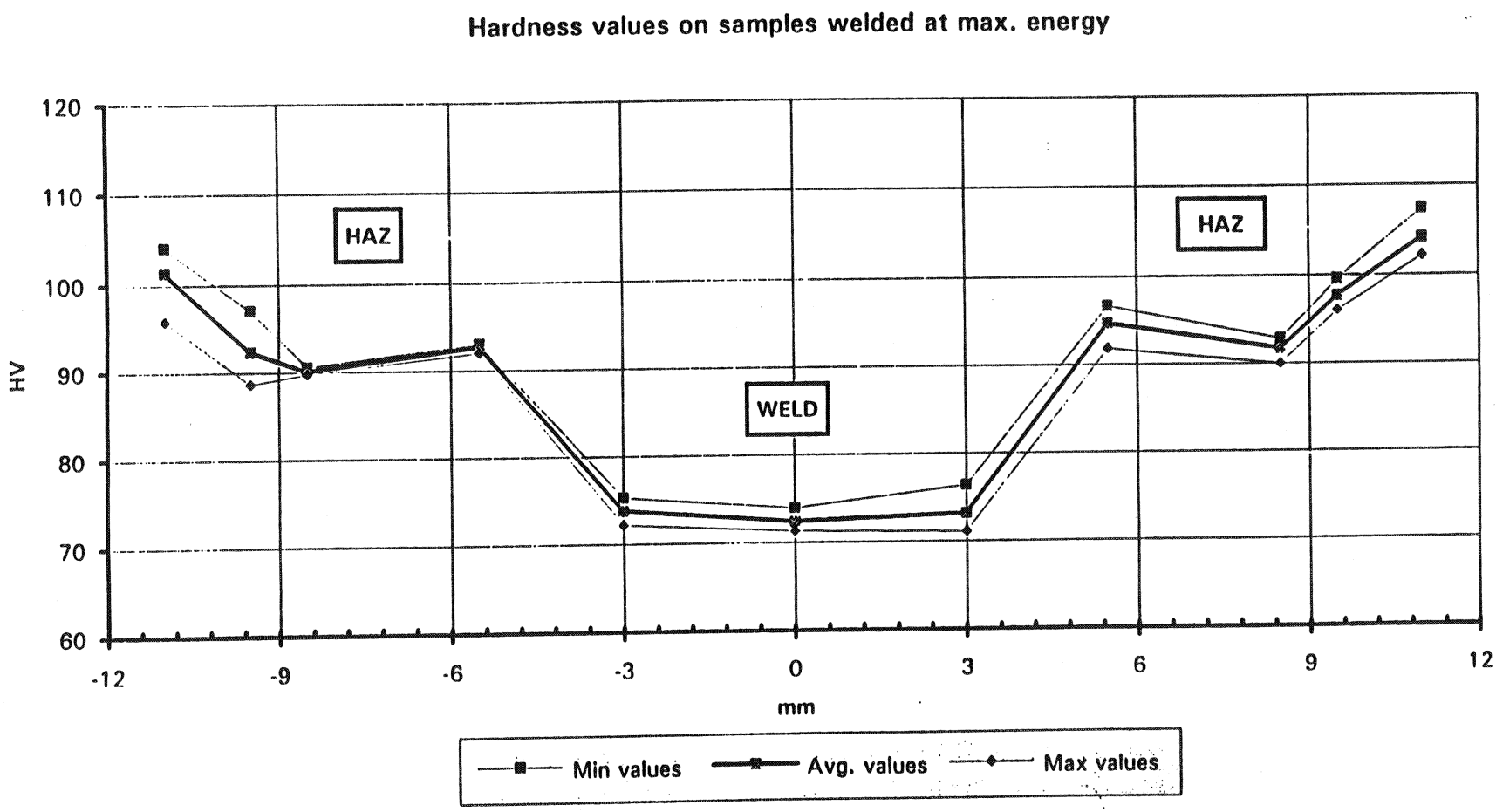
Hardness values on welded samples with mismatch



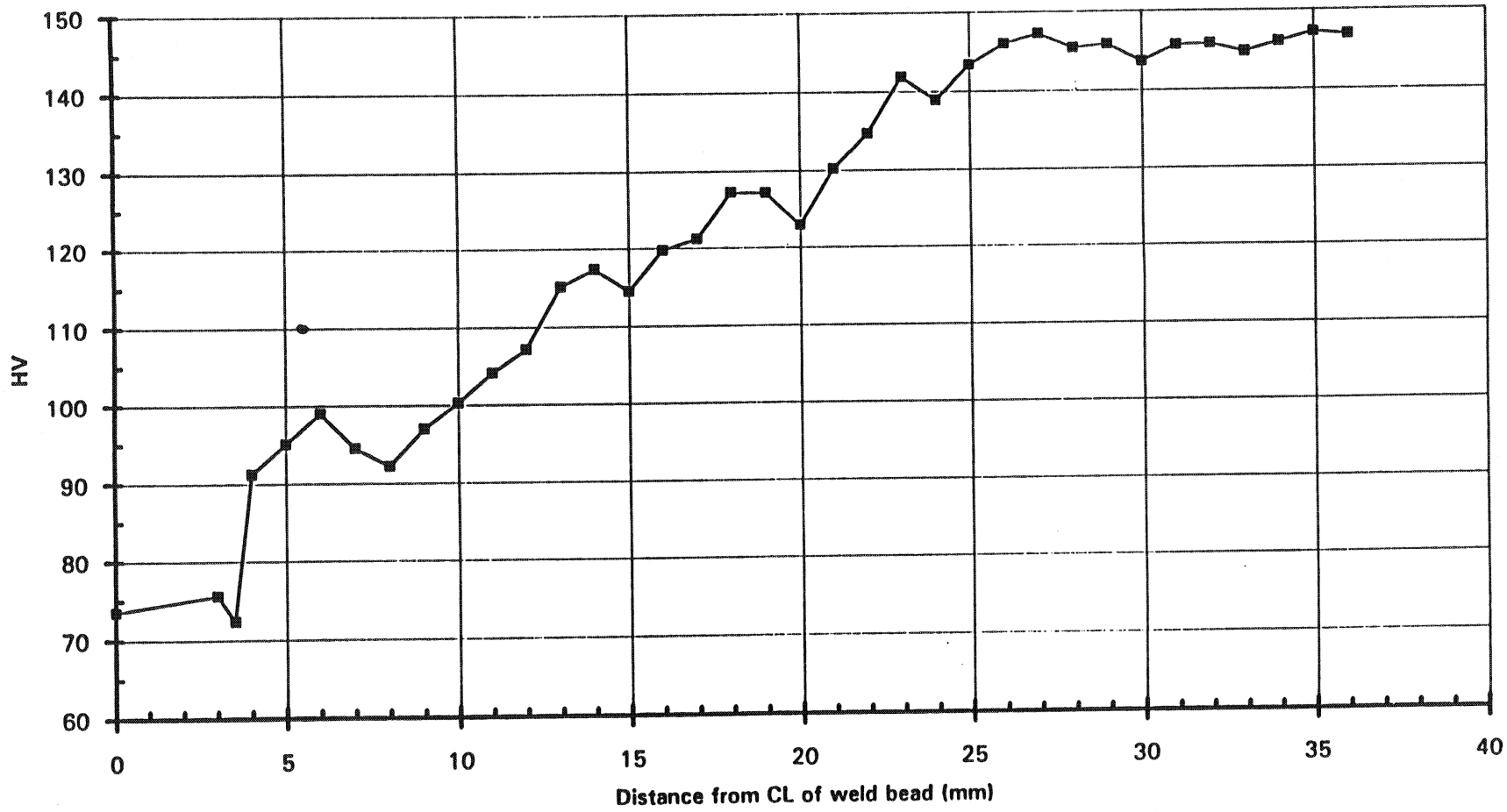
Hardness values on welded samples with peaking




Hardness values on welded samples at min. energy
HV
120
110
100
90
80
70
60
-12
-9
-6
-3
0
3
6
9
12
mm
HAZ
WELD
HAZ
Max value
Avg. value
Min value


Hardness values on samples welded at max. energy
HV
120
110
100
90
80
70
60
-12
-9
-6
-3
0
3
6
9
12
mm
HAZ
WELD
HAZ
Min values
Avg. values
Max values

Typical trend of hardness value transverse to CL of weld



\\ANNEX B 01

GEOMETRICAL EXAMINATION RESULTS OF WELDS.

Geometrical examination results of weld

Nominal welding parameters (without peaking and mismatch)

Serial Number:	Point of meas.	A:	B:	C:	D:
LAX001	1	9.8	2.1	7.3	1.4
	2	10.1	2	7.2	1.5
	3	10.1	2.2	7.2	1.4
	4	10.2	2.1	7.3	1.3
	5	10.2	1.9	7.2	1.3
LAX002	1	9.9	2.1	7	1.2
	2	10.2	2.1	7.1	1.3
	3	10.2	2.2	7.1	1.2
	4	10.4	2.1	7.3	1.2
	5	10.1	1.9	7.3	1.3
LAX003	1	10	2.15	7.4	1.3
	2	9.8	2.1	7.2	1.2
	3	10.1	2.1	7.2	1.2
	4	10.1	2.1	7.1	1.3
	5	10.2	2	7.3	1.4
LAX004	1	10	2	7.2	1.3
	2	9.7	2.1	7.2	1.4
	3	10.3	2.3	7.3	1.3
	4	10.3	2.15	7.1	1.3
	5	10.4	2	7.2	1.4
LAX005	1	10	2.1	7.4	1.2
	2	10.1	2.2	7.3	1.1
	3	10.1	2.3	7.1	1
	4	10	2.3	7.1	1.2
	5	9.8	2.1	7.3	1.1
LAX006	1	10	2	7.3	1.4
	2	10.1	2.1	7.2	1.4
	3	10.3	2.1	7.2	1.3
	4	10.4	2.2	7.1	1.4
	5	10.4	2.2	7.3	1.3
LAX008	1	10	2.1	7.2	1.4
	2	10.1	2.1	7.2	1.4
	3	10.1	2.1	7.2	1.4
	4	10.1	2.1	7.2	1.4
	5	10.1	2.1	7.2	1.4
LAX009	1	10.3	2	7.5	1.3
	2	10.1	2	7.4	1.2
	3	10.2	1.9	7.4	1.4
	4	10.4	2	7.5	1.4
	5	10.3	2	7.3	1.3
LAX010	1	10.1	2	7.3	1.2
	2	10	1.9	6.9	1.1
	3	10.2	2	7	1.3
	4	10.3	1.8	7.5	1.4
	5	9.8	1.6	7.2	1.2
LAX011	1	9.8	1.8	7.5	1.3
	2	9.8	2	7.6	1.4
	3	9.7	2	7.5	1.1
	4	9.7	1.9	7.6	1.4
	5	10	1.9	7.4	1.35
LAY001	1	9.6	2	7.2	1.4
	2	9.9	2.1	7.1	1.4

Geometrical examination results of weld

Nominal welding parameters (without peaking and mismatch)

Serial Number:	Point of meas.	A:	B:	C:	D:
LAY001	3	9.8	2	7.3	1.3
	4	9.8	2.1	7.2	1.5
	5	9.6	1.9	7.2	1.4
LAY002	1	9.8	1.9	7.4	1.5
	2	10	2	7.4	1.4
	3	10.3	2	7.1	1.2
	4	9.5	2	7.2	1.4
	5	9.8	1.9	7.4	1.4
LAY003	1	9.8	2	7.2	1.4
	2	9.7	1.9	7.1	1.3
	3	9.8	2.1	7.2	1.4
	4	9.8	2.1	7.3	1.5
	5	9.9	1.9	7.3	1.3
LAY004	1	9.7	1.9	7.2	1.6
	2	10	2	7.1	1.4
	3	9.8	1.9	7.2	1.5
	4	9.7	2	7	1.4
	5	9.7	1.9	7.2	1.3
LAY005	1	10.1	1.9	7.4	1.2
	2	10.1	2.1	7.3	1.3
	3	9.8	2	7.3	1.3
	4	10	2	7.1	1.4
	5	10.2	2	7.4	1.4
LAY006	1	10.1	2	7.3	1.4
	2	10.1	2.1	7.3	1.4
	3	10.1	2	7.2	1.3
	4	10.1	2.1	7.3	1.2
	5	10.1	2	7.4	1.3
LAY007	1	9.9	2	7.4	1.4
	2	10	2.1	7.3	1.4
	3	9.8	2.1	7.2	1.3
	4	9.8	2	7.3	1.4
	5	9.7	2	7.5	1.5
LAY008	1	9.6	2	7.3	1.5
	2	9.8	2.1	7.2	1.4
	3	9.7	2.1	7.1	1.5
	4	9.8	2	7.2	1.3
	5	9.8	1.9	7.2	1.4
LAY009	1	9.7	2	7.2	1.3
	2	10	2	7.1	1.6
	3	10	2	7.2	1.4
	4	10.1	2	7.1	1.3
	5	9.8	1.9	7.3	1.4
LAY010	1	9.9	1.8	7.1	1.3
	2	10.2	1.9	7.2	1.5
	3	10.3	2	7.3	1.5
	4	10	1.9	7.3	1.5
	5	9.8	1.9	7.4	1.5
LAY011	1	10.1	2	7.2	1.2
	2	10.2	2	7.1	1.2
	3	10	2.1	7.1	1.2
	4	10.3	2	7.2	1.3

Geometrical examination results of weld

Nominal welding parameters (without peaking and mismatch)

Serial Number:	Point of meas.	A:	B:	C:	D:
LAY011	5	10.3	2	7.4	1.4
LAY012	1	10.5	2	7.3	1.5
	2	9.8	2	7.2	1.6
	3	10.2	2	7.4	1.4
	4	9.8	2.1	7.2	1.5
	5	10	1.9	7.3	1.3
LAY013	1	10.1	2.1	7.2	1.4
	2	10.2	2	7.3	1.4
	3	9.8	1.9	7.2	1.3
	4	10.6	2	7.3	1.5
	5	9.8	1.9	7.4	1.4
LAY014	1	9.6	1.9	7.4	1.3
	2	9.8	2	7.3	1.4
	3	10.1	2	7.3	1.3
	4	9.8	1.9	7.4	1.3
	5	9.6	1.9	7.4	1.4
LAY015	1	10.2	1.9	7.2	1.4
	2	10	1.8	7.2	1.3
	3	9.8	1.9	7.3	1.4
	4	10.2	2	7.4	1.2
	5	10	1.9	7.2	1.4
LAY016	1	9.7	2.1	7.1	1.3
	2	10.1	2.1	7.3	1.4
	3	10.2	2.1	7.2	1.3
	4	9.8	2	7.2	1.3
	5	10	1.9	7.3	1.4
LAY017	1	9.8	1.9	7.1	1.2
	2	9.8	2	7.3	1.3
	3	10	2.1	7.2	1.3
	4	9.8	2	7.1	1.3
	5	9.7	2	7.3	1.3
LAY018	1	10.3	2	7	1.5
	2	9.8	2.1	7.3	1.3
	3	9.8	2	7.1	1.2
	4	9.8	2.1	7.1	1.4
	5	9.7	1.9	7.3	1.3
LAY019	1	10	1.9	7.3	1.7
	2	10	1.95	7.3	1.7
	3	10.3	1.95	7.3	1.7
	4	10	1.95	7.3	1.7
	5	10	1.82	7.4	1.8
LAY020	1	9.7	1.7	7.1	1.6
	2	9.8	1.95	7.3	1.6
	3	9.8	2	7.2	1.7
	4	8.6	1.35	7.4	1.4
	5	10.4	1.8	7.3	1.7

Geometrical examination results of weld

Nominal welding parameters with mismatch

Serial Number:	Point of meas.	A:	B:	C:	D:
LEX001	1	9.9	2	7.1	1.25
	2	10	2.1	7.3	1.3
	3	10.3	2	7.3	1.3
	4	9.6	2	7.2	1.3
	5	10.3	1.9	7.3	1.35
LEX002	1	9.9	1.9	7.3	1.2
	2	10	2	7.5	1.3
	3	10.1	2	7.5	1.3
	4	10	1.9	7.6	1.4
	5	9.7	1.8	7.7	1.3

Geometrical examination results of weld

Nominal welding parameters with peaking

Serial Number:	Point of meas.	A:	B:	C:	D:
LFX001	1	9.5	2	7.3	1.5
	2	9.5	2.1	7.2	1.45
	3	10	2.1	7.4	1.5
	4	9.5	2	7	1.4
	5	9.6	1.9	7.2	1.35
LFX002	1	9.6	2	7.5	1.1
	2	9	2	7	1.1
	3	9.5	2	7.2	1.2
	4	9.5	2.1	7.2	1.3
	5	9.7	2.1	7.2	1.1

Geometrical examination results of weld

Weld performed at minimum energy

Serial Number:	Point of meas.	A:	B:	C:	D:
LGX003	1	9.1	2.45	5.5	0.8
	2	8.9	2.5	5.4	0.8
	3	9.2	2.5	5.7	0.6
	4	9.4	2.55	5.6	0.7
	5	9.3	2.4	6.2	0.8
LGX004	1	8.9	2.5	5.3	0.6
	2	9.2	2.5	5.5	0.7
	3	9.1	2.6	5.6	0.8
	4	9.4	2.5	5.5	0.7
	5	9.1	2.3	5.5	0.9

ANNEX 2

RPS Nr. 472

"TEST REPORT FOR QUALIFICATION OF V.P.P.A. WELDING PROCESS FOLLLOWED BY AUTOMATIC REPAIR AND MANUAL REPAIR : TENSILE TESTS, METALLOGRAPHIC EXAMINATION AND MICROHARDNESS MEASUREMENTS"

ALENIA SPAZIO LABORATORIO

TEST REPORT

Program: MPLM

Title: TEST REPORT FOR QUALIFICATION OF VPPA WELDING PROCESS FOLLOWED BY AUTOMATIC REPAIR AND MANUAL REPAIR: TENSILE TESTS, METALLOGRAPHIC EXAMINATION AND MICROHARDNESS MEASUREMENTS.

ABSTRACT

Tensile tests were carried out on joints welded by automatic VPPA process and repaired. The values of tensile strength are always higher than the minimum spec. requirements. Metallographic examination exhibits good results in terms of bead geometry as well as microstructural features of the weld material and Heat Affected Zone.
Microhardness profiles appeared in the normal trend behavior associated to Al 2219 weldments.

REQUEST n° : 529

LABORATORY AREA: Mechanical tests, Chemical and Physical Analysis

PREPARED : B. BIROLO,
F. GIUGGIOLI

CHECKED : E. BONADERO
A. FERRI

APPROVED : P. MARCHESE

DOCUMENT CHANGE RECORD

ISSUE -	DATE	REASON FOR CHANGE	AFFECTED PARAGRAPHS
01	05/04/96		

TABLE OF CONTENTS

1. INTRODUCTION

2. MECHANICAL TESTS

2.1 Reference documents
2.2 Test specimens
2.3 Testing machine
2.4 Test results

3. METALLOGRAPHIC EXAMINATION

3.1 Reference documents
3.2 Metallographic observations results
3.2.1 Automatic welding followed by manual single repair
3.2.2 Automatic welding followed by double manual repair
3.2.3 Automatic welding followed by automatic repair

4. MICROHARDNESS MEASUREMENTS

4.1 Reference documents

ANNEX 1
ANNEX 2
ANNEX 3
ANNEX 4

1. INTRODUCTION

The purpose of the qualification activity of Plasma Welding technique and repair was to verify mechanical and metallurgical characteristics of the joints made of 2219 T851 Aluminum alloy welded and repaired.

This report contains the results of tests campaign performed to qualify the automatic process followed by different type of repairs:

. tensile tests
. metallurgical examination
. microhardenss measurements

on specimens automatic welded in longitudinal configuration followed by:

. automatic repair
. manual single repair
. manual double repair.

2. MECHANICAL TESTING

Tensile tests were performed on rectangular specimens with weld position perpendicular to the longitudinal axis and on cylindrical specimens obtained from all-weld metal in order to evaluate the properties of the joints.

Tensile strength requirements are given in document [2.1.02] para 3.1.3.1.

2.1 Reference documents

[2.1.01] - MLM-PL-AI-012
"Test plan for the characterization of the MPLM primary structure VPPA welding"

[2.1.02] - MLM-SP-AI-0012
"Welding of 2219 Aluminum Alloy for MPLM"

[2.1.03] - ASTM E8
"Standard test method of tension testing of metallic materials"

[2.1.04] - ANSI-B4.0-92 AWS
"Standard method for mechanical testing of welds"

[2.1.05] - PRS 014
"Procedura di utilizzo in automatico della macchina Zwick per prove meccaniche a trazione su provini rettangolari e cilindrici"

2.2 Test specimens

Test specimens were machined, from welded and repaired samples, according to the following configuration:

1) rectangular specimens (fig.2.2-1) for "transverse tensile tests"
2) round specimens (fig2.2-2) for "longitudinal tensile tests"

Specimens identification is reported in document [2.1.01] para 6.6: each specimen reproduces identification mark of the parent sample (containing the second letter to identify welding repair type: "B" for automatic repair, "C" for manual single repair, "D" for manual double repair), letter -A- to specify tensile test and a sequential number.

2.3 Testing machine

Tensile tests were performed using a mechanical testing machine UTM Zwick 1475, controlled by Zwick software "7005" with two different configurations:

1) for rectangular specimen

load cell = 100 kN
gage length of extensometer = 50 and 10 mm

test set up was:

test temperature	: room temperature
control mode	: Stroke
speed of testing	: 5 mm/min
configuration level	: TRAZSALD

2) for round specimen

load cell = 10 kN
gage length of extensometer = 16 mm

test set up was:

test temperature	: room temperature
control mode	: Stroke
speed of testing	: 3 mm/min
configuration level	: TRAZSALD

2.4 Test results

Tests results are summarized in the following tables for each homogeneous group of specimens:

Tab.2.4-1a ⎤
Tab.2.4-1b ⎦ automatic welding followed by automatic repair

Tab.2.4-2a ⎤
Tab.2.4-2b ⎦ automatic welding followed by manual single repair

Tab.2.4-3a ⎤
Tab.2.4-3b ⎦ automatic welding followed by manual double repair

Tab.2.4-1a: automatic welding followed by automatic repair

rectangular test specimens

sample identification	specimen identification	gage length [mm]	tensile strength [MPa]
LBX 007	A001	50	267.8
LBX 007	A002	50	260.1
LBX 007	A003	50	265.3
LBX 007	A004	50	266.4
LBX 007	A005	50	266.7
LBX 007	A006	50	266.3
LBX 007	A007	50	265.4
LBX 007	A008	50	267.3
LBX 007	A009	50	266.5
LBX 007	A010	50	266.7
LBX 007	A011	10	265.7
LBX 007	A012	10	266.5
LBX 007	A013	10	263.9
LBX 007	A014	10	264.3
LBX 007	A015	10	266.8

Tab.2.4-1b: automatic welding followed by automatic repair

round test specimens

sample identification	specimen identification	gage length	tensile strength [MPa]	yield strength [MPa]	elongation at fracture [%]
LBX 010	A018	16	255.9	138.2	14.9
LBX 010	A019	16	266.1	137.9	14.4
LBX 010	A020	16	267.4	140.9	16.7
LBX 010	A021	16	255.2	126.4	16.2
LBX 010	A022	16	255.6	127.5	15.8
LBX 010	A023	16	262.6	132.7	14.8
LBX 010	A024	16	259.7	127.5	15.5
LBX 011	A027	16	261.8	134.5	18.2
LBX 011	A028	16	261.8	136.7	14.3
LBX 011	A029	16	261.2	138.3	16.2
LBX 011	A030	16	261.6	133.6	20.1
LBX 011	A031	16	265.1	139.5	19.6
LBX 011	A032	16	262.2	134.9	19.6
LBX 011	A033	16	263.3	140.5	18.9
LBX 011	A034	16	264	138.6	18

Tab.2.4-2a: automatic welding followed by manual single repair

rectangular test specimens

sample identification	specimen identification	gage length [mm]	tensile strength [MPa]
LCX 014	A001	50	278
LCX 014	A002	50	277.9
LCX 014	A003	50	270
LCX 014	A004	50	273.3
LCX 014	A005	50	277.1
LCX 014	A006	50	270.9
LCX 014	A007	50	272.4
LCX 017	A008	50	272.9
LCX 017	A009	50	275
LCX 018	A010	50	278.1
LCX 018	A011	10	273.9
LCX 018	A012	10	278.3
LCX 018	A013	10	279.6
LCX 018	A014	10	275.9
LCX 018	A015	10	277.2

Tab.2.4-2b: automatic welding followed by manual single repair

round test specimens

sample identification	specimen identification	gage length	tensile strength [MPa]	yield strength [MPa]	elongation at fracture [%]
LCX 019	A018	16	275.9	146.1	19.5
LCX 019	A019	16	269	144.8	17
LCX 019	A020	16	279.4	144.6	18.7
LCX 019	A021	16	277.2	141.4	16.2
LCX 019	A023	16	275.5	153.1	13.4
LCX 022	A024	16	273.5	138.1	20.6
LCX 022	A025	16	273.7	149.4	15.5
LCX 022	A026	16	279.1	132.3	17.8
LCX 022	A027	16	269.9	129.6	21.1
LCX 022	A028	16	276.5	142.6	20.5
LCX 024	A030	16	273.3	139.9	19.7
LCX 024	A031	16	279.6	138.7	16.4
LCX 024	A032	16	282.5	135.2	21.9
LCX 024	A033	16	267.2	140.8	19.5
LCX 024	A034	16	270.3	136.2	17.7

Tab.2.4-3a: automatic welding followed by manual double repair

rectangular test specimens

sample identification	specimen identification	gage length [mm]	tensile strength [MPa]
LDX 001	A001	50	280.8
LDX 002	A002	50	270.8
LDX 002	A003	50	270.2
LDX 002	A004	50	269.3
LDX 003	A005	50	273.1
LDX 003	A006	50	270
LDX 003	A007	50	271.8
LDX 003	A008	50	271.1
LDX 003	A009	50	270.3
LDX 003	A010	50	265.5
LDX 003	A011	10	269.8
LDX 003	A012	10	271
LDX 003	A013	10	274.1
LDX 003	A014	10	275
LDX 003	A015	10	274

Tab.2.4-3b: automatic welding followed by manual double repair

round test specimens

sample identification	specimen identification	gage length	tensile strength [MPa]	yield strength [MPa]	elongation at fracture [%]
LDX 019	A018	16	274.5	148.3	20.2
LDX 019	A019	16	277.9	147.2	23.9
LDX 019	A020	16	268.9	147.5	18.2
LDX 019	A021	16	274.3	157.3	20.1
LDX 019	A022	16	262.3	148.8	19.9
LDX 022	A023	16	264.4	141.8	19.5
LDX 022	A024	16	261	134.5	17.9
LDX 022	A025	16	272.4	138.4	21.3
LDX 022	A026	16	267.3	137.5	14.4
LDX 022	A027	16	270.6	142.8	18.9
LDX 024	A028	16	266.1	138.7	17
LDX 024	A029	16	266.5	142.7	20.2
LDX 024	A030	16	272.6	136.2	20.5
LDX 024	A031	16	275.1	143.4	22.4
LDX 024	A032	16	272.7	141.6	20

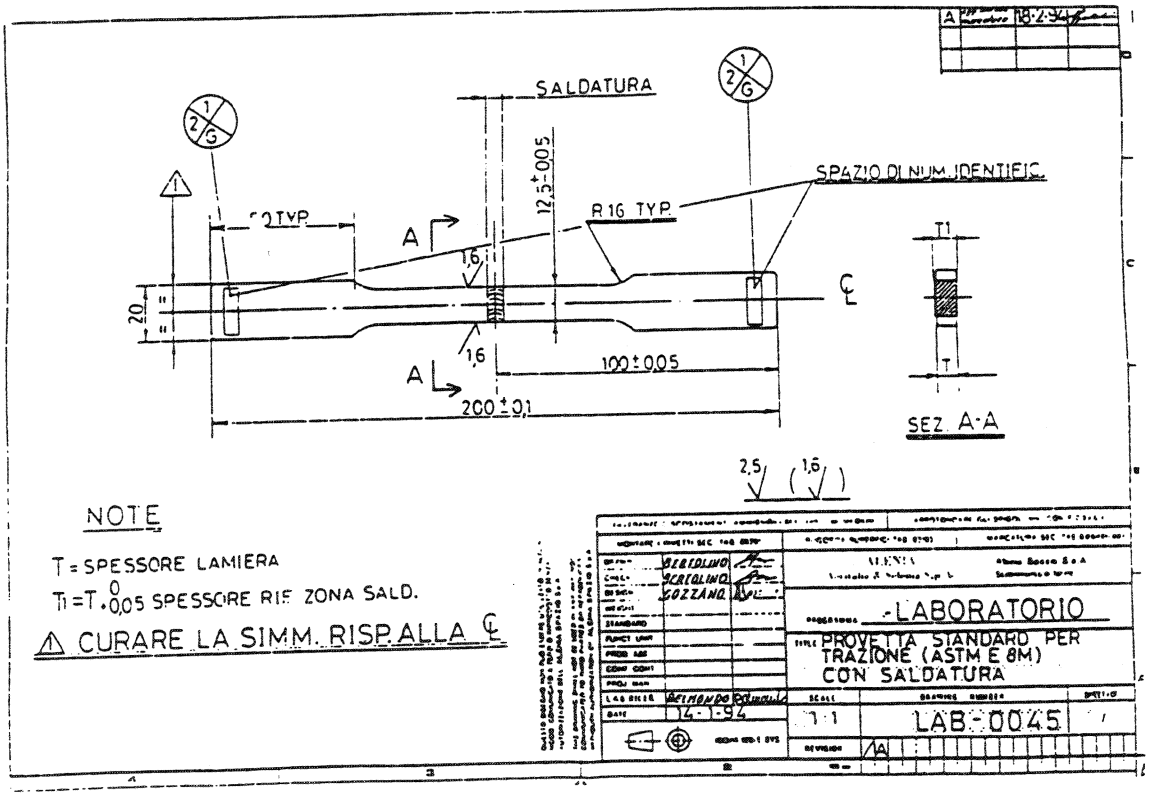


Fig. 2.2-1: rectangular specimen for "transverse" tensile test

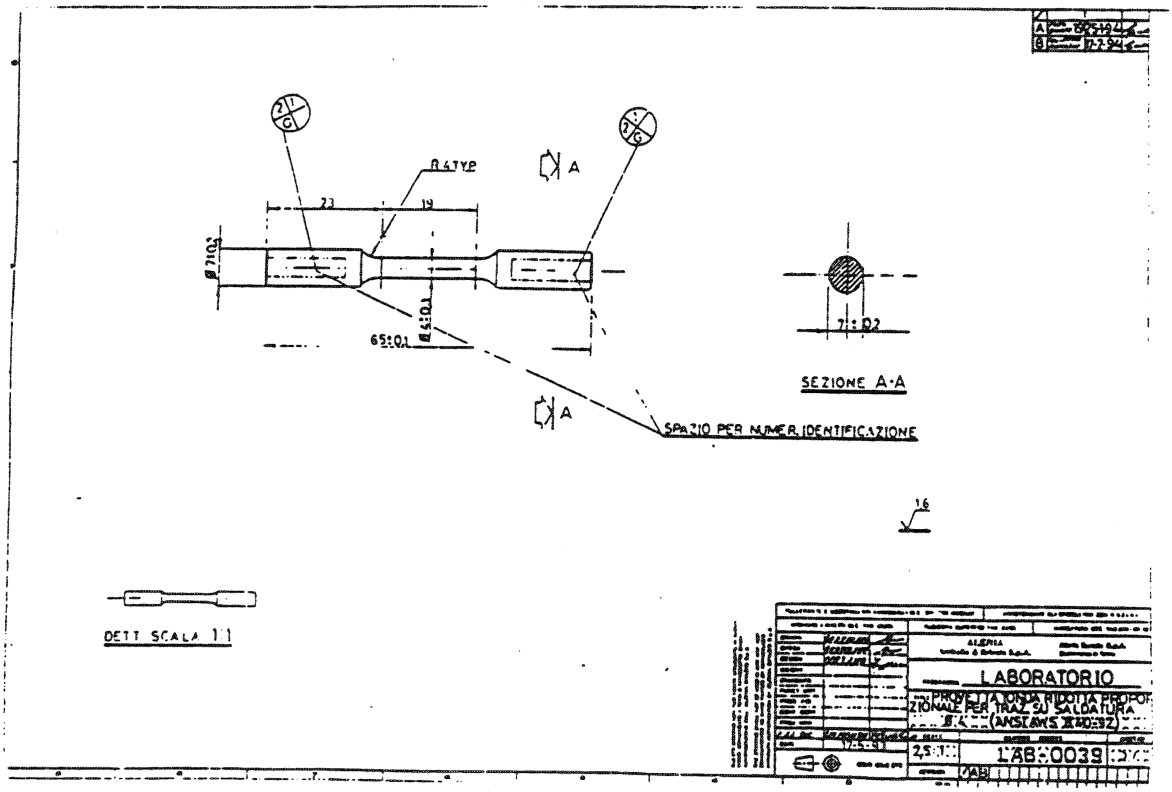


Fig.2.2-2: cylindrical specimen for "longitudinal" tensile test

3. METALLOGRAPHIC EXAMINATION

Metallographic examinations have been carried out on each group of homogeneous specimens.

Cross sections of the welding beads taken in different welding positions have been prepared for examination using Keller's reagent to reveal microstructural features under a optical microscope.
The welded area of each sample was carefully observed and the following observations have been documented:

a) macroexamination of the joint (7X magnification)

b) microexamination of the welded material (100X magnification)

c) microexamination of the transition welded material (HAZ) (100X magnification)

Specific comments and evaluations are contained in the related paragraphs, showing the results of each type of welding presented.

3.1 Reference documents

[3.1.01] MLM-PL-AI-012
" Test plan for the characterization of the MPLM primary structure VPPA welding"

[3.1.02] - ASTM E3
" Standard method for preparation of metallographic specimens"

[3.1.03] - ASTM E 407-70
"Standard test methods for microetching metals and alloys"

[3.1.04] - ASTM E 883-86
"Standard guide for metallographic photomicrography"

3.2 Metallographic observations results

3.2.1 Automatic welding followed by manual single repair

Details and remarks are reported in Annex 1.

3.2.2 Automatic welding followed by manual double repair

Details and remarks are reported in Annex 2.

3.2.3 Automatic welding followed by automatic repair

Details and remarks are reported in Annex 4.

4. MICROHARDNESS TESTS

Microhardness tests have been carried out on each group of homogeneous specimens. Cross sections of the welding beads have been taken in different welding positions and prepared for microhardness indentation.
Indentation profiles and evaluation, limited to the welded region are reported in Annex 3 together with a wider hardness trend profile from the bead centerline towards the parent metal.

4.1 Reference documents

[4.1.01] - MPLM-PL-AI-012
"Test plan for the characterization of the MPLM primary structure VPPA welding".

[4.1.02] - ASTM E384
"Standard test method for microhardness of materials"

ANNEX 1

MACRO AND MICRO EXAMINATIONS

AUTOMATIC WELDING FOLLOWED BY

MANUAL SINGLE REPAIR

AUTOMATIC WELDING FOLLOWED BY MANUAL SINGLE REPAIR

RESULTS OF: _____
Risultati di

RESULTS SUMMARY:
Risultati complessivi

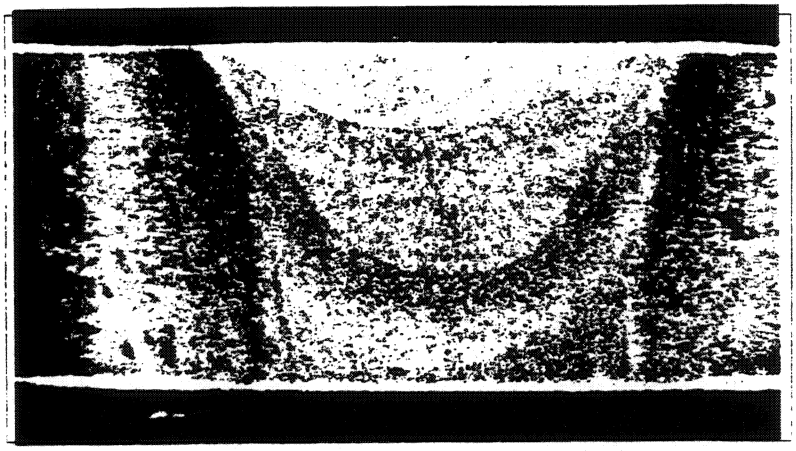
Macroexaminations on samples of automatic welding followed by manual single repair showed a geometrically regular weld bead with a ratio torch side / back side of approximately 1.3.

Microexamination showed a dendritic microstructure without discontinuities typical of high cooling rate. No significative modifications in Heat Affected Zone feature are evinced. No appreciable internal defects have been observed.

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

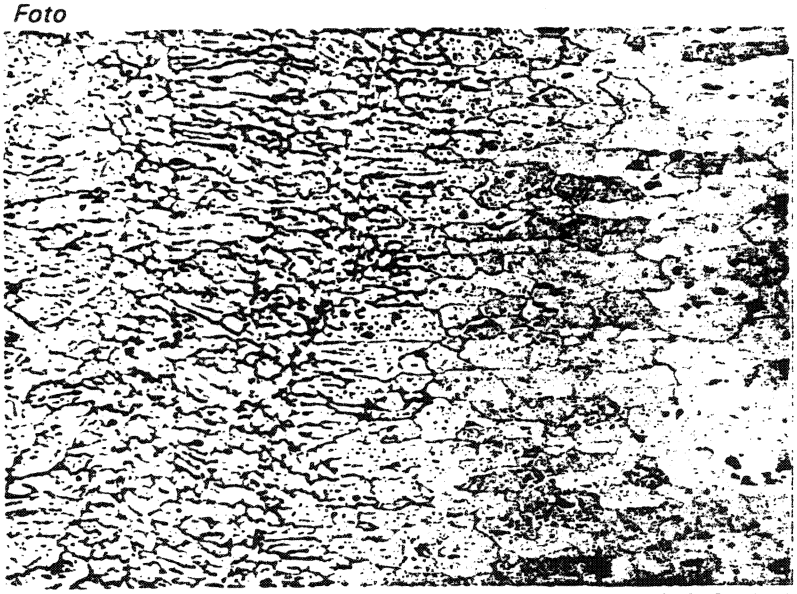
SAMPLE N° LCX018 - I001
Provino N°



MACRO OF WELD

PHOTO N°: 1015
Foto

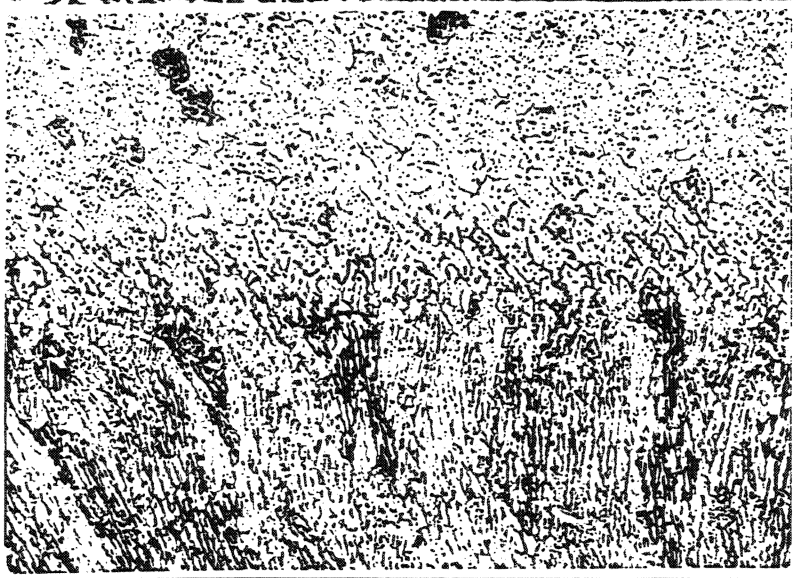
x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 1015 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

PHOTO N°: 1015 B
Foto

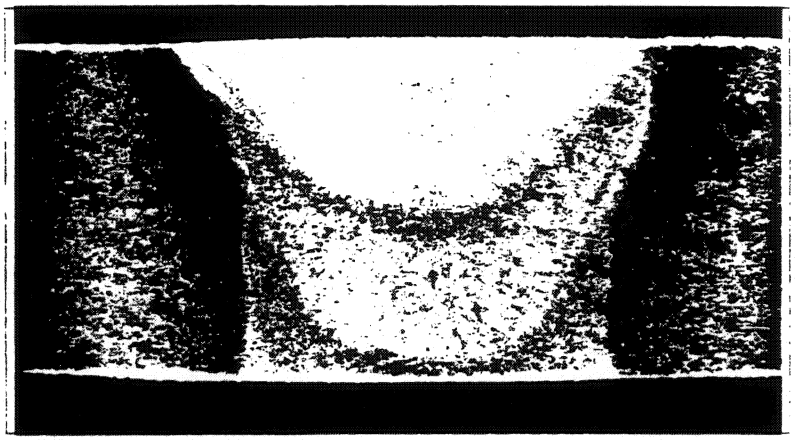
x: 100

Alenia
Alenia Spazio S.p.A.

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° LCX018 - I002
Provino N°



MACRO OF WELD

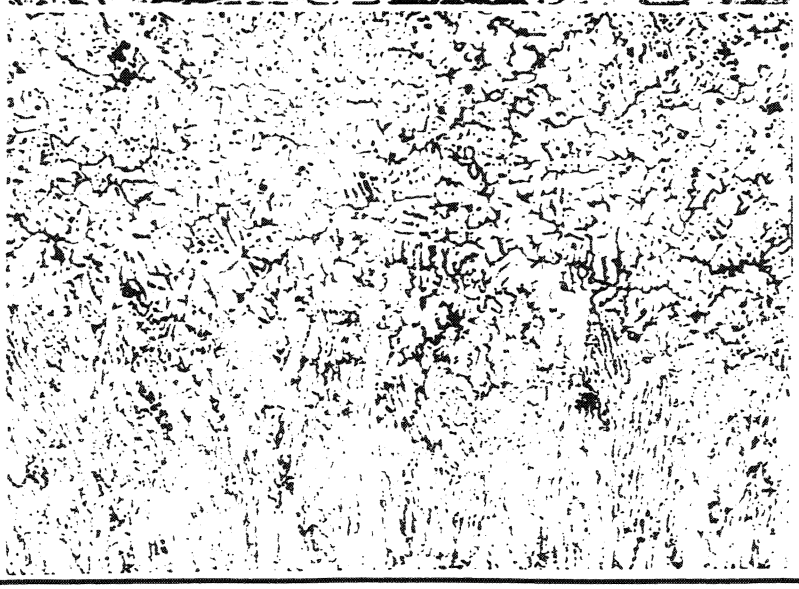
PHOTO N°: 1016
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 1016 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

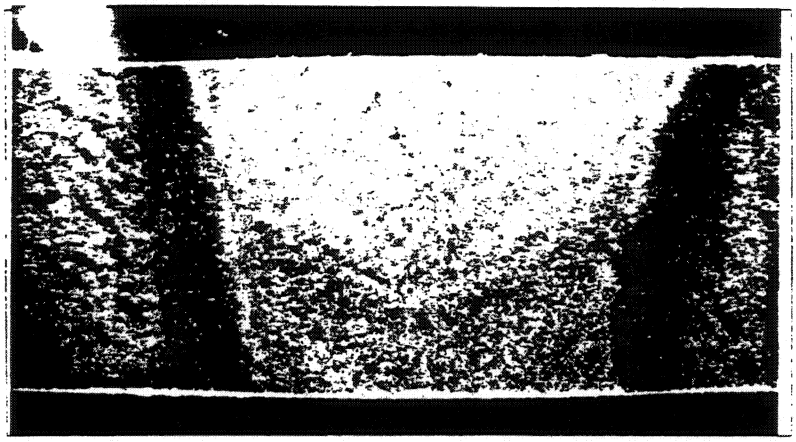
PHOTO N°: 1016 B
Foto

x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

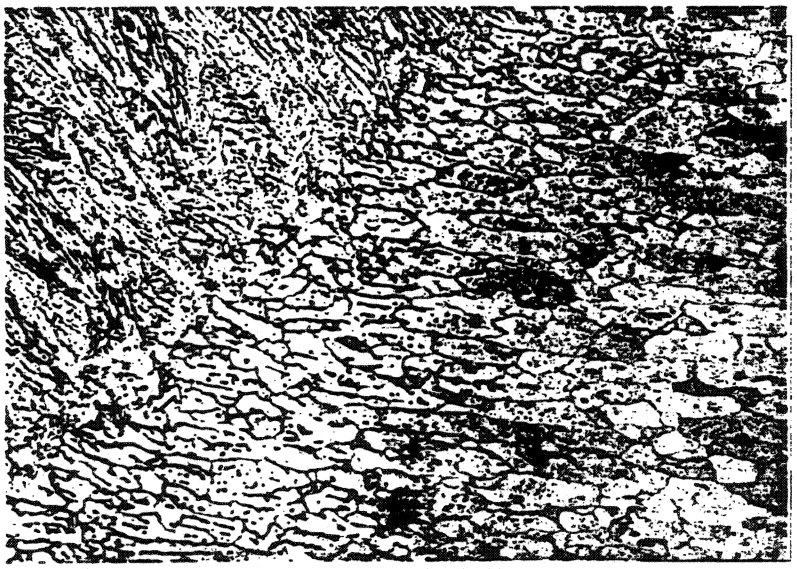
SAMPLE N° LCX018 - I003
Provino N°



MACRO OF WELD

PHOTO N°: 1017
Foto

x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 1017 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 1017 B
Foto

x: 100

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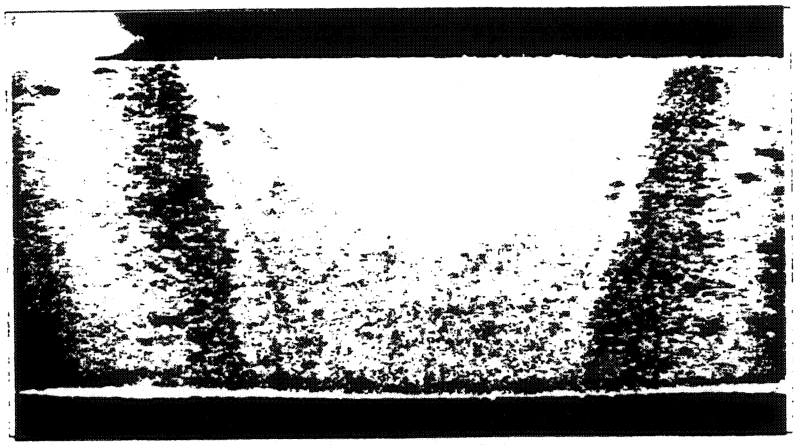
MICRO - MACRO EXAMINATION RESULTS

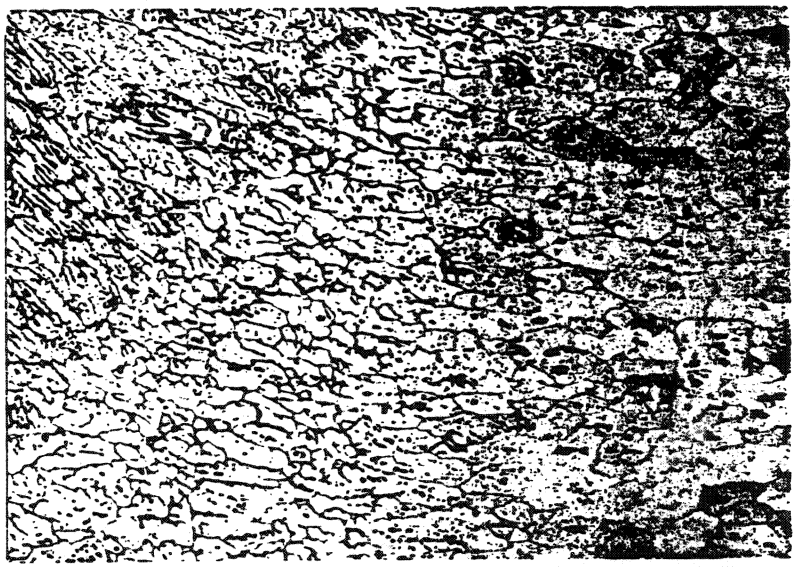
Risultati esami micro - macrografici

SAMPLE N° LCX 018 - T 004
Provino N°



MACRO OF WELD

PHOTO N°: 1018 x: 7
Foto



MICRO
HAZ WELD DETAIL

PHOTO N°: 1018 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 1018 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 1 of 1 *Pag. di*

SAMPLE N° LCX018 - I005
Provino N°

MACRO OF WELD

PHOTO N°: 1019 x: 7
Foto

MICRO
HAZ WELD DETAIL

PHOTO N°: 1019 A
Foto

x: 100

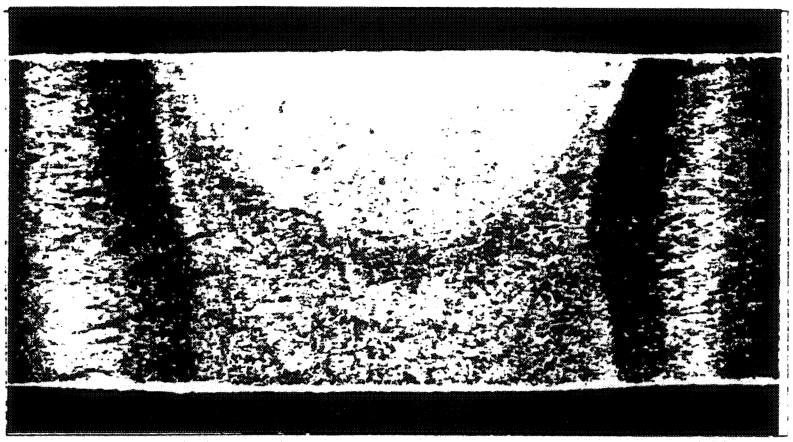
MICRO
CENTER WELD DETAIL

PHOTO N°: 1019 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page 1 of 1 *Pag. di*

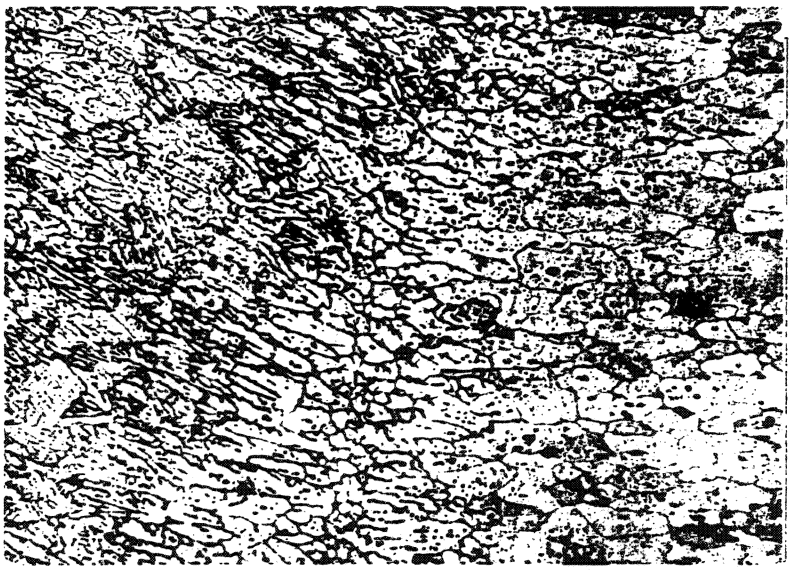
SAMPLE N° LCX 018 - I006
Provino N°



MACRO OF WELD

PHOTO N°: 1020
Foto

x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 1020 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 1020 B
Foto

x: 100

ANNEX 2

MACRO AND MICRO EXAMINATIONS

AUTOMATIC WELDING FOLLOWED BY

MANUAL DOUBLE REPAIR

AUTOMATIC WELDING FOLLOWED BY MANUAL DOUBLE REPAIR

RESULTS OF: _____
Risultati di

RESULTS SUMMARY:
Risultati complessivi

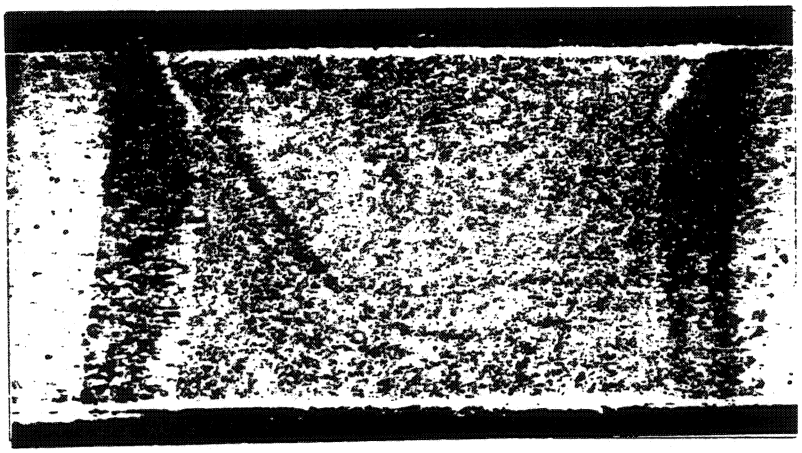
Macroexamination of the weld bead showed a satisfactory geometry even after manual double repair, no appreciable defects are evinced , the width ratio between torch side / back side varies between 0.8 and 1.07.

Microexamination at 100X showed a regular dendritic structure in the center weld and a typical structure in the HAZ.
No appreciable internal defects are present.

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° LDX 004 - I 001
Provino N°



MACRO OF WELD

PHOTO N°: 921 x: 7
Foto

MICRO
HAZ WELD DETAIL

PHOTO N°: 921 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 921 B
Foto

x: 100

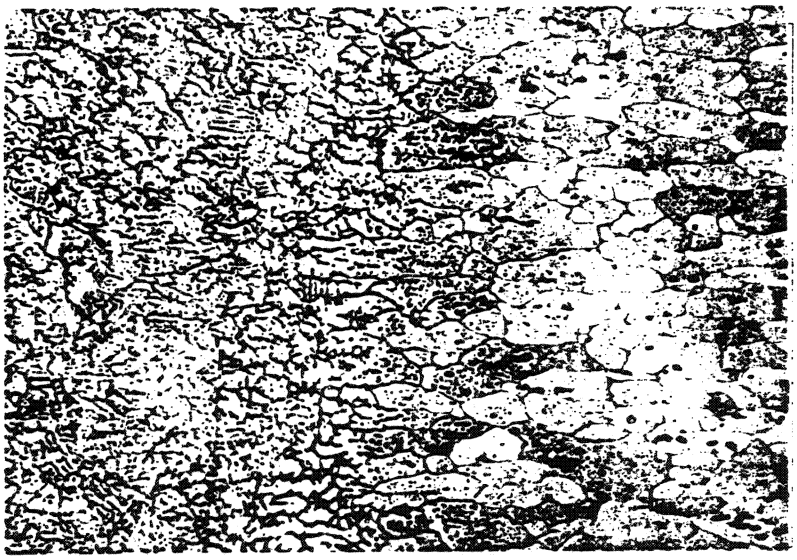
MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° *Provino N°* L DX 004 - I002

MACRO OF WELD

PHOTO N°: *Foto* 922 x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: *Foto* 922 A

x: 100

MICRO
CENTER WELD DETAIL

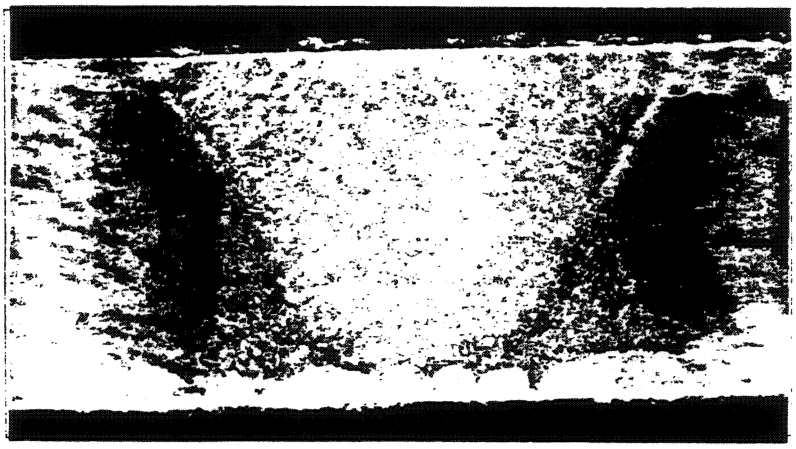
PHOTO N°: *Foto* 922 B

x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° / *Provino N°* L DX 004 - J003



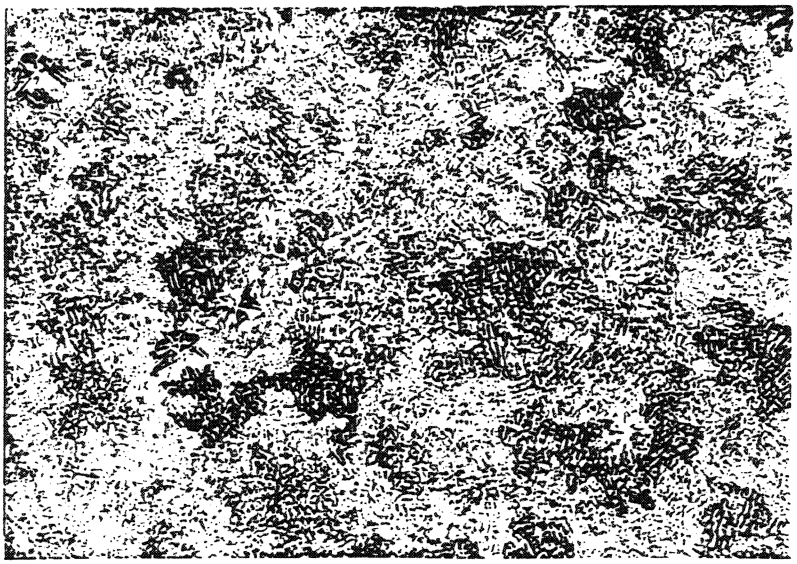
MACRO OF WELD

PHOTO N°: 923 x: 7
Foto

MICRO
HAZ WELD DETAIL

PHOTO N°: 923 A
Foto

x: 100



MICRO
CENTER WELD DETAIL

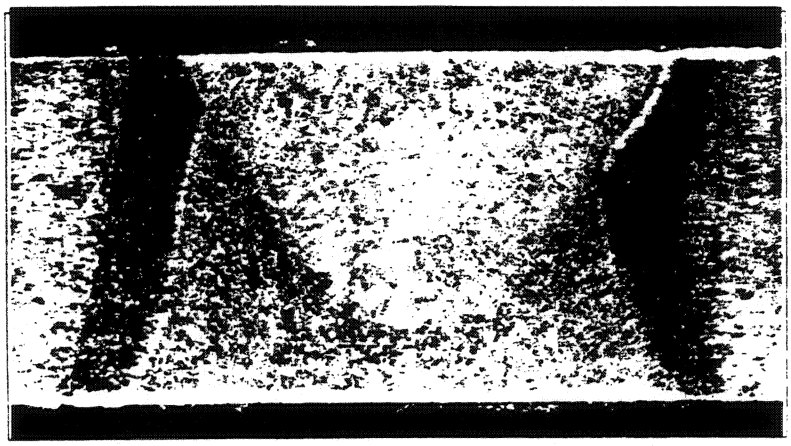
PHOTO N°: 923 B
Foto

x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° / *Provino N°* LDX 004 - I004



MACRO OF WELD

PHOTO N°: 924 x: 7
Foto

MICRO
HAZ WELD DETAIL

PHOTO N°: 924 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

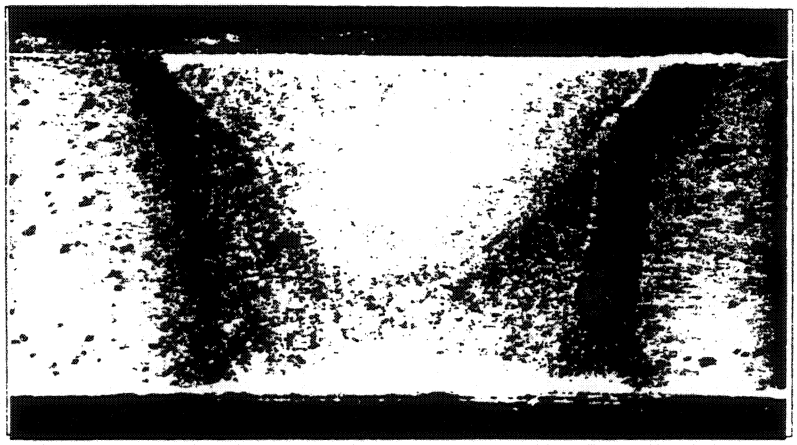
PHOTO N°: 924 B
Foto

x: 100

MICRO - MACRO EXAMINATION RESULTS

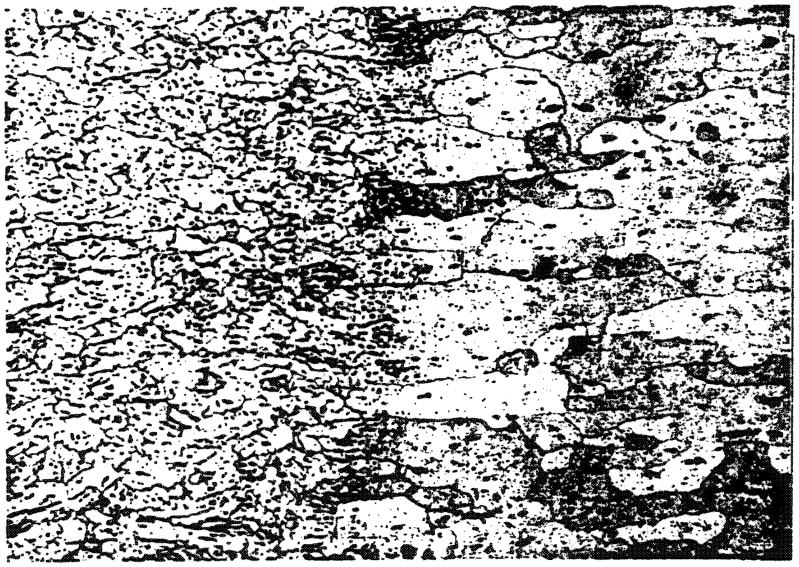
Risultati esami micro - macrografici

SAMPLE N° *Provino N°* LDX 004 - I005



MACRO OF WELD

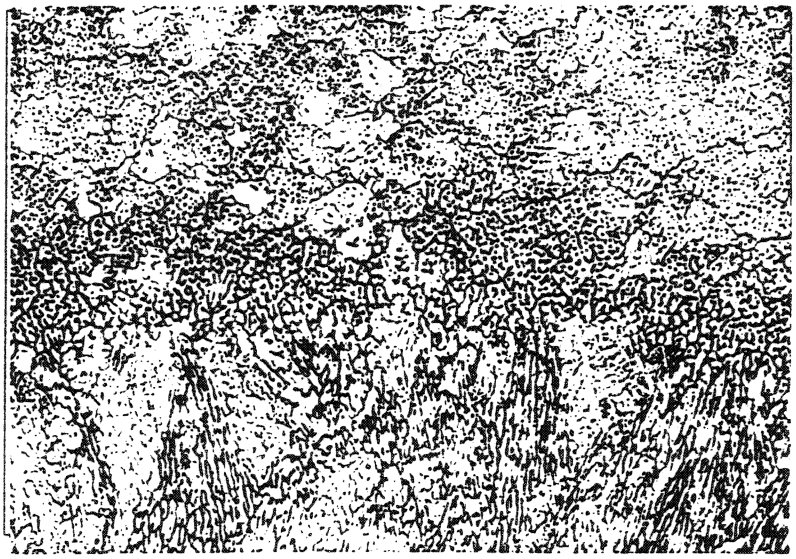
PHOTO N°: *Foto* 925 x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: *Foto* 925 A

x: 100



MICRO
CENTER WELD DETAIL

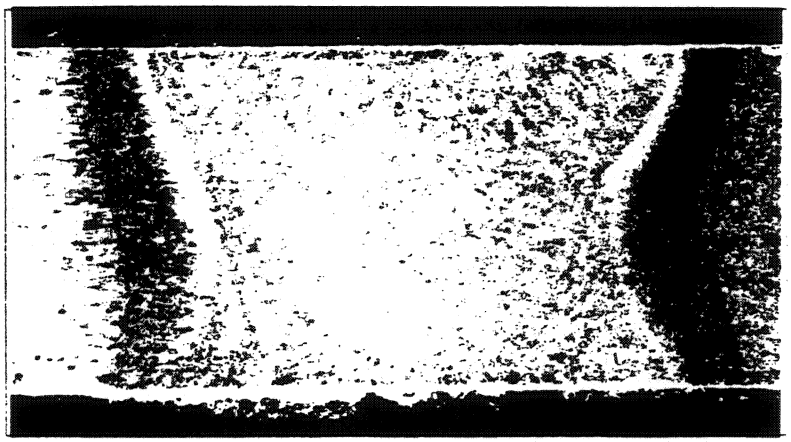
PHOTO N°: *Foto* 925 B

x: 100

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

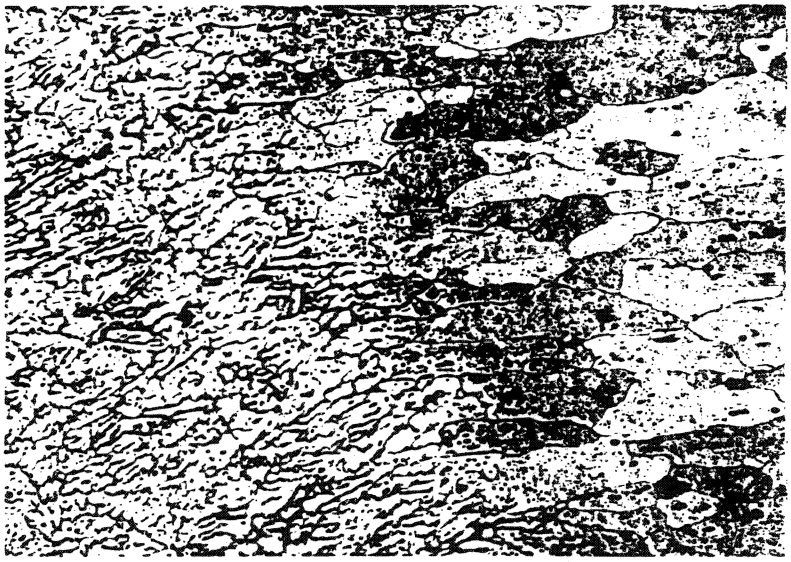
SAMPLE N° LDX 004 - I 006
Provino N°



MACRO OF WELD

PHOTO N°: 926
Foto

x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 926 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 926 B
Foto

x: 100

ANNEX 3

MICROHARDNESS TESTS RESULTS

AUTOMATIC WELDING FOLLOWED BY

MANUAL SINGLE REPAIR

MANUAL DOUBLE REPAIR

AUTOMATIC REPAIR

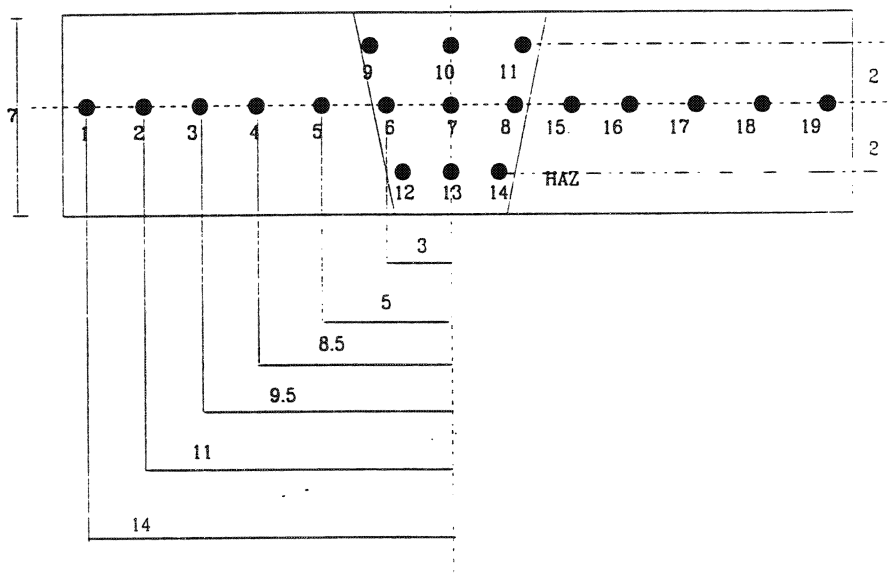
MANUAL SINGLE REPAIR

SAMPLE N°: LCX-017

FORCE : 5N

TYPE : HV

Map of measures



MANUAL SINGLE REPAIR

SAMPLE N°	LCX-017					
Specimen N°	H001	H002	H003	H004	H005	H006
Lab identif.	1002	1003	1004	1005	1006	1007
Point of meas.	HV					
1	114.50	112.11	117.34	117.05	114.04	116.68
2	101.95	100.99	101.05	106.88	100.16	101.58
3	73.84	95.27	99.81	93.93	97.49	99.58
4	95.75	93.65	94.72	90.54	93.72	91.24
5	91.75	97.93	92.99	97.56	97.08	97.99
6	81.04	81.15	87.99	83.01	84.64	87.33
7	82.18	90.03	88.92	84.98	86.38	89.16
8	78.68	88.73	89.16	82.01	87.33	88.30
9	80.72	91.11	85.62	80.72	87.39	85.15
10	81.63	90.98	87.81	82.13	79.35	83.16
11	82.01	83.17	83.67	81.75	86.68	86.79
12	84.01	85.22	90.41	83.06	81.96	85.91
13	82.18	81.31	84.98	86.63	92.86	82.45
14	83.62	89.22	83.62	83.17	83.62	86.44
15	96.24	95.96	92.79	97.15	96.09	103.80
16	91.82	96.65	91.56	90.28	93.59	91.11
17	95.26	98.79	97.78	97.78	100.75	95.34
18	105.52	100.61	107.62	103.87	102.71	101.43
19	118.66	118.85	114.77	114.68	112.19	112.37

Legend:

Base metal

Fuse zone

HAZ

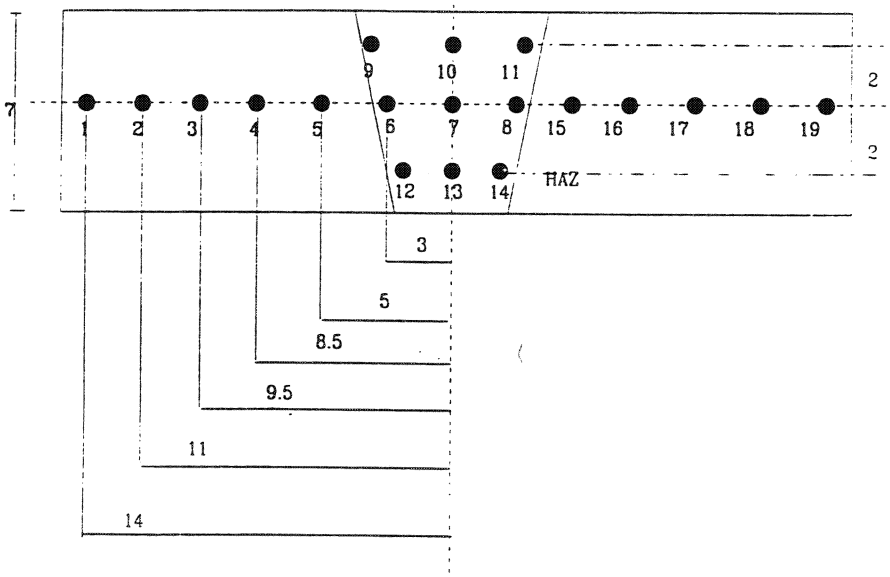
MANUAL DOUBLE REPAIR

SAMPLE N°: LDX-001 (lab. identification 889 to 893)

LDX-004 (lab. identification 920)

FORCE: 5 N TYPE: HV

MAP OF MEASURES



MANUAL DOUBLE REPAIR

SAMPLE N°	LDX-001					LDX-004
Specimens N°	H001	H002	H003	H004	H005	H006
Lab. ident.	889	890	891	892	893	920
Point of meas.	HV					
1	112.73	113.69	110.98	108.04	108.78	111.32
2	100.91	104.74	103.34	101.96	107.70	104.49
3	97.49	101.06	95.95	92.79	99.43	101.43
4	**92.73**	**92.14**	**89.10**	**89.28**	**93.25**	**95.34**
5	**102.64**	**99.79**	**97.79**	**100.61**	**92.07**	**97.07**
6	**88.00**	**84.59**	**85.33**	**87.33**	**83.35**	**83.74**
7	**88.73**	**88.12**	**86.73**	**83.29**	**86.92**	**84.70**
8	**85.10**	**86.20**	**85.62**	**78.89**	**86.74**	**82.56**
9	**85.10**	**86.91**	**80.35**	**84.76**	**85.16**	**85.97**
10	**88.37**	**85.92**	**80.29**	**85.85**	**79.92**	**85.22**
11	**84.64**	**87.70**	**82.34**	**83.96**	**80.83**	**81.96**
12	**87.51**	**87.33**	**87.39**	**80.78**	**81.85**	**81.74**
13	**89.85**	**85.98**	**83.73**	**82.45**	**83.45**	**85.21**
14	**86.14**	**83.17**	**85.45**	**85.97**	**85.92**	**82.62**
15	**100.46**	**99.87**	**101.12**	**95.14**	**94.72**	**95.69**
16	**95.20**	**95.00**	**91.94**	**92.40**	**91.69**	**89.16**
17	95.68	95.61	94.79	101.43	88.79	98.13
18	101.20	103.02	100.16	103.63	91.82	104.10
19	112.63	113.78	111.85	111.42	115.50	113.95

Legend:

Base metal

Fuse zone

HAZ

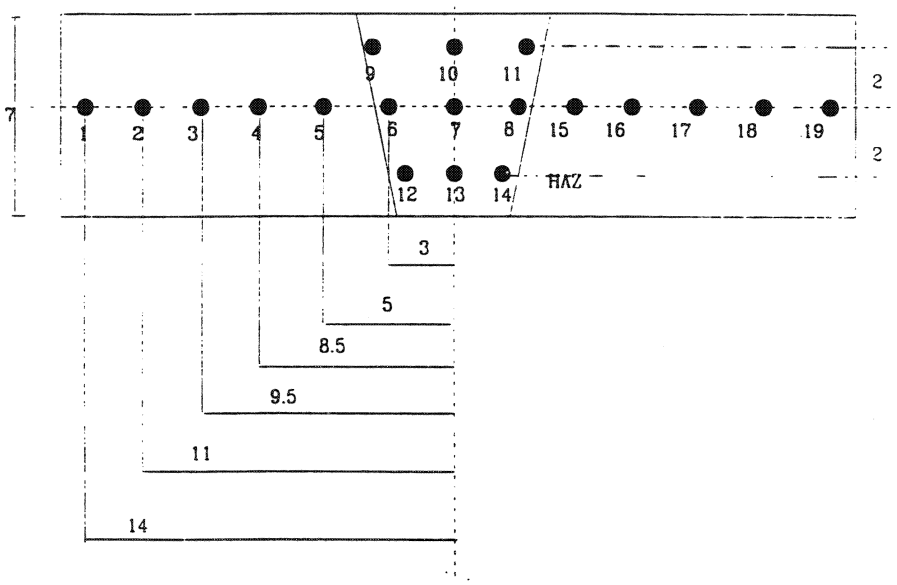
AUTOMATIC REPAIR

SAMPLE N°: LBX-009

FORCE : 5N

TYPE : HV

MAP OF MEASURES



AUTOMATIC REPAIR

SAMPLE N°	LBX-009					
Specimens N°	H001	H002	H003	H004	H005	H006
Lab. ident.	894	895	896	897	898	899
Point of meas.	HV					
1	112.2	109.27	105.28	107.54	109.96	110.38
2	105.85	99.51	101.8	100.99	101.27	102.34
3	94.66	93.99	98.2	96.79	93.72	96.65
4	93.65	89.78	94.12	91.82	91.56	92.47
5	93.39	99.87	98.99	98.49	99.51	100.61
6	82.07	81.09	76.92	78.58	84.3	72.87
7	82.07	79.46	80.14	79.66	79.25	76.23
8	82.51	77.36	73.7	83.46	78.38	81.63
9	73.8	75.02	78.23	78.78	76.42	76.28
10	79.3	73.61	76.28	80.29	80.4	76.87
11	69.43	78.83	68.55	77.52	78.23	82.57
12	74.65	81.26	82.06	83.28	82.84	81.75
13	79.77	81.52	81.09	82.9	87.45	86.44
14	80.46	76.82	80.03	80.19	81.41	76.18
15	93.98	96.1	101.27	93.52	96.72	98.28
16	91.17	87.15	95.4	94.31	93.06	93.65
17	93.98	95.07	94.86	98.92	95.61	101.88
18	104.74	101.8	100.75	101.73	96.65	101.13
19	108.19	107.43	112.45	111.58	110.81	109.19

Legend:

Base metal

Fuse zone

HAZ

ANNEX 4

MACRO AND MICRO EXAMINATIONS

AUTOMATIC WELDING FOLLOWED BY

AUTOMATIC REPAIR

RESULTS OF: AUTOMATIC WELDING FOLLOWED BY AUTOMATIC REPAIR
Risultati di

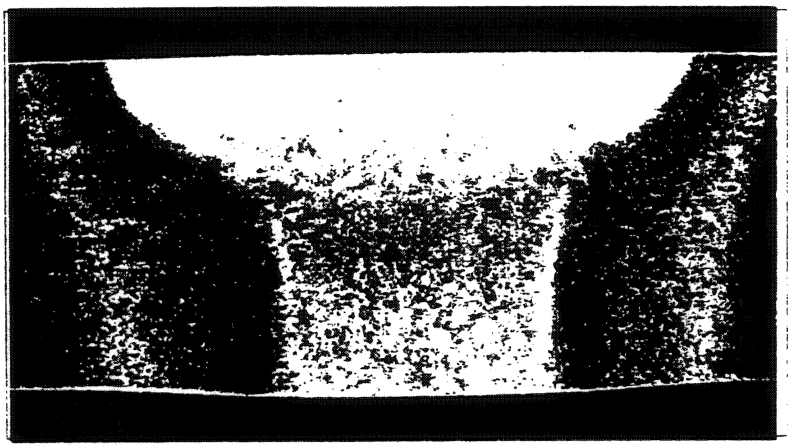
RESULTS SUMMARY:
Risultati complessivi

Macroexamination of the weld bead showed a satisfactory geometrical aspect even after automatic repair.
No appreciable defects are evidenced, the width ratio between torch side/back side varies between 1.87 and 2.28.

Microexamination at 100X showed a regular dendritic structure in the center weld (fuse zone).
The structure of the HAZ is a typical one. No appreciable internal defects are present.

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page ___ of ___ *Pag. di*

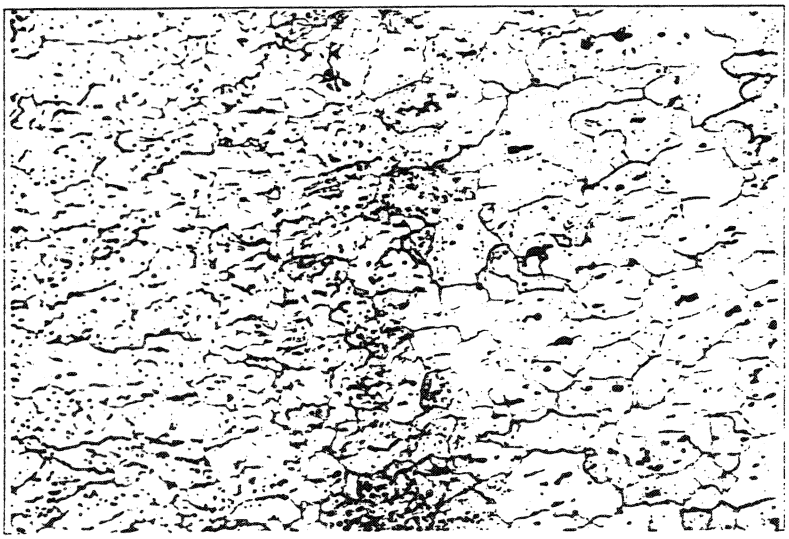
SAMPLE N°
Provino N° LBX016/I001



MACRO OF WELD

PHOTO N°: 1110
Foto

x: 7



MICRO
HAZ WELD DETAIL

PHOTO N°: 1110 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 1110 B
Foto

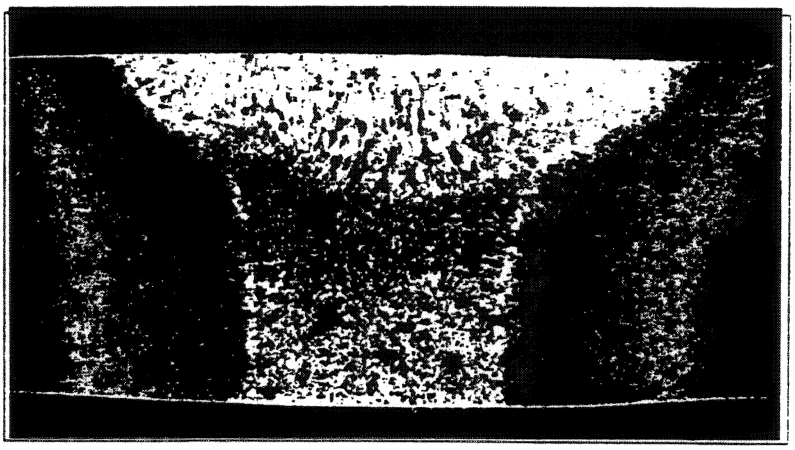
x: 100

Alenia
Alenia Spazio S.p.A.

MICRO - MACRO EXAMINATION RESULTS

Risultati esami micro - macrografici

SAMPLE N° *Provino N°* LBX016/I002



MACRO OF WELD

PHOTO N°: *Foto* 1111 x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: *Foto* 1111A

x: 100

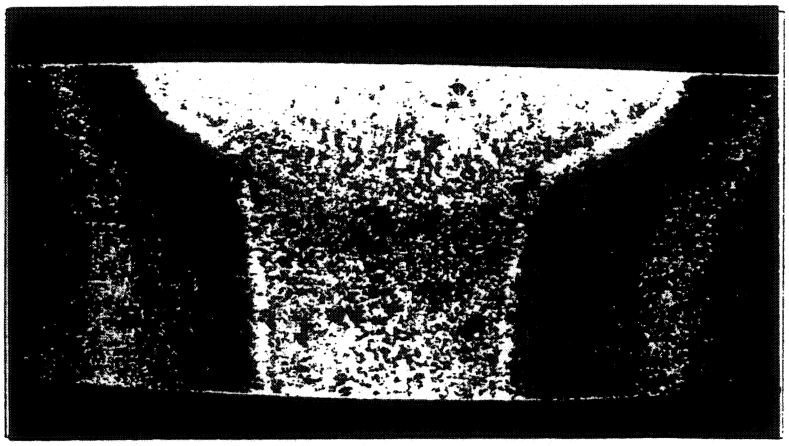
MICRO
CENTER WELD DETAIL

PHOTO N°: *Foto* 1111B

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page ___ of ___ *Pag. di*

SAMPLE N°
Provino N° LBx016 / I003



MACRO OF WELD

PHOTO N°: 1112
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 1112 A
Foto

x: 100

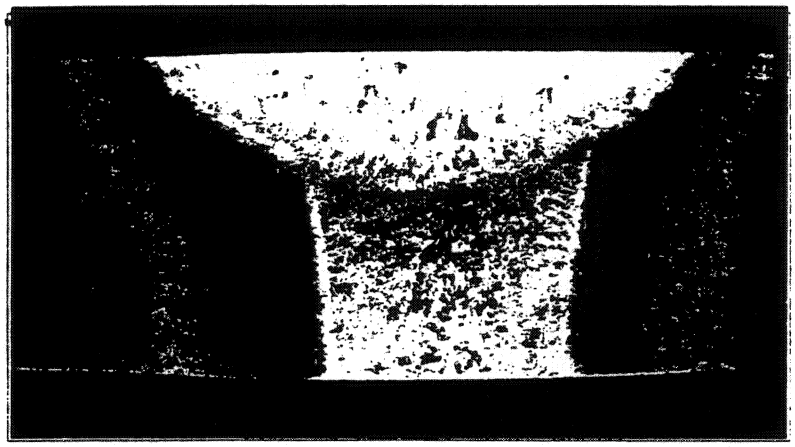
MICRO
CENTER WELD DETAIL

PHOTO N°: 1112 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page ___ of ___ *Pag. di*

SAMPLE N°
Provino N° CBX016/I004



MACRO OF WELD

PHOTO N°: 1113
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 1113 A
Foto

x: 100

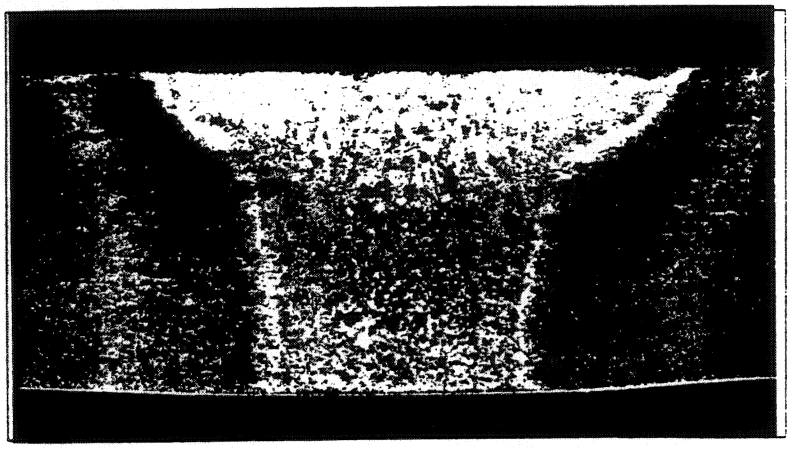
MICRO
CENTER WELD DETAIL

PHOTO N°: 1113 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page ___ of ___ *Pag. di*

SAMPLE N°
Provino N° LBX016/I005



MACRO OF WELD

PHOTO N°: 1114
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 1114 A
Foto

x: 100

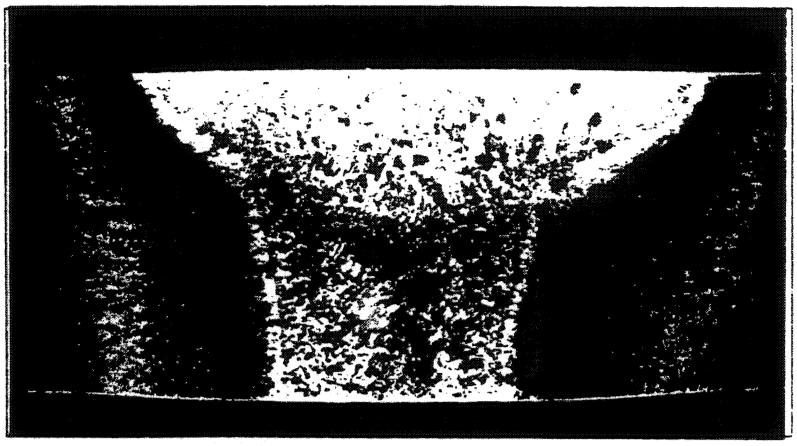
MICRO
CENTER WELD DETAIL

PHOTO N°: 1114 B
Foto

x: 100

Alenia Alenia Spazio S.p.A.	MICRO - MACRO EXAMINATION RESULTS *Risultati esami micro - macrografici*	Page ___ of ___ *Pag. di*

SAMPLE N°
Provino N° LBX016/I006



MACRO OF WELD

PHOTO N°: 1115
Foto

x: 7

MICRO
HAZ WELD DETAIL

PHOTO N°: 1115 A
Foto

x: 100

MICRO
CENTER WELD DETAIL

PHOTO N°: 1115 B
Foto

x: 100

ANNEX 3

DDIA 96-1

"PROVE DI SUSCEPTIBILITY TO STRESS CORROSION SU PROVETTE DI ALLUMINIO 2219-T8 SALDATE AL PLASMA"

DIPARTIMENTO DI INGEGNERIA AEROSPAZIALE UNIVERSITA' DEGLI STUDI DI PISA

DIPARTIMENTO DI INGEGNERIA AEROSPAZIALE

DOCUMENTI

A. Lanciotti

PROVE DI "SUSCEPTIBILITY TO STRESS CORROSION" SU PROVETTE DI ALLUMINIO 2219-T8 SALDATE PLASMA

DDIA 96-1 Gennaio 1996

UNIVERSITÀ DEGLI STUDI DI PISA

Sommario

La presente relazione descrive i risultati di una serie di prove di "Susceptibility to Stress Corrosion" effettuate su provette in alluminio, 2219-T8, saldate con processo Plasma. Le prove sono state effettuate sia su provette ricavate da lastre "as welded", sia su provette ricavate da lastre contenenti tre diversi tipi di riparazione: automatica, manuale e riparazione manuale doppia. Tale attività è stata svolta nell'ambito di un contratto di ricerca fra il Dipartimento di Ingegneria Aerospaziale dell'Università di Pisa e la Alenia Spazio, Contratto n. 9464207 del 09/03/94, relativamente al quale la presente relazione conclude il quinto punto, "Susceptibility to Stress Corrosion".

1. OGGETTO DI PROVA E IDENTIFICAZIONE DEI PROVINI

Le prove sono state effettuate su provette tipo "Dogbone", aventi una sezione di prova rettangolare di 10x7 mm e una lunghezza di prova di 50 mm.

La suscettività a stress corrosion dei materiali esaminati è stata valutata sulla base della "ESA Specification, PSS-01-737", [1], la quale prescrive l'effettuazione di prove comparative su:

- 3 provette di controllo (non pre-sollecitate e non pre-corrose);
- 3 provette immerse alternativamente per trenta giorni in una soluzione corrosiva contenente il 3.5% di Cloruro di Sodio e sollecitate staticamente, come descritto nel seguito;
- 3 provette esposte allo stesso ambiente di cui al punto precedente, ma non sollecitate.

L'identificazione delle provette è costituita da tre lettere, tre numeri, una lettera e tre numeri. Nel primo campo di tre lettere la prima e l'ultima lettera sono sempre una "L" e una "X", mentre la seconda lettera identifica il tipo di saldatura:

A: Automatica vergine;
B: Automatica con riparazione in automatico;
C: Automatica con riparazione manuale;
D: Automatica con doppia riparazione manuale;

Il secondo campo di tre numeri identifica la lastra saldata, avente dimensioni 600x1000 mm, dalla quale è stata ricavata la provetta.

Nel terzo campo la prima lettera è sempre una "L", che identifica il tipo di prova (Susceptibility to Stress Corrosion), seguita da tre numeri che identificano la singola provetta.

Per i quattro tipi di saldatura sono state sottoposte a stress corrosion le tre provette aventi come sigla identificativa: L001, L002 e L003; sottoposte a sola corrosione le provette: L004, L005 e L006; non pre-esposte e non pre-sollecitate le provette: L007, L008 e L009.

2. AMBIENTE CORROSIVO

L'ambiente corrosivo era costituito da una soluzione contenente il 3.5% di Cloruro di Sodio. Le provette corrose sono state immerse in questo ambiente per trenta giorni in modo alternato, 10 minuti di immersione seguiti da 50 minuti di asciugatura. Come specificato in [1], la soluzione è stata rinnovata dopo sette, quattordici e ventuno giorni.

3. CARICHI

Il carico da applicare per le prove di stress corrosion, P=6814.5 N, è stato stabilito dalla Alenia Spazio sulla base di prove statiche preliminari.

4. ATTREZZATURA DI PROVA

La fig. 1 mostra uno schema dell'attrezzatura utilizzata per le prove di stress-corrosion. La cella di corrosione è costituita da un tubo in Plexiglas, 120 mm di diametro, chiuso nella parte inferiore e sigillato con un O-ring. Le prove sono state effettuate su gruppi di tre provette collegate fra loro in modo da formare una catena fissata ad un estremo e caricata all'altro estremo tramite un peso agente su una leva. Il carico effettivamente applicato veniva misurato tramite una cella di carico interposta fra la tre provette e il telaio della macchina, fig.1.

La soluzione corrosiva era contenuta in un recipiente posto più in basso rispetto alla cella di corrosione. La soluzione veniva immessa nella cella tramite una pompa comandata da un timer programmabile a due canali. I tempi selezionati erano di 10 minuti "on" e cinquanta minuti "off". Riempita la cella il liquido in eccesso veniva drenato tramite un foro posto nella parte alta della cella e collegato al recipiente. Dopo dieci minuti la pompa si fermava e la soluzione scendeva nel recipiente. Quando la cella era completamente vuota, le provette venivano asciugate tramite un ventilatore comandato dallo stesso timer.

Per quanto concerne i materiali in contatto con la soluzione, si sono utilizzate materie plastiche, finchè possibile. Gli unici elementi metallici erano gli elementi di collegamento fra i provini e il tappo di chiusura della cella, realizzati in alluminio anodizzato. Al fine di evitare una eventuale corrosione galvanica, ciascun provino della catena era isolato elettricamente, avendo interposto nei collegamenti delle boccole in materiale plastico.

5. RISULTATI

5.1 Proprietà meccaniche

Le prove di stress corrosion si sono concluse senza rotture. Due provette per ciascun gruppo sono state provate staticamente per valutare la suscettività a stress corrosion. Per tali prove si è utilizzato un martinetto idraulico servocontrollato, avente una capacità di carico di 25 KN. L'allungamento delle provette sotto carico è stato misurato con un estensometro avente una lunghezza di misura di 50 mm. Le prove sono state condotte imponendo una velocità costante di separazione fra le teste della macchina di prova di circa 0.05 mm/mm per minuto.

I risultati delle prove, diagrammi carico-allungamento, sono riportati nella appendice I; la tensione di snervamento, la tensione massima e l'allungamento a rottura misurati nelle diverse prove sono riportati nella tab.I, unitamente ad uno schema del modo di rottura, e nelle fig. 2, 3, 4.

	Id.	Sy (MPa)	Smax (MPa)	A (%)	Failure Mode
Stressed and corroded	LAX-011-L001	168	261	3.8	
	LAX-011-L002	168	264	4.8	
Un-stressed and corroded	LAX-011-L004	178	264	2.4	
	LAX-011-L005	162	252	3.6	
Un-stressed and un-corroded	LAX-011-L007	164	269	5.9	
	LAX-011-L009	165	276	5.9	
Stressed and corroded	LBX-012-L001	129	266	4.1	
	LBX-012-L002	126	256	3.8	
Un-stressed and corroded	LBX-012-L004	126	259	4.1	
	LBX-012-L005	131	245	3.7	
Un-stressed and un-corroded	LBX-012-L007	132	273	5.4	
	LBX-012-L008	130	276	5.3	
Stressed and corroded	LCX-016-L001	182	275	4.0	
	LCX-016-L002	168	265	3.9	
Un-stressed and corroded	LCX-016-L004	175	270	4.2	
	LCX-016-L005	179	269	3.6	
Un-stressed and un-corroded	LCX-016-L008	177	277	4.4	
	LCX-016-L009	178	278	4.1	
Stressed and corroded	LDX-005-L001	172	263	5.4	
	LDX-005-L002	164	265	4.9	
Un-stressed and corroded	LDX-005-L004	161	266	5.2	
	LDX-005-L005	175	269	4.6	
Un-stressed and un-corroded	LDX-005-L007	173	272	4.6	
	LDX-005-L008	179	273	4.0	
	LDX-005-L009	178	263	5.2	

Tab. I - Risultati delle prove statiche.

Dall'esame dei risultati ottenuti si possono trarre le seguenti conclusioni:

- I valori della tensione di snervamento sono relativamente bassi; questa è una caratteristica del processo di saldatura in esame.
- L'esposizione ad ambiente corrosivo non produce una variazione apprezzabile della tensione di snervamento anche in presenza di carico applicato.
- La riparazione automatica produce una diminuzione della tensione di snervamento non osservabile nel caso di riparazione manuale, sia singola che doppia.
- La tensione massima praticamente non è influenzata dal tipo di riparazione e dall'esposizione ad ambiente corrosivo.
- L'allungamento a rottura è molto variabile fra le diverse condizioni di prova; per saldatura automatica vergine e riparazione automatica l'esposizione ad ambiente corrosivo riduce questa grandezza, mentre per i due tipi di riparazione manuale l'esposizione ad ambiente corrosivo non inflenza i risultati.

5.2 Osservazioni macroscopiche

Sui provini esposti ad ambiente corrosivo, sia in presenza che in assenza di carico applicato, si sono generalmente osservati pitting e esfoliazione, particolarmente nella zona termicamente alterata, dove maggiori erano i depositi di sale e di ossidi, fig.5. In questa zona potrebbe anche essere presente una corrosione di tipo galvanico fra il materiale costituente il cordone e il materiale base. Quanto esposto è risultato molto evidente sulle provette non riparate, LAX, meno evidente sulle provette con riparazione automatica e manuale singola, LBX e LCX, quasi assente sulle provette con riparazione manuale doppia, LDX.

Sezionando le provette si è osservata una pronunciata esfoliazione nella zona termicamente alterata delle provette LAX, fig. 6, mentre questo tipo di corrosione non era presente nelle provette contenenti i tre diversi tipi di riparazione, fig. 7. Nella fig. 6 risulta evidente anche il cordone di saldatura, mentre nella fig. 7 è chiaramente visibile anche il secondo cordone introdotto con la riparazione (automatica in questo caso).

In tutte le provette, avendo il materiale costituente il cordone delle proprietà meccaniche decisamente inferiori rispetto al materiale base, la rottura ha sempre riguardato il cordone, con una rilevante strizione, limitata al cordone, che metteva in evidenza il cordone stesso. L'esposizione ad ambiente corrosivo ha prodotto delle differenze nel modo di rottura. Nelle provette non riparate, sottoposte a stress corrosion, risultavano evidenti numerose cricche secondarie nel cordone e nella zona termicamente alterata, fig. 8; questo fenomeno risultava meno evidente, ma sempre presente, nelle provette sottoposte a sola corrosione, fig. 9, e completamente assente nelle provette non sottoposte a corrosione, fig. 10.

Quanto descritto per le provette non riparate era meno evidente nelle provette LBX e LCX e praticamente assente nelle provette LDX.

Sempre relativamente al modo di rottura, anche la sezione critica appare influenzata dalla esposizione ad ambiente corrosivo. Nelle provette non pre-esposte, la sezione critica è quasi sempre al centro del cordone di saldatura, tab.I, mentre nelle provette pre-esposte ad ambiente corrosivo la sezione critica quasi sempre si localizza nela zona termicamente alterata.

5.4 Osservazioni microscopiche

Per ciascun tipo di saldatura due provette, una sottoposta a stress corrosion, L003, e una sottoposta a sola corrosione L006, sono state sezionate, dopo l'esposizione ad ambiente corrosivo, per la successiva osservazione microscopica.

In nessun campione si sono osservati rilevanti danneggiamenti prodotti da stress corrosion, come d'altronde deducibile dai risultati delle provette sottoposte a prova statica.

Nelle provette tipo LAX si è osservata una corrosione di tipo intergranulare, addirittura più evidente nel campione sottoposto a sola corrosione, che non nel campione sottoposto a stress corrosion, fig. 11 e 12. Come confronto viene mostrata in fig. 13 la grana del materiale base.

Nelle provette LBX la corrosione intergranulare è più evidente nel campione sottoposto a stress corrosion, per cui potrebbe essere presente una leggera sensibilità a stress corrosion, fig. 14 e 15.

Nelle provette LCX si è osservata ancora una maggior corrosione intergranulare nel campione solo esposto ad ambiente corrosivo, fig. 16 e 17.

Nelle provette LDX stranamente non si è osservata corrosione intergranulare, ma solo diversi pits molto piccoli, fig. 18, concentrati solo in alcune aree, che sembrano essere dei micro-difetti nel cordone di saldatura, quindi non legati all'esposizione ad ambiente corrosivo.

Globalmente nei campioni contenenti la saldatura vergine e la saldatura con riparazione singola (manuale ed automatica) si è osservata una leggera corrosione di tipo intergranulare, mentre l'ulteriore riscaldamento subito dai campioni con doppia riparazione manuale, sembra essere benefico da questo punto di vista.

6. REFERENCES

[1] - Anon. "Determination of the susceptibility of metals to stress corrosion cracking" European Space Agency, Spec. n. PSS-01-737, Issue 1, September 1981.

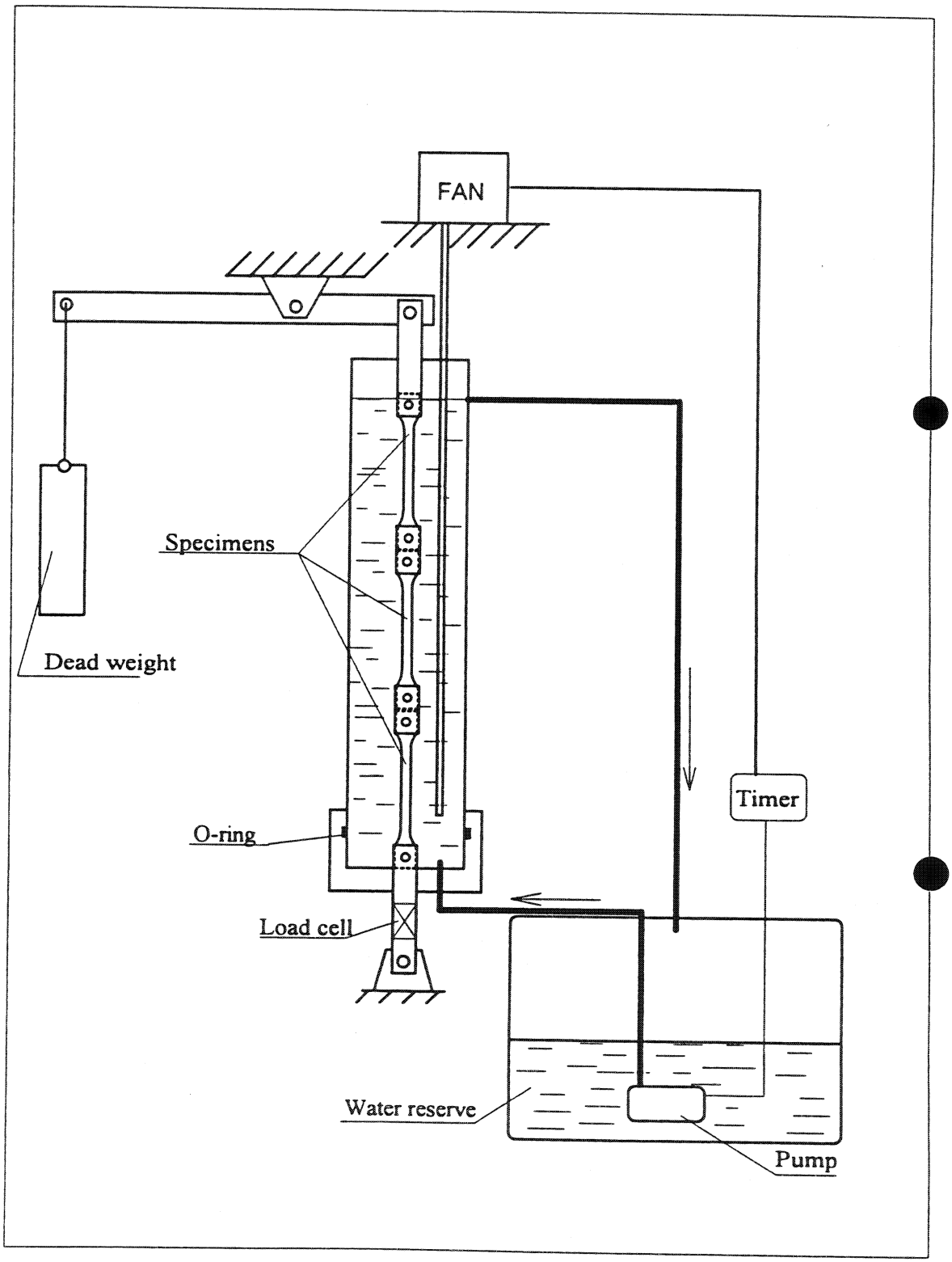


Fig. 1 - Scheme of the test equipment.

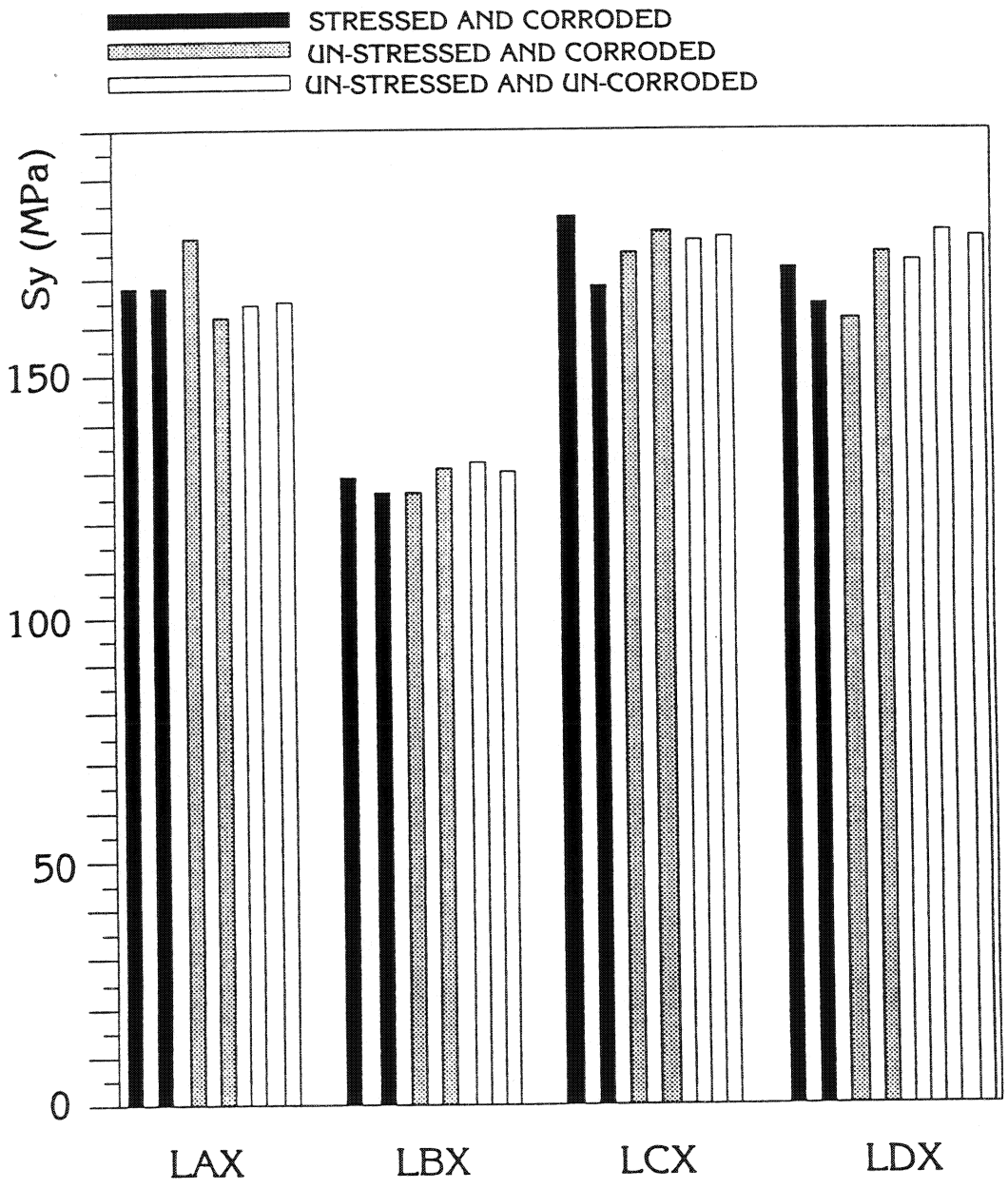


Fig. 2 - Risultati delle prove statiche: tensione di snervamento.

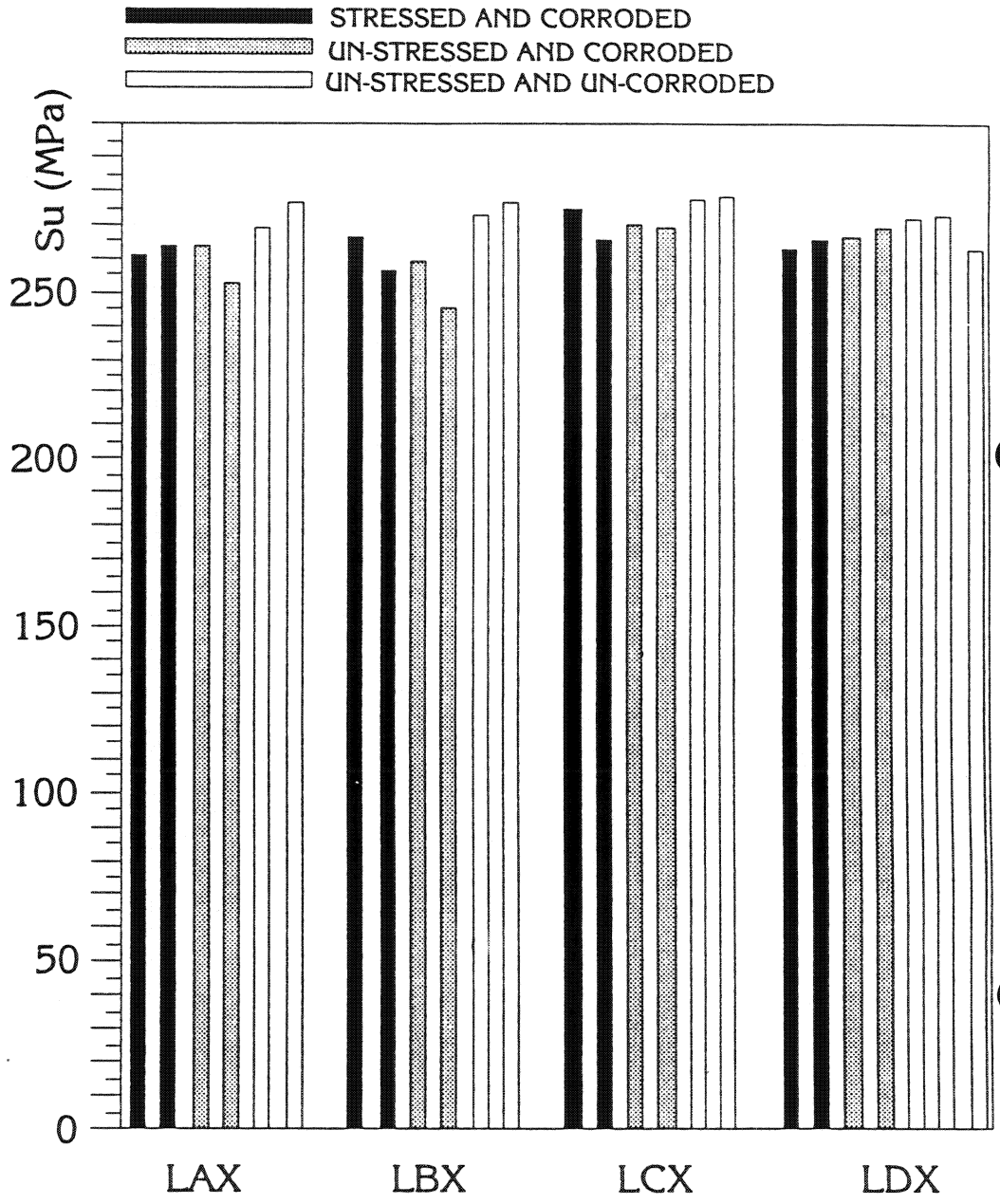


Fig. 3 - Risultati delle prove statiche: tensione massima.

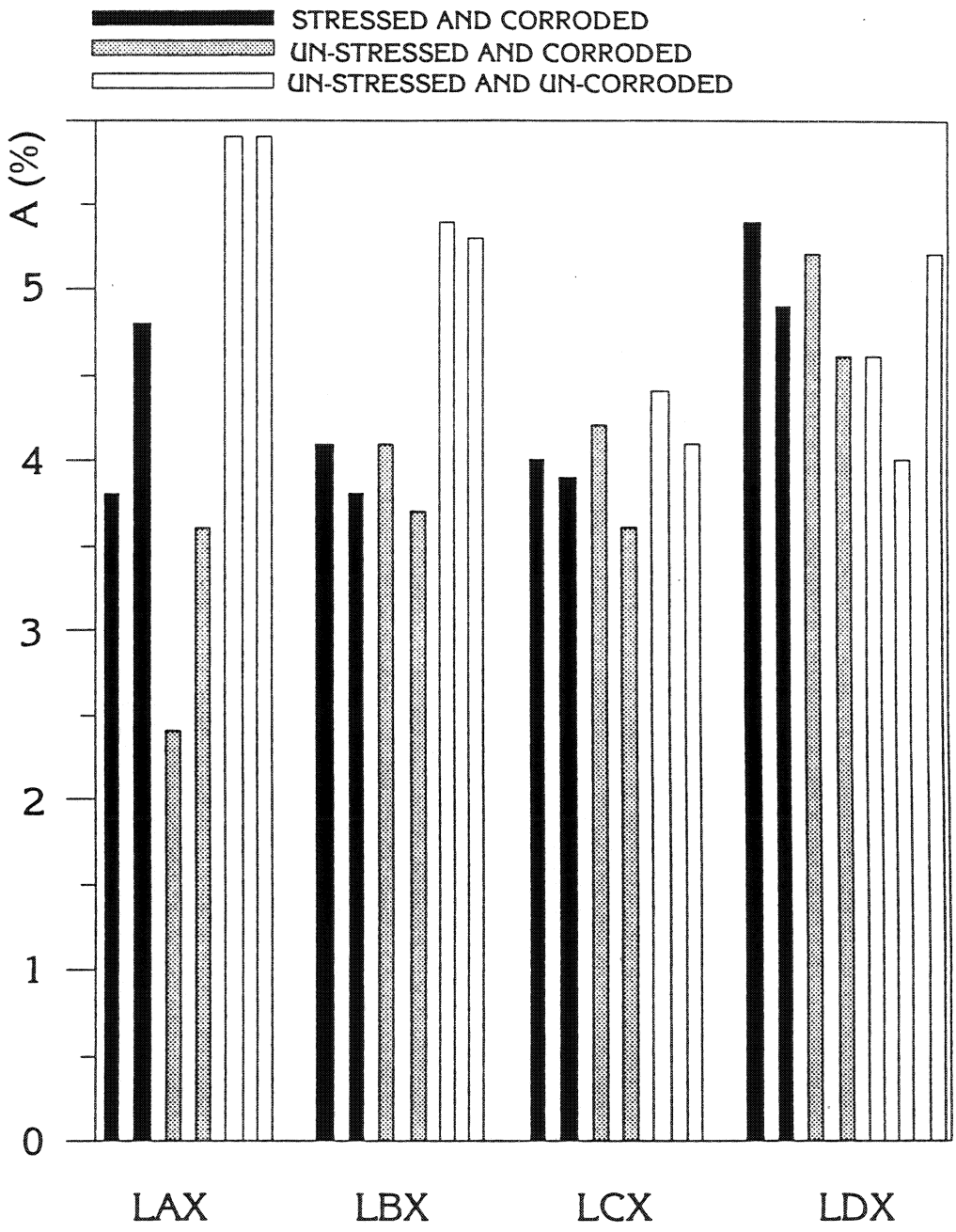


Fig. 4 - Risultati delle prove statiche: allungamento a rottura.

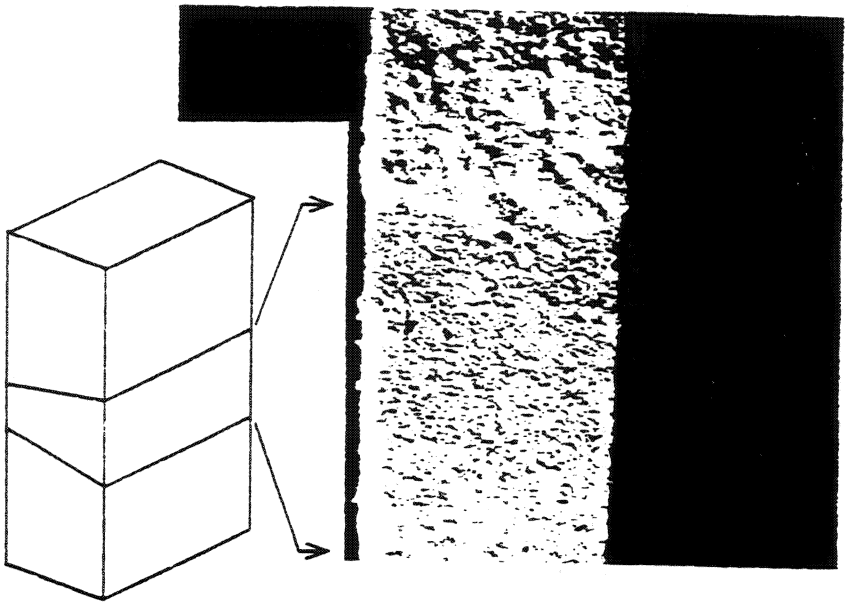


Fig. 5 - Tipico aspetto delle provette al termine della prova di corrosione.

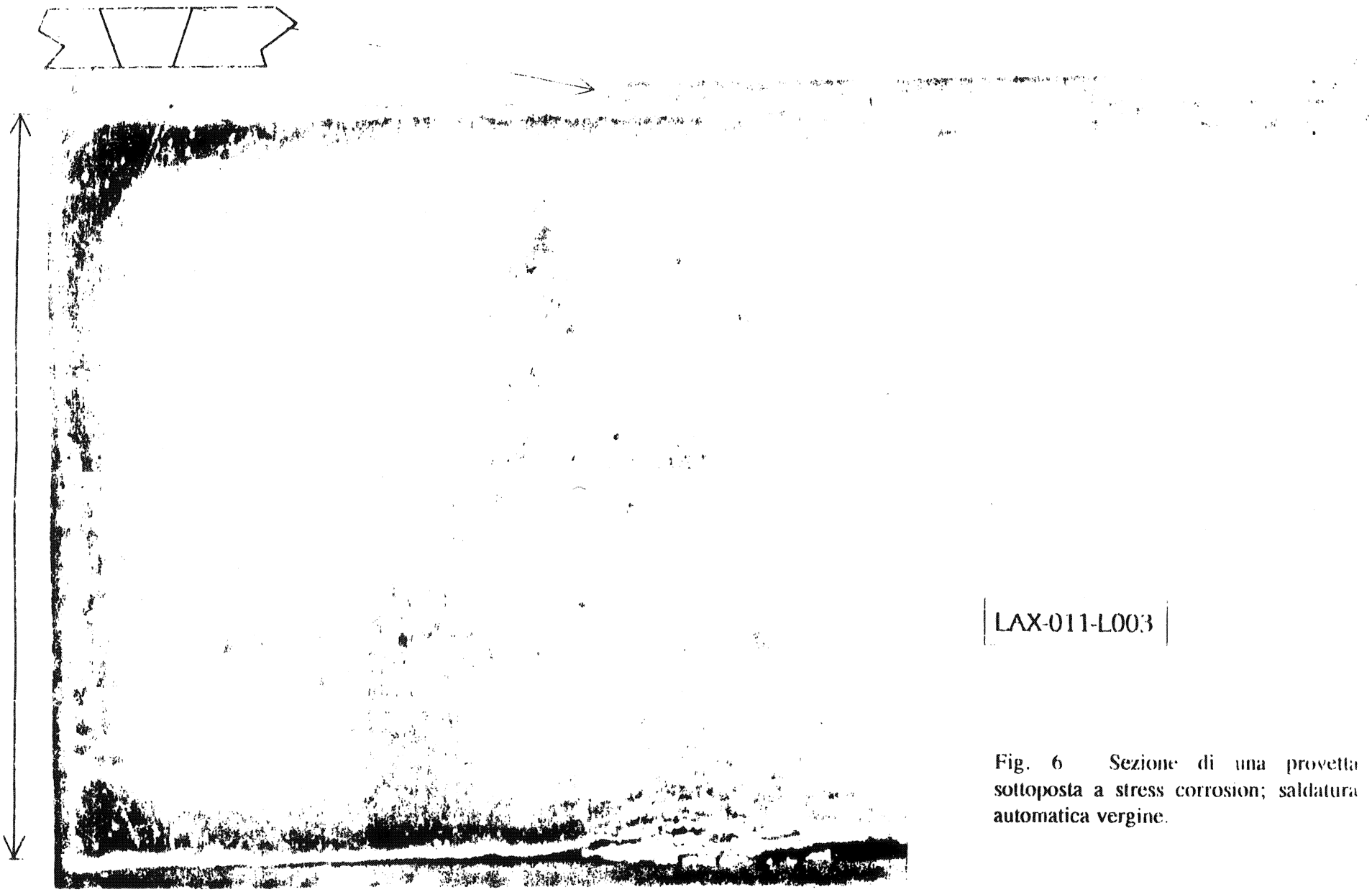
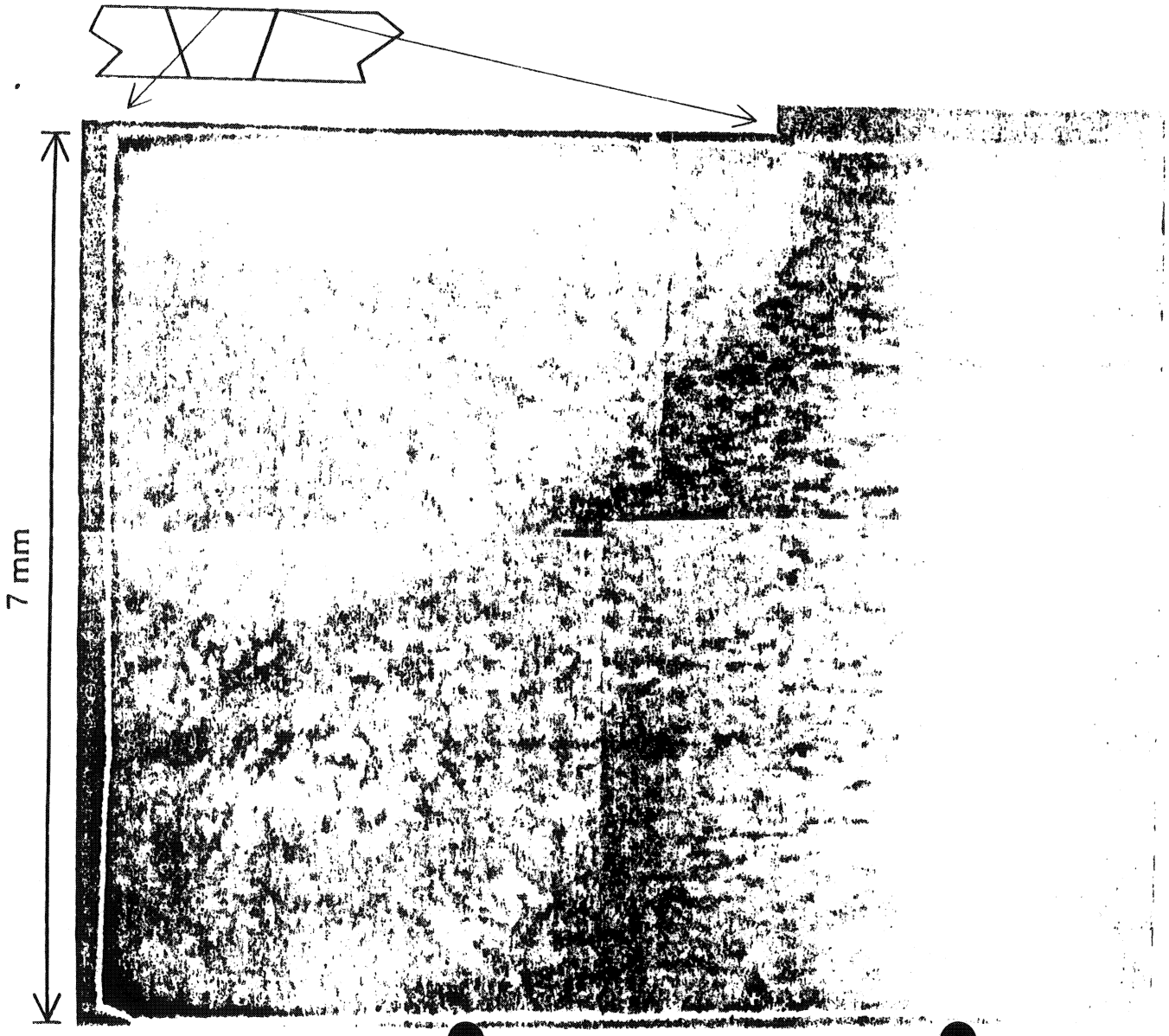


Fig. 6 Sezione di una provetta sottoposta a stress corrosion; saldatura automatica vergine.



LBX-012-L003

Fig. 7 - Sezione di una provetta sottoposta a stress corrosion; saldatura con riparazione automatica.

Fig. 8 - Modo di rottura di provette LAX sottoposte a stress-corrosion.

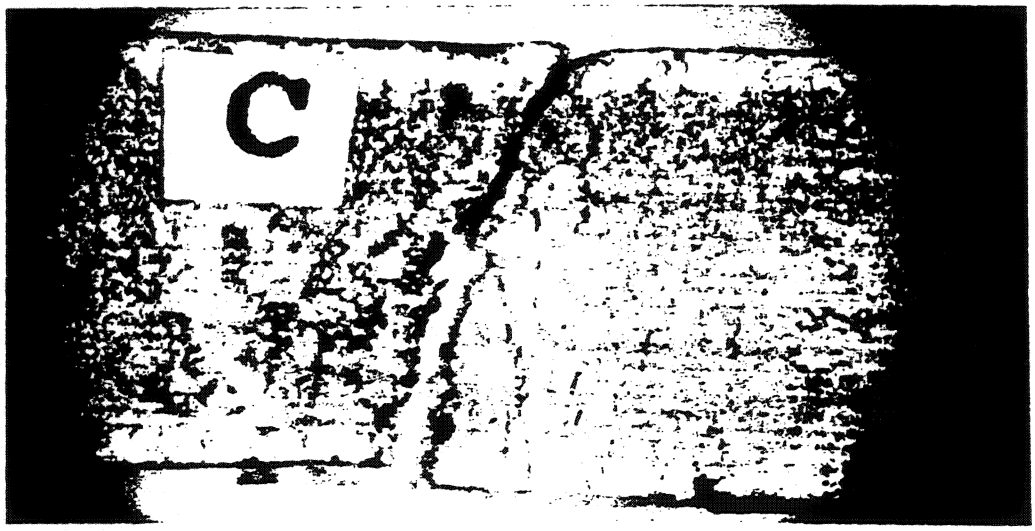


Fig. 9 - Modo di rottura di provette LAX pre-esposte ad ambiente corrosivo.

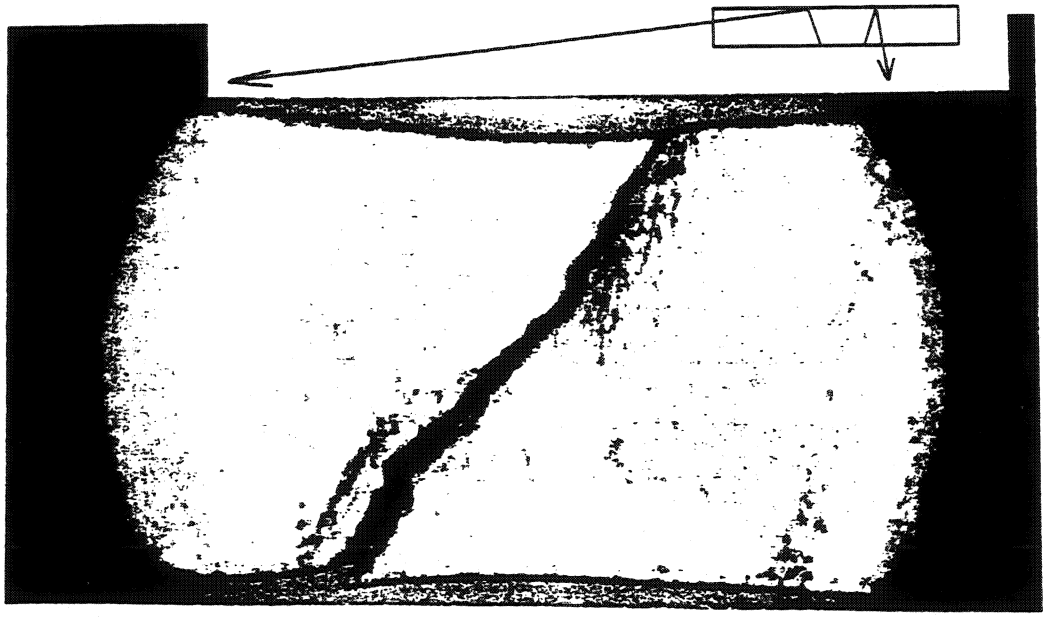


Fig. 10 - Modo di rottura di provette LAX non pre-esposte ad ambiente corosivo.

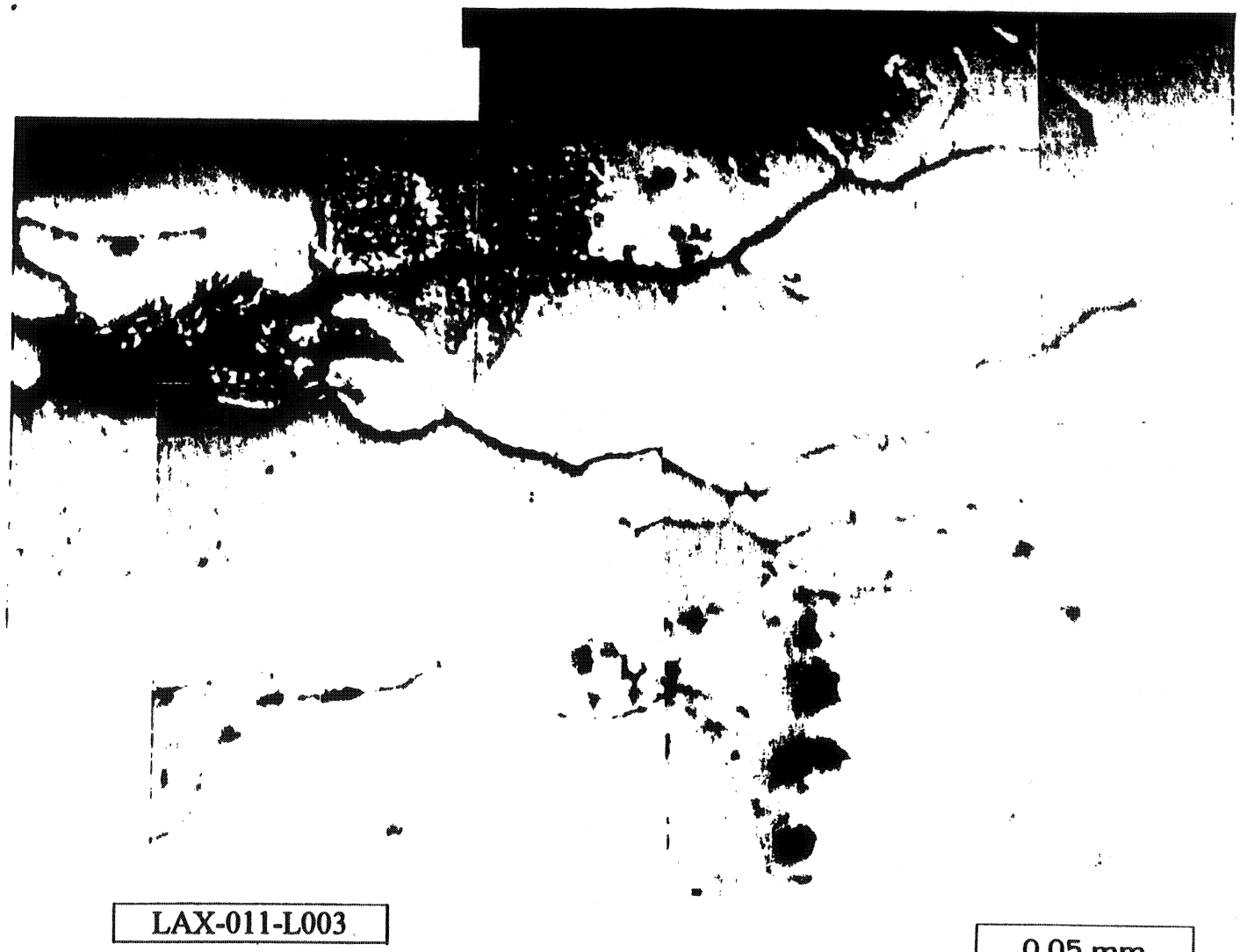


Fig. 11 - Sezione di un campione LAX sottoposto a stress-corrosion.

LAX-011-L006

0.05 mm

Fig. 12 - Sezione di un campione LAX sottoposto a sola corrosione.

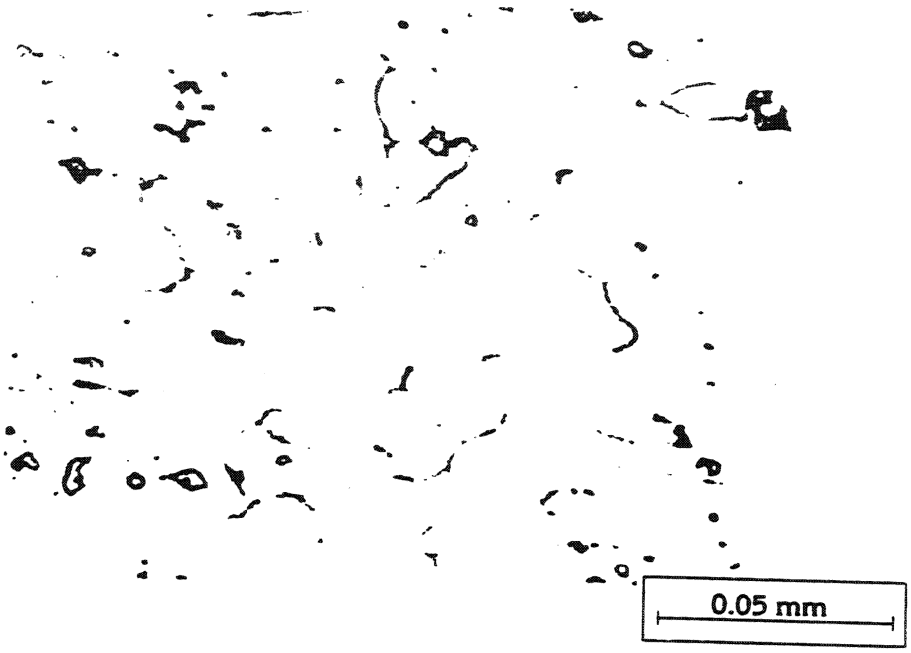


Fig. 13 - Sezione di un campione di materiale base.

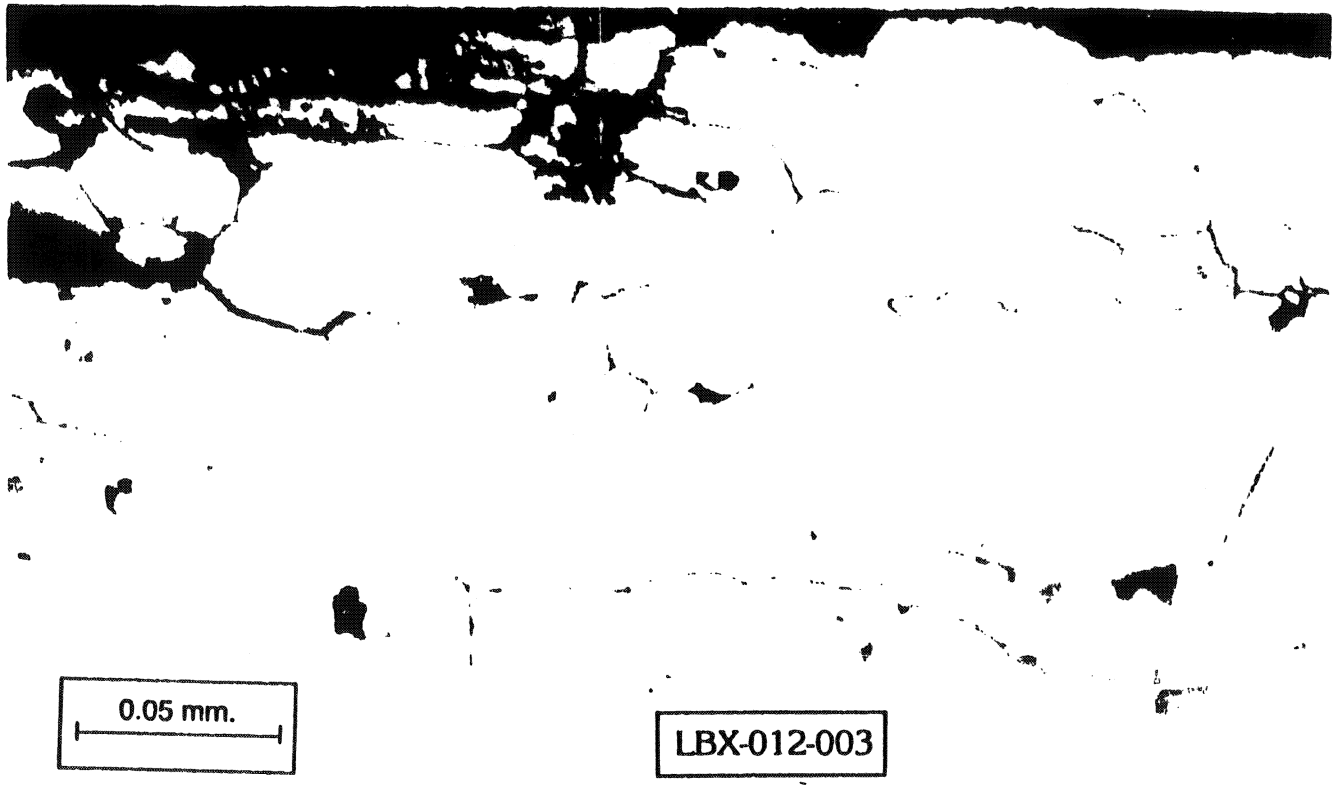


Fig. 14 - Sezione di un campione LBX sottoposto a stress-corrosion.

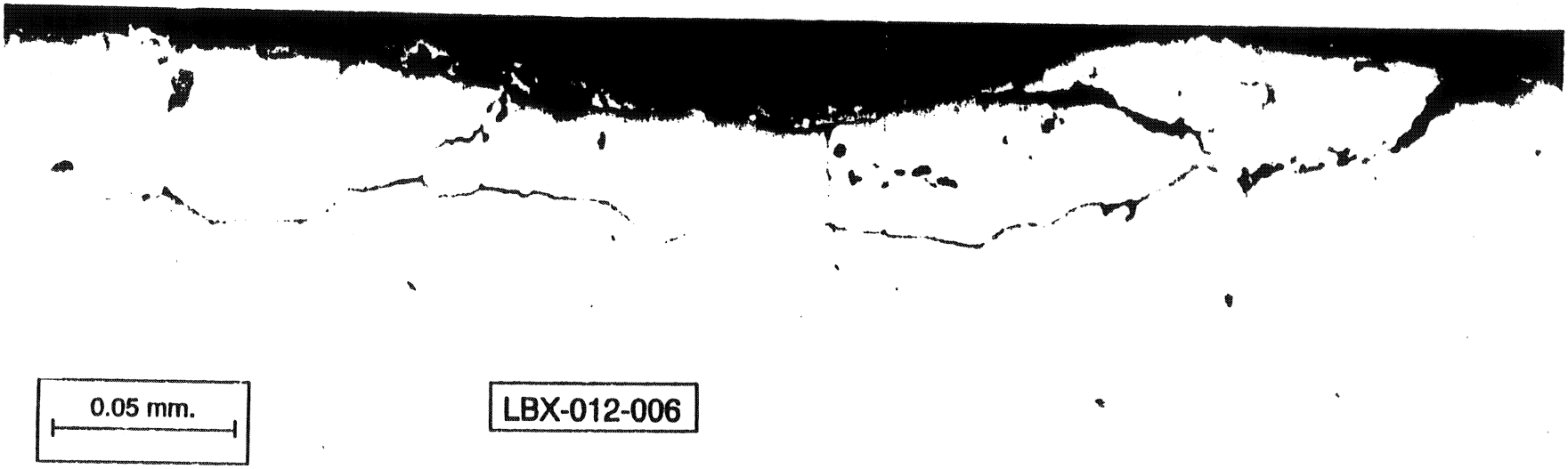


Fig. 15 - Sezione di un campione LBX sottoposto a sola corrosione.

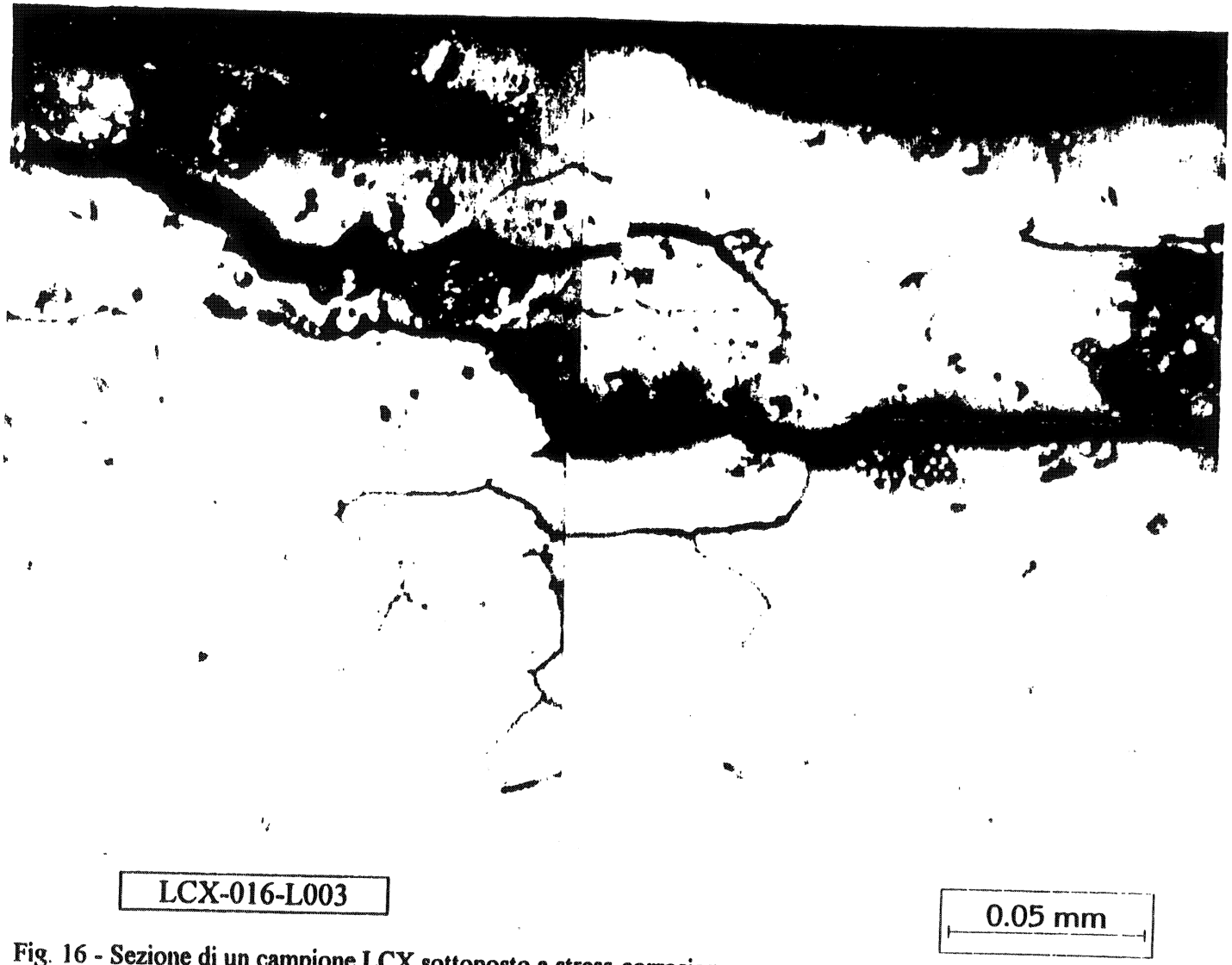


Fig. 16 - Sezione di un campione LCX sottoposto a stress-corrosion.

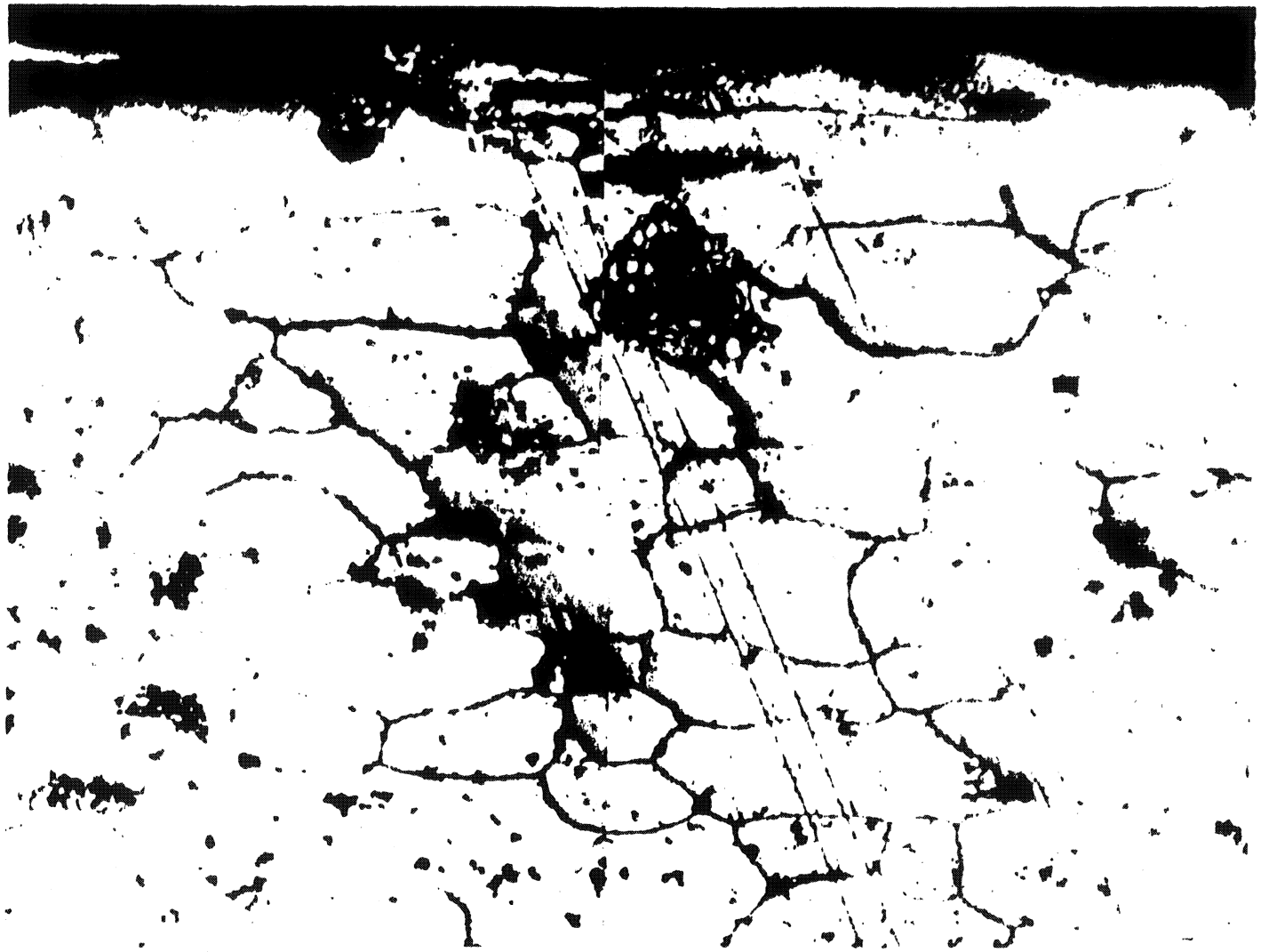


Fig. 17 - Sezione di un campione LCX sottoposto a sola corrosione.

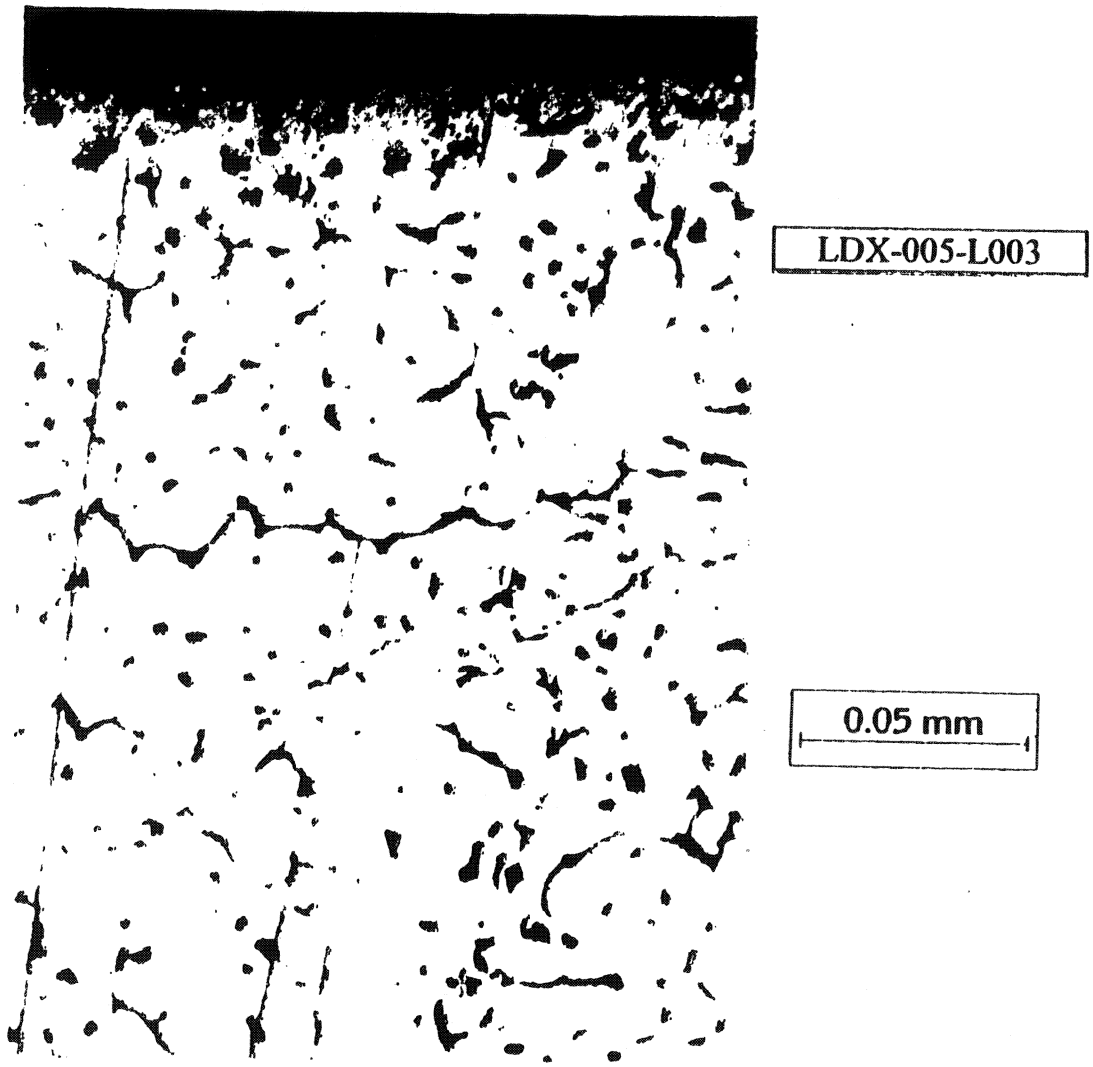
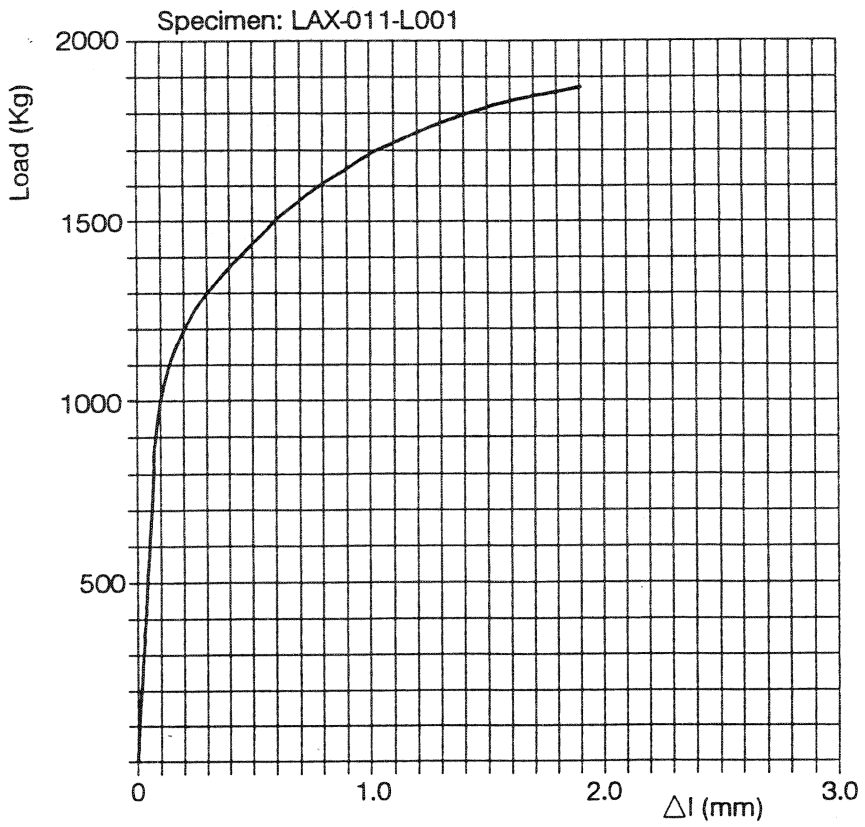


Fig. 18 - Sezione di un campione LDX sottoposto a stress-corrosion.

APPENDICE I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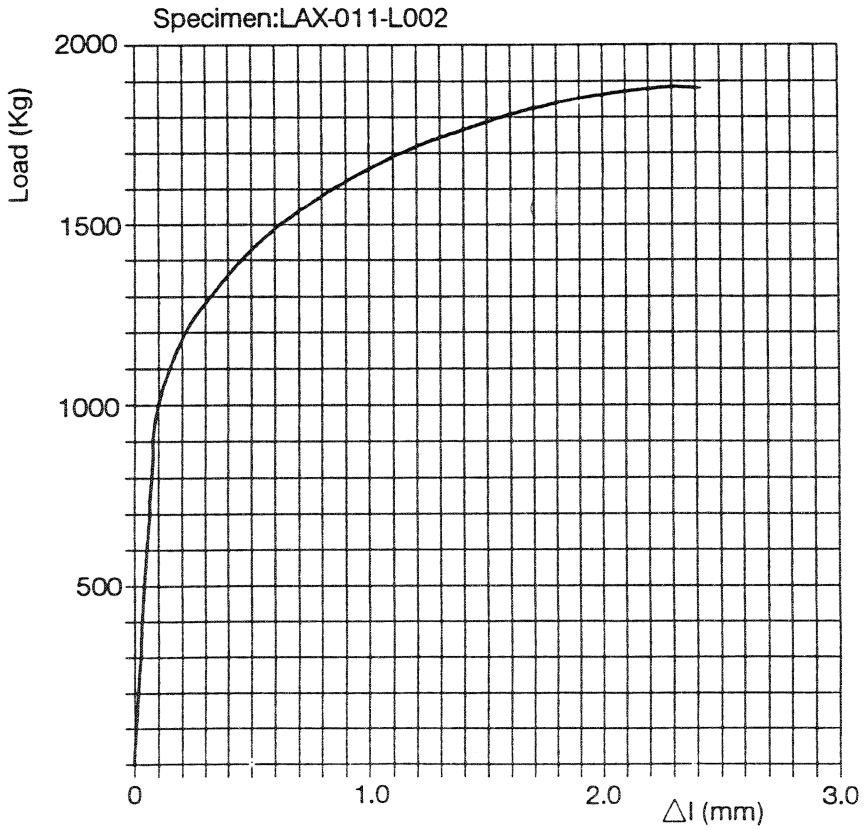
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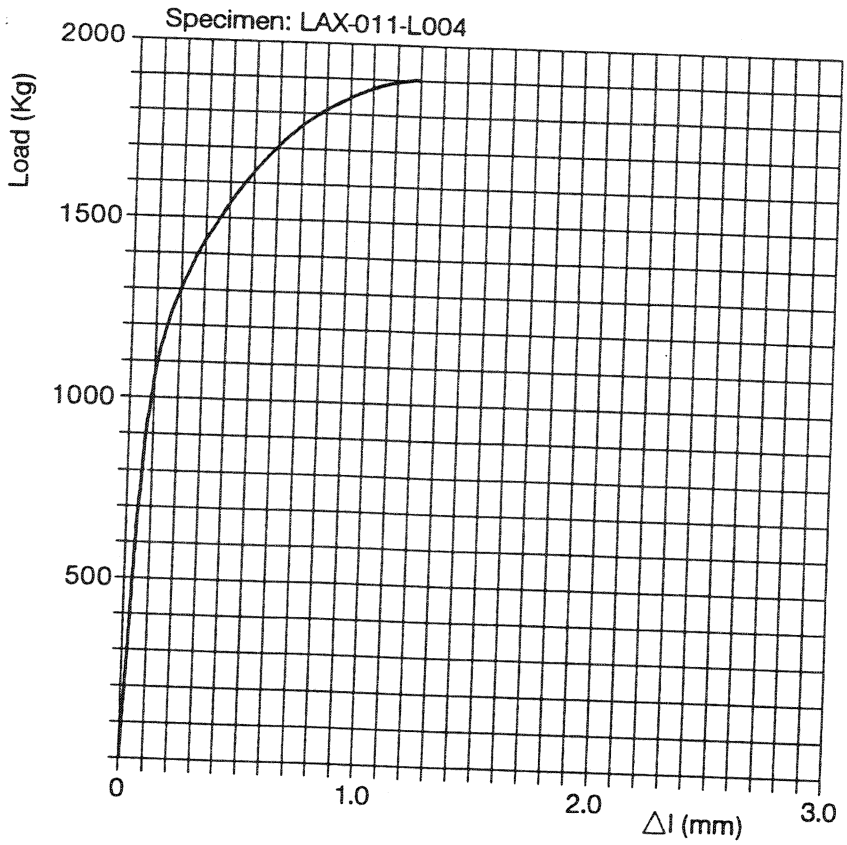
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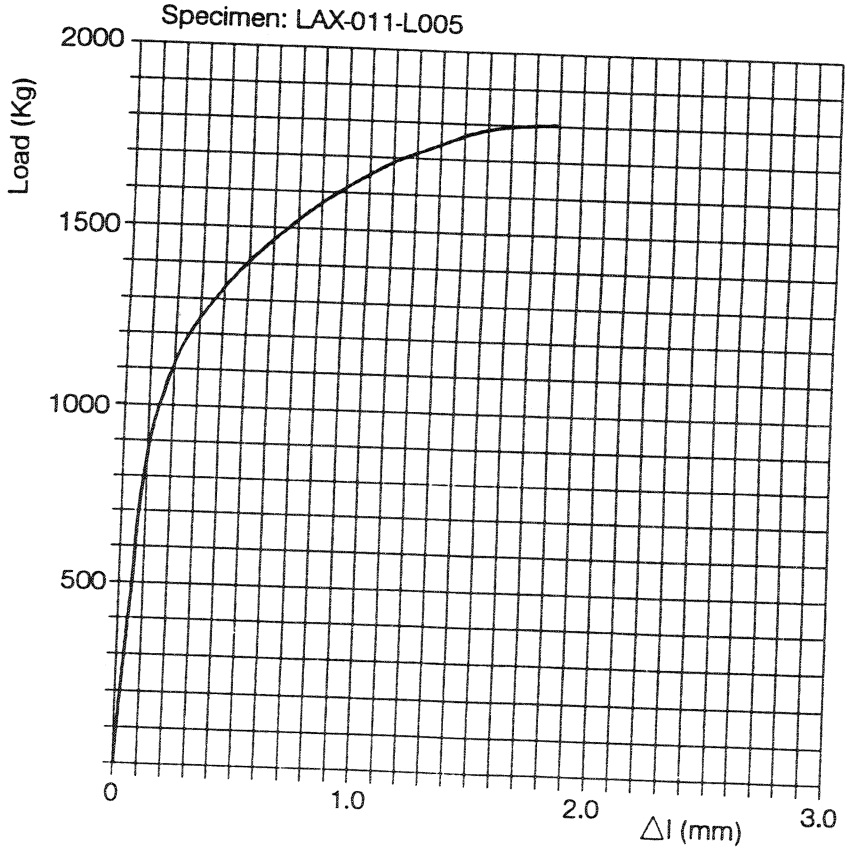
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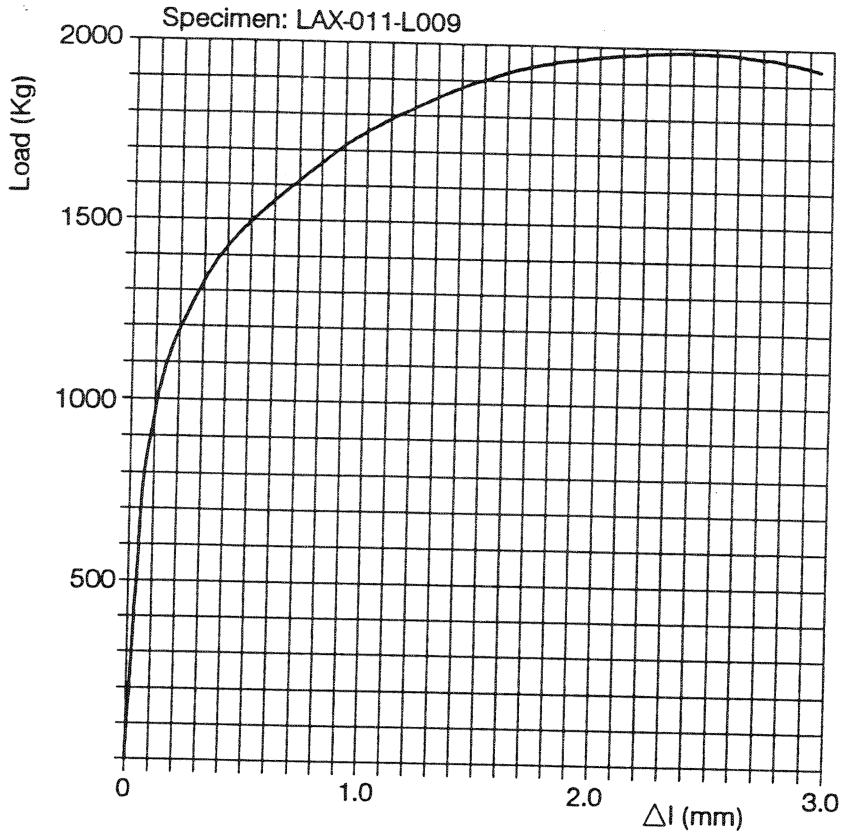
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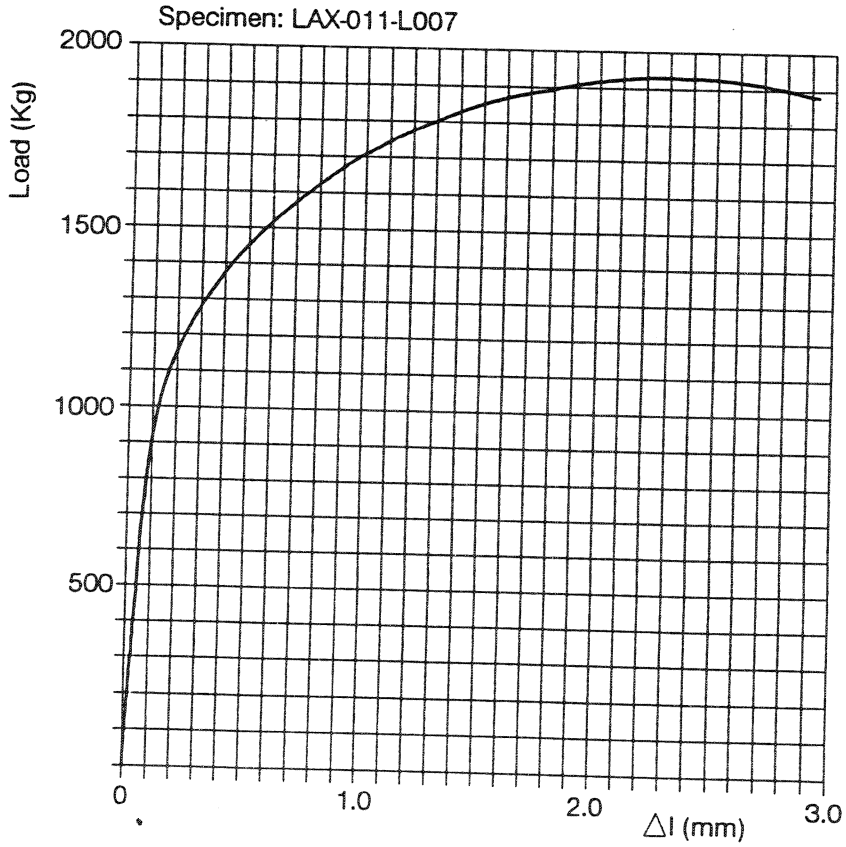
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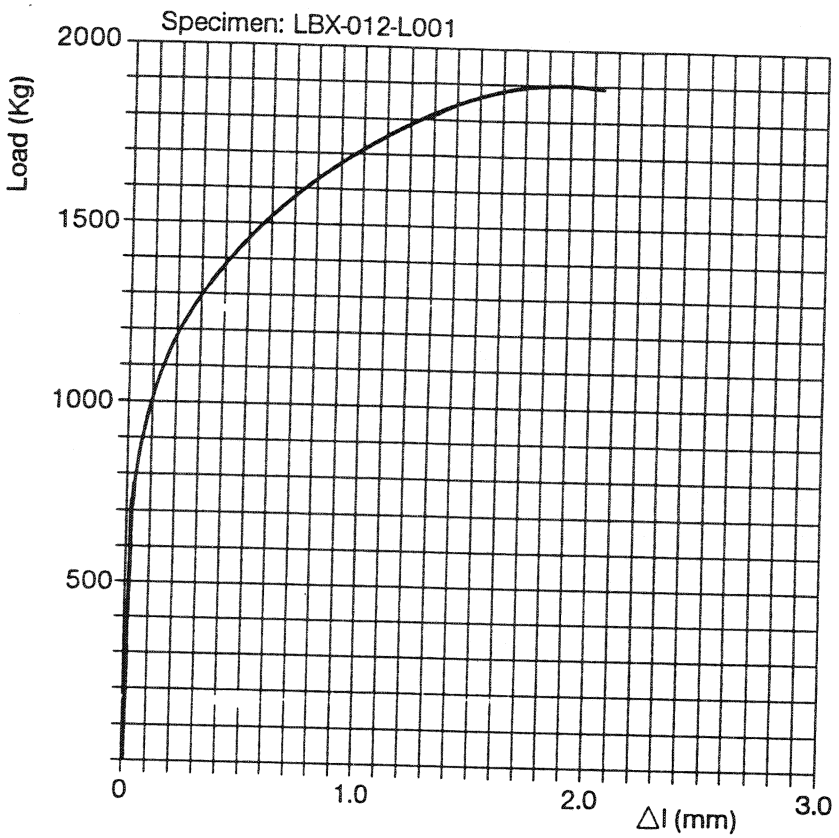
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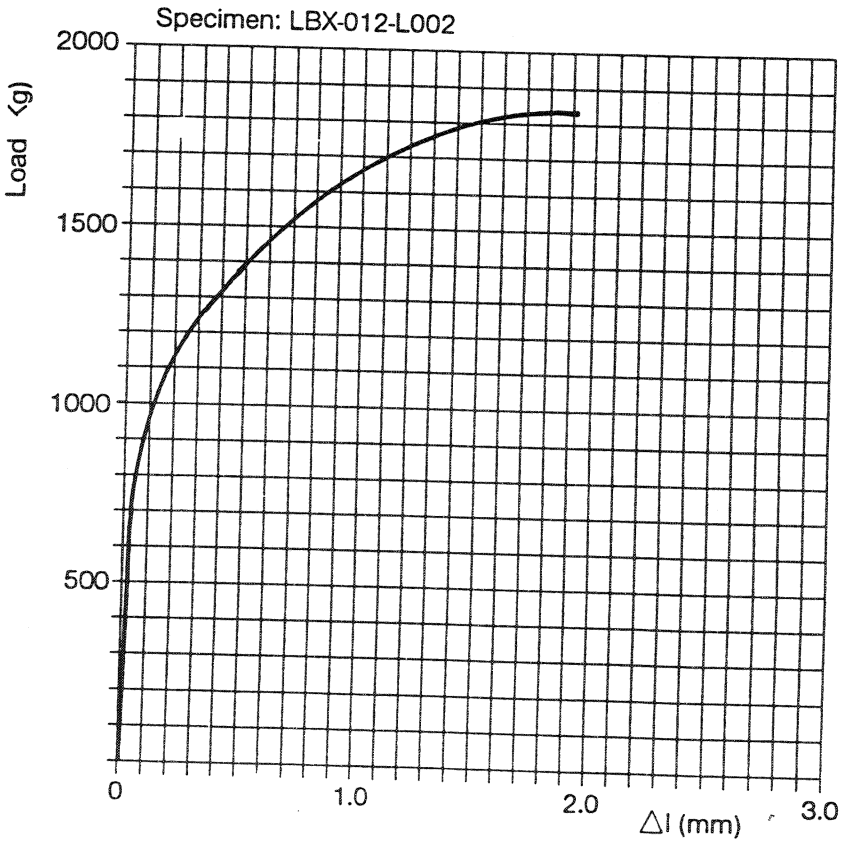
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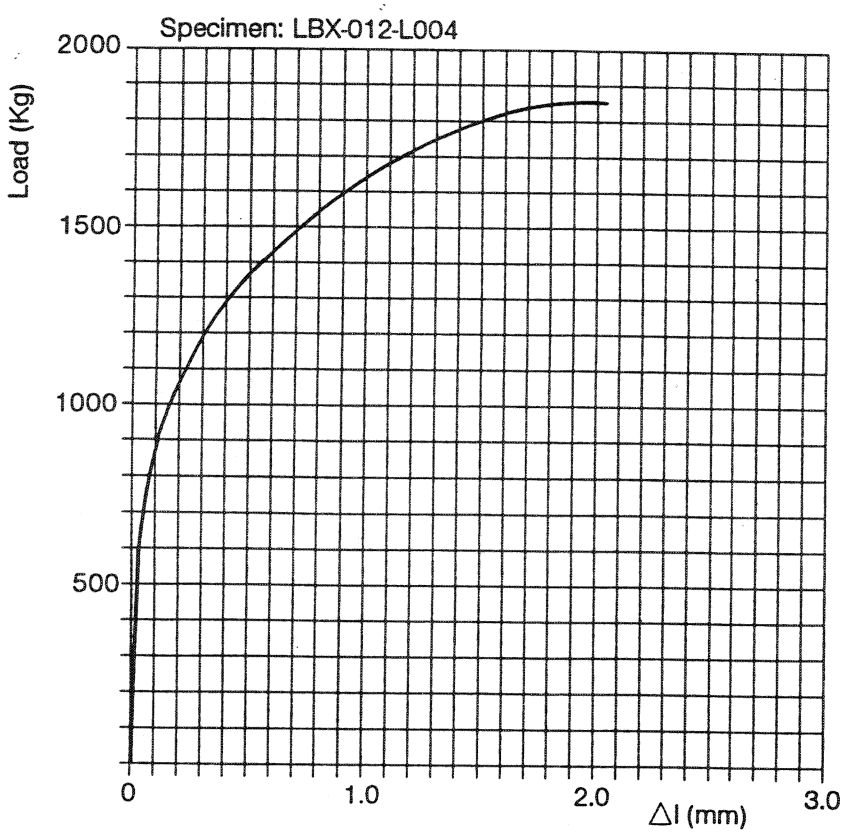
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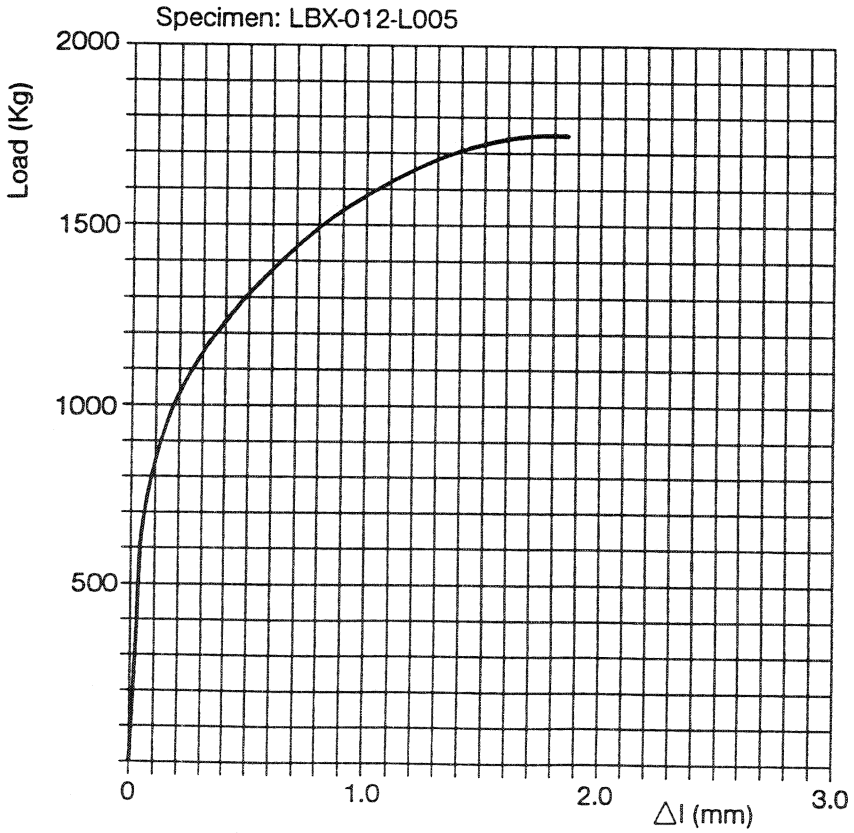
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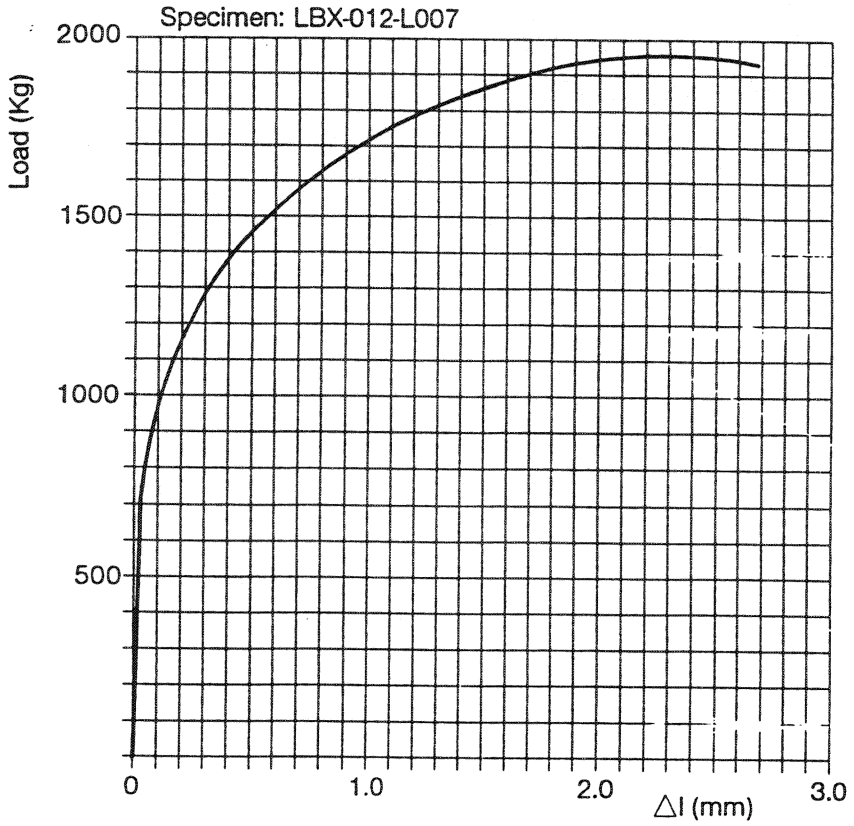
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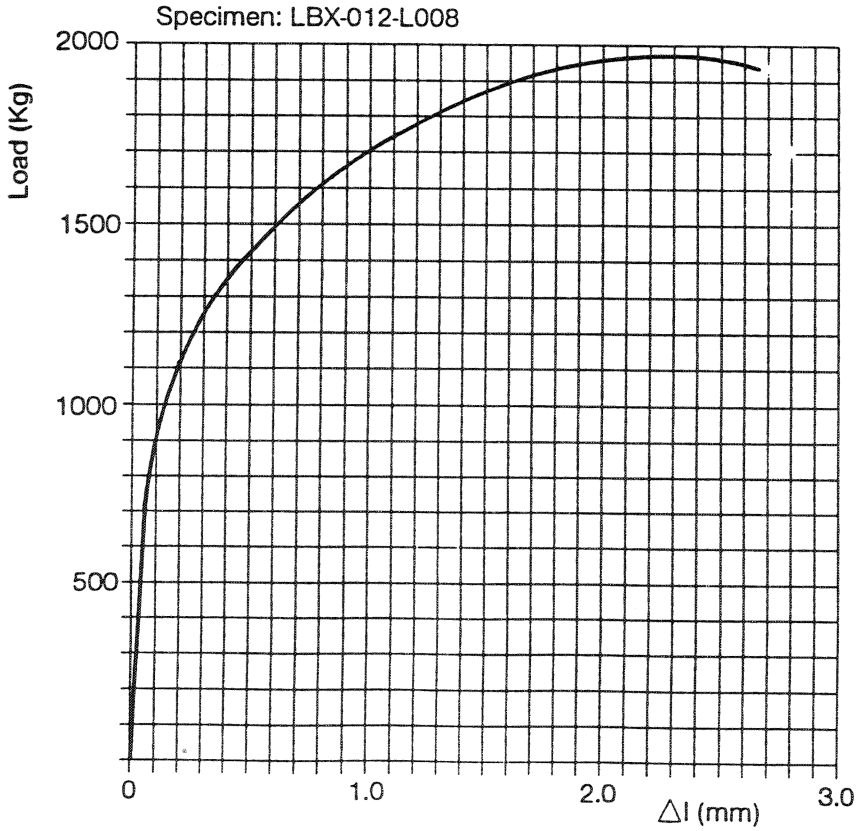
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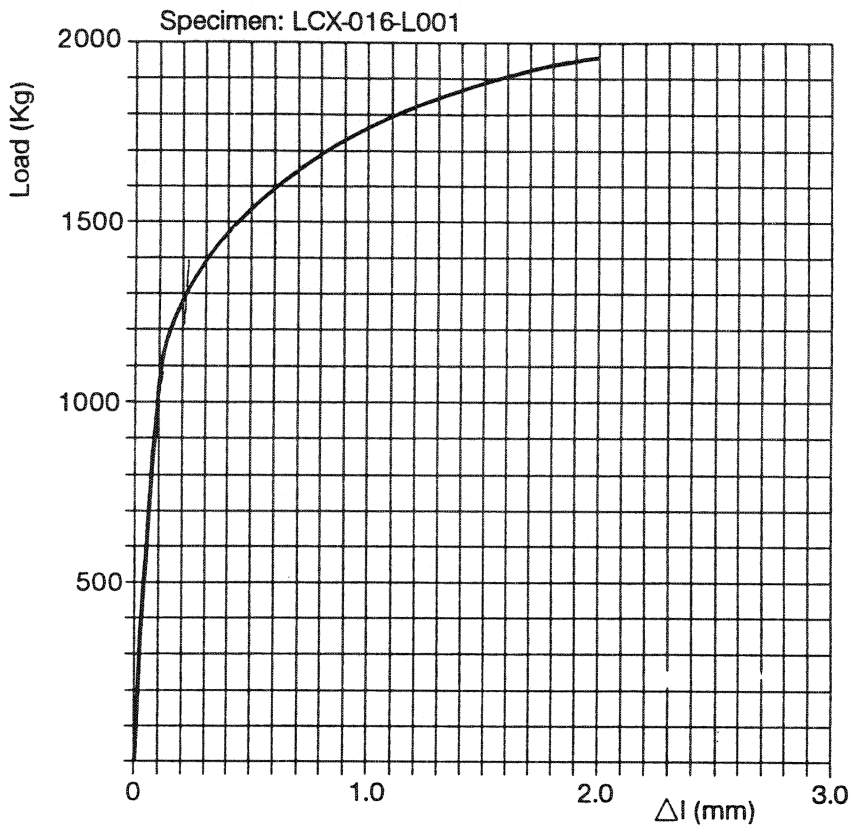
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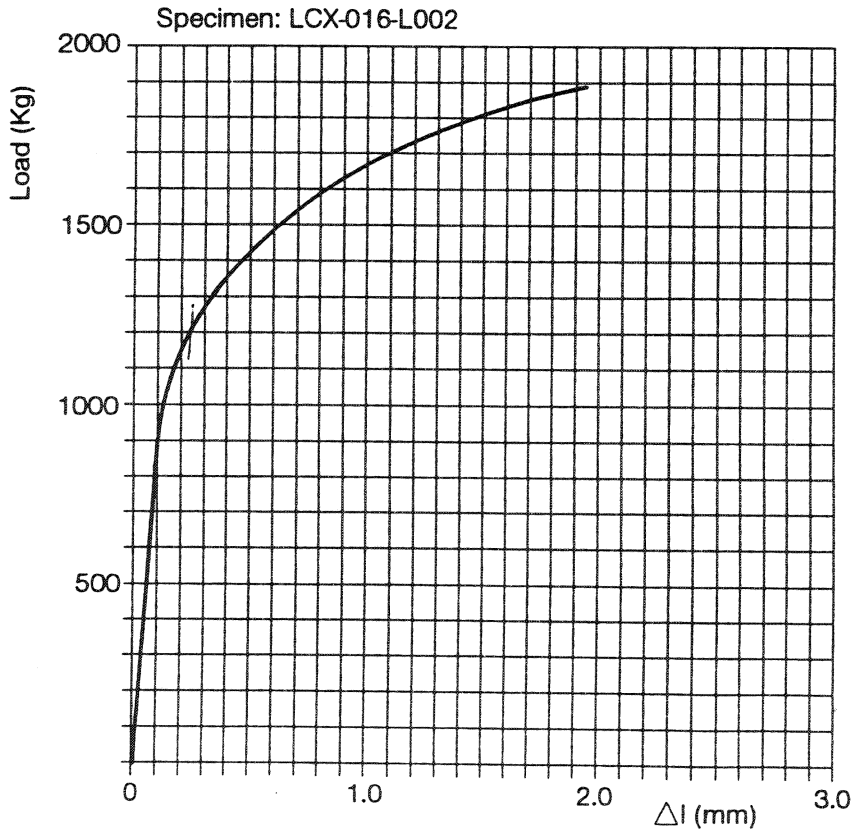
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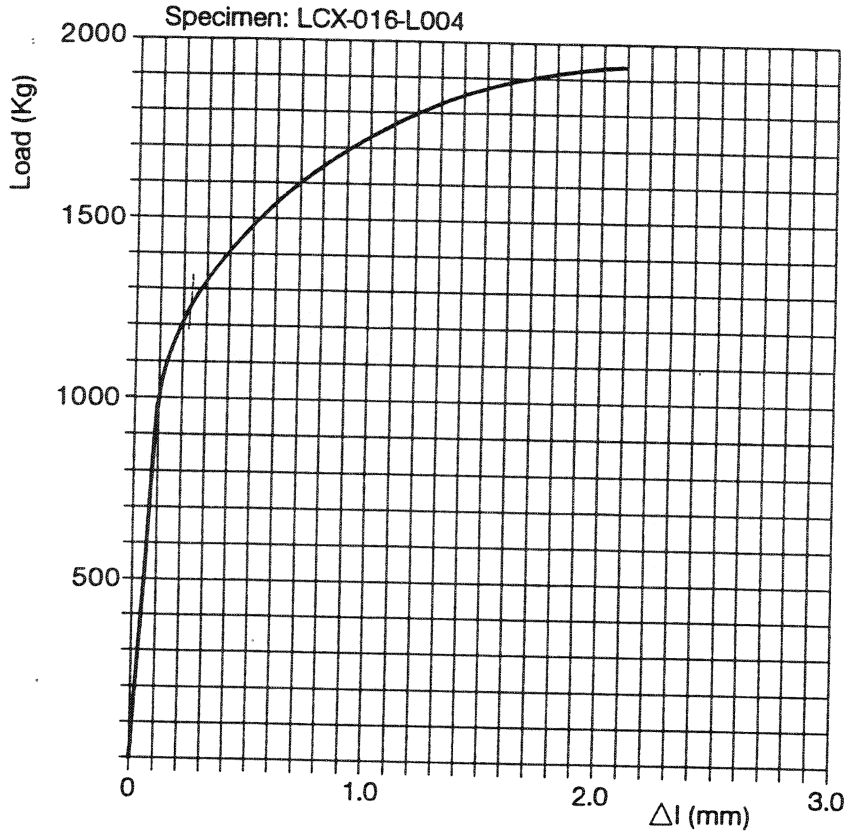
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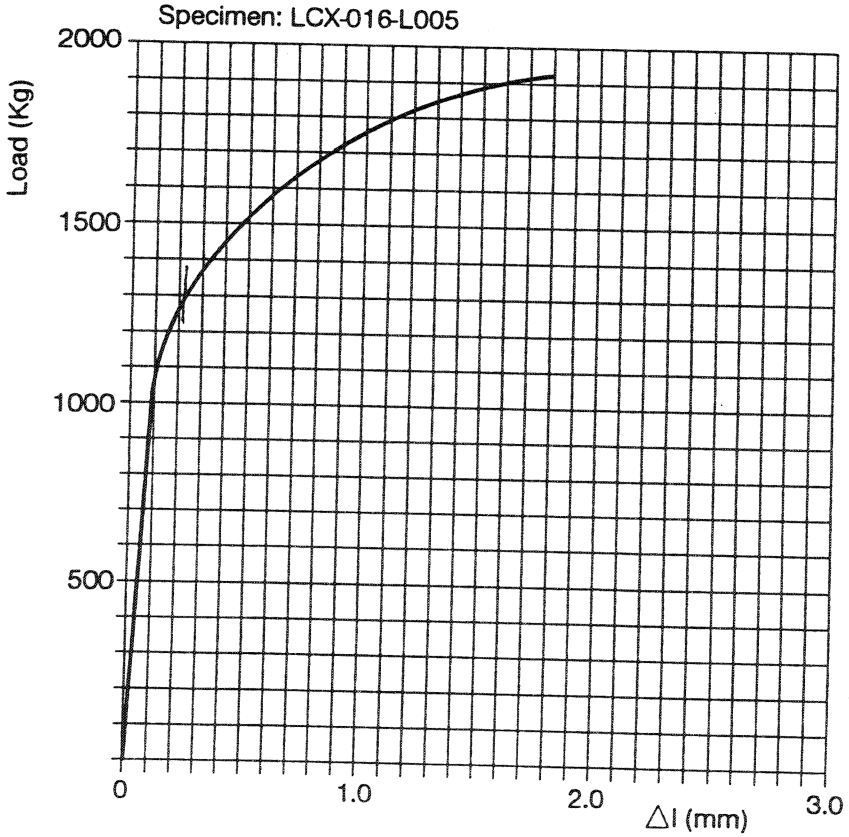
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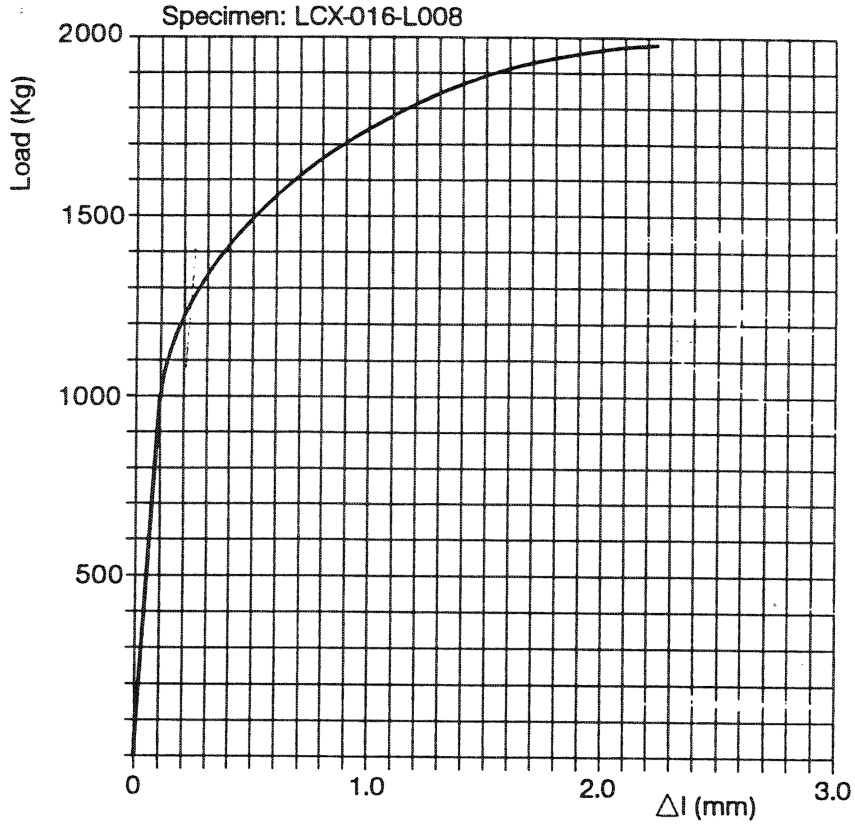
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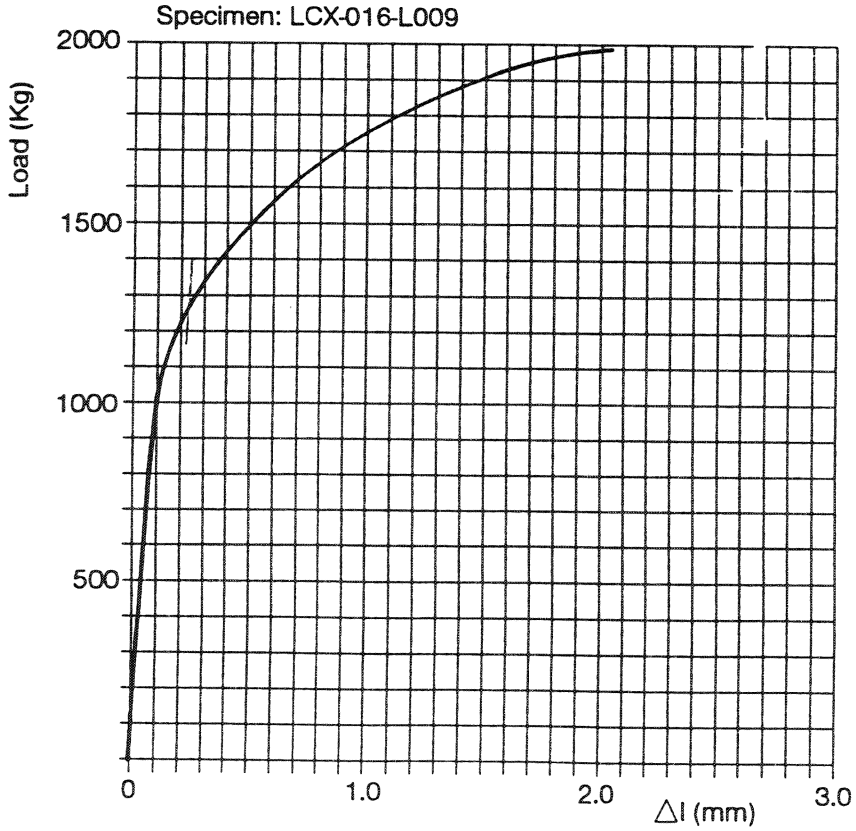
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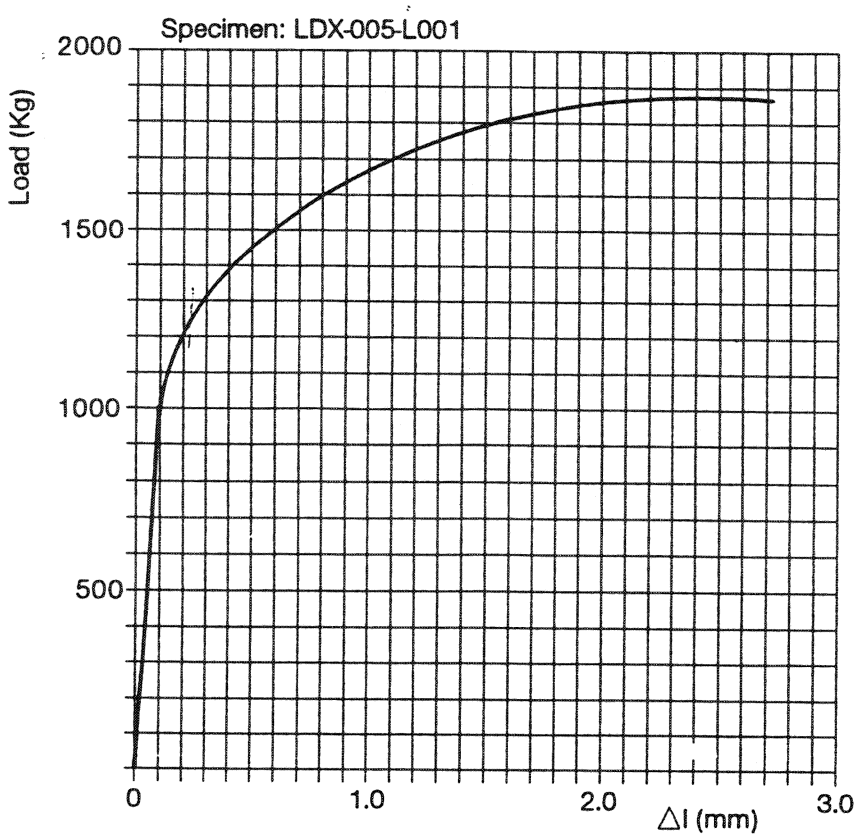
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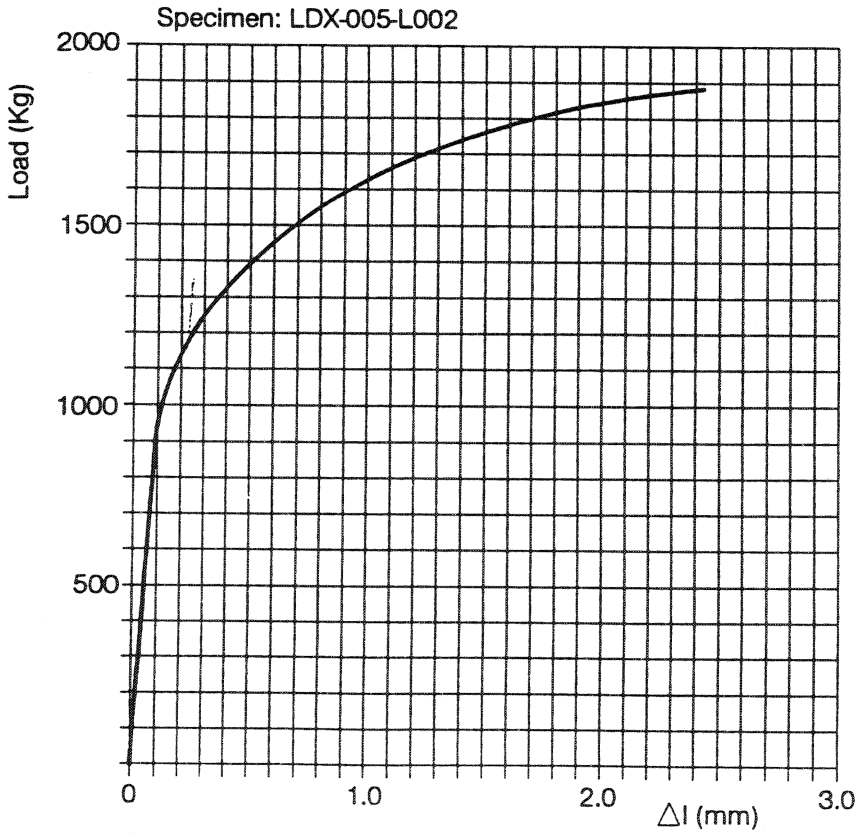
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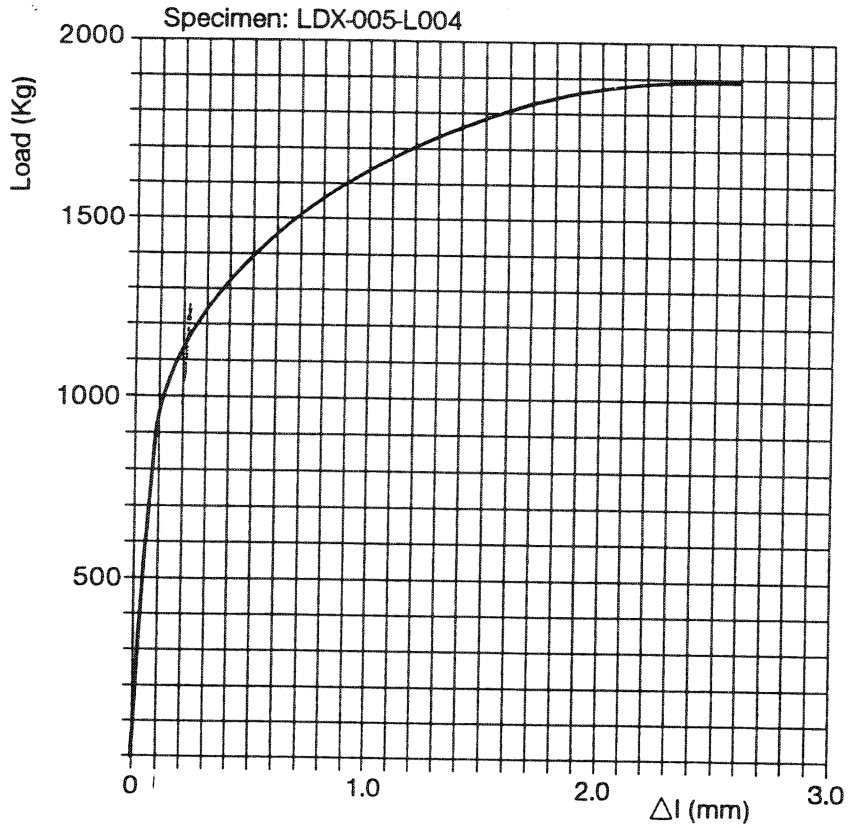
Load (Kg)
2000
1500
1000
500
0
1.0
2.0
3.0
△l (mm)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Load (Kg)
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1000
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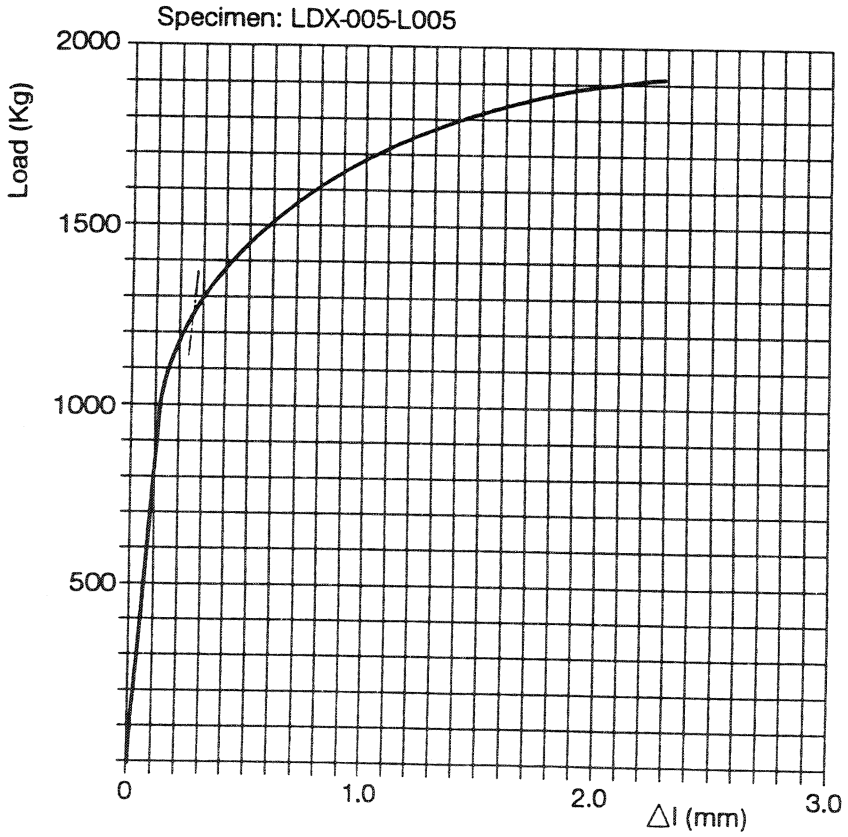
1.0
2.0
3.0
△l (mm)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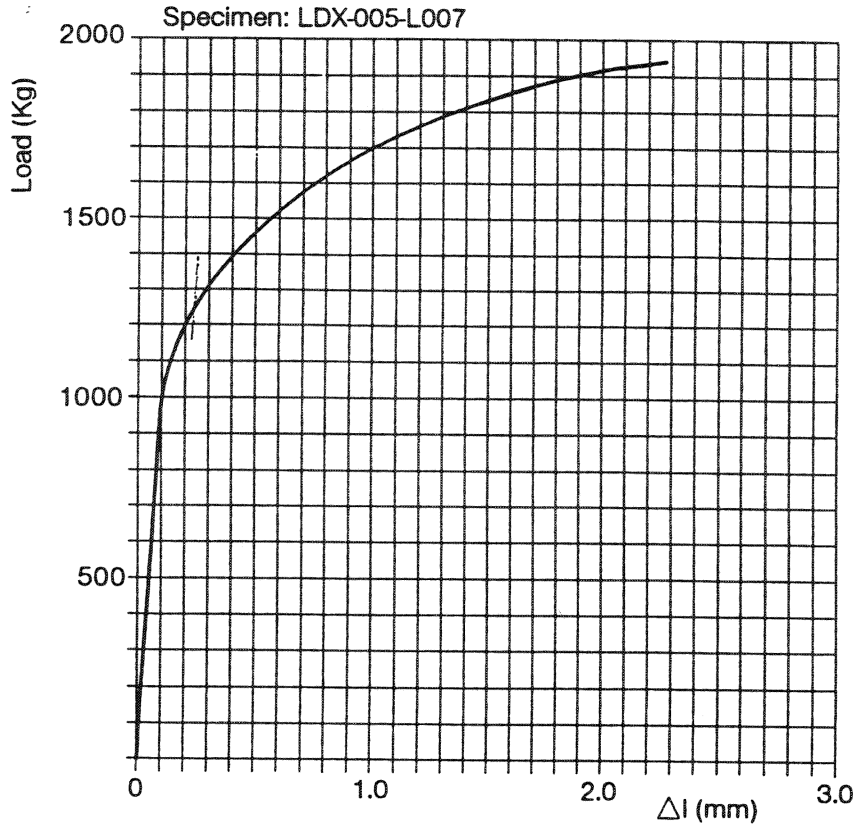
1000
500
0
1.0
2.0
3.0
△l (mm)


Specimen: LDX-005-L007
Load (Kg)
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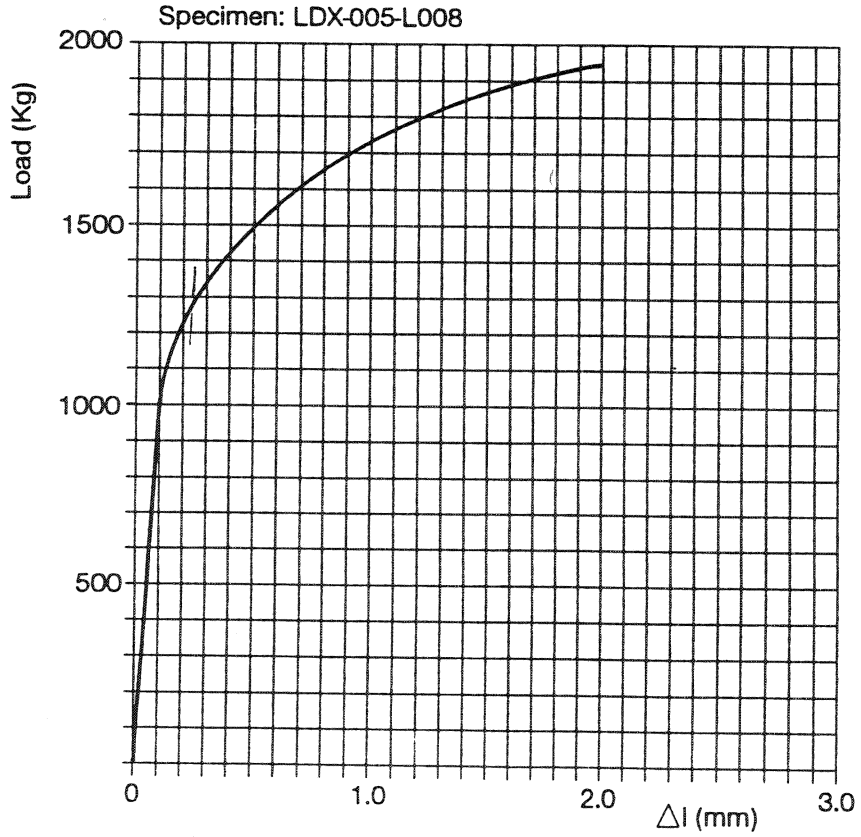
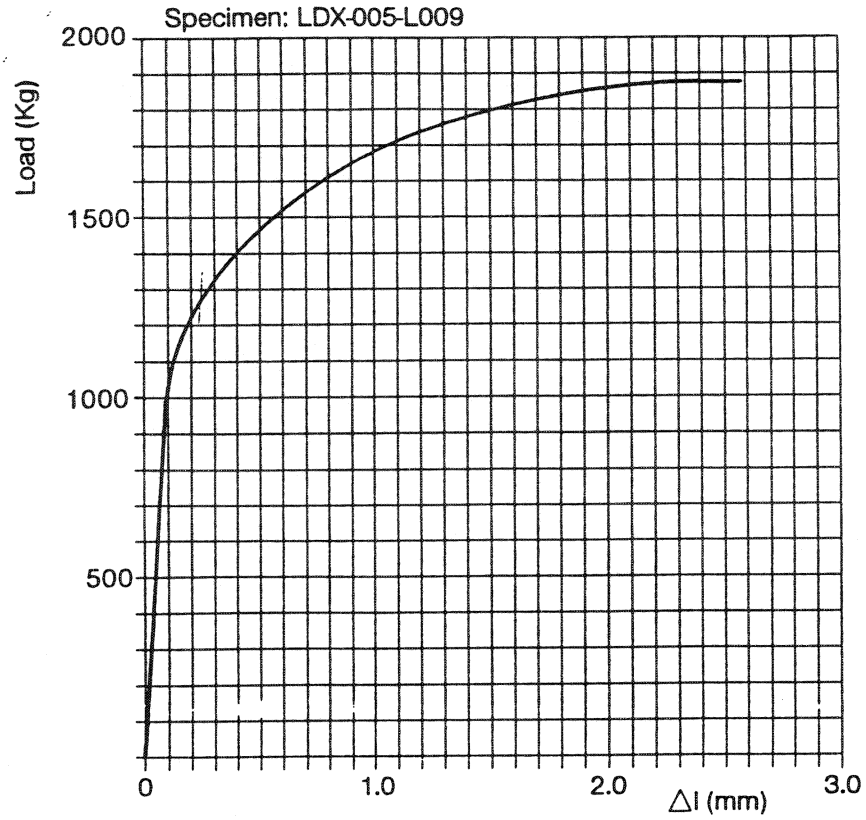
1500
1000
500
0
1.0
2.0
3.0
△l (mm)


Specimen: LDX-005-L008
Load (Kg)
2000
1500
1000
500
0
1.0
2.0
3.0
△l (mm)


Specimen: LDX-005-L009
Load (Kg)
2000
1500
1000
500
0
1.0
2.0
3.0
△l (mm)

ANNEX 4

RPS Nr. 247

"TEST REPORT FOR CHARACTERIZATION OF V.P.P.A. AUTOMATIC WELDING : CRACK GROWTH RATE TEST AND R-CURVE DETERMINATION"

ALENIA SPAZIO LABORATORIO

TEST REPORT

PROGRAM : MPLM

TITLE : TEST REPORT FOR CHARACTERIZATION OF VPPA AUTOMATIC WELDING : CRACK GROWTH RATE TEST AND R-CURVE DETERMINATION

SUMMARY

R-Curve Determination Tests and Crack Growth Rate Tests have been performed on specimens of 2219 T851 Alluminium alloy welded by automatic VPPA process in order to evaluate fracture mechanic properties.
Specimens have been machined according to the M(T) configuration of the Standard Method ASTM E647-91.
The starting notch has been machined : a) into the BEAD zone for the Crack Growth Rate tests, and b) into the BEAD and HAZ (Heat Affected Zone) zone for the R-Curve Determination tests.

TEST SHEET : 288

LABORATORY AREA : MECHANICAL TESTS

PREPARED : M. RUFFINATTO

CHECKED : E. BONADERO

APPROVED : A. BELMONDO

INDEX

1.0 INTRODUCTION

2.0 REFERENCE DOCUMENTS

3.0 TESTS

3.1 R-CURVE DETERMINATION TESTS

3.1.1 TEST SPECIMENS

3.1.2 TESTING MACHINE

3.1.3 RESULTS

3.2 CRACK GROWTH RATE TESTS

3.2.1 TEST SPECIMENS

3.2.2 TESTING MACHINE

3.2.3 RESULTS

1.0 INTRODUCTION

During VPPA welding process qualification, fracture mechanic tests were performed in order to support the design phase of MPLM VPPA welded primary structure.
The specimen used was the M(T) type, or Middle Cracked Tension and the starter notch was positioned into the BEAD for Crack Growth Rate Tests and into the BEAD and HAZ for R-Curve Determination Tests.
The purpose of the first kind of tests was to analyse the crack behaviour and the propagation rate into the BEAD zone of welded specimens loaded by sinusoidal cyclic force.
The aim of the second kind of tests was to analyze the behaviour of welded material in two critical zones as BEAD and HAZ under increasing loads.

2.0 REFERENCE DOCUMENTS

Requirements and test procedures are listed below :

[2.1] - MLM-PL-AI-0012 : Test Plan for the Characterization of the MPLM Primary Structure VPPA Welding

[2.2] - ASTM E 561-92a : Standard Practice for R-Curve Determination

[2.3] - PRS 015 : Procedura di Utilizzo della Macchina MTS per la Determinazione della Curva R su Provini di Tipo Middle Cracked Tension : M(T)

[2.4] - ASTM E 647-91 : Standard Test Method for Measurement of Fatigue Crack Growth Rates

[2.5] - PRS 013 : Procedura di Utilizzo della Macchina MTS per Prove di Propagazione in Automatico su Provini di Tipo Middle Cracked Tension : M(T)

3.0 TESTS

3.1 R-CURVE DETERMINATION

3.1.1 TEST SPECIMENS

The specimens have been machined from automatic welded plates according the to ASTM E 647-91 M(T) type, with the bead perpendicular to the load application line (see fig. 3.1.1-1 and fig. 3.1.1-2).
The starter notch was machined into the bead and into the haz to compare the responses of these two different zones under an increasing load.
Specimens identification is shown in the document [2.1] and each specimen is marked with : a) the identification mark of the belonging sample, b) the letter -D- to specify the kind of test, R-Curve determination, and a sequential number.

3.1.2 TESTING MACHINE

The testing machine was an Hydraulic Testing Machine MTS 810 with the following set up:

- Load Cell - f.s. 250 KN
- Clip On Displacement Gage (C.O.D.) - f.s. 3 mm

3.1.3 TESTS RESULTS

The results of the tests are contained in tab. 1 to 12.
The following values are summarized:

- a) applied test load [N]
- b) C.O.D. knife displacement [mm]
- c) crack length [mm]
- d) applied K_r [MPa√mm]

Specimen data are listed at the bottom of each table.
Fig. 3.1.3-1 shows the summary of tests results in terms of fracture toughness for HAZ and BEAD.

Tab.1 : specimen LAY 001-D001 - starter notch into the BEAD

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
10000	.0201	80.836	87.20956
25000	.0501	80.63548	217.6273
40000	.0801	80.58784	348.053
55000	.1101	80.56458	478.4717
70000	.1401	80.55145	608.8913
85000	.1707	80.63472	739.9276
100000	.204	81.67992	878.7938
115000	.2667	90.50383	1093.812
125000	.3207	97.76016	1268.214
135000	.3771	104.0321	1448.677
140000	.4191	109.2198	1574.547
145000	.4458	111.2318	1661.085
150000	.5013	117.5664	1822.725
155000	.5727	125.1992	2027.541
165000	.6906	134.597	2376.787

Modulo Elastico : 62500
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 001_D001

ALENIA SPAZIO

Tab.2 : specimen LAY 001-D002 - starter notch into the BEAD

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0294	80.219	130.0829
30000	.0597	81.08292	262.2156
45000	.0897	81.19506	393.7236
60000	.1293	86.48867	550.5941
75000	.1773	92.99509	729.3466
90000	.2322	99.33129	925.9894
105000	.2964	106.0035	1146.943
115000	.3363	108.6526	1286.711
125000	.3945	114.4176	1474.76
135000	.4518	118.8808	1661.019
145000	.545	127.7003	1944.671
150000	.5622	127.5694	2009.078
155000	.6408	134.8607	2239.042
160000	.6615	134.8649	2311.371
165000	.7629	143.0852	2612.773

Modulo Elastico : 63500
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 001_D002

ALENIA SPAZIO

Tab.3 : specimen LAY 001-D003 - starter notch into the BEAD

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0285	78.178	127.6816
30000	.0564	77.49163	253.7599
45000	.0849	77.57555	380.9334
60000	.1221	82.58186	531.5943
75000	.165	87.91972	697.1057
90000	.2142	93.47713	878.976
105000	.2721	99.65414	1083.437
115000	.3123	103.1157	1223.943
125000	.3612	107.7529	1387.209
135000	.4119	111.8553	1555.419
145000	.4938	120.2041	1806.741
150000	.5076	119.8182	1862.15
155000	.5526	123.6901	1997.656
160000	.6111	128.9109	2172.29
165000	.6516	131.4282	2298.839
170000	.7479	139.4643	2582.681

Modulo Elastico : 63500
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 001 D003

ALENIA SPAZIO

Tab.4 : specimen LAY 002-D004 - starter notch into the BEAD

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0276	77.912	127.371
30000	.0555	78.115	255.217
45000	.0831	78.115	382.825
60000	.1188	82.619	531.771
75000	.1605	87.941	697.238
90000	.2094	93.857	881.951
105000	.2661	100.07	1087.47
115000	.3036	103.093	1223.695
125000	.3465	106.736	1374.476
135000	.4008	111.903	1556.104
145000	.4617	117.219	1756.205
150000	.5085	121.987	1901.422
155000	.5268	122.181	1968.499
160000	.5778	126.786	2126.247
165000	.6327	131.317	2296.184
170000	.738	140.534	2614.035
175000	.7578	140.417	2687.346

Modulo Elastico : 65300
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 002_d004

ALENIA SPAZIO

Tab.5 : specimen LAY 002-D005 - starter notch into the BEAD

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0288	80.396	130.2925
30000	.0585	81.28399	262.6941
45000	.0879	81.39877	394.4513
60000	.1257	86.15021	548.9279
75000	.1722	92.57797	726.6459
90000	.2244	98.53631	919.4494
105000	.2859	105.0516	1137.135
115000	.3285	108.6431	1286.6
125000	.3804	113.4309	1461.312
135000	.4407	118.7636	1659.169
145000	.5148	125.1482	1895.776
150000	.5469	127.1632	2000.898
155000	.6063	132.4661	2183.005
160000	.6393	134.0594	2291.607
165000	.7296	141.5436	2566.543

Modulo Elastico : 65000
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 002_D005

ALENIA SPAZIO

Tab.6 : specimen LAY 002-D006 - starter notch into the BEAD

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.03	81	131.0092
30000	.0603	81.22131	262.5449
45000	.0903	81.22131	393.8173
60000	.1293	85.94263	547.908
75000	.1779	92.66882	727.2332
90000	.2334	99.12788	924.311
105000	.2991	106.0884	1147.823
115000	.3351	107.7914	1276.678
125000	.3906	113.0657	1456.38
135000	.4542	118.6827	1657.893
145000	.5292	124.8707	1890.586
150000	.5799	129.2307	2043.161
155000	.6078	130.305	2134.61
160000	.6969	138.1433	2395.268
165000	.7326	139.5557	2509.292
170000	.9339	154.5959	3113.686

Modulo Elastico : 63000
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 002_D006

ALENIA SPAZIO

Tab.7 : specimen LAY 003-D007 - starter notch into the HAZ

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0254	76.107	125.2712
30000	.0512	76.46568	251.3738
45000	.077	76.63251	377.6414
65000	.1218	82.6192	576.088
85000	.1784	90.44203	808.0252
100000	.2256	95.60626	995.3082
110000	.2664	100.7872	1146.572
120000	.299	102.8921	1274.598
130000	.3434	107.2528	1436.168
140000	.3926	111.7605	1611.62
150000	.4524	117.2833	1817.86
160000	.5148	122.2059	2032.489
170000	.5814	126.8393	2260.335
180000	.6786	134.1757	2581.246
190000	.7914	141.5364	2955.168
200000	.954	151.1712	3498.872

Modulo Elastico : 69000
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 003_D007

ALENIA SPAZIO

Tab.8 : specimen LAY 003-D008 - starter notch into the HAZ

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0282	81.01	131.0211
30000	.0573	81.92729	264.2291
45000	.0861	82.04235	396.7563
60000	.1206	85.38499	545.1754
75000	.1629	90.78672	715.1552
90000	.2151	97.65921	912.2932
105000	.2661	101.9654	1106.051
120000	.3297	107.9973	1334.679
135000	.4083	115.2607	1605.31
150000	.4989	122.4899	1910.719
165000	.6003	129.294	2248.928
175000	.6924	135.5858	2547.71
185000	.8028	142.3776	2905.448
195000	.9588	151.2337	3414.182
200000	1.2255	165.5109	4329.295
205000	1.2513	165.3149	4422.66

Modulo Elastico : 67000
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 003_D008

ALENIA SPAZIO

Tab.9 : specimen LAY 003-D009 - starter notch into the HAZ

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0282	80.869	130.8535
30000	.057	81.57259	263.382
45000	.0855	81.57259	395.073
60000	.1212	85.72743	546.8522
75000	.1644	91.43357	719.2849
90000	.2142	97.35427	909.8195
105000	.2697	102.9644	1115.997
120000	.3348	109.1541	1348.803
135000	.4074	115.0911	1602.769
150000	.4965	122.1235	1903.936
165000	.6069	130.1183	2267.972
175000	.7008	136.4836	2572.589
185000	.8154	143.5064	2943.965
195000	.9912	153.5082	3518.938
200000	1.3737	172.0621	4894.104
205000	1.3995	171.76	4985.609

Modulo Elastico : 67000
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 003_D009

ALENIA SPAZIO

Tab.10 : specimen LAY 004-D010 - starter notch into the HAZ

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0282	80.869	130.8535
30000	.0564	80.869	261.7071
45000	.0849	81.10441	393.4001
60000	.1212	85.7281	546.8554
75000	.1635	91.04439	716.7975
90000	.2127	96.84308	905.689
105000	.2688	102.7169	1113.523
120000	.3306	108.2001	1337.141
135000	.4119	115.9263	1615.336
150000	.4938	121.7089	1896.309
165000	.6006	129.331	2249.775
175000	.6927	135.6181	2548.599
185000	.8187	143.7973	2954.061
195000	.9852	153.0962	3499.442

Modulo Elastico : 67000
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 004_D010

ALENIA SPAZIO

Tab.11 : specimen LAY 004-D011 - starter notch into the HAZ

Laboratorio

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0279	80.304	130.183
30000	.0567	81.223	262.548
45000	.0852	81.338	394.236
60000	.1239	87.247	554.343
75000	.1668	92.464	725.912
90000	.2151	97.661	912.305
105000	.2721	103.621	1122.591
120000	.3339	108.951	1346.31
135000	.4074	115.093	1602.804
150000	.4977	122.306	1907.316
165000	.5976	128.954	2241.148
175000	.6978	136.164	2563.667
185000	.8196	143.875	2956.759
195000	1.017	155.243	3603.716
200000	1.0494	155.643	3716.874

Modulo Elastico : 67000
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 004_d011

ALENIA SPAZIO

Tab.12 : specimen LAY 004-D012 - starter notch into the HAZ

Laboratorio

Curva Erre su provini tipo M(T)

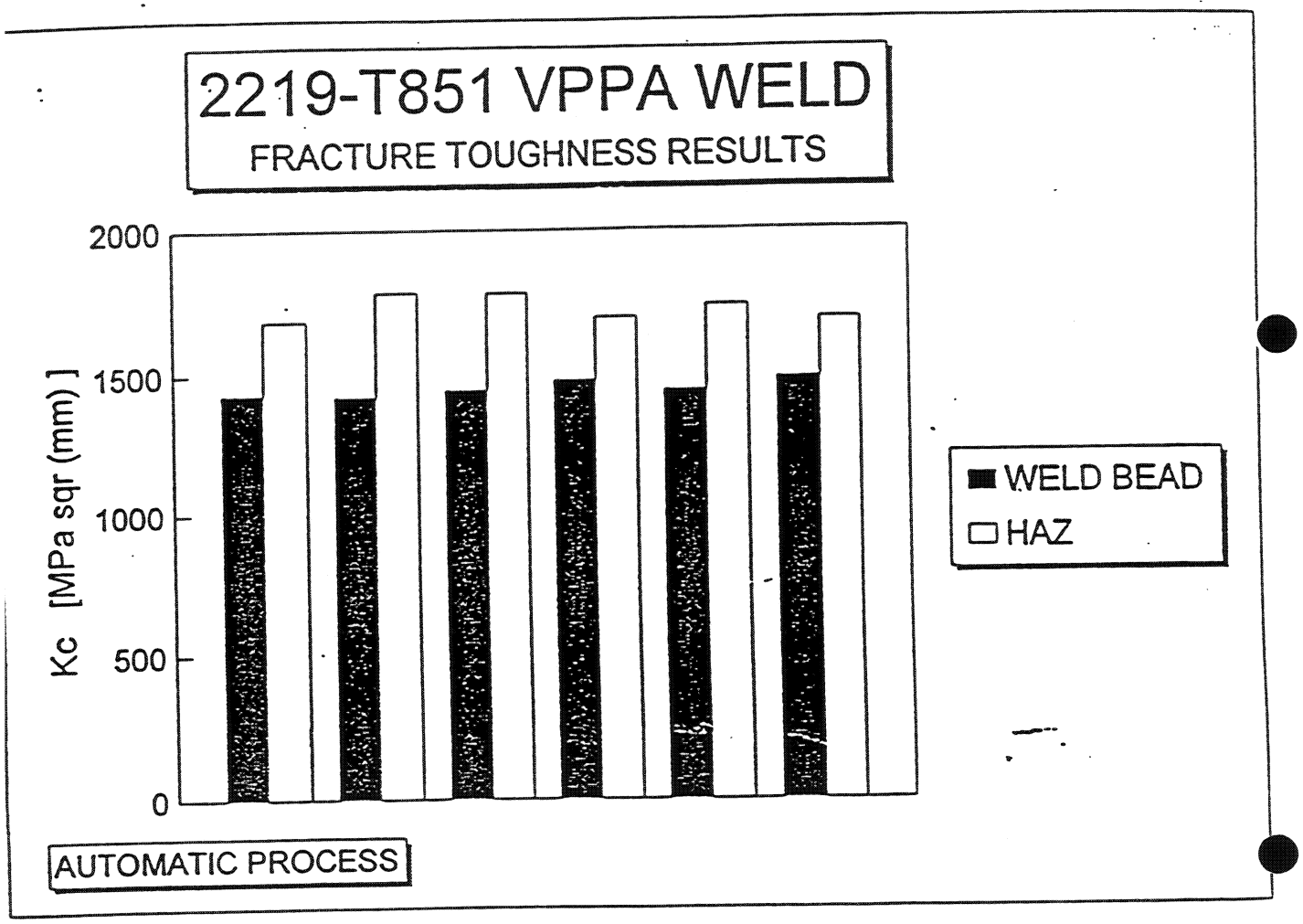
Carico	C.O.D.	2a	K r
15000	.0277	80.316	130.198
30000	.0567	81.72	263.733
45000	.0855	82.074	396.87
60000	.1239	87.763	556.905
75000	.1674	93.254	731.03
90000	.2145	97.998	915.048
105000	.2712	103.929	1125.7
120000	.333	109.308	1350.701
135000	.3984	113.962	1586.004
150000	.4893	121.576	1893.885
165000	.594	129.058	2243.528
175000	.6909	135.979	2558.542
185000	.8028	142.917	2923.728
195000	.9606	151.872	3442.904

Modulo Elastico : 67500
Spessore Provino : 7.2 [mm]
Larghezza Provino : 200 [mm]

File : 004_d012

ALENIA SPAZIO

Fig. 3.1.3-1 : fracture toughness results summary



3.2 CRACK GROWTH TESTS

3.2.1 TEST SPECIMEN

The specimens have been machined from automatic welded plates according to the ASTM E 647-91 M(T) type, with the bead perpendicular to the load application line (see fig. 3.2.1-1).
The starter notch was machined into the bead.
Specimens identification is shown in the document [2.1] and each specimen is marked with : a) the identification mark of the belonging sample, b) the letter -E- to specify the kind of test, Crack Growth Rate, and an increasing number.

3.2.2 TESTING MACHINE

The testing machine was an Hydraulic Testing Machine MTS 810 with the following set up:

- Load Cell - f.s. 125 KN
- Clip On Displacement Gage (C.O.D.) - f.s. 3 mm

3.2.3 TEST RESULTS

For each test the crack length and cycles were recorded and processed to obtain da/dN vs Delta K values.
da/dN vs Delta K curves are shown in fig. 3.2.3-1,2,3,4,5,6, while data lists are contained in annex 1,2,3,4,5,6.

Fig. 3.1.1-1 : Drawing Lab-0049
R-Curve Determination M(T) welded specimen

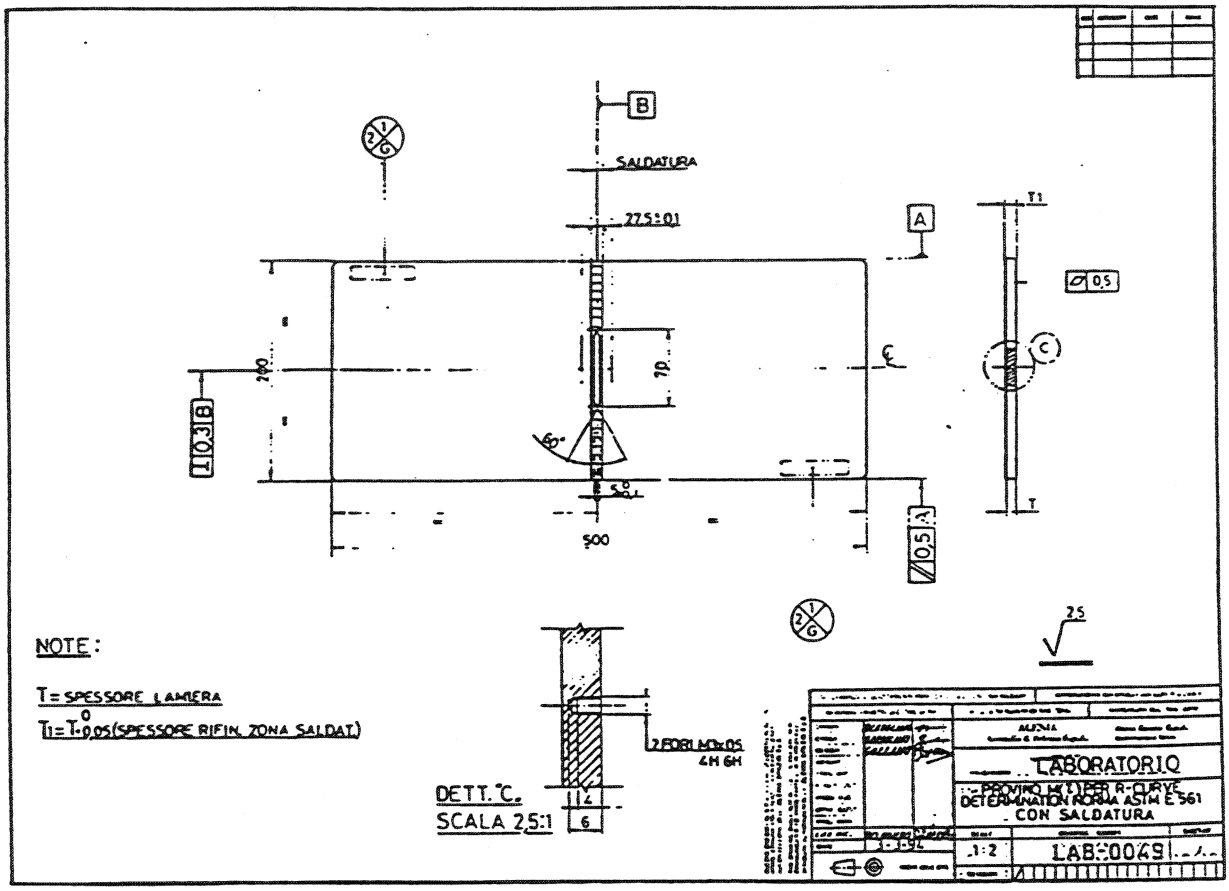


Fig. 3.1.1-2 : Drawing Lab-0050
R-Curve Determination M(T) welded specimen

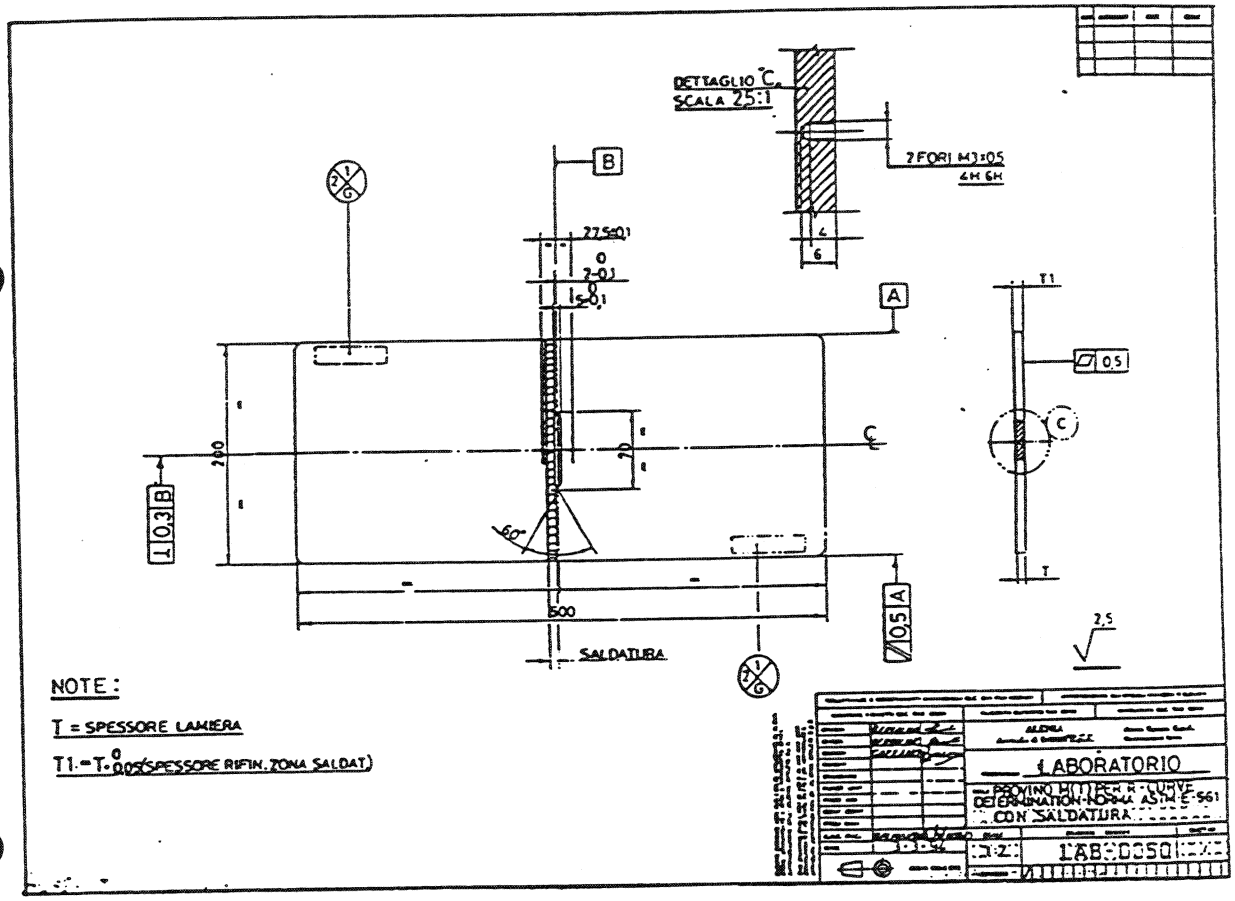


Fig. 3.2.1-1 : Drawing Lab-0051
Crack Growth Rate M(T) welded specimen

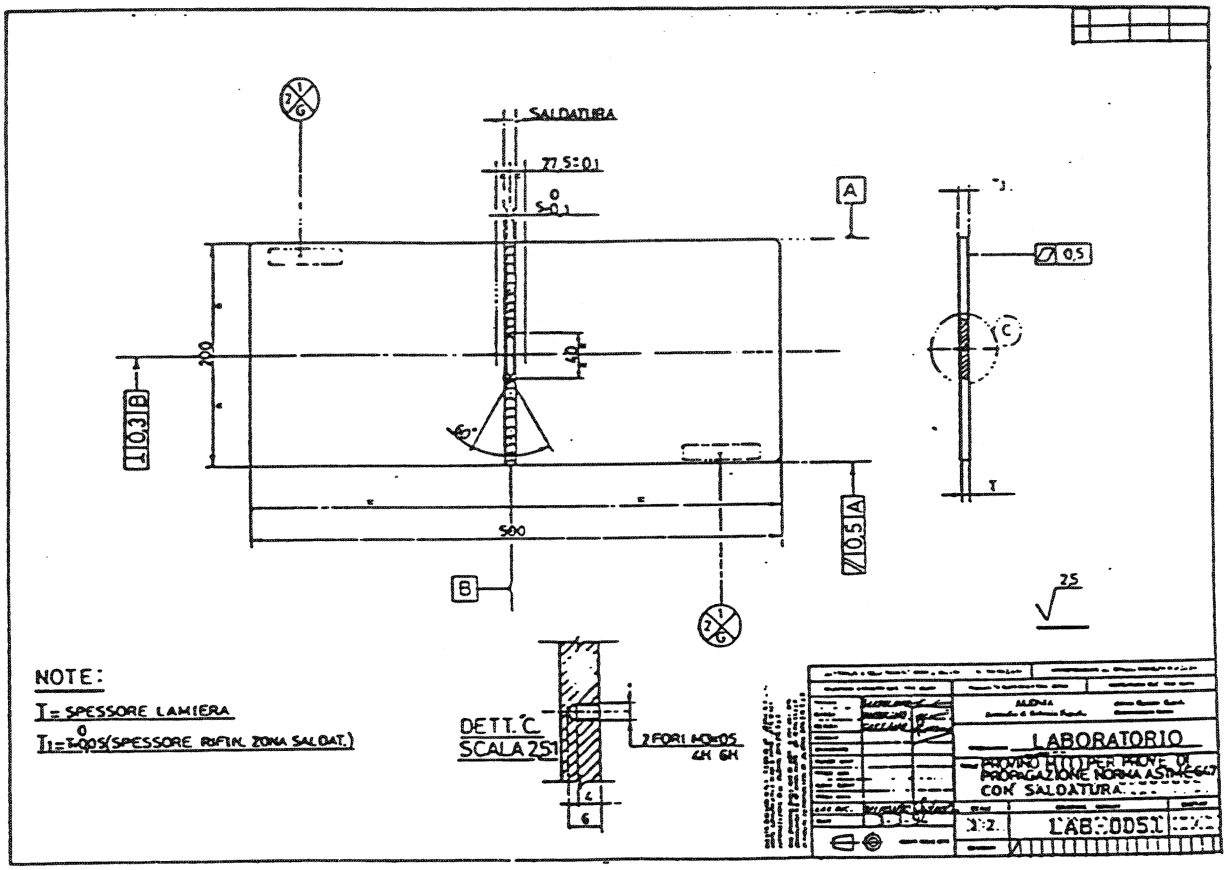


Fig.3.2.3-1 : specimen LAY 005-E002

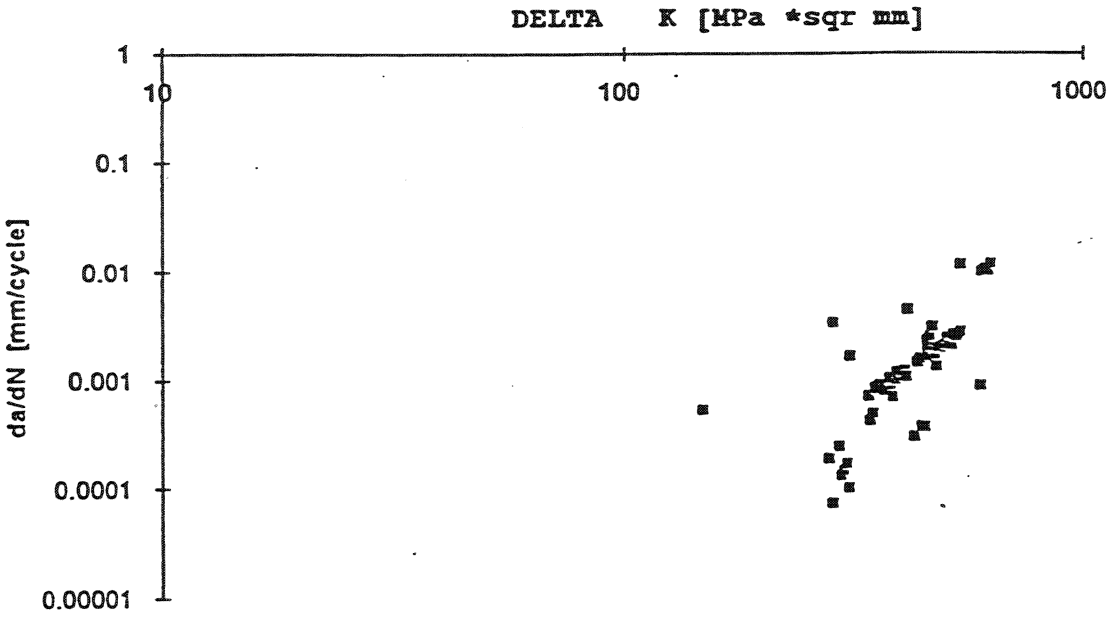


Fig.3.2.3-2 : specimen LAY 005-E003

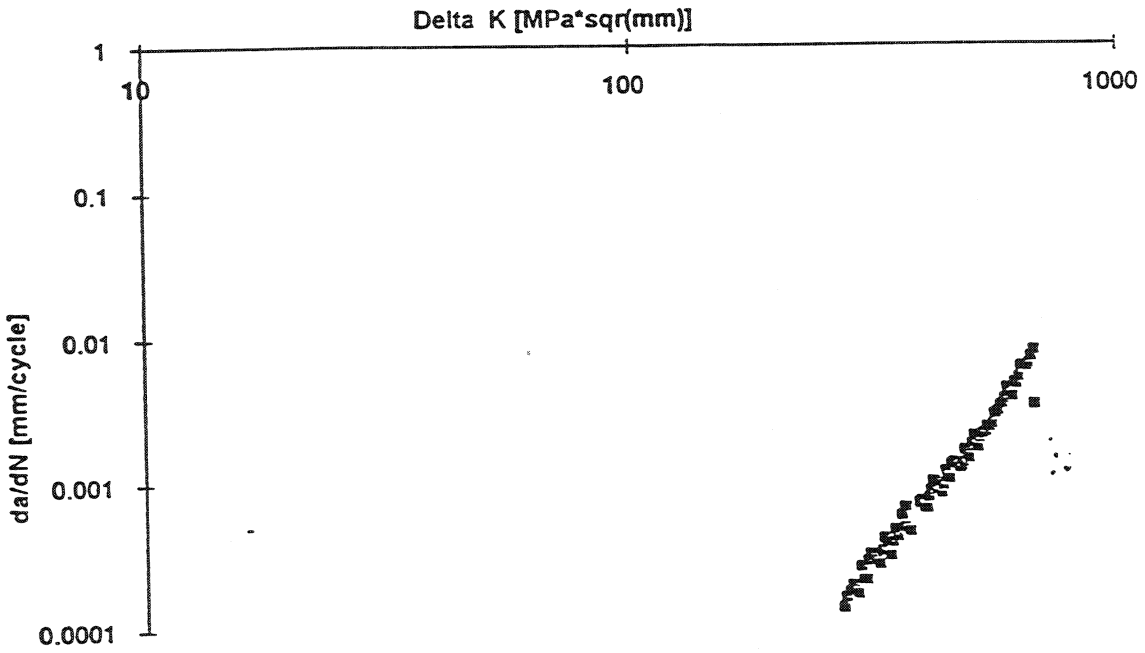


Fig.3.2.3-3 : specimen LAY 006-E001

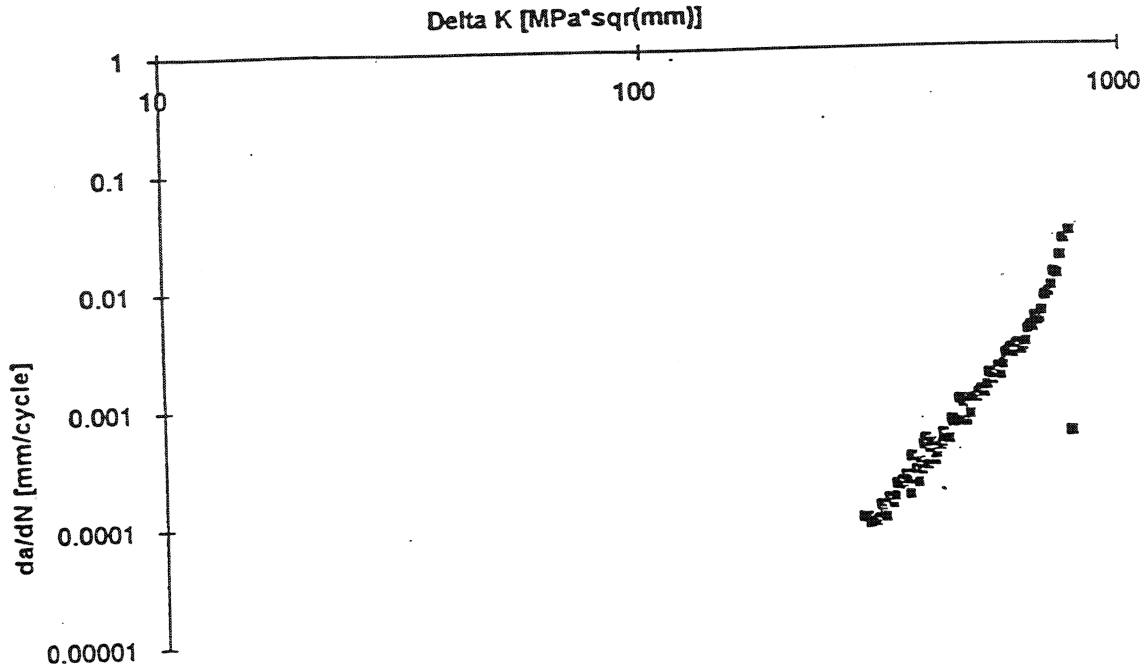


Fig.3.2.3-4 : specimen LAY 006-E002

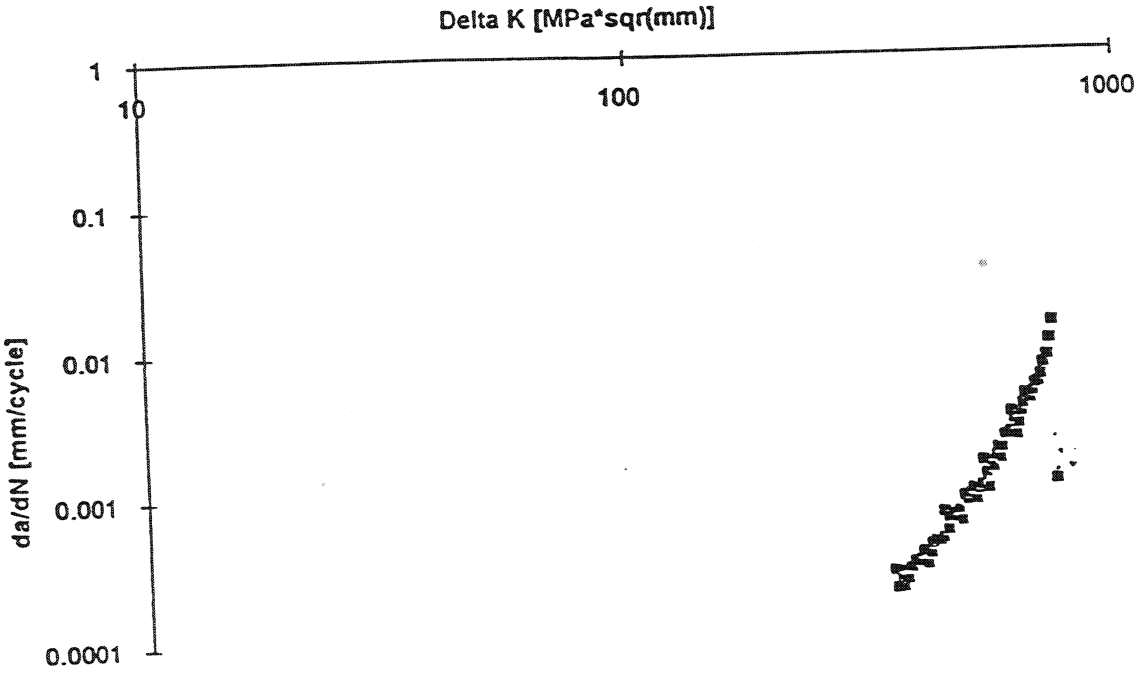


Fig.3.2.3-5 : specimen LAY 006-E003

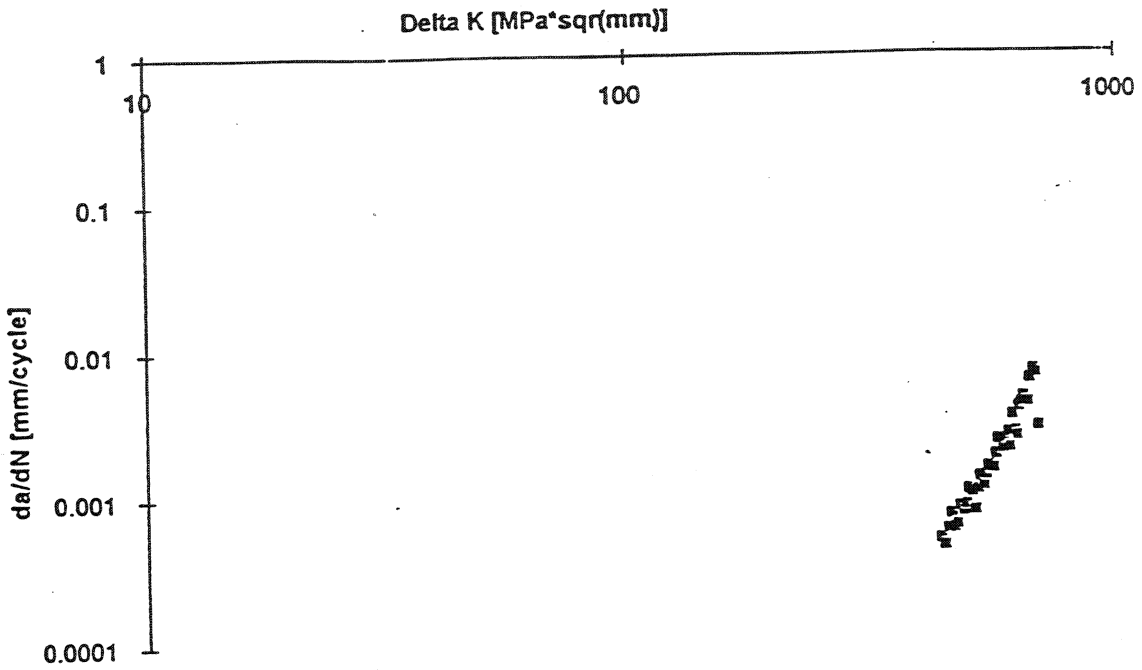
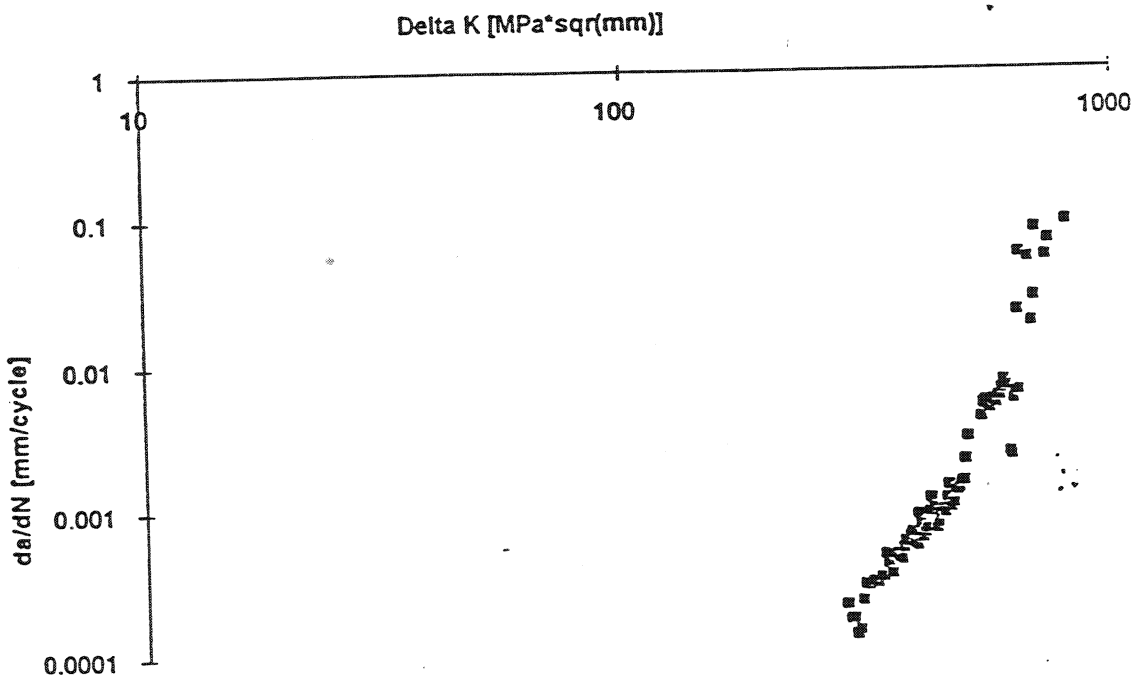


Fig.3.2.3-6 : specimen LAY 007-E007



ANNEX

ANNEX 1

File: 006_E001.DAT

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
NPTS = 82				
4607	23.449	50109.859	0.000E+00	277.588
11483	24.065	50109.859	1.043E-04	281.741
16360	24.675	50109.859	1.032E-04	285.844
23292	25.284	50109.859	9.173E-05	290.314
29587	25.889	50109.859	9.747E-05	294.358
35656	26.489	50109.859	9.453E-05	298.770
42256	27.086	50109.859	1.000E-04	302.344
47256	27.649	50170.898	1.294E-04	306.504
51169	28.240	50170.898	1.078E-04	310.437
58175	28.826	50170.898	1.028E-04	314.336
62535	29.408	50170.898	1.477E-04	317.780
66263	30.021	50109.859	1.441E-04	321.851
70545	30.563	50170.898	1.328E-04	325.457
74642	31.133	50170.898	1.533E-04	329.255
77972	31.701	50170.898	1.937E-04	332.593
80657	32.290	50109.859	1.927E-04	336.577
83801	32.824	50170.898	2.056E-04	340.556
85912	33.379	50170.898	1.872E-04	344.278
89915	33.969	50109.859	2.272E-04	347.777
90754	34.479	50170.898	2.085E-04	351.693
94980	35.025	50170.898	1.577E-04	355.391
97871	35.601	50109.859	3.327E-04	358.823
99927	36.671	50109.859	2.546E-04	366.129
104149	37.200	50109.859	1.976E-04	369.766
105255	37.724	50109.859	2.949E-04	373.384
107693	38.245	50109.859	2.506E-04	377.003
109400	38.762	50109.859	4.103E-04	380.610
110203	39.275	50109.859	4.636E-04	384.206
111603	39.783	50109.859	2.747E-04	387.791
113895	40.289	50109.859	3.811E-04	391.378
114352	40.831	50048.828	4.264E-04	395.244
117294	41.739	50170.898	3.011E-04	402.321
119125	42.269	50109.859	3.434E-04	405.626
121531	43.193	50170.898	4.014E-04	413.532
122723	43.713	50109.859	4.259E-04	416.263
123963	44.229	50048.828	5.121E-04	419.551
125475	45.122	50109.859	4.659E-04	426.862
126964	45.627	50048.828	4.594E-04	430.137
128373	46.453	50170.898	6.661E-04	437.098
129011	46.991	50048.828	6.258E-04	440.699
130583	47.836	50109.859	6.463E-04	447.376
131673	48.711	50109.859	1.000E-03	454.397
132362	49.615	50048.828	9.300E-04	461.777
133554	50.461	50048.828	6.377E-04	468.163
134921	51.247	50109.859	7.385E-04	476.093
135787	52.110	50048.828	9.888E-04	482.212
136606	52.913	50048.828	1.002E-03	489.911
137377	53.703	50048.828	1.098E-03	496.282
137989	54.431	50109.859	1.170E-03	503.583
138690	55.239	50048.828	1.102E-03	511.065

139402	55.988	50048.828	1.279E-03	517.442
139851	56.724	50048.828	1.638E-03	524.528
140292	57.446	50048.828	1.408E-03	531.612
140835	58.110	50109.859	1.578E-03	538.989
141184	58.853	50048.828	1.813E-03	545.849
141624	59.540	50048.828	1.548E-03	553.008
142062	60.213	50048.828	1.902E-03	560.166
142301	60.828	50109.859	2.343E-03	567.612
142622	61.525	50048.828	2.425E-03	573.782
142833	62.118	50109.859	2.601E-03	582.066
143127	62.838	49987.789	2.377E-03	589.604
143376	63.409	50048.828	2.800E-03	596.345
143547	64.014	50048.828	2.879E-03	602.827
143895	64.903	50048.828	2.514E-03	614.652
144149	65.528	49987.789	2.715E-03	622.606
144318	66.051	50048.828	2.989E-03	628.562
144527	66.658	49987.789	3.777E-03	635.744
144624	67.207	49987.789	4.076E-03	643.195
144794	67.746	49987.789	3.951E-03	651.552
144895	68.278	49987.789	4.899E-03	658.196
145018	68.843	49926.762	4.458E-03	665.483
145137	69.356	49926.762	4.603E-03	673.083
145239	69.860	49926.762	5.440E-03	680.714
145357	70.553	49987.789	7.365E-03	692.432
145437	71.319	49926.762	7.845E-03	703.788
145544	72.020	49926.762	8.913E-03	715.463
145572	72.522	49865.719	1.163E-02	723.064
145641	73.148	49926.762	1.132E-02	734.081
145689	73.846	49865.719	1.608E-02	745.750
145724	74.483	49865.719	2.245E-02	757.730
145765	75.553	49804.691	2.609E-02	777.735
145765	75.553	49804.691	5.183E-04	777.735

ANNEX 2

File: 006_E002.DAT 14-06-94 6:20:04 pm Page 1

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
NPTS = 64				
1268	31.622	50048.828	0.000E+00	332.065
2433	32.153	50048.828	2.850E-04	335.608
5293	32.769	50048.828	2.168E-04	339.724
7684	33.292	50048.828	2.816E-04	343.227
8999	33.813	50048.828	2.460E-04	346.727
11898	34.329	50048.828	2.203E-04	349.726
13674	34.843	50048.828	2.427E-04	353.196
16111	35.351	50048.828	2.499E-04	357.121
17736	35.858	50048.828	2.960E-04	360.569
19522	36.361	50048.828	2.988E-04	364.004
22748	37.355	50048.828	3.287E-04	370.333
25529	38.335	50048.828	3.387E-04	377.629
28379	39.263	50109.859	3.746E-04	384.639
29388	39.781	50048.828	3.880E-04	387.245
31042	40.296	49987.789	3.138E-04	390.361
33886	41.192	50048.828	3.701E-04	397.834
34830	41.697	49987.789	4.323E-04	400.934
37085	42.575	50048.828	4.545E-04	407.867
38749	43.479	50048.828	4.500E-04	414.523
40977	44.327	50109.859	4.729E-04	420.852
41653	44.852	49987.789	7.258E-04	424.236
42780	45.635	50109.859	5.338E-04	431.367
44087	46.151	49987.789	6.492E-04	433.574
44819	46.959	50048.828	6.584E-04	440.449
46583	47.794	50048.828	6.959E-04	447.648
47202	48.618	50048.828	7.324E-04	454.255
48873	49.472	49987.789	6.226E-04	459.968
49783	50.225	50048.828	9.178E-04	467.459
50548	51.009	50048.828	8.543E-04	473.421
51657	51.825	49987.789	9.484E-04	479.752
52211	52.586	49987.789	1.035E-03	486.365
53068	53.286	50048.828	8.694E-04	493.221
53914	54.067	49987.789	1.010E-03	499.574
54558	54.791	49987.789	1.092E-03	506.208
55186	55.455	50048.828	1.617E-03	513.097
55430	56.201	49987.789	1.307E-03	519.478
56283	56.889	49987.789	1.034E-03	526.133
56750	57.566	49987.789	1.560E-03	532.803
57144	58.232	49987.789	1.423E-03	539.490
57646	58.841	50048.828	1.705E-03	546.464
57906	59.531	49987.789	1.950E-03	552.160
58325	60.165	49987.789	1.629E-03	559.652
58706	60.834	49926.762	1.949E-03	565.365
58982	61.446	49926.762	2.360E-03	572.116
59201	62.002	49987.789	2.383E-03	579.951
59464	62.594	49987.789	2.496E-03	586.758
59672	63.178	49987.789	3.438E-03	592.789
59814	63.798	49926.762	3.058E-03	599.381
60059	64.361	49926.762	2.342E-03	606.245
60291	64.915	49926.762	2.806E-03	613.129

60451	65.461	49926.762	3.356E-03	620.059
60627	66.042	49865.719	3.828E-03	626.734
60741	66.571	49865.719	4.494E-03	633.723
60860	67.090	49865.719	4.429E-03	640.714
60973	67.599	49865.719	4.162E-03	647.723
61103	68.101	49865.719	4.615E-03	654.780
61232	68.794	49926.762	5.239E-03	665.671
61336	69.322	49865.719	5.406E-03	671.645
61452	69.983	49926.762	6.001E-03	682.600
61531	70.492	49865.719	7.234E-03	689.575
61616	71.170	49865.719	8.184E-03	701.360
61695	71.834	49865.719	1.059E-02	711.351
61744	72.525	49804.691	1.409E-02	722.122
61744	72.525	49804.691	1.175E-03	722.122

ANNEX 3

File: 006E0031.DAT 16-06-94 1:53:16 pm Page 1

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
NPTS = 38				
2506	44.532	50048.828	0.000E+00	421.824
3766	45.407	50048.828	5.023E-04	428.453
5871	46.223	50109.859	4.499E-04	435.898
7464	47.071	50109.859	5.817E-04	442.525
8835	47.947	50048.828	7.290E-04	448.863
9793	48.769	50048.828	5.878E-04	454.860
11606	49.576	50048.828	6.192E-04	461.448
12382	50.372	50048.828	8.209E-04	468.054
13526	51.152	50048.828	7.586E-04	475.278
14427	51.923	50048.828	8.490E-04	481.247
15326	52.680	50048.828	1.081E-03	487.350
15858	53.469	49987.789	1.021E-03	494.190
16817	54.203	49987.789	7.729E-04	501 491
17679	54.877	50048.828	1.067E-03	507.694
18157	55.632	49987.789	1.305E-03	513.365
18793	56.330	49987.789	1.134E-03	520.723
19337	56.970	50048.828	1.327E-03	527.645
19817	57.689	49987.789	1.521E-03	534.038
20247	58.354	49987.789	1.469E-03	540.735
20713	59.006	49987.789	1.472E-03	547.426
21095	59.602	50048.828	1.825E-03	553.662
21411	60.280	49987.789	2.340E-03	560.123
21781	61.207	49987.789	1.992E-03	571.026
22204	61.859	49926.762	2.321E-03	576.755
22445	62.749	49926.762	2.556E-03	587.756
22762	63.285	49987.789	2.042E-03	593.251
22987	63.856	49987.789	3.391E-03	601.717
23110	64.465	49926.762	2.613E-03	607.528
23414	64.971	49987.789	2.451E-03	614.678
23557	65.561	49926.762	3.834E-03	621.339
23707	66.095	49926.762	4.112E-03	627.420
23815	66.622	49926.762	4.535E-03	635.263
23937	67.138	49926.762	4.154E-03	642.250
24062	67.648	49926.762	4.159E-03	649.290
24180	68.149	49926.762	6.012E-03	656.352
24275	68.928	49865.719	6.931E-03	665.820
24396	69.646	49865.719	6.553E-03	676.517
24456	70.114	49865.719	2.855E-03	683.688

ANNEX 4

File: 005_E002.DAT 13-09-94 3:42:32 pm Page 1

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
9	24.481	87524.406	0.000E+00	276.430
2004	25.130	87585.453	1.847E-04	281.049
7632	25.889	87524.406	7.227E-05	285.981
13698	25.975	87524.406	3.392E-03	286.142
14956	27.406	87646.477	2.408E-04	295.398
18558	27.942	87768.547	1.303E-04	299.268
23988	28.583	87768.547	1.441E-04	303.413
27422	29.219	87768.547	1.680E-04	307.514
31545	29.853	87768.547	9.998E-05	311.608
34578	29.934	87768.547	1.673E-03	312.135
37528	34.878	87585.453	7.059E-04	343.832
38635	35.470	87585.453	4.165E-04	347.733
40302	36.034	87646.477	4.848E-04	351.953
41000	36.617	87646.477	8.322E-04	355.833
41694	37.192	87646.477	8.075E-04	359.681
42422	37.765	87646.477	8.871E-04	363.531
43005	38.355	87585.453	8.211E-04	367.005
43798	38.895	87646.477	7.846E-04	371.185
44405	39.454	87646.477	8.239E-04	375.003
45146	40.006	87646.477	8.817E-04	378.798
45654	40.555	87646.477	1.027E-03	382.598
46233	41.122	87585.453	7.878E-04	386.009
47028	41.637	87646.477	6.906E-04	390.161
47754	42.173	87646.477	9.942E-04	393.939
48100	42.703	87646.477	1.156E-03	397.711
48666	43.227	87646.477	1.081E-03	401.462
49067	43.748	87646.477	1.061E-03	405.789
49644	44.265	87646.477	1.176E-03	409.551
49962	44.801	87585.453	1.199E-03	412.331
50513	45.307	87585.453	1.067E-03	416.065
50908	45.810	87585.453	4.463E-03	419.811
50941	47.217	64636.230	5.271E-04	149.094
54633	47.774	87585.453	2.980E-04	434.733
55134	48.466	87646.477	1.444E-03	440.739
55602	49.173	87646.477	1.560E-03	446.324
56051	49.897	87585.453	3.726E-04	451.491
59395	50.586	87585.453	3.664E-04	457.087
59716	51.240	87646.477	1.948E-03	463.110
60087	51.935	87585.453	1.630E-03	468.269
60142	51.934	87585.453	2.036E-03	468.265
61135	51.240	87646.477	2.313E-03	463.111
61459	51.935	87585.453	2.528E-03	468.270
61671	52.595	87585.453	3.105E-03	473.866
61881	53.245	87585.453	1.572E-03	479.464
62449	53.818	87646.477	1.325E-03	484.466
62732	54.373	87585.453	1.978E-03	488.695
63006	54.920	87524.406	2.009E-03	492.906
63261	55.436	87524.406	2.072E-03	498.281
63501	55.946	87524.406	2.139E-03	502.269
63769	56.522	87585.453	2.455E-03	508.354

63989	57.144	87524.406	2.086E-03	514.248
64348	57.730	87524.406	2.105E-03	519.173
64542	58.308	87524.406	2.608E-03	524.831
64778	58.851	87585.453	2.515E-03	530.976
64992	59.440	87524.406	2.657E-03	536.186
65208	59.994	87524.406	2.805E-03	541.882
65222	60.085	87524.406	1.184E-02	542.832
66431	65.007	87463.383	8.827E-04	598.364
66496	65.507	87402.344	1.004E-02	602.866
66540	66.101	87463.383	1.066E-02	612.075
66609	66.712	87463.383	1.016E-02	619.973
66659	67.310	87463.383	1.187E-02	627.907

ANNEX 5

File: 005_E003.DAT 15-09-94 11:42:38 am Page 1

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
NPTS = 81				
146	22.785	87585.453	0.000E+00	265.676
3170	23.339	87585.453	1.393E-04	269.329
7857	23.859	87524.406	1.622E-04	272.367
10394	24.511	87585.453	1.771E-04	277.011
15287	25.175	87585.453	1.959E-04	281.346
17164	25.837	87585.453	1.826E-04	285.646
21694	26.345	87524.406	1.720E-04	288.540
23720	26.964	87646.477	2.613E-04	293.361
25992	27.468	87585.453	2.122E-04	296.210
29140	28.115	87585.453	2.152E-04	300.387
31320	28.615	87524.406	2.848E-04	303.193
33071	29.234	87585.453	3.212E-04	307.613
35216	29.866	87585.453	3.093E-04	311.696
37150	30.496	87585.453	2.904E-04	315.762
39537	31.121	87585.453	2.722E-04	319.809
41728	31.742	87585.453	3.389E-04	323.829
43121	32.336	87646.477	4.138E-04	328.145
44687	32.966	87585.453	3.785E-04	331.788
46786	33.723	87585.453	3.131E-04	336.731
49022	34.323	87585.453	3.870E-04	340.663
49935	34.942	87524.406	4.721E-04	344.249
51538	35.511	87585.453	4.201E-04	348.488
52684	36.096	87585.453	4.767E-04	352.369
53986	36.678	87585.453	5.992E-04	356.240
54617	37.255	87585.453	4.937E-04	360.100
55490	37.420	87585.453	6.821E-04	361.211
58837	38.487	87768.547	4.632E-04	368.410
61245	41.050	87646.477	7.316E-04	386.041
61946	41.598	87646.477	7.567E-04	389.885
62865	42.275	87646.477	6.820E-04	394.668
63729	42.814	87646.477	6.700E-04	398.504
64464	43.347	87646.477	7.976E-04	402.324
65057	43.873	87646.477	8.914E-04	406.131
65642	44.397	87646.477	1.039E-03	409.945
66183	45.043	87646.477	9.385E-04	414.696
66877	45.556	87646.477	9.182E-04	418.500
67295	46.064	87646.477	9.960E-04	422.303
67893	46.568	87646.477	8.538E-04	426.104
68497	47.091	87585.453	9.686E-04	429.483
69043	47.682	87646.477	1.219E-03	435.236
69404	48.196	87585.453	1.091E-03	438.013
70043	48.773	87646.477	1.073E-03	443.154
70411	49.277	87585.453	1.362E-03	446.523
70828	49.843	87646.477	1.408E-03	451.684
71329	50.569	87585.453	1.359E-03	456.945
71850	51.232	87646.477	1.275E-03	463.044
72295	51.800	87646.477	1.313E-03	467.792
72730	52.387	87585.453	1.394E-03	472.094
73113	52.941	87585.453	1.712E-03	476.168
73373	53.488	87585.453	1.560E-03	481.576

Geometrical examination results of weld

Weld performed at maximum energy

Serial Number:	Point of meas.	A:	B:	C:	D:
LHX001	1	9.3	1.8	8.6	1.8
	2	9.6	1.3	8.8	2
	3	10.2	1.6	8.2	2
	4	10	1.5	8.5	1.8
	5	10.2	1.5	9	1.6
LHX002	1	9.7	1.5	8.5	1.7
	2	9.75	1.6	8.8	1.7
	3	9.9	1.6	8.8	1.8
	4	9.8	1.5	8.4	1.8
	5	10	1.5	8.8	1.8

73810	54.028	87585.453	1.500E-03	485.642
74090	54.564	87585.453	1.889E-03	491.083
74373	55.092	87585.453	2.143E-03	495.844
74628	55.717	87585.453	1.913E-03	501.559
74968	56.230	87585.453	1.782E-03	506.325
75201	56.738	87585.453	2.072E-03	510.389
75455	57.239	87585.453	2.176E-03	515.883
75717	57.861	87524.406	2.223E-03	520.444
75986	58.419	87585.453	2.282E-03	526.668
76184	58.926	87524.406	2.461E-03	530.987
76451	59.564	87585.453	2.440E-03	538.203
76686	60.151	87524.406	2.560E-03	543.518
76885	60.675	87585.453	3.000E-03	549.791
77051	61.246	87524.406	3.056E-03	555.129
77247	61.781	87524.406	3.130E-03	560.949
77391	62.310	87524.406	3.419E-03	566.810
77554	62.831	87524.406	3.515E-03	572.671
77685	63.344	87524.406	3.821E-03	578.555
77835	63.905	87585.453	4.557E-03	585.922
77959	64.593	87524.406	4.213E-03	593.320
78127	65.135	87585.453	3.955E-03	600.779
78237	65.692	87585.453	4.900E-03	607.735
78358	66.267	87524.406	4.818E-03	614.196
78468	66.805	87524.406	5.345E-03	621.201
78558	67.336	87524.406	6.296E-03	628.247
78635	67.857	87524.406	6.397E-03	635.313
78731	68.442	87524.406	6.328E-03	643.440
78811	68.970	87463.383	6.582E-03	650.028
78893	69.509	87524.406	7.344E-03	658.762
78969	70.131	87524.406	8.185E-03	668.034
78969	70.131	87524.406	3.484E-03	668.034

ANNEX 6

File: 007_E007.DAT 16-09-94 2:57:58 pm Page 1

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
NPTS = 53				
29	23.108	87646.477	0.000E+00	267.435
2268	23.748	87768.547	2.147E-04	271.638
6056	24.402	87829.594	1.711E-04	276.302
9968	25.065	87829.594	1.727E-04	280.630
12858	25.577	87768.547	1.354E-04	283.563
18593	26.233	87768.547	1.452E-04	287.814
21751	26.868	87829.594	2.290E-04	292.329
24198	27.516	87829.594	2.937E-04	296.521
26148	28.159	87829.594	2.915E-04	300.674
29146	28.959	87829.594	3.057E-04	306.260
30898	29.611	87768.547	3.084E-04	309.615
33807	30.396	87768.547	3.042E-04	314.679
36044	31.176	87768.547	3.312E-04	319.720
38029	31.795	87768.547	3.294E-04	323.721
39783	32.408	87768.547	4.778E-04	327.698
40588	33.017	87768.547	4.092E-04	331.195
42699	33.601	87829.594	3.505E-04	335.934
44022	34.221	87768.547	4.709E-04	339.516
45280	34.817	87768.547	4.791E-04	343.427
46497	35.406	87768.547	4.466E-04	347.312
47963	36.015	87707.523	4.394E-04	351.336
49154	36.574	87768.547	5.259E-04	355.052
50124	37.151	87768.547	5.861E-04	358.905
51112	37.722	87768.547	5.828E-04	362.730
52076	38.289	87768.547	6.300E-04	367.068
52907	38.852	87768.547	6.744E-04	369.860
53738	39.410	87768.547	5.575E-04	374.702
54896	39.961	87768.547	5.481E-04	377.964
55746	40.510	87768.547	9.064E-04	381.756
56102	41.054	87768.547	7.660E-04	385.536
57159	41.593	87768.547	6.167E-04	388.760
58057	42.260	87768.547	6.677E-04	393.458
58950	42.789	87768.547	7.189E-04	397.210
59519	43.311	87768.547	9.379E-04	400.946
60061	43.831	87768.547	1.158E-03	405.255
60523	44.473	87768.547	9.972E-04	410.504
61343	45.109	87768.547	7.129E-04	414.604
62120	45.612	87768.547	7.730E-04	418.333
62830	46.259	87707.523	9.015E-04	422.584
63492	46.849	87768.547	9.653E-04	427.640
64073	47.458	87768.547	9.137E-04	432.303
64714	47.965	87707.523	1.162E-03	434.999
64999	48.535	87768.547	1.429E-03	440.660
65543	49.150	87707.523	9.982E-04	444.892
66174	49.708	87768.547	1.063E-03	449.967
66632	50.307	87707.523	1.313E-03	454.175
67045	50.851	87768.547	1.301E-03	458.617
67503	51.440	87707.523	1.347E-03	462.831
67874	51.968	87768.547	1.487E-03	467.898
68246	52.544	87707.523	1.529E-03	472.776

68605	53.086	87707.523	2.131E-03	476.753
68852	53.836	87707.523	3.036E-03	483.948
69528	57.131	87646.477	4.165E-03	514.842
69659	57.743	87585.453	5.122E-03	520.750
69755	58.293	87646.477	5.379E-03	525.420
69872	58.888	87585.453	4.961E-03	530.605
69988	59.449	87585.453	4.763E-03	536.282
70106	60.003	87585.453	5.436E-03	541.978
70190	60.547	87585.453	5.279E-03	547.675
70311	61.085	87585.453	5.149E-03	553.397
70397	61.613	87585.453	5.801E-03	559.113
70492	62.135	87585.453	5.764E-03	564.857
70577	62.651	87585.453	6.469E-03	570.632
70654	63.183	87524.406	7.408E-03	575.893
70735	63.821	87585.453	6.788E-03	584.122
70844	64.473	87585.453	2.367E-03	592.704
71228	64.988	87524.406	2.257E-03	596.459
71340	65.592	87585.453	5.480E-03	605.630
71442	66.161	87524.406	6.212E-03	611.978
71513	66.667	87585.453	6.283E-03	620.258
71636	66.961	87585.453	2.209E-02	622.377
71668	67.552	87585.453	5.486E-02	630.272
71683	69.539	87585.453	5.061E-02	658.290
71718	70.082	87585.453	1.857E-02	666.362
71748	70.746	87585.453	2.754E-02	676.517
71762	71.294	87524.406	8.097E-02	684.160
71779	73.256	87585.453	5.213E-02	717.892
71811	73.848	87585.453	6.781E-02	728.417
71840	77.393	87402.344	9.076E-02	794.674

ANNEX 5

RPS Nr. 471

"TEST REPORT FOR CHARACTERIZATION OF V.P.P.A. WELDING AND REPAIR : R-CURVE DETERMINATION AND CRACK GROWTH RATE"

ALENIA SPAZIO LABORATORIO

TEST REPORT

Program: MPLM

Title: TEST REPORT FOR CHARACTERIZATION OF VVPA WELDING AND REPAIR: R-CURVE DETERMINATION AND CRACK GROWTH RATE.

ABSTRACT

R-curve Determination Tests and Crack Growth Rate Tests were performed on specimens of 2219 T851 Alluminum alloy welded by automatic VPPA process and repaired in order to evaluate fracture mechanic properties.
Specimens were machined according to the M(T) configuration of the Standard Method ASTM E 647.
The starting notch was machined into the BEAD and HAZ (Heat Affected Zone) for R-Curve determination and into the BEAD area for Crack Growth Rate tests.

REQUEST n°: 528

LABORATORY AREA: Mechanical Tests

PREPARED: B. BIROLO

CHECKED: E. BONADERO

APPROVED: P. MARCHESE

DOCUMENT CHANGE RECORD

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TABLE OF CONTENTS

1.0 INTRODUCTION

2.0 REFERENCE DOCUMENTS

3.0 R-CURVE DETERMINATION TESTS

3.1 TEST SPECIMENS
3.2 TESTING MACHINE
3.3 RESULTS

4.0 CRACK GROWTH RATE TESTS

4.1 TEST SPECIMENS
4.2 TESTING MACHINE
4.3 RESULTS

ANNEX 1
ANNEX 2

1.0 INTRODUCTION

In the frame of VPPA welding process qualification, fracture mechanic tests were performed in order to support the design phase of MPLM welding primary structure.

The present document contains the results of R-CURVE determination tests and Crack growth Propagation tests carried out on M(T) or Middle Cracked Tension type specimens. The starter notch was located into the bead and HAZ (for R-Curve determination) and into the bead (for Crack Growth Rate tests) of the specimens obtained using VPPA welding automatic process followed by manual and automatic repair.
Additional investigation was carried out on test specimens produced joining a "forged plate" with a plate in order to compare the properties of the HAZ in the forged side with the HAZ in the plate side.

The aim of these types of test was to analyze the behaviour of welded material in two critical zones as BEAD and HAZ under increasing loads and to evaluate the propagation of a crack in specimens loaded by sinusoidal cyclic force.

2.0 REFERENCE DOCUMENTS

[2.1] - MLM-PL-AI-012: Test PLan for the Chracterization of the MPLM Primary Structure VPPA Welding

[2.2] - ASTM E 561: Standard Practice for R-Curve Determination

[2.3] - PRS 015: Procedura di utilizzo della macchina MTS per la determinazione della curva R su provini di tipo Middle Cracked Tension M(T).

[2.4] - ASTM E 647: Standard Test Method for Measurement of Fatigue Crack Growth Rates

[2.5] - PRS 013: Procedura di utilizzo della Macchina MTS per prove di propagazione in automatico su provini di tipo Middle Cracked Tension M(T).

3.0 R-CURVE DETERMINATION TESTS

3.1 TEST SPECIMENS

The specimens were machined from automatic welded and repaired large samples according to ASTM E 647 M(T) type, with the bead perpendicular to the load application direction. The starter notch was machined into the bead and into the HAZ to compare the behaviour of these two diffrent area under an increasing load.
Specimens identification is reported in the following tables and each specimen is marked with:

- the identification mark of the belonging sample
- the letter -D- to specify the kind of test (R-curve determination)
- a sequential number

Table 3.1-a: Test specimens of automatic welding followed by manual single repair
Table 3.1-b: Test specimens of automatic welding followed by manual double repair
Table 3.1-c: Test specimens of automatic welding followed by automatic repair
Table.3.1-d: Test specimens of automatic welding between forging with plate

IDENTIFICATION CODE	STARTER NOTCH LOCATION
LCY016-D001	bead
LCY016-D002	bead
LCY016-D003	bead
LCY019-D004	HAZ
LCY019-D005	HAZ
LCY019-D006	HAZ

Table 3.1-a: Test specimens of automatic welding followed by manual single repair

IDENTIFICATION CODE	STARTER NOTCH LOCATION
LDY001-D001	bead
LDY001-D002	bead
LDY002-D003	bead
LDY018-D004	HAZ
LDY018-D005	HAZ
LDY018-D006	HAZ

Table 3.1-b: Test specimens of automatic welding followed by manual double repair

IDENTIFICATION CODE	STARTER NOTCH LOCATION
LBY001-D001	bead
LBY001-D002	bead
LBY002-D003	bead
LBY005-D004	HAZ
LBY005-D005	HAZ
LBY005-D006	HAZ

Table 3.1-c: Test specimens of automatic welding followed by automatic repair

IDENTIFICATION CODE	STARTER NOTCH LOCATION
CAY003-D001	HAZ forging
CAY009-D003	HAZ forging

Tab.3.1-d: Test specimens of automatic welding between forging with plate

3.2 TESTING MACHINE

The testing machine was an Hydraulic Testing Machine MTS 810 with the following set up:

- Load cell f.s. 250 kN
- Clip on Displacement Gage (C.O.D.) f.s. 3 mm

3.3 TEST RESULTS

The results are contained in ANNEX 1 and are summarized for each group of homogeneous specimens. The following value are reported:

. applied test load [N]
. C.O.D. displacement [mm]
. crack length [mm]
. applied Kr [MPa√mm]

4.0 CRACK GROWTH TESTS

4.1 TEST SPECIMENS

The specimens were machined from automatic welded plates and repaired according to ASTM E647 M(T) type, with the load application direction perpendicular to the bead.
The starter notch was machined into the bead.
Specimens identification is reported in the following tables and each specimen is marked with:

- the identification code of the belonging sample
- the letter -E- to specify the kind of test (crack growth rate)
- a sequential number

Table 4.1-a: Test specimens of automatic welding followed by manual single repair
Table 4.1-b: Test specimens of automatic welding followed by manual double repair
Table 4.1-c: Test specimens of automatic welding followed by automatic repair
Table 4.1-d: Test specimens of automatic welding between forging and plate

IDENTIFICATION CODE	LOAD RATIO
LCY013-E001	0.1
LCY013-E002	0.1
LCY014-E003	0.5
LCY014-E004	0.5

LCY013-E002 was invalid test

Tab. 4.1-a: Test specimens of automatic welding followed by manual single repair

IDENTIFICATION CODE	LOAD RATIO
LDY003-E001	0.1
LDY016-E002	0.1
LDY016-E003	0.5
LDY017-E005	0.5

Tab.4.1-b: Test specimens of automatic welding followed by manual double repair

IDENTIFICATION CODE	LOAD RATIO
LBY003-E001	0.1
LBY003-E002	0.5
LBY004-E004	0.1
LBY004-E005	0.5

Tab.4.1-b: Test specimens of automatic welding followed by automatic repair

IDENTIFICATION CODE	LOAD RATIO
CAY005-E002	0.5
CAY006-E003	0.1

Tab.4.1-d: Test specimens of automatic welding between forging with plate.

4.2 TESTING MACHINE

The testing machine was an Hydraulic Testing Machine MTS 810 with the following set up:

. Load cell - f.s 125 kN
. Clip on Displacement Gage (C.O.D.) - f.s. 3 mm

4.3 TEST RESULTS

For each test the crack length and cycles were recorded and processed to obtain da/dN vs Delta K values.
Data lists, for each group of homogeneous test specimens, are contained in Annex 2.

ANNEX 1

TEST RESULTS

OF R-CURVE DETERMINATION

LCY 016-DO01

Laboratorio

Curva Erre su provini tipo M(T

Carico	C.O.D.	2a	K r
15000	.0276	79.5	131.054
30000	.0552	79.5	262.109
45000	.0837	80.214	395.728
60000	.1197	84.928	550.593
75000	.1626	90.714	724.76
90000	.21	95.976	911.39
105000	.2625	101.02	1112.186
115000	.3018	104.622	1258.1
125000	.3495	109.378	1427.699
135100	.4041	114.483	1617.349
145150	.4692	120.384	1837.25
155000	.5445	126.706	2087.14
165000	.6537	135.744	2440.125
170000	.6909	137.637	2566.462
175100	.8327	148.972	3020.004

Modulo Elastico : 68000
Spessore Provino : 7.1 [mm]
Larghezza Provino : 200 [mm]

File : 016-1wd

ALENIA SPAZIO

LCY016-D002

Laboratorio

Curva Erre su provini tipo M

Carico	C.O.D.	2a	K r
15170	.0198	59.73708	109.5748
30120	.0399	60.54377	219.3794
45000	.0603	61.1721	329.8759
60100	.0843	63.72668	452.0881
75000	.1104	66.50977	579.9039
90000	.1386	69.19405	714.2155
105150	.1713	72.6356	862.1678
120000	.2043	75.41183	1009.765
130000	.2307	78.08472	1121.2
140000	.2589	80.80097	1237.736
150100	.2919	84.18402	1368.216
160000	.3282	87.8563	1507.251
170150	.3696	91.88457	1661.455
180000	.4218	97.3441	1845.101
190150	.4878	104.0183	2068.971
200000	.5703	111.9636	2339.112
210000	.6867	122.374	2709.629

Modulo Elastico : 69000
Spessore Provino : 7.1 [mm]
Larghezza Provino : 200 [mm]

File : 016-2WD

ALENIA SPAZIO

LCY016-D003

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0177	57.17743	105.4748
30000	.0363	58.33035	213.5366
45000	.0552	59.05935	322.7588
60000	.0741	59.42467	431.985
75000	.0987	62.92117	559.631
90000	.1293	67.99536	706.0128
105000	.1614	72.1022	856.6241
110000	.1704	72.58186	901.4792
120000	.1965	76.08652	1016.092
130000	.2235	79.24974	1133.212
140000	.2747	88.20931	1323.008
150000	.2965	88.72299	1424.023
160000	.3237	90.35712	1541.245
170000	.3612	93.841	1689.129
180000	.4041	97.82662	1853.045
190000	.4725	105.3913	2093.054
200000	.5475	112.6237	2353.395
210000	.6138	117.5989	2588.552
220000	.7272	126.9485	2969.585

Modulo Elastico : 72500
Spessore Provino : 7.1 [mm]
Larghezza Provino : 200 [mm]

File : RC17

ALENIA SPAZIO

LCY019-D004

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0255	76.23794	127.1894
30000	.0546	80.69299	264.9693
45000	.0855	83.58368	407.9809
60000	.1194	86.75153	559.6641
75000	.1569	90.24198	721.7181
90000	.1974	93.60596	892.3777
105000	.2415	97.03303	1073.332
120000	.2928	101.3689	1275.037
130000	.3297	104.235	1417.254
140000	.3795	109.2285	1596.85
150000	.4242	112.428	1761.859
160000	.4839	117.5254	1970.861
170000	.5589	123.8768	2225.903
180000	.6687	133.1102	2588.253
190000	.8157	143.7584	3075.22

Modulo Elastico : 70000
Spessore Provino : 7.1 [mm]
Larghezza Provino : 200 [mm]

File : RC08

ALENIA SPAZIO

LCY019-D005

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.018	56.23159	104.4135
30000	.0363	56.49328	209.4143
45000	.0591	60.85891	328.8201
60000	.0852	65.25724	458.2492
75000	.1143	69.43027	596.5295
90000	.1467	73.56879	744.4346
105000	.183	77.84748	903.6166
120000	.2181	80.6037	1059.018
130000	.2466	83.47018	1177.407
140000	.2772	86.40418	1301.829
150000	.3087	89.08942	1428.685
160000	.348	93.00222	1577.954
170000	.3876	96.40182	1728.042
180000	.4377	101.1147	1908.212
190000	.4926	105.8822	2102.349
200000	.5562	111.1584	2321.855
210000	.6543	119.7891	2642.994

Modulo Elastico : 70000
Spessore Provino : 7.1 [mm]
Larghezza Provino : 200 [mm]

File : RC09

A ENIA SPAZIO

LCY010-D006

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0171	55.048	103.815
30000	.0351	56.204	210.246
45000	.0561	59.55	326.711
60000	.0789	62.484	448.896
75000	.1044	65.724	579.531
90000	.1332	69.352	720.373
105000	.165	73.032	870.28
120000	.201	77.088	1032.797
130000	.2298	80.618	1155.555
140000	.2577	83.335	1275.41
150000	.2922	87.214	1414.925
160000	.3294	91.089	1562.321
170000	.3717	95.397	1724.815
180000	.4221	100.507	1911.333
190000	.4755	105.334	2106.808
200000	.5415	111.254	2340.379
210000	.6294	118.968	2640.984
220000	.7458	128.325	3032.381
230000	.9174	140.452	3608.532

Modulo Elastico : 72500
Spessore Provino : 7.05 [mm]
Larghezza Provino : 200 [mm]

File : RC10

ALENIA SPAZIO

LDY001-D001

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0183	57.68143	106.3398
30000	.0372	58.37005	214.2291
45000	.0573	59.79364	326.15
60000	.0804	62.60479	447.5406
75000	.1047	64.92744	572.5601
90000	.1341	68.75827	713.2392
105000	.1674	72.89268	865.4581
120000	.2061	77.63367	1033.591
130000	.2367	81.47821	1159.675
140000	.2694	85.2205	1291.729
150000	.3084	89.82077	1442.092
160000	.3483	93.88133	1594.831
170000	.3936	98.34763	1763.207
180000	.4626	106.0773	2000.846
190000	.5295	112.1796	2232.873
200000	.6369	122.3147	2586.4

Modulo Elastico : 71000
Spessore Provino : 7.08 [mm]
Larghezza Provino : 200 [mm]

File : RC11

ALENIA SPAZIO

LDY001-D002

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0168	56.39178	103.5721
30000	.0348	58.05492	210.8398
45000	.0558	61.66723	328.3087
60000	.0795	65.41993	454.5043
75000	.1071	69.85667	593.1213
90000	.1386	74.53445	743.8412
105000	.1752	79.71947	910.2416
120000	.2169	85.09597	1092.077
130000	.2475	88.68746	1221.717
140000	.2862	93.72911	1376.097
150000	.3315	99.38813	1550.559
160000	.3834	105.3823	1745.224
170000	.4359	110.4725	1942.055
180000	.5094	117.9599	2204.609
190000	.5988	126.1413	2519.214
200000	.7404	138.2088	3008.794

Modulo Elastico : 74500
Spessore Provino : 7.17 [mm]
Larghezza Provino : 200 [mm]

File : RC12

ALENIA SPAZIO

LDY002-D003

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0261	78.258	129.758
30000	.0534	79.603	262.724
45000	.0873	85.393	415.253
60000	.1248	90.237	578.164
75000	.168	95.532	757.56
90000	.2214	102.394	966.459
105000	.2775	107.747	1183.269
120000	.3495	115.093	1446.817
130000	.4023	119.709	1637.189
140000	.4755	126.779	1889.202
150000	.5541	133.113	2159.974
160000	.6681	142.164	2545.503
170000	.8211	152.448	3071.416

Modulo Elastico : 70500
Spessore Provino : 7.09 [mm]
Larghezza Provino : 200 [mm]

File : RC13

ALENIA SPAZIO

LDY019-D004

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0249	74.63	125.484
30000	.0501	75.012	251.861
45000	.0803	79.296	392.985
60000	.1092	80.601	530.244
75000	.1443	84.34	685.58
90000	.1833	88.264	852.119
105000	.2307	93.627	1042.775
120000	.2748	96.618	1223.862
135000	.3357	102.666	1453.226
140000	.3483	102.702	1507.534
150000	.4057	108.953	1709.026
160000	.4557	112.857	1889.438
170000	.5307	119.828	2143.383
180120	.6084	125.822	2407.517
190070	.7272	135.201	2798.421
200100	.9039	147.291	3384.3

Modulo Elastico : 70000
Spessore Provino : 7.09 [mm]
Larghezza Provino : 200 [mm]

File : RC06

ALENIA SPAZIO

LDY018-D005

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0201	59.569	108.158
30000	.0408	60.374	218.124
45000	.0636	62.497	334.347
60000	.0909	66.474	463.759
75000	.1215	70.48	602.539
90000	.1563	74.803	753.055
105000	.195	79.137	914.346
120000	.24	84.092	1092.936
135000	.2871	88.322	1277.042
140000	.2997	88.78	1329.762
150000	.3426	93.369	1484.171
160000	.3846	97.06	1635.943
170000	.4326	101.235	1804.139
180000	.4866	105.732	1989.005
190000	.552	111.154	2205.677
200000	.6522	119.924	2520.377
210000	.7584	127.681	2855.52
220000	.913	138.086	3337.772

Modulo Elastico : 67000
Spessore Provino : 7.1 [mm]
Larghezza Provino : 200 [mm]

File : RC07

ALENIA SPAZIO

LDY018-D006

Laboratorio Ricerca

Curva Erre su provini tipo M(

Carico	C.O.D.	2a	K r
15000	.0177	56.459	104.669
30000	.0366	58.03	212.863
45000	.0567	59.757	325.109
60000	.0808	63.445	450.063
75000	.1086	67.64	586.32
90000	.1446	73.996	747.41
105000	.1815	78.693	910.639
120000	.2226	83.394	1086.092
130000	.2565	87.627	1222.138
140000	.2865	90.184	1346.514
150000	.3264	94.556	1499.918
160000	.3675	98.483	1656.814
170000	.4143	102.849	1830.398
180000	.4764	109.024	2049.272
190000	.5272	112.592	2235.077
200000	.6084	119.582	2512.169
210000	.7209	128.761	2886.894
220000	.8904	141.016	3449.387

Modulo Elastico : 71500
Spessore Provino : 7.1 [mm]
Larghezza Provino : 200 [mm]

File : R[illegible]4

ALENIA SPAZIO

LBY001-D001

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0282	81.068	132.937
30000	.0564	81.068	265.873
45000	.0849	81.161	399.145
60000	.1224	86.464	558.224
75000	.1641	91.365	728.969
90000	.2133	97.105	920.592
105000	.2688	102.777	1129.812
120000	.3348	109.215	1368.555
135000	.4269	118.711	1681.695
145000	.4893	123.654	1894.426
155000	.5889	132.62	2217.[illegible]3
160000	.6756	140.449	2492.509
170000	.8673	153.814	3123.92

Modulo Elastico : 68000
Spessore Provino : 7.1 [mm]
Larghezza Provino : 200 [mm]

File : B01_D001

ALENIA SPAZIO

LBY001-D002

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15170	.018	56.38394	105.7697
30120	.0381	59.58768	217.2238
45070	.0591	61.55537	331.6834
60000	.0804	62.76113	446.984
75000	.105	65.25385	572.7924
90000	.1359	69.72885	717.8848
100020	.1605	73.4758	826.5952
110070	.1863	76.86861	938.7617
120000	.2142	80.3468	1056.548
130000	.2454	84.10428	1184.148
140000	.2841	89.0976	1333.536
150020	.3231	93.31318	1483.626
155120	.3423	95.06168	1558.103
160100	.3798	100.3366	1685.489
165120	.393	100.5795	1742.113
170100	.4227	103.7752	1846.772
175120	.4611	108.1053	1977.113
180000	.4992	112.0245	2106.381
190050	.6201	124.3768	2500.676
200150	.7725	137.011	3000.948

Modulo Elastico : 71000
Spessore Provino : 7.1 [mm]
Larghezza Provino : 200 [mm]

File : RC01

ALENIA SPAZIO

LBY001-D003

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0204	59.769	109.932
30000	.0411	60.002	220.394
45000	.0618	60.134	331.042
60000	.0897	64.879	463.06
74970	.1209	69.341	604.294
90020	.1566	74.015	758.39
100020	.1827	77.13	867.315
109970	.2106	80.225	980.984
120000	.2427	83.889	1106.526
130120	.2772	87.453	1238.808
140070	.3162	91.524	1382.836
150220	.3645	96.71	1553.042
160020	.4179	102.106	1735.968
165100	.4317	102.198	1792.55
170100	.4782	107.606	1939.065
180150	.591	119.3	2288.985
190150	.7356	131.797	2735.399

Modulo Elastico : 67000
Spessore Provino : 7 [mm]
Larghezza Provino : 200 [mm]

File : RC03

ALENIA SPAZIO

LBY005-D004

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15020	.0192	56.501	106.354
30000	.0384	56.501	212.424
45120	.0579	56.534	319.598
60120	.0834	60.681	444.766
75000	.1122	64.918	579.052
90000	.1449	69.245	724.771
100070	.1692	72.239	829.135
110070	.1944	74.974	935.624
120100	.2214	77.726	1047.161
130050	.252	81.007	1168.377
140020	.2829	83.817	1290.301
150020	.321	87.76	1432.188
155020	.333	88.031	1483.518
160050	.3597	91.209	1575.651
165050	.3705	91.209	1624.875
170150	.3996	94.349	1722.528
175020	.4128	94.658	1776.709
180270	.456	99.75	1914.896
190170	.5226	105.897	2134.583
200200	.5949	111.784	2370.98
210270	.7491	125.572	2839.585
220200	.7722	124.461	2941.223
230120	.975	138.57	3560.228

Modulo Elastico : 67000
Spessore Provino : 7 [mm]
Larghezza Provino : 200 [mm]

File : RC02

ALENIA SPAZIO

LBY005-D005

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0195	55.639	105.231
30000	.039	55.639	210.462
45000	.0582	55.546	315.372
60000	.0771	55.221	419.016
85000	.1077	54.512	589.033
107000	.1368	54.793	743.772
119400	.158	56.554	845.928
125000	.1806	61.248	930.137
130000	.1965	63.776	992.353
140000	.2232	66.856	1101.675
150000	.2568	71.137	1229.952
160000	.2946	75.695	1369.179
170000	.336	80.308	1517.622
180150	.3852	85.616	1687.154
190150	.4359	90.466	1859.635
200200	.5088	97.876	2091.353
210000	.5916	105.49	2348.519
220120	.7011	114.748	2679.418
230270	.8544	126.357	3134.027
240850	1.203	148.254	4175.522

Modulo Elastico : 65000
Spessore Provino : 7 [mm]
Larghezza Provino : 200 [mm]

File : RC04

ALENIA SPAZIO

LBY005-D006

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0261	75.34502	125.6117
30000	.0525	75.55886	251.7219
45000	.0807	77.13072	383.1032
60000	.1137	80.74889	527.9768
75000	.1509	84.78642	684.472
90000	.1908	88.39588	848.3386
105000	.2364	92.64361	1027.892
110000	.2481	92.77266	1078.076
120000	.291	98.00494	1232.121
130000	.3285	101.0312	1371.33
140000	.3699	104.3361	1521.234
150000	.4197	108.6329	1694.492
160000	.4788	113.7118	1893.768
170000	.546	119.0886	2116.371
180000	.6276	125.3346	2380.87
190000	.7266	132.3118	2697.854
200000	.8865	143.2081	3202.688
210000	1.2321	162.2423	4348.968

Modulo Elastico : 67000
Spessore Provino : 7.13 [mm]
Larghezza Provino : 200 [mm]

File : RC05

ALENIA SPAZIO

CAY009-D001

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0267	79.18636	131.0488
30000	.0546	80.50661	265.2682
45000	.0846	82.67628	405.7991
60000	.1176	85.50829	555.0291
75000	.1548	89.09662	716.4063
90000	.1959	92.8577	888.9633
100000	.2277	96.10014	1016.634
110000	.2661	100.5267	1163.295
120000	.2958	101.9134	1284.884
130000	.351	108.7153	1480.041
140000	.3906	111.1897	1630.358
150000	.4473	116.2393	1830.603
160000	.5103	121.3541	2049.977
170000	.5949	128.3955	2334.936
180000	.7143	137.806	2730.168
190000	.9069	151.0478	3374.835

Modulo Elastico : 70000
Spessore Provino : 7.08 [mm]
Larghezza Provino : 200 [mm]

File : RC16

ALENIA SPAZIO

CAY003-D003

Laboratorio Ricerca

Curva Erre su provini tipo M(T)

Carico	C.O.D.	2a	K r
15000	.0273	77.633	129.199
30000	.0552	78.342	260.083
45000	.0834	78.817	391.823
60000	.1125	79.579	526.075
75000	.1578	87.38	705.513
90000	.2121	95.42	909.452
105000	.2727	102.539	1130.59
110000	.2856	102.539	1184.428
120000	.3521	111.686	1403.845
130000	.3849	112.369	1530.429
140000	.441	117.074	1722.02
150000	.5076	122.528	1943.82
160000	.6024	130.611	2247.876

Modulo Elastico : 67000
Spessore Provino : 7.08 [mm]
Larghezza Provino : 200 [mm]

File : RC15

ALENIA SPAZIO

ANNEX 2

TEST RESULTS

OF CRACK GROWTH RATE

TEST SPECIMEN: LCY013-E001

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
7	30.051	43945.309	0.000E+00	285.877
35	30.728	43945.309	7.500E-05	289.876
17163	31.338	43945.309	5.205E-05	293.481
24553	32.005	43945.309	1.144E-04	297.431
28755	32.665	43945.309	1.974E-04	301.350
31224	33.321	43945.309	2.153E-04	305.260
34819	33.971	43945.309	2.343E-04	309.139
36746	34.615	43945.309	3.899E-04	313.488
38220	35.297	43884.281	4.676E-04	317.107
40146	36.205	43945.309	4.567E-04	322.604
41577	36.830	43945.309	4.949E-04	326.411
42663	37.450	43945.309	4.211E-04	330.721
44509	38.064	43945.309	4.888E-04	334.508
45166	38.674	43945.309	4.214E-04	337.763
48100	39.578	43945.309	3.671E-04	343.405
49376	40.219	43884.281	5.671E-04	347.440
50187	40.761	43945.309	5.421E-04	350.876
51455	41.346	43945.309	5.174E-04	354.607
52436	41.925	43945.309	2.064E-04	358.883
57278	42.548	43884.281	2.491E-04	361.802
58350	43.398	43884.281	8.191E-04	367.358
59339	44.236	43884.281	6.762E-04	372.901
60407	44.789	43884.281	7.275E-04	376.597
60849	45.335	43884.281	6.585E-04	380.276
62059	45.877	43884.281	6.935E-04	384.559
62404	46.413	43884.281	1.058E-03	388.246
63069	46.946	43884.281	7.704E-04	391.334
63776	47.470	43884.281	9.219E-04	395.624
64204	47.992	43884.281	1.036E-03	398.686
65025	48.754	43884.281	7.790E-04	404.199
65844	49.270	43884.281	7.612E-04	408.492
69197	50.622	43945.309	0.000E+00	418.474
69441	51.161	43884.281	1.071E-03	421.220
70552	52.073	43945.309	5.169E-04	429.504
72678	52.834	43884.281	5.473E-04	434.760
73120	53.478	43945.309	1.411E-03	440.537
73659	54.218	43884.281	1.322E-03	445.111
74322	55.067	43945.309	1.517E-03	453.459
74690	55.783	43884.281	1.606E-03	458.030
75275	56.597	43945.309	6.385E-04	465.686
77050	57.289	43884.281	6.222E-04	471.712
77402	57.920	43884.281	1.683E-03	477.305
77793	58.540	43884.281	1.777E-03	482.890
78094	59.150	43884.281	1.643E-03	488.496
78651	59.950	43884.281	1.391E-03	495.991
79092	60.538	43884.281	1.393E-03	501.626
79490	61.118	43884.281	5.756E-04	506.499
81091	61.689	43884.281	6.229E-04	512.948
81307	62.250	43884.281	2.882E-03	518.630
81414	62.620	43884.281	4.026E-03	521.614
82158	64.085	43762.211	2.772E-03	536.291
82442	64.733	43823.238	2.705E-03	545.089
82651	65.419	43823.238	3.468E-03	552.819
82848	66.141	43762.211	3.435E-03	559.440
83053	66.800	43762.211	2.150E-03	567.242
83425	67.382	43823.238	1.881E-03	576.091
83642	67.908	43762.211	1.198E-03	580.833
84511	68.683	43762.211	1.251E-03	590.716
84745	69.288	43762.211	2.633E-03	598.659
84966	69.881	43762.211	3.308E-03	606.648
85143	70.604	43762.211	3.576E-03	616.686
85327	71.172	43762.211	2.708E-03	624.790
85557	71.726	43762.211	2.944E-03	632.914
85700	72.270	43762.211	1.405E-03	641.106
86452	72.983	43701.172	1.457E-03	651.165
86634	73.630	43701.172	3.312E-03	661.549
86800	74.136	43701.172	3.391E-03	669.302
86987	74.827	43762.211	4.524E-03	682.767
87017	75.117	43701.172	1.343E-02	687.855

TEST SPECIMEN: LCY014-E003

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
461	25.812	75195.313	0.000E+00	248.319
7248	26.605	75134.281	8.090E-05	252.384
20144	27.404	75195.313	7.142E-05	257.289
30123	28.239	75134.281	9.369E-05	261.555
37665	29.045	75134.281	1.047E-04	266.076
45459	29.845	75134.281	1.042E-05	270.559
45603	29.128	75134.281	6.565E-04	266.539
46992	33.809	75073.242	4.841E-04	293.385
48790	34.564	75073.242	4.853E-04	297.690
50091	35.313	75073.242	2.331E-04	301.984
55178	36.053	75073.242	2.347E-04	306.246
56371	36.787	75073.242	5.289E-04	310.500
57937	37.512	75073.242	5.439E-04	314.726
59026	38.231	75073.242	6.284E-04	318.945
60211	38.941	75073.242	6.105E-04	323.139
61342	39.645	75073.242	-9.349E-05	327.330
63991	38.588	75073.242	2.519E-03	321.047
65223	38.941	75073.242	3.277E-04	322.613
68754	39.789	75073.242	2.118E-04	328.188
72627	40.510	75012.203	2.078E-04	331.978
75530	41.197	75012.203	2.253E-04	336.136
78689	41.876	75012.203	2.689E-04	340.276
80557	42.549	75012.203	1.395E-04	344.419
81285	45.983	75012.203	1.253E-03	366.201
82107	46.581	75073.242	4.997E-04	370.724
84067	47.373	75012.203	3.527E-04	375.368
85993	47.952	75073.242	3.141E-04	379.256
87929	48.586	75012.203	3.274E-04	383.559
89657	49.152	75073.242	3.893E-04	387.443
90971	49.770	75012.203	3.901E-04	391.102
92731	50.351	75012.203	2.588E-04	395.178
93447	50.411	75012.203	4.335E-03	396.249
94618	55.683	75012.203	1.812E-03	435.897
94912	56.194	75012.203	1.979E-03	440.012
95132	56.701	75012.203	2.020E-03	444.156
95425	57.230	74951.172	2.112E-03	447.813
95717	57.936	75012.203	2.484E-03	454.498
96001	58.660	75012.203	1.985E-03	459.979
96337	59.167	74951.172	1.901E-03	464.407
96637	59.869	74951.172	2.053E-03	469.891
97000	60.528	75012.203	1.774E-03	477.425
97391	61.206	75012.203	1.929E-03	482.942
97696	61.871	75012.203	6.860E-04	490.036
99356	62.554	74951.172	7.057E-04	495.057
99575	63.197	74951.172	2.833E-03	501.411
99794	63.795	75012.203	2.804E-03	508.291
100020	64.444	74951.172	2.681E-03	515.007
100262	65.050	74951.172	2.565E-03	520.570
100489	65.647	74951.172	3.021E-03	527.881
100653	66.231	74951.172	3.195E-03	534.347
100852	66.807	74951.172	3.013E-03	539.977
101031	67.370	74951.172	3.486E-03	547.379
101067	67.557	74951.172	8.883E-03	548.670

TEST SPECIMEN: LCY014-E004

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
16988	40.554	50170.898	0.000E+00	221.856
20235	41.107	50170.898	1.226E-04	224.092
25733	41.626	50170.898	7.993E-05	226.200
33017	42.129	50170.898	1.244E-04	228.258
34462	42.712	50170.898	1.906E-04	231.223
38832	43.237	50170.898	1.363E-04	232.844
42076	43.749	50109.859	1.348E-04	234.413
46457	44.266	50109.859	1.501E-04	236.584
48979	44.785	50170.898	2.570E-04	239.372
50452	45.292	50170.898	2.045E-04	241.543
54129	45.839	50109.859	1.083E-04	243.904
60689	46.401	50170.898	1.932E-04	246.959
70565	46.184	50170.898	7.658E-04	245.406
73747	46.612	50415.039	1.103E-04	246.680
84361	47.142	50354.000	6.833E-05	249.018
94970	48.062	50415.039	6.997E-05	253.744
104913	48.580	50354.000	6.088E-05	254.846
118127	49.472	50415.039	1.310E-06	259.561
118319	48.598	50415.039	1.040E-03	256.176
119570	51.829	50292.969	1.857E-04	270.741
127630	52.707	50292.969	1.094E-04	275.728
135881	53.613	50231.930	1.204E-04	279.596
142171	54.457	50231.930	1.093E-04	283.920
143610	54.458	50231.930	2.283E-03	283.229
144746	57.429	50048.828	6.063E-04	299.162
146088	58.090	50048.828	3.668E-04	302.885
148110	58.663	50048.828	3.162E-04	306.167
149685	59.228	50048.828	4.224E-04	309.457
151203	59.969	50048.828	3.993E-04	314.631
152911	60.516	50048.828	3.692E-04	317.172
154142	61.054	50048.828	4.438E-04	320.489
155321	61.585	50048.828	1.672E-04	323.817
160450	62.109	50048.828	1.718E-04	327.153
161370	62.625	50048.828	4.815E-04	330.496
162575	63.132	50048.828	5.234E-04	333.845
163298	63.634	50048.828	6.501E-04	337.211
164576	64.453	50048.828	5.677E-04	342.837
166148	65.252	50048.828	5.699E-04	348.486
167380	66.034	50048.828	6.483E-04	354.183
168529	66.795	50048.828	2.740E-04	359.894
172336	67.391	50048.828	2.456E-04	364.488
173343	67.978	50048.828	6.775E-04	369.112
174047	68.551	50048.828	9.041E-04	373.742
174601	69.115	50048.828	1.032E-03	378.411
175128	69.666	50048.828	1.050E-03	383.087
175644	70.210	50048.828	4.151E-04	387.809
178035	70.873	50048.828	4.300E-04	393.722
178391	71.392	50048.828	1.455E-03	398.476
178829	72.028	50048.828	1.277E-03	404.476
179313	72.569	49987.789	1.314E-03	408.715
179672	73.136	50048.828	1.568E-03	415.365
180053	73.730	50048.828	1.776E-03	421.460
180293	74.239	49987.789	2.037E-03	425.791
180583	74.810	49987.789	1.701E-03	431.975
180761	75.035	49987.789	2.023E-03	434.473

TEST SPECIMEN: LDY003-E001

LDY Riparaz.man.doppia

N.Cicli	Lunghezza	Carico max	da/dN	Delta K
4522	24.258	45043.95	0.00E+00	258.207
9029	24.916	45104.98	1.62E-04	262.239
12834	25.6	45104.98	1.80E-04	266.412
16431	26.249	45166.02	2.37E-04	270.765
18422	26.923	45166.02	3.21E-04	274.866
20620	27.594	45166.02	2.90E-04	278.944
23037	28.259	45166.02	2.31E-04	282.977
24046	28.294	45104.98	3.71E-04	282.762
26625	28.957	45104.98	2.08E-04	286.341
30384	29.615	45104.98	2.01E-04	290.321
33163	30.268	45104.98	1.80E-04	294.268
37593	30.915	45104.98	1.63E-04	298.184
41097	31.557	45104.98	2.04E-04	301.624
43878	32.196	45104.98	2.18E-04	305.959
46930	32.828	45104.98	1.94E-04	310.278
50385	33.457	45104.98	1.84E-04	313.651
53753	34.081	45104.98	2.12E-04	317.472
56232	34.698	45104.98	3.25E-04	321.269
57536	35.311	45104.98	2.71E-04	325.048
60745	35.92	45104.98	2.17E-04	328.327
63127	36.522	45104.98	2.55E-04	333.073
65447	37.12	45104.98	3.53E-04	336.314
66503	37.714	45104.98	3.59E-04	339.535
92715	38.928	45043.95	3.58E-04	347.753
99944	39.505	45043.95	1.01E-04	350.915
104102	40.078	45043.95	1.23E-04	355.136
108831	40.602	45104.98	1.42E-04	359.073
112073	41.21	45043.95	2.12E-04	362.501
114340	41.768	45043.95	2.19E-04	366.167
117148	42.321	45043.95	2.80E-04	369.27
118271	42.87	45043.95	4.93E-04	372.926
119358	43.411	45043.95	3.12E-04	377.127
121740	43.951	45043.95	2.81E-04	380.783
123169	44.482	45043.95	4.28E-04	384.415
124221	45.011	45043.95	5.18E-04	388.057
125198	45.533	45043.95	3.99E-04	391.682
126829	46.052	45043.95	4.86E-04	395.317
127321	46.565	45043.95	5.32E-04	398.332
128750	47.074	45043.95	5.46E-04	402.566
129177	47.577	45043.95	4.49E-04	406.187
131092	48.126	44982.91	6.04E-04	408.312
131633	49.061	45043.95	7.32E-04	416.426
133096	49.593	44982.91	5.93E-04	419.762
134059	50.5	45043.95	7.05E-04	426.613
135121	51.021	44982.91	6.56E-04	430.609
136191	51.898	45043.95	1.10E-03	438.102
136381	52.407	44982.91	1.01E-03	440.792
137587	53.308	44982.91	7.00E-04	449.383
138785	54.089	45104.98	7.01E-04	455.791
139467	54.626	44982.91	9.20E-04	459.575
140246	55.433	45043.95	1.07E-03	466.409
140953	56.222	45104.98	1.07E-03	473.946
141466	56.739	44982.91	1.30E-03	477.052
142285	57.958	44982.91	1.16E-03	488.011
143195	58.75	44982.91	1.35E-03	495.335
143450	59.526	44982.91	1.27E-03	503.44
144442	60.339	44921.88	8.19E-04	509.778
146749	66.229	44921.88	1.78E-03	573.549
146957	66.91	44860.84	2.11E-03	581.834
147341	67.475	44921.88	2.05E-03	588.883
147553	68.131	44860.84	2.31E-03	596.355
147883	68.725	44860.84	2.10E-03	604.136
148111	69.305	44860.84	2.63E-03	611.926
148302	69.825	44921.88	2.73E-03	620.024
148524	70.434	44860.84	3.04E-03	627.662
148683	70.982	44860.84	2.99E-03	634.627
148887	71.519	44860.84	2.88E-03	643.567
149053	72.046	44860.84	3.72E-03	651.597
149168	72.562	44860.84	4.99E-03	658.656
149258	73.069	44860.84	4.73E-03	666.751
149390	73.613	44799.8	5.09E-03	674.651
149508	74.34	44799.8	5.80E-03	686.985
149637	75.045	44799.8	5.47E-03	699.398

TEST SPECIMEN: LDY016-E002

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
NPTS = 10				
3311	23.694	37780.762	0.000E+00	212.479
14601	24.558	37719.730	5.852E-05	216.118
31456	25.341	37780.762	4.546E-05	220.495
49727	26.155	37780.762	6.203E-05	225.028
57610	26.964	37780.762	9.860E-05	229.124
66040	27.764	37780.762	6.238E-05	232.747
83861	28.601	37719.730	6.784E-05	236.541
89366	29.346	37780.762	9.550E-05	240.723
100304	30.172	37719.730	6.731E-05	244.443
101612	30.170	37719.730	3.008E-04	244.879
101621	31.382	37719.730	2.975E-02	250.546
101678	32.134	37780.762	2.567E-04	254.809
107624	32.923	37780.762	1.917E-04	259.283
110123	33.753	37719.730	1.457E-04	263.044
110889	33.468	38085.941	1.338E-04	261.118
113397	34.191	38146.969	2.189E-04	265.283
117891	35.001	38085.941	1.139E-04	268.953
127132	35.756	38085.941	1.002E-04	272.344
131879	36.403	38208.012	1.850E-04	277.192
135174	37.243	38085.941	2.368E-04	281.074
138514	37.974	38085.941	1.462E-04	283.883
145119	38.697	38085.941	1.108E-04	288.218
145994	38.803	37963.871	3.295E-04	288.776
147295	39.414	38085.941	3.320E-04	293.091
149968	40.122	38085.941	3.327E-04	296.898
151532	40.824	38085.941	3.510E-04	301.248
154093	41.570	38024.898	2.734E-04	304.785
156772	42.257	38024.898	2.161E-04	308.578
160408	42.934	38024.898	1.816E-04	311.791
164190	43.604	38024.898	1.863E-04	316.120
167560	44.267	38024.898	2.564E-04	319.308
169332	44.922	38024.898	3.060E-04	323.062
171821	45.570	38024.898	1.801E-04	327.407
176484	46.210	38024.898	1.871E-04	331.155
178618	46.842	38024.898	2.490E-04	334.294
181535	47.468	38024.898	2.497E-04	338.033
183834	48.145	37963.871	2.233E-04	341.510
187038	48.697	38024.898	2.102E-04	345.507
189337	49.301	38024.898	3.339E-04	349.250
190813	49.957	37963.871	3.606E-04	352.719
192621	50.486	38024.898	3.249E-04	356.711
194419	51.129	37963.871	3.890E-04	360.187
195598	51.644	38024.898	5.156E-04	364.188
196635	52.271	37963.871	3.765E-04	367.652
198760	52.834	37963.871	3.143E-04	371.402
200187	53.388	37963.871	5.207E-04	375.136
200875	53.936	37963.871	5.783E-04	378.194
202071	54.477	37963.871	5.175E-04	382.633
202957	55.013	37963.871	5.347E-04	387.095
204059	55.540	37963.871	6.600E-04	390.144
204548	56.063	37963.871	1.250E-03	393.915
204889	56.577	37963.871	8.843E-04	396.952
205705	57.086	37963.871	4.327E-04	401.446
207228	57.589	37963.871	4.529E-04	404.491
208048	58.147	37902.828	8.532E-04	407.997
209025	59.123	37902.828	8.976E-04	415.572
210195	60.075	37902.828	8.037E-04	423.951
211363	61.002	37902.828	7.605E-04	430.806
212605	61.907	37902.828	8.882E-04	438.476
213377	62.790	37902.828	1.025E-03	446.176
214306	63.652	37902.828	9.596E-04	453.910
215152	64.494	37902.828	1.136E-03	461.702
215821	65.373	37841.801	1.315E-03	470.098

TEST SPECIMEN: LDY016-E003

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
22226	23.308	38024.898	0.000E+00	120.826
127637	23.577	38024.898	1.489E-05	119.109
127731	24.879	38208.012	3.823E-05	123.250
184371	25.746	38146.969	1.055E-05	125.336
288213	26.571	38146.969	8.406E-06	128.100
296664	26.690	37963.871	9.869E-05	127.612
297322	27.470	38024.898	1.770E-05	130.243
430221	29.054	50415.039	1.628E-05	178.641
430551	29.639	50415.039	7.706E-05	180.845
445380	30.222	50415.039	2.878E-05	183.038
472096	30.835	50354.000	2.124E-05	184.898
499675	31.375	50415.039	1.986E-05	187.387
529737	31.980	50354.000	1.763E-05	189.211
564164	32.512	50415.039	1.904E-05	192.156
587290	33.075	50415.039	4.847E-05	193.827
597250	34.116	50537.109	1.619E-04	197.794
597348	34.704	50476.070	1.182E-04	200.532
606520	35.212	50537.109	6.234E-05	201.996
614193	35.755	50537.109	5.094E-05	204.087
627743	36.293	50537.109	3.295E-05	206.173
646799	36.829	50537.109	2.885E-05	208.760
664622	37.357	50537.109	4.461E-05	210.828
670448	37.884	50537.109	4.338E-05	212.382
688800	38.406	50537.109	3.175E-05	214.963
703195	38.924	50537.109	4.531E-05	216.491
711583	39.438	50537.109	5.157E-05	218.542
723089	39.949	50537.109	3.910E-06	220.589
730421	39.512	50476.070	3.174E-04	218.837
737461	46.393	50292.969	0.000E+00	247.622
750588	47.301	50292.969	7.480E-05	251.654
762102	48.237	50231.930	8.014E-05	255.253
773225	49.116	50231.930	8.899E-05	259.911
781667	49.978	50231.930	4.050E-05	263.297
783896	49.548	50231.930	9.753E-04	261.284
784947	51.085	50354.000	0.000E+00	268.564
789851	51.851	50354.000	1.210E-04	272.943
797495	52.604	50354.000	1.269E-04	275.993
801611	53.344	50354.000	1.308E-04	279.706
809074	54.119	50292.969	1.375E-04	282.974
812474	54.837	50292.969	2.382E-04	286.704
815050	55.542	50292.969	2.473E-04	290.429
818133	56.237	50292.969	3.248E-04	294.164
820329	57.257	50292.969	3.454E-04	299.048
823019	57.924	50292.969	2.751E-04	302.797
825136	58.579	50292.969	4.193E-04	306.549
826229	59.270	50231.930	4.586E-04	310.581
828023	59.903	50231.930	4.867E-04	313.581
828815	60.529	50231.930	6.356E-04	317.366
829970	61.141	50231.930	5.988E-04	321.146
830847	61.745	50231.930	6.712E-04	324.151
831755	62.339	50231.930	8.152E-04	328.759
832291	62.923	50231.930	1.004E-03	332.578
832954	63.542	50170.898	1.035E-03	335.062
833437	64.108	50170.898	1.122E-03	338.903
833913	64.618	50231.930	1.181E-03	343.274
834331	65.164	50231.930	1.306E-03	347.987
834331	65.164	50231.930	1.292E-03	347.957b

TEST SPECIMEN: LBY003-E001

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
1771	23.673	45043.949	0.000E+00	289.412
7170	24.286	45104.980	1.100E-04	293.834
13454	24.958	45043.949	1.158E-04	298.222
18451	25.593	45043.949	1.350E-04	302.779
22587	26.192	45104.980	1.583E-04	307.542
26191	26.818	45104.980	-1.913E-03	311.577
45674	28.089	45043.949	7.327E-05	320.716
52545	28.699	45043.949	9.185E-05	324.627
58934	29.307	45043.949	6.321E-08	330.005
59183	28.700	45043.949	8.951E-04	325.121
60111	29.237	45166.020	2.146E-04	328.999
64645	29.836	45166.020	1.505E-04	333.342
67818	30.396	45227.051	1.538E-04	337.921
72351	31.021	45166.020	1.477E-04	341.971
75770	31.571	45227.051	1.870E-04	346.514
78595	32.189	45166.020	2.322E-04	350.537
80907	32.763	45166.020	2.453E-04	354.780
83263	33.334	45166.020	3.590E-04	359.020
84068	33.898	45166.020	4.274E-04	363.231
85894	34.459	45166.020	2.272E-04	367.996
88974	35.013	45166.020	2.104E-04	371.626
91146	35.563	45166.020	3.208E-04	375.815
92385	36.107	45166.020	3.235E-04	379.975
94498	36.648	45166.020	3.017E-04	384.145
95947	37.182	45166.020	3.683E-04	388.287
97568	39.355	45043.949	9.303E-04	405.496
98144	39.864	45043.949	9.414E-04	409.612
98646	40.370	45043.949	7.554E-04	413.739
99476	40.870	45043.949	8.165E-04	417.857
99917	41.407	44982.910	1.060E-03	421.684
100863	42.340	45043.949	7.821E-04	430.174
101779	42.864	44982.910	1.059E-03	433.997
102210	43.767	45043.949	1.064E-03	442.483
105251	44.232	45043.949	5.241E-04	446.580
106464	44.738	44982.910	5.352E-04	450.393
107893	45.646	44982.910	7.453E-04	458.589
108878	46.537	44982.910	8.111E-04	466.796
110065	47.408	44982.910	9.126E-04	474.997
110718	48.216	45043.949	9.767E-04	482.771
111796	49.099	44982.910	8.196E-04	491.451
112793	49.917	44982.910	9.488E-04	499.690
113505	50.720	44982.910	1.065E-03	507.200
114284	51.505	44982.910	1.458E-03	515.464
114570	52.273	44982.910	1.327E-03	523.748
115430	53.025	44982.910	1.067E-03	532.062
115966	53.763	44982.910	1.332E-03	540.413
116525	54.484	44982.910	1.687E-03	548.782
116839	55.236	44921.879	1.773E-03	556.883
117339	55.928	44921.879	1.487E-03	565.321
117759	56.604	44921.879	1.875E-03	573.779
118054	57.268	44921.879	3.061E-03	582.294
118082	57.593	44921.879	3.614E-03	586.539

TEST SPECIMEN: LBY003-E002

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
9	24.126	45166.020	0.000E+00	161.034
145	24.711	45166.020	6.392E-05	163.354
18285	25.294	45166.020	4.180E-05	165.662
27945	25.873	45166.020	4.919E-05	167.954
41709	26.447	45166.020	4.020E-05	170.222
56407	27.017	45166.020	2.442E-06	172.481
72699	26.522	45166.020	4.790E-04	170.521
115095	28.705	45166.020	4.027E-05	178.691
129822	29.223	45227.051	3.774E-05	181.237
143754	29.258	45166.020	6.189E-05	180.886
147103	29.773	45227.051	5.531E-05	183.433
153555	30.353	45166.020	5.643E-05	185.251
166343	30.859	45227.051	5.054E-05	187.785
174205	31.396	45227.051	4.741E-05	189.951
189669	31.965	45166.020	5.124E-05	191.730
195620	32.494	45166.020	1.041E-04	193.874
199800	33.019	45166.020	-5.678E-05	196.012
203716	32.034	45166.020	4.718E-04	192.011
222350	35.576	45166.020	7.135E-05	207.143
230555	36.115	45104.980	8.452E-05	208.285
240389	37.101	45104.980	7.909E-05	212.461
254741	38.028	45166.020	7.204E-05	217.030
260483	38.549	45104.980	1.088E-04	218.701
267410	39.407	45227.051	9.714E-05	223.674
274546	39.915	45166.020	8.017E-05	224.719
280020	40.417	45104.980	5.818E-05	226.353
283493	40.435	45166.020	5.297E-04	227.666
287350	41.733	45166.020	1.995E-04	233.584
292458	42.662	45104.980	1.666E-04	237.914
298141	43.531	45104.980	1.733E-04	241.378
302390	44.383	45104.980	1.581E-04	245.484
308836	45.221	45104.980	1.628E-04	249.600
314935	45.633	45104.980	2.094E-04	251.648
318793	46.446	45104.980	2.097E-04	255.756
321452	46.491	45043.949	2.735E-04	255.987
324703	47.292	45043.949	2.432E-04	260.114
327963	48.075	45043.949	2.805E-04	264.235
330237	48.844	45043.949	2.599E-04	268.367
333826	49.598	45043.949	2.361E-04	272.503
336562	50.338	45043.949	3.055E-04	276.642
338470	51.017	45104.980	2.703E-04	281.290
341882	51.776	45043.949	2.687E-04	284.184
343719	52.428	45104.980	3.010E-04	288.851
346478	53.159	45043.949	2.896E-04	292.518
348562	53.830	45043.949	3.163E-04	296.697
350680	54.488	45043.949	3.159E-04	300.888
352545	55.089	45104.980	3.217E-04	306.454

TEST SPECIMEN: LBY004-E004

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
NPTS =				
2008	23.619	50170.898	0.000E+00	283.045
7773	24.204	50170.898	8.287E-05	286.660
16106	24.787	50170.898	8.423E-05	290.238
21246	25.339	50231.930	9.772E-05	294.776
27937	25.944	50170.898	9.603E-05	298.067
32903	26.458	50292.969	1.263E-04	302.770
36758	27.058	50231.930	1.439E-04	306.408
41000	27.624	50231.930	1.148E-04	310.229
46599	28.187	50231.930	1.319E-04	313.601
49525	28.749	50231.930	1.378E-04	318.242
54704	29.304	50231.930	1.415E-04	321.553
57365	29.858	50231.930	1.964E-04	325.286
60320	30.407	50231.930	1.934E-04	329.437
63208	30.988	50170.898	2.060E-04	332.460
65613	31.498	50231.930	2.055E-04	335.901
68307	32.036	50231.930	2.543E-04	340.001
69841	32.573	50231.930	1.753E-04	343.644
74407	33.105	50231.930	1.368E-04	346.792
77586	33.633	50231.930	2.833E-04	350.858
78123	34.158	50231.930	3.170E-04	354.447
80888	34.679	50231.930	2.042E-04	358.022
83220	35.198	50231.930	2.537E-04	361.592
84958	35.712	50231.930	2.914E-04	365.135
86738	36.224	50231.930	3.734E-04	368.681
87690	36.732	50231.930	2.625E-04	372.720
90590	37.235	50231.930	2.522E-04	375.727
91669	37.736	50231.930	4.179E-04	379.240
94156	38.725	50231.930	2.456E-04	386.229
95994	38.798	50231.930	4.113E-04	387.271
96433	41.177	50170.898	7.382E-04	403.871
97880	41.689	50109.859	6.787E-04	406.519
98500	42.580	50170.898	5.063E-04	414.205
100632	43.082	50109.859	3.773E-04	416.825
102135	43.951	50170.898	5.355E-04	423.927
103931	44.849	50170.898	5.394E-04	431.358
105436	45.732	50170.898	5.597E-04	437.598
107060	46.600	50170.898	5.149E-04	443.811
108787	47.457	50170.898	6.524E-04	450.625
109728	48.341	50109.859	6.817E-04	457.768
111235	49.126	50170.898	7.332E-04	464.842
111971	49.985	50109.859	8.530E-04	471.383
113182	50.787	50109.859	7.799E-04	478.832
114009	51.575	50109.859	8.911E-04	484.325
114887	52.306	50170.898	9.345E-04	491.400
115656	53.114	50109.859	1.137E-03	497.937
116216	53.818	50170.898	1.198E-03	505.010
116897	54.601	50109.859	1.010E-03	512.261
117397	55.011	50048.828	2.612E-03	514.706
118761	60.352	50170.898	3.403E-03	570.350
118903	60.980	50170.898	3.605E-03	577.302
119107	61.599	50170.898	3.442E-03	584.296
119273	62.253	50109.859	3.173E-03	591.031
119487	62.805	50170.898	3.604E-03	598.324
119589	63.392	50170.898	4.402E-03	605.362
119762	64.015	50109.859	3.795E-03	612.163
119891	64.538	50170.898	3.436E-03	619.526
120090	65.143	50109.859	3.984E-03	626.382
120181	65.693	50109.859	4.787E-03	633.548
120318	66.234	50109.859	4.235E-03	640.727
120434	66.765	50109.859	3.918E-03	647.924
120587	67.288	50109.859	4.332E-03	655.164
120673	67.800	50109.859	5.755E-03	662.403
120764	68.307	50109.859	4.850E-03	669.709
120921	69.003	50170.898	4.970E-03	680.940
121011	69.534	50109.859	5.379E-03	689.019
121152	70.246	50109.859	5.108E-03	699.185
121250	70.755	50048.828	5.341E-03	706.394
121367	71.394	50109.859	5.571E-03	717.882
121492	72.103	50048.828	5.958E-03	728.947
121588	72.711	50109.859	5.944E-03	740.606
121708	73.387	50048.828	5.910E-03	751.842
121800	73.964	50109.859	6.279E-03	763.658
121896	74.567	50109.859	7.224E-03	775.313
121965	75.155	50109.859	7.972E-03	787.045

TEST SPECIMEN: LBY004-E005

N. Cicli	Lunghezza	Carico Max	da/dN	Delta K
NPTS =				
9	24.288	56396.480	0.000E+00	179.278
2520	24.806	56396.480	5.028E-05	181.873
20562	25.322	56396.480	2.377E-05	184.062
45881	25.837	56396.480	-1.915E-05	186.245
47467	24.807	56396.480	5.631E-04	181.874
52221	25.044	62622.070	5.884E-05	203.116
77940	25.925	62622.070	3.039E-05	207.262
109939	26.798	62622.070	3.227E-05	211.361
131891	27.665	62622.070	1.902E-05	215.843
132797	27.233	62622.070	3.277E-04	213.398
137551	25.044	62622.070	5.884E-05	203.116
163270	25.925	62622.070	3.039E-05	207.262
195269	26.798	62622.070	3.227E-05	211.361
217221	27.665	62622.070	1.902E-05	215.843
218127	27.233	62622.070	3.277E-04	213.398
226525	32.862	62683.109	1.647E-04	240.238
231481	33.724	62683.109	1.756E-04	244.324
236284	34.575	62683.109	1.801E-04	248.371
240887	35.418	62683.109	1.808E-04	252.403
245729	36.282	62622.070	1.755E-04	255.561
250513	37.108	62622.070	1.897E-04	260.050
254369	37.922	62622.070	1.999E-04	264.013
258618	38.728	62622.070	2.196E-04	267.968
276343	39.633	62622.070	2.790E-04	271.917
279879	40.398	62683.109	2.979E-04	276.267
281554	41.186	62683.109	3.475E-04	280.238
284472	41.994	62622.070	2.939E-04	284.353
286807	42.730	62683.109	2.929E-04	288.136
289679	43.519	62622.070	3.172E-04	291.671
291659	44.268	62622.070	3.332E-04	295.600
294140	45.006	62622.070	2.883E-04	299.514
298200	47.899	62561.039	6.407E-04	315.335
299035	48.592	62561.039	6.383E-04	319.250
300352	49.272	62561.039	5.571E-04	323.774
301466	49.947	62561.039	6.063E-04	327.691
302557	50.609	62561.039	7.058E-04	330.300
303333	51.264	62561.039	6.694E-04	334.851
304501	51.911	62561.039	6.750E-04	338.095
305236	52.549	62561.039	7.873E-04	343.343
306109	53.177	62561.039	7.639E-04	346.577
306917	53.833	62500.000	7.261E-04	350.723
307805	54.408	62561.039	7.772E-04	354.409
308435	55.013	62561.039	6.925E-04	358.343
309535	55.606	62561.039	1.963E-04	362.260
314449	56.194	62561.039	2.098E-04	366.199
315096	56.773	62561.039	1.001E-03	370.144
315597	57.343	62561.039	9.630E-04	374.083
316310	57.942	62500.000	1.029E-03	377.556
316683	58.460	62561.039	1.204E-03	381.995
317225	59.044	62500.000	1.063E-03	385.477
317705	59.547	62561.039	9.814E-04	389.174
318317	60.116	62500.000	9.299E-04	392.658
318317	60.116	62500.000	2.626E-03	392.658

TEST SPECIMEN: CAY005-E002

CICLI	a	P max	da/dN	Delta K
42	28.862	56396.48	0	199.003
10259	29.388	56335.45	0.000062	201.215
24044	30.34	56396.48	0.000077	205.671
29460	30.858	56335.45	0.000038	207.41
62157	31.793	56396.48	0.000036	211.818
69556	32.304	56335.45	0.000077	213.522
81038	33.255	56335.45	0.00004	217.085
116338	34.16	56396.48	0.000044	221.42
123088	35.087	56396.48	0.000064	225.88
145117	36.004	56396.48	0.000053	229.845
150079	36.524	56274.41	0.000157	231.103
153929	37.389	56335.45	0.000127	235.378
163835	38.277	56335.45	0.000108	239.282
170305	39.153	56335.45	0.000136	242.638
176585	40.017	56335.45	0.000133	247.031
183203	40.869	56335.45	0.000086	250.883
186548	40.871	56396.48	0.000223	251.436
195675	41.602	56518.55	0.000146	254.228
200640	42.394	56579.59	0.000159	258.439
206052	43.25	56518.55	0.000151	261.864
211664	44.055	56518.55	0.000144	265.665
217200	44.85	56518.55	0.000161	269.458
235434	46.024	56518.55	0.000065	275.147
241082	46.791	56518.55	0.000143	278.928
246372	47.587	56457.52	0.000155	282.293
250822	48.295	56518.55	0.000157	286.495
255576	49.031	56518.55	0.000168	290.274
259541	49.756	56518.55	0.000171	294.0[illegible]7
264002	50.47	56518.55	0.000193	297.82
266908	51.174	56518.55	0.000224	301.597
270260	51.868	56518.55	0.000209	305.379
273505	52.554	56518.55	0.000206	309.168
277045	53.268	56457.52	0.00023	312.502
279316	53.892	56518.55	0.00022	316.057
283036	54.586	56457.52	0.000217	320.073
285475	55.231	56457.52	0.000217	323.867
288940	55.867	56457.52	0.000231	327.673
290937	56.492	56457.52	0.000264	331.473
293653	57.109	56457.52	0.000245	335.287
295926	57.716	56457.52	0.000224	338.367
299040	58.314	56457.52	0.00024	342.929
300876	58.904	56457.52	0.00027	346.765
303380	59.486	56457.52	0.000269	349.853
305164	60.057	56457.52	0.00032	353.69
305164	60.057	56457.52	0.000506	353.69

CICLI	a	P max	da/dN	Delta K
316099	53.931	56457.52	0.00022	316.283
317959	54.586	56457.52	0.000436	319.377
318989	55.191	56518.55	0.000521	323.633
320339	55.826	56518.55	0.000492	326.717
321635	56.492	56457.52	0.000457	330.752
323057	57.068	56518.55	0.000446	335.032
324292	57.676	56518.55	0.000455	338.116
325800	58.316	56457.52	0.000498	342.192
326678	58.864	56518.55	0.000549	346.504
327858	59.445	56518.55	0.000513	350.34
328921	60.016	56518.55	0.00047	354.95
330273	60.58	56518.55	0.000538	358.039
331003	61.136	56518.55	0.000602	361.125
332034	61.641	56579.59	0.000515	365.484
333110	62.222	56518.55	0.000478	369.673
334358	62.752	56518.55	0.000552	372.75
335019	63.276	56518.55	0.000607	376.656
336138	63.832	56457.52	0.000535	380.048
337006	64.339	56457.52	0.000534	383.966
338027	64.84	56457.52	0.000583	388.748
339060	65.537	56518.55	−0.00264	395.22
339612	60.663	56396.48	0.001933	357.829
340158	61.58	56335.45	0.00075	364.258
341045	62.091	56396.48	0.000703	368.721
341715	62.674	56335.45	0.000795	372.986
342452	63.209	56335.45	0.000753	376.154
343122	63.734	56335.45	0.000762	380.131
[illegible]3323	64.2[illegible]3	56335.45	0.000856	384.135
344373	64.805	56274.41	0.000849	387.629
345066	65.308	56274.41	0.000718	391.649
345989	65.966	56396.48	0.000858	399.624
346491	66.53	56274.41	0.000948	401.749
347337	67.244	56274.41	0.000821	407.868
347976	67.75	56213.38	0.000879	411.418
348600	68.354	56335.45	0.000967	419.573
349147	68.883	56213.38	0.001004	421.693
349745	69.504	56274.41	0.000986	428.472
350430	70.148	56274.41	0.000941	434.724