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wtndt@metu.edu.tr http://rd.kredit.metu.edu.tr

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Test
TS EN ISO IEC 17025
AB-0943-T

AB-0943-T
15-349
01-16

TEST REPORT
DENEY RAPORU

Customer name *Müşterinin adı*	Vastaş Valf Armatür Sanayi Tic. A.Ş.
Customer Address *Müşterinin Adresi*	Organize San. Bölgesi 2. cad. No:20-22 Çerkezköy / Tekirdağ
Weld No. *Kaynak Numarası*	TNP-012-BW1
WPS / PQR No. *WPS / PQR Numarası*	WPS-94/PQR -20
Pipe / Heat No. (Pipe 1) *Boru / Döküm Numarası (Boru 1)*	VST-012-1
Pipe / Heat No. (Pipe 2) *Boru / Döküm Numarası (Boru 2)*	VST-012-2
Form / thickness of specimen *Numune formu / kalınlığı*	Pipe / 22.5 mm
Parent / filler material *Ana malzeme / Dolgu malzemesi*	Ast A350 Gr. LF2 / ER70S-6
Date of receipt of the specimens *Numunelerin kabul tarihi*	25.12.2016
Number of pages of the report *Raporun sayfa sayısı*	8

Definition of the material used and the process of manufacturing information are based on statements of the client. Our laboratory accepts no liability for the correctness, relevance or consistency between results of tests/examinations and the material specified.
(Deney numunelerinin hazırlandığı malzeme ve yöntem bilgileri için müşteri beyanı esas alınır. Laboratuvarımız deney ve inceleme sonuçları ile malzeme tanımları arasında oluşacak tutarsızlıktan sorumlu değildir.)

The test and/or measurement results, the uncertainties (if applicable) with confidence probability and test methods are given on the following pages which are part of this report.
Deney ve /veya ölçüm sonuçları, genişletilmiş ölçüm belirsizlikleri (olması halinde) ve deney metodları bu sertifikanın tamamlayıcı kısmı olan takip eden sayfalarda verilmiştir.

Seal *Mühür*	Date *Tarih*	Persons in Charge *Deney Sorumluları*	Head of the Center *Merkez Başkanı*
METU Welding Technology & NDT Research Application Center ANKARA TURKEY	13.01.2016	M. Tolga ERTÜRK	Prof. Dr. C. Hakan GÜR

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FRACTURE TOUGHNESS
Kırılma Tokluğu

Test Standard: *Deney Standardı*	**ISO 15653**		
Test Personnel: *Deney Sorumlusu*	Murat Tolga Ertürk	**Date of precracking:** *Ön çatlak açma tarihi*	5.1.2016
Test Temperature: *Deney sıcaklığı (°C)*	-10	**Date of test:** *Deney tarihi*	5.1.2016
Weld Metal Yield strength *Akma dayancı – Oda Sıcaklığı (MPa)*	589	**Weld Metal Yield strength*** **@Test Temperature** *Akma dayancı – Test Sıcaklığı (MPa)*	611
Weld Metal Tensile strength *Çekme dayancı – Oda Sıcaklığı (MPa)*	660	**Weld Metal Tensile strength*** **@Test Temp.** *Çekme dayancı – Test Sıcaklığı (MPa)*	685
Base Metal Yield strength *Akma dayancı – Oda Sıcaklığı (MPa)*	497	**Base Metal Yield strength*** **@Test Temp.** *Akma dayancı – Test Sıcaklığı (MPa)*	519
Base Metal Tensile strength *Çekme dayancı – Oda Sıcaklığı (MPa)*	250	**Base Metal Tensile strength*** **@Test Temp.** *Çekme dayancı – Test Sıcaklığı (MPa)*	261
Modulus of elasticity @RT *Elastik modulus – Oda Sıcaklığı (GPa)*	202	**Modulus of elasticity @Test Temp.** *Elastik modulus – Test Sıcaklığı (GPa)*	202
Force Span S *Mandrel mesafesi (mm)*	160	**Knife edge "stand off" z** *Bıçak kalınlığı (mm)*	0
Test speed *Deney hızı (mm/min)*	0.8	**Type of Displacement Control** *Deplasman kontrolü*	Displacement

* *Values are derived from the relation expressed for ferritic steels according to ISO 15653:2010 item 12.1.*
* *Değerler ISO 15653:2010 standardı 12.1. maddesde ferritik çelikler için verilen formülasyon esas alınarak hesaplanmıştır.*

Specimen Information
Numune bilgileri

	Specimens *Numuneler*								
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
Crack-plane orientation **Çatlak düzlem konumu**	NP	NP	NP	NP	NP	NP	NP	NP	NP
Location of specimen **Numune konumu**	Weld	FL	FL+2	Weld	FL	FL+2	Weld	FL	FL+2
Thicknesses B / B_n **Kalınlıklar (mm)**	19.83	19.80	19.55	19.82	19.81	19.83	19.80	19.86	19.76
Width W **Genişlik (mm)**	39.96	39.99	40.03	40.01	39.96	40.00	39.40	39.96	39.98



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Crack Length Measurements
Çatlak boyu ölçümleri

	Specimens *Numuneler*								
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
Mach. notch length (a_m) *İşlenmiş çentik boyu (mm)*	16.20	16.20	16.20	16.20	16.20	16.20	16.20	16.20	16.20
Initial crack length (a_0) *İlk çatlak boyu*	19.81	19.83	20.34	19.99	20.09	19.81	20.05	19.74	19.78
Precrack length (a_0–a_m) *Ön çatlak boyu (mm)*	3.61	3.63	4.14	3.79	3.89	3.61	3.85	3.54	3.58
Final crack length (a_f) *Son çatlak boyu (mm)*	20.15	20.16	19.69	20.02	19.87	20.19	19.35	20.22	20.20
Stable crack extension(Δa) *Ortalama çatlak uzaması*	1.06	1.12	1.00	0.93	1.10	1.11	1.16	8.86	1.11
Initial relative crack length a_0/W	0.50	0.50	0.51	0.50	0.50	0.50	0.51	0.49	0.49

Test results
Deney sonuçları

	Specimens *Numuneler*								
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
Type of fracture *Kırılma tipi (c, u, m)*	M	M	M	M	M	M	M	U	M
Extensometer displacement V_P *Ekstansometre deplasmanı (mm)*	1.88	4.62	4.57	2.31	4.60	4.61	2.70	3.43	4.58
Force at CTOD Fcrit *CTOD değerindeki yük (kN)*	40.70	41.08	39.13	41.22	40.59	41.64	39.33	42.47	42.60
CTOD value δ *CTOD değeri (mm)*	**0.586**	**1.378**	**1.319**	**0.706**	**1.349**	**1.380**	**0.798**	**1.043**	**1.376**



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Fracture Surfaces
Kırılma yüzeyleri

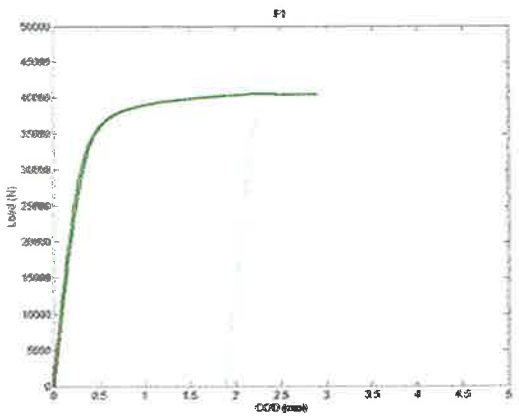
F1	F2	F3
		
Remarks *Notlar* -	**Remarks** *Notlar* -	**Remarks** *Notlar* -
F4	**F5**	**F6**
		
Remarks *Notlar* -	**Remarks** *Notlar* -	**Remarks** *Notlar* -
F7	**F8**	**F9**
		
Remarks *Notlar* -	**Remarks** *Notlar* -	**Remarks** *Notlar* -

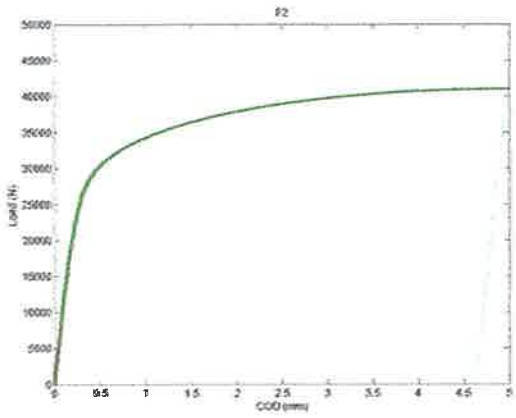


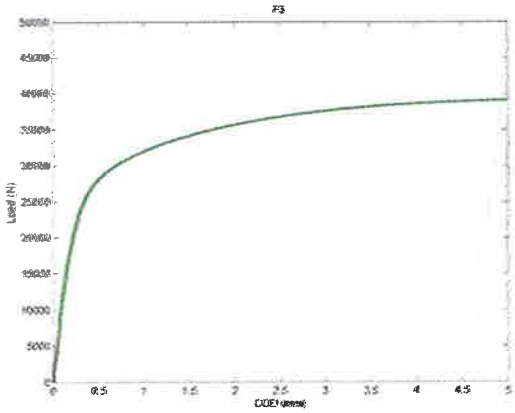
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Fracture curves
Kırılma Eğrileri

F1, F2, F3





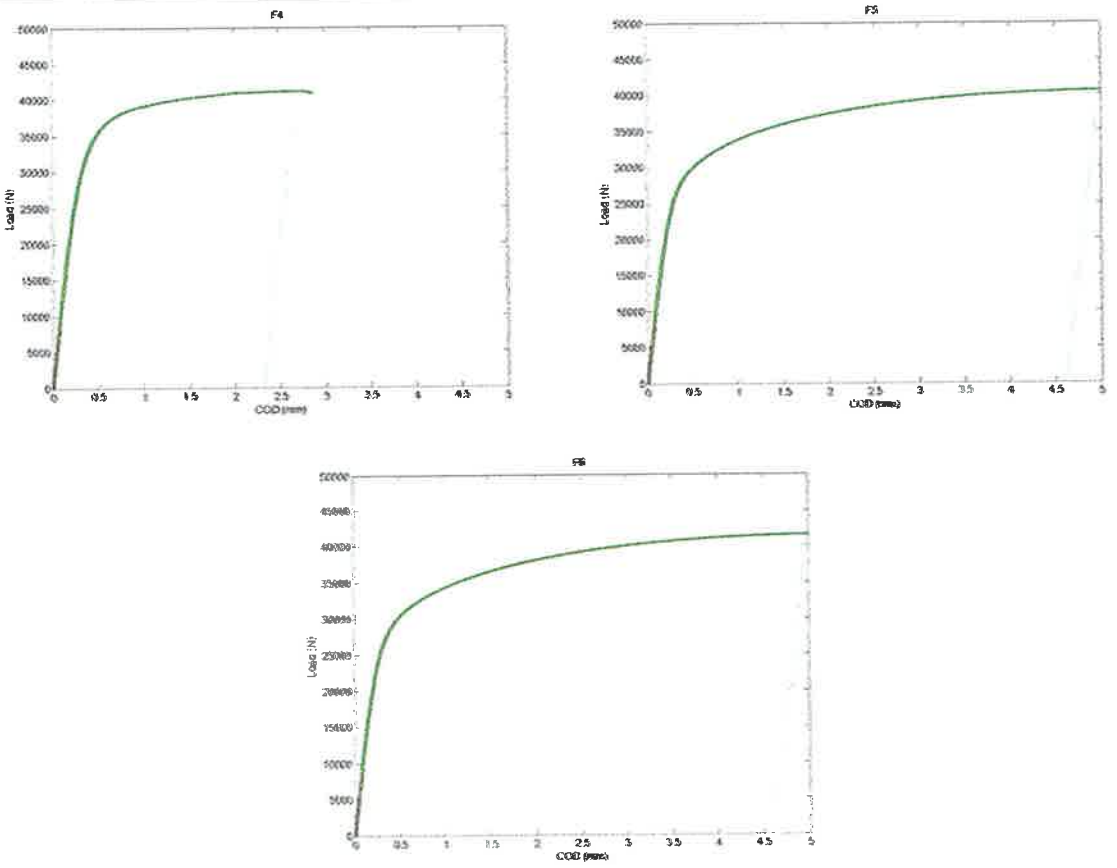


Remarks *Notlar*	

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F4, F5, F6

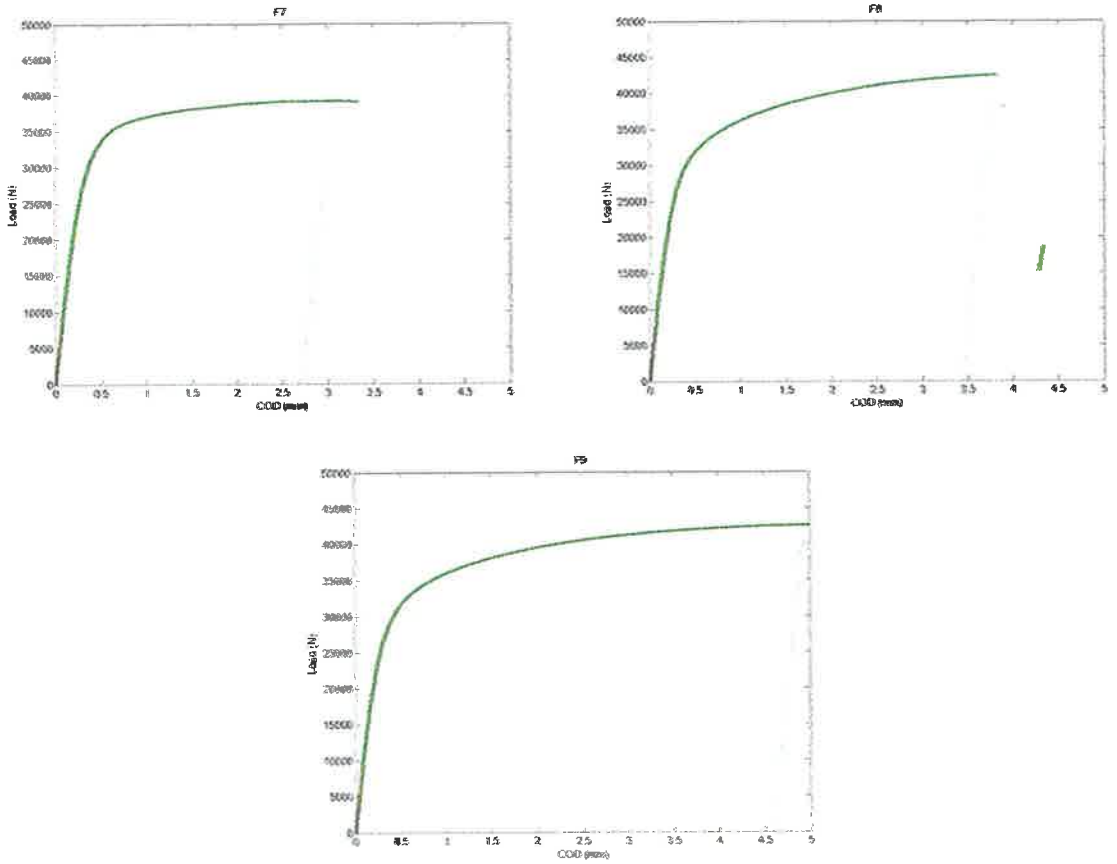


Remarks *Notlar*	

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F7, F8, F9

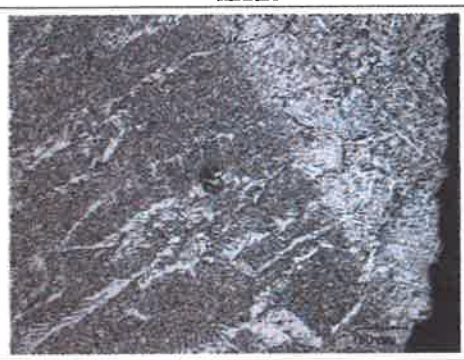
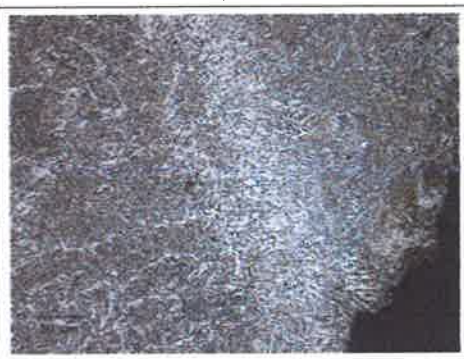
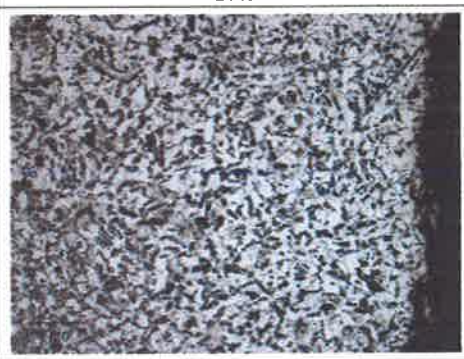
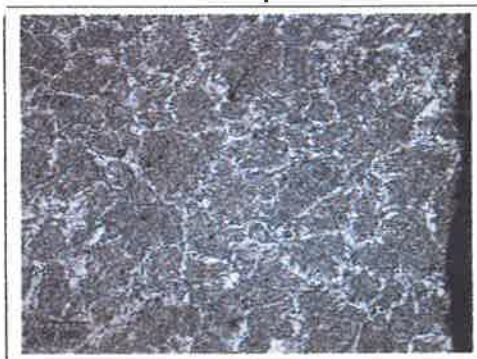
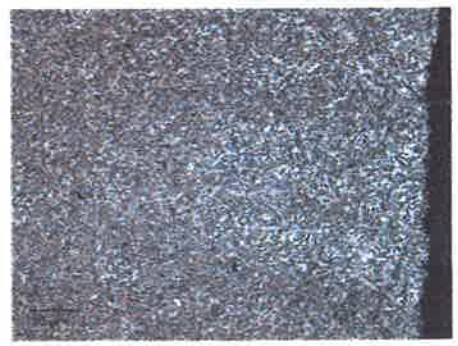


Remarks *Notlar*	

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Post-Test Metallography
Metalografik İnceleme

$F2_{top}$	$F2_{middle}$	$F2_{bottom}$
		
Remarks *Notlar* -	**Remarks** *Notlar* -	**Remarks** *Notlar* -
$F5_{top}$	$F5_{middle}$	$F5_{bottom}$
		
Remarks *Notlar* -	**Remarks** *Notlar* -	**Remarks** *Notlar* -
$F8_{top}$	$F8_{middle}$	$F8_{bottom}$
		
Remarks *Notlar* -	**Remarks** *Notlar* -	**Remarks** *Notlar* -

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TEST REPORT
DENEY RAPORU

Customer name *Müşterinin adı*	Vastaş Valf Armatür Sanayi Ticaret A.Ş.
Customer Address *Müşterinin adresi*	Organize Sanayi Bölgesi 2. Cad. No: 20-22 59500 Çerkezköy / TEKİRDAĞ
Procedure No. *Yöntem numarası*	Not specified *Belirtilmedi*
Form / thickness of specimen *Numune formu / kalınlığı*	Pipe *(Boru)* t= 22.5mm
Parent / filler material *Ana malzeme / Dolgu malzemesi*	ASTM A350 Gr. LF2 / ER70S-6
Weld method *Kaynak yöntemi*	GTAW + GMAW
Date of receipt of the pipe rings *Boru halkalarının teslim alındığı tarih*	21.12.2015
Purpose of tests and examination *Deney ve inceleme nedeni*	WPS qualification *Yöntem vasıflandırma*
Number of pages of the report *Raporun sayfa sayısı*	4

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The test and/or measurement results, the uncertainties (if applicable) with confidence probability and test methods are given on the following pages which are part of this report.

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Mühür

METU Welding Technology & NDT Research/Application Center
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Date
Tarih
12.1.2016

Persons in charge of test
Deney sorumluları
Yücel ATEŞ

Head of the Center
Merkez Başkanı
PROF. Dr. C. HAKAN GÜR

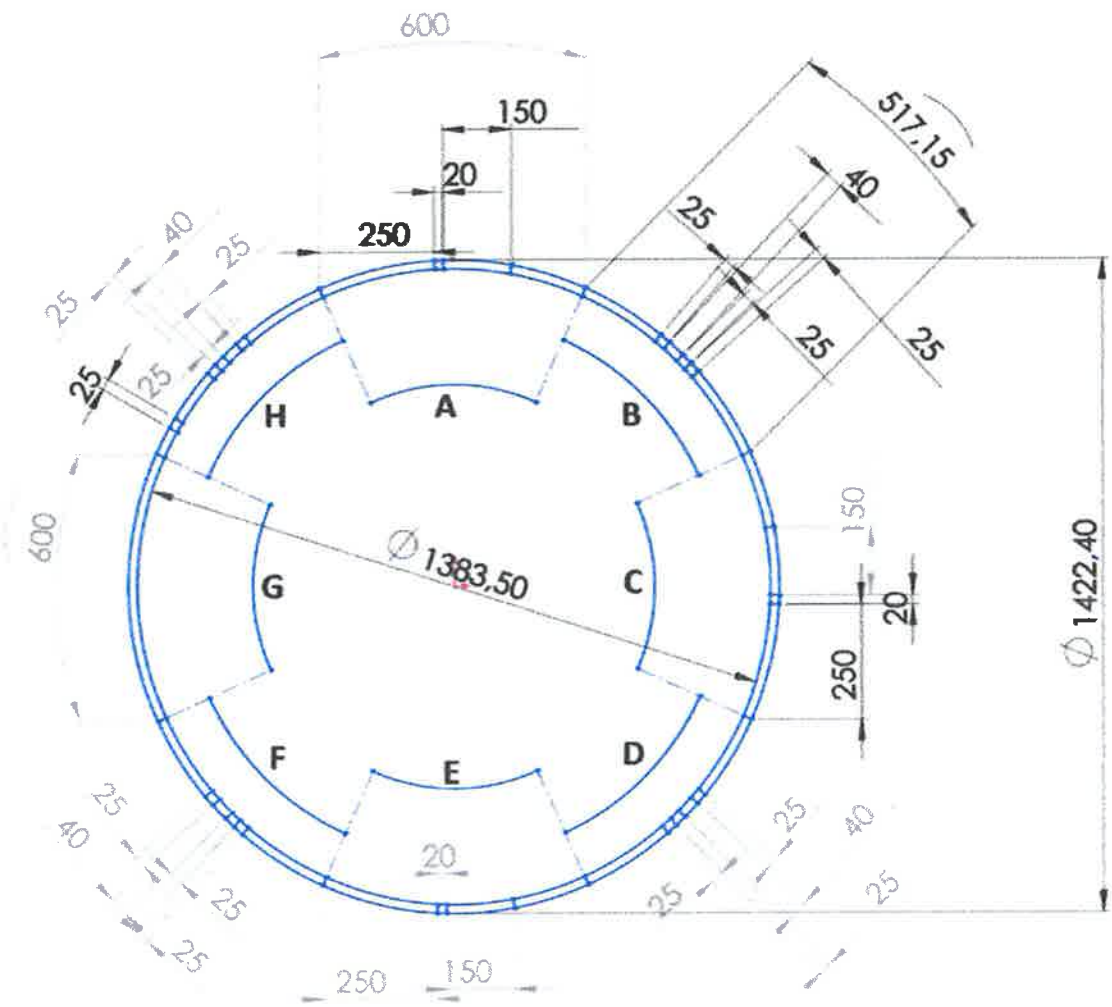
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TEMPLATE FOR SPECIMEN LOCATIONS

Numune bölgeleri için şablon



PIPE INFORMATIONS

Boru Bilgileri

Pipe code *Boru kodu*	Manufacturer *Üretici*	Heat number *Döküm numarası*	Pipe number *Boru numarası*
1	-	-	-
2	-	-	-

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IMPACT TOUGHNESS TEST
Çentik Darbe Deneyi

Test Data
Deney Bilgileri

Test Standard: *Deney Standardı*	API 1104 / ASTM E23		
Test Personnel: *Deney Sorumlusu*	Yücel ATEŞ	**Date of test:** *Deney Tarihi*	11.01.2016
Type of notch: *Çentik tipi*	V	**Size of specimens** *Numunelerin boyutu*	10x10x55

Test Results
Deney sonuçları

Specimens *Numune*	Test temperature *Deney sıcaklığı(°C)*	Dimensions *Boyutlar (mm)*	Location of the specimen *Numune Bölgesi*	Location of the notch *Çentik bölgesi*		Absorbed energy *Soğrulan enerji (J)*	Remarks *Notlar*
				On cross-section *Kesitte*	On pipe *Boruda*		
1	-46	10x10x55	Arc A	Weld Center *Kaynak merkezi*	-	78	-
16	-46	10x10x55	Arc C	Weld Center *Kaynak merkezi*	-	69	-
31	-46	10x10x55	Arc E	Weld Center *Kaynak merkezi*	-	88	-
4	-46	10x10x55	Arc A	Fusion Line *Erime Çizgisi*	1	194	-
19	-46	10x10x55	Arc C	Fusion Line *Erime Çizgisi*	1	195	-
34	-46	10x10x55	Arc E	Fusion Line *Erime Çizgisi*	1	214	-
7	-46	10x10x55	Arc A	Fusion Line +1mm *Erime Çizgisi + 1mm*	1	164	-
22	-46	10x10x55	Arc C	Fusion Line +1mm *Erime Çizgisi + 1mm*	1	176	-
37	-46	10x10x55	Arc E	Fusion Line +1mm *Erime Çizgisi + 1m*	1	174	-



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IMPACT TOUGHNESS TEST
Çentik Darbe Deneyi

Test Data
Deney Bilgileri

Test Standard: *Deney Standardı*	API 1104		
Test Personnel: *Deney Sorumlusu*	Yücel ATEŞ	**Date of test:** *Deney Tarihi*	7.1.2016
Type of notch: *Çentik tipi*	V	**Size of specimens** *Numunelerin boyutu*	10x10x55

Test Results
Deney sonuçları

Specimens *Numune*	Test temperature *Deney sıcaklığı(°C)*	Dimensions *Boyutlar (mm)*	Location of the specimen *Numune Bölgesi*	Location of the notch *Çentik bölgesi*		Absorbed energy *Soğrulan enerji (J)*	Remarks *Notlar*
				On cross-section *Kesitte*	On pipe *Boruda*		
1	-10	10x10x55	Arc A	Weld Center *Kaynak merkezi*	-	129	-
16	-10	10x10x55	Arc C	Weld Center *Kaynak merkezi*	-	131	-
31	-10	10x10x55	Arc E	Weld Center *Kaynak merkezi*	-	183	-
4	-10	10x10x55	Arc A	Fusion Line *Erime Çizgisi*	1	185	-
19	-10	10x10x55	Arc C	Fusion Line *Erime Çizgisi*	1	148	-
34	-10	10x10x55	Arc E	Fusion Line *Erime Çizgisi*	1	203	-
7	-10	10x10x55	Arc A	Fusion Line +1mm *Erime Çizgisi + 1mm*	1	260	-
22	-10	10x10x55	Arc C	Fusion Line +1mm *Erime Çizgisi + 1mm*	1	289	-
37	-10	10x10x55	Arc E	Fusion Line +1mm *Erime Çizgisi + 1m*	1	196	-



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Fracture toughness assessment of as-welded A350 LF2

Assessment Report

Dr. Koray Yurtışık (IWE/EWE D-S-80636-1173-051207-0510691)

1. Introduction

The economic viability of construction of new long-distance high-capacity pipelines for gas transmission is dependent on the cost-revenue balance. Once consideration of operational and environmental factors is completed, material selection then becomes the most critical issue in engineering and design processes.

Whereas Grade X70 M that is manufactured to product specification level PSL 2 is identified as suitable for line pipe material and for non-sour service in the TANAP project, A/SA-350 Grade LF2 would be the material for the manufacture of flanges and fittings, and applications which require cold temperature service. LF2 is a general Carbon steel usually supplied in the normalized, normalized and tempered or quench and tempered condition. Moderate strength and impact toughness are its typical characteristics.



Figure 1. Delivered LF2 pipe material.

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The purpose of this document is to present and assess the strength and fracture toughness properties of as-welded LF2 pipe material that was delivered by VASTAŞ Valves and Actuators in terms of ductile fracture propagation/arrest toughness.

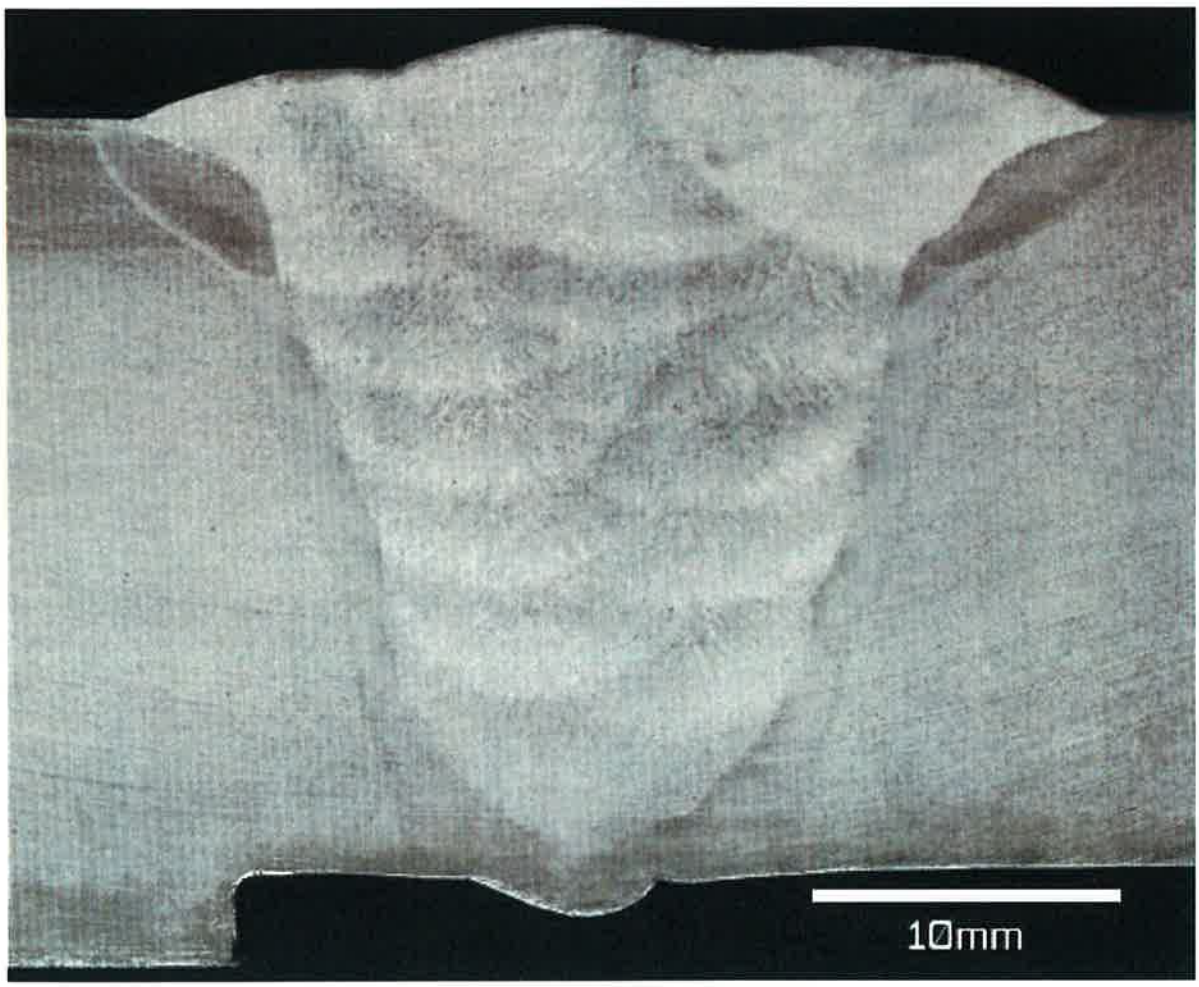


Figure 2. Macro section of the welding joint.

2. The Material subjected to fracture toughness tests

LF2 is readily weldable by any technique. VASTAŞ Valves and Actuators delivered 12" A/SA-350 Grade LF2 pipe with a circumferential welding joint. GTAW and GMAW techniques were applied during root and successive (fill and cap) weld passes, respectively. AWS A/SFA 5.18 ER70S-6 was deposited as filler metal

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under proper shielding atmosphere. 14 weld passes were introduced to the bevel and heat input of the process was 2.7 kJ mm^{-1} and less according to the welding procedure specification.

Weld seam on the pipe material (Figure 1) was observed to be quite successful in terms of form of the reinforcement and root. Macro section of the weld is represented in Figure 2.

3. Strength of the all-weld metal

All-weld tensile test was conducted at room temperature to determine strength properties of the all-weld metal. The test specimens are of circumferential cross section with reduced width at the mid-length. The specimens were prepared in accordance with the requirements of the standard ISO 6892-1. L_o is specified according to the definition,

$$L_o = 5.65\, S_o{}^{1/2}$$

Visual examination and dimension check procedure was applied to guarantee that the dimensions were proper per the standard.

Yield and ultimate tensile strength were determined with the ultimate load (F) and the original cross-sectional area of the parallel length (S_o). Ductility parameter was determined via measuring L_o, L_u, S_o and S_u. Using the caliper gauge, the diameter and the gauge length shall be measured % ±1 or better accuracy with decimal sensitivity.

Strain rate ($\dot{e}_{L_c}$) was less than 0,00025 s^{-1} according to ISO 6892-1 Clause 10.3. Divergence speed of crossheads (V_c) are calculated by multiplying parallel length (L_c) with strain rate and corresponded to 0.6 mm min^{-1} up to initiation of the plastic strain. Exceeding the yield, divergence speed was set to 5 mm min^{-1}. 20 N pre-load was applied to guarantee proper gripping.

Testing operation finalized when a complete fracture of the specimen was obtained. Unifying the two pieces of the broken specimen carefully in a way that both axis of the broken pieces were in same direction, final dimensions of the specimen was measured and percent elongation was calculated as follows:

$$EL\% = 100\,\frac{L_u - L_o}{L_o}$$

Ultimate tensile strength shall be determined as follows:

$$R_m = \frac{F}{S_o}$$

Measured and calculated parameters (Figure 3) were recorded as follows:

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E = 201.6 GPa,
$R_{p0.2}$ = 588.7 MPa,
$R_{p0.5}$ = 592 MPa, and
R_m = 660.3 MPa.

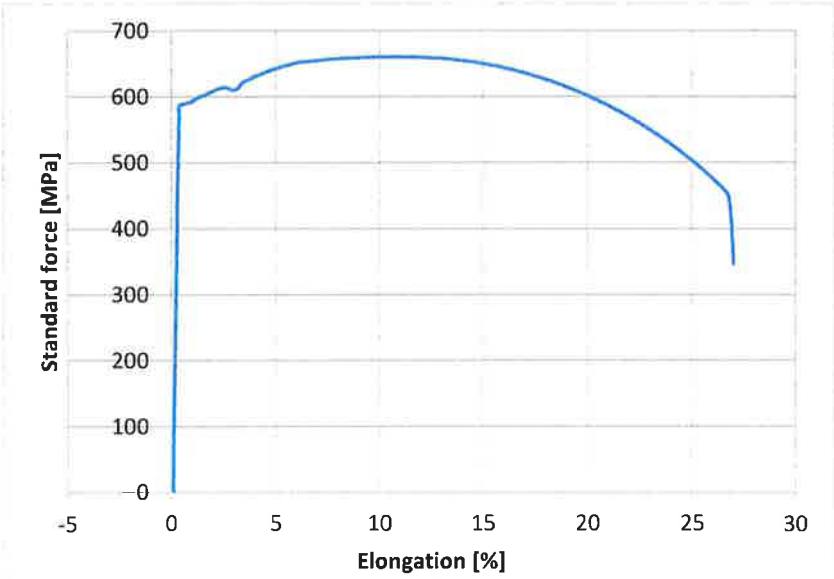


Figure 3. Stress vs strain curve of weld metal of LF2 joint

4. Ductile fracture propagation/arrest

Controlling the crack initiation and propagation is an important design issue. Crack propagation rates due to leakage, gas pressure and ambient conditions may reach hyperacoustic level and may result in gross damage along pipeline sections [1].

The basic approach for the fracture control is to obstacle a possible crack propagation with convenient crack arrest mechanism. Reduced propagation rate or total crack arrest is observed during passage from low toughness initiation pipe to tougher metal body [1]. In order assess required toughness level for the arrest mechanism fracture initiation models have been developed [2].

Ductile fracture propagation process is a complex interaction of structural behavior of the cracking pipe and the fluid mechanics of the escaping gas. Research at Batelle [3] and British Gas [4] had identified correlations

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between both fracture velocity and appearance and the energy absorbed, percentage shear area and the transition temperature. Tests for brittle fracture could be carried out using comparatively simple tests on pipes, pressurized with a mixture of air and water, namely West Jafferson Test [3]. Subsequently the Drop Weight Tear Test (DWTT) and Charpy V-notch Test (CVN) became the accepted criterion for avoiding brittle fracture propagation; while the former provides an assessment of impact energy during ductile fracture testing of full-scale thickness, the later can be executed more simply and quickly. DWT tests should provide with 85% or higher shear surface on fractured section [5]. By DWTT method application thickness and thus stress triaxiality of the application at higher deformation rate could be attained on test piece properly. The upper shelf Charpy energy has been widely used as a measure of resistance to ductile crack propagation.

The minimum design metal temperature (MDMT) is one of the design conditions for pressure vessel and piping engineering calculations, design and manufacturing according to the ASME Boilers and Pressure Vessels Code. The precise definition can sometimes be a little elaborate, but on simple terms the MDMT is a temperature arbitrarily selected by the user of the vessel according to the type of fluid and the temperature range the enclosing assembly is going to handle.

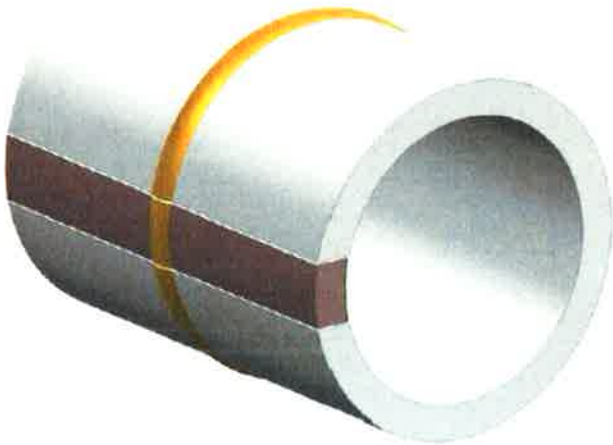


Figure 4. Orientation of Charpy V-notch and 3-point bending CTOD specimens.

MDMT could be defined according to the ambient or operational temperature and/or possible supercritical (pressure/temperature) conditions like during a gas release due to a leakage. The so-called arbitrary MDMT must be lower than or equal to the critical exposure temperature (CET), which is an environmental or "process" property. MDMT is accepted as the lowest expected in service expected in service except when lower temperatures are permitted by the rules of the division of the code [6] (see also

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UCS-66, UCS-160, and footnote 37, UG-116). CET is the lowest anticipated temperature to which the vessel will be subjected, taking into consideration lowest operating temperature, operational upsets, autorefrigeration, atmospheric temperature, and any other sources of cooling. In some cases it may be the lowest temperature at which significant stresses will occur and not the lowest possible temperature. According to composition, flow and pressure of the transmitted gas operating temperature may vary. Lowest metal temperature is dependent on ambient air/ground temperature, operating temperature and thickness. Impact testing should be applied at or below lowest expected metal temperature during service and lower effects of ground and air temperature is considered.

In general, the temperature of the natural gas exiting a compressor station ranges from 100°F to 120°F (40 – 50°C). Once the natural gas leaves the compressor and travels underground, the temperature of the gas falls rapidly and approaches the ambient underground temperature. In the winter, pipelines located above the frost line may have flowing gas temperatures less than 32°F (0°C), while the gas temperature in pipelines buried below the frost line is not likely to fall below freezing and will remain fairly constant. MDMT, and so fracture toughness testing temperature, has been specified as -10°C in the project for pipes.

5. Fracture toughness of the as-welded and parent metals

Charpy-V notch and crack tip opening displacement fracture toughness tests were conducted on as-welded LF2 material. Testing procedures were in accordance with API Standard 1104 21st Edition, Errata 1 (2014) and the TANAP / WorleyParsons Specification for Welding and NDT of Onshore Pipelines, WRP-SPC-MTE-PLG-006. The testing laboratory is accredited per ISO/IEC 17025 by Turkish Accreditation Institution and the testing procedures were also approved by The Welding Institute (UK).Charpy-V notch testing procedure conforms to ASTM E23. Charpy V-notch impact test specimens were prepared with their lengths parallel to the pipe axis (Figure 4). The standard size specimens were tested as shown in Figure 5.

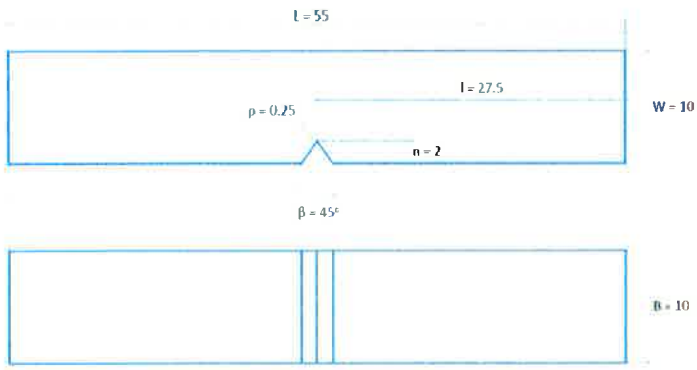


Figure 5. Dimensions of the standard specimen. B and W tolerances are ± 0.075 mm. Tip radius, ρ, tolerance is ± 0.025 mm. L can be minimum 52.5 mm and maximum 55.0 mm.

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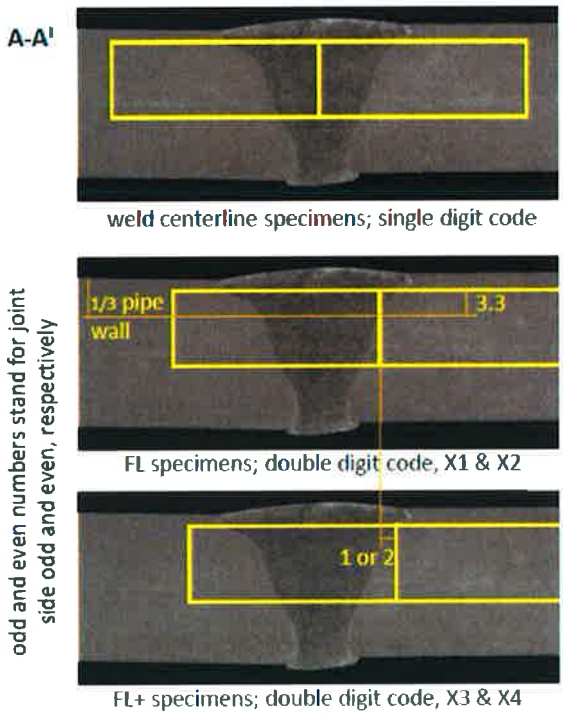


Figure 6. Location of the notch per type of the specimen and identification.

3 sets of 3 specimens were sectioned from each of the positions of 12, 6, and 9 o'clock, for a total of 9 specimens. For each of these positions,

- 3 specimens had the V-notch placed at the weld centerline,
- the other 3 had the V-notch placed on the fusion line (FL), and
- the other 3 had the V-notch placed on the FL+2 mm as shown in Figure 6.

FL and FL+ specimens should sample 50% HAZ and 50% WM.

Using the caliper gauge, linear dimensions of the specimen was measured % ±1 or better accuracy with decimal sensitivity. Notch geometry was verified by notch depth caliper (go-no go) gauge.

The specimen was immersed and retained in silicon oil that was cooled by CO_2 for at least 60 s mm^{-1} of B after the specimen surface had reached the testing temperature. The specimen test temperature was determined to an accuracy of ± 1°C until maximum 5 seconds before the hit because impact values were

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variable bound to temperature. Temperature measurement was conducted by a thermocouple that was placed in contact with the surface of specimen in the proximity of the crack tip.

Absorbed energies at testing temperatures are tabulated on the report 15-349 issued on 12.1.2016. Average impact toughness energies were recorded as 148 and 78, 179 and 201, and 248 and 171 Joules where the testing temperatures were -10°C and -46°C, respectively.

Fracture toughness behavior of as-welded LF2 material at the testing temperature was also determined with respect to crack tip opening displacement (CTOD). CTOD testing is an approximation to quantify the crack retarding ability of the material that is subjected to the testing. Loading an as-precracked specimen and examination of the crack extension process at the tip of the fatigue crack is the testing method. The force is recorded versus the displacement of the notch mouth opening (NOD). Utilizing the mathematical definitions in the standards, the opening at the crack tip can be determined at the onset of crack extension. This increase in width by elastic-plastic deformation at the crack tip is a measure for the crack sensitivity of the material, called CTOD-value that is in mm.

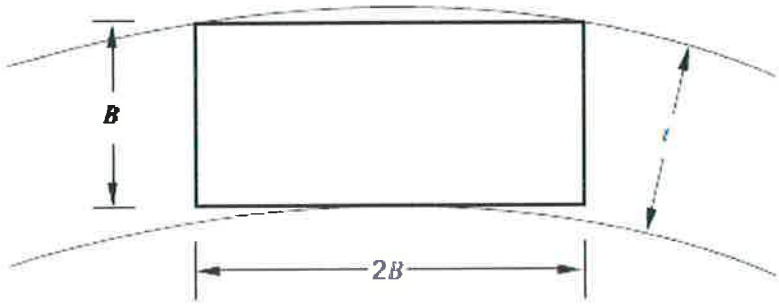


Figure 7. Machining objective for CTOD test specimen with respect top pipe wall [2].

Single edge notched Bx2B specimens (Figure 7) were subjected to 3-point bending loads during fatigue pre-cracking and displacement controlled fracturing. Circumferential locations of the specimens and sectioning were typical to CVN specimens. Specimen and testing parameters and individual values were specified and tabulated in the report 15-349 that was issued on 13.1.2016.

Average CTOD values were calculated as 0.697 at weld centerline, 1.257 at the fusion line (FL) and 1.358 at the 2-mm proximity of the FL.

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Figure 8. Fracture surface of SENB specimens after CTOD testing.

6. Conclusion

Deviations from the average toughness values and fracture surfaces (Figure 8) of both CVN and SENB specimens revealed that homogeneity and soundness of the weld metal is quite consistent and toughness behavior of the weld metal is suitable for low temperature service, as well as the parent metal itself. Weld metal yields relatively lower fracture toughness values. Even though fracture toughness properties fit for service requirements, a specially alloyed filler metal for fill and cap passes would be advised such as A/SFA 5.18 ER70S-G to get closer values relative to the parent metal.

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