Global Journal of Researches in Engineering
Mechanical and Mechanics Engineering
Volume 12 Issue 4 Version 1.0 July 2012
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN:0975-5861

Optimization of Submerged Arc Welding Heat Affected Zone Toughness in X-120M line Pipe Steel

By Jai Dev Chandel & Nand Lal Singh
M S University of Baroda, Vadodara, India

Abstract - In view of the ever-increasing demand for energy and ever increasing operating pressure of line pipe, it is very essential to develop high strength steel and production technology for manufacturing the line pipes of high strength of level to X-120M. Recent experiments show that the grade (X- 80M) with respect to grade (X-70M) could give investment cost saving of pipe line construction project. if we use X-120M steel line pipes, the cost saving is much higher. Therefore, economic transport of gas from remote sources is an important consideration in today's global economic environment. To solve these challenges, a high strength grades, large diameter line pipe of X-120M strength level through J-C-O-E technique has to be developed. The J-C-O-E longitudinal double submerged arc welding (LDSAW) of X- 120M line pipe has major challenge to establish the toughness for heat affected zone (HAZ) at theX-120M strength level, as the SAW welding is high heat input welding process. So the maintaining the strength and toughness at the strength level of X-120M of heat affected zone (HAZ) is very critical as the cooling rate is very high.

Keywords : X-120M, LDSAW, HAZ, CTOD, toughness, heat input, macro hardness.

GJRE-A Classification : FOR Code: 091505,091399

OPTIMIZATION OF SUBMERGED ARC WELDING HEAT AFFECTED ZONE TOUGHNESS IN X-120MLINE PIPE STEEL

Strictly as per the compliance and regulations of:

Optimization of Submerged Arc Welding Heat Affected Zone Toughness in X-120M line Pipe Steel

Jai Dev Chandel [α] & Nand Lal Singh [σ]

Abstract - In view of the ever-increasing demand for energy and ever increasing operating pressure of line pipe, it is very essential to develop high strength steel and production technology for manufacturing the line pipes of high strength of level to X-120M. Recent experiments show that the grade (X-80M) with respect to grade (X-70M) could give investment cost saving of pipe line construction project. if we use X-120M steel line pipes, the cost saving is much higher. Therefore, economic transport of gas from remote sources is an important consideration in today's global economic environment. To solve these challenges, a high strength grades, large diameter line pipe of X-120M strength level through J-C-O-E technique has to be developed. The J-C-O-E longitudinal double submerged arc welding (LDSAW) of X-120M line pipe has major challenge to establish the toughness for heat affected zone (HAZ) at theX-120M strength level, as the SAW welding is high heat input welding process. So the maintaining the strength and toughness at the strength level of X-120M of heat affected zone (HAZ) is very critical as the cooling rate is very high. In this paper the heat input for LDSAW process has been optimized with respect to the toughness down to -20 ^{0}C in HAZ of X-120M strength level. The effect of varying level of heat input in increasing order form minimum heat input of LDSAW process has been studied with three wire tandem system of submerged arc welding system. The experimental procedure at varying level of heat input has been established similar to line pipe welding except line pipe formation. The testing performed on test coupons are charpy V-notch testing, crack tip opening displacement (CTOD), Vicker's macro hardness testing. The said tests for all level of heat input established the optimum level of heat input for toughness of X-120M in the HAZ of LDSAW weld down to -20 ^{0}C.

Keywords : X-120M, LDSAW, HAZ, CTOD, toughness, heat input, macro hardness.

I. Introduction

Heat affected zone (HAZ) is the portion of the base metal (Plate Material) lying next to the fusion line of longitudinal double submerged arc weld (LDSAW), which has not been melted but whose mechanical properties or microstructures have been altered by the heat of the welding. The HAZ is subjected to a complex thermal cycle (sudden heating followed by rapid cooling), in which all temperatures from melting range of the steel down to mere warming involved, and therefore HAZ consists of series of graded structures . Microalloying technique [1] and dynamic accelerated cooling process after controlled rolling were applicable to develop low composition parameter (Pcm) high grade line pipe steel which is required for prevention of cold cracking in girth welding. The HAZ toughness was improved by adding small amount of titanium ('Ti'). The hardenability of boron ('B') treated new type of steel was considered by using the effective 'B' contents calculated equilibrium as free 'B'. The effect and its mechanism of 'B' [2] addition to steel containing fine 'Ti_2O_3' particles on toughness improvement of HAZ in large heat input welding process has been studied. The formation of intergranular ferrite (IGF) in HAZ is promoted and HAZ toughness is improves markedly after large heat input welding by adding 'B' in steel containing 'Ti_2O_3'. While 'B' segregates of gamma (γ) grain boundaries suppresses nucleation of grain boundaries alpha(α) ferrite, 'B' at gamma (γ)/Ti_2O_3 interface doesn't suppress nucleation of IGF from 'Ti_2O_3' because of 'B' absorption into 'Ti_2O_3'. Consequently fine IGF nucleation is accelerate by the effect of both 'Ti_2O_3' and 'B' so that refining of HAZ microstructure and improvement of HAZ toughness are achieved even after large heat input welding process. The CGHAZ has been studied [3, 4] for different steel composition like carbon with Al-Si and Al, Si-face, Al-free, 'Si' and 'Nb' alloyed. The above combination did not make much difference but the difference made by the reduction in the carbon percentage to improve low temperature toughness of HAZ is appreciable. The matrix microstructures [5] are also reported to have a strong influence on HAZ toughness. In bainitic and mertensitic steel the austenite grain transform to lath structure, the lath structure occurs in bundles or packets with low range boundaries between the laths and large misorientation occurs across packet boundaries. In such structures the packet width is the main microstructural features controlling cleavage crack propagation. It was reported that the ductile-brittle transition temperature is a logarithm function of the inverse square root of the product of the pocket diameter. The presence of M-A phase is the dominate factor for determining the toughness of intercritically cooled coarse grain (ICCG) HAZ. The evaluation of the mechanical properties [6, 7] for the base metal and the weld together with field weldability were carried out for X-80M TMCP steel plates. The steel has a bainite microstructure and has excellent

Author α σ : M S University of Baroda, Vadodara, India.
E-mails : jaidev.chandel@jindalsaw.com, singhnl_msu@yahoo.com

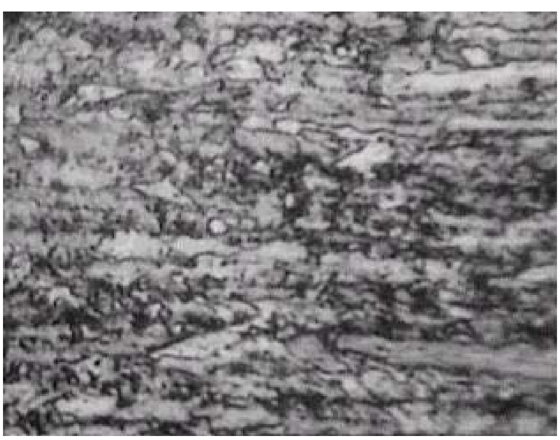
arrestability to unstable ductile fracture. With lowered 'Si' content the HAZ fusion line show excellent toughness. Fracture mechanics [8] test results reveals that the weld joints are affected the mechanical and metallurgical heterogeneity in welds. It was exhibited that the CGHAZ corresponds to potential local brittle zone in welds which controls the initiation brittle fracture. It was claimed that strength overmatching of weld metal was not always beneficial, because the HAZ toughness was decreased with increasing the degree of strength overmatching of weld metal. This is due to the constraint effect of the overmatching weld metal. The overmatching weld metal elevates the local stress in the HAZ which facilities fracture initiation in the HAZ. Recent investigation on structural significance of low toughness HAZ showed no implication on the integrity [9, 10]. It is therefore recommended that the existing procedures for defining and testing HAZ toughness are reconsidered under consideration of the actual loads, the defect probability and incorporating the size of the local brittle zone (LBZ), also their significance on the structural integrity.

II. Materials and Experimental Methods

Experimental TMCP and ACC steel plate is of API-5L, X-120M and Chemistry of experimental plate shown in table # 01. The parameters Pcm and C_{EQ} are calculated as per formulae given as Pcm = C + Ni / 60 + Si / 30 + (Mn + Cu + Cr) / 20 + Mo/15 + V / 10 + 5B and C_{EQ} = C + Mn/6 + (Cr+Mo+V)/5 + (Ni + Cu)/15. The light micrograph of the experimental TMCP and ACC steel plate shown in figure # 01.

Table 1 : Weight Percentage of Elements of X-120M Steel Plates

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu
Wt. (%)	0.065	0.290	1.950	0.012	0.005	0.170	0.040	0.130	0.042	0.021
Element	Ti	V	Nb	Ca	N	B	Al/N	Nb+V+Ti	Pcm	CE
Wt. (%)	0.012	0.001	0.042	0.001	0.002	0.004	21	0.055	0.211	0.454



Base Plate 1200 X

Figure 1 : Bainitic Microstructure of X-120M Steel Plate

To establish the toughness of heat affected zone (HAZ), number of test coupon has been made from V-Nb-Ti-B microalloyed steel with low Pcm plate of API-5L, X-120M. The steel plate used in this study has been produced through TMCP and accelerated cooled process to achieve the strength, toughness and weldability the level of X-120M with bainitic microstructure. The welding of the test coupons has been carried out by the combination of gas metal arc welding (GMAW) and double submerged arc welding (DSAW) processes. The root pass weld (Continuous tack weld) by GMAW and the final welding were completed with three wire tandem submerged arc welding (SAW) technique by one pass from first side opposite to the root run and second pass on the root weld side of the test coupons. The welding procedure has been made to maintain the minimum HAZ, optimum cross penetration, defect free elliptical weld pool shape, competitive epitaxial dendrite growth in the weld. The test coupon assembly is shown in figure # 02 (a) having (2800 mm X 300 mm X 14.3 mm) with double-Y joint geometry as shown in figure # 02 (b). The heat input of GMAW kept constant as shown in the table # 02. The different heat put levels of test coupons is shown in the figure # 03. After first pass of SAW welding, the test coupons were allowed to cool down room temperature to achieve the fast cooling rate.

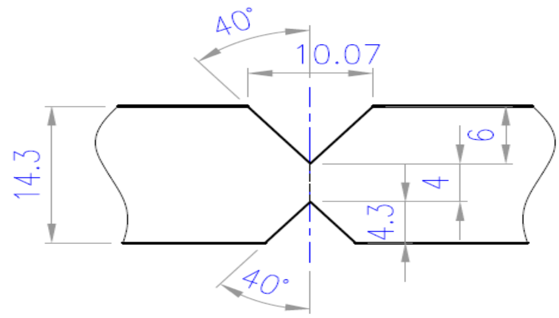


Figure 2 (a) : Weld Test Coupon Assembly, (b) Double-V joint geometry for Test Coupon

Table 2 : GMAW heat put level

Current (A)	Voltage (V)	Speed (m/min.)	Heat Input (kJ/mm)	Shielding Gases	Flow Rate (lpm)	Wire Diameter (mm)
190	21	0.6	0.48	CO_2	15	1.2

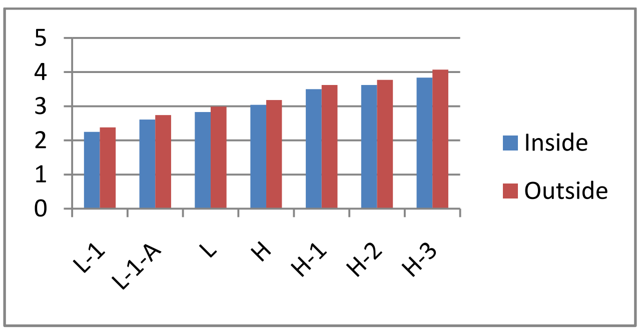


Figure 3 : SAW process at different heat put level (kJ/mm)

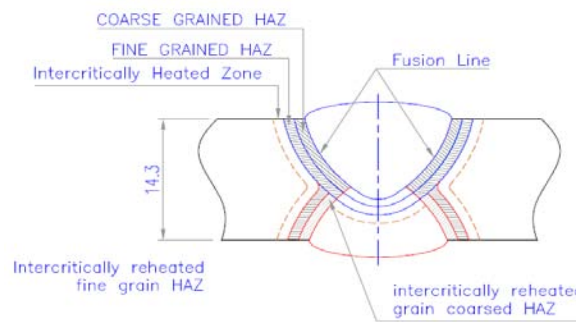


Figure 4 : HAZ of Double Submerged Arc Weld

III. Results and Discussion

a) *Evaluation of Heat Affected Zone (HAZ)*

The test coupon welded with different heat input level as shown in the table # 03, the HAZ of each test coupon is shown in figure # 04 was evaluated for non destructive examination (Visual Examination, X-ray examination and manual ultrasonic examination) and destructive examination (charpy V-notch test. Fracture toughness 'δ' (CTOD), Vickers macro hardness (HV_{10}) testing and light microscopy.

b) *Visual Examination*

All the samples welded at different heat input have been visually inspected for any visual defects as per AWS specification AWS – B1.11 (Guide for visual examination of welds) and API-5L. All the welded samples has no defect such as undercut and under fill is observed except the test coupon # L-1, H-2 and H-3, having very high convexity weld bead, which is beyond the acceptance level of the line pipe standards/ specifications.

c) *Manual Ultrasonic Examination*

The test coupons welded at different heat input have been scanned by manual ultrasonic as per ASME Section-V and API-5L. The test coupon # L-1 was having indication along the entire length and test coupons # H-2 and H-3 were having two indications each. Rest of coupons was having no significant indications.

d) *X-rays Examination*

The test coupons welded at different heat input have been exposed to the X-rays as per ASME Section-V and API-5L. The test coupon # L-1 was having lack of penetration (LOP) along the entire length and test coupons # H-2 and H-3 were having slag inclusions. Rest of coupons was having no significant defect as per API-5L. Hence the test coupon L-1 was discarded from further investigation in the present study.

e) *Charpy V-Notch Toughness (CVN)*

The sample for CVN drawn for each test coupon from the HAZ and prepared with notch at the CGHAZ is shown in the figure # 05. The results of the each Heat Input Transition temperature CVN values are shown in the figure # 06.

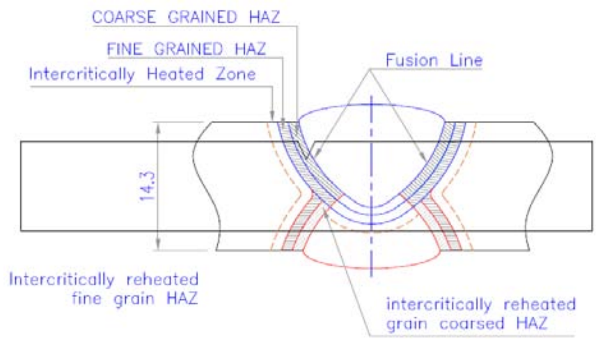


Figure 5 : Charpy V-Notch Located in CGHAZ

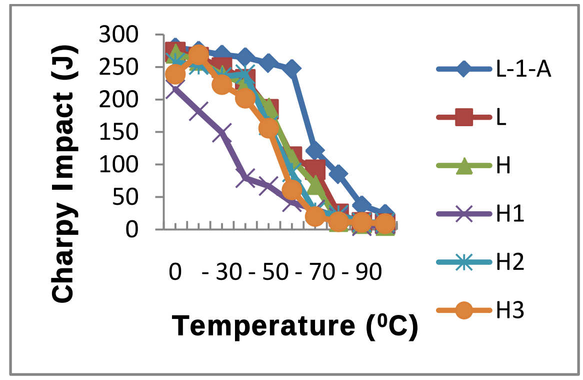


Figure 6 : Charpy V-Notch Toughness Values in Joules for HAZ

f) Fracture Toughness 'δ' (CTOD)

The sample drawn for Fracture Toughness test δ (CTOD) of HAZ for all the weld test coupon for HAZ has been prepared with notch at CGHAZ as shown in figure # 07. The samples prepared have the CT type configuration. The results of the 'δ' (CTOD) for HAZ are shown in the figure # 08.

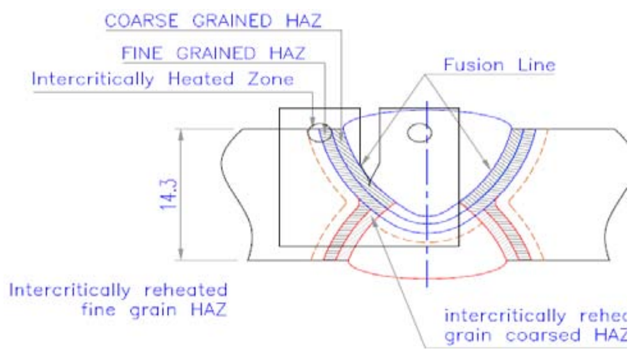


Figure 7 : CTOD Tip Located in CGHAZ

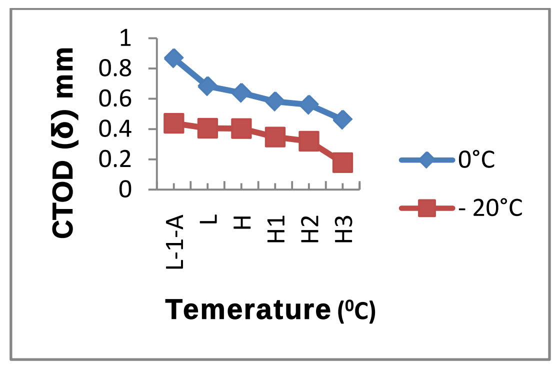


Figure 8 : CTOD (δ) Values-HAZ of the test coupons

g) Macro Hardness of HAZ Test Coupons

The Vickers's hardness testing in the HAZ for all test coupons has been performed on the samples drawn from the welded test coupons along the cross section perpendicular to the weld. The hardness of the HAZ has been taken on the location shown in figure # 09 and results are shown in the figure # 10.

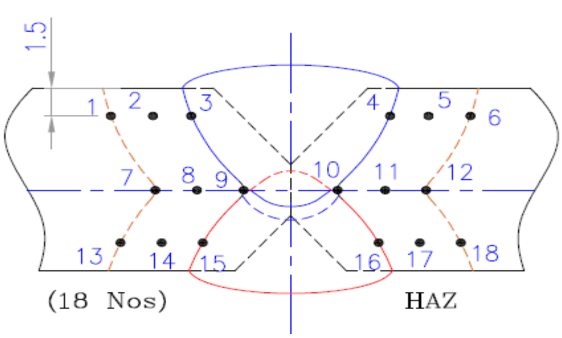


Figure 09 : Spots of Indentation in the HAZ

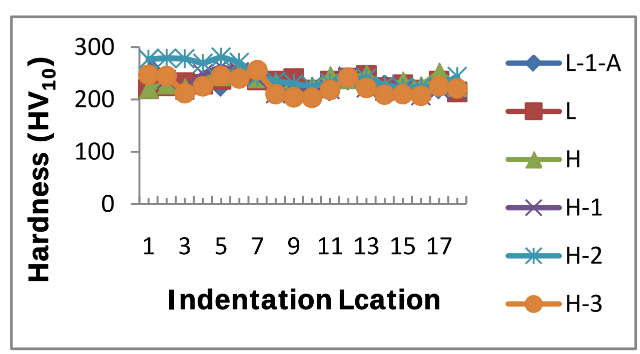


Figure 10 : HAZ Hardness (HV_{10}) of the Test Coupon

h) Microstructural Evaluation

The light microscopy on the welded plates for HAZ evaluation has been performed with a 2% nital solution as an enchant for grain. HAZ micrographs (i.e. L-1-A, L, H, H1, H2, H3) are shown in Figures # 11-16 respectively.

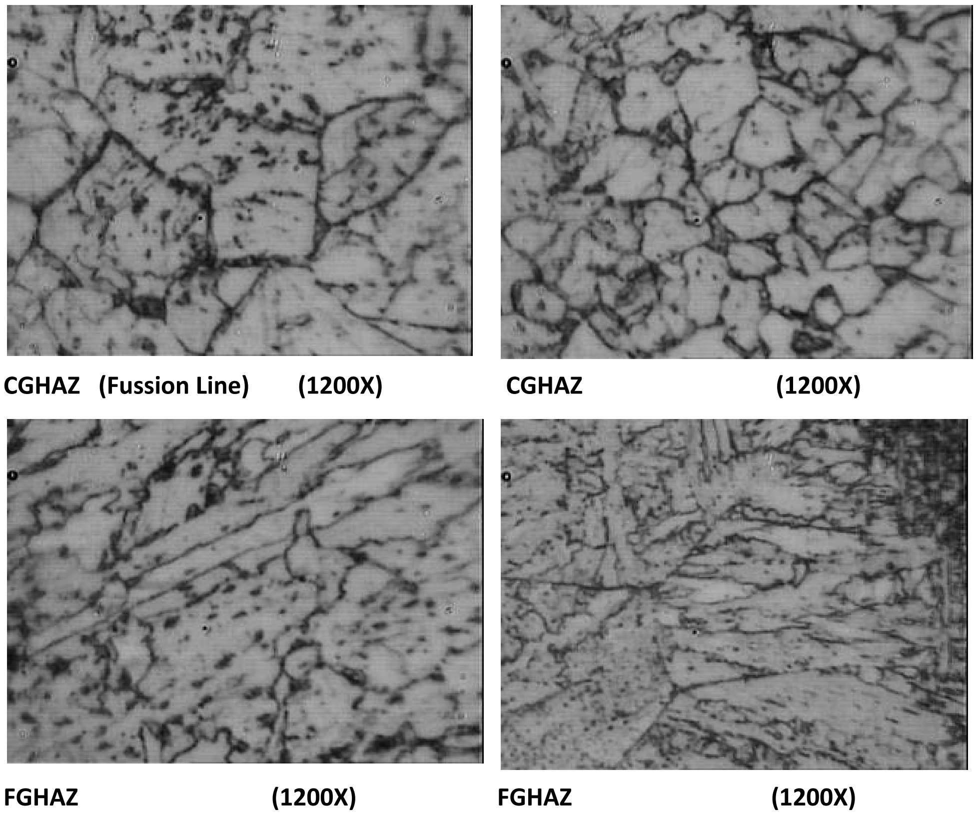


Figure 11 : Micrographs shows bainitic type ferrite and lath type ferrite along with coarsed precipitates in the ferrite matrix of HAZ Test Coupon of 'L-1-A' HAZ

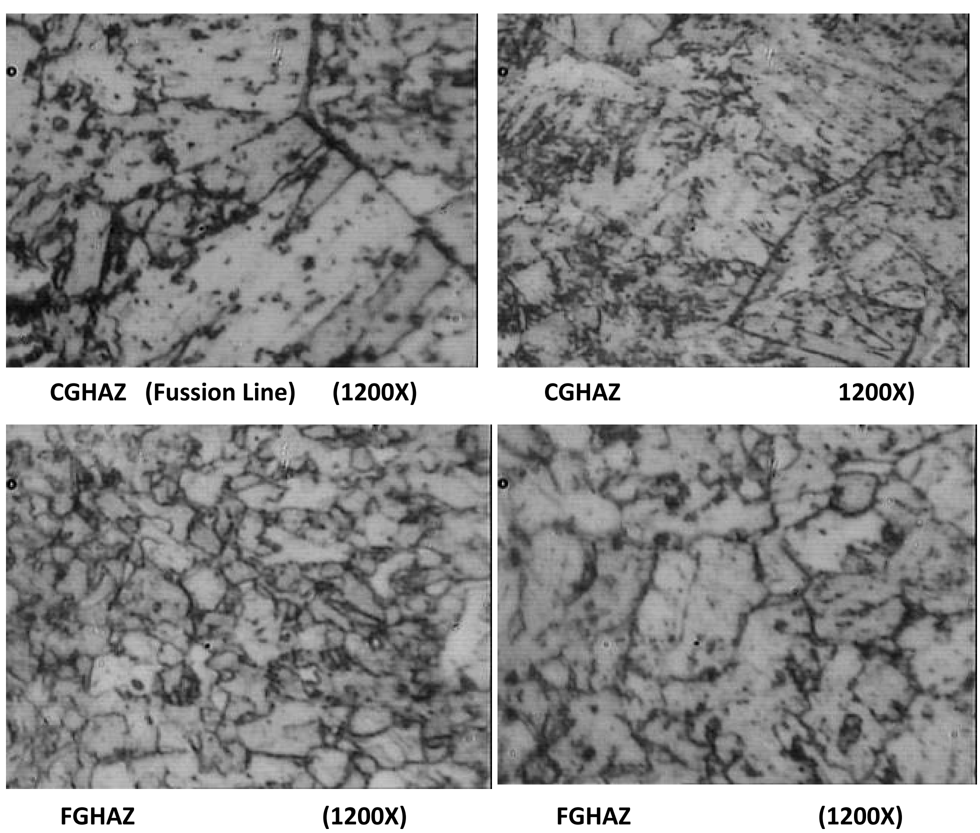


Figure 12 : Micrographs shows non polygonal type ferrite with coarsed precipitates in the ferritic matrix of HAZ Test Coupon of 'L' HAZ along with Panoramic View

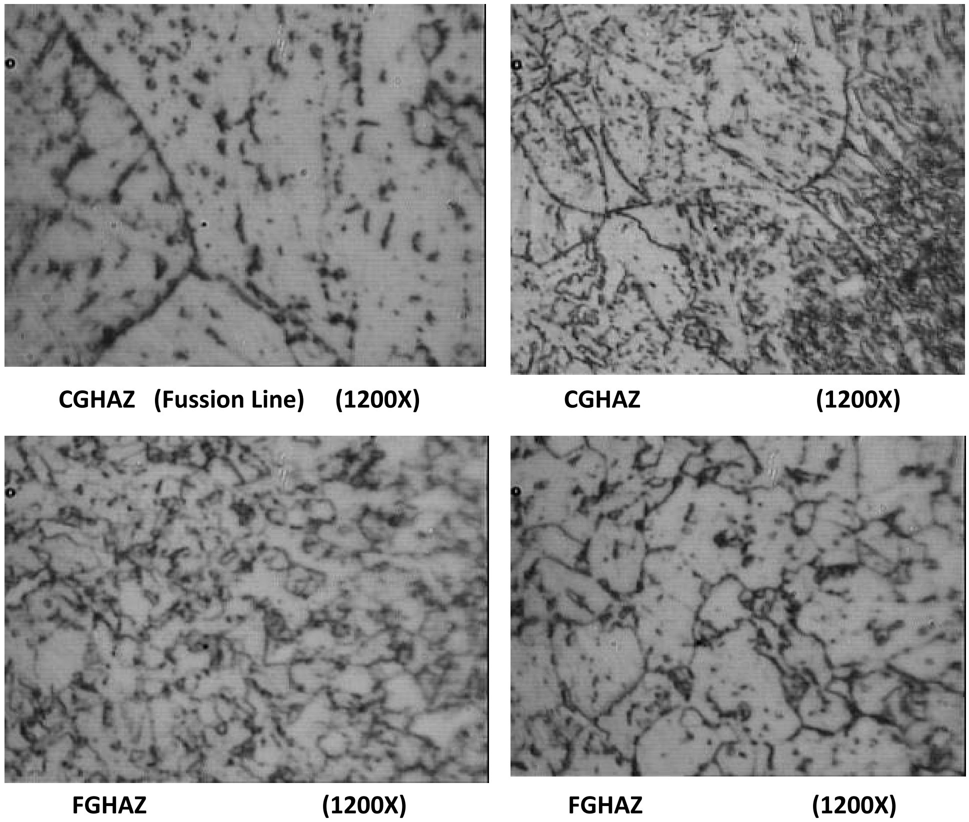


Figure 13 : Micrographs shows non polygonal type ferrite with coarsed precipitates in the ferritic matrix of HAZ Test Coupon of 'H' HAZ

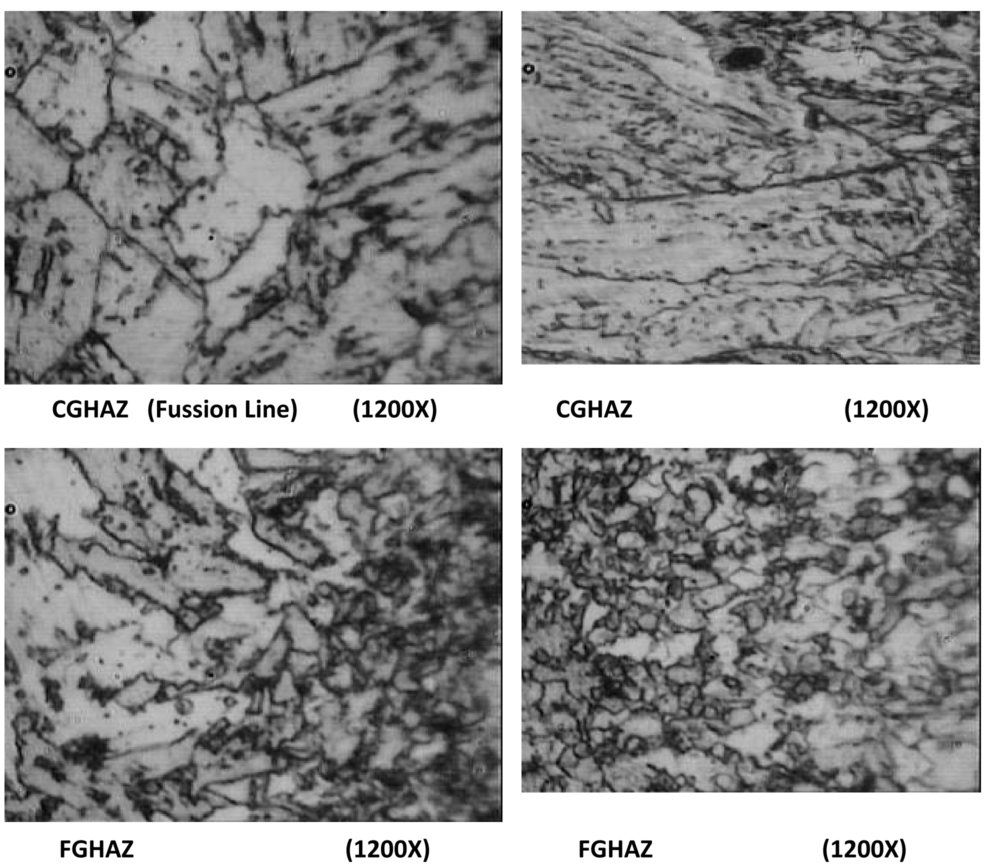
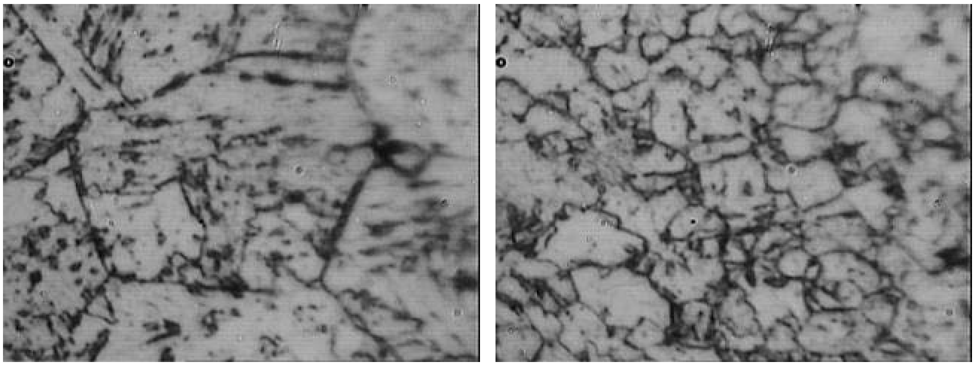
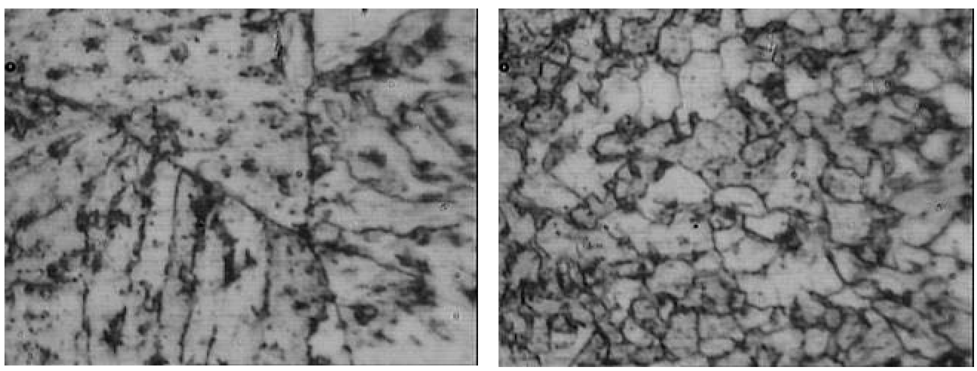


Figure 14 : Micrographs shows lath type ferrite with coarsed precipitates in the ferritic matrix of HAZ Test Coupon of 'H-1' HAZ



CGHAZ (Fussion Line) (1200X) FGHAZ (1200X)

Figure 15 : Micrographs shows granular type ferrite with carbides and coarsed precipitates in the ferritic matrix of HAZ Test Coupon of 'H-2' HAZ



CGHAZ (Fussion Line) (1200X) FGHAZ (1200X)

Figure 16 : Micrographs shows non polygonal type ferrite with coarsed precipitates in the ferritic matrix of HAZ Test Coupon of 'H3' HAZ

For optimization of HAZ in API-5L, X-120M TMCP and accelerated cooled steel plate, seven heat input level in increasing order have been studied for best candidate heat input level to have required level of toughness or the required resistance of ductile fracture propagation in TMCP and ACC steel plate material. The experiment is designed to verify the toughness for all level of heat input as shown in the figure # 03. All the level of heat input test coupons are examined visually and no significant defect such as undercut and under fill was observed. Test coupons # L-1, H-2 and H-3, convexity is found very high in the weld bead, which is beyond the acceptance level of the line pipe specifications API-5L. In X-rays examination and ultrasonic examination there was lack of penetration along the entire length of the test coupon in L-1 and has been discarded from further investigation in the present study. In rest of the test coupons, no significant non-conformity was observed. It is found that dendrites are epitaxially grown from the base metal (fusion boundary between base and weld) and terminates in the center of the weld competitively without any center line segregation. None of the sample has the defect like lack of fusion, lack of penetration and crack like defects in the HAZ and weld except L-1. As the heat input increases the cross penetration also increases. In charpy V-notch toughness the CVN values are excellent down to the -40 ^{0}C and starts decreasing suddenly after -40 ^{0}C (i.e. at -60 ^{0}C) except the one heat input level 'L-1-A' which show the excellent CVN values at -60 ^{0}C as shown in figure # 06. The CVN values (toughness) decreases suddenly to -80 ^{0}C i.e. behavior is transiting from ductile to brittle in 'L-1-A'. The fracture toughness test has been performed for all level of heat input test coupons. The heat input level 'L-1-A' found to have the highest crack tip opening displacement (CTOD) values at -20 ^{0}C among all the test coupons of heat input levels. The results of Vicker's macro hardness test showing the general trend of increase in hardness but confusing. The Vicker's hardness measurement is on macro scale and might not able to pin point hard and soft structures. In light microscopy the microstructure at HAZ shows good fusion between parent metal and weld without any micro-defects. Immediate after fusion line, coarse grain HAZ was seen, microstructure at coarse-grained HAZ shows mixture of lower transformation products with carbides. At fine-grained HAZ microstructure comprises of uniform grains of lower transformation products with carbides. The only difference is the size of phases (grains) and percentage of carbide, martensite and ferrite contents. As the level of heat input increases the grain grows proportionally and the percentage of the carbide and martensite is increasing. The test coupon # L-1-A Micrographs shows Bainitic type ferrite and lath type ferrite along with coarsed precipitates in the ferrite matrix of HAZ. As the heat input increases the Bainitic type ferrite and lath type ferrite starts decreasing i.e. more coarsed type structure. The above observation is also supported by data of mechanical testing namely CVN and CTOD.

The result of various tests shows the trend of different properties the heat input level corresponding to the test coupon number 'L-1-A' showing the best results for toughness as the target values of heat affected zone (HAZ). From the above study, it was found that the heat input level named "L-1-A" produce the minimum HAZ and highest toughness level and appropriate hardness.

References Références Referencias

1. Nakanishi M, Hashimoto T, Komizo Y, Akasaka M, 1986. Weldability of Low C-Nb-Ti-B Steel for Line Pipe – Transactions of the Iron and Steel Institute of Japan Vol. 26 No. 5.
2. Yamamoto Kohichi, Hasegawa Toshiei, Takamura Jin-Ichi, 1996. Effect of Boron on Intra-Granular Ferrite Formation in Ti-Oxide Bearing Steels. - ISIJ International, Vol. 36, No. 1.
3. Graf M K, Niederhoff K, 1990. Toughness Behaviour of the Heat-Affected Zone (HAZ) in Double Submerged-Arc Welded Large Diameter pipe- Pipeline Technology Conference Proceedings, Belgium.
4. Graf M, Niederhoff K, 2000. Properties of HAZ (Heat Affected Zone) in Two Pass Submerged - arc Welded Large - Diameter Pipe. (Means of Influencing, Specified & Necessary Tests Accompanying Pipe Production) - Pipeline Technology Proceedings, 3rd International Conference Belgium.
5. Li Y, Crowther N, Green M J W, Mitchell P S, Baker T N, 2001. The Effect of Vanadium and Niobium on the Properties and Microstructure of the Intercritically Reheated Coarse Grained Heat Affected Zone in Low Carbon Microalloyed Steels. - ISIJ International, Vol. 41 No. 1.
6. Bersch B, Dortmund, 1976. Influence of Heat Input on the HAZ (Heat Affected Zone) Properties of Line Pipe Steels – Proceedings of International Conference, Welding of HSLA (Microalloyed) Structural Steels, Rome Italy.
7. Itakura N, Kawabata F, Amano K, Yamaura T, Aoki M, Ihara K, 1999. X-80 UOE Line Pipe with Excellent Heat Affected Zone Toughness of Longitudinal Welds – ASME International.
8. Minami F, 1996. The Local Approach to Fracture Strength Evaluation OF Welded Joints- Transactions of JWRI, Vol. 25, No. 2.
9. Andreas Liessem, Marion Erdelen-Peppler, 2004. A Critical View on the Significance of HAZ Toughness Testing. – International conference IPC, Calgary, Alberta, Canada.
10. Woo-Sik Kim, Jong-Hyun Baek, Dongil Kwon, 2004. Failure Assessment Diagram for Assessing Cracks in the Weldment Heat- Affected- Zone of a Natural Gas Pipeline. - Pipeline Technology Proceedings, Conference, Ostend, Belgium.

IV. Acknowledgement

I am grateful to Prof. N L Singh (Department of Physics, M S University of Baroda - 392 002, India) for his endless support and encouragement during this study. I acknowledge the support from Welspun Gujarat Stahl Rohren Ltd. India.