Repair Welding Procedure for P460NH Grade Steel Making Ladles

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DOI : 10.22486/iwj/2018/v51/i2/170308

ABSTRACT

P460NH steels are extensively used in steel plants as ladle fabrication material. However, fusion welding of these steels leads to the problems such as cold cracking, residual stress, distortion and fatigue damage, these steels may require welding of the cracks that can develop during fabrication, handling and transportation stages, or during the service life of the plant. Present work explains repair welding procedure used for P460NH steel ladles welded by using shielded metal arc (SMA) welding and flux cored arc (FCW) welding processes and evaluation of its weld metal and heat affected area (HAZ) microstructure. Butter bead tempered bead technique followed to fill the joint groove and simulated repair welding of SMA and FCA welds was carried out at the weld/base metal interface, i.e. at the location at which cracks are usually reported to occur during fabrication. SMA repair welding procedure conforming to the ASME Boiler and pressure Vessel Code were used followed by post heating of welds at 300°C for 2 hours per 25mm thickness of the weld. Tensile properties, bend tests, hardness profiles, impact tests and metallography studies using scanning electron microscope (SEM) were determined for both SMA and FCA welds to evaluate simulated repair welds. Analysis of the test results showed that the cooling rate maintained by means of preheating, interpass and post heating plays an important role in repairing of P460NH steel weld cracks.

Keywords: Repair Welding; Ladles; Welding Procedure; P460NH Grade Steel; microstructure.

1.0 INTRODUCTION

In steel plant construction, heavy fabrication involves for manufacturing of steel making ladles. These ladles operate at temperature of 400°C with high reliability being specified at the design stage. To meet design specifications high temperature steels with relatively high thickness are being used for these applications. P460NH steel is micro alloyed C-Mn steel with relatively high carbon equivalent (<0.5) [2]. Welding of these steels is frequently susceptible to a crack-sensitive microstructure leading to cold cracking [3]. However repairing these cracks are usually highly challenging, as it needs to take account of special considerations like minimum chemical composition difference, minimum notch toughness, special service requirements, and changes in metal properties could lead to affect its weld metal and heat affected zone properties (HAZ) and they can acts as stress raisers [4]. These cracks are removed and repaired with high integrity of weld metal. However thermal cycles including preheat, interpass, post heating and post weld heat treatment (PWHT) during welding repair decides the hardness value [5]. Suitable HAZ hardness can be obtained without hydrogen induced cracking in repair welds of C–Mn steels by using low hydrogen consumables and post-weld normalizing. However, in case of P460NH steels PHWT are unnecessary or even detrimental during subsequent service. A.Aloraier, R.Ibrahim, P. Thomson [1], while discussing the FCA welding process to avoid the use of post weld heat treatment, concluded that the most of the repairs in industry are performed with SMA welding. In such cases, the butter bead temper bead repair welding method followed [6]. In this

Table 1 : Chemical composition (wt.%) of parent metal.

C	Mn	S	P	Si	Al	Cu	Cr	Ni	Mo	V	Nb	Ti
0.20	1.250	0.010	0.025	0.60	0.020	0.70	0.08	0.080	0.10	0.020	0.05	0.03

Table 2 : SMA Welding parameters used

AWS Classification	Electrode Diameter (mm)	Welding Current (A)	Arc Voltage (V)	Travel Speed Range (mm/min)	Heat Input kJ/mm
E 8018-G	3.15	105 - 115	26 - 28	70 - 90	1.82 - 2.76
E 8018-G	4	190 - 195	26 - 28	200 - 230	1.29 - 1.64

Table 3 : FCA Welding parameters used

AWS Classification	Electrode Diameter (mm)	Welding Current (A)	Arc Voltage (V)	Travel Speed Range (mm/min)	Heat Input kJ/mm
E 81T5-G	1.2	210 - 250	32 - 36	320 - 360	1.12 - 1.69

Table 4 Welding conditions used for repair welding by using SMAW process

Welding conditions	Welding parameters
Consumable diameter, mm	3.15
Welding current, A	100-110
Arc voltage, V	26-28
Welding travel speed, mm/min	60-80
Consumable specification	E8018-G
Heat input, kJ/mm	1.95 - 3.01
Preheat and interpass temperature, C	150
Post heating, C	300

study cooling rate controlled by means of pre heat and post heating to achieve hydrogen free welds. Using this method, significant HAZ refinement may be achieved by carefully controlling the heat input and bead overlap without PWHT.

2.0 EXPERIMENTS

The chemical composition of the base metal is given in **Table 1**. Normalized P460NH steels, with dimensions 300X150X60 mm and a 60° included angle single V groove joint geometry chosen for experimentation.

Two weld pads were prepared and pre-heated to a temperature of 150°C, and each pad welded by the SMA and FCA process using matching composition electrodes. SMA and FCA welding parameters used are given in **Table 2** and **Table 3** respectively.

In both welding of the pads, welding carried out in flat position and direct current with reverse polarity (DCEP) current used. Multi pass welding carried out to fill up the joint. Interpass temperature of 250°C maintained to control cooling rate during welding. After completion of the final layer welding, the pads were post heated to 300°C for 150 minutes followed by air cooling to room temperature.

The welds were first non-destructively examined by dye penetrant and X-ray radiography tests. The welded pads then undergone through simulated repair by machining a 60° included angle single V groove close to the fusion line **(Fig.1)** where simulated repair welds were made using SMA welding process due to its advantages like positional welding and process control. In the repair welding, 3.15 mm diameter electrodes were used to deposit all layers. To achieve the effect of bead refinement, temper bead technique followed during repair welding. The pre-heat, interpass and post heating temperatures maintained same as actual welds, The other welding conditions used for both the welding pads are given in **Table 4**. No PWHT was applied to the actual weld or simulated repair welds. All the simulated repair welds were non-destructively tested for their soundness and were found to be free from unacceptable defects.

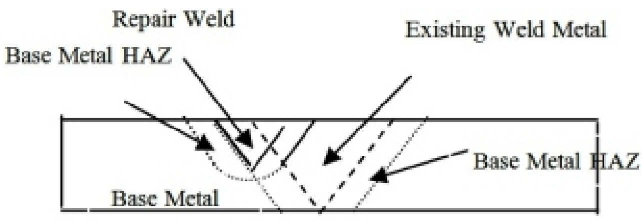


Fig.1 : Schematic diagram of repair weld indicating various microstructural zones

Transverse weld specimen blanks, with the weld located at the center, were obtained from both the weld pads for the following conditions:

(i) Parent metal

(ii) SMA weld

(iii) SMA weld with SMAW repair

(iv) FCA weld

(v) FCA weld with SMAW repair

For metallographic observation, the specimens were etched with 2% nital for 20s and consequently the microstructures of the base, weld and the heat affected zone were defined. Weld cross section samples were cut to study weld bead geometry, optical microscopy and micro hardness. Stereoscope was used to identify weld, HAZ and unaffected base material area regions. These welds were polished, and micro hardness profiles across the weld interface and at HAZ (2 mm away from fusion line) were measured at intervals of 0.3 mm using a load of 300g. Weld cross section samples were individually mounted in bakelite resin and polished by conventional metallographic techniques. The polished and etched samples microstructure analysis was carried out using optical microscope.

ASTM E8M-04 guidelines were followed for preparing the tensile test specimens and to evaluate the tensile properties. In each condition, three specimens were tested and the average value was presented. Charpy impact specimens were prepared to evaluate the impact toughness of the HAZ and weld metal, and hence for the weld metal the notch was placed (machined) in the center of weld metal and for HAZ the notch was placed at 2mm away from fusion line, all the tests were conducted at room temperature. The amount of energy absorbed in fracture was recorded. The absorbed energy is defined as the impact toughness of the material. SEM was used to obtain fractography.

3.0 RESULTS

3.1 Microstructures

Parent Metal

Typical microstructure of base metal is consisting of ferrite and bands of pearlite (α-Fe + Fe_3C) **(Fig. 2)**. It is largely consisting of equiaxed ferrite grains.

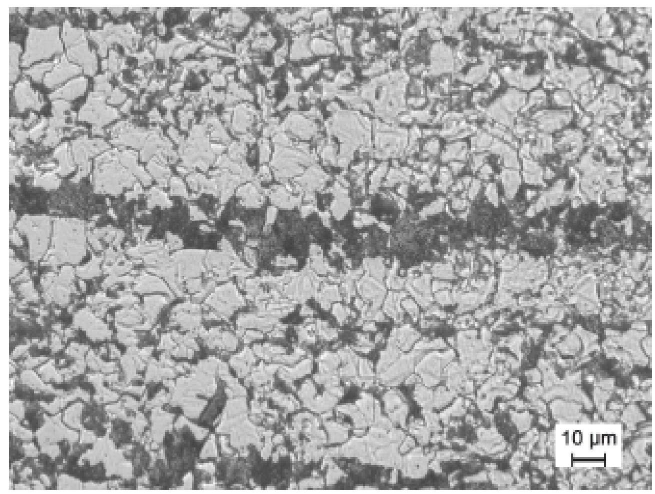


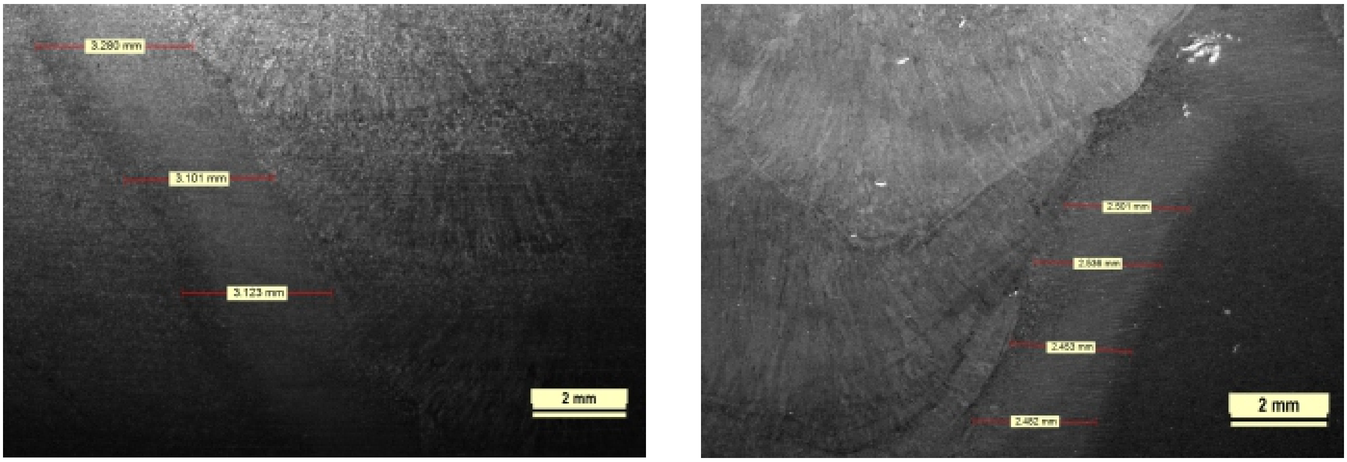
Fig. 2 : P460NH Base metal optical image

Also, the bands of perlite rich area (banding) were observed. This macro segregation phenomenon, which is called banding, is due to the presence of high percentage of Mn (1.51%) in these zones.

Weld Metal

The macrograph of SMAW and FCAW joints reveal the regions like weld area, coarse grain heat affected zone (CGHAZ) and fine grain heat affected zone (FGHAZ). In SMAW process, the resultant bead structure was a coarser due to high heat input leading to the slower cooling rate. The wider arc column is also a reason for this wide fusion zone (**Fig. 3(a)**). In FCAW process, the energy density is comparatively higher than that in SMAW process. The high self-quenching rates that are associated with this process certainly promote the fast cooling rates. This could be attributed to this narrow fusion zone **(Fig. 3(b))**.

SMA welded samples optical micrograph of the coarse grain HAZ region that was obtained after multi-pass welding revealed the formation of intergranular perlite. Optical micrograph of inter-critically reheated coarse grain HAZ is shown in **Fig.4(a)**. A magnified image of the fine-grained



(a) Sample welded by SMAW process (b) Sample welded by FCAW process

Fig.3 : HAZ of welded regions

region **(Fig. 4(b))** shows that the pearlite bands present in the base material has dissociated and has formed very fine pearlite and ferrite grains. The multi pass welds reveals that former deposited weld beads show the presence of equiaxed grains with proeutectoid ferrite nucleating at the austenite grain boundary followed by acicular ferrite at the center **(Fig. 4(c))**.

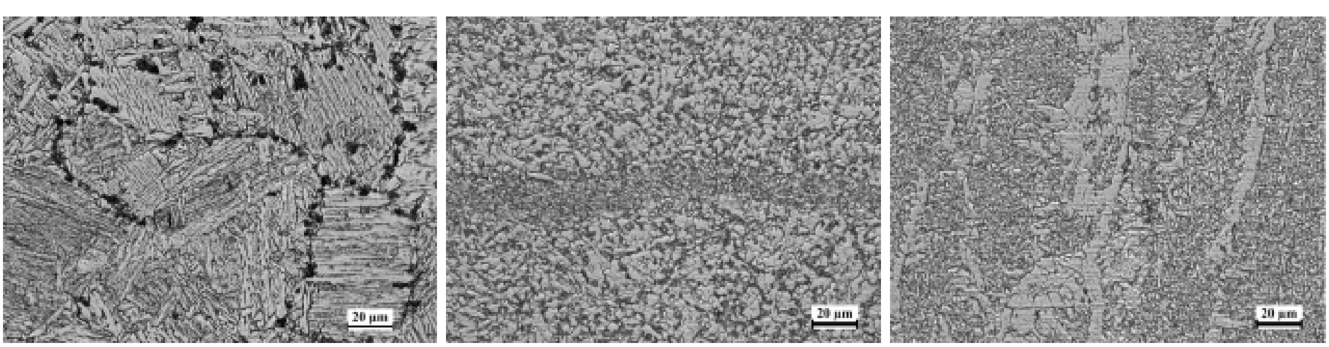
FCA welded samples optical micrograph of the coarse grain HAZ region that was obtained after multi-pass welding revealed the formation of intergranularly nucleated pearlite, with acicular ferrite (**Fig. 5(a)** and **Fig. 5(b)**). Weld micro-structure consists of fine proeutectoid columnar grains, with large cementite blocks along with accicular ferrite **(Fig. 5(f))**.

3.2 Hardness

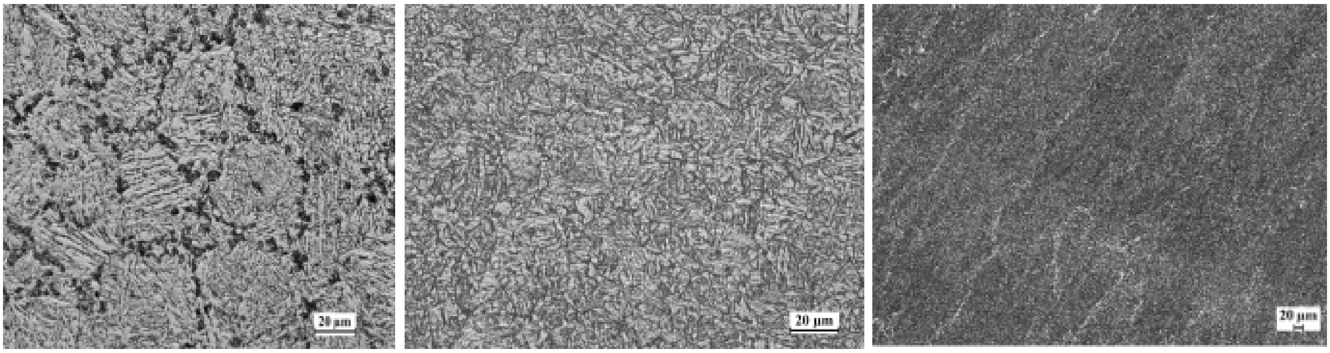
The hardness of the as-received parent metal is approximately 205 HV. The microhardness of weld metal regions of SMAW and FCAW joints vary from 245 HV to 257 HV, and hardness is found to be very high in HAZ (Fusion line + 2mm) i.e. 265HV and 287HV for SMAW and FCAW joints respectively and after SMAW repair process hardness values of weld metal vary from 213 to 215 HV and at HAZ this value vary from 234HV and 240 HV for SMA and FCA welded pads respectively. These values are depending on the grain size and phases sampled from each indentation.

3.3 Tensile Test

The tensile properties of the parent metal and welded joints are presented in **Table 5**. The yield strength and tensile strength of parent metal was 446MPa and 595MPa, respectively. Similarly, the yield strength and tensile strength of SMA Welded joint are 487MPa and 601MPa, respectively, which are 1% higher than those of parent metal. And, the yield strength and tensile strength of SMA weld repair joint are 486 MPa and 587MPa, respectively, which are 1.3% lower than those of parent metal. But the yield strength and tensile strength of FCA welded joint are 536MPa and 636MPa, respectively which are 10.5% higher than those of parent metal and FCA weld repair joint are 511MPa and 656MPa respectively which are 10.2% higher than those of parent metal. Of the four welded joints, the joints fabricated by FCAW



(a) SMAW: CGHAZ (b) SMAW:FGHAZ (c) SMAW:Weld



(d) FCAW: CGHAZ (e) FCAW: FGHAZ (f) FCAW:Weld

Fig.4 : At 500X, Optical micrographs of various regions of welded steel joints.

Table 5 : Mechanical properties of the parent metal and welded joints

Joint	0.2% Offset yield Strength (MPa)	Tensile strength (MPa)	Elongation 25 mm gauge Length (%)	Impact toughness @ RT (J)	Impact toughness at FL+2 mm @ RT(J)	Hardness @ 300 g load (HV)	Hardness at FL+2 mm @ 300g load (HV)
Parent Metal	422	595	30	182	--	205	--
SMAW	487	601	25	149	166	245	265
SMAW Repair	486	587	23	139	156	215	234
FCAW	536	658	18	90	176	257	287
FCAW Repair	511	656	21	114	127	213	240

process exhibited higher strength values. Percentage of elongation of parent metal is 30%, whereas the percentage of elongation of SMA welded and SMA welded repair joint are 25% and 23% respectively. This suggests that there is a 16.6% decrement in ductility due to SMAW process and 23.3% decrement in ductility due to SMAW repair process.

And the percentage of elongation of FCA welded and FCA weld repair joint are 18% and 21% res respectively. This suggests that there is a 40% and 30% decrement in ductility due to FCA process and FCA weld repair by SMA process. Of the four types of welded joints, the joints fabricated by SMAW exhibited higher ductility values compared to FCAW joints.

3.4 Impact Test

Charpy impact toughness test results are presented in **Table 5**. The impact toughness of parent metal is 182J at room temperature. When the joint is welded by SMAW and FCAW process, it exhibits 149J and 90J respectively, which are 18% and 50% lower than that of the parent metal. After repairing using SMAW process, the impact toughness value of SMAW joint decreased (139J). Whereas when the FCAW joint repaired by SMA process the impact strength increased (114J). But there is an increment in impact toughness strength at HAZ (2mm away from fusion line), the values for SMAW and FCAW joints are 166J and 176J respectively. When these joints repaired by using SMAW process, the impact strength decreased to 156J and 127J respectively.

The fractured surfaces of impact tested specimens of parent metal and welded joints were analyzed using a scanning electron microscope. The fractography of specimens are displayed in **Fig. 5**. The mode of failure of the impact tested parent metal is ductile with acceptable plastic deformation, no brittle cleavage fracture was found in the impact tested fractography, shown in **Fig. 5**.

And in weld metal region the cleavage planes were clearly visible in both the weld impact fractured surfaces indicting mixed mode of failure (Brittle / Ductile). Fracture surface area showed in **Fig 6. (a-c)** that the area of brittle fracture in FCAW is more compared to SMAW leading to the drop-in toughness. In case of HAZ region, the impact toughness of SMAW and FCAW values depend on the notch area in the HAZ, accordingly the fracture surfaces were brittle or ductile with respect to coarse grain and fine grain regions. **Fig. 6 (b)** and **Fig. 6(d)** indicates ductile fracture regions.

4.0 DISCUSSIONS

4.1. Effects of welding processes on microstructure

The weld metal microstructure of fusion welded joints is greatly influenced by the chemical composition of filler metal and the heat input of the process. In general, higher heat input leads to slower cooling rate which results in the coarse grains in weld metal [8]. However, lower heat input leads to fast cooling rate which results in fine microstructure. Though the lower heat input can produce finer grains compared to higher heat input, the intrinsic nature of the process also plays major role in refining the weld metal microstructure. Of the two processes used in this investigation, the FCAW process supplies lower heat input (1.12 – 1.69 kJ/mm) to the weld region compared to SMAW processes which supply (1.68 – 2.70 kJ/mm). Parent metal microstructure (ferrite and small amount of pearlite) was transformed into acicular ferrite **(Fig. 7)**, small amount of bainite and tempered martensite due to multipass welding, heat input and chemical composition. Variations in filler metal and parent metal chemical composition lead to the thermal variations in weld metal and parent metal as well as the solidification of weld metal. An acicular ferrite microstructure has the potential of combining high strength and high toughness [9]. Microstructural stability is more in acicular ferrite compared to bainite in higher temperatures.

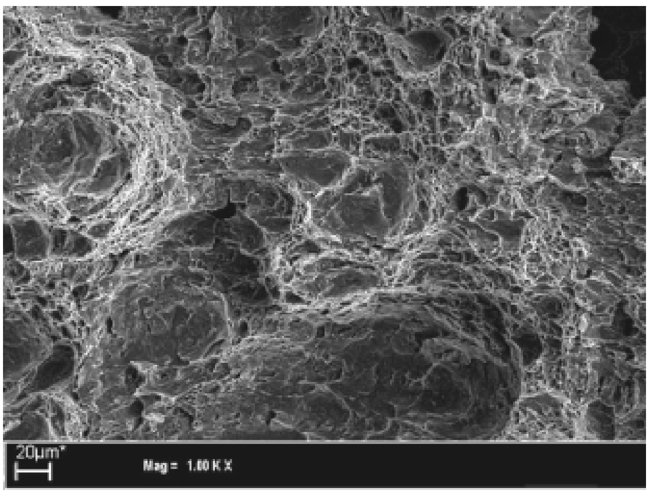
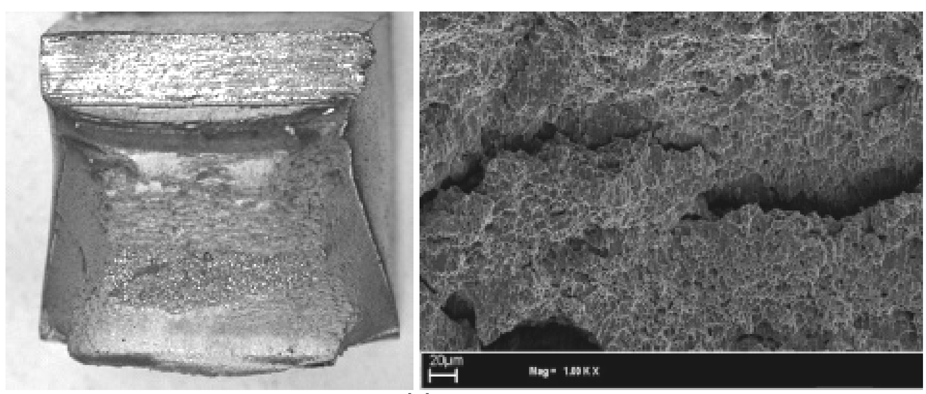


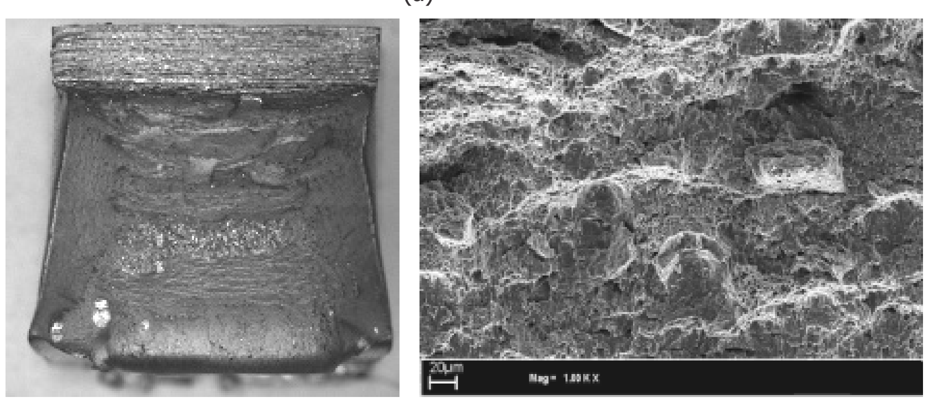
Fig.5 : SEM image of P460NH fracture surface

SMAW: Weld metal



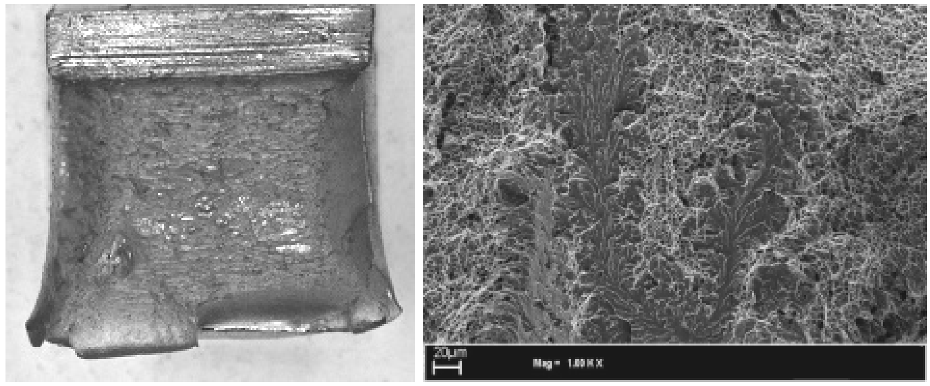
(a)

SMAW: HAZ



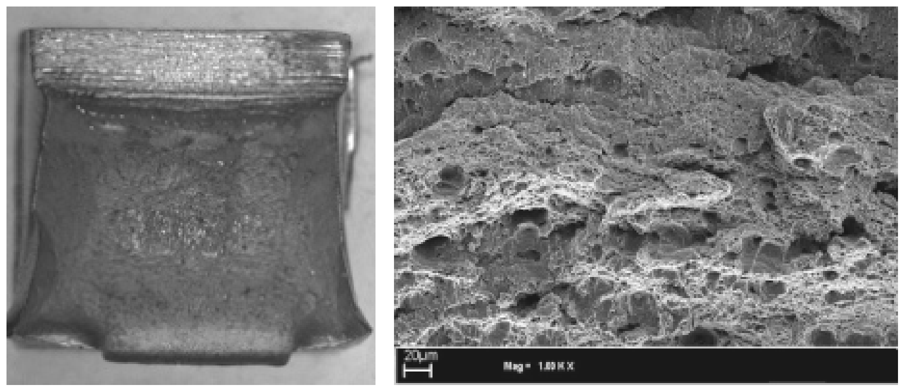
(b)

FCAW: Weld Metal



(c)

FCAW: HAZ



(d)

Fig.6 : Fractured surfaces SEM micrographs of weld metal and HAZ regions

Due to high heat input and intensity of SMAW process, the coarse grains in weld metal and HAZ were formed. The relatively cooling rate in both welding process led to the formation of detrimental phases like intergranular perlite **(Fig. 7)** in HAZ.

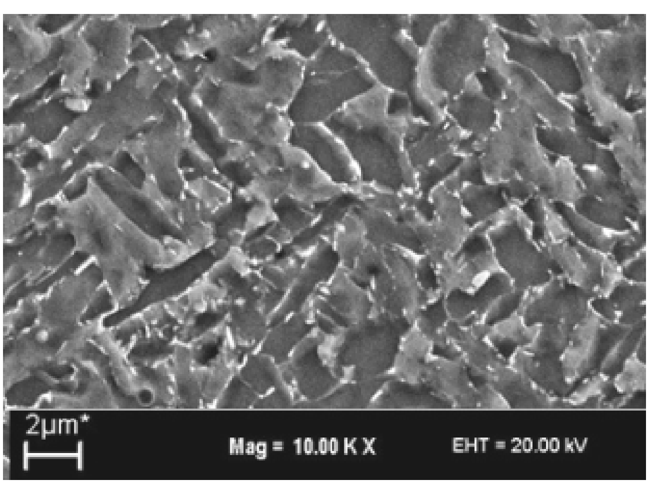


Fig.7 : SEM image of acicular ferrite present in weld metal

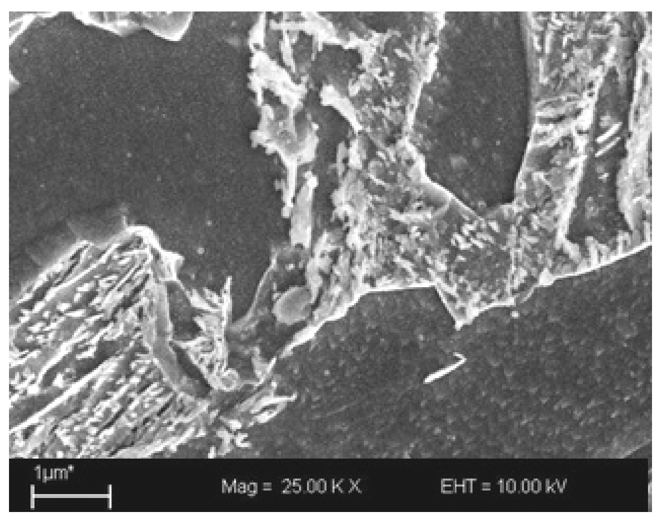


Fig.8 : SEM image of intergranular perlite in coarse grain HAZ

4.2 Effects of SMAW repair welding procedure using temper bead method

In repair welding SMAW process with lower diameter electrode (3.15mm) used to achieve better dilution, also higher heat input (1.95-3.01KJ/mm) used, which results in slower cooling effect and enhances desirable microstructure. On repair welding by using temper bead method, the hardness values at the weld interfaces decreased to about 234 and 240 for SMA and FCA process welds respectively. The reason for the narrower HAZ in the repair weld could be the use of the 3.15 mm diameter electrode for the all layers.

4.3 Effect of pre-heating, post heating and heat input on microstructure

Preheating and post heating temperatures affects P460NH weld metal and HAZ microstructures, which avoids the heat-affected zone cracking. As the minimum preheating temperature of 150°C and post heating temperature of 300°C for 2 hours used, it results in slower cooling rate and which affects the coarse grain size in HAZ. The effects of coarse grain size with varying heat inputs had a great influence on the microstructure, hardness and toughness of HAZ of P460NH steel. Thus, taking into consideration the plate thickness, a higher heat input should be used with respect to the maximum toughness of the HAZ in the welding of grain-coarsened low carbon steels.

4.4 Effect of welding processes on tensile strength properties

In case of FCAW joint due to the chemical composition of the filler wire and cooling rate, the obtained weld metal microstructure was found to be acicular ferrite (Fig.7) which leads to increase in tensile properties and decrease in ductility compared with parent metal. In case of SMAW joint, the obtained weld metal microstructure was found to proeutectoid ferrite, which enhances the elongation properties. After repair weld using SMAW process the ductility of FCAW joint improved (21%).

4.5 Effect of welding processes on impact toughness properties

The increased percentage of small cluster of martensite is detrimental to impact toughness. The presence of precipitate carbides raises the impact transition temperature and lowers the charpy shelf energy. The impact strength of upper bainite adversely affected by the presence of cementite as thin film at the lath boundaries of bainite increases the presence of martensite which does not contribute to the strength but lowers the toughness [10]. This could be the reason for reduction in toughness of FCAW joint with respect to parent metal as well as SMAW weld joints.

SMAW joint exhibited higher impact toughness than FCAW joint due to slower cooling rate. The formation of acicular ferrite with high angle grain boundaries and the parallel stacking of ferrite and carbides arranged in the packets could make the propagation path of critical crack pass through an acicular ferrite microstructure, thereby leading to an improvement in toughness without compromising strength. However, the reduced toughness of the fusion zone in FCAW joint compared to SMAW joint with respect to parent metal is attributed to the presence of the tempered martensite microstructure which leads to void the formation in the austenite during deformation.

4.6 Effects of welding processes on hardness

Lower hardness was recorded after repairing using SMAW process at HAZ and weld metal. The raising of hardness value towards the CGHAZ and FGHAZ is due to the presence of coarse distorted microstructure invariably in weld metal compared to fine and coarse grain heat affected zone. The higher hardness was found in the coarse grain HAZ region indicating the formation of tempered martensite in the region.

5.0 CONCLUSIONS

In this investigation, an attempt was made to study the effects of welding processes with a repair procedure by evaluating the weld metal microstructure and mechanical properties of P460NH garde steel joints. From this investigation, the following important conclusions are derived:

- P460NH microstructure is susceptible to cold cracking after welding, the brittle microstructure formed in CGHAZ can act as crack initiating sites, which can be avoided by taking adequate precautions like applying pre-heat and post heating.
- Post heating of 2 hours for every 25-mm thickness at 300°C is essential to facilitate escape of hydrogen gas from the weld and eliminate cold cracking
- In SMAW and FCAW processes, Joints fabricated by using SMAW process exhibit 23% more elongation than FCAW process due to the presence of acicular ferrite in SMAW joint.
- Joints fabricated using FCAW process exhibit 10% higher tensile strength than SMAW process, due to the presence of proeutectoid ferrite in the FCAW weld metal.
- On repairing the fusion line using SMAW process at higher

heat input, desired microstructure obtained which is free from intergranular perlite.

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