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Author(s)	Sadek, Alber; Hussein, Abdel-Hamid; Goda, Mohamed et al.
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Effect of Repair Welding Technique on the Mechanical Properties of Thick Wall Structural Steel

Alber SADEK *, Abdel - Hamid HUSSEIN ** , Mohamed Goda* and Masao Ushio******

Abstract

A number of techniques based on the shielded metal arc welding process have been developed to modify the microstructure of both weld metal and heat affected zone (HAZ) in order to improve the as-welded fracture toughness. In this work, a comparative study was carried out for different repair welding techniques to determine the optimum values of mechanical properties, which can be obtained to identify the best repair welding techniques.

Also, the effect of repeated repair welding on the mechanical properties was investigated to establish the optimum quality of repair welding without post weld heat treatment (PWHT). High strength low alloy structural steel grade 52/3, 40 mm thickness was selected for this study. The present experimental results showed that the two-layer repair welding technique is superior among the various repair-welding techniques investigated.

KEY WORDS: (Repair Welding), (Carbon Steel), (Shield Metal Arc Welding), (Post Weld Heat Treatment), (Half Bead), (Two Layer), (Back Step), (Submerged Arc Welding)

1. Introduction

Many steel products require repair as a result of either fabrication defect or damage under service conditions. In several cases, repair welding of cracked part is the most economical way in comparison with the replacement of that part especially in a complex structure. So, specified repair welding procedures are necessary and a number of welding techniques have been utilized for this purpose[1-3].

For most ferrous alloys shielded metal arc welding (SMAW) is a preferred repair method because of its adaptability to difficult situations where access may be restricted. Generally, in all types of repair, the chance for creating new discontinuities, particularly metallurgical ones are increased. The harmful effects of a weld repair may include; increase of residual stresses, distortion, and degradation of microstructures and fracture toughness (e.g., grain growth, precipitation of carbides, hydrogen embrittlement, and thermal straining). Moreover, it is not always possible to repeat the original post weld heat treatment after repair welding on site. So, a number of techniques based on the shielded metal arc welding process have been developed to modify the microstructure of both weld metal and heat affected zone (HAZ) in order to improve the as-welded fracture toughness. These include conventional buttering techniques with or without post weld heat treatment (PWHT) [4], half bead techniques, back step techniques and two-layer techniques. Thus, a comparative study was carried out for different repair welding techniques to determine the optimum values of mechanical properties, which can be obtained to identify the best repair welding techniques for repeated repair welding without PWHT.

2. Experimental Work

The base metal used in this experimental work was, ASTM-A662 (DIN 17100) grade 52/3 with a minimum tensile strength of 520 and a yield strength of 345 Mpa. The steel was delivered as normalized hot rolled plates 4× 90× 900 cm. The plate was cut to 4×25×90 cm and machined before welding. The chemical composition of the investigated steel is given in Table 1. Welding was achieved by multi-pass submerged arc welding process. The dimensions and details of joints used in this investigation are shown in Fig. 1. AWS EH14 electrode wire of 4 mm. diameter with F7A4 flux were used as the welding consumables throughout this study.

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* Associate Prof., CMRDI, Cairo, Egypt
** Professor, Cairo Univ., Egypt
*** Graduate Student, CMRDI, Egypt
**** Professor, JWRI, Osaka Univ.

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Table 1 Chemical composition of steel grade 52/3

C	Si	Mn	P	S
0.245	0.273	1.54	0.029	0.013

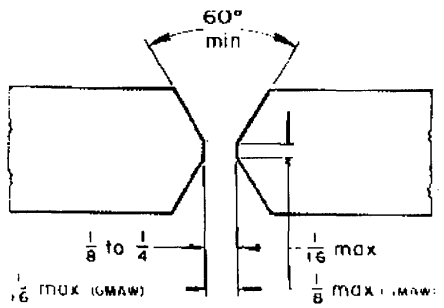

Fig. 1. Double V groove

AWS E7018 high tensile steel electrode of, 3 and 4 mm. diameters were used in all repair stages.

The submerged arc unit used in this study was a constant current type, with electrode positive. Run-on and run-off tabs were welded on both sides of the plates to be welded. Also the machined faces were tack welded with root openings of 1-5 mm. For each deposit, the current, voltage and welding speed were recorded and shown in Table 2. All welds were made under the same conditions of restraint.

2.3 Repair Welding Procedure

Generally, defects should be completely removed prior to repair by welding. In this work, air arc-gouging was used, followed by grinding. It allowed a convenient and rapid metal removal. The minimum amount of metal should be removed for economic reasons but it is necessary to produce a groove wide enough for access and manipulation of the welding electrode or filler wire. The groove shape is shown in Fig. 2. Repair welding parameters which were followed for the conventional buttering and back step techniques are given in Table 3, whereas those followed for half bead technique and the two layer technique are given in Tables 4 and 5, respectively.

Table 2 Welding condition for 52/3 steel.

Plate thickness, (mm)	40
Diameter of wire, (mm)	4
No of passes	52
Preheat temp., ^{0}C	150
PWHT, temp., ^{0}C	600
Welding Current, A	400 -450
Welding Voltage, V	29-30
Welding Speed, cm/m	31-50
Average Heat input, kJ./mm	2.1

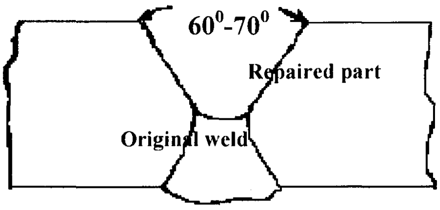

Fig. 2 Typical repair weld preparation dimensions

Table 3 Repair welding parameters for both conventional and back step techniques

Welding Position	Flat
Electrode diameter, mm	4
No of passes	28
Welding Current, A	160-180
Welding Voltage, V	21-25
Average Heat input, kJ./mm	1.65

Inspection was carried out in three stages; before, during and after welding for each sample. Dye penetrant and ultrasonic tests were used before and during the weld for both original weld and repair weld. The final inspection was carried by ultrasonic testing.

Table 4 Repair welding parameters for half bead technique

Welding Position	Flat
Electrode diameter, mm	4
No of passes	54
Welding Current, A	160-180
Welding Voltage, V	21-25
Average Heat input, kJ./mm	1.65

Table 5 Repair welding parameters for two-layer technique in flat position

	First Layer	Second Layer
Electrode diameter, mm	3	4
No of passes	12	20
Welding Current, A	120	160-180
Welding Voltage, V	21-25	21-25
Average Heat input, kJ./mm	0.6	1.65

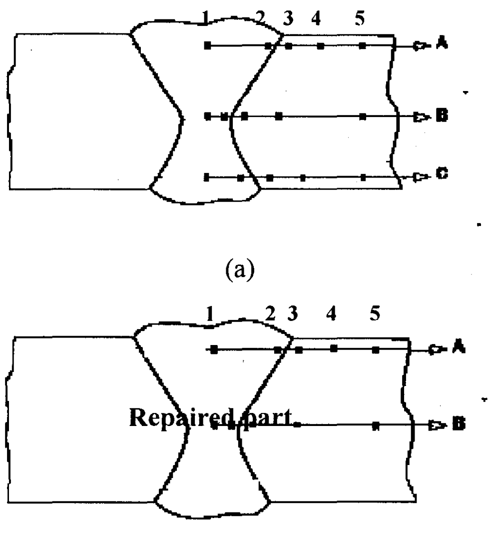

Fig. 4 Location of hardness measurements for (a) original weld and (b) different repair welding techniques

2.4 Impact test

Impact tests were carried out on both weld metal and heat affected zone. A Charpy impact-testing machine was used with a capacity of 30 Kgf. According to AWS recommendations, when the thickness of the steel product exceeds 28 mm., (as in this case) the longitudinal axis of the test piece shall be positioned at a depth of 1/4 of thickness of steel product or from the steel product surface of weld final layer side.

The testing was carried out at three different temperatures; room temperature (25^{0}C), 0^{0}C and -35^{0}C. Three specimens were tested at each temperature for each condition, cooling to 0^{0}C was done with the aid of ice. The cooling to -35^{0}C was accomplished by using liquid nitrogen. The required temperature was adjusted by means of a thermocouple with a cooled junction. Specimens were examined within 5 second after removing them from ice or liquid nitrogen.

2.5 Hardness test

Hardness was measured perpendicular to the centerline of the deposits welded for each samples as shown in Fig. 4 (a&b).

2.6 Calculation of preheating temperature

In order to calculate the minimum preheating temperature necessary for repair welding, the hydrogen test[5] was conducted for the E7018 electrodes, which were used for all repair techniques in this investigation. The measured values are tabulated in Table 6.

Table 6 Hydrogen content on E7018

Sample No / Item	1st	2nd	3rd	4th
Hydrogen content ml /100g	3	4.5	3.5	4
Average hydrogen content ml / 100g	4			

Based on a chart method the necessary preheat temperature for this type of steel was determined to be 150 ^{0}C

3. Results and Discussion

3.1 Effect of repair welding technique on HAZ width

The width of the HAZ is a function of joint design, metal thickness and amount of heat input. Through out this research work the joint design and metal thickness are fixed. Thus the only variable among those repair-welding techniques is the amount of heat input. Figure 5 shows the width of the HAZ after different repair welding techniques, compared with that of original weld. Obviously, the maximum width of HAZ was achieved by original weld where the heat input was high (2.1 kj.). Among the various repair-welding techniques the minimum width of HAZ was achieved by the two layer technique. This is related to the lower heat input used (0.6 kJ.) in first layer. On the other hand, by applying immediate PWHT after conventional buttering technique, as recommended, the width of HAZ decreased as compared to that of conventional buttering techniques without PWHT.

The width of the HAZ in the cases of back step and half bead techniques at different stages lies in the intermediate range between the conventional buttering technique and the two layer technique

3.2 Mechanical Properties of the Welded Joints

3.2.1Tensile test

The obtained ultimate and yield strength of steel grade 52/3 are graphically represented in Fig. 6. It can be observed that the change of repair welding techniques has little effect on the tensile properties of weld joints. A slight improvement in yield strength can be observed in case of two-layer technique. The improvement obtained with half bead technique results from tempering by grinding after each complete layer. On the other hand, different repair welding techniques have a comparatively higher effect on elongation percentage as shown in Fig. 7. Among all the repair welding techniques, the two-layer technique has the highest value of elongation, due to low heat input of the first layer and to the improved microstructure by increasing. the amount of acicular

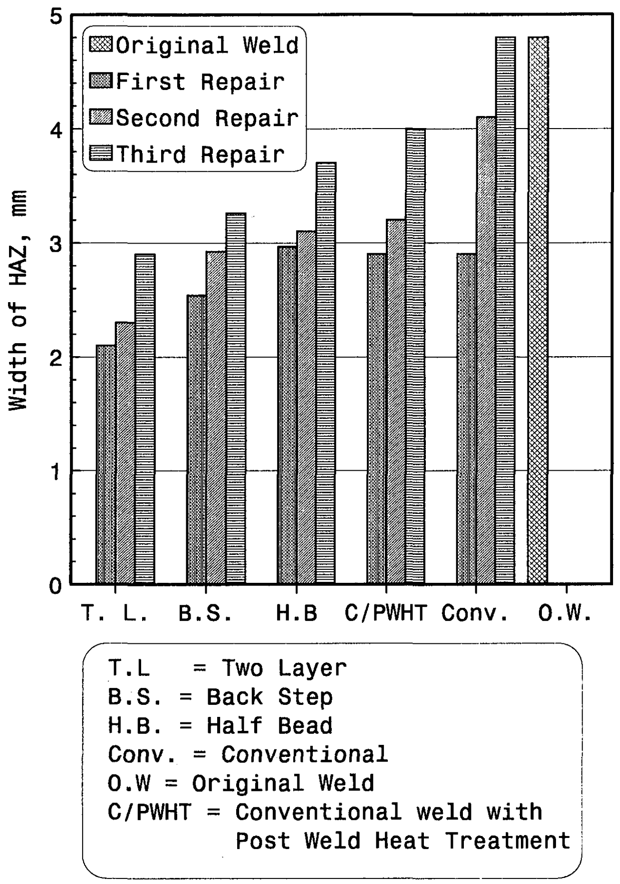

Fig. 5 Comparison between different HAZ widths

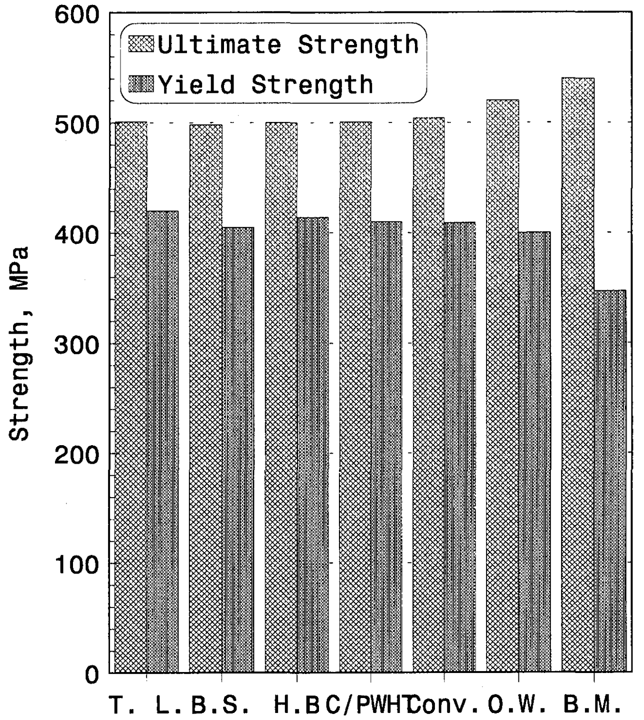

Fig. 6 Variation of tensile strength after different repair welding

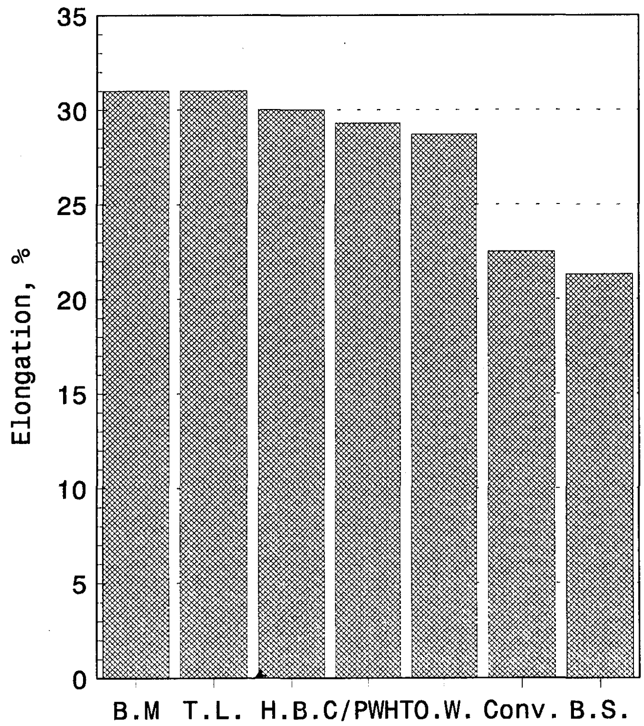

Fig.7 Elongation (%) after different repair welding techniques

ferrite at the expense of other phases. The removal of the coarse grained region of the bead reinforcement by grinding as in half bead technique improves the yield strength and elongation percent but not to the same degree as the two layer technique.

3.2.2Impact Test

The results of impact test are divided into two groups. The first group deals with the effect of different repair welding techniques on properties of the deposited weld metal in comparison with original weld deposit. The second group, is concerned with the toughness of HAZ.

(A) Weld metal toughness

Figure 8 shows the toughness of weld metal after different repair welding techniques in comparison with that of the original weld. Optimum improvement in toughness was achieved by the two-layer technique. Again, this is due to the lower heat input of the first layer, whereas the second layer reheat the first layer and refines the unfavorable coarse grain microstructure.

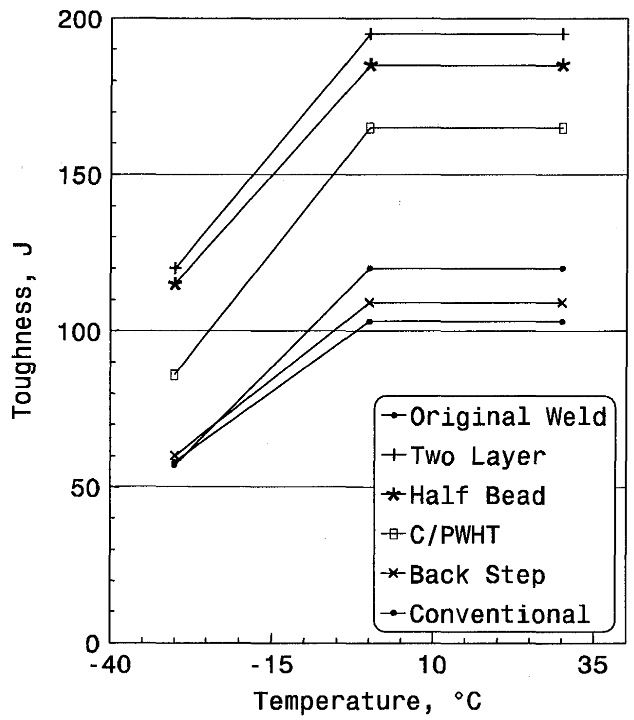

Fig.8 Toughness variation for weld metal after different repair welding techniques

The half bead technique allows better toughness after two layers due to the tempering after each complete layer by grinding. The important point to notice is that, the tempering of the two-layer technique is more effective than that of the half bead technique.
This indicates that the low heat input used in the first layer followed by relatively higher heat input in the second layer allow a higher degree of refining than grinding, especially for the heat affected zone properties. Also, the first layer works as a thin film protecting the HAZ from excessive coarsening.

Conventional buttering techniques with post weld heat treatment (C/PWHT), show an improvement in the weld metal toughness compared with other techniques, but lower than the two layer and half bead techniques. The improvement in toughness of C/PWHT is presumably due to the relieving of internal stresses during the heat treatment process.

The original weld metal shows the lower level due to the high heat input used in SAW (approximately, 2.1 kj.).

The back step technique gives somewhat better toughness compared with conventional buttering technique without PWHT, because back step depends on a balance of shrinkage stresses i.e. decreasing the internal stresses which will lead to a slight improvement in toughness. The different stages of repeated repair welding did not reveal a large effect on the toughness of welded metal.

(B) HAZ toughness

HAZ toughness after first repair

The data obtained are illustrated in Fig. 9. Optimum improvement can be achieved by the two-layer technique, in comparison with that of original heat affected zone and other repair welding techniques.

Half bead techniques allows also good toughness but lower than two layers Conventional buttering technique with post weld heat treatment (C/PWHT), which shows a toughness level below the two layer and half bead techniques but higher than other techniques due to its stress relief effect. On the other hand, the conventional buttering technique without post weld heat treatment indicates a moderate improvement in HAZ toughness compared with the back step techniques. Finally back step technique gives the lower toughness level compared with other repair welding techniques. This indicates that balancing of shrinkage stresses, which improves the toughness of the weld, are not so effective in the case of HAZ toughness.

HAZ toughness after second repair

In spite of the increase that has occurred in the width of heat affected zones due to second repair, an improvement in toughness has occurred for different heat affected zones, except conventional buttering technique with post weld heat treatment, Fig. 10. Obviously, the two layer technique is still the best method for the second repair. Generally, the heat affected zones toughness was improved compared to the first repair due to the improvement of the microstructure[6-10]. This improvement is due to tempering of the HAZ from the new repair. The marked point is the drop in toughness for conventional buttering technique with post heat treatment. This can be attributed to the deterioration of microstructure and formation of austenite-carbide and ferrite-carbide aggregates in large amount, in addition to the formation of secondary carbides[6]. Finally, the back step technique did not allow any improvement of HAZ toughness.

HAZ toughness after third repair

The main feature for third repair toughness is the marked drop in toughness in comparison with the first and second repair, for all repair-welding techniques. The two layer and half bead techniques are still the best techniques for HAZ toughness. The deterioration in HAZ toughness is due to gouging, and excessive grinding after each repair, which lead to deterioration in microstructure, formation of martensite and general coarsening of different phases. Figure 11 shows the various level of toughness for different repair welding techniques. A noticeable point is the slight improvement in the HAZ toughness for conventional buttering techniques with PWHT, due to dissociation of secondary carbides, which may have occurred during the application of the third repair[6].

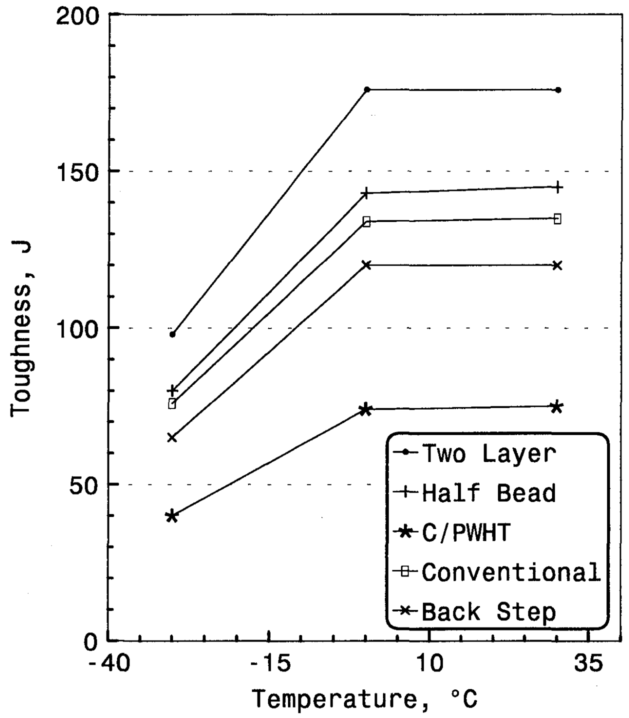

Fig. 9 Toughness variation for HAZ after first repair.

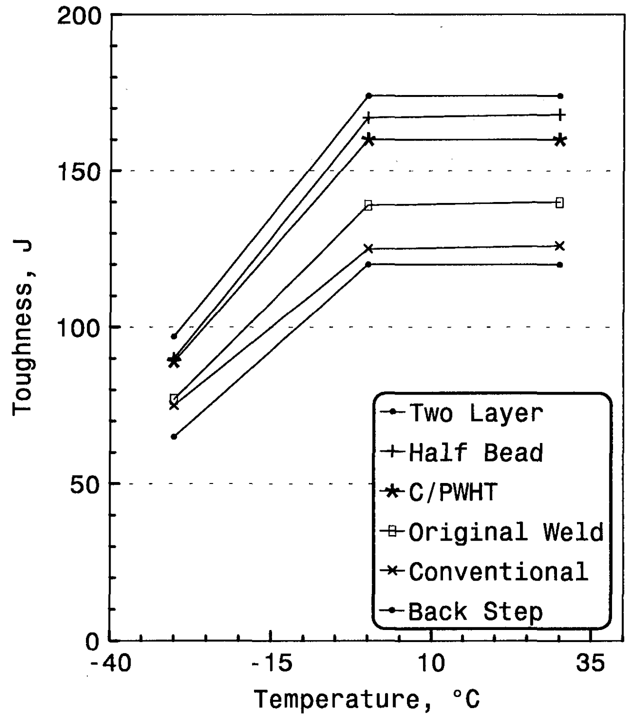

Fig.10 Toughness variation for HAZ after second repair

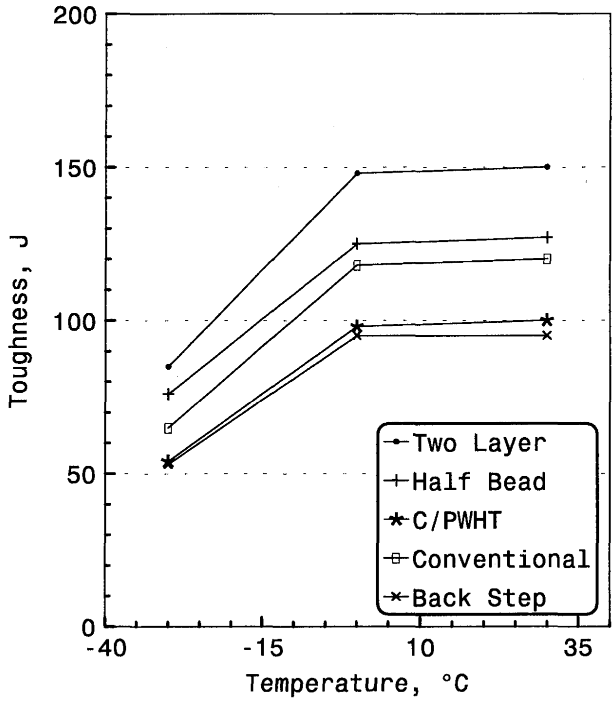

Fig. 11 Toughness variation for HAZ after third repair

3.3 Hardness Distribution

Hardness measurements were carried out on the cross sections of each specimen, to compare the influence of different repair welding technique on the hardness distribution. Figure 12 shows the hardness distribution in the original weld. It appears that the hardness of the weld metal is higher than the base metal and lower than the HAZ.

(A) Hardness distribution after first repair

The hardness distribution for two-layer technique is indicated in Fig. 13, the weld metal hardness and the HAZ hardness were not greatly increased. In the case of half bead the hardness of weld metal is nearly the same and a moderate increase has occurred in HAZ hardness. The homogeneity in weld metal hardness reflects the homogeneity of microstructure, which is due to the tempering effect of grinding after each pass.

On the other hand, the hardness of the Conventional buttering technique without/and with post heat treatment showed little improvement in hardness distribution due to PWHT. The hardness distribution in the case of the back step technique showed the same behavior.

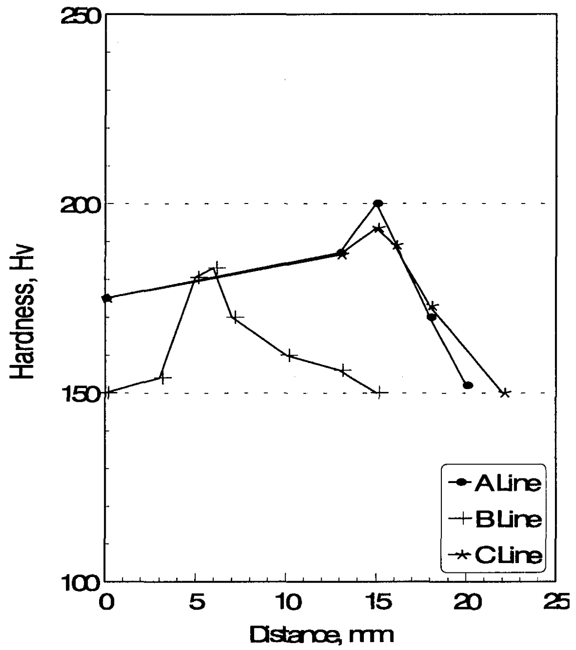

Fig. 12 Hardness distribution for SAW.

(B) Hardness distribution after second repair

Hardness distribution for the second repair by different techniques indicated a slight change in weld metal hardness but relatively higher hardness of the heat affected zones

The improvement in hardness of HAZ, is a result of the refinement that has been occurred due to second repair. Figure 14 shows different hardness distribution for different repair welding techniques. The main feature of hardness distribution after second repair is the general increase in hardness over a wide range of HAZs in conventional buttering technique with post heat treatment compared with the other techniques. This increase may be due to the formation of unfavorable microstructures[6].

(C) Hardness distribution after third repair

Hardness distribution after a third repair, has indicated a marked change for heat affected zones of the different repair welding techniques, as shown in Fig. 15. The main feature is the change in heat affected zone hardness for the two layer and half bead techniques. They exhibit lower values than other techniques. Also, the drop in hardness, which occurred in the case of the conventional buttering technique with post weld heat treatment, may be attributed to the dissociation of secondary carbides[6].

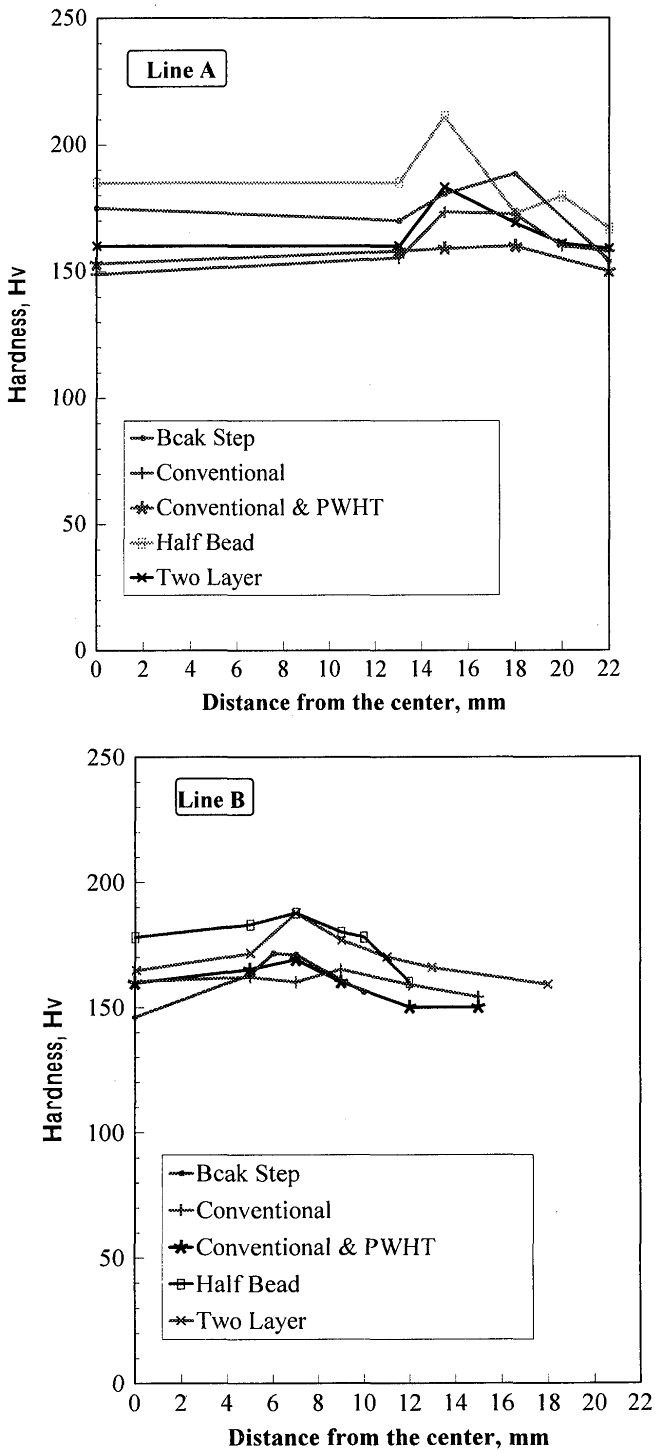

Fig. 13 Hardness distribution for different repair welding techniques after first repair

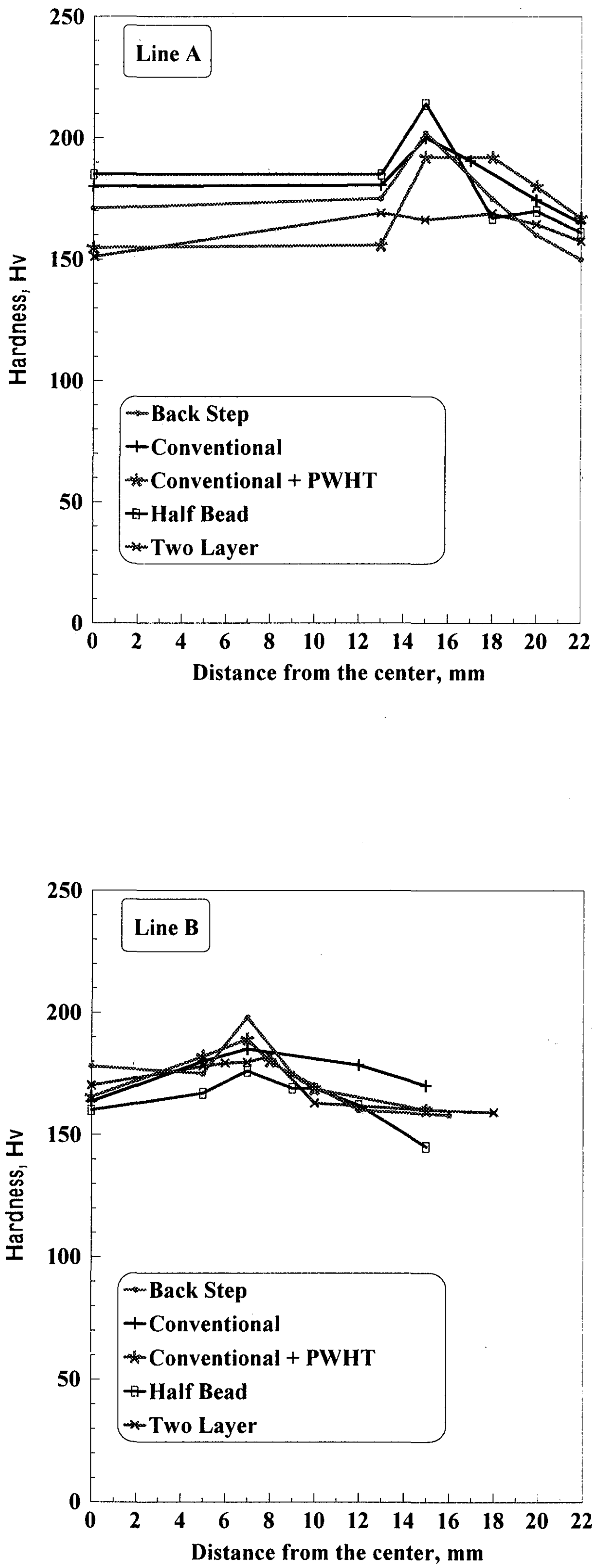

Fig. 14 Hardness distribution for different repair welding techniques after second repair

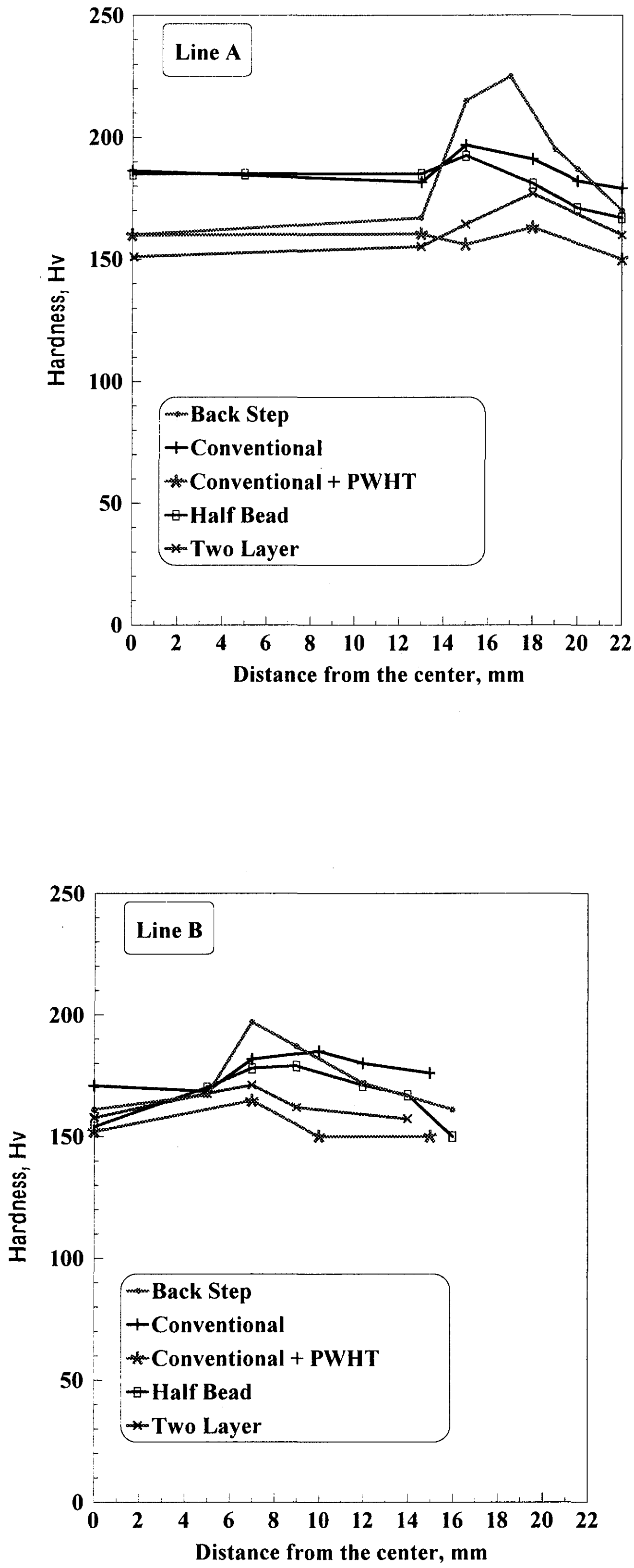

Fig. 15 Hardness distribution for different repair welding techniques after third repair

4. Conclusions

The main conclusions to be drawn from the present results are.

1. The two-layer technique is superior among the various repair-welding techniques investigated. The first layer produces a thin layer, which refines the grain size of HAZ. The second layer tempers the coarse grain region, in the fist layer and HAZ, and improves the microstructure. Also this technique minimizes residual stresses and distortion due to the low heat input in the first layer. Thus, this technique can be considered as the most economic and time saving repair welding method among the other welding techniques. The major limitation of two layer repair welding technique, that it is difficult to use it in small thickness below 12 mm. and it needs high welder skills

2. The half bead technique is the most difficult repair method, which needs more time and effort. However, it produces high toughness in both weld metal and heat affected zone as compared with other techniques. This may be attributed to the homogeneous microstructures, which can be obtained by this technique, in different parts of the weld. The two-layer technique however exhibits higher toughness of HAZ compared with that of half bead technique.

3. Conventional buttering with post weld heat treatment produces good mechanical properties after the first repair for both weld metal and heat affected zone. An opposite effect takes place however after the second repair due to the formation of unfavorable microstructures such as Widmanstatten ferrite, coarse grain pearlite and ferrite with (M-A-C) [6].

4. The back step technique which is widely used in repair welding of cast iron, due to its influence on balancing the shrinkage stresses, has little influence in repair welding of high strength structural steel.

5. Regarding the microstructure, which was investigated privously[6], it may be concluded that the mechanical properties of both weld metal and heat-affected zone are largely determined by their microstructures. Predominantly acicular ferrite has higher strength and toughness compared with other phases while fine grained microstructures have excellent mechanical properties compared with coarse microstructures. Both half bead and two layer techniques produce the necessary conditions for forming acicular ferrite and fine grained structures in the weld metal which in turn improve the weld metal toughness.

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