ANNALS OF FACULTY ENGINEERING HUNEDOARA
– International Journal of Engineering
Tome XI (Year 2013) – FASCICULE 3 (ISSN 1584 – 2673)

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EFFECT OF PARALLEL HEATING ON PROPERTIES OF A WELDED AISI 8438 STEEL

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ABSTRACT: Spring steels are susceptible to cracks under uncontrolled welding conditions due to the fact that they are significantly affected by weldment cooling rate. Under conventional welding, harder HAZ, cold crack susceptibility and residual stresses are generated in the weldment. This work did a localized heating of the weld plate at the boundaries parallel to weld line during welding. AISI 8438 spring steel materials of specification 105 x 40 x 10 mm^3 in pairs was welded along the length 105 mm. Boundary heating temperatures of 600, 400, 200^{o}C and ambient was used during the arc welding process. Mechanical test pieces were subsequently prepared from the weldment after cooling. Toughness of the welded spring steel material increased with increasing boundary heating temperature. At parallel heating boundary distance 10 mm from the weld line toughness values at distance 10 mm in the HAZ region are 1.02 , 0.88, 0.7 and 0.71 MN/m under 600 , 400 , 200^{o}C and the unwelded metal. Corresponding hardness values are 259.9, 396.9, 282.4 and 337.1 VHN. Attained maximum cooling rates at 10 mm from weld centre - line were 6.5, 5.8 and 5.4^{o}C/sec. under 600, 400 and 200^{o}C boundary heating temperatures. The observed property changes is explainable based on cooling rate control due to boundary heating with consequent effect on HAZ microstructures.
KEYWORDS: Heat-affected zone (HAZ); Spring steels; Weldment; Toughness; Hardness

INTRODUCTION

A typical arc weld thermal cycle consists of very rapid heating to a peak temperature, followed by relatively fast cooling to ambient temperature. When carbon steel is welded, the portion close to the weldline called heat affected zone (HAZ) experience microstructural changes different from the base metal [Xue et al, 2003]. Strength and toughness of carbon steel are derived from the formation of quenched and tempered martensite. Metal heating and cooling under welding is non – uniform with the consequence of harder HAZ, residual stresses and cold cracking susceptibility mainly around the HAZ [Adedayo et al, 2000; Lin et al, 1997 and Teng et al, 1997]. Spring steel is categorized as medium carbon low-alloy steel, comprising majorly of carbon and silicon making it very brittle with increased hardenability when welded. Weldability of spring steels is dependent on the maximum hardness of the heat affected zone (HAZ) and susceptibility of weld to cold cracking. Weld properties around the FZ and HAZ are more susceptible to defects than the base metal as such they govern the overall performance of the structure [Tadashi et al, 1997; Lee et al, 1992 and Xue et al, 2003].

Tempering of the martensite in the weld metal and HAZ in order to reduce hardness, increase toughness, reduce prospects of crack formation and residual stresses are effected by a controlled slow heating and cooling of the base metal and weld heat affected zone.[Hisaki et al,1988 ; Ghosh et al, 2004]. Various methods exist for reducing the cooling rates and one of them is preheating and /or post heating of weldment. The operation of heating metal at the outer boundary to some pre-determined temperature simultaneously with the welding process is described as parallel heating whereas heating metal to some pre-determined temperature before engaging in actual welding is called preheating [Funderburk, 1997].

Both methods aim at achieving milder cooling rate [Funderburk 1998] and a more favourable condition that inhibits martensite formation and associated hardness hopefully resulting in higher quality welds. Some factor that govern choice of minimum preheat temperature are carbon equivalent of the alloy, material thickness, base metal initial condition, constraint level and hydrogen entrapment risk level. Tables exist in literature that recommends preheat and interpass temperatures for welding alloy steel based on above listed factors [ASM Handbook, 1993]. Welding and simultaneous parallel boundary heating as a method of weldment cooling rate control had not been reported in literature. The effect of welding and simultaneously parallel boundary heating of the plate on selected mechanical properties and microstructure of spring steel is hereby presented.

MATERIALS AND EXPERIMENTAL PROCEDURE - Base metal composition

The composition of the base metal was determined using an Atomic Absorption Spectrometer. The compositional analysis was done at Grand Foundry and Engineering works, Lagos. Tests carried out on the weld metal showed the following percentage composition as given in Table 1.

Table 1: Percentage chemical composition of the spring steel

C	Si	S	P	Mn	Ni	Cr	Cu	AL	La		
0.383	1.840	0.053	0.023	0.890	0.271	0.223	0.233	0.011	0.001		
Mo	Co	Ti	Nb	V	Sn	Zn	As	Ce	Zr	Bi	Fe
0.035	0.013	0.002	0.011	0.004	0.025	0.002	0.007	0.006	0.002	0.001	96.00

The carbon equivalent (CE) is 0.62 indicating poor weldability when juxtaposed with an equivalent plain carbon steel.

WORK-PIECES PREPARATION AND WELDING PROCEDURE

Each un-welded work-piece length, width and thickness was machined to specification 105 x 40 x 10 mm^3. The weld edge was milled to a semi weld angle of 15°. Chromel - Alumel (type K) thermocouple probe holes of diameter 6 mm were drilled at a distance 10 mm from weld centre for monitoring the temperature with time. Preliminary annealing was carried out at 850°C, soaked for 1 hour for homogenization of internal structure of the work pieces. Materials were drawn out of the furnace after 72 hours. All test pieces were initially tack - welded in pairs and subsequently arc - welded at 1.42 mm/sec. welding speed, 80 V voltage, 140 A current, electrode diameter of 2.5 mm. Grooved metals pre-heated to temperatures 600°C, 400°C, and 200°C were slotted into weld plate boundary along the 105 mm length to serve as boundary heaters.

This was done simultaneously with the welding process. Weld plate specification and boundary heating set – up is depicted in Fig. 1.

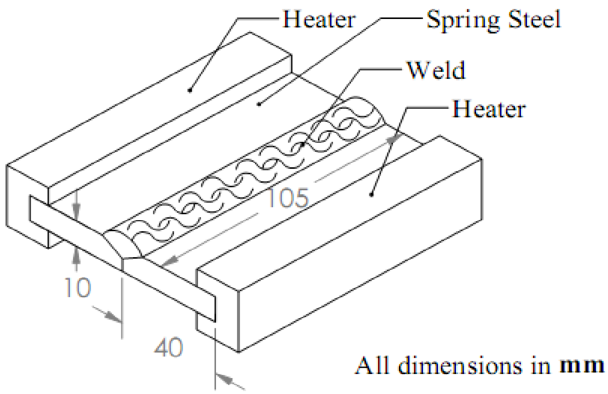


Figure 1: Butt welded plate configuration with the boundary heaters

MECHANICAL TESTS AND MICROSTRUCTURAL EXAMINATION

Toughness tests were carried out by cutting rectangular specimens of cross – section 10 mm x 10 mm with total length 75 mm. V – notches 2 mm deep, average root radius of 0.167 mm were milled into the specimen with a 45^0 groove angle. Absorbed energy was divided by the fracture area to give crack extension force [Balogun et al., 1985]. They were cut at 10 mm equispaced distances parallel to the weld line. Avery- Denison Machine with maximum range of 100 J and resolution of 1 J, Serial No: 50594, Code No: KD-A 3 FC was used for the toughness tests.

Hardness tests were based on Vickers method and carried out using Leco Microhardness Tester model LM700AT. Microhardness tests were done across all zones of the welded plate at equidistance spacings of 10 mm perpendicular to weld centre line. Test surfaces were prepared by grounding with grinding pads and then polished until a satisfactory surface is obtained. Applied load of 49.03 g was applied for 10 secs (dwell time). Measurement of indent size was made with a microscope. Figure 2 shows the relative arrangement of test piece locations

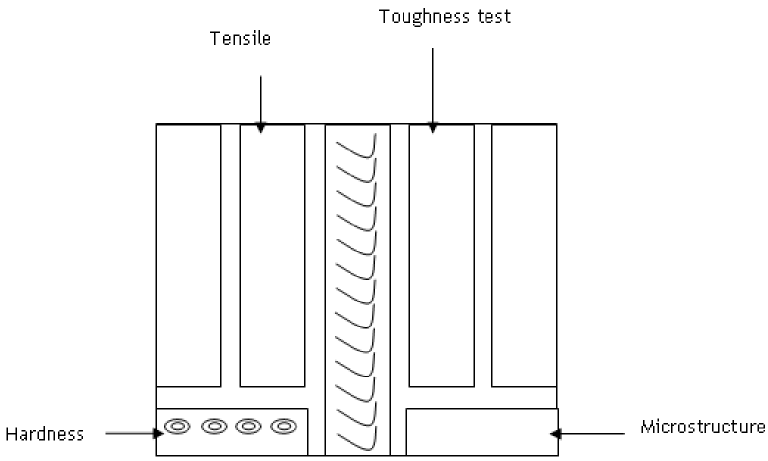


Figure 2: Test pieces and microstructural specimen location on weldment

Microstructures were performed using Daheng Software driven Microscope No: 702907. Microstructural sample was taken at a distance 10 mm from weld centre-line on a transverse section for weld pieces produced with and without boundary heating. Test surface was grinded, polished and etched by applying 2% HNO_3 (Nital) enchant before pictures was taken with the optical microscope.

RESULTS AND DISCUSSION - Cooling rate

Cooling rates were obtained from the metal temperature – time data taken at a point 10 mm from the weld centre line. Table 1 shows the cooling rate values. Maximum cooling rates of 6.5, 5.9 and 5.4°C/sec. were observed under welding carried out with 600, 400 and 200°C boundary heating. Weld plate experienced highest peak temperature with 600°C boundary heating. The differential between this peak values and ambient temperature accounted for the cooling rates calculated.

Table 1: Cooling rates at different parallel boundary heating temperatures (BHT)

Time (Sec)	Cooling rates (°C/Sec.)		
	BHT 600°C	BHT 400°C	BHT 200°C
1	2	1.2	0.4
5	3	2.6	2.0
10	4.2	3.8	3.4
15	4.9	4.4	4.1
20	4.7	4.3	3.8
25	4.9	4.5	4.1
30	5.6	4.9	4.3
35	6.5	5.9	5.2
40	6.5	5.8	5.4
45	5.4	4.8	4.3
50	4.8	4.3	3.7
55	3.5	2.8	2.1
60	2.1	1.3	0.8

Toughness of the spring steel is enhanced under all welding conditions, while that of 600°C boundary heating significantly enhanced the toughness at all zones of the weld. This can be explained in terms of a likely formation of fine grained microstructures resulting from increased peak temperatures and cooling rates.

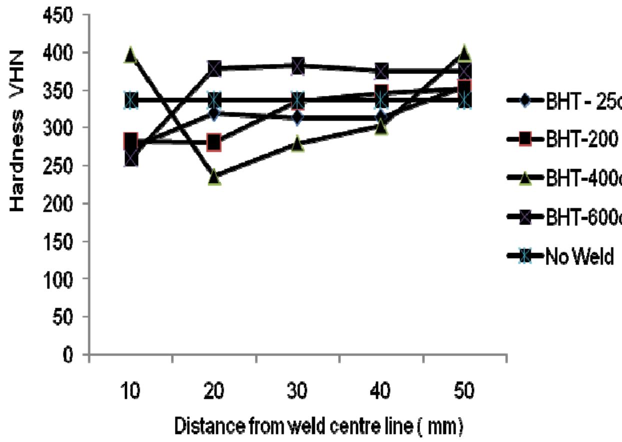


Figure 4. Hardness value variation across the weld zones

Mechanical Properties

Figure 3 shows the variation of metal fracture toughness across the weldment zones at parallel boundary heater distance location 10 mm from the weld line. Identical results were observed when the heater location was slightly increased to 20 mm. The fracture toughness of the welded metal increase with increasing boundary heater temperature, Observed toughness values were 1.02, 0.88, 0.7 and 0.86 MN/m at distance 10 mm from the weld line at boundary heating temperatures of 600, 400, 200°C and welding without parallel boundary heating.

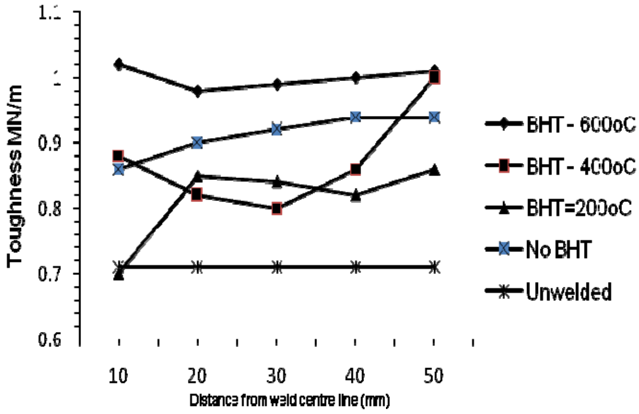
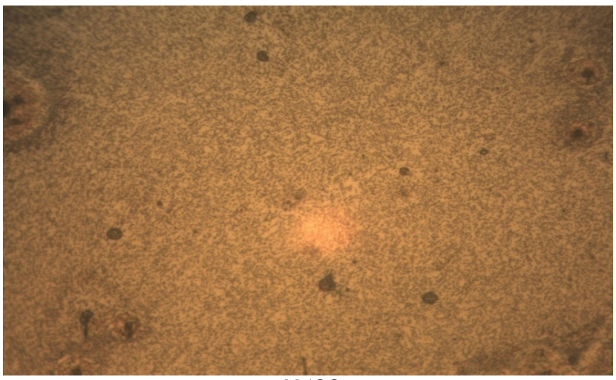


Figure 3. Effect of boundary heater temperature on metal toughness

Figure 4 shows hardness variation across the weld zones under different boundary heating temperature. At distance 10 mm from weld centre, microhardness values under 600, 400, 200°C and No BHT conditions are 259.9, 396.9, 282.4 and 273.8 VHN respectively. No distinct trend is observed with respect to effect of parallel boundary heater temperature (BHT) on metal hardness.

Microstructure

Microstructure of specimen 10 mm from weldline under 600°C parallel boundary heating and welding is as shown in Figure 5.



X400

Distance from weld line = 10 mm, BHT = 600°C

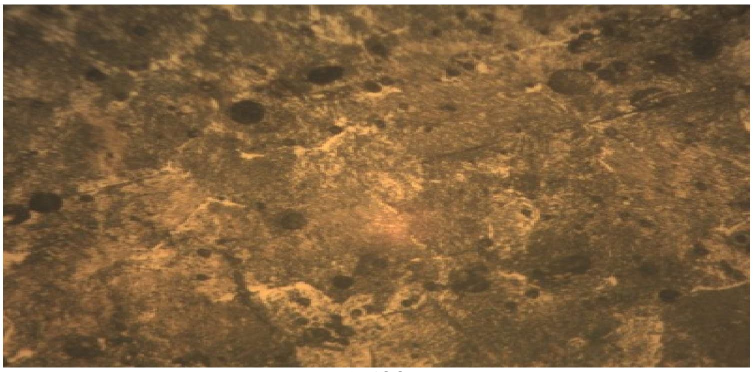
Figure 5: Microstructure with 600°C BHT

X400

Distance from weld line = 10 mm, BHT = 400°C

Figure 6: Microstructure with 400°C BHT

It is characterized by very fine grain structures with minute dark region suspected to be highland of noodles which could cause defects. Similar microstructure with 400°C parallel boundary heating is shown in Figure 6. Microstructure of the unwelded as-received spring steel is shown in Figure 7. It is composed of coarse grain with little or no traces of highlands of defects.



X400

Figure 7: Microstructure of as – received spring steel

CONCLUSIONS

1. Parallel boundary heating during welding does not distinctively affect metal hardness of spring steel.
2. Microstructures of spring steels are changed as a result of welding.
3. Parallel boundary heating and welding increases the toughness of the weldment at high boundary heating temperatures.

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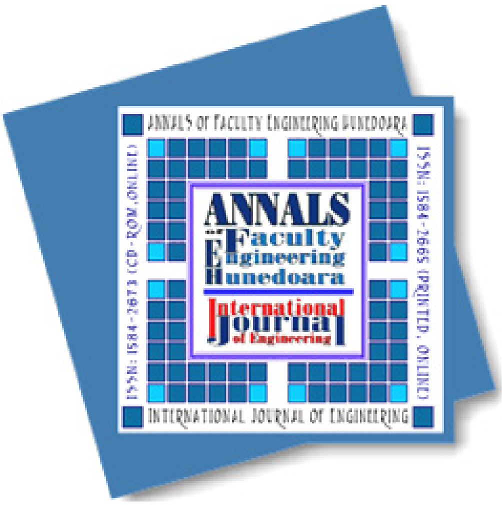

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