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EFFECT OF SALINE WATER COOLING ON SERVICE QUALITY OF A WELDED AISI1013 CARBON STEEL PLATE

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ABSTRACT: Mechanical property changes were resulting from welding and simultaneous boundary cooling with and without salinity were experimentally investigated. Welding in saline water environments is likely to induce properties different from conventional aqueous environment due to the severe quenching effect of sodium chloride. This work examines the effect of welding and simultaneous boundary saline water cooling on mechanical properties of AISI 1013 carbon steel plate. Stress free rectangular work-pieces of specification 120 x 35 x $16mm^3$ (L x W x T) were welded in pairs using low carbon consumables under boundary cooling conditions of 100% and 50% saturation salinity at 0.092, 0.105 and 0.111Litres/sec. flow rate. Average welding speed of 1.44mm/sec, welding current of 140A and 2.5mm electrode were used. Micro-hardness analysis was carried out and weldment hardness observed to increase towards weld centre-line under all welding conditions with higher values observed as coolant salinity is increased relative to water cooled weld. Observed maximum hardness values are 280.1 and 189.3HV under 100% salinity and water cooled conditions respectively. Weldment hardness was not significantly changed by changes in flow rate.

KEYWORDS: Quenchant, saline water, weldment, heat affected zone, micro-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. Strength and toughness of carbon steel are derived from the formation of quenched and tempered martensite. Formation of deleterious untempered martensite microstructures are likely possibilities during fast cooling often associated with welding in aqueous environment.

The microstructural changes in the weld zone and heat affected zone (HAZ) are greatly dependent on the heating and cooling rates which in turn depend on the weld heat input, plate thickness/geometry and the initial or inter-pass temperature. These micro-structural changes directly affect the property changes in the weld zone and HAZ. [Poorhaydai et al, 2005]. Only by improving the micro-structure of the heat – affected zone can the properties of the welded joint be improved [Gunaraj et al 2002].

Saline water is water containing a significant amount of dissolved salts (NaCl). Salinity level as classified by United States Geological Survey (USGS) are indicated as slightly, moderately and highly. Salinity of seawater is 35g/L with the following major ions: Na^+(10.76 gms/Kg, 30.74%), Cl^- (19.353gms/Kg, 55.29%) and Mg^{2+}, SO_4^{2-}, Ca^{2+}, K^+ making up the remaining percentage [Chemical composition of seawater; OCN623–Chemical Oceanography]. Seawater falls under highly saline water. Sealing of leaking ship rivets, offshore structures including oil drilling rigs, pipelines and platforms experience failures in normal usage or unexpected occurrences like storms, collisions. Any repair method will require wet or dry (hyperbaric) underwater welding [Amit M.J. 2012].

In an opinion poll carried out on 28th March, 2011 by CR4 GLOBALSPEC on undersea water welding, some of the respondents affirmed its possibility. Peculiarities of underwater arc welding are high arc temperature, concentration of oxygen and hydrogen in the reaction zone, pressure in the reaction zone relative to atmospheric pressure, presence of some chemical compounds dissolved in sea water in the reaction zone and intensive cooling of weld metal and heat affected zone. [Kononenko, 2006] Higher temperature drop of the arc and molten metal promotes higher chemical activity of the ingredient in the reaction zone. Increase of hydrogen concentration in the vapour-gas bubble promotes a greater hydrogenation of weld metal. Direct contact of the base and weld metal with the water result in 2 to 10 times higher cooling rate of the welded joint in underwater welding than in air welding (Kononenko, 2006). Increased ambient pressure also promotes intensification of metallurgical reaction in the arc zone. Manning examined the effect of water temperature on the weld metal and HAZ in ASTM A516 Grade 70 steels. He observed that welding under low temperature environments showed extensive cracking relative to others welded under higher water temperature. The diffusion rate of hydrogen in weldment held in cold water is slower than that in warm water weldments thus reducing the prospects of cracking [Manning, 1998]. Adnan, Thanaporn among others had examined the effect of quenchant types such as brine, water and oil on material properties. Their findings showed an increased level of microhardness associated with formation of pearlite and martensite when water or brine is used as compared with air or oil cooling. [Adnan et al, 2009, Korad et al, 2011, Thonaporn et al, 2011]. In this study the effects of saline water cooling on some mechanical properties of an AISI 1013 welded carbon steel plate were experimentally examined and hereby presented.

MATERIALS AND EXPERIMENTAL PROCEDURE. Base metal composition

The composition of the base metal was determined using an Atomic Absorption Spectrometer. Tests carried out on the weld metal showed the following percentage composition as given in Table 1.

Table 1: Composition of the base metal

C	Si	S	P	Mn	Ni	Cr	Cu	Al	Ca	Fe
0.10	0.32	0.08	0.01	1.16	0.23	0.03	0.22	0.03	0.03	97.85

Work-pieces preparation and welding procedure

Each un-welded work-piece length, width and thickness was machined to specification 120 x 35 x 16 mm^3 as shown in Figure 1. The weld edge was milled to a semi weld angle of 15^o. Coolant hole was drilled at 25mm from weld centre parallel to weld line. Preliminary annealing was carried out at 830^{o}C, soaked for 2 hours for homogenization of internal structure of the work pieces.

Materials were drawn out of the furnace after 24hours. All test pieces were initially tack - welded in pairs and subsequently arc-welded at 1.42mm/sec. welding speed, 80V voltage, 140A current, electrode diameter of 2.5mm. Simultaneously as welding is carried out is water and saline convective cooling with flow rates 0.092, 0.105 and 0.111Litre/sec. at distance 25mm from weld-line. 50% and 100% concentrations of saline were used as coolants. Welding was also done without any liquid coolant applied. Temperature profile was monitored at distance 12mm from weld line using type K thermocouple.

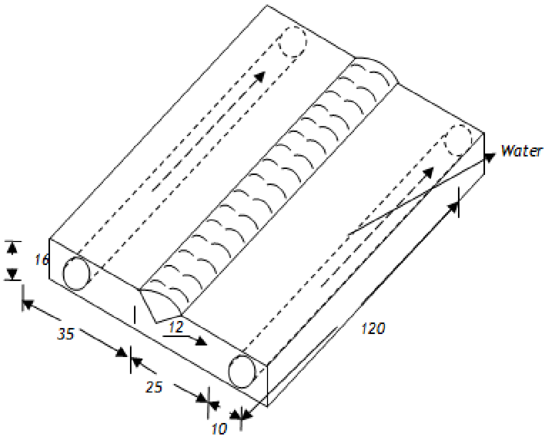

Figure 1: Butt welded specimen (all dimensions in mm)

MECHANICAL TESTS AND MICROSTRUCTURAL EXAMINATION

Tensile strength tests were carried out by cutting cylindrical specimens of diameter 6mm and 45mm gauge length with enlarged diameter at ends for tensile machine grip at distance 20mm from weld centre-line. Monsanto Tensometer type “W” with serial No. 10584 model No: A 220-9 with force indicator max. range of 20KN and resolution of 100N was used for the tests.

Toughness property of weldment was tested using Avory-Denison machine with maximum range of 100J and resolution of 1J, serial No: 50594, code No: KD-A 3 FC. Charpy specimen of cross section 10 x 10 mm and 2 mm depth notch was cut from weldment at distance 20mm from weldline.

Hardness tests were carried out using Leco Microhardness Tester LM 700AT. Microhardness tests were done on heat affected zone of the welded plate at equidistance of 5mm from a line perpendicular to weld centre line. Test pieces were grounded with grinding pads and then polished until a satisfactory surface is obtained. Applied load of 49.03g was applied for 10secs (dwell time). Measurement of indent size was made with a microscope.

Microstructures were performed using Daheng Software driven Microscope No: 702907. Microstructural sample was taken at a distance 5mm from weld centre-line on a transverse section. Samples taken include weldment with saline water cooling, ordinary water and air cooling. Prepared surface was grounded, polished and etched with 5% Nital. The relative locations where the various test specimens were cut are as shown in Figure 2.

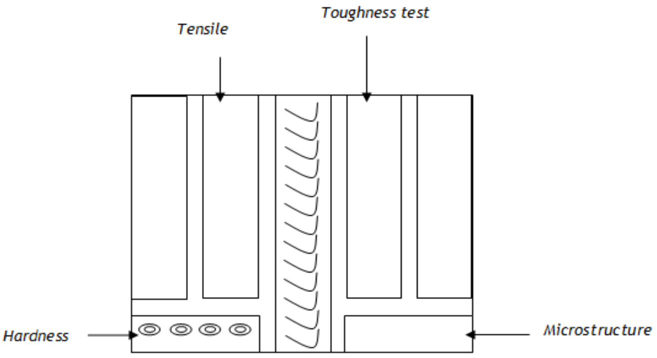

Figure 2: Relative locations of test pieces within the weldment

RESULTS AND DISCUSSION. Mechanical Properties

Figure 3 shows the effect of coolant type on weldment hardness. Hardness varied between weld centre-line and coolant channel with increasing values towards the centre-line. Welding with saline water cooling imparted higher values of hardness than water cooled weld. Maximum hardness values of 280.1HV and 189.3HV were observed at 5mm distance from weld line under saline and water cooled conditions respectively. The corresponding hardness value of the air cooled weld is 150HV. High hardness values close to the fusion zone on saline cooled was due to likely presence of bainite and martensite in the microstructure. Figure 4 shows the effect of flow rate on metal hardness. It is observed that hardness values decreased generally across the weld zones with increased coolant flow rate. Coolant flow rate reduction from 0.111Litre/sec to 0.105Litre/sec. resulted in hardness increase from 180HV to 280HV corresponding to 35.7% increase at 5mm from the weld-line. Strength under various welding conditions is presented in Table 2 and Table 3.

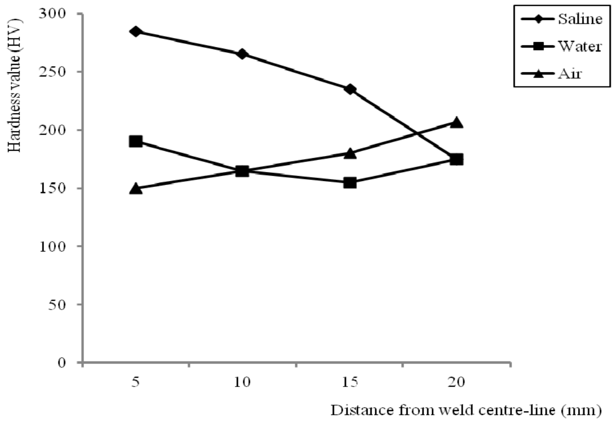

Figure 3. Effect of coolant type on weldment hardness

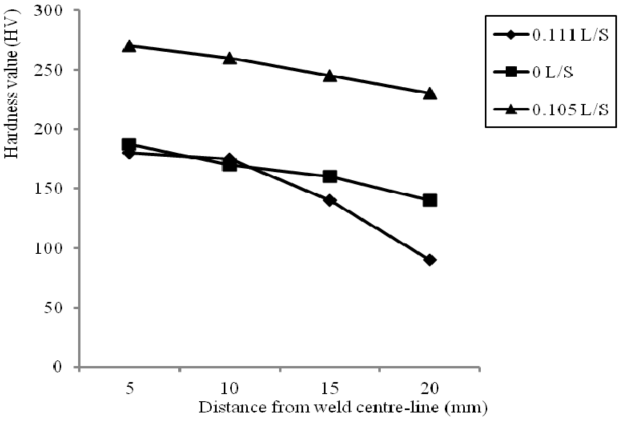

Figure 4. Effect of flow rate on weldment hardness

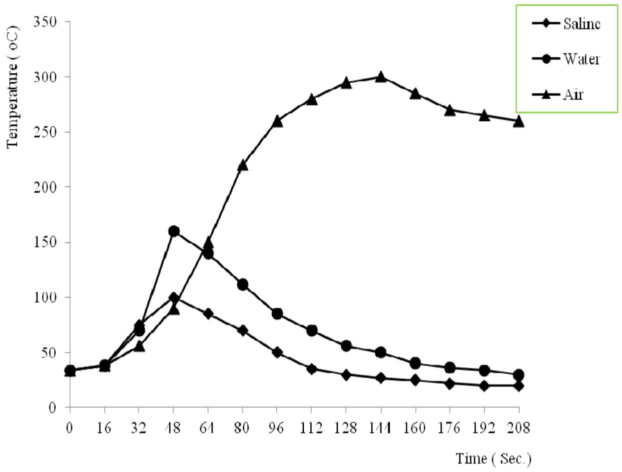

Figure 5. Coolant effect on temperature profile at distance 12 mm

Table 2: Strength variation with different weldment coolant types

Coolant Type	*Tensile Strength (N/mm^2)*	*Yield Strength (N/mm^2)*
100% Saline coolant	*338.5*	*242.9*
50% Saline coolant	*424.7*	*245.3*
Air cooling	*393.4*	*266.6*

Table 3: Strength variation with different coolant flow rates

Coolant flow rate (Litre/sec.)	*Tensile strength (N/mm^2)*	*Yield Strength (N/mm^2)*
0.092	*394.0*	*290.2*
0.105	*437.0*	*273.6*
0.111	*473.6*	*290.2*

No clear trend is observable with variation of saline concentration on tensile strength, however yield strength is observed to reduce with increasing concentration of salinity. This reflects a reduced ductility of the material due to possible formation of martensite. The highest weldment strength indicated by water cooled specimen agrees with work done by Ndaliman (2006). Table 3 shows that higher coolant flow rates resulted in higher strength of the weldment. This can be explained in terms of possible formation of martensite from rapid cooling resulting in a corresponding higher strength. This is in agreement with the work of Frank et al (2005).

Table 4 and Table 5 shows coolant effect on weldment toughness. The toughness of 100% saturation saline water cooled welded plate has the highest value of 90.67J. Table 5 shows that as the flow rate increases, the toughness of the material also increases. This can be explained in terms of the likely formation of fine structures due to rapid cooling.

Table 4: Toughness against boundary coolant type

Welding condition	*Trial 1 (J)*	*Trial 2 (J)*	*Trial 3 (J)*	*Average (J)*
100% saline concentration	*87*	*105*	*80*	*90.67*
100% water concentration	*76*	*87*	*77*	*80.00*
50% saline concentration	*80*	*80*	*80*	*80.00*
Air welding	*83*	*81*	*74*	*79.33*

Table 5: Toughness against flow rate

Welding condition	Toughness. (J) (Sample 1)	Toughness. (J) (Sample 2)	Toughness. (J) (Sample 3)	Toughness. (J) (Average)
0.092L/s flow rate	76.00	87.00	77.00	80.00
0.105L/s flow rate	73.00	98.00	82.00	84.33
0.111L/s flow rate	89.00	100.00	94.50	94.50

Microstructure

Figure 6 (a-c) shows the microstructure of heat affected zone under the following conditions (a) 100% saline concentration (b) welding without cooling (c) water cooling. Figure 6 (a) shows layer of bainite which was responsible for high hardness found in the saline cooled specimen and traces of lamellae structure, Figure 6 (b) consist of ferrite and pearlite. Figure 6 (c) shows little traces of bainite.

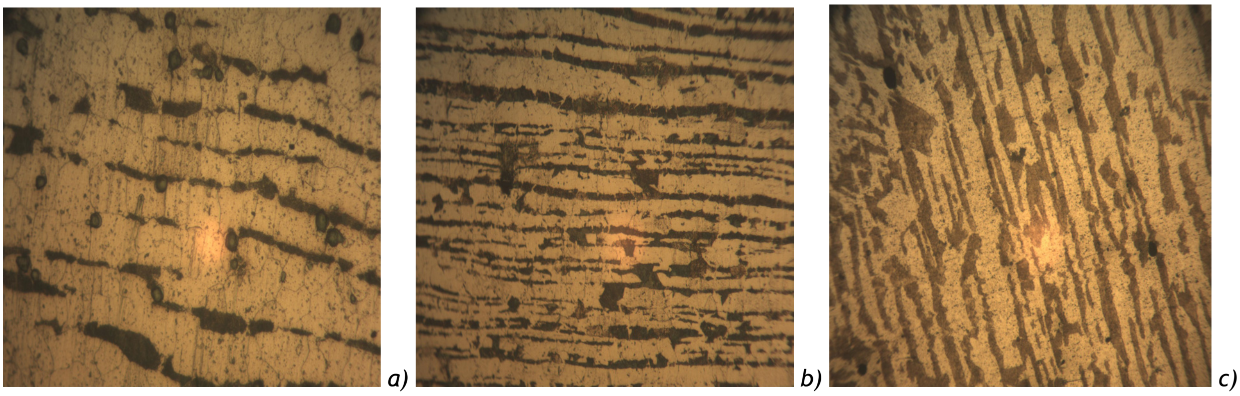

Figure 6 (a-c): Microstructure of heat affected zone
(a) 100% saline concentration, (b) Welding without cooling, (c) Water cooling

CONCLUSIONS

The major conclusions from the present study are the following:

(i). *Hardness values are high around the weld centre line and reduce toward the base metal.*
(ii). *Specimen cooled in saline water has the highest hardness compared to other quenchants.*
(iii). *Water quenchant impacted the highest mechanical strength.*
(iv). *Increase in flow rate enhanced material strength.*

REFERENCES

[1.] *Adnan C. “Effect of cooling on hardness and microstructure of AISI 1020-1040-1060 steels. International Journal of Physical Sciences. Vol.4(9), pp.514 - 518, 2009*

[2.] *Amit M.J. “Underwater welding” Mech Engrg. Dept, Indian Institute of Technology, Bombay. www.metalwebnews.com. Checked on 30th July, 2012.*

[3.] *Chemical composition of seawater; Salinity and the major constituents.OCN623-Chemical Oceanography. http://www.soest.hawaii.edu/oceanography. Checked on 30th July, 2012*

[4.] *CR4 GLOBALSPEC: The Mechanical Engineering Section. CR4-Thread: Welding a pipe under seawater. http://cr4.globalspec.com. Checked on 30th July, 2012.*

[5.] *Frank H., Falco S., and Wolfgang S. “State of art in the production and the use of high - strength heavy plates for hydropower applications”. Paper presented at the conference of High Strength Steel for Hydropower. Graz 05-07.07, 2005*

[6.] *Gunaraj V. and N. Murugan “Prediction of Heat-Affected Zone Characteristic in Submerged Arc Welding of Structural Steel Pipe” Journal of Welding Research, 2002.*

[7.] *Kononenko V.Y. “Underwater Wet Welding and Cutting”*

[8.] *Source: http//www.kononenko.kiev.ua/weldingphp/lang-ru. 2006 and Retrieved on May 19, 2010.*

[9.] *Manning R.D. “Analysis of underbead cracking in underwater wet weldments on A516 grade 70 steel”. M.Sc. thesis of Naval Postgraduate School, California, U.S.A. unpublished, 1998.*

[10.] *Ndaliman M.B. “An assessment of mechanical properties of medium carbon steel under different quenching media”, Journal Techvion 10(2) pp 100-104, 2006.*

[11.] *Poorhaydai K., Patchet B.M. and D.G. Ivey. “Estimation of Cooling Rate in the Welding of Plates with Intermediate Thickness” Journal of Welding Research, 2005.*

[12.] *Thanaporn K. “Improving quenching of low carbon steel”. Journal of Metals, Materials and Minerals. Vol.21 (1) pp.67 - 74, 2011*

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