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EVALUATION OF MECHANICAL PROPERTIES OF HAZ FOR LCS USING MMAW WITH SIMULTANEOUS COOLING EFFECT

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ABSTRACT

In fusion welding, there is flow of huge amount of heat which affects the mechanical and thermal properties of the specimen. Due to low cooling effect, the size of the grains near the HAZ increase and the work piece become brittle. This paper deals with the control of the grain structure to decrease the brittleness and hardness properties of the specimens by providing simultaneous and continuous cooling effect using water and salty-water. The size of grains remains almost constant and as a result of which, the properties like impact, strength, toughness and ductility increase in the steel plate. This is all due to the formation of sorbite and troostite structure like finer grains because of constant and simultaneous cooling. In this research paper, the effects of continuous cooling on the cooling time and the tensile strength of low carbon steel (LCS) after the welding using different coolants were investigated at the different distance from the weld zone. For low cooling rate by air at room temperature, the austenite was observed to transform into ferrite and pearlite. For higher cooling rates of water and salt water cooled samples, low temperature transformation products like bainite which is not a phase but an acicular microstructure or martensite which is a slightly harder than air cooled samples. The salt water cooled samples had more martensite regions because of the increased cooling rate.

Keywords- *Evaluation, Grain Structure, Heat Flow, HAZ, Internal Residual Stresses, Mechanical Properties, Manual Metal Arc Welding, Simultaneous Cooling Effect, Troostite, hardness, toughness, tensile strength, micro structural studies, low carbon steel.*

INTRODUCTION

Basic concept

The concept of the research work to find an economical solution to provide simultaneous and continues cooling effect to the work-pieces during Manual Arc Welding using some cheapest and effective cooling agents. As we know the various properties of any materials depends on its microstructures called grains which physical properties like shape and size depends upon its overall compositions of the constitute particles as well as thermal variables such as temperature and pressure [1]. In manual electric arc welding, high amount heat is transferred during Arc welding to the work-pieces so there is change in the size of grains' structure and microstructure after slow air cooling at the room temperature in the HAZ and near the weld zone and hence the various mechanical properties like hardness, toughness, tensile strength and the micro-constituent of the weld metals get change after the welding process due to the cyclic process of sudden heating and cooling [2]. Material becomes harder and less strength. So it needs to control the structure of grains by applying some simultaneous cooling agent [3]. Now Depending upon the heating and cooling cycles involved, different types of grains size and microstructures are obtained in the weld bead and the HAZ [5,6].These changes will affect the properties of the steel materials. The micro-grains structure that, are found in the weld work-pieces and HAZ of carbon steel material, were observed by Fonda [14], the particles could either be coarsen or dissolved in the steel during the heating cyclic process, which leads to the formation of excessive austenite in the HAZ. The coarse grain size decreases the nucleation sites for high temperature transformation products such as ferrite and pearlite, which result to oppress their formation. The slower cooling rate (air) maintence huge amount of ausenite in addition to ferrite and martensitic whereas, the high cooling rate (water) leads to changing the grains structure from granular bainite, and self-tempered martensite, finally martensite without self-tempering [15].

This paper deals with the simultaneous and continuous cooling effect using water and salty-water besides the cooling at the room temperature by air. It works on the simultaneous heat transfer process [10] from the work-pieces at high temperature to the cooling agents that at low temperature. It will not only control the micro-constituents but also will help to maintain the width of HAZ. In the simultaneous cooling process, size of grains in the weld and heat affected zone depends on the rate of cooling and the position of cooling set-up. The closer the cooling position, the more the cooling effect and the more the hardness and metallurgical properties were influenced. As the cooling rate in the weld zone and heat affected zone varied with cooling distance from the fusion zone of the weld, the phases formed from the transformation was observed to also vary with cooling distance [10]. When the steel materials is cooled after welding, the austenite, formed during the welding, will decompose to form coarse-pearlite and if faster simultaneous and continuous cooling processes are applied by using water or salty-water then there are the formation of finely dispersed pearlite, known as sorbite and Troosite respectively. In this part of thesis, the study of various simultaneous cooling processes like air, water and saline water have been done to analyses the change in mechanical properties and size of the grains structure. The strength of steels mainly depends on its microstructure which is controlled by the arrangement of the atoms of the various elements present in the steels by Aweda et-al [6]. Steels having carbon up to 0.2 % are the low-carbon steel and these are used for the various engineering, construction work, turbines and in different industries related to the automobiles and aeronautical etc [17]. Cooling processes is the processes of providing cooling effect during welding itself to analyses the various mechanical and thermal properties to control the grains structures of the parent metals. Various specimens were prepared to perform the processes with cooling effect on different position from weld zone. Depending on the different types of heating and cooling cyclic processes, different types of grains structure are obtained in the weld bed and heat affected zone due to the alteration of the thermal cycle [18, 19].

Mild Steel

As steels are one type of ferrous metal, its main constituent is iron. Steels are the alloys of iron and carbon. However, besides of its main constituents, steels also contain other elements like nickel, silicon, manganese, sulphur, phosphorus, etc. steels are mainly produced by either refining iron ore in the blast furnace or by recycling scrap steel in an arc furnace. Further, steels are also sub-divided into plain carbon steels and alloy steels based on the presence of carbon or not. Plain carbon steels have been further divided into low-carbon steels, medium-carbon steels and high-carbon steels based on the percentage of carbon present in its. For this research paper, the low-carbon steels, also known as mild steels, have been considered. Low-carbon steels contain carbon less than 0.25%.

Element	C	Si	Mn	S	P	Cr	Ni	Cu	Al	B	Mo	Ti	Fe
Average Content	0.22	0.29	0.295	0.028	0.022	0.042	0.02	0.03	0.0001	0.00015	0.0001	0.009	99.136

Table1. Constituents of LCS

LITERATURE REVIEW

Jenan Mohammed Nagie et al [1] studied the effect of cooling rate on mechanical properties of Carbon steel (St 35). He performed the various test likes tensile, torsion, impact and hardness.

Apurv Choubey et al [2] studied the influence of heat input on mechanical properties andmicrostructure of Austenite 202 grade Stainless steel weldments. He used the Cr-Mn SS as base material and 308L solid electrode rod. He found that the increase in heat input affects the micro-structures of the base metal and HAZ. He showed that the tensile strength decrease with increase in heat input while hardness increase in the weld pool and decrease in HAZ.

C. C. Doumanidiset et. al [3] performed simultaneous in process control of HAZ and cooling rate during arc welding. He developed a model for independently regulating the time-temperature relationship of the HAZ and centreline cooling rate. He addressed the problem of in-process control of several metallurgical transformation mechanisms. He worked on the concept of simultaneous regulation of both HAZ and centreline cooling rate.

Ajay N. Boob et al [4] study on effect of manual arc welding process parameters on width of HAZ for Ms 1005 steel. He investigated the width of HAZ with various process parameters like heat input and welding speed. He showed the heat input is the most significant factor for controlling width of HAZ and as the welding speed increase the width of HAZ decreases.

E. O. Aweda et al [5] investigated effects of continuous cooling on hardness, impact strength and micro-structural properties of LCS welded plate. He examined the various mechanical properties using various continuous cooling agents. Due to continuous cooling effects, there were formation of martensite structure and finer pearlite grains. He showed if the rate of cooling is increased, the more fine structure was obtained.

Sanjeev Kumar Jaiswal et al [6] studied the hardness and the micro-structure of AISI 1050 medium Carbon Steel after heat treatment processes. He carried the Annealing, Normalizing and Hardening on AISI 1050 MCS. He investigated the effect of cooling on the micro-structure and the hardness. He showed that the percentage of pearlite changes with change in the carbon content. According to him, the hardness was strongly influenced by the temperature and time.

M. A. Bodude et al [7] studied the effects of welding parameters on the mechanical properties of welded LCS. He investigated the effect of heat input on the mechanical properties of LCS using two welding processes name Oxy-Acetylene and Shielded Metal Arc Welding. He performed the tensile test, hardness test and impact tests and found that the tensile strength and hardness were reduced with the increase in heat input into the weld, whereas the impact strength of the weldment increase.

M. B. Ndaliman el al [8] studied the mechanical properties of MCS under different quenching media. He used water and palm as quenching medium and found that the water quenched steel produced its best properties in strength and hardness while palm oil has its best property in impact strength.

R. A. Mohammed et al [9] evaluated the properties of Shielded Metal Arc Welded Medium carbon steel. He investigated the mechanical.

S. M. Adedayo et al [23] studied the effect of saline water cooling on service quality of a welded AISI 1013 Carbon Steel plate. He investigated the results for the change in mechanical properties during welding with or without simultaneous boundary cooling by both normal and saline water. He found that the hardness values are high near the weld zone.

ManmohanYadav et al [10, 11] has performed heat transfer process to provide cooling effect to the Non-A/c railways' coaches at the time of running. In this research paper, the solution of Ammonium Chloride (NH_4Cl) with water has been used as the cooling agent. Air-ducts, found in roof of railways' coaches, were utilised as the main space to fix the components of proposed arrangement. In the proposed arrangement, the cooling agent was kept in a air tight plastic container and the hot air was allowed to pass through a coiled pipe of Aluminium. The coiled pipe was fixed in the container with its inlet and outlet outside the container. In his second research paper related to the welding, he showed the process to provide simultaneous cooling effect during manual arc welding using dry ice as cooling agent. There is a transfer of huge amount of heat to the work-pieces which lead to the change in grains' structure. As the various mechanical properties of any material depends on its grains structure so, it is more important to control the size of grains by providing simultaneous cooling effect.

WORKING PROCESSES

3.1. Pre-welding Process

The all specimens for the welding were prepared in proper way. There were mainly five steps performed for the preparation of the specimens. They were following:-

- Cutting of the LCW plates in required dimension.
- Performing the drill operation to make a hole in each specimen for the flow of coolants.
- Filing the specimens to make surfaces smooth.
- Preparation of the edge of each specimen to make it chamfer at the angle of 30̊ for the Vee-groove.
- Grinding operation to remove the unwanted particles and to provide uniform surfaces and edge the specimens' surface and edge smooth

The total 20 number of specimens were prepared. Among that 4 were for air as a coolant, 8 for water as a coolant and remaining 8 for salt-water as a coolant medium. Different test like impact test, hardness test, tensile test were performed and also the analysis of the microstructure were performed.
There was no any hole made in the specimens for air cooled welding operation. Among the 16 specimens that were made for water and salty water cooled welding operation, 8 were drilled at a distance of 25 mm away from the edge that was grooved for the joining by welding and remaining 8 were drilled at 35 mm away from the welding edge.

Welding process

After the all sample of specimens were cleaned and prepared for the welding processes, two same types of specimens were welded together using electric arc welding using E90xx type of coated electrode rod with the power supplied from the DC electric machine. The simultaneous cooling process also performed during welding itself using different cooling agents. Temperatures of the all finished work-pieces were measured after the welding using Digital thermometer and noted down separately for different cooling medium.

The welding parameters that were taken during all welding processes are given below in the table.

Voltage	Current	Average speed	Heat Transfer effi. Factor (MMAW)	Heat Input	Mass Flow Rate of Coolant
21V	260A	3.4 mm/s	0.65	1605.88 J/mm	820 g/s

Table 2: welding parameters

The amount of heat input has been calculated using the formula

$$\mathbf{H = \frac{IV}{S} X\ 60\ Joules/mm}$$

Post-welding Processes or Preparation of sample

After finishing the welding process for the all specimens, the work-pieces were kept for some time and the temperatures were noted down from starting temperature 1200̊ for next 60 sec after each 5 sec of interval.

After that the all work-pieces were cleaned by wire-brush and chipping hammer to remove the unwanted flux, dust particles. Then the work-pieces were taken to the grinding machine to make the surface of the work-pieces smooth using the grinder wheel made of silicon carbide of various grits size and subsequently one of the work-pieces from each cooling medium was polished for the metallographic inspection.

After the cleaning process, each of the work-pieces was cut down in small pieces parallel to the welding direction in the weld zone and heat affected zone for testing purpose. After that the cutting specimens were taken to the specific testing machine for the evaluation of mechanical properties and the microstructures.

EVALUATION

Effects of the Simultaneous And Continues Cooling

Heat treatment is the process of heating and cooling at various temperatures in such a way as to gain desire micro-structure and Mechanical properties [2, 8].When the steels are heated and cooled at various temperatures their grains structure changes. The Hypoeutectic steels (C < 0.8%) have Ferrite and Pearlite structure up to the temperature of 723ºC. On heating, its Pearlite structure starts to change into the austenite. Upon further heating above critical point, all the ferrite becomes austenite. Eutectoid steel (C=0.8%) remains Pearlite up to 723ºC and on further heating it becomes austenite. Hypereutectoid steels (C>0.8%) have a structure of Pearlite and Cementite up to 723ºC and on heating, the Pearlite start to convert into the austenite. Up to critical point it remains in mixture of Austenite and Cementite but on further heating it is totally converted into austenite.

When the already heated steels were cooled slowly at the room temperature by simple air flow, the austenite structure converted into coarse structures like Pearlite (mixture of ferrite and Cementite).

Austenite $\frac{simultaneous\ air\ cooling}{heated\ steal}$ Pearlite

When, the same work-pieces were suddenly cooled by quenching method in water/oil, the martensite.

Austenite $\frac{sudden\ cooling\ in\ water/oil}{by\ quenching\ method}$ Martensite

When the same welding processes were performed with water as a simultaneous cooling agent, the rate of cooling was increased. As the cooling rate is increased, the temperature of the work-pieces was not increased so much to affect the microstructure of the specimens and finally after simultaneous cooling by water, the fine Pearlite or Sorbite is formed as the microstructure.

Austenite $\frac{simultaneous\ cooling\ \ with\ water}{heated\ cooled}$ sorbite

Same phenomenon was occurred with the work-pieces cooled by flow of high rate of salty-water. When the same welding processes were performed with water as a simultaneous cooling agent, the rate of cooling was increased. As the cooling rate is increased, the temperature of the work-pieces was not increased so much to affect the microstructure of the specimens and finally after simultaneous cooling by water, the finest structures formed that know as Troostite.

Austenite $\xrightarrow[heated\ cooled]{simultaneous\ cooling\ with\ salty-water}$ Troostite

Impact Test

The Charpy Impact test that is the Balanced Impact Strength Test was performed for one air cooled sample, two water cooled samples and two salty-water cooled samples and the readings were noted down. Before that the Charpy V – notches were prepared for each sample. Impact tests like Izode and Charpy test are generally performed to find the toughness ability of the specimens. Toughness is the ability of a material to absorb energy and plastically deform without fracturing. One another definition of material toughness is the amount of energy per unit volume that a material can absorb before rupturing. It is also defined as a material's resistance to fracture when stressed. Toughness can also be defined with respect to regions of a stress-strain diagram. According to the stress-stain diagram the toughness is defined as the area under the stress-strain curve. In order to be tougher, a material should be both more strong and ductile.

Hardness Test

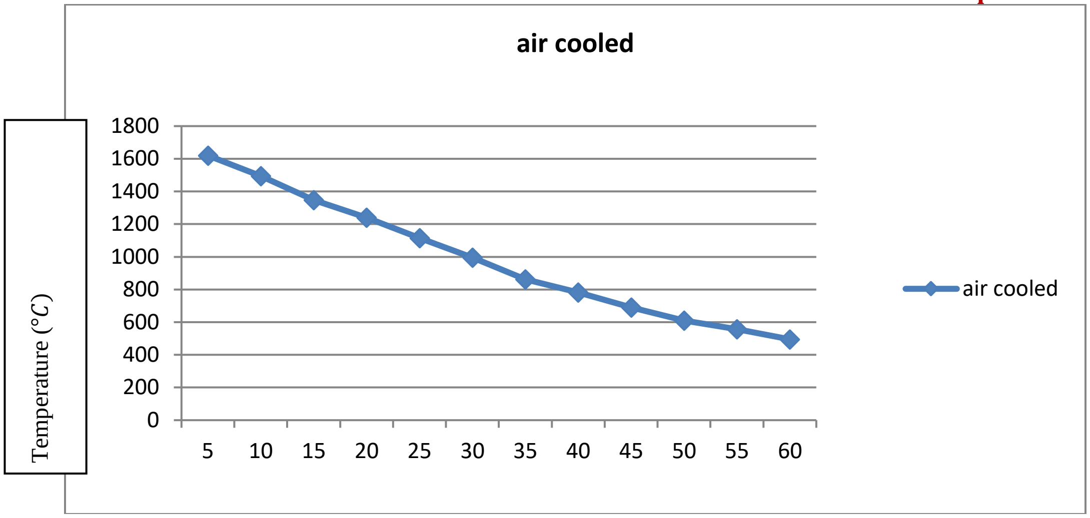
Here, indentation hardness method has been used with the help of Rockwell Hardness testing machine. It is determined by measuring the permanent depth of the indentation. More simply put, when using a fixed force (load) and a given indenter, the smaller the indentation, the harder the material. Indentation hardness value is obtained by measuring the depth or the area of the indentation. The sample specimen was placed with the surface on the anvil, and slowly turning the hand wheel until the specimen was raised to touch the indenter. The numbers were read directly from the dial indicator and converted to the Rockwell number. Welding with saline water cooling imparted higher values of hardness than water cooled weld samples. Maximum hardness values of 280HV and 189HV were observed at 5mm distance from weld line under saline and water cooled conditions respectively. This is due to the faster cooling rate of in case of salty water, which gives higher martensite formation. Also, there is an increase in the presence of fine dispersion of small particles in the pro-eutectoid Ferrite and Pearlitic that prevent the dislocation movement, may have also contributed to the higher Rockwell hardness number of the salty water cooled sample. The corresponding hardness value of the air cooled weld is 142HV. High hardness values close to the fusion zone on saline cooled was due to likely presence of Bainite and Martensite in the microstructure.

RESULT AND DISCUSSION

Cooling curves

Air Cooled Sample

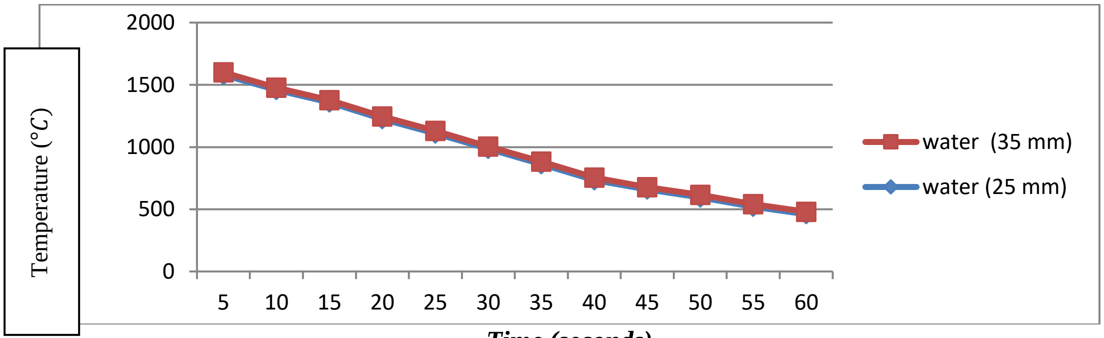
As we know the air cooling is a slow process and it takes more time to get cooled for the same temperature as in case of water and salty-water cooled samples. In the air cooled samples, the temperature rises to high and it takes more time to get cool. It was observed that in controlled air cooling process the temperature raised beyond the 1600℃. Just after the 5 sec of welding, the temperature was noted 1620℃ and further temperatures were noted for each 5 sec of interval to the next 60 second. And at 60 second after finishing the welding, the temperature was noted 495℃. So, it was found that in air cooled samples the temperatures dropped from 1620℃ to 495℃ within 60 second after the welding.



Time (seconds)
Graph 1

Water cooled samples

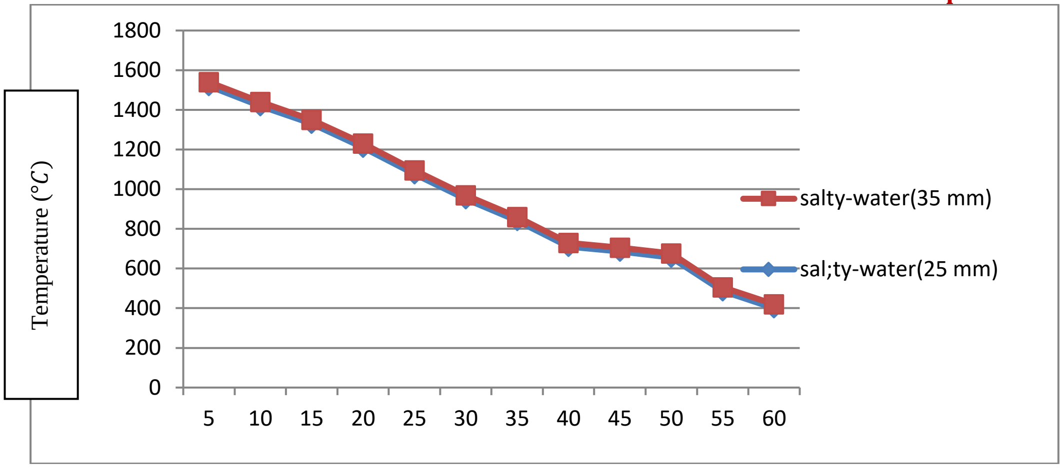
Water cooled samples were got easily cool than the air cooled. In the water cooling process, the cooling channel, for the flow of water, were provided at two different distances. For each of mechanical properties test there were two samples prepared. For the same mechanical properties testing process, one sample was prepared with the cooling channel 25 mm away from the weld zone and another sample with cooling channel 35 mm away from the weld zone. And it was observed that the cooling rate was faster in sample having cooling channel near to weld zone. In the water cooling process, some amount of temperatures was controlled during welding due to simultaneous cooling effect of water.



Time (seconds)
Graph 2

Salty-Water cooled samples

Salty-Water cooled samples were got more easily cool than the air and water cooled samples. In the saline water cooling process, the cooling channel, for the flow of water, were provided at two different distances like water cooling processes. For each of mechanical properties test there were two samples prepared. For the same mechanical properties testing process, one sample was prepared with the cooling channel 25 mm away from the weld zone and another sample with cooling channel 35 mm away from the weld zone. And it was observed that the cooling rate was faster in sample having cooling channel near to weld zone. In the water cooling process, some amount of temperatures was controlled during welding itself due to simultaneous cooling effect of salty-water.



Time (seconds)
Graph 3

Tensile Test Result

There were not much variation found in results of the tensile test, but it was clearly observed that the highest value was given by the water cooled samples. And hence, the highest strength indicated by water cooled specimens agrees with work done by Ndaliman et-al (2006).

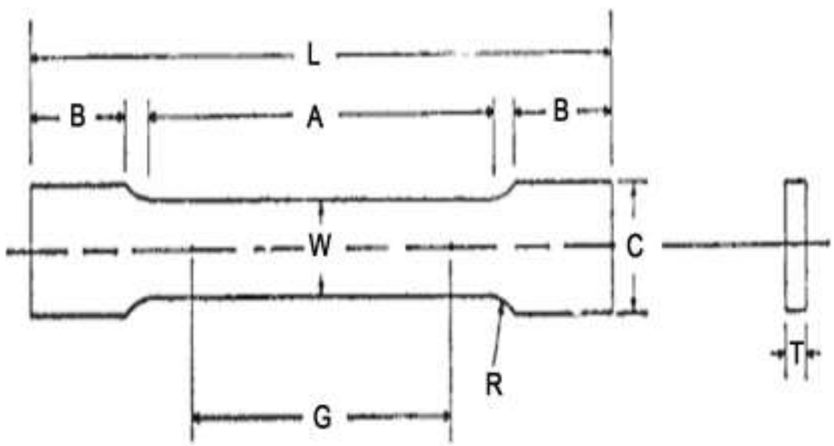


Fig. 1 Sample for the tensile test with total length 100 mm and the gauge length 50 mm

Distance from weld zone (mm)	Tensile strength (N/mm^2)
5	425
10	436
15	450
20	465
25	480

Table 3.Tensile strength of air cooled samples

Distance from weld zone (mm)	Tensile strength (N/mm^2) Cooling channel 35 mm away from WZ	Tensile strength (N/mm^2) Cooling channel 25 mm away from WZ
5	460	470
10	470	482
15	488	500

20	510	525
25	525	542

Table 14.Tensile strength values for water cooled samples

Distance from weld zone (mm)	Tensile strength (N/mm^2) Cooling channel 35 mm away from WZ	Tensile strength (N/mm^2) Cooling channel 25 mm away from WZ
5	488	510
10	502	524
15	522	545
20	550	575
25	568	594

Table 16.Tensile strength values for salty-water cooled samples with cooling channel 25 mm away

CONCLUSIONS AND FUTURE ASSETS

Conclusion

The following conclusions are drawn from the simulation and simultaneous cooling effect:

- The purposed arrangement is simple and it requires low maintains.
- The use of water and salty-water, for the simultaneous cooling effect, will don't allow the temperature to rise excessively. Since the temperature will not rise drastically, so the size of grains in the fusion zone and near the weld zone remains almost same as like parent metals.
- It was observed that the variations in the microstructures were minimal; this was possibly due to the rapid heat input, very short soaking time during welding and the low carbon content of the material.
- The closer the cooling position, the more the cooling effect and the more the hardness and metallurgical properties were influenced.
- Due to the use of water and salty-water, the tensile strength and toughness were improved.
- Due to the slow cooling process by the application of water and salty-water, there were formation of finer acicular microstructure, sorbite and troostite respectively, which were high tensile strength, more ductility and toughness.
- There was also an effect of simultaneous cooling processes on the width of HAZ. The work-pieces that were cooled by the salty-water had less width size of HAZ than water and air cooled work-pieces. Again the distances of cooling channel also affect the width of HAZ. The work-pieces, having cooling channel near to weld zone, had had less width of HAZ.

Future Scope

- This concept can be used in automobile and aeronautical industries for the bulk amount of welding processes. It will help to enhance the properties of the materials after the welding.

In the present work, water and salty-water were used as cooling agents. As water and salty-water have tendency to allow the current to pass through them, there is a chance of occurrence of short-circuit that can affect the efficiency of the welding processes. So to avoid these all, dry-ice or liquid Nitrogen can also be used as cooling agents.

REFRENCES

1. Jegan Mohan, 'The Effect of Cooling Rate on Mech Properties of Carbon Steel (St 35)', Diyala Journal of Engineering Sciences, Vol. 7, Issue. 1, March 2014, pp 109 – 118.
2. Apurv Choubey and Vijaykumar S. Jatti, 'Influence of Heat Input on Mechanical Properties and Microstructure of Austenite 202 Grade Stainless Steel Weldments', WSEAS Transaction on Applied and Theoretical Mechanics, Vol. 9, 2014, pp 222 – 228.
3. C. C. Doumanidis and D. E. Hardt, 'Simultaneous in Process Control of HAZ and Cooling Rate during Arc Welding', Paper presented at the 70th Annual AW Meeting held on April 2 – 7, 1989, in Washington D. C.
4. Ajay N. Boob and Prof. G. K. Gattani, 'Study on Effect of Manual Arc Welding Process Parameters on Width of HAZ for Ms 1005 Steel', International Journal of Modern Engineering Research, Vol. 3, Issue. 3, May-June 2013, pp 1493 – 1500.

5. E. O. Aweda, M. Dauda , I. M. Dagwa and E. T. Dauda, 'Effects of Continuous Cooling on Hardness and Micro-structural Properties of Low-Carbon Steel Welded Plate, Journal of Production Engineering, Vol. 16, Issue. 2, 2013, pp 20 – 24.
6. E. O. Aweda, M. Dauda , I. M. Dagwa and E. T. Dauda, 'Effects of Continuous Cooling on Impact and Micro-structural Properties of Low-Carbon Steel Welded Plate, Journal of Research in Humanities and Social Science, Vol. 2, Issue. 12, 2014, pp 67 – 76.
7. M. A. Bodude and I. Momohjimoh: Studies on Effect of Welding Parameters on the Mechanical Properties of Welded Low-Carbon Steel, Journal of Minerals Characterization and Engineering, Vol. 3, March 2015, pp 142-153.
8. M. B. Ndaliman: 'An Assessment of Mechanical Properties of Medium Carbon Steel under Different Quenching Media', AU J.T., Vol. 2, Issue. 10, Oct. 2006, pp 100-104.
9. R. A. Mohammed, M. Abdulwahab and E. T. Dauda: 'Properties Evaluation of Shielded Metal Arc Welded Medium Carbon Steel Material', International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue. 8, August 2013, pp 3351-3357.
10. Manmohan Yadav, Rathin Dutta and Rohit Ranjan: 'Partial Cooling of Non-A/c Railways' Coaches using Chemical Solution', National Conference on Innovative Developments in Science, Technology and Management, Ganga Technical Campus, Soldha, Bahadurgarh, March 2015, pp 39 – 44.
11. Manmohan Yadav, Rathin Dutta and Rohit Ranjan: 'Simulation of Heat Distribution of MMAW with Simultaneous Cooling Effect', International Journal of Research in Mechanical Engineering, Vol. 3, Issue. 6, Nov. – Dec. 2015, pp 25 – 31.
12. Mebarki N, Delagnes D, Lamelse P, Delmas F, Levaillant C, 'Relation between Microstructure and Mechanical properties of a 5% Cr tempered martensitic tool steel', Material Sci. Eng., Vol. 387-389 (13), 2004, pp. 171-175.
13. S. K. Hajra Choudhary, A. K. HajraChoudhary, N. Roy, 'Elements of Workshop Technology', Vol. 1 Manufacturing Processes, 1964.
14. Funda R. W and Spanos. G.'Microstructural evalution in ultra-low carbon steels weldments-part 1: controlled thermal cycling and continuous cooling transformation diagram of weld metal', Metallurgical and Materials transaction. Vol. 31(9), 2000, pp.2145-2153.
15. QiaoZX, Liu YC, Yu LM, Gao ZM,'Effect of cooling rate on the microstructural formation and hardness of 30CrNi3Mo steel', App. Phy. Vol. 95(3), 2009, pp.917-922.
16. Savage, W. F., Nippes, E. F. and Szekeres, E. S.,'Hydrogen induced cold cracking in low allow steel', Welding Journal, 1976, pp: 276-283.
17. A. O. A. Ibhadode, 'Introduction to Manufacturing Technology', Ambik Press, Benin-City, Nigeria, 2001.
18. W. Pang, N. Ahmed and D. Dunne, 'Hardness and microstructural Gradient in the HAZ of Low – Carbon Quenched and Tempered Steels'. Austral Asian Welding Journal, Vol. 56, 2011, pp 36 – 48.
19. M. Shome, O. P. Gupta and O. N. Mohanty, 'A Modified Analytical Approach for Modelling Grain Growth in the Coarse Grain HAZ of HSLA Steels', Scripta Materialla, Vol. 50, 2004, pp 1007 – 1010
20. T. Fukuoka, S. Fukui, 'Analysis for the Cooling Process of Underwater Welding Comparison with Welding in Air', Bulletin of the M.E.S.J., Vol. 22, issue. 2, 1994, pp 88 – 92.
21. Liu H.J., H.J. Zhang and L Yu, 'Homogeneity of Mechanical Propertied of Underwater Friction Stir Welded 2219-T6 Aluminium Alloy, Journal of Materials and Performance, Vol. 20, Issue. 8, 2011, pp 1419 – 1422.
22. A. Calik, 'Effect of Cooling Rate on the Hardness and Microstructure of AISI 1020/1040/1060 Steels', International Journal of Physical Science, Vol. 4, Issue. 9, 2009, pp 514 – 518.
23. S. M. Adedayo and V. O. Oyatokun, 'Effect of Sailine Water Cooling on Service Quality of Welded AISI 1013 Carbon Steel Plate', Annals of Faculty of Engineering, Hunedoara International Journal of Engineering, Vol. 11, Issue. 2, 2013, pp 25 – 28.
24. Amitabha Ghosh and Ashok Kumar Malik, 'Manufacturing Science', SME National Technical Publication, Second Publication, 2010.
25. D. A. Fadare, T. G. Fadara, Y. Akanbi, 'Effect of heat treatment on the Mechanical properties and Microstructure of NST 37-2 Steel', JMMCE, Vol. 10(3), 2011, pp. 299-308
26. J. Hu, H. L. Tsai, 'Heat and mass transfer in gas metal arc welding. Part I: The arc' IJHMT, 2006, Vol. , pp: 833-846
27. D. J. Keats, 'Underwater Wet Welding Made Simple: Benefits of Hammered Wet-spot Welding Process', International Journal of the Society for Underwater Technology, Vol. 28, Issue. 3, 2009, pp 115 – 127.