Experimental Investigation of the Effect of Welding Parameters on Mild Steel Specimens in MIG Welding Process Alongwith Metallurgical and Mechanical Analysis

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Abstract

In metal inert gas welding method, an arc is established between a continuous fed filler wire electrode and the workpiece. In the present paper mild steel was used as a base metal to carry out the MIG welding for study of metallurgical and mechanical behaviour of welded joint. The chemical composition, microstructure and Vickers microhardness examination was conducted. The effect of welding parameters on welding outcome and microhardness value for weld, parent and HAZ of mild steel was calculated. The microstructure of parent metal consisted of fine grains of ferrite and pearlite and banding of pearlite was observed. The microhardness is very high near the interface ie 240 and it get reduced to 237 as the distance from the interface increased and become constant ie 236 in the parent base materials, in the parent base materials the hardness is high near the interface which may be due to the formation of some intemetallic compounds.

Keywords: *MIG; microhardness; microstructure; mild steel; HAZ*

1. INTRODUCTION

The use of welding in today's technology is extensive. It had a phenomenal rise since about 1930; this growth has been faster than the general industrial growth [1]. Many common everyday use items,e.g., automobile cars, aircrafts, ships, electronic equipment, machinery, household appliance, etc, depend upon welding for their economical construction. The principles of gas metal arc welding began to be understood in the early 19th century, after Humphry Davy discovered the short pulsed electric arcs in 1800.Vasily Petrov independently produced the continuous electric arc in 1802 (soon followed by Davy) [2].

1.1. MIG/MAG method

In MIG/MAG welding method, an arc is established between a continuous fed filler wire(consumable) electrode and the workpiece. The electrode is fed automatically from the machine, through a liner, then out of a contact tip in the MIG/MAG gun. The weld metal is protected from the atmosphere by a flow of an inert gas, or gas mixture. The contact tip is hot or electrically charged, when the trigger is pulled and melts the wire for the weld puddle. The term MIG welding stands for Metal Inert Gas welding. This type of metal welding process is widely handled in most of the industries. It is carried out by the application of heat obtained from the electric arc over the metal work piece [5].

1.1.1. The welding arc

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A welding arc is an electric discharge between two electrodes. The welding current is conducted from the electrode to the workpiece through a heated and ionised gas, called plasma.

1.1.2. Heat generation

In the arc heat losses by heat conduction appear close to the surface of the wire electrode and the workpiece. Thermal balance is achieved because the heat that is conducted into the electrode and the joint is replaced by electric energy.

1.1.3. Polarity

MIG welding is normally used with DC current and the electrode connected to positive polarity. Negative polarity is seldom used because of the bad arc stability. The heat generation is higher at the anode than the cathode.

1.1.4. Penetration

The angle of filler wire to the joint, and polarity are the variables that influence penetration.

1.1.5. Influence of wire stick out

Welding current decreases if wire stick-out length is increased.

1.1.6. Generation of welding fumes

As a result of the intense heating from the arc, some metal is vapourised from the electrode material. When this vapour leaves the arc it is oxidised and forms the welding fume.

1.2. Equipments used

The equipments used are welding power source and cables, welding torch and wire electrode coiled on a spool, wire feed mechanism and control consisting of a pair of driving rolls, electric motor, etc.

1.2.1. Power source

Most applications of gas metal arc welding use a constant voltage power supply. As a result, any change in arc length (which is directly related to voltage) results in a large change in heat input and current. . In rare circumstances, a constant current power source and a constant wire feed rate unit might be coupled, especially for the welding of metals with high thermal conductivities, such as aluminum. This grants the operator additional control over the heat input into the weld, but requires significant skill to perform successfully [3].

1.2.2. Shielding gas

The function of shielding gas is to protect the molten metal and the electrode end against atmospheric contamination. A number of shielding gases and gas mixtures, like argon (for welding Al, Mg, Cu, Ni), helium (Al, Mg, Cu), carbon dioxide (for welding mild steel).

1.2.3. Electrode

Electrode selection is based primarily on the composition of the metal being welded, the process variation being used, joint design and the material surface conditions.

1.3. MIG welding advantages and applications

Many welders will enjoy higher productivity due to time saved by not having to constantly change rods or chip away slag, as well as not having to brush the weld repeatedly [4]. One of the top advantages of MIG welding is its simplicity. MIG provides better weld pool visibility. MIG can be used on a broad range of materials and thicknesses. Typical applications for MIG welding

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include automotive sub-assemblies and bodywork, ranging from conventional MIG for most bodywork, to heavy-duty MIG for lorry chassis and off-highway vehicles.
The term MIG welding stands for Metal Inter Gas welding. This type of metal welding process is widely handled in most of the industries. It is carried out by the application of heat obtained from the electric arc over the metal work piece [5].

2. LITERATURE REVIEW:

After studying the literature it can be concluded that a lot of work has been done in the field of MIG/MAG welding. Investigator studied the various response like weld bead, bead width, bead cross section area, with various wire speed, and find out the optimum conditions in which the desired shape of penetration achieved. Other investigated the weld quality comprises bead geometry and its microstructure which influences the mechanical properties of the weld. Other researcher studies the effect of various welding parameters on the weldability of mild steel. The weldability depends upon the welding current, welding speed, heat input rate. Many studied the development in laser technology and application of laser welding and hybrid laser Mag welding and the characteristics of both were briefly compared, while similarly other researcher studied the hybrid laser-arc welding in which the laser and the arc were coming in the same process zone, which can offer a number of benefts over autogenous laser welding including increased productivity. Da Silva [6] et al., deals with power quality analyses related to the effect of different drop transfer modes in Gas Metal Arc Welding (GMAW) processes. G B Melton and S J Mulligan [7] investigated the productivity gains by using the tandem MIG process, for butt and fillet welding of 6mm and 10 mm thick steel plates. Edwards [8] et al., investigated the effect of weld residual stress, and hardness profile on fatigue crack propagation in MIG welded 2024 and 7150 aluminium joints was studied. Allen [9] studied the Hybrid laser-arc welding processes, in which a laser and an arc were combined in the same process zone, which can offer a number of benefits over autogenous laser welding, including increased productivity and a tolerance to fit up comparable with arc welding. V. Ravisankar [10] et al., studied the selection of welding process for an unstructured decision problem involving multiple attributes (factors). Allen [11] et al., investigated the Fusion welding of 7xxx aluminium alloy plates for aerospace applications using autogenous laser welding and hybrid laser-MIG welding. Mortimer [12] examined how Jaguar Cars in the UK is making use of a robot-based intelligent adaptive metal inert gas (MIG) welding process incorporating laser diode measurement of the gap in the joint between the aluminium C-pillars and the aluminium roof structure of its new XK sports car that is being built in the company's plant in Castle Bromwich, UK. Shi and Howse [13] investigated the recent development in laser technologies and applications of laser welding and hybrid laser-MAG welding in ship building. Jerry Uttrachi [14] et al., studied the Mig shielding gas contol and optization and shielding must be none turbulent to exclude air from the arc, maximum gas flow rate and setting of the gas fow rate was studied. Gerritsen [15] et al.,studied the development of welding procedures using lower power output CO2 and Nd:YAG lasers, for a selection of DH36, D36 and S275 grade steels. Wêglowski [16] et al., carried out investigation on an automated GMAW platform. During trials, an Olympus i-SPEED high speed camera was used to image

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and record the metal transfer process for later analysis. Park [17] et al., investigated the Welding experiments that were conducted with various wire feed speeds of 0.5 m/min, 1.0 m/min, and 1.5 m/min, and the bead characteristics were evaluated. Nicholas [18] et al., investigated the benefits of an approach for estimating the hardness of the heat affected zone after tempering by the deposition of subsequent welds. Maleki [19] et al., investigated the old grades of creep resistant materials such as P11 and P22 in depth and data and prediction models were used for design and fitness for service assessment of creep rupture, creep crack growth, thermo-mechanical fatigue, etc. Zhang [20] et at., investigated the effect of loading spectra with different mean stresses on the validity of Miner's rule, and the effect of stresses below the constant amplitude fatigue limit (CAFL) on the fatigue performance of two types of weld joint. Saraswat [21] et al., studied OPTWELD (Real-time virtual prototyping tools for optimising welded products) to develop software for faster distortion prediction and fatigue life calculation. Tewari [22] et al., investigated the effect of various welding parameters on the weldability of Mild Steel specimens having dimensions 50mm× 40mm× 6 mm welded by metal arc welding. Pal [23] et al., investigated for optimum weld joint characteristics by controlling the pulse parameters in P-GMAW process. Consonni [24] et al., studied the qualification procedure used by TWI for the most commonly required defect types. Hackl [25] et al., studied the high amperages required for arc welding, in conjunction with relatively low voltage values, can be generated with various different designs of power source. ModenesiI [26] et al., studied that GMA welding is characterized by the strong dependence between its operational parameters and the high sensitivity to small variations of those. De Santana [27] et al., describes the design and validation of a mathematical model aimed at the GMAW welding. Chotai [28] studied that the gas metal arc welding process is increasingly employed for fabrication in many industries. Wei [29] et al., developed the 2D axi-symmetric FEA models for simulation of welding residual stresses in pipe girth welds. Vasile [30] et al., studied the process of welding in shielding gas environment with fusible electrode, there are used either inert or active gases. Pal [31] et al., examined the weld quality comprises bead geometry and its microstructure, which influence the mechanical properties of the weld.

3. EXPERIMENTATION

The experiments were performed on MIG welding set up.

3.1 Material

Mild steel was used as a base metal to carry out the MIG welding for study of metallurgical and mechanical behaviour of welded joint. The chemical composition of welded joint of sample A of mild steel is shown in Table 1.

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Table 1 Chemical composition of welded joint of sample A and sample B

S. No.	Elements	Percentage (Sample A)	Percentage (Sample B)	S. No.	Elements	Percentage (Sample A)	Percentage (Sample B)
1	Fe	98.4200	98.3800	10	Al	0.0070	0.0050
2	C	0.0780	0.0980	11	Cu	0.0520	0.0580
3	Si	0.3920	0.4050	12	Ti	0.0080	0.0080
4	Mn	0.9300	0.9200	13	Nb	0.0030	0.0030
5	S	0.0050	0.0080	14	Co	0.0060	0.0070
6	P	0.0160	0.0180	15	B	0.0001	0.0001
7	Ni	0.0090	0.0160	16	Pb	0.0010	0.0010
8	Cr	0.0380	0.0370	17	V	0.0010	0.0010
9	Mo	0.0210	0.0220	18	Zr	0.0060	0.0070

The chemical composition of iron was found to be highest i.e, 98.4200 % in sample A. The composition of other elements is shown in the fig 1(a).

(a) (b)

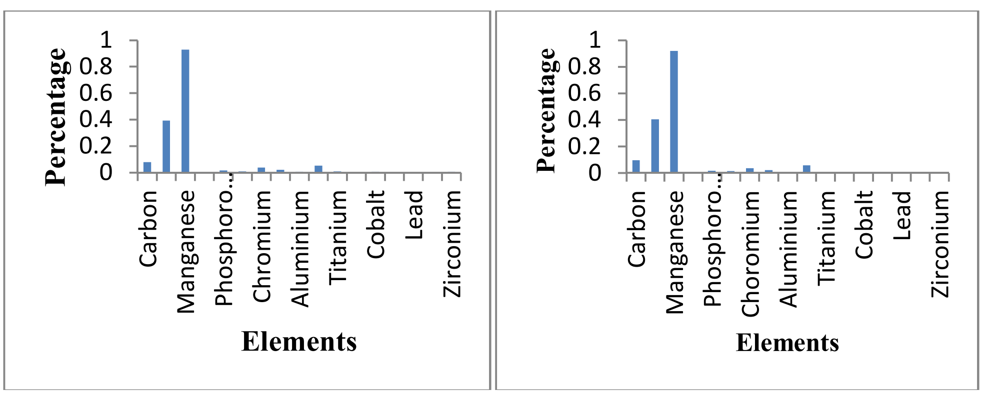

Fig 1. Chemical composition of welded joint of (a) sample A and (b) sample B

The chemical composition of iron was found to be highest i.e, 98.3800 % in sample B. The composition of other elements is shown in the fig.1(b).

3.2. Test Sample Specification

Length of the specimen = 7.5 cm.

Breadth of the specimen = 5 cm.

Height of the specimen = 0.6 cm.

Two specimen of the same size are used.

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3.3. Experimental Set Up

Three phase MIG welding machine of unimech company was used having different set up units itself as shown in fig.2(a).

(a) (b) (c) (d)

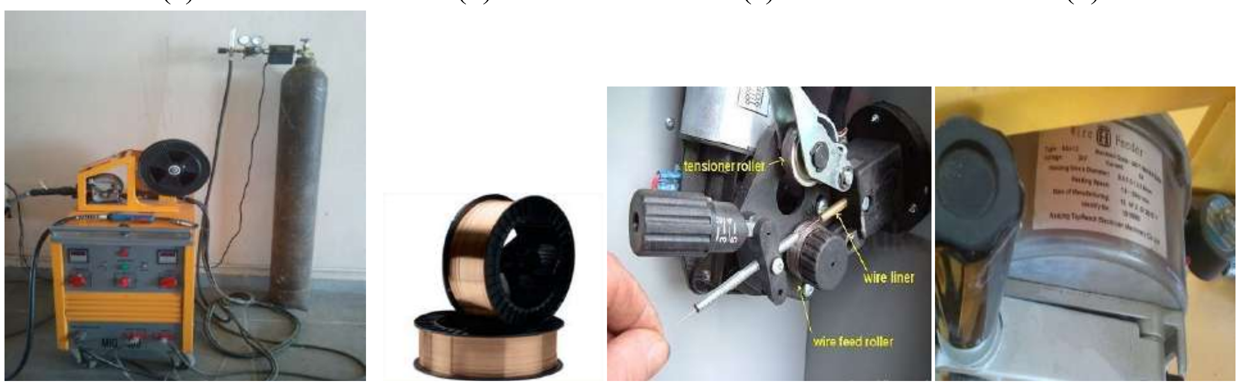

Fig. 2(a) MIG Welding set up, (b) M.S. Cu coated wire, (c) Wire feeder unit, (d) Wire feeder unit description

Fig.2(b) shows M.S. copper coated wire spool (AWS/A5.18, ER70S-6,) that was used having diameter 0.8 mm. Feeder was used to feed the wire to the torch, the speed of the feeder was maintained by the speed device and the diameter of the welding wire was 0.8mm as shown in fig. 2(c) and (d). The first 3 inches of wire should be as straight as possible to reduce the chance of damage to the liner. Carbondioxide, argon, helium inert gases were used as a shielded gas. Gas heater was used in case of carbondioxide gas because it is cool in nature need some heat before use. Double stage gas regulator , gas flow meter , welding torch was used.

3.4. Parameters Used In Welding

The three parameters have been utilized viz. wire feeder speed, voltage and current. When the wire feed speed is increased, there is also increased in current. This has an effect on the penetration, deposition rate, bead size and a slight effect of the bead width. Voltage has a little or no effect to play on the penetration, deposition rate, bead size and the bead width because voltage decides the amperage, There will be defects if correct voltage is not chosen. Welding current is the most influential variable in MIG welding process which controls the electrode burn off rate, the depth of fusion and geometry of the weldments.

3.5. Testing of MIG weld specimen

The microstructure and Vickers microhardness examination was performed on the mild steel samples.

3.5.1. Microstructure Examination

The specimen were made flat from two opposite sides on lathe machines. After that flat sides were grinded on disc which was attached to a belt grinder. After grinding on a rough emery paperpolishing of the specimen were started. For this purpose different grades of emery papers were used. Specimen were polished by different grade of emery paper viz.100, 220, 320, 400,600, 800 and 1000. Further samples were polished on cloth using aluminium oxide powder.

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(a) (b)

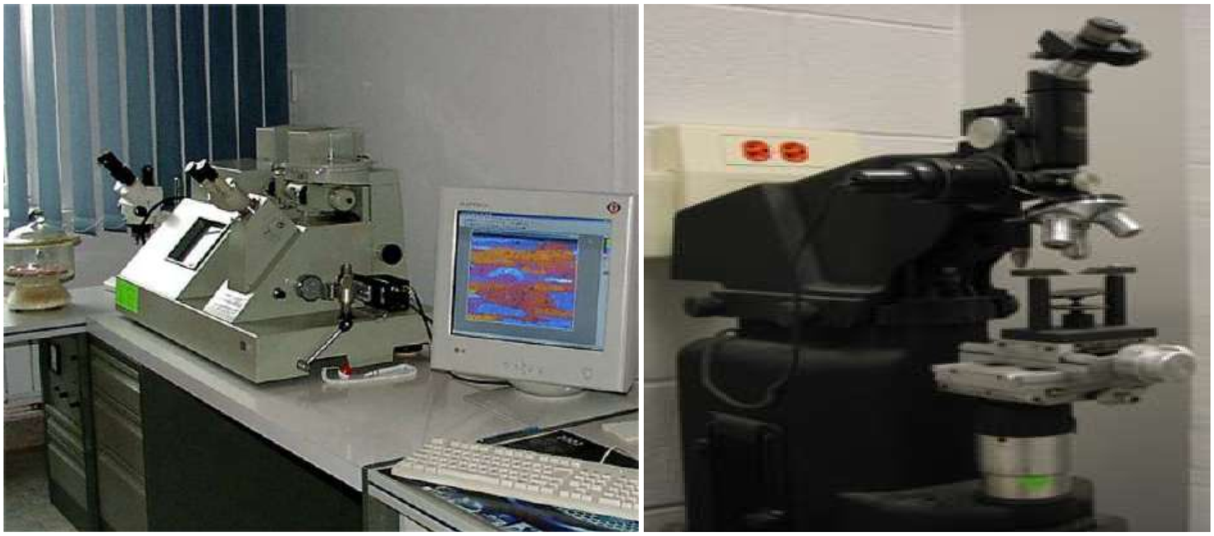

Fig 3(a) Optical microscope used for microstructure examination, (b)Vicker's hardness tester

Now etching of the specimen were carried out using etchant which contains 98% of water plus 2% of HNO3.After etching microstructure of the specimen was captured on an optical microscope fig 3(a) at 100X magnification with the help of camera attached to optical microscope. Optical images were captured at different section of the weld to examine.

3.5.2. Vickers microhardness measurement

The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). Vicker hardness tester used for microhardness is shown in fig 3(b). Hardness of welded specimen is measured at different sections like at interface, parent metal and at HAZ.Total of 8 readings were taken, 4 for the sampleA and 4 for the sample B.Maximum hardness was found at the interface.

4. RESULTS AND DISCUSSION

The results and discussions were carried out after testing the samples. Microstructure analysis and microhardness measurement has been done and explained below.

4.1. Microstructure Analysis:

Microstructure examination of mig welded joints at different locations like on base material and near interface is shown in fig 4(a), (b) and (c). The microstructure of mild steel base for sample A consists of fine grains of ferrite and pearlite. Banding of pearlite was observed. The large fine grains of ferrite and pearlite are clearly visible in the microstructure of mild steel. Mild steel was greatly deformed and refined near the weld surface. Recrystallization of weld metal occured, which may lead to change of phase constituent in the welding zone , thus formation of some

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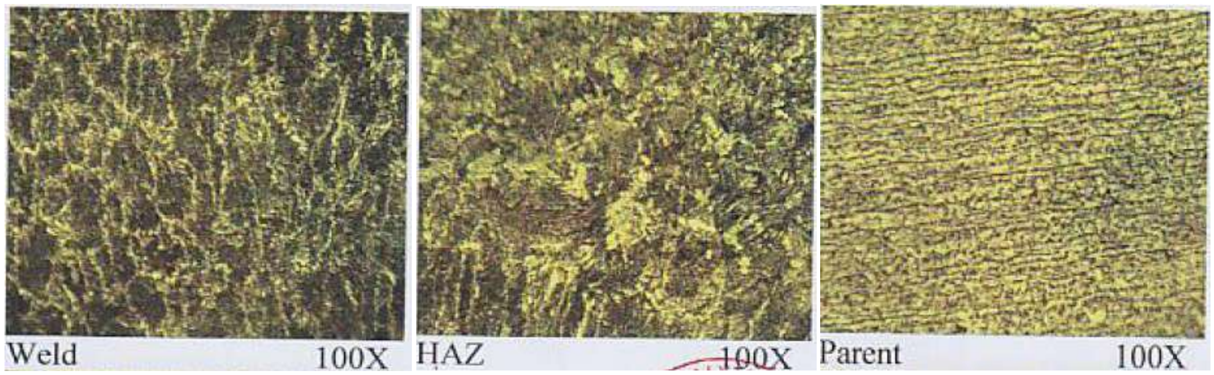
intermetallics in the weld zone and it may reduce the mechanical properties.



(a) (b) (c)

Fig 4 Microstructure of mild steel for the different zones (a) welded joint (b) parent metal (c) heat affected zone

Weld solidification process occurs after welding and it is accompanied by the evolution of heat thus dendrite and reheat refined grain were observed near interface region of the weld while comparatively coarser grain were observed away from the dendritic boundary of the interface.

4.2. Microhardness Measurement:

Table 2 shows the values of microhardness along different sections of mild steel. It can be observed from the table that micro hardness is high near the interface and go on reducing as the distance from the interface increases and become constant in the parent base material.

Table 2 Microhardness results at different sections from interface in the weld mild steel region of Sample A and Sample B

Distance from interface along mild steel direction (mm)	Hardness (HV 1) (Sample A)	Hardness (HV 1) (Sample B)
0.10	240	206
0.20	237	204
0.30	236	202
0.40	236	202

The increase in hardness near the interface may be due to the formation of some intermetallic compounds and recrystallization.

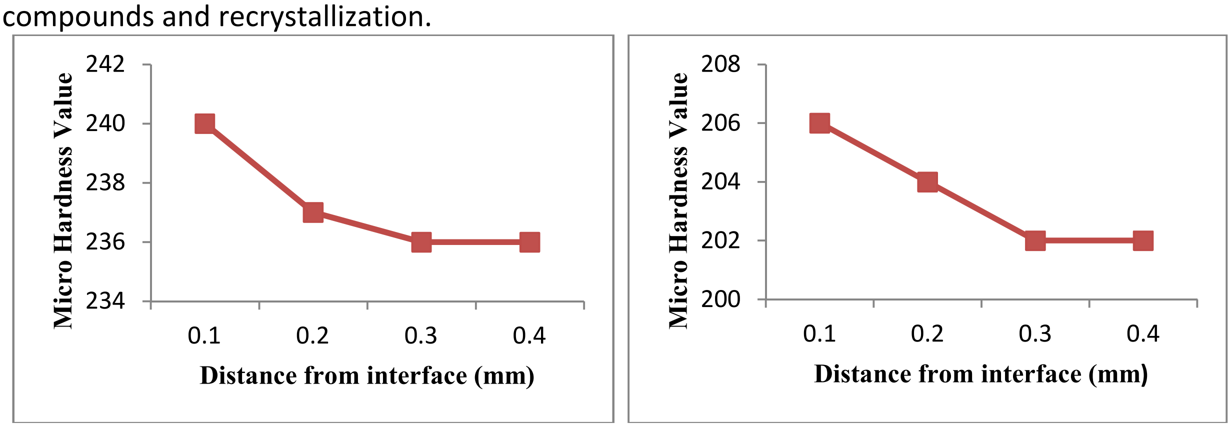


Fig 5 Microhardness value from interface in the weld mild steel region of (a) Sample A and (b) Sample B

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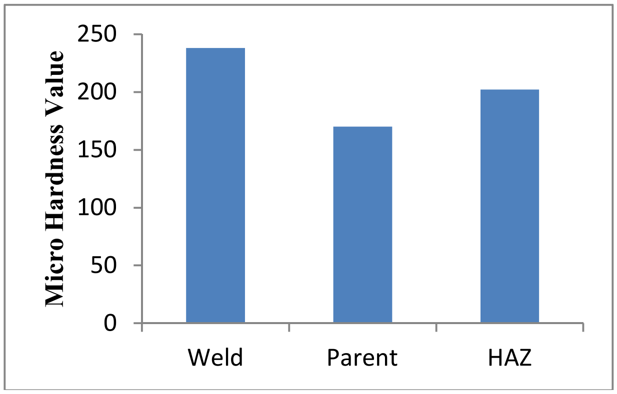

Fig 6 Microhardness value for weld, parent and HAZ of mild steel

Fig 7. MIG welding of mild steel

From fig.5(a) and (b), it is clear that microhardness value of sample A decreases with interface distance at steep rate from 0.1 to 0.2 mm distance and gradually from 0.2 to 0.3 mm distance while it is constant after further increasing the distance. In case of sample B, there is only steep decrease of microhardness value upto 0.3 mm distance. The microhardness value of weld, parent and heat affected zone (HAZ) is shown in the fig. 6.

Table 3: Effect of welding parameters on welding outcome

Voltage (V)	Current (A)	W_f (m/min)	Outcome
23	140	3	Weld bead is high, not very smooth but good.
25.7	130	3.7	Weld has some holes but smooth weld
25.8	115	3.2	Good accurate bead,smooth quality weld but with one hole.
26	103	2	Bad quality weld distortion occurs.
26	108	2	Bad quality weld.

In table 3 the effect of welding parameters is given. The voltage is set from 23 V to 26 V range, while current 108 to 140 A and the welding speed varies from 2 to 3.7 m/min.

4.3.Metals Welded By MIG Welding

MIG is used to weld many materials, and different gases are used to form the arc depending on the materials to be welded together. An argon CO2 blend is normally used to weld mild steel, aluminium, titanium, and alloy metals. Helium is used to weld mild steel and titanium in high speed process and also copper and stainless steel. Carbon dioxide is most often used to weld carbon and low alloy steels. Magnesium and cast iron are other metals commonly welded used the MIG process. Fig.7 shows the picture of the two samples that were MIG welded.

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5. CONCLUSION

The following conclusions can be withdrawn from the present study. MIG welding has been successfully employed to weld similar as well as to the disimilar materials. The microstructure of parent metal ie mild steel consist of fine grains of ferrite and pearlite. Banding of pearlite observed. The Microstructure of interface consist of fine grains of ferrite and pearlite. The microhardness is very high near the interface ie is 240 and it get reduced ie is 237 as the distancefrom the interface increases and become constant ie is 236 in the parent base materials thehardness is high near the interface may due to the formation of some intemetallic compounds. The chemical composition test of the welded joint observed that the percentage of element iron is maximum ie is 98.42% in case of mild steel while other elements also have their percentage. The perfect parameters range found for effective welding like proper setting for voltage , current and wire feeder speed. It can be observed from the experimental work ie when the wire feed speed is increased, there is also increased in current. This has an effect on the penetration, deposition rate, bead size and a slight effect of the bead width. Voltage has a little or no effect to play on the penetration, deposition rate, bead size and the bead width because voltage decides the amperage and the type of metal transfer. In order to select an appropriate voltage the thickness of the base metal, electrode size, the type of joint and the shielding gas composition should be taken into consideration. There will be defeats if correct voltage is not chosen. When traveling speed is increased the penetration is reduced. The bead size, bead width increases when the traveling speed is reduced, and vice versa. It has very slight effect on the deposition rate. When electrode extension decreases, there is increase in penetration, and when it increases there is decreased in penetration. The other changes depend on the changes in current levels with adjustment of wire feed speed. When the wire diameter is decreased the penetration increased, and when it is increased the penetration decreases. The other changes are parallel to the changes of the wire diameter.

REFERENCES

[1] Khanna OP. A textbook of welding technology. 19th ed., New Delhi, Dhanpat rai publications, p.1,83-85,2009.
[2] Development. 2012 May 8 [cited 2012 May 20] Available from URL: http://en.wikipedia.org/wiki/Gas_metal_arc_welding.
[3] Power source. 2012 May 9 [cited 2012 May 20] Available from URL: http://en.wikipedia.org/wiki/Gas_metal_arc_welding.
[4] Nadzam J. Advantages disadvantages of GMAW Welding Guide.p.2 . Available from URL:http://www.lincolnelectric.com/assets/en_us/products/literature/c4200.pdf
[5] Safety measure. 2012 April 20 [cited 2012 April 22] Available from URL:http://www.everlastgenerators.com/wordpress/category/welders/mig-welding-welders.
[6] Da Silva E. F, Macedo J. R, Scotti A, De Oliveira. Power quality analysis of Gas Metal Arc Welding process operating under different drop transfer modes, GMAW", Rev. Bras. de Ciências Mecânicas - RBCM, ABCM, Volume 20, No. 3, pp. 465-478, 1998.

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Final Accepted for publication: *14 Nov 2022*

International Journal of Research (IJR)
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Vol. 9 Issue 11
November 2022

[7] Melton G B, Mulligan S J. Tandem MIG welding for improved productivity, Presented at EUROJOIN4 - 4th European Conference on Welding, joining and cutting. Development of welding and allied processes at the beginning of the new millennium. Cavtat-Dubrovnik, Croatia, pp 313-318, 2001.
[8] Lin S J, Ganguly S, Edwards L, Irving P.E.The effect of residual stress and HAZ on fatigue crack growth in mig welded 2024 and 7150 aluminium. In FATIGUE 2003 Fatigue and durability assessment of materials components and structures, Cambridge ,UK,pp 65-73, 2003.
[9] Allen C M. Hybrid Nd:YAG Laser-AC MIG welding of thin section automotive aluminium alloy, Paper presented at Eurojoin 6, Santiago de Compostela, Spain, 2006.
[10] Ravisankar V, Balasubramanian V, Muralidharan C. Selection of welding process to fabricate butt joints of high strength aluminum alloys using analytic hierarchic process. Science Direct, Material & Design. Volume 27, No. 5, pp. 373-380, 2006.
[11] Allen C M, G Verhaeghe, P A Hilton, C P Heason, P B Prangnell. Laser and hybrid laser-MIG welding of 6.35 and 12.7mm thick aluminium aerospace alloy. Paper presented at International Conference on Aluminium Alloys (ICAA 10), Vancouver, 2006.
[12] Mortimer J. Jaguar uses adaptive MIG welding to join C-pillars to an aluminium roof section in a new sports car", Sensor Review, Volume. 26, No. 4, pp.272 – 276, 2006.
[13] Shi S, Howse D. Laser and hybrid laser-MAG welding of steel structures for shipbuilding. International Forum on Welding Technologies in Shipping Industry, 2007.
[14] Uttrachi, G. D. GMAW Shielding Gas FlowControl Systems, The Welding Journal, Volume.86, No. 4, pp. 2-20, 2007.
[15] Allen C M, Gerritsen C H J, Zhang Y, Mawella J. Hybrid laser-MAG welding procedures and weld properties in 4mm, 6mm and 8mm thickness C-Mn steels. Paper presented at the IIW Commission IV / XII, Intermediate Meeting, Vigo, Spain, 2007.
[16] Wêglowski M.S, Huang Y, Zhang Y. Effect of welding current on metal transfer in GMAW. Journal of Materials Science and Engineering Volume 33 ,No.1, Pages 49-56. 2008.
[17] Park H. J, Kim D.C, Kang M.J, Rhee S. Optimisation of the wire feed rate during pulse MIG welding of Al sheets. journalof Achievements in Materials and Manufacturing Engineering, Volume 27,No.1,2008.
[18] Nicholas M J, Abson D J. The prediction of maximum HAZ hardness in various regions of multiple pass welds, Paper presented at the 17th International Conference 'Computer Technology in Welding and Engineering' Held at the University of Cranfield, 2008.
[19] Maleki S, Zhang Y. Prediction of creep crack growth properties of P91 parent and welded steel using remaining failure strain criteria. Paper presented at WELDS Design, testing,assessement and safety of high-temperature welded structures. Fort Myers, FL. USA, 2009.
[20] ZhangY H, Maddox S J. Investigation of fatigue damage to welded joints under variable amplitude loading spectra. International Journal of Fatigue, Volume 31, Issue 1,pp.138-152,2009.
[21] R Saraswat, Zhou D. Fatigue life prediction in welded structures. Paper presented at NAFEMS , Oxford, UK, 2010.
[22] Tewari S. P, Gupta A, Parkash J.Effect of welding parameter on the weldability of material, International Journal of Engineering Science and Technology, Volume 2, No.4, pp 512-516, 2010.
[23] Pal K, Pal SK. Effect of Pulse Parameters on Weld Quality in Pulsed Gas Metal Arc. Welding Journal of Materials Engineering and Performance. Volume 20, No. 6, pp.918-931, 2011.
Hackl. Digitally controlled GMA power sources**.** Fronius International GmbH, Wels, Austria.

Received*: 22 Oct. 2022*
Revised*: 7 Nov. 2022*
Final Accepted for publication*: 14 Nov 2022*

[24] Modenesi P J. Evaluation of basic parameters of short-circuit GMA welding ,Soldag. insp. (Impr.) Volume 16 ,No.1, 2011.
[25] Santana J D, Modenesi P J. Mathematical modeling of GMA welding - free transfer fligth .Soldag. insp. (Impr.) Volume 16, No.3, 2011.
[26] H Chotai. A Review on Parameters Controlling Gas Metal Arc Welding (GMAW) Process. International conference on currenttrends in technology, volume 4 , 2011.
[27] M Consonni, C Wee, C Schneider. Manufacturing of welded joints with realistic defects. Paper presented at NDT 2011 - 50th annual conference of the British Institute of Non-Destructive Testing, Telford, UK, 2011.
[28] Wei L, Weijing, Smith S. The effects of loadings on welding residual stresses and assessment of fracture parameters in a welding residual stress field. Paper presented at the ASME 2011 Pressure Vessels & Piping Division Conference, Baltimore, Maryland, USA, PVP2011-57518, 2011.
[29] Vasile A. Development technology for welding in MIG/MAG shielding environment.Aectia technica corviniensis-Bulletin of engineering, 2011.
[30]Pal K, Pal S K. Effect of Pulse Parameters on Weld Quality in Pulsed Gas Metal Arc Welding. Journal of Materials Engineering and Performance, Volume 20, No. 6, pp 918-931,2011.
[31] Singh B, Dhull S, Modelling of Slag Produced in Submerged Arc Welding Advances in Electromechanical Technologies, 137-143, 2019

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