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Analysis of weld bead characteristics on GMAW by changing wire electrode geometry

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ABSTRACT

Purpose: Welding is one of the important processes for the manufacture of a wide variety of products. Most of the manufactured products have to be produced by welding due to its greater productivity and economical viability. Still quality has to be enhanced in the products. To attain the perfect quality in weld a new attempt has been tried out while existing process are being optimized. In this direction, the conventional Gas Metal Arc Welding (GMAW) has been developed to encourage high welding performance variant. Influence of changing filler metal geometry is one of the ways to improve the capability of giving high deposition rate and penetration. Accordingly, a flat wire arc welding system has been developed and weld bead characteristic has been investigated. The overall results show that, the proposed technique of changing wire electrode geometry can be used effectively to improve the weld bead characteristics. In this article, how does a change in electrode geometry contribute to the weld quality in manufacturing industries, is well- verified by experimental results, which are also explored here.

Keywords: Gas metal arc welding; Wire feed mechanism; Welding torch; Fat wire electrode; Electrode orientation; Weld bead characteristics

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ANALYSIS AND MODELLING

1. Introduction

Until the end of the 19th century, metal parts were joined together by heating and hammering process called forge welding [1]. Today, a variety of welding technologies are available, such that welding is extensively used as a fabrication process for joining materials in a wide range of compositions, part shapes and sizes. Weld quality is a vital factor in today's manufacturing industries, as it depends on mechanical properties of the weld which in turn depends on metallurgical characteristics of the weld. There is a need to address the increasing demand for quality and higher productivity in welding, high performance welding processes has to be developed. For developing such a high performance arc welding processes, mostly GMAW is used [2,3]. GMAW process has been optimized over this time period; it still has possibilities for improvement. In this way a new attempt has been made to increase GMAW capabilities through changing the electrode geometry [4-8]. Use of flat wire electrode has a rectangular cross section, closely simulates the weld performance as that of two independent wire technologies [9]. This paper highlights the investigations carried out to discover the performance of flat wire electrode with varying geometrical sizes. Therefore it necessitates developing the welding torch for formed flat wire electrode in order to obtain continuous flow of flat wire electrode. At this end, welding performance has been investigated.

2. Description of flat wire welding system

In this section, details of the experimental work and formation of Flat Wire Electrode have been discussed.

2.1. Experimental work

Gas metal arc welding is operated in semi-automatic and automatic modes. It is utilized particularly in high production welding operations [10]. Normally welding equipment consists of a welding torch, power supply, shielding gas supply and wire-drive system which pulls the wire electrode from a spool and pushes it through a welding torch. These are the components that directly affect the weld quality, welder comfort, downtime and the productivity [11]. Therefore, proper design of welding torch and wire feeder improves the welding performance with flat wire electrode [8,12]. However, conventional GMAW torch and wire feeder available are designed to handle cylindrical wire, but are not suitable for welding with flat wire electrode. Therefore special welding torch and wire feeder is to be developed for this investigation. Figure1 shows the schematic diagram of flat wire welding system with torch and feeder arrangement. The wire feeder is directly coupled with the welding torch and this design makes the system as easily accessible as GMAW welding system using flat wire electrode.

In the new approach of flat wire welding system, a wire feed roller shown in Figure 1 was designed to give rectangular (flat) shape to the electrode. The formation of flat wire electrode has been made possible with different types of load applied by the modified wire feed mechanism. The modified wire feeder is not only used to feed the electrode at defined feeds but also to form flat wire from cylindrical wire. In order to form a flat wire continuously with the required cross section, driver wheel of the wire feeder mechanism having a rectangular groove on the face is used, as shown in part number 9 of Fig. 1. The flat wire from the wire feeder is fed into the welding torch through a wooden guide path as shown in part number 3 of Fig. 2(b) To get a smooth and continuous flow of flat wire electrode, the existing welding torch has been modified as shown in Figure 2(a), (b) and (c). The Fig. 2 shows the details of CAD model with shielding gas flow path for flat wire welding torch. The newly developed torch has significant advantages of compact design with length to diameter ratio of 4.25:1. Since a straight head is used it provides easy accessibility and weld visibility. Automatic welding requires a complete wire feed system, which conveys the flat wire smoothly and consistently over long distances.

2.2. Formation of flat wire electrode

In order to form the flat wire electrode from the conventional cylindrical electrode, an experimental set up has been developed as in Figures 1 and 2. Flat wire electrode with different cross sections have been achieved by applying various loads in the modified wire feed mechanism. The investigation was carried out with Al4043 electrode of 1.2 mm diameter as the control sample. The chemical composition of the wire is given in Table 1.

The investigation involves testing of electrode geometry with various geometrical sizes; 1.4 x 1.1 mm, 1.7 x 1 mm, 1.9 x 0.9 mm and 2 x 0.8 mm with help of modified wire feeder mechanism. Fig. 3 and Table 2 highlights the welding performance of different geometrical sizes of Al flat wire electrode.

The experimental result shows, there is an increase in surface length of the flat wire electrode which in turn increases the welding performance. Comparatively better welding quality of penetrations was obtained with the geometrical dimension of 2 x 0.8 mm. Hence further investigations were carried out with Al flat electrode of 2 x 0.8 mm dimension.

3. Result and discussion

3.1. Formed flat wire electrode

This research paper focused on changing filler metal geometry with the size of 2 x 0.8 mm and the investigating the welding performance during different weld orientation.

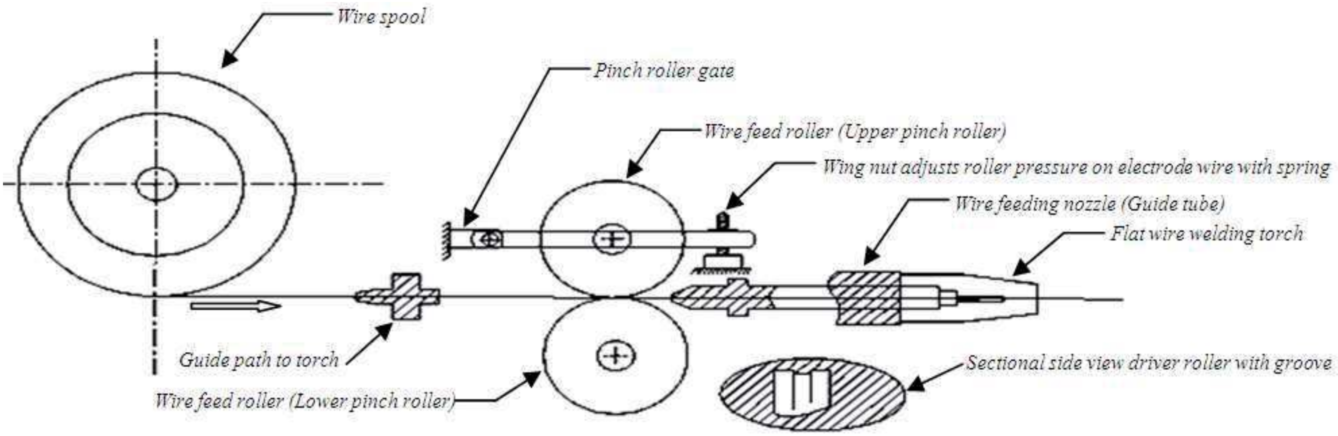


Fig. 1. Schematic diagram of strip wire welding system with torch and feeder arrangement

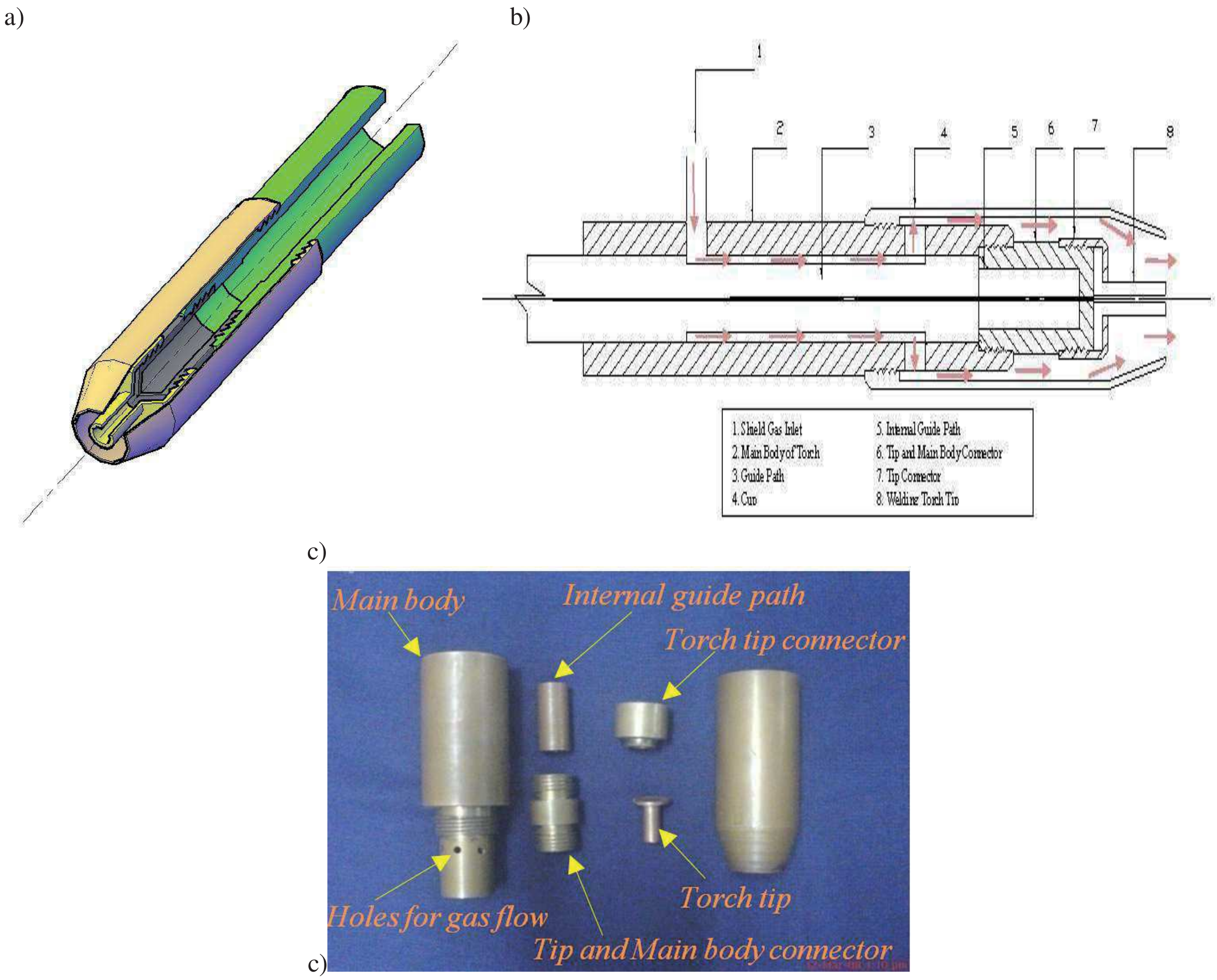


Fig. 2. Newly developed welding torch for strip wire electrode welding a) CAD model torch for strip wire welding torch, b) gas flow path for strip wire welding torch, c) fabricated strip wire electrode torch and their parts

Table 1.
Chemical composition of filler material Al Si/5 Er 4043(AWS/ASTM A5.10)

Elements	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al	Be	Other
Chemical composition, %	4.5-6	0.8	0.3	0.05	0.05	0.1	0.2	Remainder	0.0003	0.05-0.15

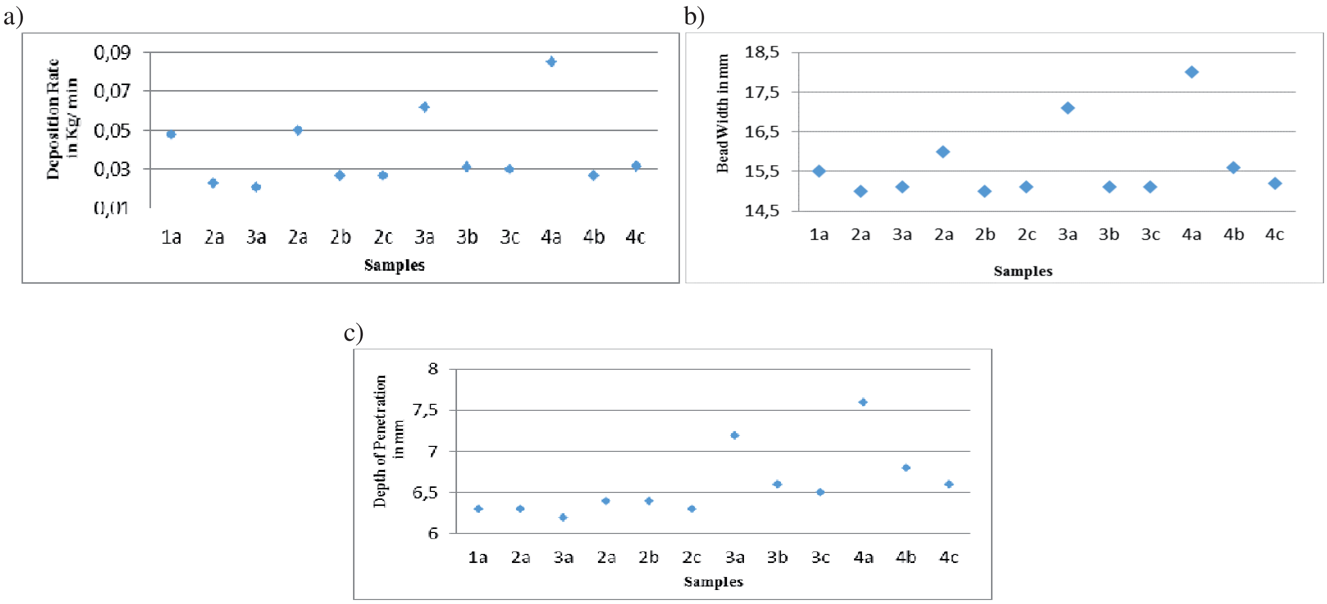


Fig. 3. a) Deposition Rate on different geometrical sizes of strip wire electrode, b) Bead Width on different geometrical sizes of strip wire electrode, c) Depth of Penetration on different geometrical sizes of strip wire electrode

Table 2.
Different geometrical sizes of Al flat wire electrode with their welding parameter

Sample	Orientation	Dimension, mm	Current, A	Voltage, V	WS, mm/min	WFR, m/min
1a	Parallel (0°)	1.4X1.1	350	28	500`	6
2a	Inclined (45°)	1.4X1.1	350	28	500	6
3a	Perpendicular (90°)	1.4X1.1	350	28	500	6
2a	Parallel (0°)	1.7X1	350	28	500	6
2b	Inclined (45°)	1.7x1	350	28	500	6
2c	Perpendicular (90°)	1.7X1	350	28	500	6
3a	Parallel (0°)	1.9x0.9	350	28	500	6
3b	Inclined (45°)	1.9x0.9	350	28	500	6
3c	Perpendicular (90°)	1.9x0.9	350	28	500	6
4a	Parallel (0°)	2X0.8	350	28	500	6
4b	Inclined (45°)	2X0.8	350	28	500	6
4c	Perpendicular (90°)	2X0.8	350	28	500	6

The end results were analysed and compared with cylindrical electrode. Fig. 4 shows the formed Al flat wire electrode with geometrical size of 2 x 0.8 mm.

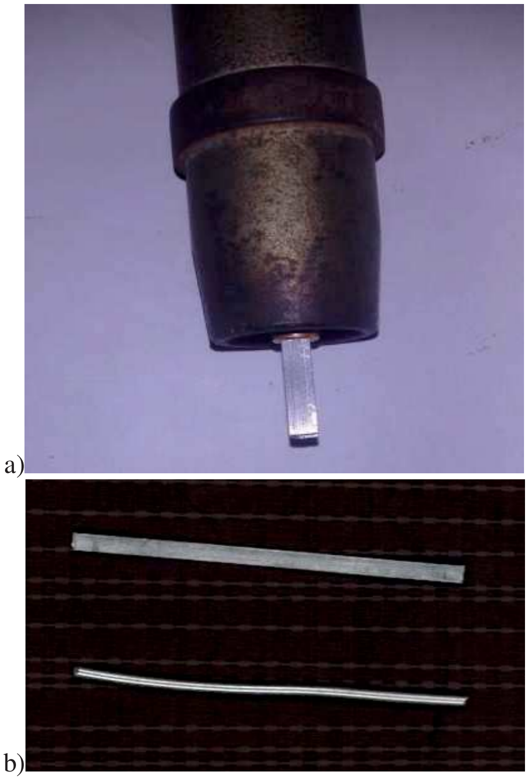


Fig. 4. The comparison of flat wire and cylindrical electrode: a) formed flat wire electrode, b) Al electrode before and after forming

The process results show that the perimeter of the formed flat wire electrode is measured to be 7.2 mm while the conventional cylindrical wire electrode is 3.769 mm. So, the flat wire produced is found to have 52% more perimeter length as shown in Figure 5(a) and 5(c). The flat wire electrode is formed by either rolling or slitting [11]. The rolled flat wire is found to have round edge where as the electrode with slitting process has sharp edge [11,12]. Round edge flat wire is preferable for quality aspect as a continuous flow is obtained during the welding process.

From the micrographic observation, the electrodes have been evaluated and found that the cylindrical wire has lot of porosity and gas pockets as shown in Figure 5(b). Whereas fine structure is observed in the flat wire electrode as shown in Figure 5(d) which is expected to have better weld quality.

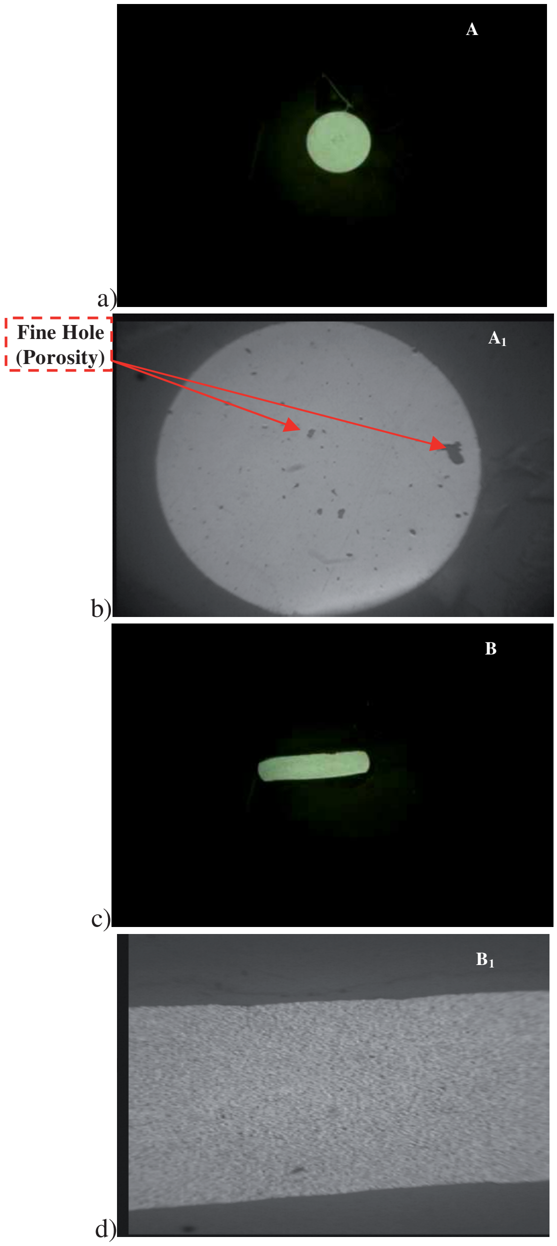


Fig. 5. Shows the details of strip wire and cylindrical: a) aluminium electrode ø 1.2 mm, b) macro view of aluminium electrode ø 1.2 mm, c) flat wire electrode of 2 x 0.8 mm, d) macro view of strip electrode of 2 x 0.8 mm

3.2. Performance characteristics with flat wire electrode

The base material used for this investigation is Aluminium Alloy 6063 plate with thickness 8 mm of

ASTM B221; the chemical composition of which is given in Table 3.

In flat wire welding, the welding results investigated with different welding orientation namely; the flat wire electrode is fed parallel to welding direction (0º), inclined to welding direction (45º) and normal to the welding direction (90º) as mentioned in Figure 6.

In order to make continuous flow of flat wire electrode, the welding torch was fixed near the wire feed mechanism. A bead on weld has been carried out with initial wire extension of 15 mm during welding [13,14]. Fig. 7 shows that macrograph of weld bead and weld penetration profile welded with cylindrical electrode and flat wire electrode positioned parallel to the welding direction. From the photograph, it was observed that there is complete fusion on both faying edge without any undercut or significant defects in welded with flat wire electrode samples. Weld bead shape is also very good with smooth surface.

Table 3.
Chemical composition of base material Al 6063 (ASTM B221)

Elements	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other each	Others total
Chemical composition, %	Bal	0.2-0.6	0.35	0.10	0.10	0.45-0.9	0.1	0.10	0.10	0.05	0.15

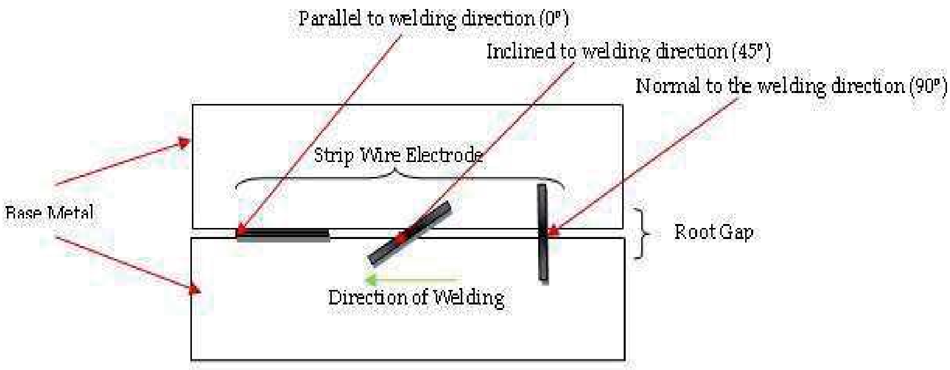
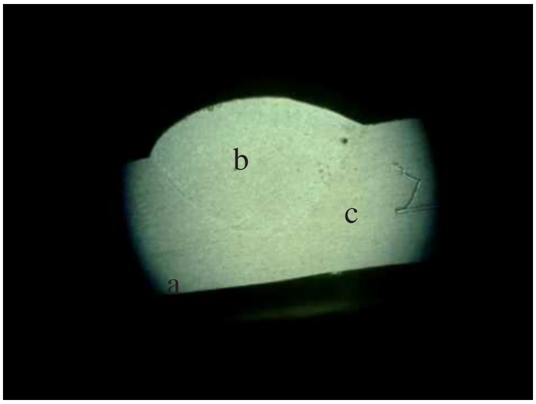


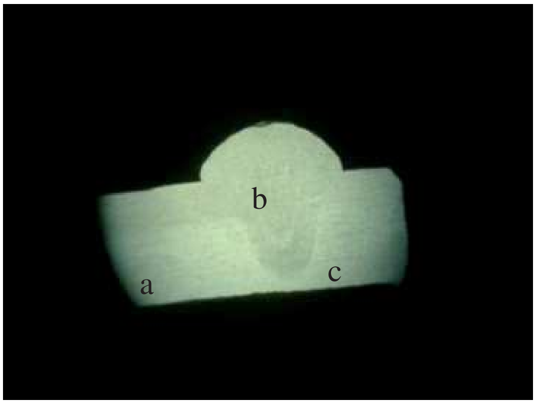
Fig. 6. Different welding orientation of strip wire electrode

a)



a – base metal
b – weld metal and
c – HAZ of cylindrical electrode welded sample

b)



a – base metal
b – weld metal and
c – HAZ of strip wire electrode welded sample position parallel to the welding direction

Fig. 7. Weld samples: a) weld macrograph of weld bead and penetration profile welded with cylindrical electrode, b) weld macrograph of weld bead and penetration profile welded with strip wire electrode parallel to welding direction

When compared with the cylindrical electrode due to the same welding parameter, flat wire electrode shows an increase in weld performance a result of higher welding current flow through the flat wire. Even at high speed of the welding, deeper penetration and wider bead width is achieved as in Figure 7. The flat wire electrode with orientation parallel to the direction of welding is found to give greater bead width of 18 mm as well as penetration depth 7.6 mm as compared to normal cylindrical electrode which has given a bead width of 15 mm and penetration depth of 6.2 mm as mentioned in Table 4.

The performance characteristics of flat wire in terms of welding rate and filling volume are stated to be comparable to two wire technologies. Further, the advantage of flat wire over the two wire technology is that only one power source is needed and easier to set the welding parameters. Power source with a welding current of 350 amps with wire feed of 6 m/min has been used for this research. Wire feeder and the welding torch transfer the flat wire powerfully and consistently over long distance. In MIG/MAG, flat wire welding process takes place under the same process conditions as those applicable to cylindrical wire.

Table 4.
Weld bead characteristics with different geometrical sizes of Al flat wire electrode

Samples	Weld bead characteristics			
	Orientation	Deposition rate, kg/ min	Bead width, mm	Depth of penetration, mm
1a	Parallel (0°)	0.048	15.5	6.3
2a	Inclined (45°)	0.023	15	6.3
3a	Perpendicular (90°)	0.021	15.1	6.2
2a	Parallel (0°)	0.050	16	6.4
2b	Inclined (45°)	0.027	15	6.4
2c	Perpendicular (90°)	0.027	15.1	6.3
3a	Parallel (0°)	0.062	17.1	7.2
3b	Inclined (45°)	0.031	15.1	6.6
3c	Perpendicular (90°)	0.030	15.1	6.5
4a	Parallel (0°)	0.085	18	7.6
4b	Inclined (45°)	0.027	15.6	6.8
4c	Perpendicular (90°)	0.032	15.2	6.6

When the welding current flows through the flat wire electrode a magnetic field is established not only in its direct vicinity but also in the wire itself [7,8,15]. This magnetic field will change over time as a result of the continuous changes in current strength. Current strength varies greatly due to droplet short circuits, droplet extensions and material transitions, inherent movements of the cathode and anode insertion points on the drop and weld pool as well as changes to the conversion of energy during pulse operations [16]. So, the magnetic field of the conductor section near the axis produces induction voltage in the centre of the conductor with reverse polarity to the rest of the electrical circuit in the centre, but sharing the same polarity as that of the circuit in the peripheral areas. The induction voltage overlaps with the changing magnetic field of the outer areas [4,5,15]. The overlap of both influences produces a counter voltage which falls from the axis to the periphery. Current is best conducted in the outer layer which results in less resistance.

3.3. Mechanical analysis

Mechanical testing was carried out on samples welded with flat wire and the cylindrical electrode weld samples. The result shows that the flat wire weld sample found to have increased in hardness and flexural test when compared with cylindrical electrode weld sample. The hardness was measured at various points in the weld, HAZ and parent metal regions and the result shows all three regions have greater hardness. Also bend test result show 19.04% greater bending strength in flat wire welding sample over use of cylindrical electrode welding sample. The Fig. 8(a) and 8(b) show that the maximum force obtained during the bend test.

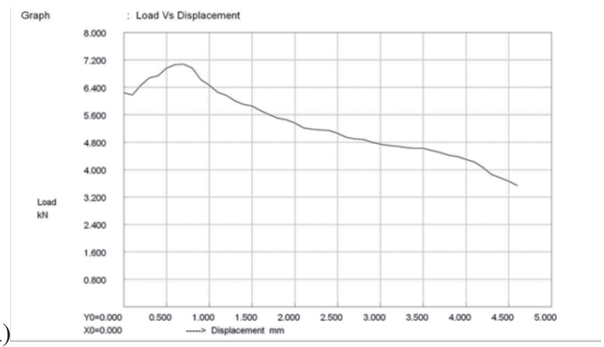
From the mechanical observation, the use of flat wire electrode, especially positioned parallel to the welding direction has abundant mechanical advantage over that of cylindrical wire weld.

3.4. Metallographic observation

Samples for optical metallographic were prepared by sectioning the welded joint at right angles to the bond-line. The microstructure examinations were prepared as per standard metallographic procedure [10]. The welded samples are examined in the metallurgical microscope and microstructures are analysed in base metal, weld metal zone and HAZ of the samples. Microstructures of weld metal has revealed spheroid particles of MgZn (black precipitates) and light grey particles of $FeAl_3$ present in the Al solution as shown in Figure 9(a) and 9(b). Grain elongation in one direction was also seen. For cylindrical electrode weld metal, the microstructure of the weld metal has revealed interdendritic eutectic with light grey particles of $FeCl_3$ present in the Al solid solution as shown in Figure 9(c). Similarly for cylindrical electrode weld metal, the weld microstructure consists of slightly elongated grains as shown in Figure 9(d).

The important factors which justify the quality of welding are deposition bead width and depth of penetration. In this way, all three factors are analysed and found to have greater performance using flat wire electrode. The influence of changing electrode geometry of 2 x 0.8 mm has been described in the Table 5.

On comparing the bead characteristics of weld beads deposited with flat wire electrode and normal cylindrical electrode, the following observation has been made. Flat wire electrode with orientation parallel to the direction of welding gives greater bead, greater weld depth of penetration and greater deposition rate than all other orientations of flat wire electrode geometry and normal cylindrical wire electrode as shown in Figure 10.

a) 

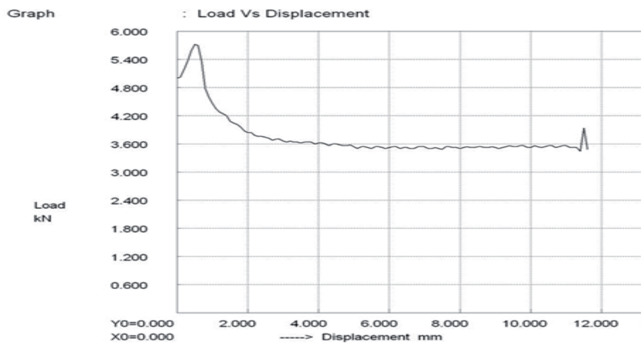
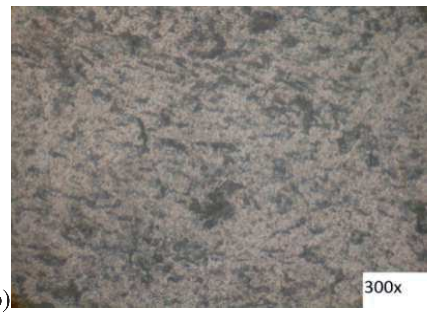
b) 

Fig. 8. a) Load vs displacement curve for strip wire electrode welding, b) Load vs displacement curve for cylindrical wire electrode welding

a) 

b) 

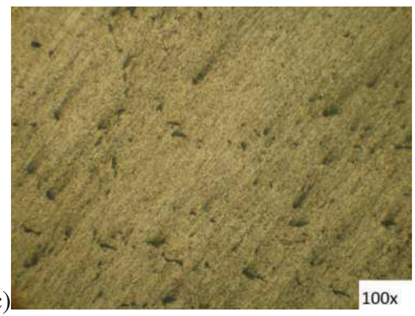
c) 

Fig. 9. a) Microstructure of the base metal, welded by strip wire electrode, b) microstructure of the weld metal, welded by strip wire electrode, c) microstructure of the base metal, welded by cylindrical electrode

Table 5.
Compression of bead characteristics

Sample	Orientation	Plate weight before welding, Kg	Current, A	Voltage, V	Plate weight after welding, Kg	Bead on length, mm	WS, mm/min	WFR, m/min	Deposition, kg/min	Bead width, mm	Depth of penetration, mm
4_a	Parallel (0°)	0.988	350	28	1.03	100	500	6	0.085	18	7.6
4_b	Inclined (45°)	1.123	350	28	1.15	100	500	6	0.027	15.6	6.8
4_c	Perpendicular (90°)	1.108	350	28	1.14	100	500	6	0.032	15.2	6.6
4	Cylindricaele ctrode	1.106	350	28	1.154	100	500	6	0.048	15	6.2

WS – Welding Speed, WFR – Wire Feed Rate

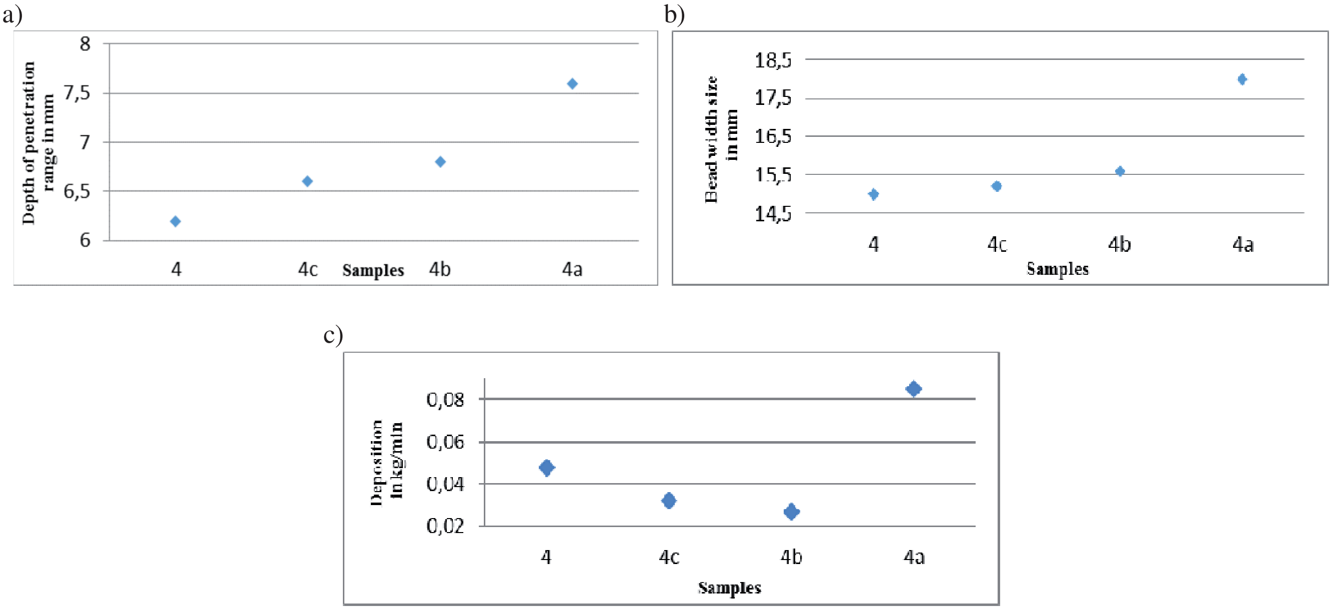


Fig. 10. Weld performance of strip wire electrode, a) deposition rate, b) bead width size, c) depth of penetration range

4. Conclusions

The purpose of this investigation is to understand the use of flat wire electrode welding and also to predict the weld quality in different flat wire electrode orientation. The flat wire electrode welding has been successfully investigated using modified GMAW setup. The analysis of the data obtained from experimentation revealed that welding torch and wire feeder plays a dominant role in obtaining a good weld finish. One important characteristic of the flat wire electrode is 16% more perimeter length over the regular cylindrical electrode. Flat wire electrode with orientation parallel to the direction of welding gives 52% greater bead width, 18% greater penetration and also the metal deposition is found to be 43.5% greater as compared to normal cylindrical wire electrode. The experimental results revealed that the flat wire electrode is a better option for producing a good welding quality. The finishing experiment performed on the flat wire electrode with parallel to welding direction arrangement is capable of producing good weld quality like bead width, deposition rate and depth of penetration.

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