ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XV [2017] – Fascicule 3 [August]

ISSN: 1584-2665 [print; online]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

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EVOLUTION OF ELECTRODE GEOMETRY SHAPE AND THEIR WELD QUALITY IN FCAW

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Abstract: For structural steel applications, bridge construction and heavy equipment repair, flux-cored welding has become a standard and reliable process due to its ability to provide high-deposition rates and good weld quality. Still reduction in cycle time and improved quality are the important significance in all manufacturing industries. It applies equally for every manufacturing process and more so for welding process. To attain the above objectives newer attempt has been tried out while existing process are being optimized. In this direction the conventional experimental setup has been developed to encourage high welding performance variant. Influence of changing filler metal geometric one way to improve the capability of giving high weld quality. Accordingly a strip wire electrode has been developed and weld characteristic has been investigated with three different orientations. The overall results show that, the proposed technique of changing flux cored wire geometry can be used effectively to improve the welding performances. The paper indicates how the electrode wire geometry modification helped in order to improve the quality of welding as well as cycle time reduction and also how production is increased with the use of the strip wire flux cored arc welding (SW-FCAW) instead of regular flux cored arc welding (FCAW) as described in this paper.
Keywords: FCAW process, E70T1, Strip wire electrode, electrode orientation and weld quality

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 arc welding is used [2, 3]. FCAW 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 FCAW capabilities through changing the electrode geometry [4, 5, 6, 7 & 8]. The recent studies on arc welding have indicated that the electrode diameter and electrode tip geometry play an impotent role in the weld bead quality. Kanin R chan et al. [9] had investigated the effect of electrode geometry on resistant spot welding through numerical analysis. They found that, the shape of electrode has an influence on development and final shape of weld bead. H.R. Ghazvinloo et al. [10] successfully found that, with increasing filler diameter, weld drop size increases which results in poor penetration. Also the depth of penetration values changed with increasing in filler diameter from 0.8 to1.2 mm. Suraj Mattoo et al. [11] explained the effect of different filler rod on SMA welding. It was found that increasing diameter of filler rod has an influence to desire the tensile and hardness of the weld bead. Talabli S.I et al [12] reported that, welding current and electrode size are significant parameters that must be monitored for tensile properties on arc welding. M.C.Tsai et al. [13] presented a heat transfer and fluid flow in the arc produced by the flat and sharpened electrodes. It was found that with flat tip the arc velocity and pressure was low as compared to the sharp tip and also Ushio Masao et al [14] developed a mathematical model to investigate the different electrode shapes in arc welding, they inferred that calculated velocity was maximum with sharp electrode tip. Sripriyan et al [15, 16 & 17] has been investigated flat wire electrode in arc welding process, they found that increasing geometry of electrode in increasing weld quality like bead width and penetration. From the review of literature, it is observed that electrode diameter, tip geometry shape and changing wire geometry of electrode plays significant role in improving the weld quality.

This paper gives a general opinion about the influence of changing electrode geometry in arc welding on weld quality. However, these effects will change if the joint type and geometry size of wire electrode changes.

2. DESCRIPTION OF STRIP WIRE WELDING SYSTEM

In this section, details of the experimental work, strip wire electrode – process description, performance characteristics with strip wire electrode and current distribution in strip wire electrode

≡ Experimental Work

Flux cored arc welding is operated in semi-automatic and automatic modes. It is utilized particularly in high production welding operations [18]. 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 [19]. Therefore, proper design of welding torch and wire feeder improves the welding performance with strip wire electrode [20]. However, conventional GMAW torch and wire feeder available are designed to handle cylindrical wire, but are not suitable for welding with strip wire electrode.

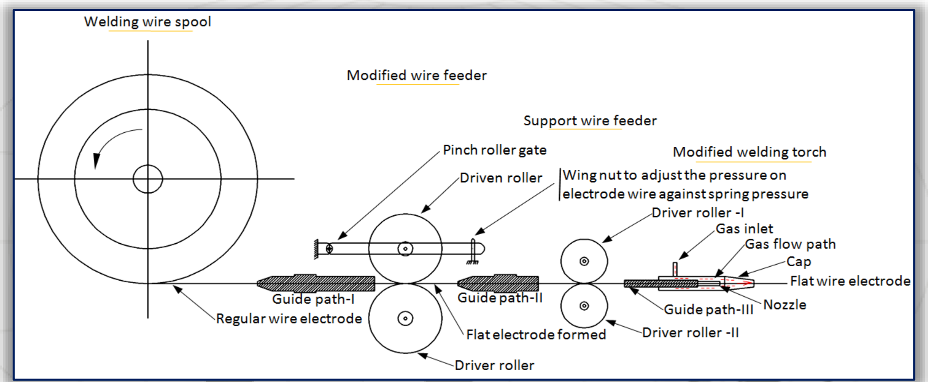
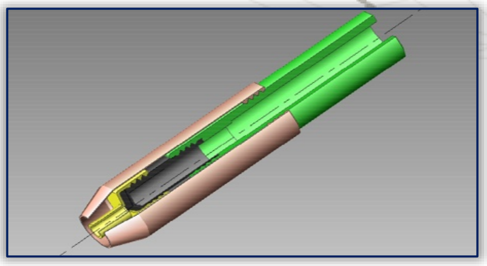
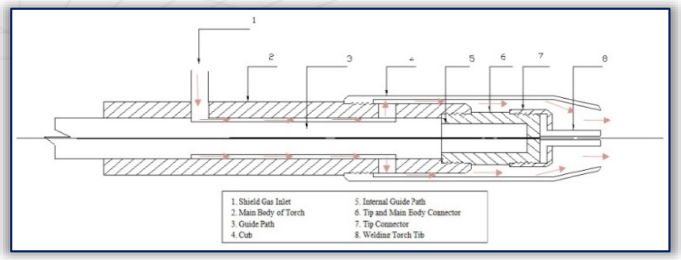


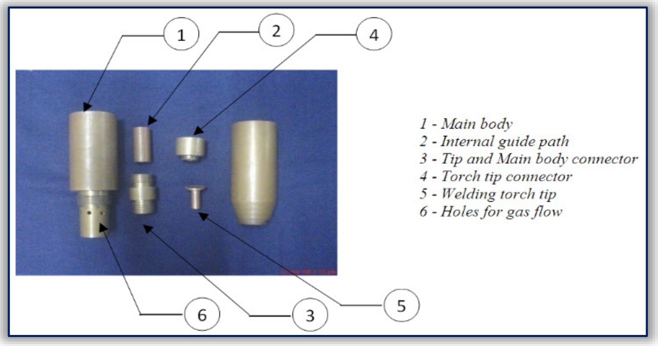
Figure 1. Schematic diagram of strip wire welding system with torch and feeder arrangement



(a) AD model torch for strip wire welding torch



(b) Gas flow path for strip wire welding torch



(c)Various parts of strip wire electrode welding torch

Figure 2. Newly developed welding torch for strip wire electrode welding

Therefore special welding torch and wire feeder is to be developed for this investigation. Figure1 shows the schematic diagram of strip 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 FCAW welding system using strip wire electrode.
In the new approach of strip wire welding system, a wire feed roller shown in Figure1 was designed to give rectangular (strip) shape to the electrode. The formation of strip 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 strip wire from cylindrical wire. In order to form a strip wire continuously with the required cross section, driver wheel of the wire feeder mechanism having a rectangular groove on the face is used. The strip wire from the wire feeder is fed into the welding torch through a wooden guide path. To get a smooth and continuous flow of strip wire electrode, the existing welding torch has been modified as shown in Figure 2.a, b and c. Figure 2 shows the details of CAD model with shielding gas flow path for strip 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 strip wire smoothly and consistently over long distances.

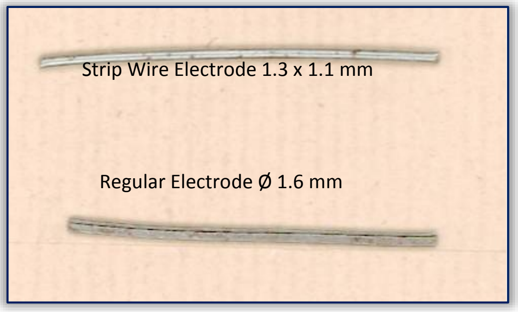
≡ Strip Wire Electrode – Process Description

The strip wire flux cored arc welding (SW-FCAW) technique has been developed to increase productivity by increasing the deposition rate and penetration rate compared with regular flux cored arc welding (FCAW) process. In order to form the strip wire electrode from the conventional cylindrical electrode, an experimental set up has been developed; details are in Figure1 and Figure 2. The variety of strip wire electrode geometry has been achieved by applying various loads by modified wire feed mechanism. In order to get a smooth flow of strip wire electrode continuously, the existing welding torch has been modified as shown in Figure 2. It uses reverse polarity that is electrode strip is made positive. Also wire killing roller system has used for SW-FCA welding technique, in order to maintain the straightness of the strip wire electrode continuously [21]. The present investigation is carried out with E70T1 flux core electrode of 1.2mm diameter as the control sample. The chemical composition of the wire is given in Table 1.

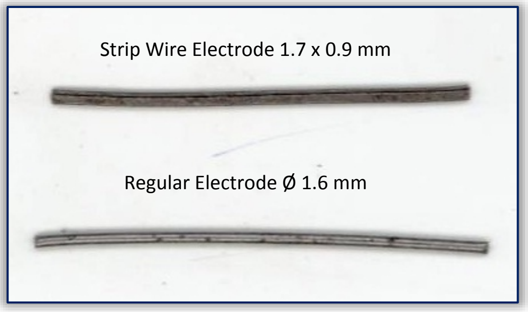
Table 1. Chemical composition of filler material AWS/SFA-5.20: E70T1

Elements	C	Mn	Si	P	S	Others
Chemical Composition (%)	0.06	1.50	0.55	.03	0.03	Remainder

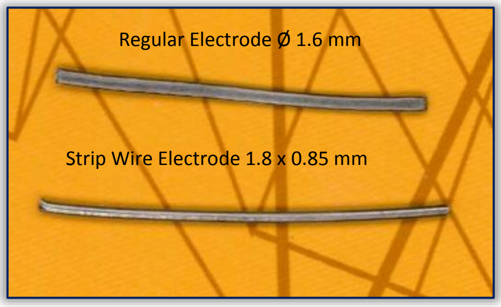
The investigation involves testing of various geometrical sizes; cross section of the various samples to be tested is1.3x1.1mm, 1.7x0.9mm, 1.8x0.85mm and 2x0.8mm. Figure 3 shows that changing geometry of flux core electrode. The Figure 3 (a-d) shows the regular and flat wire electrode and Figure 4 (a-b) shows the macro view of changing shape of the electrode geometry.



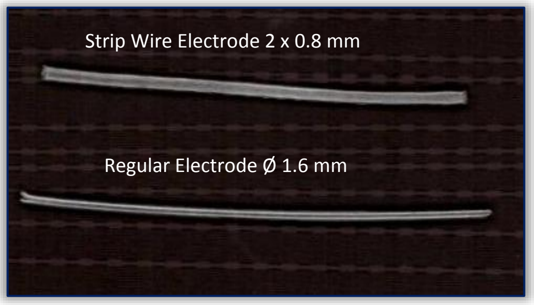
(a) Dimension of strip wire 1.3x1.1mm



(b) Dimension of strip wire 1.7x0.9 mm



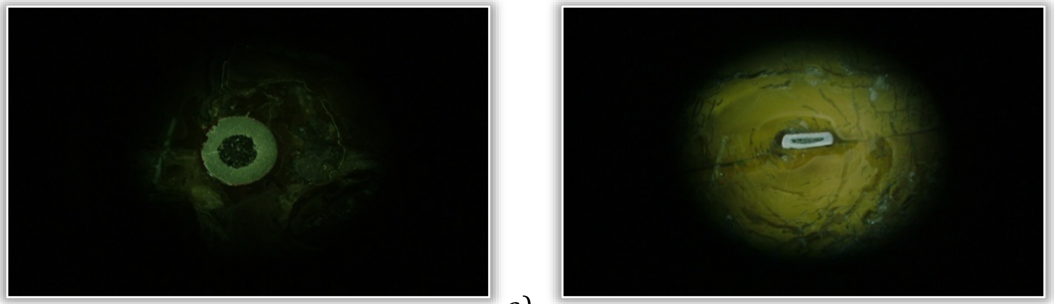
(c) Dimension of strip wire 1.8x0.85 mm



(d) Dimension of strip wire 2x0.8 mm

Figure 3. Electrode before and after Deforming

Investigation result indicates that, the perimeter length of the formed strip wire electrode is measured to be 5.6 mm while the conventional cylindrical wire electrode is 3.77mm. So, the strip wire produced is found to have 32.6% more perimeter length as shown in Table 2, the producing of strip wire electrode, either rolling or slitting. The rolled strip wire found to be round edge whereas slit – to be sharp edge [22]. From the modified wire feed point of view, round edge strip wire is preferable for quality aspect and also get a continuous flow during the welding process [3, 5].



a) b)

Figure 4. End view of the regular electrode and strip wire electrode
(a). Macro view of Flux core electrode ø1.2mm; (b). Macro view of Strip wire electrode of 2x0.8mm

Table 2. Welding performance with different geometrical sizes of strip wire flux cored electrode

Filler wire	Dimension of filler wire (mm)	Cross sectional area (mm²)	Perimeter length (mm)
Regular filler wire	Ø 1.2	1.13	3.77
Strip wire	1.3 x 1.10	1.43	4.80
	1.7 x 0.90	1.53	5.20
	1.8 x 0.85	1.53	5.30
	2.0 x 0.80	1.6	6.60

≡ Performance Characteristics with Strip Wire Electrode

The performance characteristics of strip wire in terms of welding rate and filling volume are stated to be comparable to two wire technologies. Further advantage of strip wire over the two wire technology is that only one power source is needed and easier to set the welding parameters. Wire feeder and the welding torch convey the strip wire powerfully and consistently over long distance. In strip wire flux cored arc welding (SW-FCAW) technique takes place under the same process conditions as those applicable to regular wire in FCAW. When the welding current flows through the wire electrode a magnetic field is established not only in its direct vicinity but also in the wire itself [7]. 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 [23]. So, the magnetic field of the conductor section near the axis produces induction voltage in the center of the conductor with reverse polarity to the rest of the electrical circuit in the center, but sharing the same polarity as that circuit in the peripheral areas. The induction voltage has overlaps with that induced by 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 layers in this respect with less resistance.

≡ Current Distribution in Strip Wire Electrode

The cross-section of a single wire in free space carrying a high-frequency current, if the frequency increases; the current moves toward the outside of the conductor. This current crowding is called the skin effect. Depth of penetration is defined as the distance from the outer surface to the point where the current density has fallen to 1/e of the outer surface current density [24, 25, and 26]. The current is mostly contained in an area bounded by the depth of penetration and the width of the conductor, rather than the depth of penetration by the thickness of the conductor. Therefore, the AC resistance of these conductors is significantly lower. The resistance of the formed strip wire electrode is measured to be 1.6x10-3 Ω while the conventional cylindrical wire electrode is 2.3x10-3 Ω. So, the strip wire produced is found to have 30.4% less resistance.

3. RESULT AND DISCUSSION

≡ Experimental Measurements

This study is aimed at obtaining a relationship between the influence of changing electrode geometry size, welding quality and also to select optimum strip wire electrode geometry size. For this reason, an experimental study has been realized. The welding parameters such as the arc current, arc voltage, and welding speed are held as constant. For this approach base material used as mild steel IS2062 grade-A of thinness 8 mm. In strip wire welding, the different welding results are possible depending on whether the strip wire electrode has fed parallel to welding direction (0º), inclined to welding direction (45º) and normal to the welding direction (90º). The effect of these three orientations on the electrode geometry has been studied, details in Figure 5, the Figure shows that the different orientation of strip wire electrode. The welding operation perform with T joint with initial wire extension of 15 mm maintain for during welding [22].

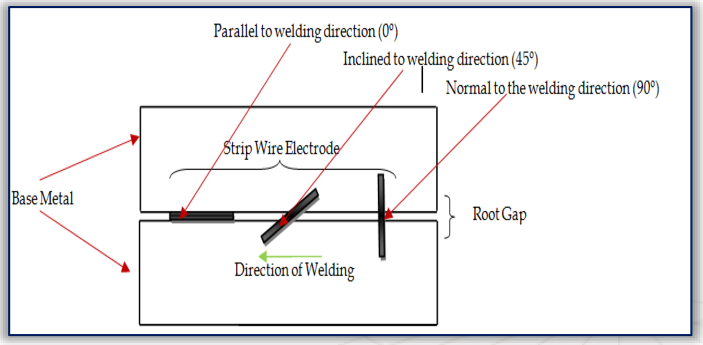


Figure 5. Different orientation of strip wire electrode

Figure 6. Setup of the SW – FCA Welding Process. 1 – SW-FCA welding torch; 2 – SW-FCA welding nozzle; 3 – Strip wire electrode.

The investigation involves testing of electrode geometry with various geometrical sizes; 1.3 x 1.1 mm, 1.7 x 0.9 mm, 1.8 x 0.85 mm and 2 x 0.8 mm with help of SW-FACW setup as shown in Figure 6. There are three important factors like deposition, width and depth are analyzed. These factors are important to justify the quality of welding. In this research paper deals with all the process parameter are constant, the influence of electrode geometry shows in Table 3. Especially, an orientation parallel to welding direction gives better results.

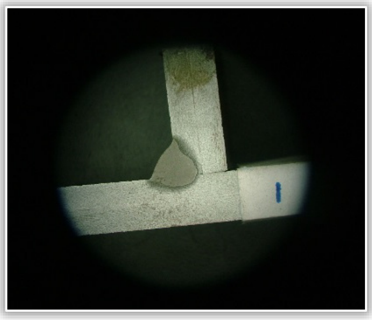
Table 3. Welding performance with different geometrical sizes and different orientation in SW-FCA welding

Samples No.	Strip Wire Electrode Dimension (mm)	Welding performance			
		Strip Wire Orientation (°)	Deposition Rate (kg/min)	Bead Width (mm)	Penetration (mm)
1	1.3X 1.1	0°	0.046	13.1	4.9
2		45°	0.018	12.8	4.6
3		90°	0.019	13.0	4.8
4	1.7X 0.9	0°	0.049	13.8	5.0
5		45°	0.022	13.0	5.0
6		90°	0.023	13.1	4.9
7	1.8 X 0.85	0°	0.058	15.2	5.2
8		45°	0.028	13.3	5.0
9		90°	0.027	13.5	5.1
10	2 X 0.8	0°	0.077	16.0	5.8
11		45°	0.025	14.1	5.4
12		90°	0.023	13.8	5.1

In Figure 7(a-d) shows that weld samples of weld bead and weld penetration profile welded with regular FCA welding and SW-FCA welding with different orientations. From the photograph, it was observed that there is complete fusion on both faying edge without any undercut or significant defects. Weld bead shape is also very good with smooth surface. When compared with a cylindrical wire of same cross section and using the same welding parameter, a higher welding current flow through the strip wire as a results of greater circumferential length which results in increase in performance. Even at high speed of the welding deeper penetration and wider bead width is an achieved detail are in Figure 8(a & d) and it shows that the macro views of the weld bead profile. It is interesting to note that the strip wire electrode with orientation parallel to the direction of welding is found to give greater bead width of 16 mm as well as penetration depth 5.8 mm as compared to normal cylindrical electrode has given bead width of 13 mm and penetration depth of 4.1 mm.

The experimental result shows, there is an increase in surface length of the strip wire electrode which in turn increases the welding performance. Comparatively better welding quality of penetrations was obtained with the geometrical dimension of 2x0.8mm.

(a) Weld sample weld by SW-FCAW normal to the welding direction

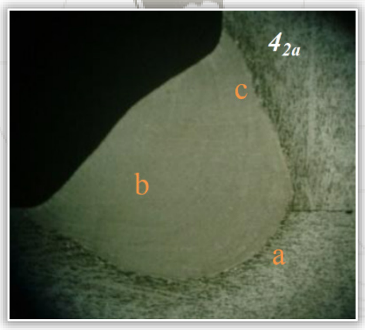


(c) Weld sample weld by SW-FCAW inclined to welding direction

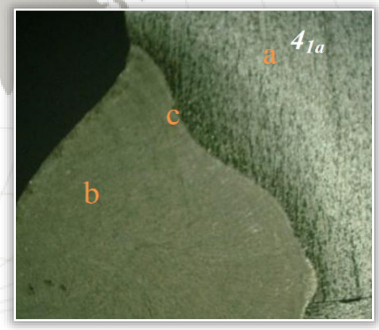
(b) Weld sample weld by SW-FCAW parallel to welding direction

(d) Weld sample weld by FCA Welding

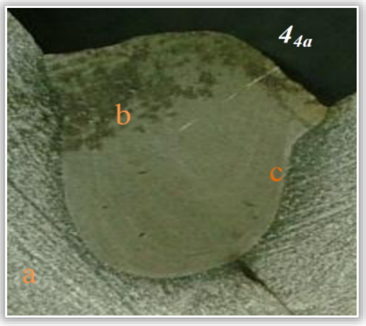
Figure 7. Weld Samples



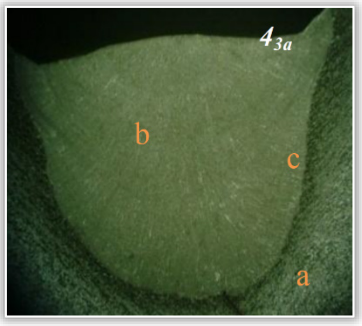
(a) The macrograph of (a) base metal, (b) weld zone and (c) HAZ of SW-FCAW normal to the welding direction



(b) The macrograph of (a) base metal, (b) weld zone and (c) HAZ of SW-FCAW inclined to welding direction



(c) The macrograph of (a) base metal, (b) weld zone and (c) HAZ of SW-FCAW parallel to welding direction



(d) The macrograph of (a) base metal, (b) weld zone and (c) HAZ of FCA Welding

Figure 8. Macrograph profiles of weld samples with SW-FCA welding / FCA welding

≡ **Mechanical Analysis**

The newly developed SW-FCA welding was used to weld and the weld samples were subjected to bend test, micro hardness and impact test [27, 28]. The results are shown in Table 4, 5 & 6. The mechanical properties of the specimens obtained from the welded joints with FCA welding and SW-FCA (Parallel to welding direction only) welding. The bend test was conducted the result shows that 12.5% greater bending strength in SW-FCA welding sample over use of regular FCA welding sample. The Figure 9(a) & 9(b) shows that the maximum force obtain during the bend test.

Table 4. Bending test of FCA weld sample and SW-FCA weld (Parallel to welding direction only) sample

Welding process	Maximum force (KN)	Bending strength KN/mm2
FCAW	4.98	0.042
SW-FCAW	5.76	0.048

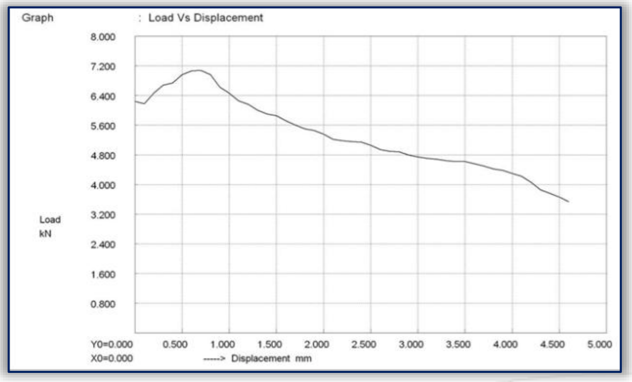


Figure 9. (a) load with displacement graph by SW-FCA welding

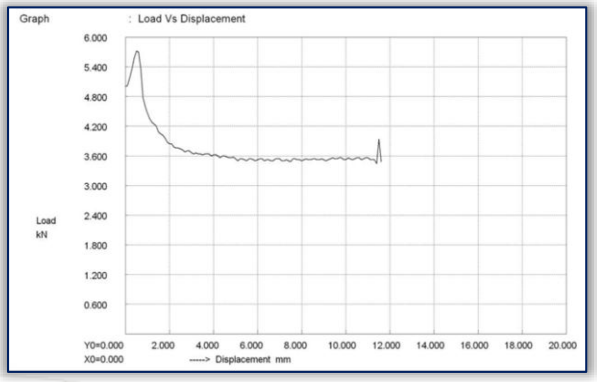


Figure 9. (b) load with displacement graph by FCA welding

Table 5 and Table 6 indicate the hardness and impact toughness distribution along with the base metals and weld metal zone. The weld deposited with FCA welding shows the highest hardness whereas the SW-FCA welding which is greater to the base metal. The overall results shows that the regular FCA welding samples having 8.45% greater hardness than weld samples by SW-FCA welding (Parallel to welding direction only). Similarly, toughness also indicates that SW-FCA weld (Parallel to welding direction only) sample having 11% of greater impact strength over the FCA weld sample.

Table 5. Micro hardness of FCA weld sample and SW-FCA weld (Parallel to welding direction only) sample

Micro hardness (Hv)	Base metal zone	Weld metal zone
FACW	247.8	369.1
SW-FCAW		337.9

Table 6. Notch Toughness of FCA weld sample and SW-FCA weld (Parallel to welding direction only) sample

Notch toughness	No of division on the scale	Impact strength joules
FCAW	62	128
SW-FCAW	72	144

4. CONCLUSIONS

SW-FCA welding technique is highly appropriate both to increase the quality as well as to reduce production time, due to that it has received a great deal of attention from the investigation. The conclusion from this study;

≡ The purpose of this investigation is to understand the use of strip wire electrode and also to predict the weld quality in different strip wire electrode orientation. The strip wire electrode 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 strip wire electrode is 32.6% more perimeter length over the regular cylindrical electrode.

≡ SW-FCA welding 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 regular FCA welding.

≡ SW-FCA welding with orientation parallel to the direction of welding gives 12.5% greater bending strength, 11% of greater impact strength and 8.45% of less hardness over the regular FCA welding.

≡ The experimental results revealed that the strip wire electrode is a better option for producing a good welding quality. The finishing experiment performed on the strip 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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