COMPARATIVE MICROSTRUCTURAL ANALYSES OF MINI-ROBOT AND MANUAL ARC WELDED MILD STEEL PLATES

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Abstract
Mild steel plates of variable thicknesses 0.5 mm, 0.6 mm, 0.7 mm, 0.8 mm, 0.9 mm and 1.0 mm were selected as parent materials to conduct arc welding. Thirty welding numbers each were prepared using robot welding and manual arc welding, respectively. Time, welding length and welding speed, and material thickness were chosen as variable input parameters. Welding conditions for the welding robot are: duty cycle (10% - 60%), welding current (45 A- 90 A), welding voltage (16.25 V – 18.5 V), electrode size of 0.8 mm. The welding condition for manual welding are: duty cycle (10% - 60%), welding current (150 A- 250 A), welding voltage (24.0 V – 28.0 V), electrode size 2.5mm. Complete sixty numbers of experiments were performed using an interfaced device with an optical microscope in which study of microstructure was performed. Results showed that the built welding robot can weld mild steel plates at welding times linearly along the length of the guide 470 mm on the X-axis, 350 mm on the Y-axis and 110 mm on the Z-axis (4.7-32.94s) faster than the conventional Electric Arc Welding Machine's (15-45s). It has also been discovered that welding robot test samples have more Pearlite and less Ferrite structure than Electric Arc welding test samples. Results show that the mini-welding robot built as a substitute for the traditional welding technique is more effective than and promising.

Key words: welding robot, arc welding, microstructure, mild steel

1 Introduction

Welding is a process in which localized coalescence (permanent joint) is created with or without applying heat, with or without applying pressure or pressure on its own, or with or without applying filler material to similar or disassembled materials. In welding, fusion of two welded materials forms a permanent joint. Filler material is usually applied to reinforce the joint. Welded joint is more durable and cost efficient. After welding many steels, the transfor-mation process and mechanical actions were investigated. For example, Bayaraktar *et al*., [1] studied the process of grain growth while interstitial free steels were welded. Observations in welded joints indicate the presence of very large grains along the fusion line, and these are oriented in the direction of heat flow. Karadeniz *et al*., [2] investigated the influence of welding parameters on joint penetration of welds. Boob *et al*., [3] proposed heat input is the most significant factor in regulating the width of the affected heat zone (HAZ) with an improvement in the heat input range of changes in HAZ. Talabi *et al*., [4] proposed an improvement in the voltage of the arc and the welding current resulting in improved hardness values and reduced yield strength, tensile strength and impact power. Norman *et al*., [5] investigated the impact of TIG welding on Al-Mg-Cu-Mn on the microstructure. The welding current obtained is 100-190 A and the welding speed varies from 420-1500 mm / min. Hargopal *et al*., [6] investigated the impact on mechanical properties of alloy Al-65032 of welding parameter with Taguchi cycle. Sharma *et al*., [7] examined the effect on welded joint penetration depths of welding parameters such as welding rate, voltage, and current. Chandel *et al*., [8] derived a relation between bead height, bead width, melting rate, current penetration depth, voltage, diameter of the electrode, extent of the electrode in submerged arc welding. Furuya *et al*., [9] investigated the true heaviness of the weld zone. They developed a linkage between the toughness of HAZ's chemical composition. Both the single layer and multilayer weld joint are used when measuring hardness in HAZ. Lakshmanan *et al*., [10] studied microstructural characterization and mechanical properties of P91 and Incoloy 800HT dissimilar laser beam welded joint. The δ-ferrite content of the welds was predicted and it was correlated with the results measured by ferritoscope. The traces of δ-ferrite in the interface of P91 side led to higher strength and microhardness of the weld. Failure of tensile specimens in the HAZ of Incoloy 800HT side was because of lower ferrite content (0 to 0.36) in that region and also due to the presence of the brittle intermetallic phases. The tensile strength of higher specific point energy welds was greater compared to other welds because of precipitation hardening and presence of δ-ferrite. Irfan *et al*., [11] investigated the influence of the welding parameter of galvanized steel on depth of penetration in MIG welding. The feasibility of stir friction welding (FSW) for mild steel joining was confirmed by Lienert *et al*., [12]. Sato *et al*., [13] welded ultrahigh carbon steel free from defects using a polycrystalline cubic boron nitride friction method. They are also researching the microstructure of welding process parameters and their consequences. They used resistance spot welding to weld and investigate the relationship between fault mode and weld fusion zone, austenitic stainless steel and galvanized low carbon steel. The outcome of Marashi *et al*., [14] welding work suggests that the strength of the spot weld in the pull-out failure mode is determined by the force and fusion zone size of the galvanized steel hand. Saeid *et al*., [15] focused on the impact of SAF 2205 duplex stainless steel welding speed in friction stir welding (FSW) on the microstructure and mechanical properties of the stir zone (SZ);

The effect of welding on low-carbon industrial steel used to make gas storage cylinders was examined by Zakaria *et al*., [16]. The methods of characterization included optical microscopy, EBSD, X-ray diffraction and hardness checking. The micro-structures were determined in different zones from base metal to weld metal. The core microstructure of the weld area is completely different from the region which is affected by heat. The HAZ includes Widmanstatten ferrite, large ferrite grains, and colonial pearlite. They observed that the coarse bands of grain grow along certain preferred crystallographic directions. Moreover, they found that the highest values of hardness are in the area of weld metal and HAZ, which indicates its specificity.

It is also recognized that welded steel's final microstructures and mechanical properties depend on certain parameters, such as carbon percentage and the presence of certain elements such as sulfur or phosphor. Low carbon steels with a carbon content of less than 0.25 per cent have good welding efficiency, as they can typically be welded using most available methods without special precautions. With regard to the welding of low carbon steels, it has been shown that the grain-coarsened zone (GCZ) and heat-affected zone (HAZ) are very critical because the embrittlement concentration in those areas is high [17]. Preceding studies of low carbon steel welding have limited publication [17], [18], [19], [20], [21], [22], [23]. For example, Gural *et al*. [17] studied heat treatment in two phase regions and their effects on the microstructure and mechanical strength after the low carbon steel was welded. On the other hand, Eroglu and Aksoy [18] have investigated the impact of initial grain size on the microstructure and durability of an inter-critical heat-affected region with low carbon steel.

Over time, robots have evolved and become part of

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many industrial enterprises, and are of great interest to many industries including modern machinery shops, medical fields, construction, and manufacturing, home space exploration [24]. Dallaway *et al*., [25] stated that in the automotive industry, the implementation of robotic assistive devices is a relatively underdeveloped research area within the robotics rehabilitation community. Past occupational robotics implementations were with few exemptions in companies. With technical advancements in the developing world and ever-increasing complexity in manufacturing, it became imperative to embark on this research at this present stage of technological growth for the country. The result of this work has brought recognition and a consequent massive use of the application of this aspect of robotics (welding robots) to the doorstep of a developing country like Nigeria where production of work in this field of study is still not possible.

2 Materials and Methodology

Mild steel is one of the inexpensive steel materials, and is commonly used in all applications. It is used where a great quantity of iron is required. It has a high carbon content of 0.29 per cent, manganese up to 0.9 per cent and a small amount of phosphorus, sulphur and silicon. Electrical current can be quickly passed through it, leaving no effect on the metals' internal structure. It has superior welding properties as compared to steel. Table 1 displays the chemical composition of a mild steel. In Table 2 below, the thermal and mechanical properties of mild steel are given.

Table 1: Chemical composition of mild steel

Element	**C**	**Mn**	**Si**	**S**	**P**
Percentage	0.16-0.18	0.70-0.90	0.40 Max.	0.40 Max.	0.40 Max.

Source: Bijaya *et al*., [26].

Table 2: Various properties of mild steel

Property	**Value**	**Unit**
Conductivity	42	W/m K
Specific heat	481	J/Kg-K
Density	7872	Kg/m
Poisson's ratio	0.27-0.30	
Elastic Modulus	190 to 210	GPa

Source: Bijaya *et al*., [26].

2.1 Welding machine

A general welding machine (Fronius MW 2200), is the welding machine used. The machine's technical specification is given in Figure 1 below. Table 3, displays the type of welding machine used for the experiment.

Figure 1: Arc welding machine [Fronius, Model- NW2200]

Table 3: Specification of welding machine

Specification	**MW 2200**
Range	10-180 A
Primary voltage	230 V, 50-60 Hz
Open circuit	voltage 88 V
Operating voltage	20.4-27.2 V

2.2 Developed welding mini-robot

The built welding robot can weld mild steel plates linearly along the length of the guide 470 mm on X-axis, 350 mm on Y-axis and 110 mm on Z-axis. The specification of the developed welding mini-robot is shown in Table 4

Plate 4: Assembly of the developed welding robot (front view)

Table 4: Specification of the developed welding mini-robot

Specification	**Cartesian type**
duty cycle Range	(10% - 60%)
welding current range	(45 A- 90 A)

welding voltage range	(16.25 V – 18.5 V)
electrode size	0.8 mm

2.3 Experimental parameter

In welding process current was varied along with the thickness of work piece. The current is varied in three steps as shown in following Table 4.

Table 4: Experimental parameter

Welding current in Amp	Material Thickness in mm
90	5
	6
	8
100	5
	6
	8
110	5
	6
	8

2.4 Experimental methodology

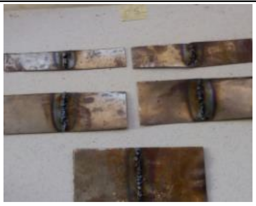
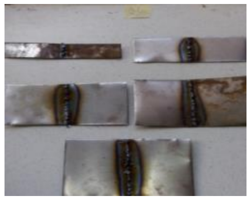
60 specimens of the thickness 0.5, 0.6, 0.7, 0.8, 0.9 and 1 mm are considered for performing the experiment. Before the specimens were welded, the oil in a molten metal tub was washed off dust to eliminate impurities. Since welding was performed through a closed butt joint, the edges of the piece of work are prepared accordingly. To conduct the welding the work pieces were held in relative place. Safety precautions and corrective steps were taken to avoid accidents and to achieve good weld bead efficiency.

3 Welded Mild Steel Plates for Test Using the Developed Welding Robot

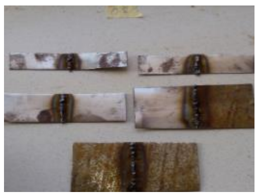
Table 5 shows the various times of weld and welding speeds at some set lengths of weld for the welded mild plates of different sizes used as test specimens. Plate 1 shows the specimens considered for the welding quality of the developed welding robot. The welding condition for the welding robot are: duty cycle (10 % - 60 %), welding current (45 A- 90 A), welding voltage (16.25 V – 18.5 V), electrode size of 0.8 mm.

Table 5: Time, length of weld and welding speed of developed welding robot

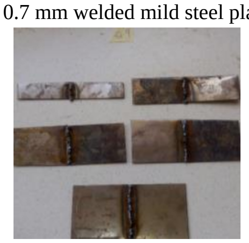
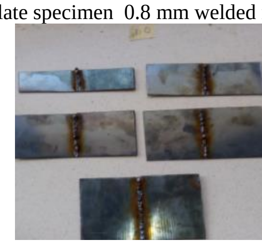
Welding Operation using the Developed Welding Robot						
Length of Weld (mm)	25	50	75	100	125	150
		0.5 mm Mild Steel Plate				
Time of Weld (s)	5.37	10.94	17.01	21.82	26.53	32.94
Welding Speed (mm/s)	4.66	4.57	4.41	4.58	4.71	4.55
		0.6 mm Mild Steel Plate				
Time of Weld (s)	5.25	10.89	16.99	21.74	26.45	32.82
Welding Speed (mm/s)	4.76	4.59	4.41	4.60	4.73	4.57
		0.7 mm Mild Steel Plate				
Time of Weld (s)	5.12	10.77	16.92	21.69	26.33	32.44
Welding Speed (mm/s)	4.88	4.64	4.43	4.61	4.75	4.62
		0.8 mm Mild Steel Plate				
Time of Weld (s)	5	10.66	16.84	21.64	26.3	32.43
Welding Speed (mm/s)	5.00	4.69	4.45	4.62	4.75	4.63
		0.9 mm Mild Steel Plate				
Time of Weld (s)	4.88	10.58	16.75	21.42	26.02	32.42
lding Speed (mm/s)	5.12	4.73	4.48	4.67	4.80	4.63
		1.0 mm Mild Steel Plate				
Time of Weld (s)	4.7	10.13	16.51	21.3	25.74	31.52
Welding Speed (mm/s)	5.32	4.94	4.54	4.69	4.86	4.76

0.5 mm welded mild steel plate specimen 0.6 mm welded mild steel plate specimen

0.7 mm welded mild steel plate specimen 0.8 mm welded mild steel plate specimen

0.9 mm welded mild steel plate specimen 1.0 mm welded mild steel plate specimen

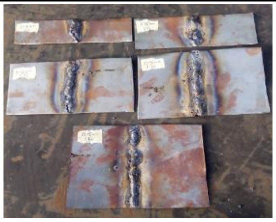
Plate 1: Welded mild steel plate specimens using the developed welding robot

3.1 Welded mild steel plates for test using electric arc welding (manual)

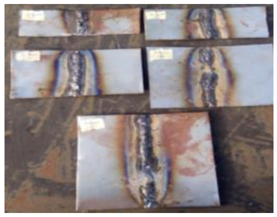
Table 6 shows the various lengths of weld and welding speeds at some set time of weld for welded mild plates of different sizes used as test specimens. Plate 2 shows the specimens considered for the welding quality of the electric arc welding (Manual). The welding condition for manual welding are: duty cycle (10 % - 60 %), welding current (150 A- 250 A), welding voltage (24.0 V – 28.0 V), electrode size 2.5mm.

Table 6: Time, length of weld and welding speed of electric arc welding machine

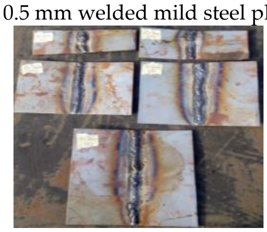
Welding Operation using Electric Arc Welding							
Time of Weld (s)	15	20	25	30	35	40	45
0.5 mm Mild Steel Plate							
Length of Weld (mm)	35	45	56	75	88	101	107
Welding Speed (mm/s)	2.33	2.25	2.24	2.50	2.51	2.53	2.38
0.6 mm Mild Steel Plate							
Length of Weld (mm)	45	53	61	78	92	107	135
Welding Speed (mm/s)	3.00	2.65	2.44	2.60	2.63	2.68	3.00
0.7 mm Mild Steel Plate							
Length of Weld (mm)	46	56	67	95	106	117	148
Welding Speed (mm/s)	3.07	2.80	2.68	3.17	3.03	2.93	3.29
0.8 mm Mild Steel Plate							
Length of Weld (mm)	62	88	114	123	144	165	174
Welding Speed (mm/s)	4.13	4.40	4.56	4.10	4.11	4.13	3.87
0.9 mm Mild Steel Plate							
Length of Weld (mm)	65	97	129	158	175	184	192
Welding Speed (mm/s)	4.33	4.85	5.16	5.27	5.00	4.60	4.27
1.0 mm Mild Steel Plate							
Length of Weld (mm)	70	102	134	165	180	187	195
Welding Speed (mm/s)	4.67	5.10	5.36	5.50	5.14	4.68	4.33



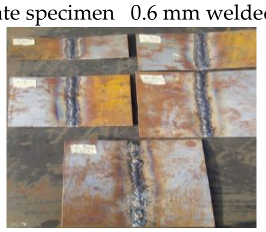
0.5 mm welded mild steel plate specimen



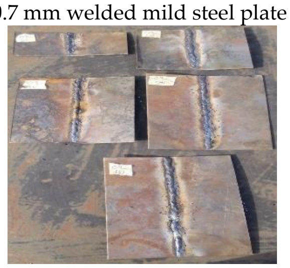
0.6 mm welded mild steel plate specimen



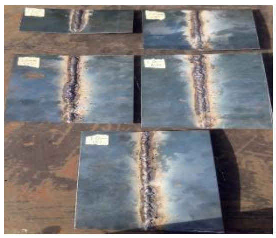
0.7 mm welded mild steel plate specimen



0.8 mm welded mild steel plate specimen



0.9 mm welded mild steel plate specimen

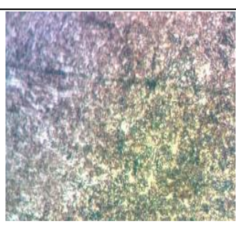


1.0 mm welded mild steel plate specimen

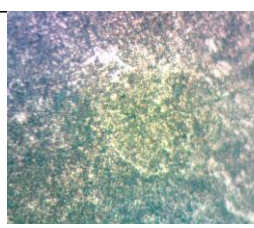
Plate 2: Welded mild steel plate specimens using electric arc welding (manual)

4 Microstructure of Welded Mild Steel Plate with the Developed Welding Robot

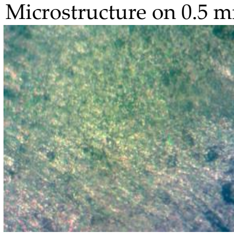
The microstructures of the welded specimen using the developed welding robot for different thickness of mild steel plate are shown in Plates 3 to 8. Five (5) specimen of the size 0.5mm, 0.6mm, 0.7mm, 0.8mm, 0.9mm and 1.0mm respectively were taken for the experiment as shown in Plate 1. Table 5 shows that, on each mild steel plate subjected to test, as welding time increases, length of weld also increases.



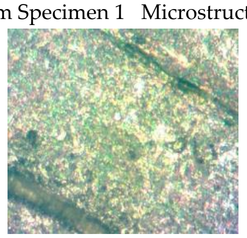
Microstructure on 0.5 mm Specimen 1



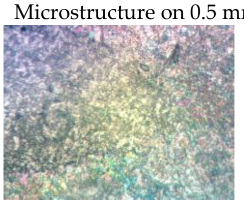
Microstructure on 0.5 mm Specimen 2



Microstructure on 0.5 mm Specimen 3

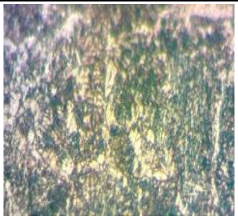
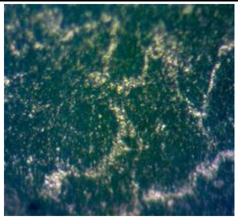


Microstructure on 0.5 mm Specimen 4

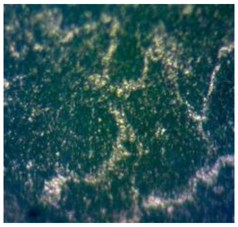
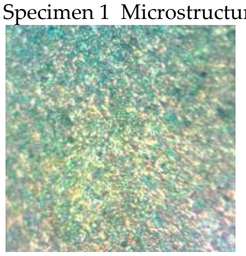


Microstructure on 0.5 mm Specimen 5

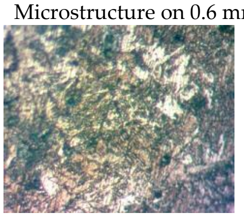
Plate 3: Microstructure of 0.5 mm welded specimens for the developed welding robot

Microstructure on 0.6 mm Specimen 1 Microstructure on 0.6 mm Specimen 2

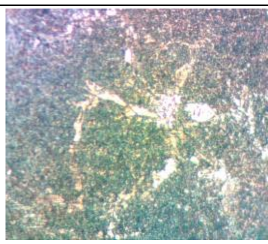
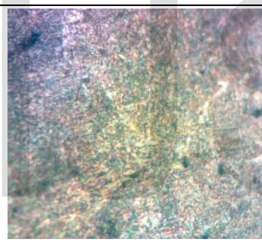



Microstructure on 0.6 mm Specimen 3 Microstructure on 0.6 mm Specimen 4

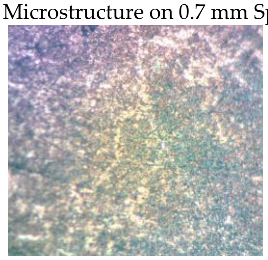
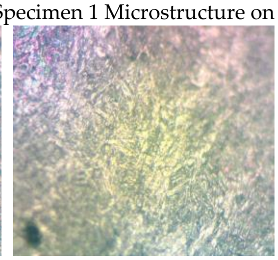


Microstructure on 0.6 mm Specimen 5

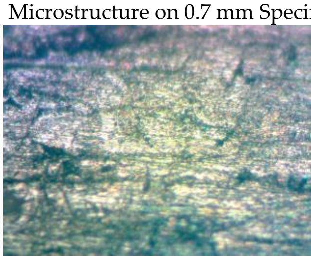
Plate 4: Microstructure of 0.6 mm welded specimens for the developed welding robot

Microstructure on 0.7 mm Specimen 1 Microstructure on 0.7 mm Specimen 2

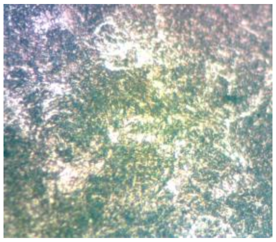
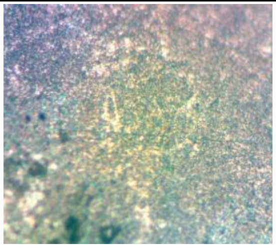



Microstructure on 0.7 mm Specimen 3 Microstructure on 0.7 mm Specimen 4

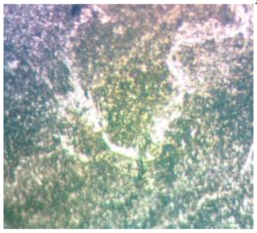
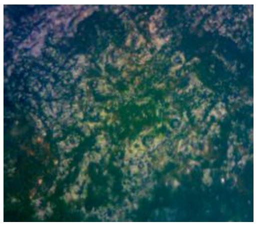


Microstructure on 0.7 mm Specimen 5

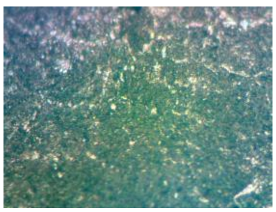
Plate 5: Microstructure of 0.7 mm welded specimens for the developed welding robot

Microstructure on 0.8 mm Specimen 1 Microstructure on 0.8 mm Specimen 2

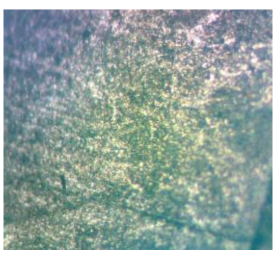
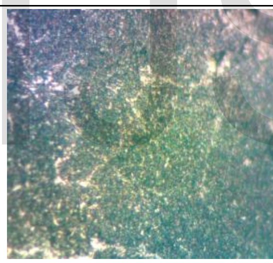



Microstructure on 0.8 mm Specimen 3 Microstructure on 0.8 mm Specimen 4

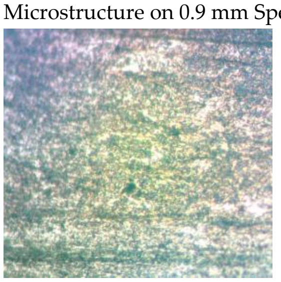
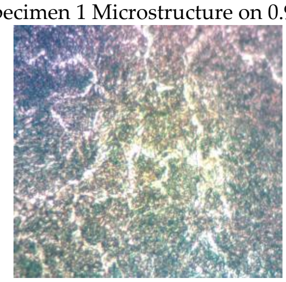


Microstructure on 0.8 mm Specimen 5

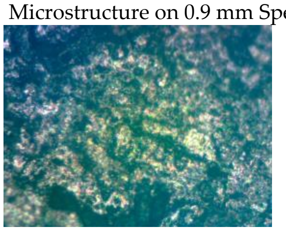
Plate 6: Microstructure of 0.8 mm welded specimens for the developed welding robot

Microstructure on 0.9 mm Specimen 1 Microstructure on 0.9 mm Specimen 2

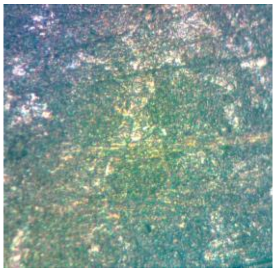
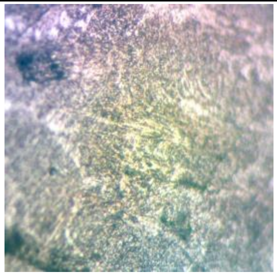



Microstructure on 0.9 mm Specimen 3 Microstructure on 0.9 mm Specimen 4

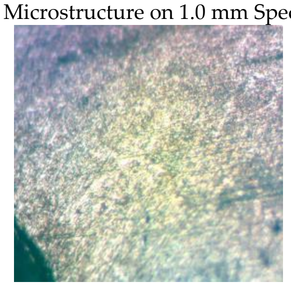
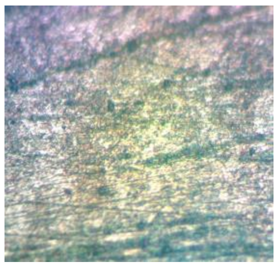


Microstructure on 0.9 mm Specimen 5

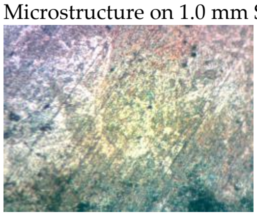
Plate 7: Microstructure of 0.9 mm welded specimens for the developed welding robot

Microstructure on 1.0 mm Specimen 1 Microstructure on 1.0 mm Specimen 2

Microstructure on 1.0 mm Specimen 3 Microstructure on 1.0 mm Specimen 4

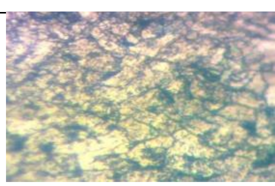


Microstructure on 1.0 mm Specimen 5

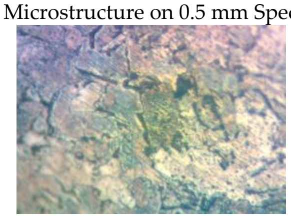
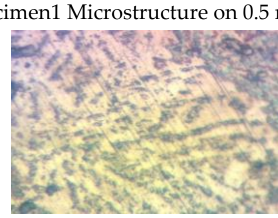
Plate 8: Microstructure of 1.0 mm welded specimens for the developed welding robot

4.1 Microstructure of welded mild steel plate with electric arc welding (manual)

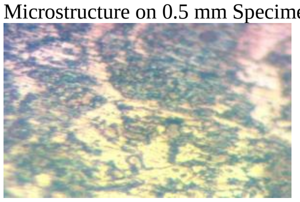
The microstructures of the welded specimen using Electric Arc welding for different thicknesses of mild steel plate are shown in Plates 9 to 14. Five (5) specimen of the size 0.5mm, 0.6mm, 0.7mm, 0.8mm, 0.9mm and 1.0mm respectively were taken for the experiment as shown in Plate 2. Table 6 shows that, on each mild steel plate subjected to test, as welding time increases, length of weld also increases.

Microstructure on 0.5 mm Specimen1 Microstructure on 0.5 mm Specimen 2

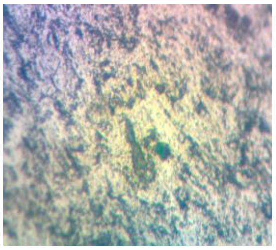
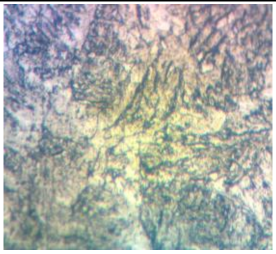
 

Microstructure on 0.5 mm Specimen 3 Microstructure on 0.5 mm Specimen 4

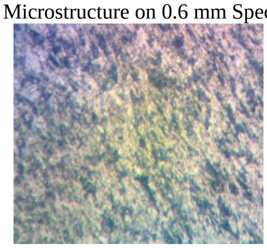
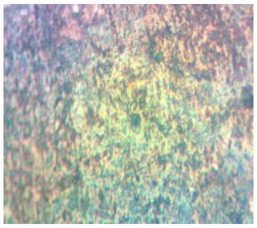


Microstructure on 0.5 mm Specimen 5

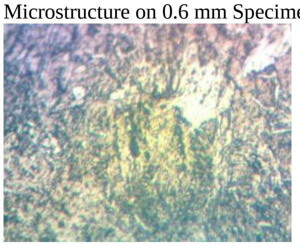
Plate 9: Microstructure of 0.5 mm welded specimens for the electric arc welding

Microstructure on 0.6 mm Specimen 1 Microstructure on 0.6 mm Specimen 2

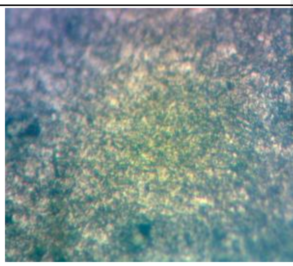
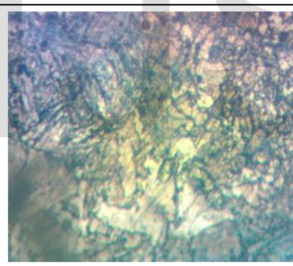



Microstructure on 0.6 mm Specimen 3 Microstructure on 0.6 mm Specimen4

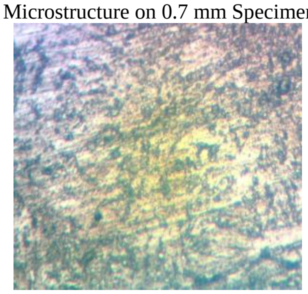
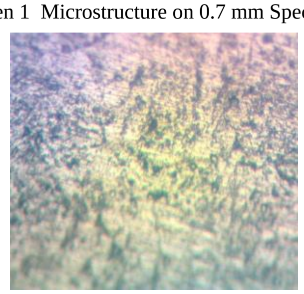


Microstructure on 0.6 mm Specimen 5

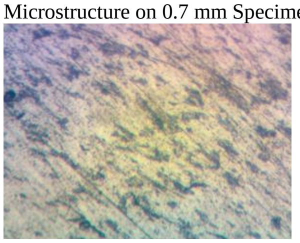
Plate 10: Microstructure of 0.6 mm welded specimens for the electric arc welding

Microstructure on 0.7 mm Specimen 1 Microstructure on 0.7 mm Specimen 2

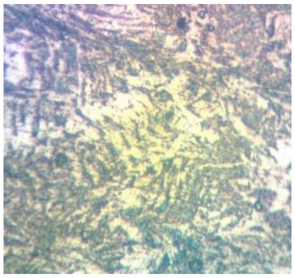
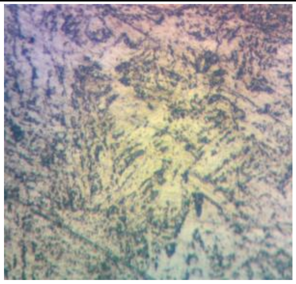



Microstructure on 0.7 mm Specimen 3 Microstructure on 0.7 mm Specimen 4

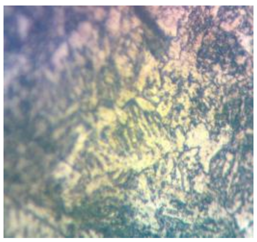
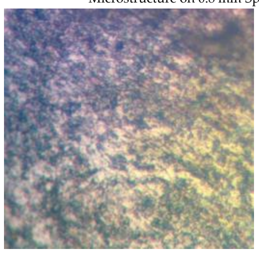


Microstructure on 0.7 mm Specimen 5

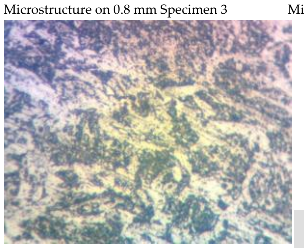
Plate 11: Microstructure of 0.7 mm welded specimens for the electric arc welding

Microstructure on 0.8 mm Specimen 1 Microstructure on 0.8 mm Specimen 2

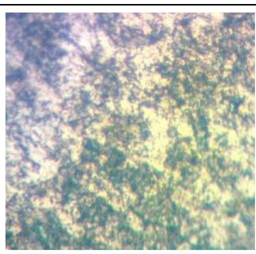
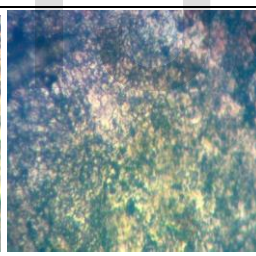



Microstructure on 0.8 mm Specimen 3 Microstructure on 0.8 mm Specimen 4

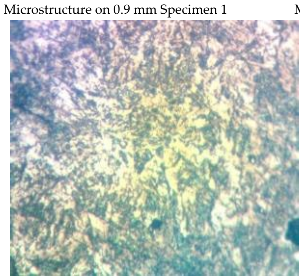
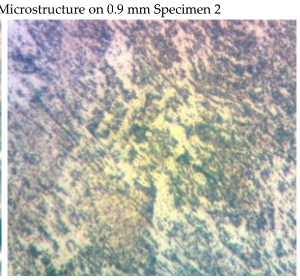


Microstructure on 0.8 mm Specimen 5

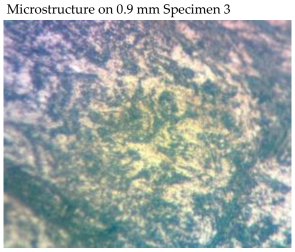
Plate 12: Microstructure of 0.8 mm welded specimens for the electric arc welding

Microstructure on 0.9 mm Specimen 1 Microstructure on 0.9 mm Specimen 2

Microstructure on 0.9 mm Specimen 3 Microstructure on 0.9 mm Specimen 4



Microstructure on 0.9 mm Specimen 5

Plate 13: Microstructure of 0.9 mm welded specimens for the electric arc welding

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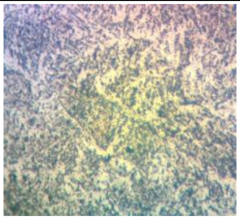
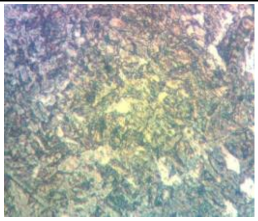
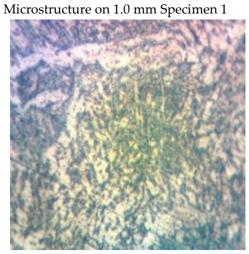
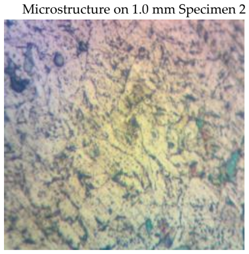

Microstructure on 1.0 mm Specimen 1


Microstructure on 1.0 mm Specimen 2


Microstructure on 1.0 mm Specimen 3


Microstructure on 1.0 mm Specimen 4

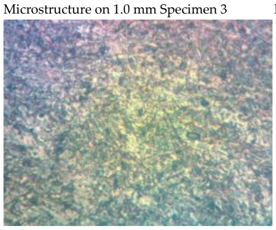

Microstructure on 1.0 mm Specimen 5

Plate 14: Microstructure of 1.0 mm welded specimens for the electric arc welding

5 Results and Discussion

The microstructure investigation of the welded mild steel plates has been performed by the help of an optical microscope. The optical microscope with an interfaced computer in which microstructure study was done is shown in the Plate 15. There is more pearlite ($\alpha + Fe_3C$) than ferrite (α) in the microstructural test of the welded materials using developed welding robot as shown in Plates 3 to 8. This indicates that the weldment portion is hard. The high hardness and high strength and decrease in porosity of the weld bead are caused by the fine grain in the microstructure.

There is more ferrite (α) than pearlite ($\alpha + Fe_3C$) in the microstructural test of the welded materials using electric arc welding as shown in Plates 9 to 14. This indicates that the weldment portion is soft. The lower hardness and low strength and increase in porosity of the weld bead are caused by the coarse grain in the microstructure.


Plate 15: Accuscope microscope with camera (serial no 0524011, maker (Princeton, US)

6 Conclusion

This research presents an experimental study of effect of processes of welding on the weld quality of mild steel plate of variable thickness of work piece in arc welding. The microstructural properties of the welded joint have been discussed. The results shows that more of coarse structure is formed in using electric arc welding (that is more ferrite than pearlite) and more of fine structure is formed in using developed welding robot (that is more pearlite than ferrite). The developed welding robot has also presented, from experimentation, significantly less welding time, higher length of weld and hence, a higher range of welding speed when compared with the conventional electric arc welding technique adopted in this research work. The developed welding robot is faster in terms of welding time (4.7-32.94s, as compared to electric arc welding's 15-45s); welding speed (starting from 4.41mm/s , when compared to the electric arc welding's starting from 2.24mm/s) over same range of mild steel plate thicknesses from 0.5-1.0mm and length of weld. The higher the thickness of the mild steel plate, the lower the time of weld and the higher the welding speed. This is true in the use of both the developed welding robot and electric arc welding machine. The developed welding robot has worked very well and presented better quality of weld from the results of microstructural analyses.

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