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Study of Microstructure and Mechanical Properties of Feritic Stainless Steel (AISI 430) Weldment using ER309L and ER430 electrodes by MIG welding process

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Abstract— **Ferritic stainless steel is generally considered to have poor weldability when compared to austenitic stainless steel but has recently drawn greater attention owing to their lower costs and better resistance to stress corrosion resistance than austenitic stainless steel. Ferritic stainless steel has been widely used in vessels, vehicles, household appliances, kitchen equipment and building decoration because of its excellent performance of chloride stress corrosion and spot corrosion resistance addition to excellent strength. This work reports the microstructural and mechanical behaviour of AISI 430 FSS weldment welded by MIG welding using electrodes ER309L and ER430. The work has been divided into three sections. The first section deals with microstructural analysis of the weldments. It was found that weldment using electrode ER309L (austenitic stainless steel) the austenitic phase microstructure was formed in fusion zone (FZ) this increases the toughness of the weld metal. In case of ferritic stainless steel electrode, the microstructure of the fusion zone and the heat affected zone was greatly influenced by rapid grain growth that results in poor ductility and low impact toughness of the weldment. The second section describes the mechanical properties evaluation and correlation with microstructure. It was observed that the joints produced by MIG welding using ER309L exhibit superior impact properties when compared with welded joints using ER430. The last section deals with hardness test across fusion zone (FZ) of the weldments and base metal. Higher value of hardness in welded joint was reported as compared to base metal. This increment in hardness value could be mainly due to the formation of martensite in the fusion zone (FZ) and heat-affected zone (HAZ) of the weldments.**

Keywords— Ferritic stainless steel, microstructure, MIG welding, electrode, mechanical properties

INTRODUCTION

Stainless steels are iron-base alloys containing at least 10.5% Cr. Stainless steels contain iron as the main element and Cr in amounts ranging from 10.5% to 30%. Carbon is normally present in amount ranging from less than 0.03% to over 1.0% in certain martensitic grades. Manganese normally ranges from 1% to 2% [1]. They achieve their stainless characteristics through the formation of an invisible and adherent chromium-rich oxide surface film. These steels do not rust and strongly resist attack by a great many liquids, gases and chemicals. Chromium provides the basic corrosion resistance to stainless steel by forming a thin film of Cr-oxide on the metal surface when it is exposed to ambient air. This film acts as a barrier to further oxidation, rust and corrosion. Many of these stainless steels have good low temperature toughness and ductility. They also exhibit good strength properties and resistance to scaling at elevated temperature [2]. The alloying elements in addition to chromium and nickel such as molybdenum, copper, and manganese are added to improve desirable mechanical properties and others elements such as carbon, silicon, niobium, and titanium can enhance the properties, if added carefully, in controlled amounts or can be detrimental if their presence is uncontrolled. The third group of alloying elements including sulphur, phosphorous, and selenium are considered to be detrimental to the weldability of stainless steel even though they may improve machinability of the alloy [3]. They are used in a variety of application where corrosion resistance rather than mechanical properties (strength, toughness and ductility), is the primary service requirements. Low chromium (10.5-12.5 wt %) grades are used for application such as automotive exhaust system, where resistance to general corrosion is superior to carbon steels. Medium and high chromium grades are used in more aggressive corrosion environments. High chromium grades are also used in high efficiency furnaces [4]. The ferritic stainless steels generally have lower tensile strengths and elongation than the austenitic stainless steels but higher yield strength.

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I. EXPERIMENTAL WORK

Base Material and Filler Wire Material

Cold rolled, annealed AISI 430 ferritic stainless steel 3 mm thick sheet was taken for the study. The chemical analysis of the base metal was obtained by spectrometer and by melting process as shown in Table 1.

Table 1: Chemical Composition of Base metal (wt. %)

Elements	Base metal (Spectrometer)	Base metal (Melting)
Cr	16.37	16.02
Ni		
C	0.0337	0.039
Si	0.3132	0.272
Mn	0.4918	0.458
S	0.123	0.014
P	0.0213	0.025
Fe	Bal	Bal

Ferritic stainless steel electrode (ER430) having nearly same composition (as shown in Table 2) of base metal was used. Filler metal of matching or similar composition provides maximum strength properties and corrosion resistance to the welded joint. Another filler metal used was austenitic stainless steel ER309L (composition given in Table 3).

Table 2: Chemical composition of ER430 filler material (wt. %)

Filler material	ER 430
Cr	17.0
Ni	0.164
C	0.044
Si	0.296
Mn	0.246
S	0.002
P	0.023
Fe	Bal

Table 3: Chemical composition of austenitic stainless steel filler material (wt. %)

Filler material	ER309L
Cr	23-25
Ni	12-14
C	0.03
Si	0.30-0.65
Mn	1.0-2.5
S	0.03
P	0.03
Cu	0.75

II. PREPARATION OF TEST SPECIMEN

Square butt weld design was used to join the test plates of size 320 mm × 100 mm × 3 mm. Weld design is shown in Fig.1. MIG welding process was used using consumable electrode ER430 and ER309L of diameter 1.2 mm. Welding was completed in a single pass. The samples were tack welded at either end so that a 2 mm gap was left at the bottom of the plates. The shielding gas used was pure argon with flow rate 6 L/min. A set of preliminary trials were performed in order to optimize the experimental welding parameter and ensure good weld quality. Used welding condition and process parameters are given in Table 4.

Table 4: Welding condition and process parameters

Process Parameters	MIG Welding	
	Austenitic stainless steel filler metal	Ferritic stainless steel filler metal
Welding current (A)	174-209	127-242
Welding speed (mm/min)	304.74	304.74
Electrode polarity	DCEP	DCEP
Arc voltage (V)	18	17.6
Filler wire diameter (mm)	1.2	1.2
Electrode	ER309L	ER430
Number of passes	1	1
Shielding gas flow rate (L/min)	6	6
Feed rate (m/min)	6.1	6.1
Stick out length (mm)	12	12

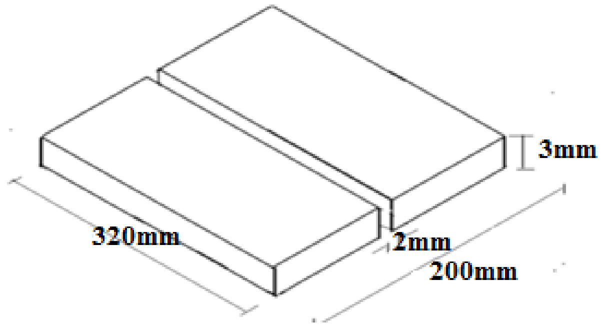

Fig.1 Square butt joint design for MIG welding

III. TENSILE TEST

The welded joints were sliced using a power hacksaw and then machined to the required dimensions for preparing tensile test specimens. The specimens were prepared as per ASTM standard [5]. Dimension of standard tensile specimen is shown in Fig. 2(a). The transverse tensile properties such as ultimate tensile strength, and percentage of elongation of the FSS joints were evaluated. Fig. 2(b) and 2(c) show welded tensile specimens using ER309L filler and ER 430 filler metal respectively. Fig. 2(d) shows tensile specimens of base metal. Fig. 2(e) and Fig. 2(f) show broken tensile specimen welded by ER309L filler metal and ER 430 filler metal. Fig. 2(g) shows the broken tensile specimen of base metal. As the tensile specimens in both the cases broken outside the welded joint, hence efficiency of welded joint can be considered more than 100%. From this result we can conclude that a good welded joint can be obtained in case of welding of FSS.

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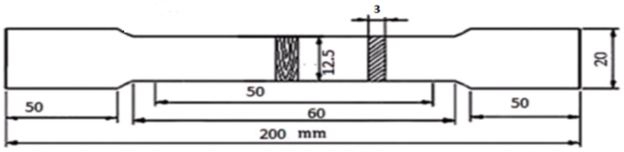

Fig. 2(a) Standard specimen size for tensile test

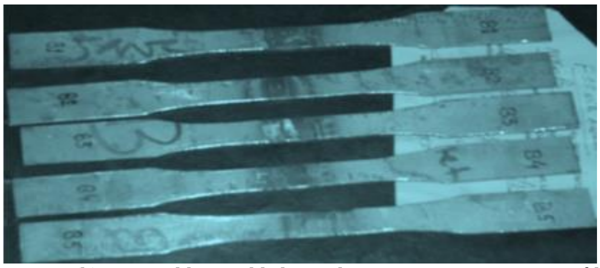

Fig. 2(b) MIG welding welded tensile specimens using ER309L filler metal.

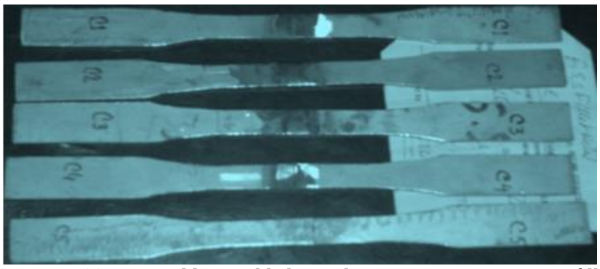

Fig. 2(c) MIG welding welded tensile specimens using ER430 filler metal.

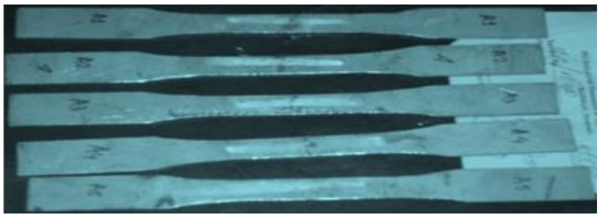

Fig. 2(d) Tensile specimens of base metal.

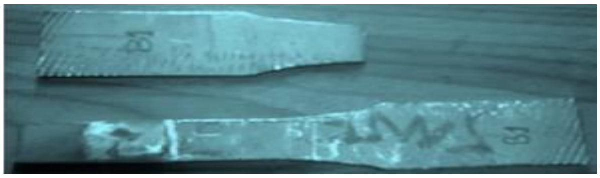

Fig. 2(e) Broken tensile specimen welded by MIG welding using ER309L filler metal

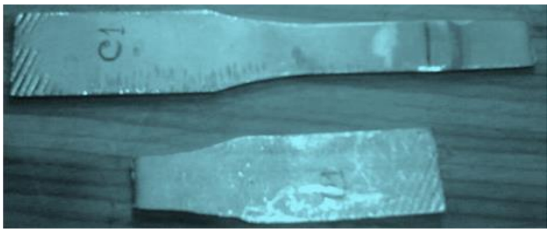

Fig. 2(f) Broken tensile specimen welded by MIG welding using ER430 filler metal.

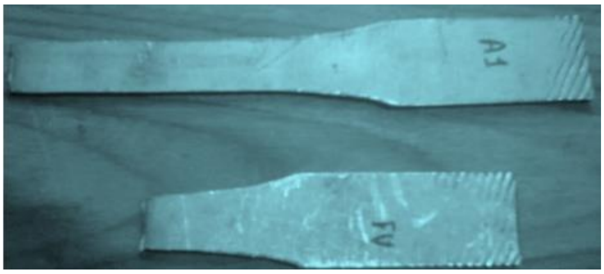

Fig. 2(g) Broken tensile specimen of base metal.

IV. HARDNESS TEST

For the hardness test also 3 mm thick FSS plate was used. ASTM standard was followed. The required size of specimen was cut from the welded plate and finished by filing followed by emery papers. Then to get extra smoothness, polishing machine was used. A total of nine samples were prepared, three each for welded joints prepared by ER430, ER309L and base metal for comparison. Vickers hardness test was conducted to evaluate the hardness by using a major load of 5 kg and applied for 15 second.

V. TOUGHNESS TEST

American society for testing and materials (ASTM) guidelines were followed for preparing the test specimens for impact test. The 3 mm thick plate was used for toughness testing. Fig. 3(a) shows the dimension of the toughness specimen. A total of 15 samples were prepared, five each for ER430, ER309L filler metal weldments and base metal. Fig. 3(b) and 3(c) show the specimens for impact test welded by ER309L and ER430 electrode respectively. Toughness test was carried out on an Impact Testing Machine with a capacity of 30 kg.

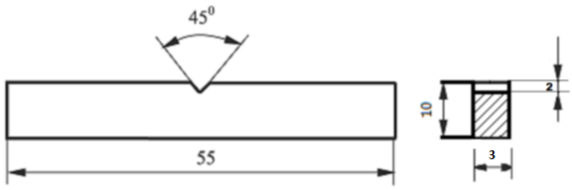

Fig.3(a) Standard specimen size for Charpy impact test

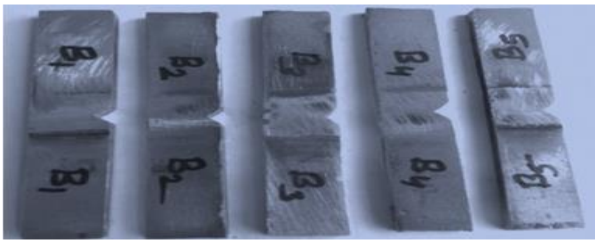

Fig. 3(b) MIG joints using ER309L filler metal specimen for impact test

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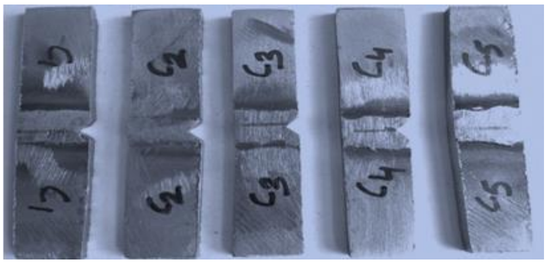

Fig. 3(c) MIG joints using ER430 filler metal Specimen for impact test

VI. METALLOGRAPHY

To examine the microstructure of AISI 430 ferritic stainless steel welds, specimens were cut to the required size from the joint comprising weld metal fusion zone, HAZ and base metal zone. Weld metal zone is the part melted during welding and retained in the weld. HAZ is the part of the parent metal that was not melted but metallurgically affected by the welding heat. These specimens were polished using different grades of emery papers ranging from 180 to 800 meshes. The final polishing was done by cloth polishing in the disc polishing machine using alumina powder. The specimens were etched by using a etchant which comprised a mixture of 6% concentrated $FeCl_3$, 18% concentrated HCl and water (H_2O) in the ratio 1:1:1, applied for 30 sec. Microstructural changes in the weldments were studied and recorded by optical microscope incorporated with image analysing software

VII. RESULT AND DISCUSSION

Tensile test result

Table 5(a), and 5(b) contain the tensile testing results obtained for weldments welded by ER309L and ER430 electrode respectively. Table 5(c) contains the tensile testing results of base metal.

Table 5(a): Tensile properties of MIG weldments using ER309L filler metal

S.N	Load In (N)	Thickness in (mm)	Width in (mm)	Area in mm^2	UTS in Mpa
1	14420.70	2.92	12.50	34.88	413.43
2	14813.10	2.97	12.78	36.30	408.07
3	15352.65	2.96	12.83	37.26	412.04
4	15303.60	3.00	12.92	37.54	407.66
5	14960.25	2.90	12.81	36.64	408.30
Average UTS (Mpa)					409.9

Table 5(b): Tensile properties of MIG weldments using ER430 filler metal

S.N	Load In (N)	Thickness in (mm)	Width in (mm)	Area in mm^2	UTS in Mpa
1	15254.55	2.96	12.83	37.97	401.75
2	15352.65	2.96	12.96	38.36	400.22
3	14715.00	2.93	12.37	36.24	406.04
4	15254.55	2.96	13.00	38.48	396.42
5	15303.60	3.00	12.84	38.52	397.28
Average UTS (Mpa)					400.34

Table 5 (c): Tensile properties of base metal

S.N	Load In (N)	Thickness in (mm)	Width in (mm)	Area in mm^2	UTS in Mpa
1	17265.60	2.92	12.50	36.50	473.03
2	17265.60	2.97	12.78	37.95	454.95
3	17412.75	2.96	12.83	37.97	458.59
4	17559.0	3.00	12.92	38.76	453.04
5	16873.20	2.90	12.81	37.14	454.31
Average UTS (Mpa)					458.84

Fig. 4 compares the UTS of welded joint of both types with the base metal. UTS of 409.9 MPa, 400.34 MPa and 458.89 MPa were found in case of austenitic, ferritic stainless steel filler wire and base metal respectively. Lower value of strength in case of ferritic stainless steel electrode may be due to grain coarsening and formation of martensite in heat affected zone. It was found that in both the welding conditions the specimens were broken at outside of fusion zone and HAZ. Hence it can be concluded that the joint efficiency of ferritic stainless steel welded joints is more than 100%.

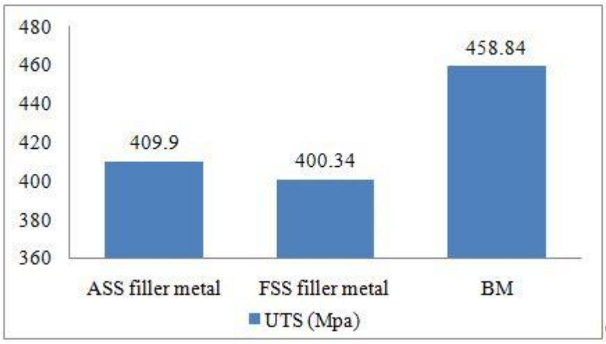

Fig. 4: Comparison of UTS value of weldments with base metal

VIII. PERCENTAGE (%) ELONGATION

Table 6(a) and 6(b) contain the data of percentage elongation of weldments for austenitic stainless steel electrode and ferritic stainless steel electrodes. Table 6(c) contains the data of percentage elongation of base metal

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Table 6 (a): Elongation of MIG weldments using ER309L filler metal

Sample	**Original gauge length (mm) B**	**Length after breaking (mm) A**	**Difference A - B (mm) C**	**% Elongation**
1	50	58	8	16
2	50	58	8	16
3	50	59	9	18
4	50	58	8	16
5	50	57	7	14
Average Elongation				16

Table 6 (b): Elongation of MIG weldments using ER430 filler metal

Sample	**Original gauge length (mm) B**	**Length after breaking (mm) A**	**Difference A - B (mm) C**	**% Elongation**
1	50	60.00	10.00	20
2	50	60.00	10.00	20
3	50	60.00	10.00	20
4	50	59.50	9.50	19
5	50	60.00	10.00	20
Average Elongation				19.8

Table 6 (c): Elongation of Base metal

Sample	**Original gauge length (mm) B**	**Length after breaking (mm) A**	**Difference A - B (mm) C**	**% Elongation**
1	50	61.50	11.50	23
2	50	61.00	11.00	22
3	50	60.50	10.50	21
4	50	59.50	9.50	19
5	50	59.50	9.50	19
Average Elongation				20.8

Fig. 5 compares the percentage elongation in all the three cases. It can be seen that the percentage elongation of ferritic stainless steel (FSS) filler metal welded joint is higher than the austenitic stainless steel (ASS) filler metal welded joint. But in both the cases elongation is less than base metal

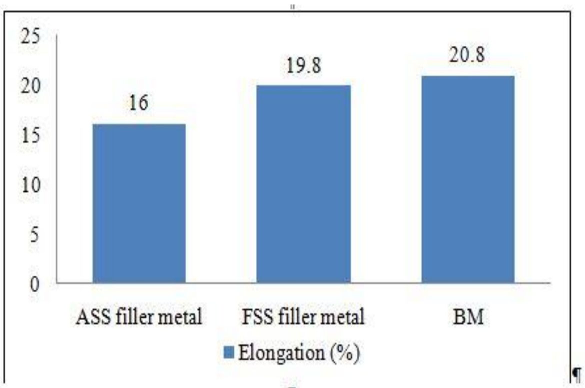

Fig. 5 Comparison of % of elongation of weldments with base metal

IX. TOUGHNESS TEST RESULTS

Table 7(a), 7(b) and 7(c) contain the data of toughness test for all the three conditions. Fig. 6 compares the results of toughness test. The impact strength of base metal was found 0.6980 J/mm^2. However, the impact strength of MIG joints using ER430 filler wire is 0.0176 J/mm^2. This indicates that there is a 97% reduction in the impact strength value due to filler wire ER430. Similarly, the impact toughness of MIG joints using austenitic filler wire is 1.3512 J/mm^2, which is 48% higher when compared to the base metal. Hence, it can be concluded that toughness of the welded joints can be increased by using austenitic stainless steel filler metal.

Table 7(a): Notch impact strength of weldments welded by ER430 filler metal

Sample no.	**Energy absorbed K, (joule)**	**C/S area at notch A, (mm^2)**	**Impact strength I = K/A (J/mm^2)**
1	0.588	8.06×2.96 = 23.86	0.0246
2	0.392	8.43×2.94 = 24.78	0.0158
3	0.196	8.06×2.98 = 24.01	0.0081
4	0.392	8.46×3 = 25.38	0.0154
5	0.588	8.13×2.97 = 24.15	0.0243
Avg. value	0.431	24.43	0.0176

Table 7(b): Notch impact strength of weldments welded by ER309L filler metal

Sample no.	**Energy absorbed K, (joule)**	**C/S area at notch A, (mm^2)**	**Impact strength I = K/A (J/mm^2)**
1	23.05	8.43×2.92 = 24.61	0.9366
2	38.25	8×2.94 = 23.52	1.6262
3	39.24	8.26×2.93 = 24.20	1.6214
4	31.39	8.56×2.90 = 24.82	1.2647
5	31.39	8.06×2.98 = 24.01	1.3073
Avg. value	32.66	24.23	1.3512

Table 7(c): Notch impact strength of base metal

Sample no.	Energy absorbed K, (joule)	C/S area at notch A, (mm^2)	Impact strength I = K/A (J/mm^2)
1	19.62	8.2×2.94 = 24.10	0.8141
2	16.77	8.36×2.99 = 25	0.6708
3	15.99	8.6×2.93 = 25.19	0.6347
4	14.42	8.06×3.0 =24.18	0.5963
5	19.32	8.43×2.96 = 24.95	0.7743
Avg. value	17.22	24.68	0.6980

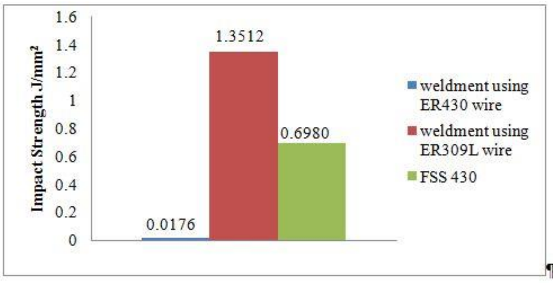

Fig 6: Comparison of toughness value of weldments with base metal

X. HARDNESS TEST RESULTS

Table 8(a) contains the data of hardness across fusion zone for both the type of weldments. Table 8(b) contains the data of hardness of base metal.

Table 8(a) Hardness value across fusion zone of weldments

SI. NO	Vickers hardness numbers (HV	
	ER309L MIG joints	ER430 MIG joints
1	223	239
2	241	251
3	236	244
Avg. value	233.3	244.6

Table 8 (b) Hardness value of base metal

SI. NO	Vickers hardness numbers (HV
1	212
2	208
3	210
Avg. value	210

Fig. 7 compares the hardness value of fusion and base metal zone of the weldments. Hardness value of the welded joints was found more than the value of base metal. This increment in hardness value could be mainly due to the formation of martensite in the fusion zone and HAZ of the weldments.

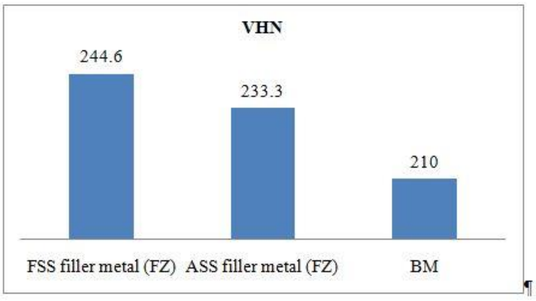

Fig.7: Comparison of Hardness value across different region of weldments

XI. MICROSTRUCTURAL EVALUATION

Evaluation of microstructure of MIG welded ferritic stainless steel weldments were done using both the types of electrodes and compared with the base metal. Fig. 8(a) shows microstructure of hot rolled base metal consists of ferrite matrix in longitudinal direction containing elongated layers of martensite. Fig. 8(b) shows the microstructure of fusion zone (FZ), heat-affected zone (HAZ) and base metal of the weldment using ER430. It has been observed that the grain growth took place from the edge of the heat-affected zone (HAZ) to the fusion boundary after welding and some amount of martensite were also found. Grains size and morphology were very different in the fusion and heat affected zone as compared to base metal zone. Fig. 8(c) shows the microstructure of fusion zone (FZ) of the weldment using ER430 electrode. Due to presence of C and N, some amount of martensite at the grain boundary and intergranular precipitates were found within the fusion zone. Fig. 8(d) shows the microstructure of fusion zone (FZ), heat-affected zone (HAZ) and base metal of the weldment using ER309L as filler metal. It consists of some amount of martensite in heat-affected zone (HAZ). Carbide precipitates was also found within the HAZ. Grains size was very different in the fusion zone and heat-affected zone as compared to base metal zone. Fig. 8(e) shows the dendritic grain growth and austenite phase within fusion zone (FZ). Fusion zone (FZ) shows the austenitic phase due to use of austenitic stainless steel as filler metal.

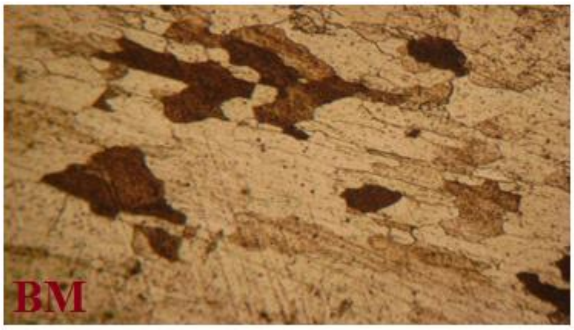

Fig. 8(a) Microstructure of base metal (100×)

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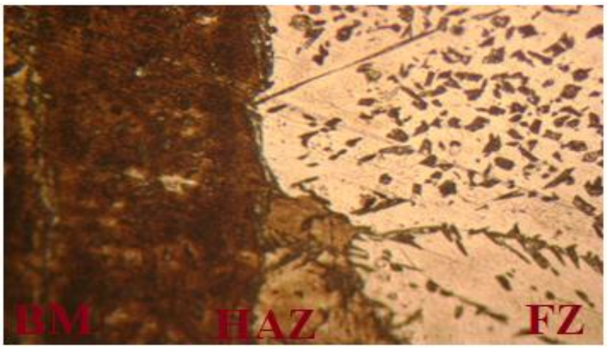

Fig. 8(b) Microstructures of HAZ using ER430 filler metal in MIG welds (100×)

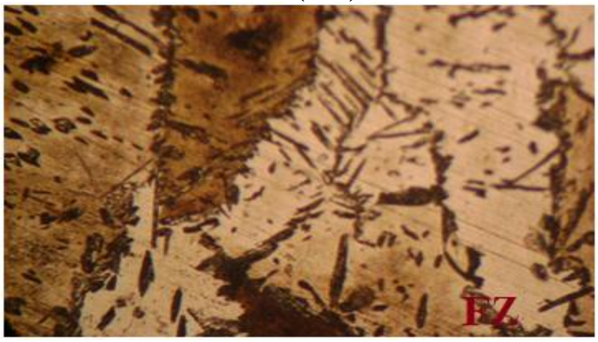

Fig. 8(c) Microstructures of fusion zone using ER430 filler metal in MIG welds (100×)

Fig. 8 (d) Microstructures of HAZ using ER309L filler metal in MIG welds (100×)

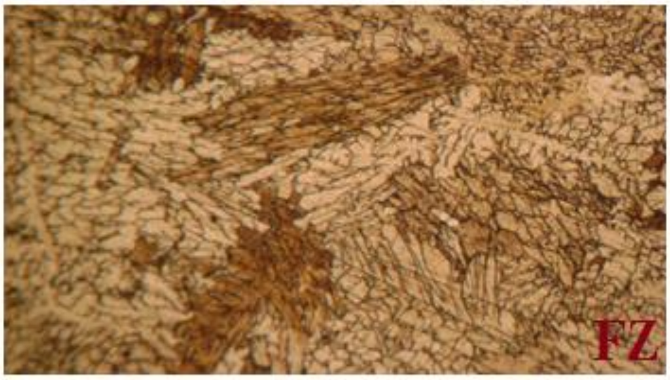

Fig. 8(e) Microstructures of fusion zone using ER309L filler metal in MIG welds (100×)

XII. CONCLUSION

Based on the experimental results obtained from the different welding conditions,the following conclusions may be drawn.

1. The fusion boundary and heat affected zone of the AISI 430 stainless steel weldments using ER430 electrode exhibit significant grain growth with respect to the base metal that affect the mechanical properties, especially toughness of the weldments.
2. Under the tensile testing, weldments broken outside the welded joint; hence, efficiency of the joints can be considered more than 100%. This indicates the good quality by welded joints can be obtained in case of welding of ferritic stainless steel.
3. The impact strength of the welded joints produced by using austenite filler wire found to be more than the base metal. The joints welded by using ER430 filler wire exhibited lower impact strength and the reduction in impact toughness value was 75% when compared with the base metal. Lower value of impact strength may be due to excessive grain coarsening and the formation of martensite and other precipitates at grain boundaries of the weldments.
4. The hardness value of the welded joint was found to be more than the value of base metal. This increment in hardness value could be mainly due to the formation of martensite in the fusion zone and HAZ of the weldments.

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[5] ASM Handbook, Vol. 8, Mechanical Testing, 9th edition, p 30-466.