Effect process parameters in TIG/MIG welding on the mechanical properties and corrosion behaviour of dissimilar welded DSS/HSLA steel

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Abstract: The metallurgical factors controlling dissimilar metal weld is more challenging and intricate than similar welding due to the necessity of obtaining required mechanical properties with desired microstructure for marine applications. The fundamental reason for this exploration work is to study the tensile behaviour and Tafel polarisation of dissimilar weld between duplex stainless steel (DSS) and HSLA steel, to establish a sound weld free from weld discontinuities for distinctive welding parameters common for two TIG and MIG welding systems. The dissimilar DSS and HSLA steel are welded with TIG and MIG welding process using a single-V groove test specimen; with angle of 70°, face root and root gap is kept at 1 mm. E309L-16 filler rod is used for TIG welding and E304l filler wire is used for MIG welding. The feller metals are selected based on the best matching suitable chemical compositions for welding dissimilar metals. The mechanical properties are evaluated by microhardness and tensile test. Potentiostat is used for plotting Tafel plot to indicate the corrosion behaviour of dissimilar weldments.

Keywords: dissimilar welding; TIG/MIG welding; duplex stainless steel; DSS; high strength low alloy steel.

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1 Introduction

Duplex stainless steel (DSS) has microstructure that consists of austenitic and ferritic grains in equal proportion or in different fraction based on the chemical composition. The two-phase microstructure guarantees improved mechanical properties, higher resistance to pitting and stress corrosion cracking in comparison with conventional stainless steels (Gunn, 1997; Muthupandi et al., 2003). DSS is originally created for high strength, to combat corrosion problems caused by chloride-bearing cooling waters and other aggressive chemical process fluids. Owing to their interesting properties, these steels are in application in oil and gas industries (Charles, 1991).

HSLA steels are micro-alloyed steels having interstitial in very low concentrations and they inhabit a significant presence in overall steel production in the world (Sharma and Maheshwari, 2017). HSLA steels have excellent strength combined with superior formability partake to special acceptance in petrochemical and transportation industries. The transportation industries are the principal users of HSLA steels. The HSLA steel contains vanadium, niobium and or titanium in amounts at least an order magnitude smaller than the amounts of the normal alloys in alloy or low alloy steels. In-spite of the low levels of alloying elements these HSLA steel can cause major strength and toughness improvements. The evident economic advance associated with using such small additions of alloying elements together with the significant benefits to mechanical properties is the reasons for the acceptance of HSLA steels in the commercial automotive industry and these steels were major mainstay for the US automotive industry to reduce weight without losing strength (Skobir, 2011).

With the expanding employment of new materials and higher requests for such materials, an overwhelming need emerges for the part or structure of with unique dissimilar materials with specific properties superior than the individual materials. The increasing application needs of new materials and higher demands for such materials, a great need arises for the component or structure of different materials. Dissimilar joint of DSS and HSLA steel channels have been generally utilised in the oil and gas industry (Kotecki and Lippoid, 2005). Higher temperature input increased the corrosion resistance due to the presence of higher austenite in the grain boundaries, Widmanstatten austenite and low content of inter granular austenite in heat affected zone and weld deposition area when compared to low temperature input (Verma et al., 2017). Many research works have been done on the topic of microstructural developments, weldability behaviour and the response of mechanical property during dissimilar welding of DSS and HSLA steel. It is shown that in heat affected zone of high strength low alloy steel two different phases are formed for low and high heat input and it also had significant influence on the mechanical property of the base metals. In concise, the filler metal and applied heat input which is not appropriate for GTAW welding procedure for dissimilar metal joining SDSS and HSLA steel is reported (Sadeghian et al., 2014).

The effect of surface hybrid composite by the inclusion of graphite and silicon carbide into the base matrix of AA7075 was investigated. The tensile strength was greatly improved by the addition of these particles along with the improved corrosion resistance (Periasamy et al., 2019). The performance of double phase nanocrystalline Al_{20} Mg_{20} Ni_{20} Cr_{20} Ti_{20} high entropy alloy was studied for its thermal stability. The resistance towards structural deformation under high temperature condition was improved by about 12.5%. The silicon carbide addition to the aluminium alloy base matrix was studied for its wear resistance (Godwin Antony et al., 2018). The addition of titanium with the above mentioned composites have been a great aid in reducing the wear of proposed composite through 6.87% while testing on pin-on-desk apparatus. The synthesis of SiO_2 through easiest route was decided to be sol-gel technique (Saravanan et al., 2019). The better amount of austenite phase enhanced the localised corrosion resistance mostly in the melted region. It is due to reduction of ferrite phase fraction and creation of bigger grains, for higher heat input (Lopes et al., 2018). The effect of the filler metal is noticeably perceived in the microstructure of the weld metal and HAZ where high austenite phase is attained, but is significant to consider the effect of the thermal cycles of the multi-pass weld which assists the austenite restructuring (Mendoza et al., 2010). The process had improved the tool strength that is validated by the application of DOE concept. Advanced DOE methodologies like RSM and fuzzy logic concepts may be used for further analysis of process parameters (Srivastava et al., 2018). The ferrite number of the welded specimens made by different electrodes shifts somewhere in the range of 0.5 and 9.5. It is discovered that the expansion in measure of δ ferrite in the microstructure of the weld metals causes the reduction in the impact energy of the welded specimens (Khalifeh et al., 2013). Dissimilar joints made using the explosive welding are satisfactory, as the joints possess acceptable ductility during bend test; however, corrosion rate is high and it is acceptable as corrosion attack is on the stainless steel portion of the joint (Kamachi Mudali et al., 2003). They have identified and presented the influencing process parameters in their report.

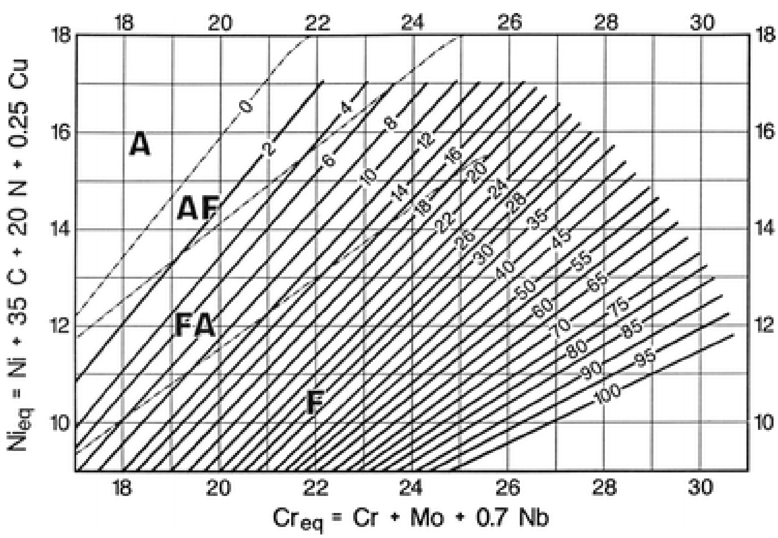
The preferential attack occurred in the ferrite and in the boundary interfaces between austenite and ferrite of HAZ. Some chromium nitride precipitates also formed in the similar location after welding (Shi et al., 2018). The reinforcement particle additions have proved improved corrosion resistance in AA2024-B_4C-TiC MMCs (Muthusamy and Pandi, 2018). Cadmium electroplated plated dissimilar welds proved to be superior in corrosion resistance up to 96 hrs in salt spray atmosphere (Shabir et al., 2014). The maraging steel grade 250 was laser welded with three different heat inputs and the welded samples were heat treated at six different temperatures (Karthikeyan et al., 2017). As a proposed joining method FSBR has been proven to be a quick process for making similar and dissimilar joints of aluminium alloys and copper (Bothiraj and Saravanan, 2018). Based on the literature survey on TIG/MIG, it is concluded that using higher welding speed with higher current enhance the mechanical properties of the weld metal and welding speed seriously affects the bead geometry of welded joints (Agrawal et al., 2017). The major application of DSS/HSLA steel alloy goes into an application where corrosion is a major concern in the marine service conditions.

Therefore, a research program has been formulated to examine the effect process parameters in TIG/MIG welding on the mechanical properties and corrosion behaviour of dissimilar welded DSS/HSLA steel. A rigorous analysis of the experimental data on mechanical and corrosion properties is done and finally an acceptable conclusion was made.

2 Experimental details

The base materials employed in this research are UNS S32205 DSS and high strength low alloy steel-HSLA 950C. The chemical conformations of the UNS S32205 DSS and high strength low alloy steel-HSLA 950C are exposed in Table 1. The chemical composition of base material was appropriately selected based on the Schaeffler phase prediction for Ni and Cr equivalent and Pseudo-binary phase diagram based on WRC-1992 equivalent relationships 37 s to avoid the effect of undesirable phase transformations on the mechanical property of weldments. The Schaeffer diagram for stainless steels and Pseudo-binary phase diagram based on WRC-1992 equivalent relationships 37 s is shown in Figures 1 and 2. The chemical composition of welding electrodes hired is shown in Table 2.

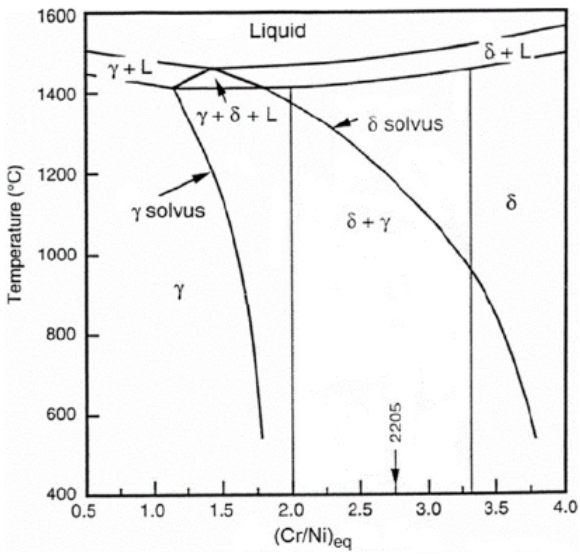
Figure 1 Schaeffler diagram for predicting phase formation in stainless steels



Source: Kell et al. (2005)

The plates with dimensions 200 × 150 × 10 mm were prepared for the test experiment. A single V-shape groove is made with angle of 70° by using milling machine, the root face and root opening value was kept as 1 mm. Weld tracking was done for proper positioning, alignment and to combat welding distortion during weld deposition. Two types of welding techniques TIG and MIG were utilised for joining DSS and HSLA steel.E309L-16 filler rod was used for TIG welding of DSS and HSLA steel. For MIG welding, E304l filler wire was used for joining the DSS and HSLA steel at 1 G position (welding of plate in horizontal or flat position). TIG and MIG welding was concluded for three passes. Commercial pure argon gas was utilised for the purpose of shielding the base alloys and to overcome contamination problems in weld bead. After TIG and MIG welding process the surface of weld bead was well ground with the help of disk grinder to remove slag from the surface before starting next pass. Slag from all over the surface of first and second pass was first chipped off before starting next pass.

Figure 2 Pseudo-binary phase diagram based on WRC-1992 equivalent relationships 37 s



Source: Xavier et al. (2015)

Table 1 Chemical composition of UNS S32205 DSS and HSLA 950C

UNS S32205 DSS								
Grade	*EN no./UNS*	*Chemical composition*						
		Cr	*Ni*	*Mo*	*N*	*Mn*	*W*	*Cu*
2205	S32205	22	5.7	3.1	0.17	-	-	-
HSLA 950C								
Grade		*Chemical composition*						
		C	*Mn*	*P*	*S*	*Si*	-	-
SAE 950C		0.25	1.60	0.04	0.05	0.90	-	-

Table 2 Chemical composition of welding electrodes

Grade	*C*	*Mn*	*Si*	*S*	*P*	*Cr*	*Ni*	*Mo*	*Cu*
E304l	≤0.04	0.5–2.5	≤0.9	≤0.03	≤0.04	18–21	9–11	≤0.75	≤0.75
E309L-16	0.04 max	0.5–2.5	0.90 max	0.03 max	0.04 max	22.0–25.0	12.0–14.0	0.75 max	0.75 max

Welded plates were machined by the milling machine to prepare different samples for mechanical testing, during the milling operation coolant was applied continuously to avoid the overheating of welded area of specimens and to avoid undesirable phase transformations in the microstructures. Rockwell micro hardness and tensile test was performed along the cross plane of the welded sample. Hardness measurement was done at randomly selected locations nearby for each sample and the average value is reported. Surface morphology characterisation was carried out by scanning electron microscope (SEM) and EDAX was taken in the centre of the weld zone. Confined chemical characterisation was attained by an energy dispersive X-ray spectroscopy. Tafel plot was plotted by potentiostat in the centre of weld zone for both TIG and MIG welded samples.

3 Results and discussion

In any arc welding process, the welding speed and voltage or the heat input during the welding process plays a very considerable role in deciding the weld microstructure and mechanical properties. Based on the inputs from literatures two different welding parameters, i.e., voltage and welding speed was taken for this study. The welding parameters and procedure nominated for welding of DSS and HSLA steel is shown in Table 3. Mechanical properties were evaluated by tensile test done uniformly for four parameters in TIG and MIG welded samples. The samples were made flat by surface grinding and weld cap on the top and bottom side of the plate were removed before the tensile testing. The photograph and schematic of samples prepared for tensile test is shown in Figures 3 and 4. The test specimen dimensions are shown in Table 4. The grips used in the UTM were properly saw-toothed so that there was no change of slippage of the specimen during the test. The specimens were properly aligned uniformly during all the tests. If any specimen breaks in the middle of the test due to any other reason; the tensile test is discarded, other tensile test specimen was taken and the test procedure was repeated. The thickness and dimension of tensile specimen was prepared according to the ASTM standards detailed for macro tensile test.

Table 3 Welding parameters for TIG and MIG welding

S. no.	*Welding process and specimen ID*	*Welding parameters*		
		Voltmeter (V)	*Current (A)*	*Welding speed (m/s)*
1	TIG (T1)	23	110	70
2	TIG (T2)	24	120	76
3	MIG (M1)	23	110	70
4	MIG (M2)	24	120	76

Figure 3 Schematic diagram of tensile specimen

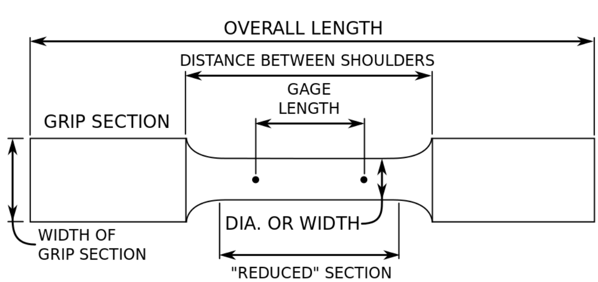


Table 4 Tensile test specimen dimensions

Specimen thickness (T)	10 mm
Gauge length (L)	115 mm
Head (or) specimen width (WO)	20 mm
Total length (LO)	300 mm
Radius at shoulder (R)	35 mm

Figure 4 Photograph of samples for tensile test (see online version for colours)

Table 5 Tensile test results for dissimilar TIG welded DSS/HSLA steel

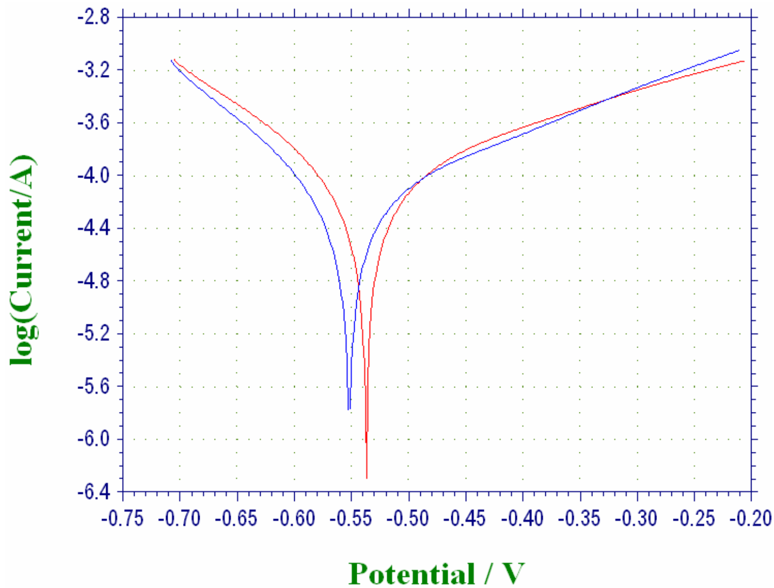
S. no.	*Welding process and sample ID*	*Tensile test results*	*(T1)*	*(T2)*
1	TIG (T1 and T2)	Load of yield (kN)	78	55
		Yield stress (N/mm^2)	436	280
		Tensile strength (N/mm^2)	538	350
		Load at break (kN)	92	27
		% elongation	21	30

Table 6 Tensile test results for MIG welded DSS/HSLA steel

S. no.	*Welding process and sample ID*	*Tensile test results*	*(M1)*	*(M2)*
1.	MIG (M1 and M2)	Load of yield (kN)	56	74
		Yield stress (N/mm^2)	280	413
		Tensile strength (N/mm^2)	350	537
		Load at break (kN)	28	71
		% elongation	30	17

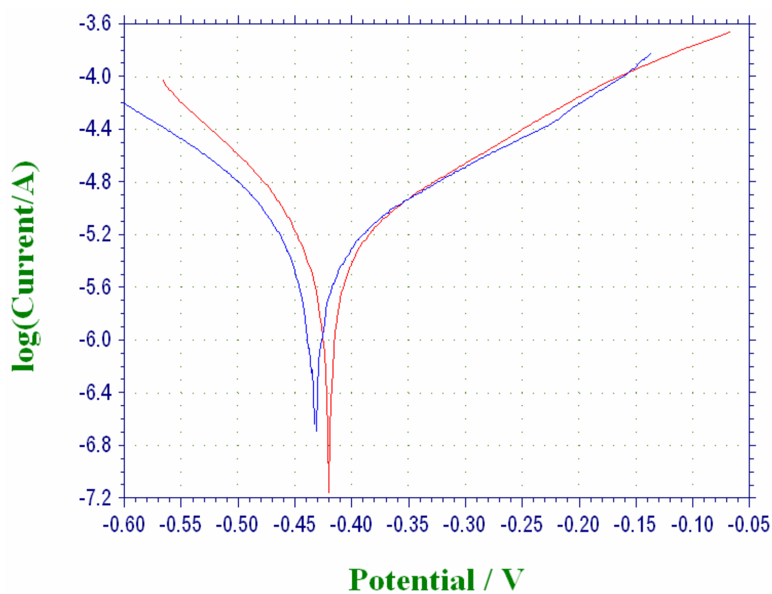
The tensile test values for TIG and MIG dissimilar DSS/HSLA steel welded specimens for two different weld parameters is shown in Tables 5 and 6. The mechanical behaviour of the weld joints were appraised by simple tensile test. Weld parameter T1 and M2, the tensile strength obtained maximum value with adequate elongation and it was due homogeneous weld formation, free of weld discontinuities. The strength obtained was due to good solubility of alloying elements in the weld zone and that circumvented the formation of brittle intermetallic and it can lead to brittleness of the weldment.

Figure 5 Tafel plot for TIG welded dissimilar materials (see online version for colours)



Note: Red: weld parameter T1 and blue: weld parameter T2.

Figure 6 Tafel plot for MIG welded dissimilar materials (see online version for colours)



Note: Red: weld parameter M1 and blue: weld parameter M2.

Table 7 gives the corrosion current, in A cm^{-2} and corrosion potential, in mV for the two welding techniques and process parameters. It is observed for both the welding techniques; the corrosion current is less and potential is more for the process parameter T2 and M2. The chemical composition formed in the weld zones for process parameter T2 and M2 evidently improve the corrosion resistance of the weldments. The Tafel plots for TIG and MIG welding for welding parameters T1, T2, M1 and M2 is shown in Figures 5 and 6. The Tafel plot for TIG and MIG welded DSS/HSLA steel for two different process conditions shown in the Figure 7. Among the two welding techniques MIG welded DSS/HSLA steel considered for notable corrosion resistance than the TIG welded DSS/HSLA steel. The very high susceptibility for more corrosion in TIG welded specimens is attributed to slow surface passivation and deprived passive film stability.

Figure 7 Tafel plot for TIG and MIG welded DSS/HSLA steel for two different process conditions (see online version for colours)

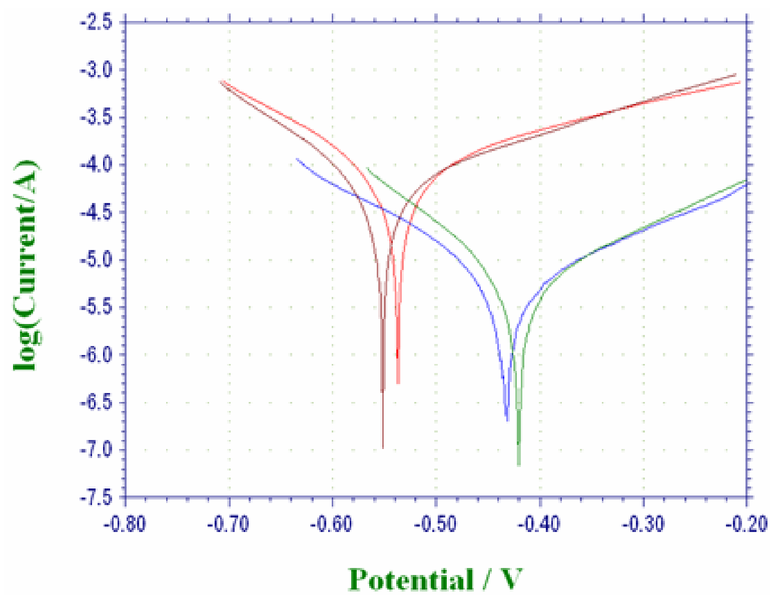


Table 7 Corrosion test results for TIG and MIG welded DSS/HSLA steel

S. no.	*Welding process and specimen ID*	*Corrosion potential (mv)*	*Corrosion current (A cm^-2)*
1	TIG (T1)	–537	85.68 * (10^-6)
2	TIG (T2)	–552	67.09 * (10^-6)
3	MIG (M1)	–420	63.4 * (10^-6)
4	MIG (M2)	–432	62.85 * (10^-6)

Figures 8 and 9 shows the SEM micrographs of the TIG weld beads at low magnification obtained for welding parameters T1 and T2. The chemical composition of the weld beads was confirmed by EDAX. Neither solidification cracking nor intermetallic phase nor inclusions was detected in the weld bead for both welding parameters.

Figures 10 and 11 shows the SEM micrographs of the MIG weld beads at nominal magnification obtained for welding parameters M1 and M2. There were no visual weld discontinuities was seen in both the processes conditions. The EDAX results confirmed that there was no oxidation took during the both TIG/MIG welding and the shielding was very adequate to prevent oxidation and related loss in the mechanical properties.

Figure 8 SEM micrograph of interface of TIG weld DSS-HSLA steel (welding parameter-T1) (see online version for colours)

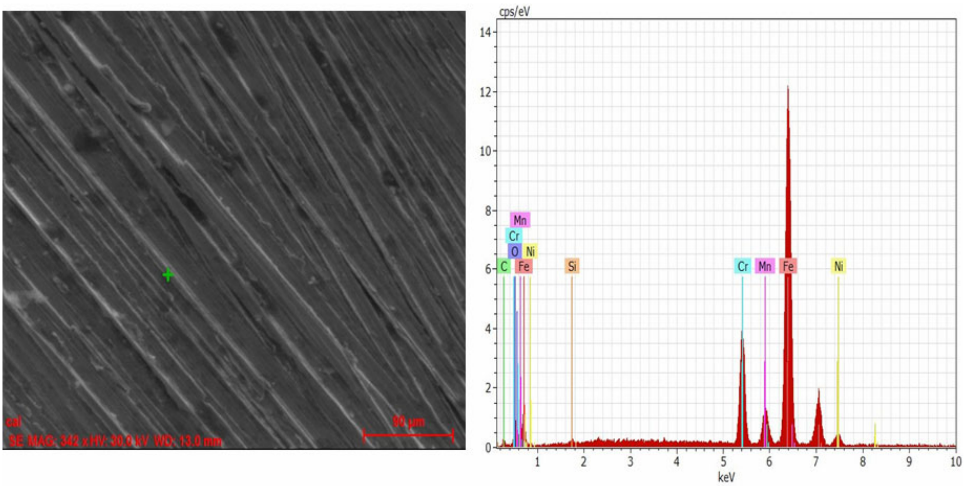


Figure 9 SEM micrograph of interface of TIG weld DSS-HSLA steel (welding parameter-T2) (see online version for colours)

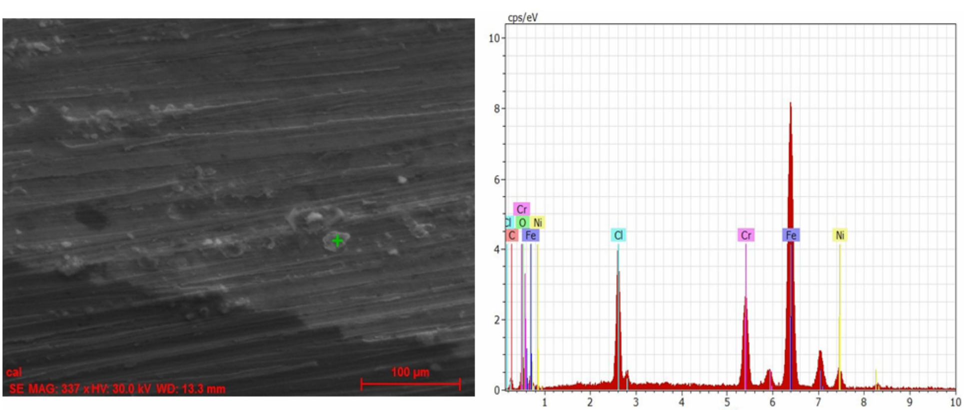


Figure 10 SEM micrograph of interface of MIG weld DSS-HSLA steel (welding parameter-M1) (see online version for colours)

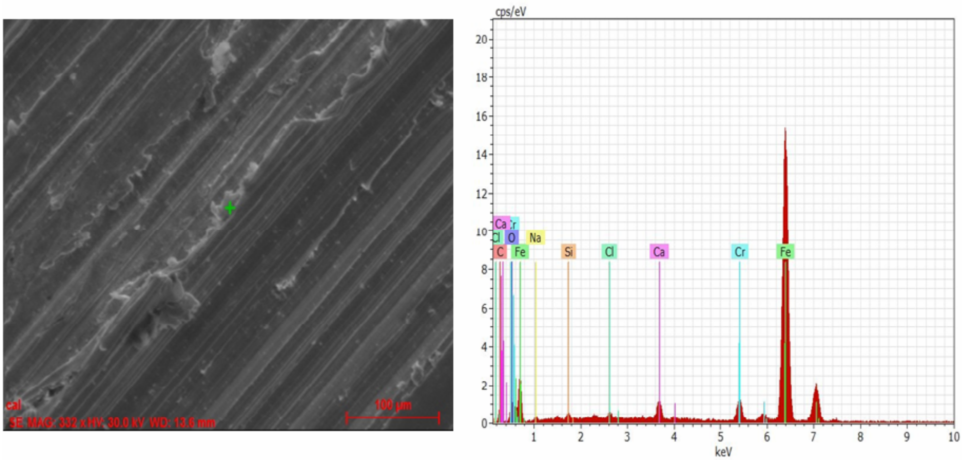
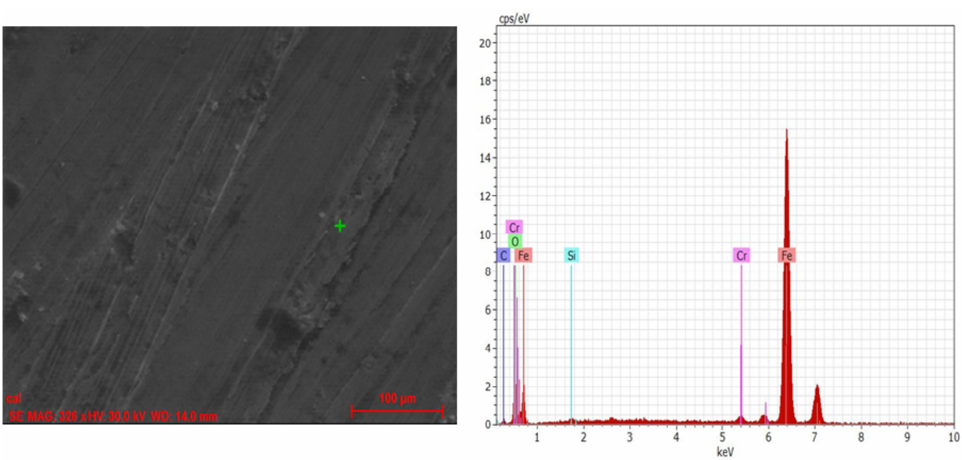


Figure 11 SEM micrograph of interface of MIG weld DSS-HSLA steel (welding parameter-M2) (see online version for colours)



4 Conclusions

The study on TIG and MIG welding between DSS and HSLA steel at two different welding parameters touched the following conclusions:

- it was concluded that MIG welds possess greater corrosion resistance as compared to the TIG welds

- the chemical composition formed in the weld zones for process parameter T2 and M2 evidently improve the corrosion resistance of the weldments
- for weld parameter T1 and M2, the tensile strength obtained maximum value with adequate elongation
- neither solidification cracking nor intermetallic phase nor inclusions was detected in all the weld bead for both welding technique and parameters
- the energy dispersive spectroscopy results confirmed that there was no problem of oxidation for the both TIG/MIG welding and the defending atmosphere was very adequate to prevent oxidation and related loss in the mechanical properties.

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