Comparative Studies on microstructure, mechanical and corrosion behaviour of DMR 249A Steel and its welds

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Abstract.DMR249A Medium strength (low carbon) Low-alloy steels are used as structural components in naval applications due to its low cost and high availability. An attempt has been made to weld the DMR 249A steel plates of 8mm thickness using shielded metal arc welding (SMAW) and gas tungsten arc welding (GTAW). Welds were characterized for metallography to carry out the microstructural changes, mechanical properties were evaluated using vickers hardness tester and universal testing machine. Potentio-dynamic polarization tests were carried out to determine the pitting corrosion behaviour. Constant load type Stress corrosion cracking (SCC) testing was done to observe the cracking tendency of the joints in a 3.5%NaCl solution. Results of the present study established that SMA welds resulted in formation of relatively higher amount of martensite in ferrite matrix when compared to gas tungsten arc welding (GTAW). It is attributed to faster cooling rates achieved due to high thermal efficiency. Improved mechanical properties were observed for the SMA welds and are due to higher amount of martensite. Pitting corrosion and stress corrosion cracking resistance of SMA welds were poor when compared to GTA welds.

1. Introduction

DMR 249A steel is one of the prestigious grade of steel and developed indigenously for structural applications in hull and body of warships and submarines [1,2]. Medium strength (low carbon) Low-alloy steels exhibit excellent mechanical properties and are extensively used in offshore applications and construction/repair of naval ships, where corrosion resistance against marine environment is significantly required. Poor corrosion resistance of low alloy steel fails the entire ship during the service. DMR 249A steels have high strength and are easy to weld [3,4]. Conventional fusion welding processes i.e., gas tungsten arc welding (GTAW), submerged arc welding (SAW) are used for construction and fabrication of naval ships and bridges [5]. For onsite repairs of ship body and hulls are manually welded using shielded metal arc welding process[6]. Studies on the stress corrosion cracking (SCC) behavior of HSLA steel showed high susceptibility to stress corrosion cracking and due to high strength [7,8]. The welding process may lead to change in the original microstructure of the alloy due to welding thermal cycles which can affect the localized corrosion behavior of the alloy. During welding, it resulted in some amount of welding defects during welding and residual stresses in welded components [9]. Thus a risk of stress corrosion cracking (SCC) will occur during service. The main hazardous risk is that SCC always causes unexpected brittle failures without any externally visible indication, which will significantly restrict its application in the marine environment. Cathodic protection system has been used to protect the HSLA steel from corrosion and improve service life in the offshore and naval ships. In view of the above problems, an attempt has been made to study on DMR249A steel welds and to compare and correlate the microstructural changes with observed mechanical properties and corrosion resistance for the DMR 249A steel welds made with shielded metal arc welding (SMAW) and gas tungsten arc welding (GTAW) process.

2. Experimental Details

DMR 249A Low alloy steel plates of 300X150X8mm^3 were used in the present study. Chemical composition of the base metal and filler wire/electrode are given in Table 1. Welds made with Shielded metal arc welding (SMAW) and Gas Tungsten arc welding (GTAW) are shown in Fig.1. Microstructure studies were characterized at various zones of the welds using optical microscopy. Micro-hardness measurements were carried out with a load of 0.5Kgf for 20 seconds along the longitudinal directions of the weld as per ASTM E384-09. Tensile testing is carried out using a universal testing machine at room temperature as per ASTM-E8. Pitting corrosion resistance of base metal and welds were determined using potentio-dynamic polarization testing in 3.5%NaCl solution using a basic electrochemical system. Constant load Stress corrosion cracking (SCC) testing was carried out with applied stress of 50% yield strength and in 3.5% NaClsolution.

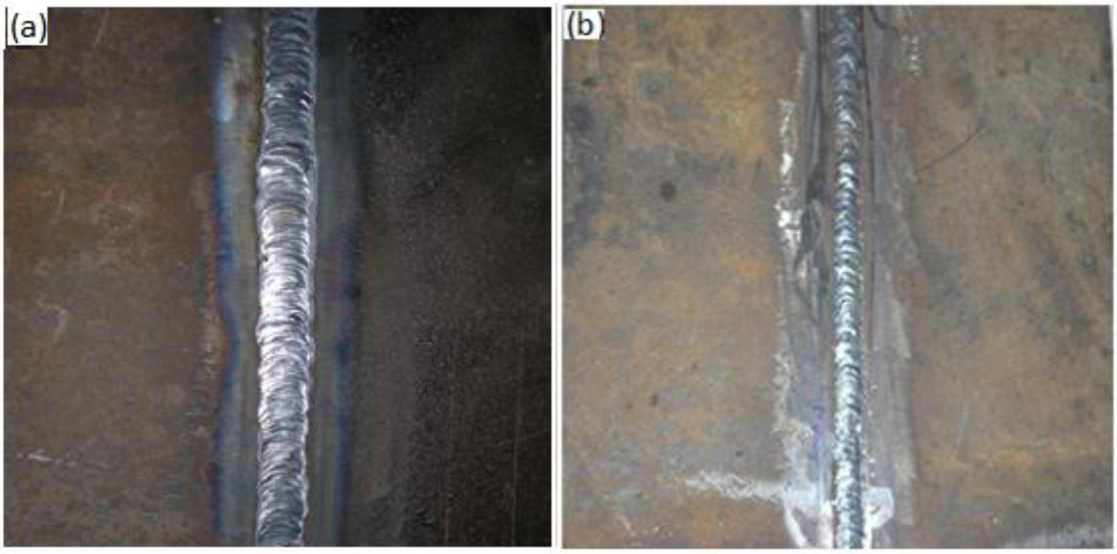

Fig. 1 DMR 249A steel welds made with (a). SMAW and (b). GTAW

Table.1 Chemical composition of DMR 249A Steel and Filler/Electrode

Material	C	Cr	Ni	Mn	Si	S	P	Mo	Cu	V	Al
DMR 249A	0.095	0.30	1.05	1.5	0.29	0.007	0.01	-	0.45	0.05	0.04
Filler wire/Electrode	0.039	-	2.15	0.91	0.22	0.028	0.015	-	-	-	-

3. Results and Discussions

3.1. Microstructural Studies

Optical microstructure of the different regions of the base metal and its welds made with SMAW and GTAW are shown in Figs.2& 3. Base metal microstructure consists of ferrite and pearlite whereas weld region was found to have martensite in both the welds which may be due to fast cooling rates during welding. However HAZ region consisted of partly bainite and martensite in both the welds. Base metal has a fine grain structure whereas weld region and HAZ region are coarse dendritic grain structure. So weld and HAZ regions resulted in having more tendencies to crack formation. SMAW welding process has a high heat input and thermal efficiency than GTAW welding process. High thermal efficiency of SMAW results in faster cooling rate during welding and solidification when compared to GTAW process. Formation of martensite in the weld region is mainly due to faster cooling rate of welding processes and more amount of martensite is formed in SMAW welds when compared to that of GTA welds.

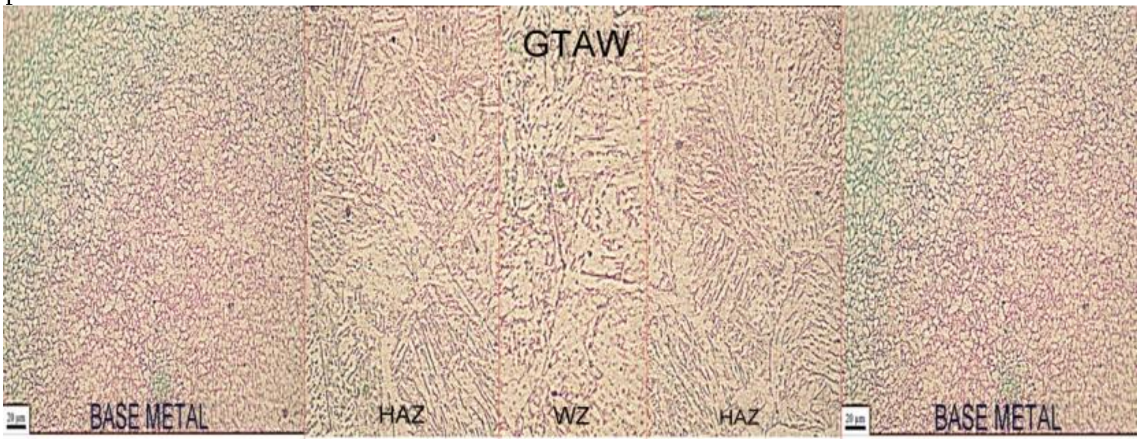

Fig 2 Optical Microstructures of different regions of DMR 249A steel and its GTA welds

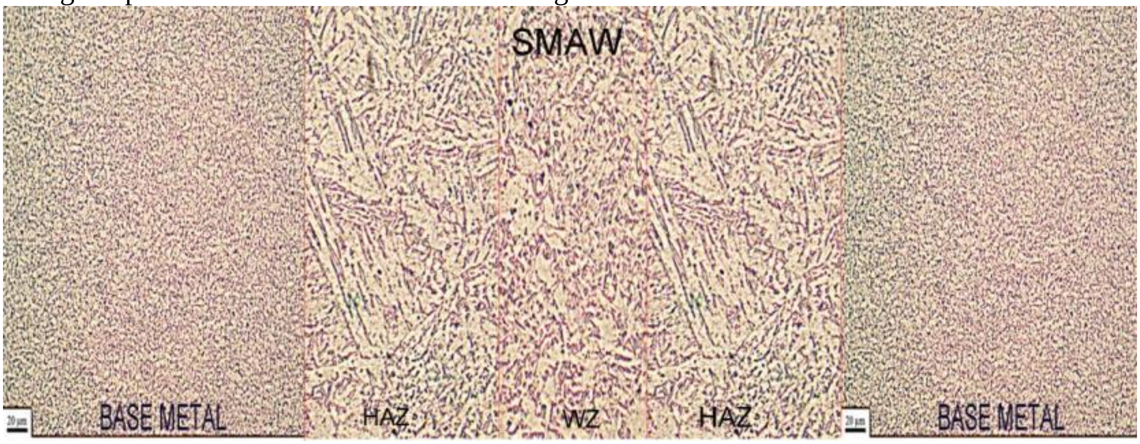

Fig 3OpticalMicrostructures of different regions of DMR 249A steel and its SMA welds

3.2. Hardness Studies

Hardness testing (VHN) results of the welds are given in Table2. In the weld region hardness of GTAW is slightly lower than that of SMAW. In the HAZ region, hardness in SMAW is slightly higher than that of GTAW. In both welds, hardness of weld region is much higher when compared to base metal. This may be attributed to the observed martensite formation in the weld region. HAZ hardness was found to be lower than weld region mainly because of bainite and tempered martensite. Relatively higher hardness of SMAW welds is due to more amount of martensite which forms because of faster cooling rate.

Table 2 Average Vickers Hardness values of various zones of DMR 249A welds.

Zone/Region	SMAW	GTAW
Base Metal	167 VHN	167 VHN
HAZ	201 VHN	204 VHN
Weld Zone	216 VHN	210 VHN

3.3. Tensile studies

Failed tensile specimens are shown in the Figs. 4-6. Both the welds failed in HAZ region. Stress-strain curves were shown in Fig. 7. Tensile testing data is given in Table 3. Tensile strength of the SMAW is observed to be higher than that of base metal and GTA Welds. Improvement in strength may be correlated with observed microstructure. Similarly yield strength value of SMAW is higher than that of base metal and GTAW.

Table 3 Tensile test data of DMR 249A low alloy steel welds

S.No	Material	Tensile Strength (MPa)	Yield Strength(MPa)	% Elongation
1	BASE METAL	605.49	400	39.06
2	SMAW	652.67	430	45.93
3	GTAW	550.67	410	31.33

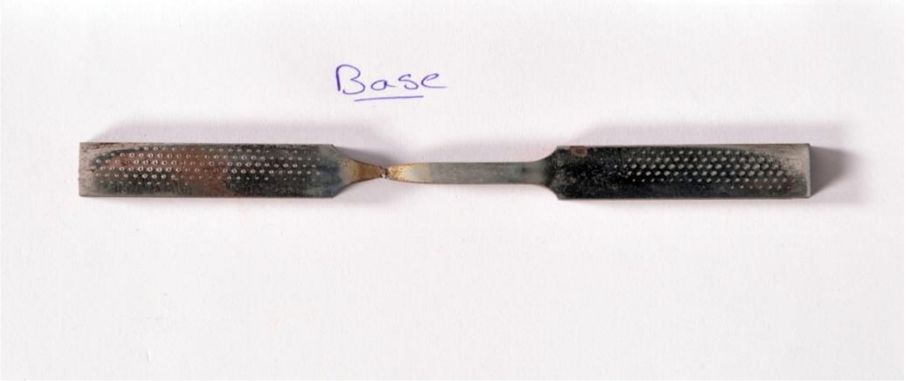

Fig. 4 Failed tensile specimen of Base metal (DMR 249A)

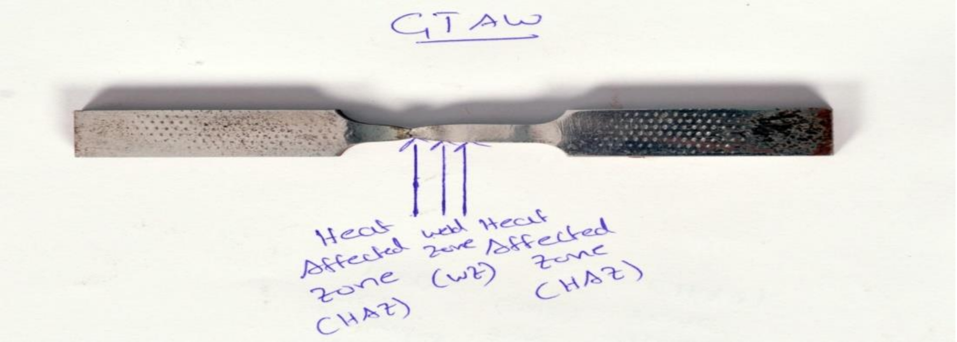

Fig. 5 Failed tensile specimen of DMR 249A GTA weld

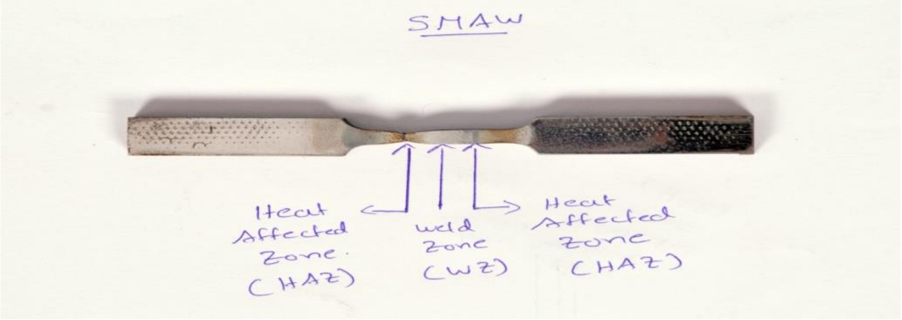

Fig. 6 Failed tensile specimen of DMR 249A SMA weld

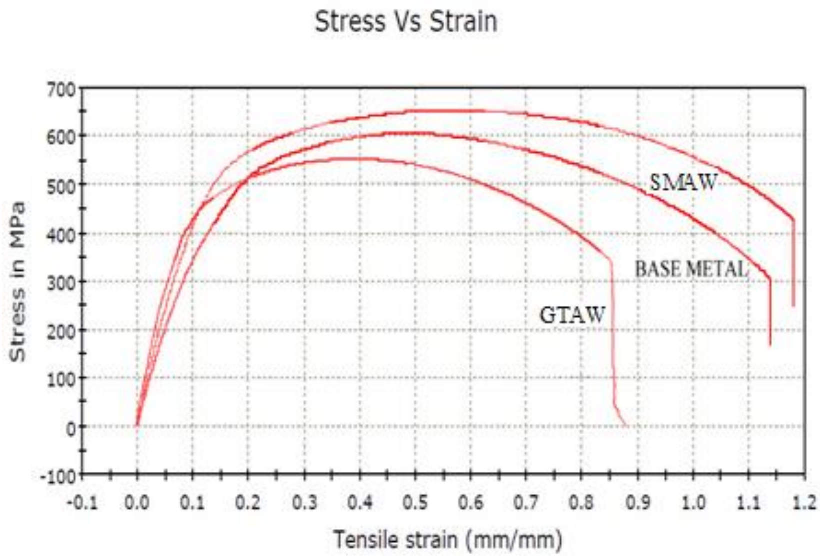

Fig. 7 Stress-strain curves of DMR 249A and its welds

3.4. Pitting Corrosion Studies

Potentio-dynamic polarization curves of the different regions of the welds made with SMAW and GTAW are shown in Figs. 8-9. Corrosion potential values (Ecorr) are recorded to compare the pitting corrosion resistance of various regions of the welds. More the positive value of Ecorr, better will be the corrosion resistance. Results clearly revealed that HAZ is having poor pitting corrosion resistance than weld zone and base metal in both the welds. Crack initiates in HAZ region, it is due to relatively lower corrosion potential which acts as anodic site when compared to base metal and weld region. It can also be observed that weld region of GTAW is having relatively better pitting resistance than that of SMAW. This may be correlated to the observed microstructure of martensite formation in the weld zone. Generally it is believed that interface between the microstructure phases ferrite, pearlite and martensite acts as source of nucleating pits. Relatively less amount of martensite in the GTA welds may be the reason for better pitting corrosion resistance.

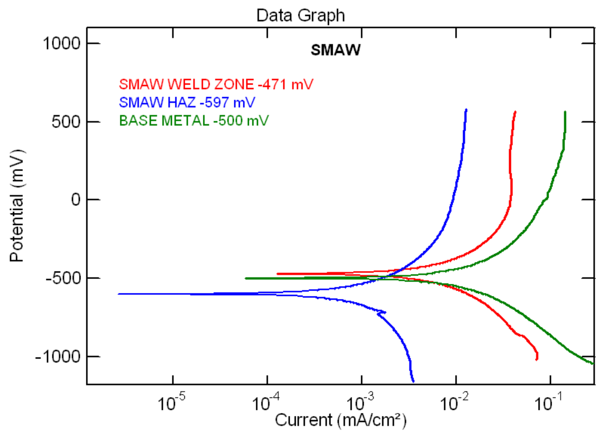

Fig. 8Potentio-dynamic polarization curves of SMAW

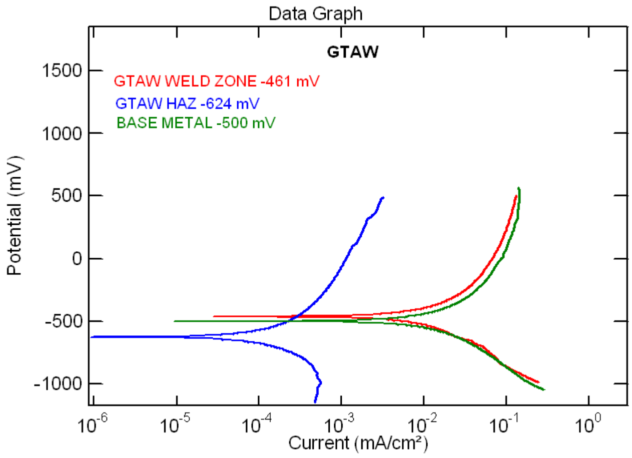

Fig. 9 Potentio-dynamic polarization curves of GTAW

3.5. Stress Corrosion Cracking Studies

Base metal, Gas Tungsten Arc Welding (GTAW) and Shielded Metal Arc Welding (SMAW) specimens were tested in sodium chloride environment in the constant load type machine. Time to failure at constant load of 50% yield strength is the criteria for assessing stress cracking corrosion resistance. Failed SCC test specimens are shown in Fig. 10. SCC test data is given in Table 4. Base metal which has a combination of ferrite and pearlite fine grained microstructures was observed to be less susceptible to stress corrosion cracking (SCC). Investigation results clearly revealed that the time to failure of GTA Welds is higher when compared to base metal and SMA Weld samples. SMA welds were found to be susceptible to stress corrosion cracking and are attributed to the observed microstructure changes that occur during welding. Interface between martensite and ferrite will act as source of crack initiation and propagation for stress corrosion process. Relatively more number of interfaces of ferrite / martensite in SMA welds might have caused the less SCC resistance when compared to GTAW welds of steel. Lower heat efficiency of GTAW process decreases the cooling rate and hence less amount of martensite formation. This reduces the number of favourable sites of crack initiation of SCC in GTAW welds and improves the SCC resistance.

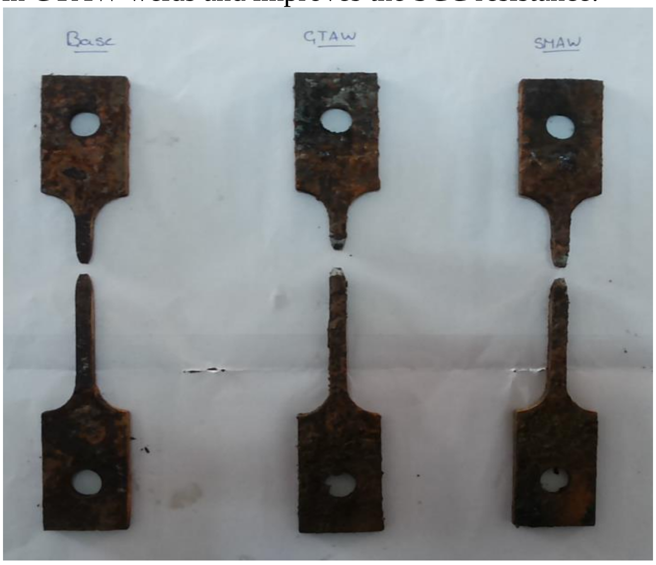

Fig. 10Failed SCC specimens of DMR 249A and its welds

IOP Conf. Series: Materials Science and Engineering **330** (2018) 012018 doi:10.1088/1757-899X/330/1/012018

Table 4 SCC test data for Base metal, GTAW and SMAW specimens

Material	Constant Load (MPa) (50% Y.S)	Time to SCC Failure (Hours)
Base Metal	200	1050 (44 Days)
SMAW	215	860 (36 Days)
GTAW	205	1224 (51 Days)

4. Conclusion

1. DMR 249A steels are successfully welded using shielded metal arc welding and gas tungsten arc welding process and obtained defect free weld joints.
2. In both the welds, formation of martensite is observed in the weld region and is due to faster cooling rates whereas partly bainite and martensite is observed in heat affected zone.
3. Relatively coarse and dendritic martensite was observed for the welds made with SMAW and is due to high heat input and thermal efficiency.
4. Improved mechanical properties are observed due to the presence of high amount of martensite in SMA welds when compared to GTA welds.
5. Pitting corrosion and SCC resistance of DMR 249 steel welds was found to be sensitive to welding process. Cooling rate of weld depends on Heat input and heat efficiency of welding process.
6. GTA welding due to its low heat efficiency results in slow cooling rate and less amount of martensite. Better pitting corrosion and SCC resistance of DMR 249 welds is attributed to the less number of ferrite/martensite interfaces which are sources of corrosion initiation.

References

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