International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.12 No.04, pp 63-72, 2019

Effect of Welding parameters on Corrosion behavior of Dissimilar weld joints of Al5052 and Galvanized mild steel

Shaik Shajahan[1]*, Bhargavi Rani Anne[2]

[1]PhD scholar, Department of Metallurgical & Materials Engineering, NIT Rourkela, Rourkela, India, 769008.
[2]Department of materials Sci. & Eng. Kyushu University, 744 Motooka Fukuoka , Japan, 819-0395.

Abstract : The current study investigated the effect of intermetallic formation on the corrosion behavior of dissimilar alloy welds of Al 5052 and Galvanized mild steel.Al 5052 alloy and galvanized mild steel plates welded in the form of lap joint by Cold Metal Transfer (CMT) welding process and Pulsed Arc Metal Inert Gas (PAMIG) welding process using 4043 Aluminumalloy filler. Welding conducted at different welding parameters viz., welding speed (0.8 m/min and 1.0 m/min) and wire feed rate (5.5 m/min and 6.5 m/min). The microstructure and phase determination of the weld joints analyzed by Field Emission Scanning electron microscopy and X-Ray Diffraction respectively. Resistance of galvanic, crevice and intergranular corrosion of the welds were studied as a function of different welding parameters as per ASTMG67-Al-alloys. The effect of welding parameters on the corrosion resistance of the joints and correlation of microstructural features such as formation of intermetallics at the interfaces etc. throughout specimens studied in detail.
Keywords : Al5052, Galvanized mildsteel, intermetallic phases, dissimilar weld joints, welding parameters, Microstructure, Corrosion.

Introduction

Steel is widely used in automobile industries, construction industries, ships, aircrafts etc., due to having good strength, high formability and low production cost as compared to other materials. Nevertheless, the disadvantage with Steel is high weight and more fuel consumption. Currently, the concentration of automobile industries to reduce the weight of components or to employ alloys having low weight. Al alloys have been popular in automobile industries, aircrafts etc. due to its low weight and good corrosion resistance. However, Al alloys have less strength compared to steels and other alloys. Hence, an optimum of weight reduction and strength retention is the solution and a hybrid structure of Steel and Aluminum alloys would be ideal for this

DOI= http://dx.doi.org/10.20902/IJCTR.2019.120411

purpose. The components of the vehicle where strength is the primary requirement constituted of steel and the other components made up of Al alloys. In order to make vehicles more fuel efficient as well as to sustain its required strength, the automobile industries have shifted the focus towards partial replacement of steel with Al alloys[1-5].

However, this introduces challenges in thefabrication of good quality 'joints' or in other words dissimilar alloy welds which would be the key in determining the strength of the automobile by ensuring the safety issues. There are different welding technologies involved in producing this kind of hybrid structure. The primary challenges in producing dissimilar weld joints of Al alloys and steel arise due to the difference in thermal conductivity, electrical conductivity and solid solubility, large variance in melting points chemical composition etc. [6-9].The dissimilar weld joints contribute many advantages such as low manufacturing cost, reduction of processing steps, production of controlled low weight to high strength ratio objects, high fuel efficiency etc.[10-12]

They also have few disadvantages such as formation of brittle intermetallic phases, precipitates, welding defects etc. The welding defects occur due to the difference in melting points of joining metals. In case of aluminum alloy and steel, they have large variance in melting point that leads to formation ofblowholes, porosity, pits etc. in the weld zone. In addition to melting point, introduction of residual stresses in the weld zone comes from the differences in specific heat, conductivity, thermal expansion etc.[13-15]. The weld zone also may effected by the selection of filler metal. The filler selected will determine mechanical properties of the weld metal. The formation of intermetallic phases during welding process also depends on selection of filler metal.There are several researches in the progress to determine the effect of different filler metals on the formation of intermetallic phases and welding process. The corrosion behavior of the dissimilar metal weld joint effected by the formation of intermetallic phases, selection of filler metal, selection of welding process, welding parameters etc.[16-18].The present work focuses on determining the effect of welding parameters on corrosion rate of Al5052-Galvanized mild steel lap joint by immersion corrosion test. To determine the effect of intermetallic phases and precipitates on dissolution of metal at the interfaces of Al5052-Galvanized mild steel by analyzing the microstructures that led to corrosion at the interfaces.

Materials and Methods:

In this study, four Al-5052 aluminum alloy and Galvanized mild steel (GMS) plates were lap welded by CMT welding process and PAMIG welding process with different welding parameters as per ASTMG67-Al-alloys [19]. The filler metal used was 4043 Aluminum alloy with diameter of 1.2 mm. The compositions of Metal alloys, filler metaland welding parameters presented in Table 1 and Table 2 respectively.

Table 1: Composition of metal alloys and filler wire (wt%).

	C	**S**	**Si**	**Fe**	**P**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Al**
Al5052	-	-	0.069	0.35	-	0.055	0.057	2.28	0.23	0.008	0.018	Bal.
GMS	0.06	0.004	0.27	Bal.	0.004	0	0.014	0	0	3.7	0	-
4043	-	4.5-6	-	0.8	-	0.30	0.05	0.05	-	0.4	0.20	Bal.

Table 2: Welding parameters.

Designation	**Sample**	**Welding Speed [m/min]**	**Feed rate [m/min]**
Sample 1	Al5052-GMS, CMT	0.8	5.5
Sample 2	Al5052-GMS, PAMIG	0.8	5.5
Sample 3	Al5052-GMS, CMT	1.0	6.5
Sample 4	Al5052-GMS, PAMIG	1.0	6.5

According to ASTM standard G67-04 5xxx aluminum alloys [20], the immersion corrosion test of Al-5052-Galvanized mild steel lap joints were conducted in 5% NaOH solution at 80^0C for 1 min, HNO_3 for 30 sec and HNO_3 for 24 h at 30^0C. Silicon Carbide cutting blade was used to cut the samples of required size (15mm×6mm) and initial polishing was done with grits of 100,200,600,800,1200,1/0,2/0,3/0,4/0 g and followed by 1μm diamond paste final polishing. Polished samples alternatively etched with Nital solution and Keller's reagent to get a clear microstructure of the samples under FESEM (Field Emission Scanning Electron Microscope) to analyze the metallographic changes in the samples.

The immersion corrosion test of Al-5052-Galvanized mild steel lap joints were conducted in 5% NaOH solution at 80^0C for 1 min, HNO_3 for 30 sec and HNO_3 for 24hrs at 30^0C. The weight of the samples taken at every step before and after immersion. The difference between weight before and after immersion test of samples was calculated and observed the weight reduction of samples due to effect of welding parameters and formation of intermetallics. Moreover, the reduction in surface area and volume fraction of the samples were calculated. Galvanic ,crevice corrosion and intergranular cracking observed at the interfaces.

Results and Discussion:

Microstructural Characterization:

Figure 1 represents the basic microstructure of the cross-section of Al5052-Galvanized mild steel lap joint. It shows interface between galvanized mild steel and weld pool at different welding parameters. CMT weld at welding speed 0.8 m/min and feed rate 5.5 m/min [Fig 1 (a)], CMT weld at welding speed 1 m/min and feed rate 6.5 m/min [Fig 1 (b)], PAMIG weld at welding speed 0.8 m/min and feed rate 5.5 m/min [Fig 1 (c)], PAMIG weld at welding speed 1 m/min and feed rate 6.5 m/min [Fig 1 (d)]. The formation of intermetallic phases at the interfaces clearly indicated in all cases with two different welding processes at two different welding parameters.

The intermetallics formed at the interface of galvanized mild steel and weld poolidentified as Al-Fe based (Fig 1). The intermetallic phases expanded zig-zag manner towards weld pool side with plate like shape. The EDS analysis shown in Table 3 was confirmed that the samples having intermetallc phases which were formed at the interface of weld pool and steel are Al-Fe based viz., $Al_5Fe_{2,}$ AlFe,$Al_{13}Fe_{4,}$ $AlFe_3$ in all the samples [19,21,22]. Among the all the samples volume fraction of intermetallic phases was more in sample Fig 1 (a) and sample Fig 1 (c). which were welded with welding speed: 0.8 m/min, feed rate: 5.8 m/min by CMT and welding speed: 0.8 m/min, feed rate: 5.5 m/min by PAMIG respectively.

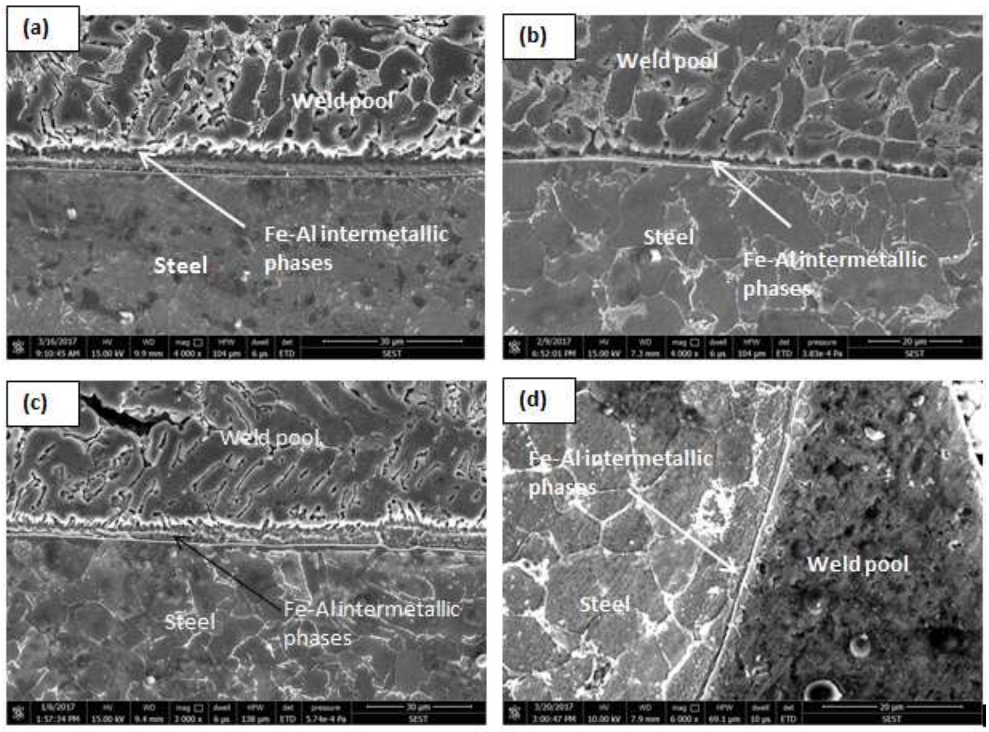

Figure 1:Interface between GMS and weld pool under FESEM at different welding parameters (a) Sample 1(b)Sample 3(c) Sample 2(d) Sample 4.

Table 3: EDS analysis at interface of steel and weld pool (welding speed/feed rate) (wt%)

Element	CMT 0.8/5.5	CMT1/6.5	PAMIG1/6.5	PAMIG 0.8/5.5
C	0.16	1.85	1.48	1.49
Al	62.29	57.76	48.73	56.29
Si	1.30	1.58	1.44	1.19
Fe	36.25	38.81	48.35	41.03

Figure 2shows the microstructure of the cross-section of Al5052-Galvanized mild steel lap joint representing the interface between Aluminum and weld pool at different welding parameters. CMT weld at welding speed 0.8 mm/min and feed rate 5.5 m/min [Fig 2 (a)], CMT weld at welding speed 1 m/min and feed rate 6.5 m/min [Fig 2 (b)], PAMIG weld at welding speed 0.8 m/min and feed rate 5.5 m/min [Fig 2 (c)], PAMIG weld at welding speed 1 m/min and feed rate 6.5 m/min [Fig 2 (d)]. The evolution of secondary precipitates took place at the interface of Aluminum and weld pool in all the four samples with different parameters.Inter-dendritic structure and eutectic formation of Al-Si observed in all the samples at the weld pool region. The EDS analysis presented in Table 4 depicting the type of precipitates, which formed at Aluminum, side near the interface of Aluminum and weld pool. By EDS analysis, it was pointed that the precipitates formed were Mg_5Si_6, Mg_2Si,Al_4Si and Al-Mg-Si based precipitates,which were observed at Al side and Al-Si eutectic formations were found at weld pool side [19,21,22].

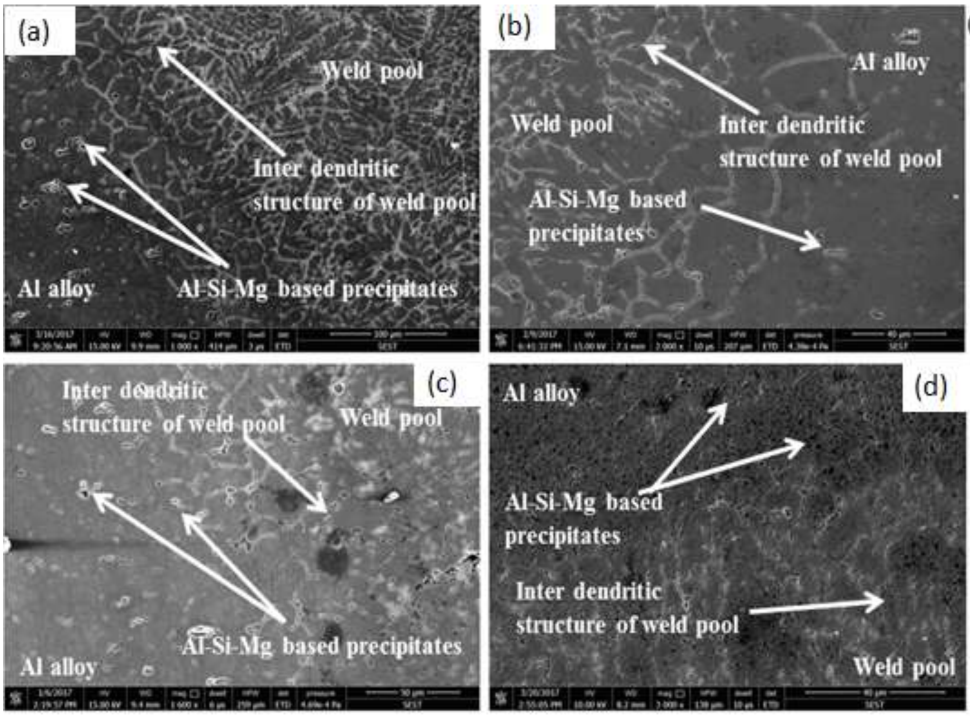

Figure 2: Interface between Al-weld pool under FESEM.(a) Sample 1, (b) Sample 3, (c) Sample 2, (d)Sample 4.

Table 4: EDS analysis at interface of Al and weld pool (welding speed/feed rate) (wt%).

Element	CMT 0.8/5.5	CMT 1/6.5	PAMIG 1/6.5	PAMIG 0.8/5.5
C	0.62	4.23	3.13	0.00
Al	80.46	64.75	31.56	91.67
Si	17.49	8.33	11.37	2.35
Fe	1.43	10.28	10.02	5.98

Immersion corrosion test:

The weld joints of Al5052-Galvanized mild steel with 4043 filler metal at different welding parameters were immersed in 5%NaOH solution at 80^0C for one min and observed the microstructure changes under FESEM to investigate the corrosion effect on weld joints. Dissolution of intermetallic phases occurred after the corrosion testthat shown in Fig 5. However, the dissolution of intermetallic phases was higher than anticipated which comes from theeffect of galvanic corrosion on the weld joint. Corrosion on steel side took place due to formation of oxides, as Galvanized steel is highly prone to oxidize. Reduction in surface area that leading to weight loss of the samples has encountered due to the effect of corrosion.

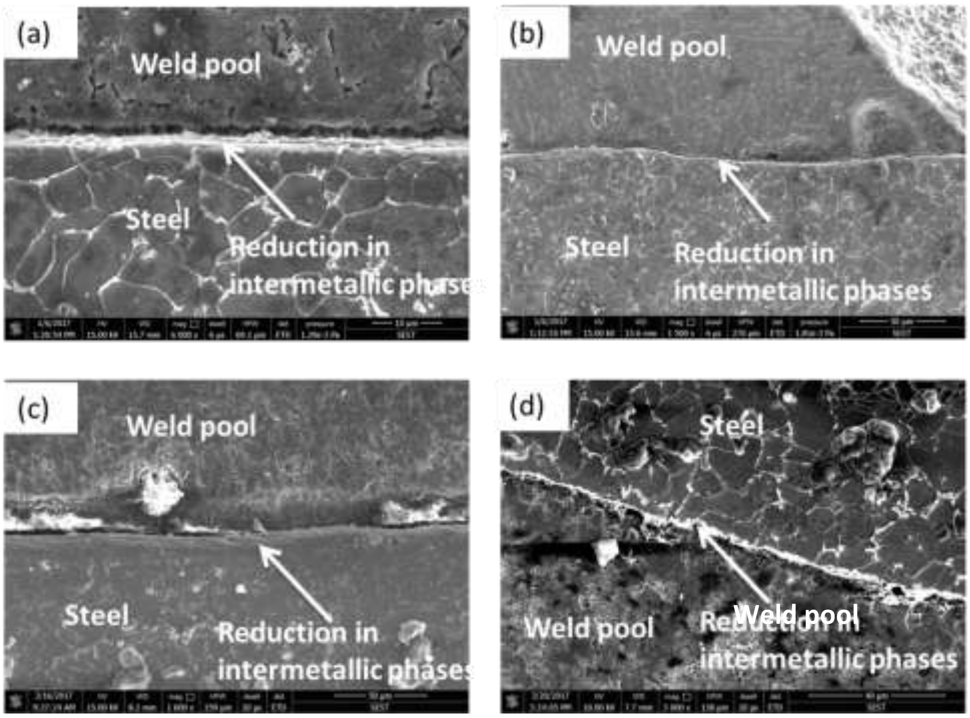

Figure 5:Interface of Galvanized steel and weld pool after 5% NaOH immersion corrosion test for 1 min at 80^0C under FESEM. (a)Sample 1, (b) Sample 3, (c) Sample 2, (d) Sample 4.

The Al5052-Galvanized mild steel welded with different welding techniques and different welding parameters to determine the effect of feed rate and welding speed on corrosion behavior of the welded joint. The samples welded with welding speed: 0.8 m/min, feed rate: 5.5 m/min by CMT and welding speed: 0.8 m/min, feed rate: 5.5 m/min by PAMIG have less dissolution of intermetallic phases at the interface that shown in Fig.5 (a), (b) respectively. Reduction in volume of intermetallic phases was also became lower that quantitatively shown in Table 6. Hence, the corrosion effect also was lower in sample 1 and sample 3 when compared with sample 2 and sample 4. Whereas, the dissolution of intermetallic phases in the sample 2 and sample 4 was higher as shown in Fig 5 (c), (d) that led to high reduction in volume fraction of intermetallic phases. Weight loss and surface area reduction were calculated which shown in Table 6. The complete corrosion rate calculated after 5% NaOH test for all the samples as shown in Table4 and 5.Fig 6 shows the interface of Aluminum and weld pool of the four samples. However, Notable changes did not occur at the interface region. The main site of corrosion attack in each sample depicted as precipitate-matrix interface. The corrosion effect was higher in sample 2 and sample 4 as shown in Fig 6 (c), (d) respectively.

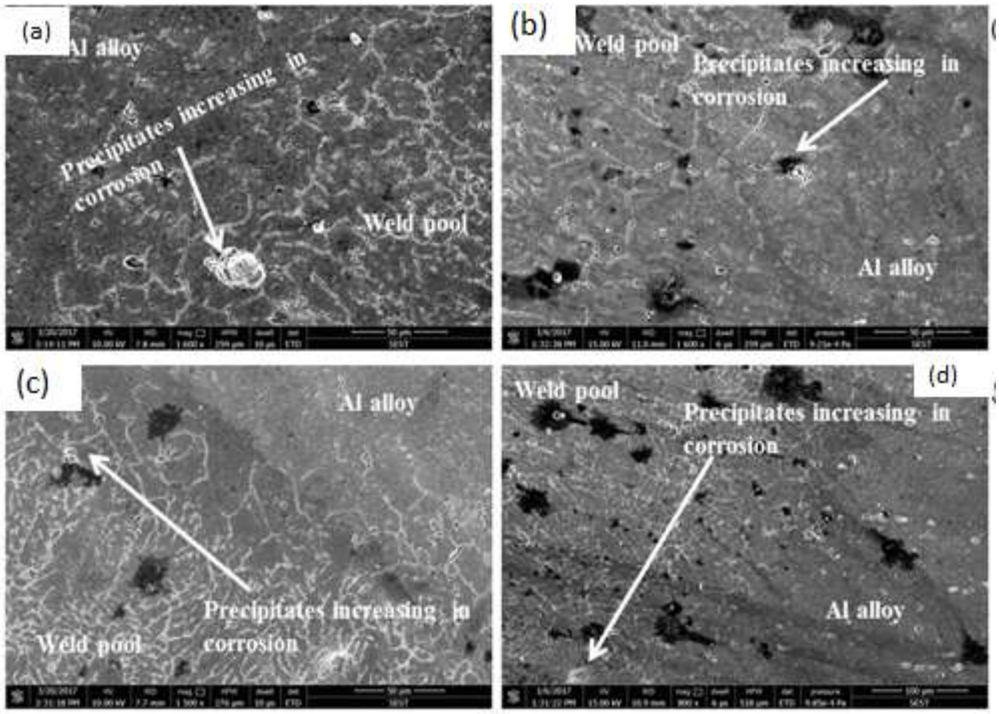

Figure 6: Microstructure of aluminum and weld pool interface after 5% NaOH immersion corrosion test for 1 min at 80°C through FESEM. (a)Sample 1, (b) Sample 3, (c) Sample 2, (d) Sample 4.

Fig 7 and 8 shows that the microstructure of the interface between Galvanized steel and weld pool and the interface between Al alloy and weld pool respectively after HNO_3 immersion corrosion test. High dissolution of intermetallic phases took place at the interface of Galvanized mild steel and weld pool.Almost all intermetallic phases dissolved after 24 hr exposure to HNO_3 acid as shown in Fig 7. After HNO_3 immersion corrosion test, volume fraction of intermetallic phases reduced drastically for all the four samples as shown in Table 4, 5 and 6. The dissolution of 95% intermetallic phases has seen in sample 2, sample 3 and sample 4, on other hand in sample 1 it was only 90% volume reduction. The gap in the microstructure was observed after the dissolution of intermetallic phases (at the place of dissolution of intermetallic phases) in the weld joint which led to higher dissolution of the metal further led to crevice corrosion in the area of weld joint of Al-alloy and weld pool for all the four samples and galvanic corrosion at the interface of steel and weld pool. Amongst of all the samples, sample 1 has less dissolution of intermetallic phases in the solution thus shown less galvanic and crevice corrosion when compared to the remaining samples. Corrosion rate also was very low in case of sample 1 because of less dissolution of intermetallic phases in volume fraction when compared to the remaining samples as shown in Table 4, 5 and 6. In addition to the crevice corrosion and galvanic corrosion, in sample 1 inter granular corrosion took place due to presence of residual stresses in the steel region as shown in Fig 7(a). The intergranular cracking was first initiated near the interface of steel and weld pool further propagated towards the interface of steel-weld pool that clearly indicated in Fig 7 (a). The requirement of optimization of the parameters in case of CMT welding processnoticed.

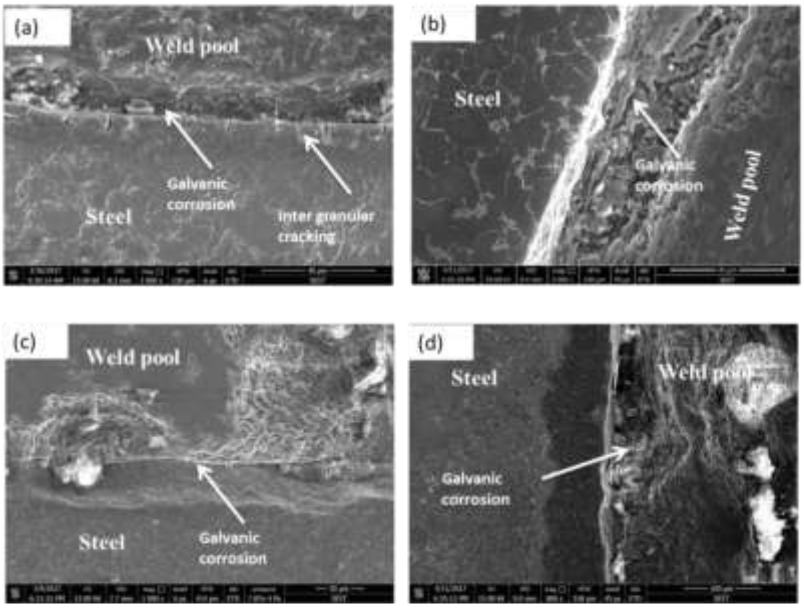

Figure 7: Microstructure of Galvanized steel and weld pool interface after 24hrs HNO_3 immersion test. (a) Sample 1, (b) Sample 3, (c) Sample 2, (d) Sample 4.

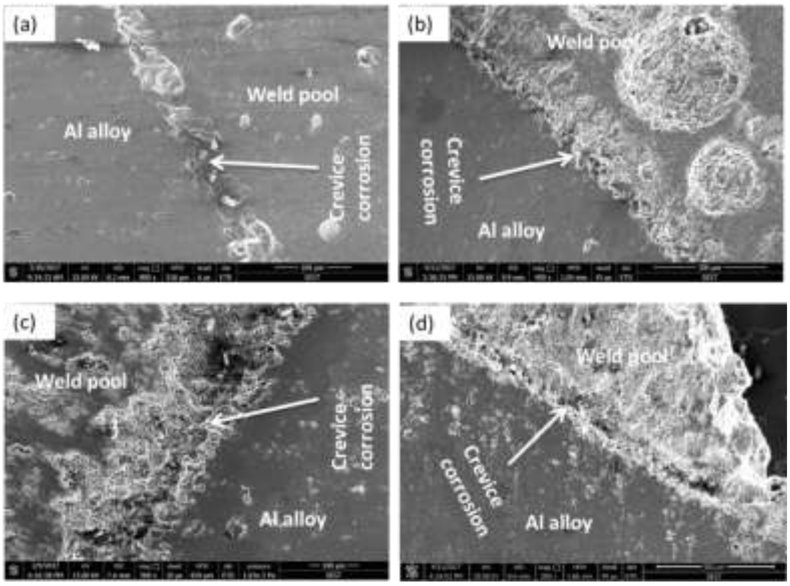

Figure 8: Microstructure of Aluminum and weld pool interface after 24hrs HNO_3 immersion test. (a) Sample 1, (b) Sample 3, (c) Sample 2, (d) Sample 4.

The interface of Aluminum alloy and weld pool after HNO_3 immersion corrosion test was highly damaged due to presence of precipitates and dissolution of the metal at the interface. Pits nucleated at the precipitate-matrix interface. The size of the pits further increased thatcontributed to overlapping of pits. The formation of pits resulted in crevice corrosion at the interface as shown Fig 8. Fig 8 also describes, crevice corrosion was very low insample 1 [Fig 8 (a)], whereas other samples were fully effected by crevice corrosion as shown in Fig 8 (b),(c) and (d). Corrosion rate calculated comparatively for all the samples presented in Table 10.

Table 4:Corrosion rate of Al5052-Galvanized mild steel welded samples.

Sample	W_1 (mg)	A_1 (in^2)	W_2 (mg)	A_2 (in^2)	ΔW (mg)	W_3 (mg)	A_3 (in^2)	ΔW (mg)	W_4 (mg)	A_4 (in^2)	ΔW (mg)	Total weight loss (mg)
PAMIG 0.8/5.5	3410	0.67	3387	0.63	23	3372	0.62	15	3334	0.52	38	80
CMT 1/6.5	3300	0.67	3268	0.61	32	3242	0.60	26	3183	0.47	59	117
PAMIG 1/6.5	3350	0.67	3316	0.61	34	3294	0.60	22	3245	0.45	49	105
CMT 0.8/5.5	3310	0.67	3301	0.66	9	3289	0.65	12	3259	0.60	30	52

(W_1=Initial weight of the sample, A_1=Initial Area of the sample, W_2= Weight of the sample after 1min NaOH test and corresponding area is A_2, ΔW=Weight loss, W_3= Weight of the sample after 30 sec HNO_3 test and corresponding area is A_3, W_4= Weight of the sample after 24 hr HNO_3 test and corresponding area is A_4,

Table 5:Corrosion rate of Galvanized mild steel and Al5052 weld joint with different parameters.

Sample id	Corrosion rate $\frac{534\,W}{DAT}$ (mpy) for 24hr HNO_3 test
0.8/5.5 PAMIG	405
1/6.5 CMT	696
1/6.5 PAMIG	603
08/5.5 CMT	277

Table 6: Volume fraction of intermetallic phases.

Sample id	V_1	V_2	V_3	ΔV
0.8/5.5 CMT	6.5 %	2.25%	0.7%	90%
1.0/6.5 CMT	6.3%	2%	0.5%	93%
0.8/5.5 PAMIG	6.1%	2%	0.4%	94%
1.0/6.5 PAMIG	6.3%	1.8%	0.35%	96%

V_1=Initial volume fraction of intermetallic phases, V_2=Volume fraction of intermetallic phases after 5% NaOH test for 1 min, V_3=Volume fraction of intermetallic phases after HNO_3 test for 24hr, ΔV=Total percentage of reduction in volume fraction of intermetallic phases.

XRD analysis:

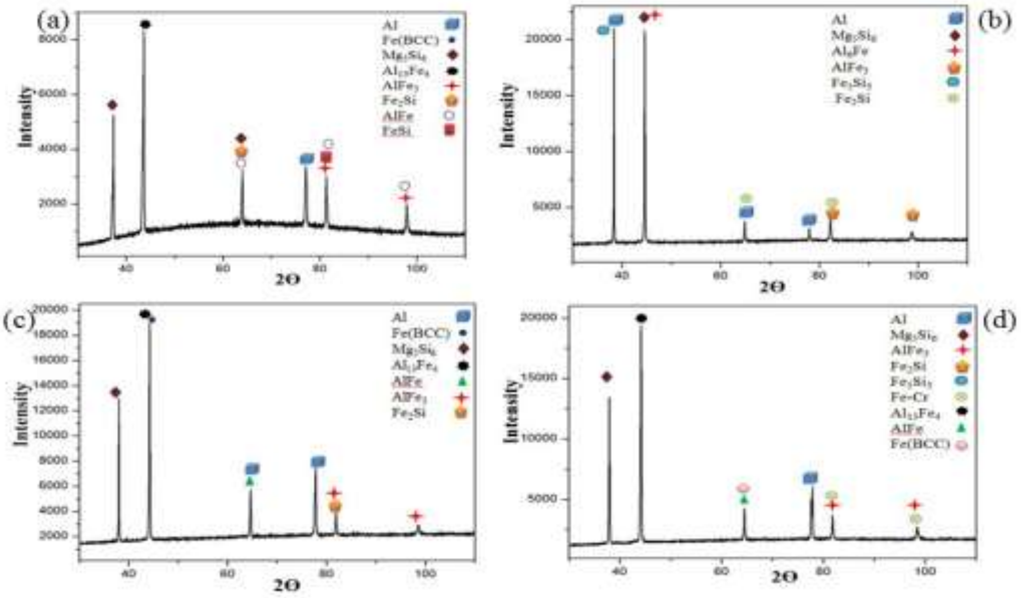

Figure 9: XRD analysis of Al5052-GMS weld joint (a) Sample 1, (b) Sample 3, (c) Sample 2, (d) Sample 4.

The XRD analysis of the four samples are shown in the Fig 9. It was shown that a number of phases were formed after the welding process and the analysis of XRD confirmed that the Fe and Al based intermetallic phases such as $AlFe_3$, $Al_{13}Fe_4$, Al_5Fe_2,AlFe were formed at the interfaces of each sample. Some of the possible precipitates such as Mg_5Si_6, Fe_2Si, Fe_5Si_3, FeSi etc. were also observed at the interfaces. In all four samples, Mg_5Si_6 is the most common precipitatewhich is formed at aluminum and weld pool interface region[20-21].

Conclusions:

The corrosion behaviour of Al5052-Galvanized mild steel lap joint with 4043 filler metal at different welding parameters by Cold metal transfer welding process and Pulsed arc welding process was investigated by immersion corrosion test. The conclusions drawn as follows:

I. Galvanic, crevice and intergranular corrosion occurred when Al 5052-Galvanized mild steel lap welded joints immersed in 5% NaOH solution for 1 min at 80^{o}C and 30 sec & 24 hr in HNO_3 solution. The corrosion rate varied with welding parameters. 0.8/5.5 CMT sample showed least corrosion rate (277 mpy)as compared to 0.8/5.5 PAMIG(405 mpy), 1/6.5 CMT(696 mpy), and 1/6.5 PAMIG(603 mpy).
II. High volume fraction of intermetallic phases detected at the interfaces of weld joints rigorously reduced the corrosion resistance of the joints in each case.
III. The intermetallics present at the interface of aluminum and weld pool were highly prone to corrosive attack. The dissolution of intermetallicsresulted in initiation of pitting corrosion.
IV. Intergranular cracking observed in 0.8/5.5 CMT sample due to presence of residual stresses and requirement of optimization of the CMT parameters suggested.
V. Galvanic corrosionobserved at the interface of galvanized mild steel and weld pool due to dissolution of intermetallic phases and crevice corrosion at the interface of Al-alloy and weld pool due to formation of overlapped pits, thosecreated by precipitates-matrix interface.
VI. Immersion corrosion test indicated that the corrosion resistance of Al5052-Galvanized mild steel sample, which is lap welded by CMT with welding parameters: welding speed 0.8 m/min, feed rate 5.8 m/min is superior for dissimilar weld joint than remaining samples.

References:

1. J.L. Song, S.B. Lin, C.L. Yang, G.C. Ma, H. Liu, SpreadingBehavior and Microstructure Characteristics of Dissimilar Metals TIGWelding–Brazing of Aluminum Alloy to Stainless Steel, Mater. Sci.Eng. A. 509 (2009) 31–40.

2. M. Sonia, G. Supriyo, W. Stewart, M. Norman, Effect of LaserProcessing Parameters on the Formation of Intermetallic Compounds in Fe- Al DissimilarWelding, J. Mater. Eng. Perform. 23 (2014) 3361–3370.
3. M. Watanabe, K.Y. Feng, Y. Nakamura, S. Kumai, Growth Mannerof Intermetallic Compound Layer Produced at Welding Interface ofFriction Stir Spot Welded Aluminum/Steel Lap Joint, Mater. Trans. 52 (2011) 953–959.
4. J. Lin, N.S. Ma, Y.P. Lei, H. Murakawa, Shear Strength of CMTBrazed Lap Joints Between Aluminum and Zinc-Coated Steel, J.Mater. Process Technol. 213(2013) 1303–1310.
5. H.T. Zhang, J.K. Liu, Microstructure Characteristics and MechanicalProperty of Aluminum Alloy/Stainless Steel Lap Joints Fabricatedby MIG Weld-Brazing Process, Mater. Sci. Eng. A. 528 (2011) 6179–6185.
6. H.G. Dong, W.J. Hu, X.C. Zhang, Detachment of InterfacialLayers During Arc-Brazing of Aluminum Alloy to Carbon Steel withFiller Wire, Trans. Nonferr. Metal. Soc. China. 23(2013) 1583–1588.
7. Y. Shi, L. Shao, J.K. Huang, Y.F. Gu, Effects of Si and MgElements on the Microstructure of Aluminum-Steel Joints Produced byPulsed DE-GMA Weld-Brazing, Mater. Sci. Technol. 29 (2013)1118–1124.
8. H.G. Dong, W.J. Hu, Y.P. Duan, X.D. Wang, C. Dong, DissimilarMetal Joining of Aluminum Alloy to Galvanized Steel with Al-Si, Al-Cu, Al-Si-Cu and Zn-Al Filler Wires, J. Mater. Sci. Technol. 212 (2012) 458–464.
9. H. Springer, A. Kostka, E.J. Payton, D. Raabe, A. Kaysser-Pyzalla,G. Eggeler, On the Formation and Growth of Intermetallic PhasesDuring Interdiffusion Between Low-Carbon Steel and AluminumAlloys, Acta Mater. 59(2011) 1586–1600.
10. F. I. Saunders, R. H. Wagoner, The use of tailor-welded blanks in automotive applications, Simulation of Mat. Proces.Theory, Methods and Appli. Rotterdam: Shen& Dawson (1995).
11. B. Kinsey, V. Viswanathan, J. Cao, Forming of aluminium tailor welded blanks, J. Mat. & Manuf. 110 (2001) 673-679.
12. J. Tusek, Z.Kampus, M. Suban, Welding of tailored blanks of different materials, J.Mat. Proces. Tech. 119 (2001) 180-184.
13. R. Qiu, C. Iwamoto, S. Satonaka, The influence of reaction layer on the strength of aluminium/steel joint welded by resistance spot welding, Mat. Charact. 60 (2009) 156-159.
14. J. Song,S. B. Lin, C.L. Yang, C.L. Fan, Effects of Si addition on intermetallic compound layer of aluminium-steel TIG welding-brazing joint,J.Alloys&Com. 488 (2009) 217-222.
15. D. Lohwasser, Z. Chen, Friction stir welding: From basics to applications, Cambridge: Woodhead, UK, 2010.
16. H. Dong, W. Hu, Y.Duan, X. Wang, C. Dong, Dissimilar metal joining of aluminium alloy to galvanized steel with Al-Si, Al-Cu, Al-Si-Cu and Zn-Al filler wires. J.Mat. Proces. Tech. 212 (2012) 458-464.
17. A. M. Saeed, Z.Hussain, A.Badri, T. Ariga, The effect of welding parameters on the weldability of different materials using brazing alloy fillers, Mat. & Des. 31 (2010) 3339-3345.
18. S.G. Shiri, M.Nazarzadeh, M.Sharifitabar, M.S.Afarani, Gas tungsten arc welding of CP-copper to 304 stainless steel using different filler metals, Tran.Nonfer. Met. Soc. China. 22 (2012) 2937-2942.
19. G.Padmanabham, Y. Krishna priya, K.V. Phaniprabakar, N.B. Ravi,Report on Comparison of interface characteristics and Mechanical properties of aluminium–steel joints made by pulsed-MIG and cold metal transfer (CMT) process International advanced research center for powder metallurgy and new materials (ARCI),Hyderabad, Telangana, India.
20. Standard Test Method for Determining the Susceptibility to Intergranular Corrosion of 5XXX Series Aluminum Alloys by Mass Loss After Exposureto Nitric Acid (NAMLT Test) ASTM international, Designation G 67 – 04.
21. Yu Shi, Jie Li, Gang Zhang, J. Huang, Y. Gu, Corrosion Behavior of Aluminum-Steel Weld-Brazing Joint, J.Mat.Engg.&Perf. 25 (2016) 1916-1923.
22. L. H. Shah, Z. Akhtar, M. Ishak,Investigation of aluminum-stainless steel dissimilar weld quality using different filler metals, Int.J.Auto&Mech.Engg, 8 (2013) 1121-1131.

*****