EXPERIMENTAL INVESTIGATION OF MICRO STRUCTURE AND MECHANICAL PROPERTIES OF SURFACE MODIFICATION OF AA 6082-T6 – B_4C COMPOSITES PROCESSED BY MULTI PASS FRICTION STIR PROCESSING

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ABSTRACT:-Aluminium materials has a huge requirement in the fields of automotive, aerospace and different engineering applications in order to meet requirements of various fields a material with good mechanical and thermal properties is developed which is metal matrix composites in which aluminium alloys is used as common matrix phases and reinforced used are different material particulates.

In this thesis B_4C is used as reinforcement. **AA6082** is used as base matrix material. Metal matrix composites are fabricated using B_4C powder and **AA6082** material using friction stir processing (**FSP**)technique. Mechanical properties are evaluated for the metal matrix composites like hardness test, tensile test, bending test and corrosion test. The fabricated surface composites were examined by optical microscope (OM) for dispersion reinforcement particles. It was found that B_4C particles are uniformly dispersed in the stir zone. Mechanical properties like tensile, flexural strength were also evaluated. The observed mechanical properties are correlated with microstructure and fracture features.

KEY WORDS: Friction Stir Processing, Boron Carbide (B_4C), Mechanical Properties.

1. INTRODUCTION:

Friction stir processing (**FSP**) is a method of changing the properties of a metal through intense, localized plastic deformation.During the last two decades, severe plastic deformation (SPD)has been demonstrated as an effective approach to produce ultrafine grain (UFG) materials. Extensive research has been carried out to develop SPD techniques and to establish processing parameters to produce UFG metals and alloys; especially Aluminum Alloys (AA), with more desirable properties. The Friction stir processing (FSP) is modification of FSW techniques which refines the microstructure, improves the mechanical properties and also be used for production of composite in solid state itself. Further this process produces a homogeneous distribution of reinforcement particles in the aluminum matrix. This process is environmentally clean technology as it does not produce any fumes and harmful gases and noise like in other conventional techniques.

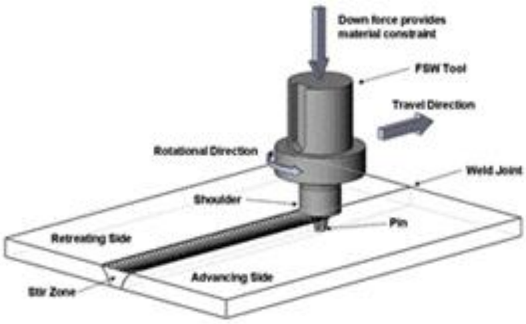

Fig.1.1 Schematic diagram of Friction Stir Processing

The temperatures developed during the FSP was below the melting point of material which avoids interfacial reactions, defects like pin hole porosity, air inclusions be eliminated.

1.1 FRICTION STIR PROCESSING PARAMETERS

FSP involves complex material movement and plastic deformation. Process parameters, tool geometry, and significant effect on the material flow pattern and temperature distribution, thereby influencing the micro structural evolution of material.

- Tool Rotational Speed (RS)
- Tool Travel Speed (TS)
- B_4C Particles Vol.%

- No. of Passes

The tool should be designed in such a way that it can generate sufficient heat, through the means of rotational surface contact to create a plasticized region beneath the tool. It was realized early on in the development of FSP that the tool's design is critical in producing the strong nugget. The tool consists of three generic features. They are:

- A shoulder section,
- A probe (also known as pin)
- Any external features on the probe

1.2 ALUMINUM ALLOY 6082:

Aluminum alloy 6082 is a medium strength alloy with excellent corrosion resistance. It has the highest strength of the 6000 series alloys. Alloy 6082 is known as a structural alloy. In plate form, Aluminum alloy 6082 is the alloy most commonly used for machining. As a relatively new alloy, the higher strength of Aluminum alloy 6082 has seen it replace 6061 in many applications. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy.

Table1.0 Mechanical Properties of Base Metal

Material	UTS (MPa)	YS (MPa)	% of Elongation	Flexural Strength (MPa)	Hardness (Hv)
Al 6082 T6	320	255	11	480	95

Table 1.1 Chemical Properties of Base Metal

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
Weight. %	1.1	0.4	0.08	0.6	0.75	0.1	0.07	0.2	Balance

1.3REINFORCEMENT USED IN FSP

B4C:

Boron Carbide $B_4C$is one of the hardest materials known, ranking third behind diamond and cubic boron nitride. It is the hardest material produced in tonnage quantities. Originally discovered in mid-19 century as a byproduct in the production of metal borides, boron carbide was only studied in detail since 1930. Boron carbide powder is mainly produced by reacting carbon with B_2O_3 in an electric arc furnace, through carbothermal reduction or by gas phase reactions. For commercial use B_4C powders usually need to be milled and purified to remove metallic impurities.

Fig. 1.2Boron carbide (B_4C) powder

2. EXPERIMENTAL DESIGN:

In friction stir processing the parameters used in this experimental work are tool travel speed, tool rotation speed, and vol. % age of reinforcement particles. Feasible levels of the process parameters were chosen in such a way that the surface composite should be free from defects.

Table 2.0 Experimental Design

Ex pt.	**Rotatio n Speed (rpm)**	**Transvers e Speed (mm/min)**	**Vol. % of Reinforcement Particles B_4C**	**No. Of Passes**

No.				
1	1120	40	16	1 Pass
2	1120	40	16	2 Pass
3	1120	40	16	3 Pass
4	1120	40	16	4 Pass

2.1 EXPERIMENTAL PROCEDURE:

A CNC milling machine was used for Friction Stir Processing (FSP) of aluminum alloys. The maximum speed and power of machine were 6000rpm and 10-horse respectively.

The materials used in this work is commercial AA6082, Boron Carbide (B_4C) as an reinforcement particles and Hardened H13 tool steel was used that consists of a shoulder with a diameter of 18mm and pin length of 6mm as shown in the figure.

The surface plates were cleaned with grinding paper and methanol before Processing. Work pieces of AA6082 alloys were prepared with a length, width and thickness 200x100x6 mm^3 respectively.

Fig.2.0.Tapered with threaded tool

FSP was emerged as novel technique to fabricate metal composites and is based on the FSW. In this process, the aluminum alloys metal matrix composites in the solid state itself. At first, the groove made in the plates and reinforcement particles are packed in it. Then particles are filled in the groove and compacted with pin less tool. Finally tool pin was plunged at one end of plate and transverse across the plate. The shoulder touches the surface of plate and produces frictional heat which plasticized the material. The tool pin stirs and mixes the matrix material with reinforcement and produces the composites.

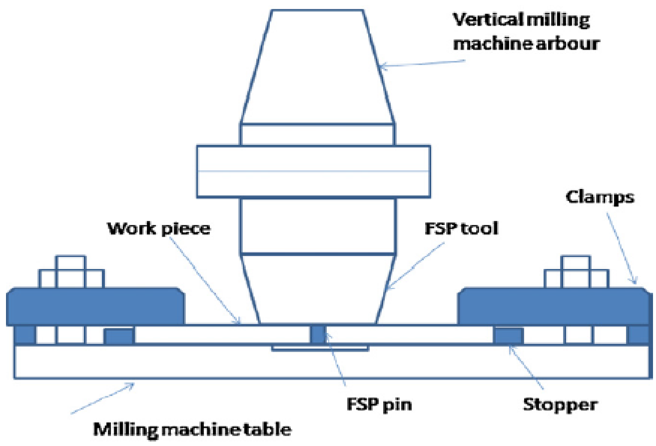

Fig 2.1 Experimental set-up of FSP

The following are the experiments done with different parameters listed in the above design Table 2.0

Fig.2.2. BASE METAL

Fig 2.3.Expt. SAMPLE-1

Fig.2.6

Fig.2.4 Expt. SAMPLE-2

Expt. SAMPLE-4

Fig. 2.5 Expt. SAMPLE-3

3.0RESULTS AND DISCUSSIONS:

3.1MICROSTRUCTURE:

After FSP, micro structural observations were carried out at the cross section of stir zone (SZ) of the surface composites normal to the FSP direction mechanically polished and etched with 10% potassium dichromate in 100 cc of water +2 cc of Conc. HCL. Micro structural changes were observed by optical microscope (OM) in SZ/NZ.

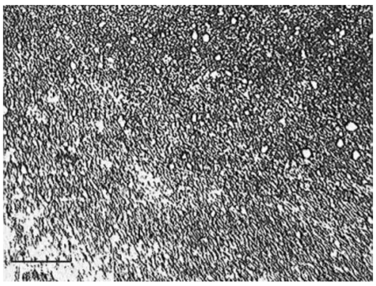

Fig.3.0 Microstructure of Sample-1

Fig.3.0 shows the interface zone of the HAZ and the nugget zone and the heat affected zone shows the distribution of composite particles

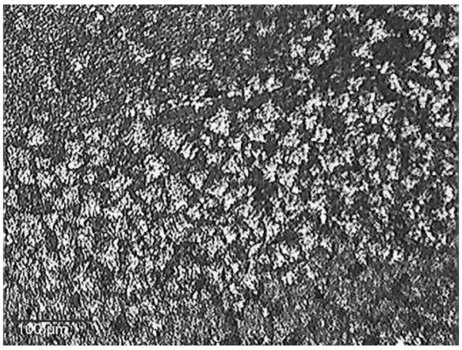

Fig.3.1 Microstructure of Sample-2

Fig.3.1 shows the upper zone of the nugget with uniform grains but the grains are bigger than the bottom zone

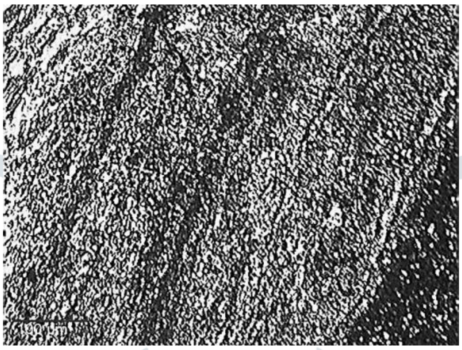

Fig.3.2 Microstructure of Sample-3

Fig.3.2 shows the fusion zone/nugget zone with two layers of fusion probably due to passes. The grain orientation is vertical and some composite particles observed in the zone

Fig.3.3 Microstructure of Sample-4

Fig.3.3 shows the layers of the fusion between the parent metal and the nugget zone. The hardness is higher at this zone

3.2MECHANICAL PROPERTIES:

3.2.1TENSILE TEST:

A tensile test consists of a test specimen that is grasped at each end by tensile testing machine jaws and subjected to a tensile axial load. The specimens required for tensile test were prepared by WIRE CUT EDM according to ASTM standard. The American society for testing and materials (ASTM-E8) maintains a library of testing specimens, including procedures for tensile testing for different materials under wearing circumstances.

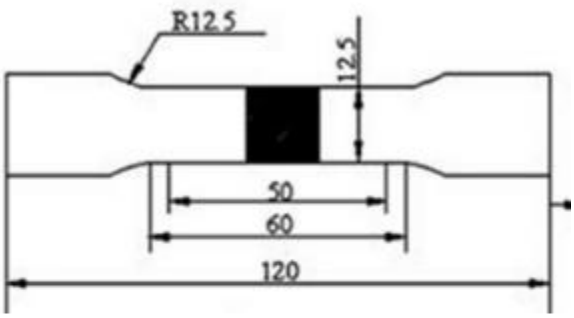

Fig.3.4Schematic diagram of tensile test specimen

The standards are specific in many cases. The specimen is generally a rectangular cross section piece, although other specimen geometries can be used to evaluate certain situations. Gauge marks are scribed on to the surface of the specimen and separated by a known distance. A servo control universal testing machine was use for the tensile test.

Fig.3.5Tensile test specimens

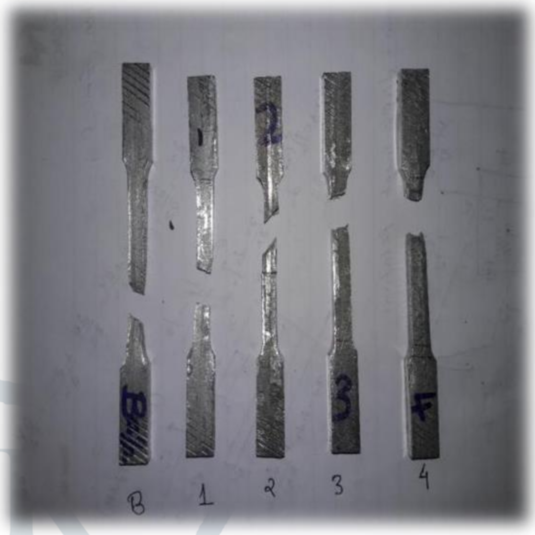

Fig.3.6 Tensile Tested Specimens

3.2.1.1SEM FRACTOGRAPH IMAGES:

SEM Fractograph images for the tensile tested specimen metal is given below

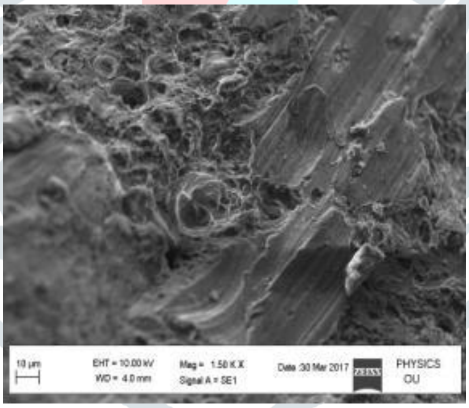

Fig.3.7Fractographs of Base metal

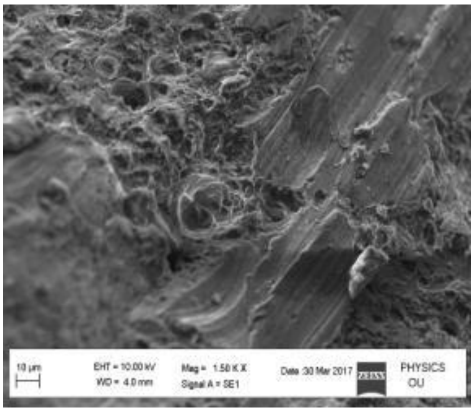

Fig.3.8Fractographs of Sample-1

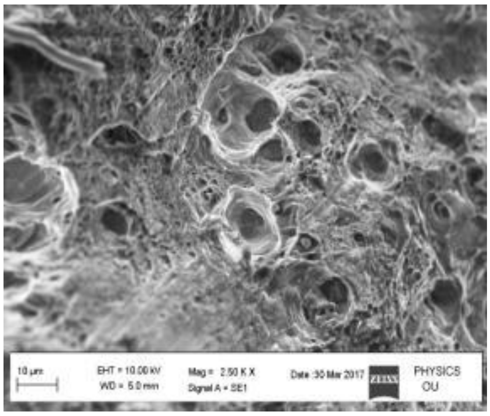

Fig.3.9Fractographs of Sample-2

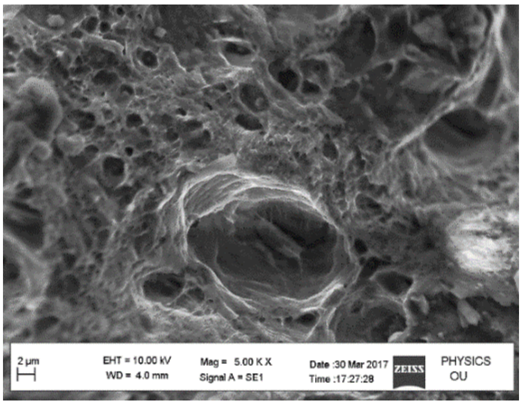

Fig.3.10Fractographs of Sample-3

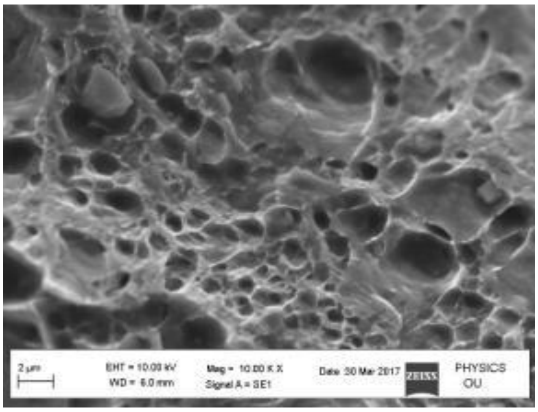

Fig.3.11Fractographs of Sample-4

Fig.3.7 to Fig.3.11 ShowsDimples observed in SEM Fractographs represented micro voids created during the tensile test. The parabolic shaped impressions shown in micrograph at failure may be representing shear failure as expected in ductile materials the dimples in lower strain rate were smaller and well centered in shape.

However a combination of small and large dimples was observed in high strain rate. As the strain rate increased, the percentage of dimples decreased, which meant that the material showed more brittleness. Besides, the dimples under lower strain rate were deeper than those under higher strain rate. With the strain rate increasing, the plastic strain decreased and showed more brittleness. Usually, dimples were on behalf of toughness, and Cleavage fracture represented brittleness. Dimples were the result of empty aggregation. At first, spaces formed inside the material and gradually grew together with other spaces under the action of the slip and then the dimples were formed. Cleavage fracture surface occurred along a certain crystal plane, when two cleavage crack intersected, cleavage steps formed. Because there existed the situation that when positive cleavage comes across negative cleavage, they will offset one another, the cleavage tends to expand to plane. As more cleavage appeared at a higher strain rate, the plastic strain got smaller than that at a lower strain rate.

Generally, the second phase particles on the grain boundary had pinning effect, which hindered the grain boundary sliding and grain growth to improve the strength of the material. With more precipitates generated in fracture, the dislocation would encounter more obstacles when moving, thus reducing the amount of plastic deformation. Meanwhile, particles crossed by the dislocation loop will have a repulsive force, which will create resistance against the dislocation loop propagation; the existence of more dislocation loops will face more resistance by the particles generating higher resistance forces. In order to maintain deformation compatibility, more dislocations would start to move, so the material could bear higher stress.

3.2.2 FLEXURAL TESTING:

The test method for conducting the test usually involves a specified test fixture on a universal testing machine. The sample is placed on two supporting pins a set distance apart and a third loading pin is lowered from above at a constant rate until sample failure. The specimen is prepared as per ASTM D790standards.

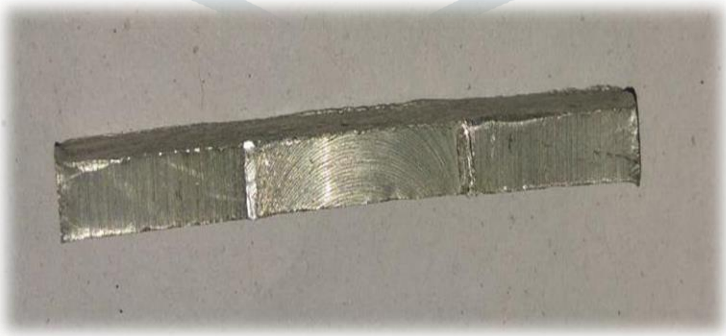

Fig. 3.12Flexural Specimen before Testing

Fig. 3.13 Flexural Base MetalSpecimen after Testing

Fig. 3.14
Flexural Sample-1 Specimen after Testing

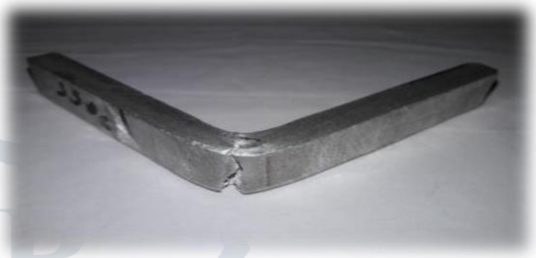

Fig. 3.15
Flexural Sample-2 Specimen after Testing

Fig. 3.16
Flexural Sample-3 Specimen after Testing

Fig. 3.17
Flexural Sample-4 Specimen after Testing

Table 3.1 Evaluated Mechanical properties

Expt. No.	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	% of Elongation	Flexural Strength (MPa)
1	296.65	248.79	10.46	439.9
2	330.26	241.70	9.96	495.3
3	351.82	227.04	8.06	517.7
4	345.87	238.06	10.2	508.8

3.2.3 HARDNESS TESTING:

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated.

Table 3.2 Evaluated Hardness properties

Expt. No	Sample-1	Sample-2	Sample-3	Sample-4
Hv	102.7	116.5	121.3	129.1

3.2.4 CORROSION TEST:

The **salt spray (or salt fog) test** is a standardized and popular corrosion test method, used to check corrosion resistance of materials and surface coatings. Salt spray testing is an accelerated corrosion test that produces a corrosive attack to coated samples in order to evaluate (mostly comparatively) the suitability of the coating for use as a protective finish.

The apparatus salt spray corrosion tests were carried out in 3.5 wt% NaCl (PH 7.0) solutions for 24 hours to find out the corrosion resistance as per ASTM B 117 standards. The specimens for test was cut stir area perpendicular to stirring direction of size 10 mm × 10 mm × 6 mm and masked on all sides except to surface. The samples are polished with emery paper and degreased with acetone and rinsed with distilled water before immersion of thespecimens. The weight of samples was measured before and after the corrosion test. The weight loss of material was themeasure ofcorrosion rate. The samples were cleaned ultrasonically to remove the salts sticking to the surface for examination of surface with scanning electron microscope.

Fig.3.18 Corrosion test specimen

3.2.4.1 CORROSION TEST:

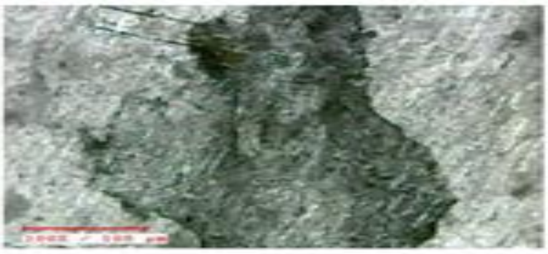

Fig. 3.19Corroded surface of Base metal

Fig. 3.20 Corroded surface of Sample-1

Fig. 3.21 Corroded surface of Sample-2

Fig. 3.22 Corroded surface of Sample-3

Fig. 3.23 Corroded surface of Sample-4

Table 3.3 Corrosion rate

Expt. No.	Weight loss (gm)	Corrosion (mm/year)	Corrosion (miles/year)

Base	0.007	0.00429	2.03
1	0.004	0.00264	1.25
2	0.005	0.00334	1.57
3	0.002	0.00121	0.58
4	0.001	0.00059	0.27

4.0 CONCLUSION

4.1.1TENSILE TEST:

The ultimate tensile strength 3-Pass FSP exhibited high strength (351.8MPa) compared to the Base Material (320MPa)

4.1.2FLEXURAL STRENGTH:

The Flexural strength 3-Pass FSP exhibited high strength (517.7MPa) compared to the Base Material.

4.1.3 MICRO HARDNESS:

The Hardness of 4-Pass FSP exhibited high hardness (129.1Hv) compared to the 1-Pass FSP (102.7HV), 2-Pass FSP (116.5Hv), 3-Pass FSP (121.3Hv) and Base Material (95HV) Respectively.

4.1.4 CORROSION TEST RESULTS:

It is observed that the mass loss and corrosion rate of composites were low as compared to the base metal. This indicates that composites will be suitable for sea environments and marine applications. The corrosion rate was decreased for 4-Pass FSP AA 6082-T6 –B_4C Surface composites.

AA 6082-T6 –B_4C Composites tangibly showed better mechanical properties compared with Base material Sample by applying one through Four-100% overlapping passes. Mechanical properties of Al 6082-T6 –B_4C Surface composites increased with increase in the No. of Passes, whereas the specimens of multipass FSP with B_4C particles exhibits a poor elongation and Yield strength, and the improvements in ultimate tensile strength (351.81Mpa) by (9.94%), flexural strength (517.7MPa) by (7.85%) were attained in the 16 Vol. % B_4C 3-Pass FSP and Hardness (129.1Hv) by (35.89%) attained in the 16 Vol. % B_4C 4-Pass FSP.

Microstructure of the FSP composite nugget cross section was observed by optical microscope. It was observed that the B_4C reinforcement particles were uniformly distributed in the stir zone without any defects

The following can be concluded:

a. Friction stir processing being eco-friendly joining process, improves safety due to absence of toxic fumes.
b. Using FSP composites are fabricated successfully with multi-passes.
c. It is found that mechanical properties are improved with no. of passes.
d. It is found that corrosion rate is lesser for composites.

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