Original Article

Novel investigation on tensile strength, compressive strength, hardness, and corrosion resistance of Al6061 hybrid composite with 15 % weight fraction of Silicon carbide and Fly ash and comparing the outputs with as-cast Aluminium 6061

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Abstract

Aim: The aim of this research is to fabricate an aluminium hybrid metal matrix composite reinforced with a 15% weight fraction constituting 7.5% of silicon carbide and 7.5% of fly ash using the stir casting method under controlled process parameters and compare tensile strength, compressive strength, hardness and corrosion resistance with pure as-cast Aluminium 6061. **Materials and Methods:** Samples of dimensions 150mm x 150mm and thickness 10mm are prepared under Identical conditions adhering to standards. For g power calculations (threshold level: 0.20, confidence interval: 80%) gives a sample size of 80. Mechanical tests are taken individually on each sample for 20 samples of the experimental group (AHMMC) and control group (As-cast AL6061) as per ASTM standards. **Results:** One-way ANOVA using SPSS software shows that AHMMC with a 15% weight fraction of SiC and Fly ash has a significantly higher tensile strength (38.97 MPa), compressive strength (55.91 kN), and hardness (76 HV) but has slightly lower corrosion resistance (1.659 mm/year) than that of as-cast Al6061 with a significance level of 0.036 ($p<0.05$). **Conclusion:** Within the limitations of this study, It is revealed that AHMMC with a 15% weight fraction of SiC+Fly ash exhibited enhanced Mechanical and physical properties when compared to as-cast Al6061.

Keywords: Novel experiment, Corrosion resistance, Metal matrix composite, Muffle furnace, Statistical analysis, Stir casting

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INTRODUCTION

Aluminium hybrid metal matrix composites are highly used in industries instead of conventional aluminium alloys because of their improved characteristics like tensile strength, Compressive strength, weight ratio, energy-saving capabilities, and corrosion resistance. Various researches have been undergone to determine the stable weight fraction for aluminium 6061 reinforced with various materials such as B_4C, Al_2O_3, TiC, SiC, Gr, etc. (Sandeep Kumar Ravesh November- December 2012) attempted to analyze the applications of AMCs which are increasingly being used in high-tech structural and functional applications such as aerospace, defense, automobiles, and thermal management due to their increased characteristics. (G. B. V. Kumar et al. 2012) instigated the hardness of an Al6061-SiC composite and noted a significant increase of 67% for a 6 % weight fraction. This increase in hardness can be attributed to the high hardness that SiC possesses. (2011) conducted research on Al6061 composite reinforced with fly ash and found that the tensile strength, compressive strength, and hardness of the Al6061 composite is decreasing when the particle size is increased at a constant proportion. The addition of SiC reinforcement decreased the wear rate for all the composites in work undertaken by (Yalcina and Akbulut 2006) employing two different smelting techniques for the manufacture of Al-SiC. Comparably in this novel experiment, an Aluminium hybrid composite with a 15% weight fraction of SiC (7.5%) + Fly ash (7.5%) is fabricated and studied. Mechanical properties such as tensile strength, compressive strength, hardness, and corrosion resistance of the experimental group which is the aluminium hybrid composite are compared with the properties of the control group which is the pure as-cast aluminium 6061.

On reviewing the past research related to aluminium hybrid metal matrix composites, it is found that there are around 734 papers in Google Scholar and 349 papers in ScienceDirect. An increase in tensile strength and hardness with the increase in weight percentage of B_4C particles is discussed in the study of aluminium metal matrix composite reinforced with Boron carbide with an average particle size of 25 micrometers at different weight percentages (Ravi, Balu Naik, and Udaya Prakash 2015)(G. B. V. Kumar et al. 2012)(Ravi, Balu Naik, and Udaya Prakash 2015). Mechanical properties, tribological properties, and microstructural properties of aluminium 2xxx series alloys processed powder metallurgy along with reinforcement materials like SiC and Al_2O_3 are presented (Ashwath and Anthony Xavior 2016). Microstructural properties of Al-4.5Cu alloy reinforced with TiC particulate are studied and optimum process parameters for stir casting are derived (Das et al. 2016). In a study on reinforced Al7075, the parent group is evaluated and reinforcement of 6% SiC in Al7075 shows improved density, hardness, bending strength, and elongation is observed (P. Kumar et al. 2018). On review of the following pieces of literature, it is observed that research work by (P. Kumar et al. 2018) showed identical findings, thus it can be said that the work is closely studied for this research.

Our team has extensive knowledge and research experience that has translate into high quality publications(Bhansali et al. 2021; Jayanth et al. 2021; Sudhakar, Ravel, and Perumal 2021; Sathiyamoorthi et al. 2021; Deepanraj et al. 2021; Raju et al. 2021; Arun Prakash et al. 2020; Kamath et al. 2020; Shanmugam et al. 2021; Rajasekaran et al. 2020; Adhinarayanan et al. 2020; Rajesh et al. 2020; Aurtherson et al. 2021). Even though a lot of research works related to metal matrix composites can be found, only a handful of works related to Al6061, SiC, and fly ash with a higher weight fraction can be found as no comparison is made between samples with 15% wt. This research gap is due to the limitations in the conventional stir casting method which cannot produce stable composites at higher weight fractions with normal process parameters. In this research, we inculcate modified optimal process parameters in stir casting to achieve a weight fraction of 15% SiC+Fly ash, which is rarely achieved before. Then we compare the mechanical properties of AHMMC with Pure Al6061 to investigate and conclude the enhancements in AHMMC.

Materials And Methods

Sample preparation and testing of samples as per standards are accomplished with the aid of facilities provided by the Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai. This novel experiment is composed of 2 groups, the experimental group (AHMMC) and the control group (As-cast Al6061). According to g power calculations with standard deviation (0.05) and mean (0.2) for a 0.20 threshold level and 80% confidence interval (Kang 2021), it is determined that each group should consist of a sample size of 80 which makes the total sample size to be 160. Each sample is produced in the form of a square plate with dimensions 150x150mm and a thickness of 10mm. All four tests were conducted on a single sample by machining out required shapes separately for each test as per ASTM standards and it is repeated for all 160 samples.

To Prepare the Experimental group, We add two reinforcement materials with matrix material in this research, Silicon Carbide (SiC) and Fly ash at equal proportions of 7.5% making 15% on whole. We choose Silicon Carbide because it exhibits adequate bonding capability even though its density of 3.2g/cm^3 is higher than Al6061. SiC has good thermal conductivity and strength in nature. Fly ash is a low-density (2.1g/cm^3) material readily available at a low price in the form of solid waste as a by-product of burning coal in power plants. The addition of fly ash helps to prevent the formation of undesirable Al_4C_3 which may destabilize the composite. The fly ash for this research was obtained from Ennore thermal power station and it has a particle size of 12μm. The experimental group is prepared by melting 1.5kg of industrial-grade Aluminium 6061 in a muffle furnace at a temperature of 750^{o}C for complete melting of the metal. The hybrid metal matrix composite is synthesized by the stir casting method under controlled process parameters as given in Table 1. From the total weight of the molten metal 15% is reduced. Now the molten metal is stirred in a mechanical stirrer at a speed of 1350 rpm for about 30 minutes, and powders of silicon carbide and fly ash are added at a constant interval and at definite proportions. Proportions of SiC and fly ash are 250g and 400g respectively which is 15% (7.5%+7.5%) of 1.5kg. After 30 minutes of stirring, the liquid composite is poured into a preheated Steel mould with dimensions 150x150mm and a thickness of 10mm to form a casting as shown in Fig 1. The mould is preheated to 250^{o}C to avoid capturing moisture from the atmosphere. The casting is allowed to solidify and cool for 8 hours and then the cast is retrieved. The obtained sample is machined to obtain a smooth surface finish.

For this research to Prepare Control group, we employ standard industrial-grade Aluminium 6061. Aluminium 6xxx series is by far the most popular material due to its effortless manufacturing process and its consumption in various industrial components and structures that require high strength, weldability, and corrosion resistance, such as pipes, rods, heat exchangers, ships, furniture, mechanical parts, precision processing, etc (Georgantzia, Gkantou, and Kamaris 2021)(G. B. V. Kumar et al. 2012)(Georgantzia, Gkantou, and Kamaris

2021). Typical Al6061 is composed of 97.9% Al, 0.6% Si, 1.0% Mg, 0.2% Cr, and 0.28% Cu with a density of 2.7g/cm^3. The control group is prepared by melting 1.5kg of industrial-grade Aluminium 6061 in a muffle furnace at 750ºC temperature and directly pouring it into the preheated mould with dimensions 150x150mm and thickness 10mm to form a casting as shown in Fig 2. The casting is allowed to solidify and cool for 8 hours before retrieving the cast. The obtained sample is machined to obtain a smooth surface finish. This process is repeated for all 80 samples.

Tensile strength is the ability of a material to withstand tearing under load. Tensile strength for samples from both groups is conducted on a universal testing machine (UTN 40., 1/2011-4540) with 30 tonne capacity at a constant 26ºC room temperature. The required samples to conduct the tensile test were cut out in the shape of a dogbone (M.a. and Unnikrishnan 2020) as per ASTM E8-21 standard as shown in Fig 3. The outputs obtained in Megapascal (MPa) and also a computerized graph for Force (N) and Stroke (mm) are obtained. Compressive strength is the ability of a material to withstand a load without a reduction in size. Compressive strength for samples of both groups is carried out on a universal testing machine (UTN 40., 1/2011-4540) with 30 tonne capacity at a constant 26ºC room temperature.

The required samples to carry out the compressive test were machined in a cylindrical shape as per ASTM E9 standard as shown in Fig 4. The outputs are obtained in Kilonewton (KN) and also a computerized graph for Force (N) and Stroke (mm) are obtained. Hardness is the ability of a material to resist plastic deformation. Hardness for individual samples from both groups is performed on a Brinell hardness tester (B-3000 OIAL/ME/09) with an indenter diameter of 5mm for a load of 0.5Kg. The testing is carried out as per Indian Standards (IS 1501-20 P1) and the values are obtained in Vickers hardness (HV). Hardness on three different spots is recorded in a single specimen to get a more clear understanding of the variation of accurate value. Corrosion resistance is the ability of a material to withstand chemical or electro-chemical deterioration. The corrosion test is carried out in an engineered space adhering to the given parameters in Table 2. The sample is dipped in salt spray solution for 24 hours and the salt spray test is carried out as per ASTM B117-19 standards (Okazaki and Gotoh 2005).

Statistical analysis

The SPSS (v.26) software is utilized in this research for statistical analysis. On considering the values of Tensile Strength, Compressive strength, and hardness of experimental and control groups as dependent variables and considering the 20 trails and aluminium group as independent variables, one-way ANOVA and post hoc Bonferroni tests were carried out (Cox and Holcomb 2021). Bar graphs and descriptive data were obtained by performing group statistics as tabulated in Table 3.

Results

This study is carried out in 3 broad steps, The first step is to fabricate the samples for the experimental group and control group by taking into account the stir casting process parameters as given in Table 1. The second step is to perform mechanical tests on the prepared samples of both groups. The corresponding test results for as-cast aluminium are tabulated in Table 2, and results for AHMMC are tabulated in Table 3. The third and final step is to perform a statistical analysis on the results obtained. Table 4, shows the descriptive statistics of the tests for both groups with a 95% confidence interval. Whereas Table 5, shows the ANOVA Post Hoc Bonferroni pairwise comparison of the material properties understudy with a 95% confidence interval.

Figure 1 shows a bar chart representing the comparison of mean values (± 1 SD) of Tensile Strength, Compressive Strength, and Hardness among the examined aluminium groups. From the graph, it is inferred that the mean of Al6061 MMC with 15% weight fraction of SiC + Fly ash is better than that of as-cast Al6061. Similarly, Fig. 2 shows the comparison of mean values (± 1 SD) of Corrosion resistance among the examined aluminium groups and it can be seen that the mean of as-cast Al6061 is not significantly different from that of Al6061 MMC with a 15% weight fraction of SiC + Fly ash. The prepared samples for the Experimental and Control groups are shown in Fig. 3 and Fig. 4 respectively and the machined Dogbone sample and cylindrical sample for the tensile test and compressive test are shown in Fig. 5 and Fig. 6 respectively.

Discussion

The comparison was made between Aluminium hybrid metal matrix composite (experimental group) and as-cast Aluminium 6061 based on the results obtained for tensile strength, compressive strength, hardness, and corrosion resistance. The mean tensile strength for the experimental group and control group is found to be 37.5 MPa and 17 MPa respectively and a significant improvement of 76% in tensile strength is noted in the Aluminium hybrid metal matrix composite (experimental group). The mean compressive strength for the experimental group and control group is found to be 56 kN and 53 kN respectively and a significant improvement of 3% in compressive strength is noted in the Aluminium hybrid metal matrix composite (experimental group). The mean hardness for the experimental group and control group is found to be 86 HV and 84 HV respectively and a significant improvement of 4% in hardness is noted in the Aluminium hybrid metal matrix composite (experimental group). Whereas there are no significant changes in values of corrosion resistance for both the groups.

All the values of different mechanical tests for AHMMC (experimental group) and for as-cast Al6061(control group) obtained in this experiment are summarized in Table 3 and these findings are very much in correlation with the findings of (Sivananthan, Ravi, and Samuel 2020)(G. B. V. Kumar et al. 2012)(Sivananthan, Ravi, and Samuel 2020). From Fig. 2 and Fig. 3 it can be inferred that AHMMC has the highest of all the property values under investigation. This is also evident in the study conducted by (Murugan, Velmurugan, and Jegan 2016)(G. B. V. Kumar et al. 2012) (Murugan, Velmurugan, and Jegan 2016) where the values are increasing with wt% and stirring time likewise exhibited in (Mali, Sonawane, and Dombale January-2015)(G. B. V. Kumar et al. 2012)(Mali, Sonawane, and Dombale January-2015). From Table 6 it is evident that there is a statistically significant difference in the material properties of investigated groups of aluminium ($p < 0.001$ one-way ANOVA) and this statement is in agreement with the findings of (Ghosh, Sahoo, and Sutradhar 2012)(G. B. V. Kumar et al. 2012)(Ghosh, Sahoo, and Sutradhar 2012). For fly ash reinforced AA6061, (Raja, Robinson, and Dinaharan 2013)(G. B. V. Kumar et al. 2012)(Raja, Robinson, and Dinaharan 2013) managed to show similar effects on the mechanical properties for 12% wt.

It is concluded that there is an aggregate average enhancement of 16.7% in Aluminium hybrid metal matrix composite when compared to as-cast aluminium 6061. This study is limited by the number of tests performed. Furthermore, tests like the surface roughness of the drilled holes can be performed to determine their application in the threading and fabrication processes. The obtained property values of AHMMC (with a 15% weight fraction of Sic+Fly ash) are valid only for 1350 rpm and a temperature of 600^{o}C used, contrasting to the standard 500 rpm and 850^{o}C. These results from this study can be interpreted and integrated for special application materials and for future studies. This research work will be extended in the future by varying the stir casting temperature, reinforcement preheating temperature, stir casting rotational speed, and stirring time.

Conclusion

Thus the motive of the research, which is to cast an aluminium hybrid composite with a 15% weight fraction of silicon carbide and fly ash using stir casting and compare the results of various mechanical tests such as tensile strength (as-cast Al6061: 17 MPa, AHMMC: 37.5 MPa), compressive strength (as-cast Al6061: 53 kN, AHMMC: 56 kN), hardness (as-cast Al6061: 84 HV, AHMMC: 86 HV), and corrosion resistance (as-cast Al6061: 0.85, AHMMC: 0.83) against the control group which is the as-cast aluminium 6061 is achieved. Analysis of the results and output tells that there is a significant improvement of 29.27% in the overall Mechanical properties of the aluminium hybrid metal Matrix composite whereas there is no change in corrosion resistance for a test of 24 hours. Within the limitations of this study, aluminium hybrid composite has greater mechanical properties than as-cast aluminium 6061. This result and methods can be adopted and utilized in industrial manufacturing and applications of special materials.

DECLARATIONS:

Conflict of Interests

The authors of this paper declare no conflict of interest.

Authors' Contribution

Author LR was involved in data collection, data analysis, and manuscript writing. Author GB was involved in the conceptualization, data validation and critical review of the manuscript.

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TABLES AND FIGURES

Table 1. Stir casting Process Parameters

S.no	Parameter	Value
1	Temperature	600^{o}C
2	Speed	1350 rpm
3	Duration	30 minutes
4	Powder adding interval	8 minutes
5	Powder adding proportions	1.8%

Table 2. Parameters of Corrosion test

S.no	Test Conditions	Values
1	Chamber Temperature	34.1 - 34.8^{o}C
2	pH of Solution	6.6 - 6.9
3	Air Pressure	15 psi
4	Concentration of sodium chloride	5.1 - 5.4%
5	Collection of solution per hour	1.1 - 1.5 ml
6	Test hours	24 hours

Table 3. Tensile strength, Compressive strength, Hardness, and Corrosion resistance values of as-cast Aluminium 6061

Sl.No	Tensile strength (MPa)	Compressive strength (kN)	Corrosion resistance (mm/year)	Hardness (HV)
1	12.73	52.86	0.967	73
2	14.71	51.09	0.748	74
3	16.7	51.76	0.77	73
4	**18.88**	52.44	0.784	70

5	12.06	52.61	0.641	68
6	11.53	51.71	1.141	68
7	17.63	52.15	0.814	66
8	13.95	52.37	0.593	73
9	14.44	51.78	1.015	**75**
10	16.2	52.81	1.168	75
11	17.23	51.38	0.794	72
12	12.55	51.36	**1.272**	71
13	12.03	51.18	0.896	69
14	13.58	51.46	0.658	75
15	12.19	52.22	1.122	70
16	17.88	**52.93**	0.699	73
17	17.33	52.92	1.107	72
18	14.5	52.82	0.828	67
19	17.98	51.66	0.535	69
20	17.85	52.87	1.224	70

Table 4. Tensile strength, Compressive strength, Hardness, and Corrosion resistance values of Aluminium 6061 Hybrid composite with 15% SiC and Flyash

Sl.No	**Tensile strength (MPa)**	**Compressive strength (kN)**	**Corrosion resistance (mm/year)**	**Hardness (HV)**
1	32.92	55.2	0.764	69

2	35.68	55.47	0.878	72
3	34.01	54.77	**1.659**	75
4	37.57	55.8	1.146	73
5	33.42	54.38	1.299	69
6	38.2	54.56	0.856	72
7	34.85	54.23	0.759	74
8	35.08	55.77	0.518	**76**
9	36.5	55.32	1.024	74
10	37.02	54.36	0.452	69
11	**38.97**	54.26	0.901	73
12	32.67	54.5	0.95	75
13	36.05	55.39	0.574	70
14	36.55	55.84	0.709	74
15	35.73	54.82	0.692	71
16	37.62	55.48	0.765	72
17	35.48	55.03	0.507	70
18	38.8	**55.91**	0.726	73
19	32.5	54.75	0.69	69
20	36.75	54.76	0.916	71

Table 5. Descriptive table showing the comparison of material properties of different aluminium groups with 95% confidence interval.

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Tensile Strength	Al6061	20	15.0975	2.45093	0.54804	13.9504	16.2446	11.53	18.88
	AHMMC	20	35.8185	1.97545	0.44172	34.8940	36.7430	32.50	38.97
	Total	40	25.4580	1.12007	1.69499	22.0296	28.8864	11.53	38.97
Compressive Strength	Al6061	20	52.1190	0.64557	0.14435	51.8169	52.4211	51.09	52.93
	AHMMC	20	55.0300	0.56563	0.12648	54.7653	55.2947	54.23	55.91
	Total	40	53.5745	1.59113	0.25158	53.0656	54.0834	51.09	55.91
Corrosion Resistance	Al6061	20	0.88880	0.223773	0.050037	0.78407	0.99353	0.535	1.272
	AHMMC	20	0.83925	0.286597	0.064085	0.70512	0.97338	0.452	1.659
	Total	40	0.86402	0.255031	0.040324	0.78246	0.94559	0.452	1.659
Hardness	Al6061	20	71.35	3.014	0.674	69.94	72.76	66	76
	AHMMC	20	72.05	2.235	0.500	71.00	73.10	69	76
	Total	40	71.70	2.643	0.418	70.85	72.55	66	76

Table 6. ANOVA table showing the statistically significant difference in material properties among the examined aluminium groups. It is observed that on performing One-Way ANOVA, there is a statistical significant difference for all the investigated properties ($p<0.05$).

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.

Tensile Strength	Al6061	4293.598	1	4293.598	866.567	0.001
	AHMMC	188.279	38	4.955		
	Total	4481.878	39			
Compressive Strength	Al6061	84.739	1	84.739	230.053	0.001
	AHMMC	13.997	38	0.368		
	Total	98.736	39			
Corrosion Resistance	Al6061	0.025	1	0.025	0.371	0.036
	AHMMC	2.512	38	0.066		
	Total	2.537	39			
Hardness	Al6061	4.900	1	4.900	0.696	0.009
	AHMMC	267.500	38	7.039		
	Total	272.400	39			

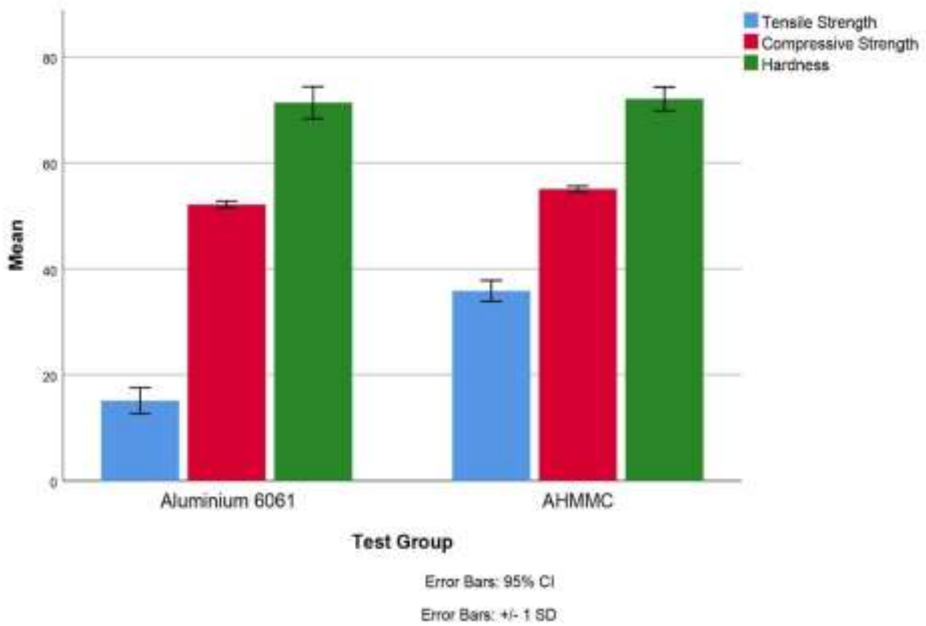

Fig. 1. Bar chart showing the comparison of mean values of Tensile Strength, Compressive Strength, and Hardness among the examined aluminium groups. The mean of Al6061 MMC with 15% weight fraction of SiC + Fly ash is better than that of as-cast Al6061. X-axis: Al6061 MMC with 15% SiC + Fly ash vs as-cast aluminium 6061. Y-axis: Mean value of properties ± 1 SD

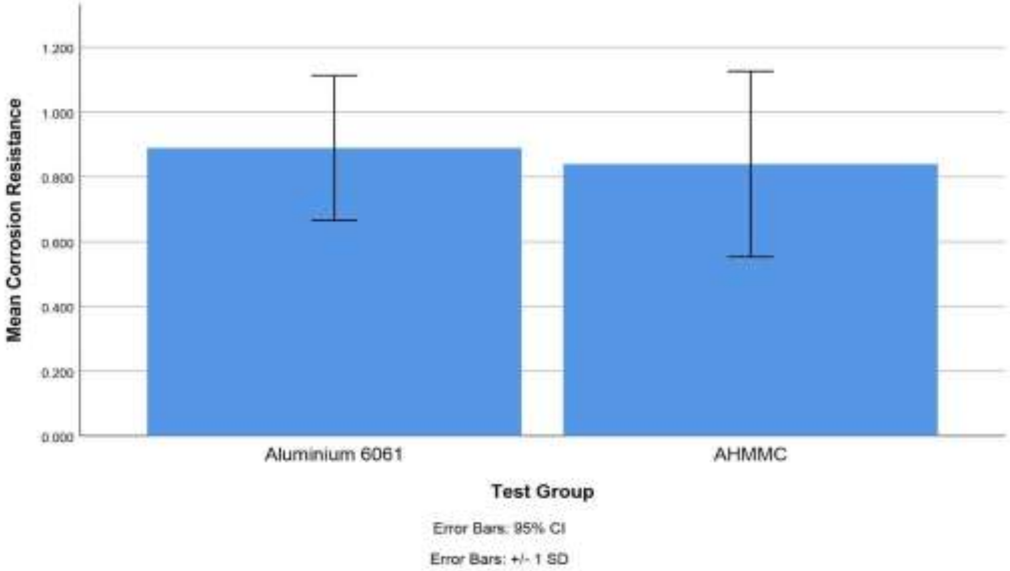

Fig. 2. Bar chart showing the comparison of mean values of Corrosion resistance among the examined aluminium groups. The mean of as-cast Al6061 is not significantly different from that of Al6061 MMC with 15% weight fraction of SiC + Fly ash. X-axis: Al6061 MMC with 15% SiC + Fly ash vs as-cast aluminium 6061. Y-axis: Mean value of properties ± 1 SD

Fig. 3. Experimental Group(Al6061+SiC+Fly ash) Sample

Fig. 4. Control Group(as-cast Al6061) Sample

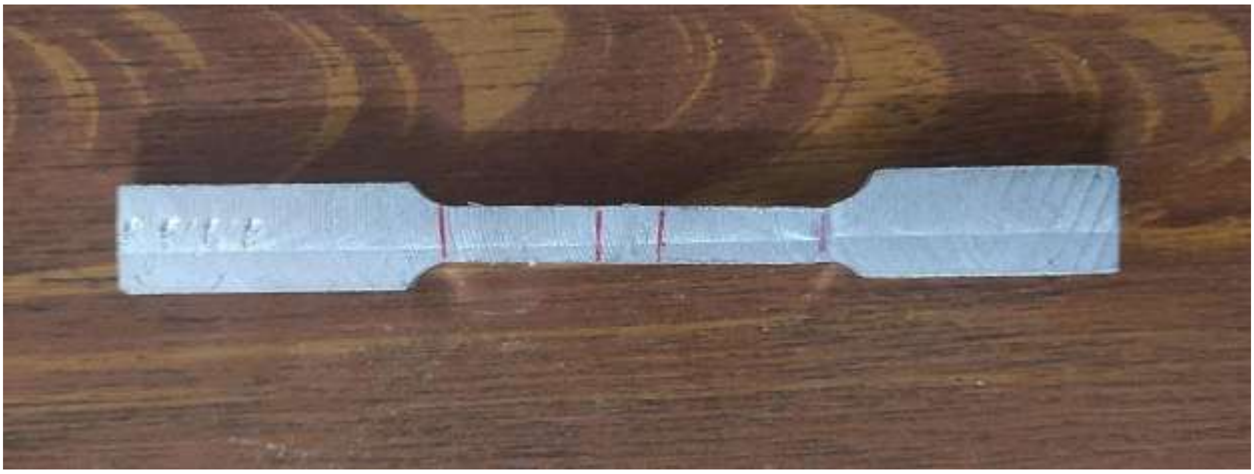

Fig. 5. Tensile test Dogbone sample

Fig. 6. Compressive test cylindrical sample