Mechanical Characterization of Al6061 Alloy Reinforced with SiC and Gr through Stir Casting Method

Lakshminarayana T H[1], Vinay A N[2], Shilpa T V[3]
Department of Mechanical Engineering[1,2,3]
R L Jalappa Institute of Technology, Doddaballapur, India
lakshminarayanath@rljit.in, vinayan@rljit.in, shilpatv@rljit.in

Abstract*: Hence, this project work focuses on the development of composites of the Aluminium Alloy 6061 metal matrix hybrid composite. The objective was to evaluate the physical properties of the aluminium alloy (Al6061) in the presence of Silicon Carbide (SiC) and Graphite (Gr) with their variations to study the microstructure and mechanical characteristics. In this study, electric arc resistance furnace is utilized to prepare the aluminium alloy-based metal matrix hybrid composites with variable weight fractions of 0, 2, 4, 6 and 8% SiC/Gr particles (40 to 50 microns). Based on the ASTM standard, the manufactured aluminium alloy-based metal matrix hybrid composites endure the evaluation of microstructure and mechanical characteristics.*

Keywords: Al6061; SiC; Gr; Hybrid composites.

I. INTRODUCTION

Over time, the idea of "sustainable development" for an advanced civilization with a rapidly expanding global population has come to be understood as a condensed strategy that emphasizes scientific analysis as well as the continual improvement and growth of environmental, social, and financial considerations. Due to its advantages over other materials used in structural applications, such as strength, low cost, low density, and ease of availability, aluminum-based alloys are frequently used in modern engineering implementations such as aircraft and automotive applications. Composites are promising materials that were developed primarily in response to unique technological demands brought on by the fast-evolving behavior of the aerospace, automotive, and aerospace sectors. Compared to common metal alloys such metals [1-5], these materials overall strength and modulus are improved by their low specific gravities.The features of composites are influenced by the size of the particle and how it is dispersed inside the matrix material, as well as by the volume or weight ratio between the matrix and reinforcement.Al, magnesium, copper, titanium, Al-lithium, and super-alloys are widely used as the matrix materials in these composites. Al-based metal matrix composites were extensively used in a number of different sectors. The use of aluminium as a matrix material to form MMCs has developed in response to the desire for lightweight materials with high strength and stiffness. Reinforcing SiC, TiB_2, TiC, B_4C, SiC, Al_2O_3, and ZrO_2 containing minute ceramic particles results in aluminum-based MMCs [6-10].A wide variety of material that typically comprise a metallic matrix with reinforcement for desired qualities are referred to as MMC. Aluminum, magnesium, and their alloys are good examples of metals with outstanding ductility, formability, or strong heat conductivity in their metal matrix. Due to its high degree of rigidity, strength, hardness, and wear resistance as well as its low coefficient of thermal expansion, ceramic is frequently employed as reinforcement. Ceramics constructed of SiC, Al_2O_3, and B_4C are common examples. MMC is intended to alleviate some of the mechanical or thermal limits of the matrix while minimizing the benefits of the matrix. In other words, MMC takes advantage of both the benefits of reinforcement and the matrix [16].The materials used in AMMCs today are among the most well-known composites because they have higher qualities like stiffness, hardness, low wear, and good corrosion resistance. These materials are perfect for a wide range of applications, including valve assembly, slide contacts, cylinder liners, stator vanes, annulus fillers, fans, and automobile pistons, thanks to their outstanding wear resistance, high thermal conductivity, and low thermal expansion coefficients. The expanding use of particulate aluminium metal matrix composites in different industries has substantially increased the researcher's urge to create a new processing and estimating approach [17].

II. SELECTION OF THE MATERIALS

The selection of material for the preparation of Al6061/SiC/Gr composite is done based on the research gap on the use of matrix and reinforcement material. Other criterions for selection of the material are availability, cost, and easy of fabrication.

2.1 Matrix Material

Aluminium alloy (Al6061) is an aluminium alloy with zinc as the primary alloying element. It has excellent mechanical properties and exhibits good ductility, high strength, toughness, and good resistance to fatigue. The Al6061 is widely used for construction of aircraft structures, such as wings and fuselages. Its strength and light weight are also desirable in other fields. Rock climbing equipment and bicycle components are commonly made from 6061aluminium alloy. Aluminium alloy matrix as shown in figure 4.1 and table 4.1 shows the chemical compositions of Al6061 alloy.

Table 1: Chemical composition of Al6061 alloy

Chemical composition [%]					
Element	wt. %	Element	wt. %	Element	wt. %
Si	0.67	Ti	0.2	Fe	0.6
Mg	1.58	Zn	0.17	Cu	0.27
Cr	0.2	Mn	0.22	Al	Bal.

Silicon carbide and graphite are polycrystalline composite materials, consisting of silicon carbide and graphite grains (single crystals) embedded in a matrix of amorphous or partially crystallized glassy phase. Their properties are not only determined by the intrinsic properties of silicon carbide and graphite single crystals, but strongly depend on the size and morphology of silicon carbide and graphite grains, as well as the volume fraction and chemistry of glassy phase at the grain boundaries of silicon carbide and graphite. In the first part, the article describes the structure, properties and manufacturing routes of silicon carbide and graphite single crystals. The last part describes the room temperature mechanical properties (hardness, strength, fracture toughness), high temperature mechanical properties (oxidation and creep resistance), and functional properties (thermal conductivity and biological properties) of silicon carbide and graphite.

III. RESULTS AND DISCUSSIONS

3.1 Microstructure

Significant improvements in mechanical characteristics was observed mainly due to the restructured grain structure, whereas increased splitting was mainly due to the presence of refurbishing particles that reduced the elongation properties and improved cargo capacity. Studies of particle additions found that with heterogeneous nucleation of the reinforcement grains, mechanical characteristics improved with the development of the precise structure. Composite characterization refers to the wide-ranging and general method by which composite structure and properties are analyzed and evaluated to ensure that materials meet performance criteria for various applications. In scanning electron microscopy, Figure 1 shows the slicked pattern observed systematically, with different magnifications and measurements. Analyses of 100X magnification of the microscopic structure show that the deformation observed can be attributed to the formation of a solid SiC/Gr solution. The visible dark grey area is determined to be the solid solution of the reinforcement particles with the rest of the area being the Al alloy matrix. The dark and white part in the image of the microstructure, as shown in Figure 1 a, explains the aggregation of SiC/Gr particles.Comparison of microscopic illustrations on Al alloy and divergence breaks was observed in both samples. However, the dendrite arm distance was not as large as the reinforcing-parts inhibition width during solidification, as seen in figure 1 b. Dendrite arm distance in the composite was observed in both samples. Particulate involvement in matrix molecules greatly improves its microstructure, weakening roughness when freezing of the primary dendrites. Ni3S4 particles mainly pass through primary dendrite boundaries of the Al alloy though some are found in aluminum slab. Porosity in the cluster region of SiC/Gr particles was seen frequently after small scale engraving. Processing of microstructures on the silicon surface throughout the SiC/Gr particles occurred. The microstructure had a viscous solution from the Al alloy, with some unspecified non-metallic additions. The combined surface appeared to include small boulders, with the whole dendritic form being clearly visible at 200X. Microstructural qualities of the metal matrix Al combination composites rely basically on the idea of lattice amalgam fortification, their holding, and dissemination. The present discussion relies upon 6 wt. % fortresses since mechanical properties are optimum in the 6 wt. % of SiC/Gr. Further augmentation in the stronghold substance (to 8 wt. %) lead to at the care group improvement which self-destructs the mechanical properties due to the distinction between the thickness and higher percentage of reinforcement

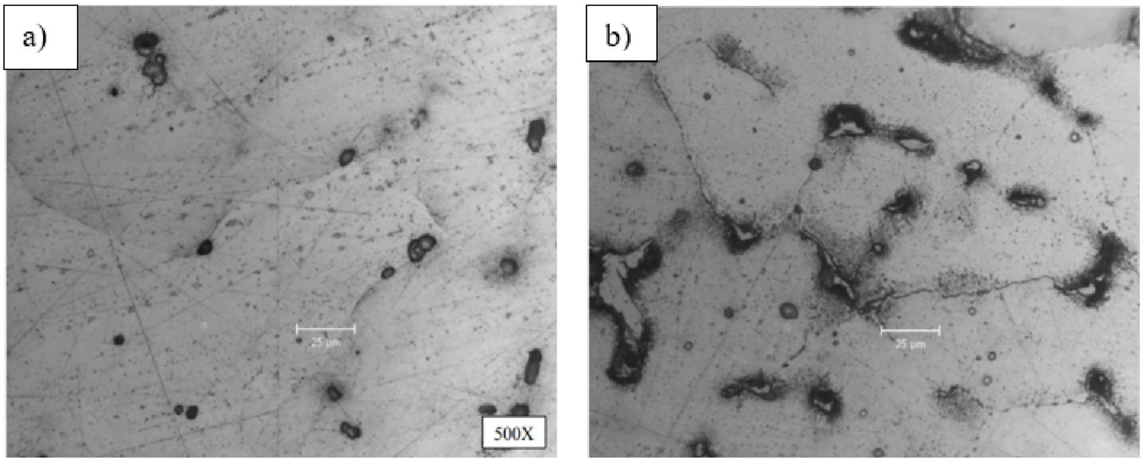

Figure 1: Microstructure of Base alloy

3.2 Tensile Strength

Tested for tensile strength, the obtained values in Table 2 are samples of the unreinforced Al alloy and composite series. From the diagram it is evident that the composites can withstand considerably heavier loads than alloys, mainly due to tensile strength increasing considerably with additional strengthening. Figure 5.2 shows that, compared to the non-reinforced Al alloy, the tensile strength of the metal matrix composites improved significantly. The increase in tensile strength can be linked to the incorporation solid reinforcing materials with better mechanical properties into the base alloy ofSiC/Gr. The transfer works twice while the applied tensile load resists.

These particles hinder the dislocation of the material and strengthen it by forming a better link between the non-reinforced alloy and the neighbouring metal matrix and by increasing the composite tensile strength. With the increase in tensile loads, microgrooves created spread and formed large vacuums resulting in the formation of cracks when the load exceeded maximum tensile strength. A fracture was present at this point. The result shows that hard reinforcements present in the array, which significantly increased yield strength. It can be confirmed that increases in the percentage of reinforcement reduced the yield strength of the composites, as indicated in Figure 2.

Table 2: Results of the mechanical properties of Al alloy with composites

Specimen	Composition	Yield Stress (N/mm^2)	Tensile Stress N/mm^2	Hardness (BHN)
A	Al6061 alloy	155.01	174.87	85.8
B	Al6061 alloy + 2% SiC/Gr	159.32	179.62	88.7
C	Al6061 alloy + 4% SiC/Gr	180.23	194.39	90.7
D	**Al6061 alloy + 6% SiC/Gr**	**182.61**	**205.49**	**92.8**
E	Al6061 alloy + 8% Si_3N_4	118.44	140.5	104

Composite yield stress also depends on the modulus of the particle, as well as the shear modulus difference between the matrix and particle, in addition to the in-situ matrix yield stress. A large modulus difference between the matrix and reinforcement significantly limits strengthening. The decreased yield strength for the higher reinforcement specimen may be attributed to agglomeration and also the insufficient adhesive bond between the reinforcement particles and the matrix compared to that of the other two composite specimens. This improvement in tensile strength can be explained by the Orowan strengthening mechanism, where the composite matrix is obstructed by the scattered refreshing particles.

The presence of strengthening part produces disturbances that enhanced dislocation intensity and also created loosening loops. Together these particles prevented crawling that disturbed dislocation. Dissociation occurs only when it bends between dispersive enhancement particles during deformation. Broken samples from the tensile test were then analyzed using SEM for further study on how composites behave under fracture. Uniform distribution of reinforcements may have been obtained by the effect of vortex during stirring. Tensile strength was enhanced with the addition ofSiC/Grparticles up to 6% weight and beyond which at 8% weight the trend reversed due to the bonding between the matrix and the reinforced particles at weak locations. Thus 6% of the weight of the SiC/Gr particles was the ideal/optimal.

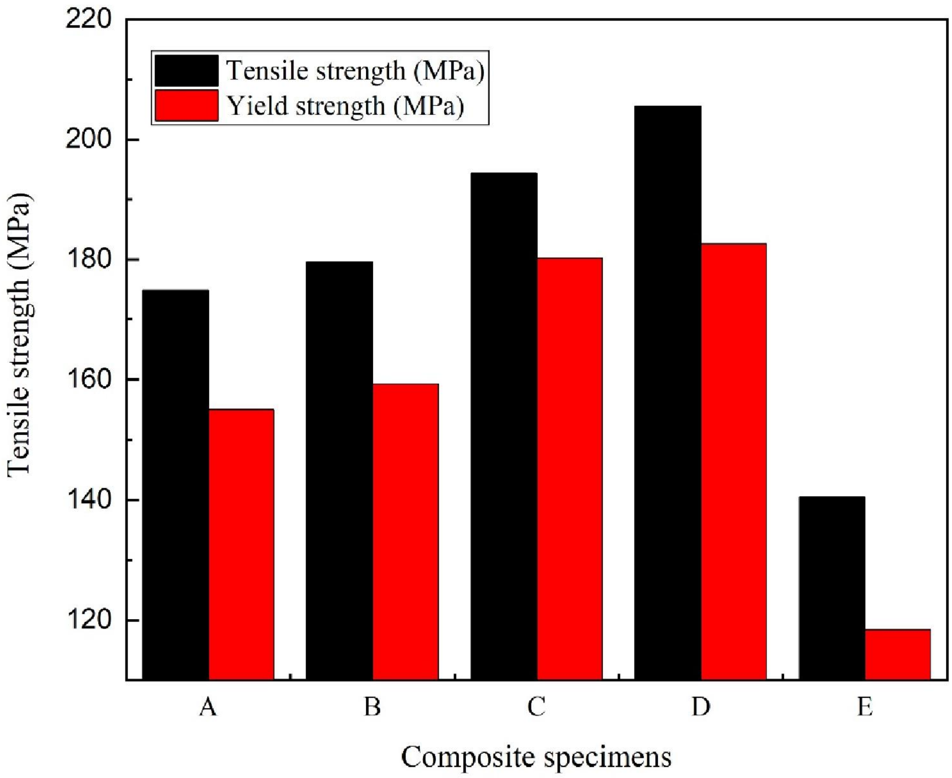

Figure 2: Tensile strength of composites

3.3 Hardness

Hardness test measures the resistance to penetration of a material by a harder material. Hardness cannot be precisely defined. Hardness, depending on the competition, represents a qualitative measure of the resistance and resistance of materials to scratching or bleeding. Measured hardness is relative and care is determined by different techniques while comparing the values. Hardness tests are performed more frequently than other mechanical tests for various reasons. They are simple and inexpensive and generally do need the preparation of special models, while test equipment is relatively inexpensive. Hardness test was performed on the samples prepared and the results obtained are shown in table 2. The results revealed that metal matrix composite hardness (104 BHN) increased due to the solid nature of the reinforcing particles inserted in comparison to the base metal alloys (85.8 BHN). Increase in the hardness of the combined substances was due to the following methods, such as particles enhancement, grain boundary strengthening and dispersion strengthening, employed in the metal matrix solution.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 2, August 2023

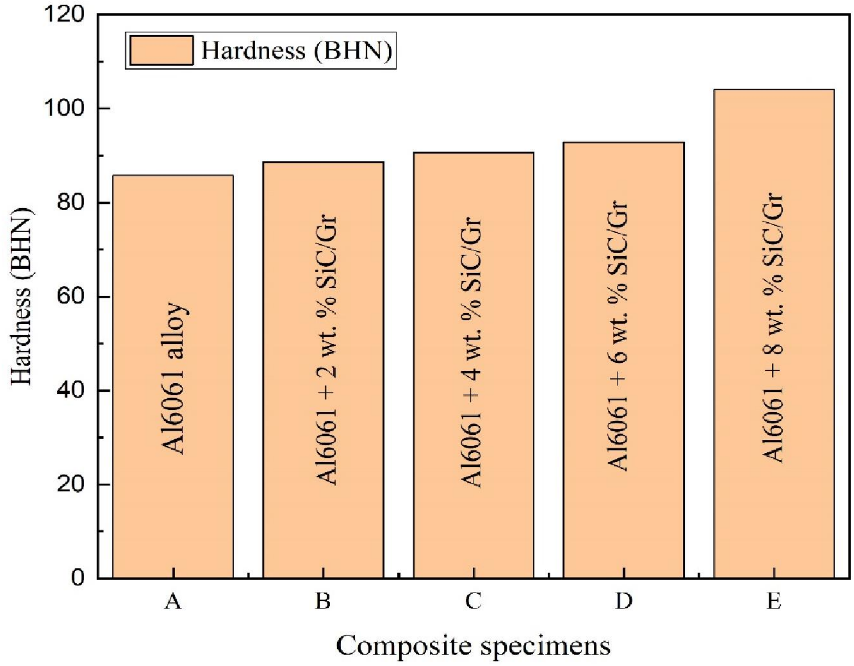

Figure 3: Hardness of composites

When reinforcing enters a soft, elongated metal matrix structure and the movement of atoms is dispersed, particles are introduced by increasing resistance to plastic deformations. The increase in the weight relation of reinforcement provides force to the matrix resulting in an increased hardness of the composites while the strength of the grain boundary decreased as the intensity of the disruption of the atoms decreased. Composites with more rigidity than Al alloys and Al alloys + 8 wt. % of SiC/Gr compared to other composite weight ratios, according to results in figure 5.3. An improper mixing of molten composites caused by higher viscosity of particle matter and good interfacial connection between the particle matrix interfaces can be the reason for the increases hardening. Therefore, when working above 8 wt. % particles to produce a uniform dispersed particulate matrix, it is suggested to optimize stirring parameters. The increased content of wt. % of reinforcement improved composite hardness up to 8 % wt. of SiC/Gr due to hard ceramic silicon carbide and graphite particles inclusion into Al6061 alloy.

IV. CONCLUSIONS

The present research work contributed significantly to the development of Al-based alloycompositeswith varying wt. % of SiC/Gr from 2to 8 wt. % in increments of 3%. The composites were developed by stir casting using electrical resistance furnace, which is considered to be the most economical casting method. In this research work, Al-based metal matrix composites were developed successfully through conventional stir casting. Consistent distribution of SiC/Grgrain particulates in the Al alloy base metal were achieved by mechanical stirring. The main contributions of this thesis have been summarized and the scope for future work listed at the end of this chapter.

Microstructure SEM analysis showed uniform distribution of SiC/Gr particulates with the smallest amount of porosities and agglomeration was observed. Fine grains dendritic structure was formed by adding SiC/Gr particles.

Formation of columnar dendrite structure was observed in all composite specimens due to faster solidification and density change of the composites by metal casting.

Agglomeration of hard ceramic nano-particles was observed in higher composites i.e.8 wt. % SiC/Grdue to higher volume rations and insufficient stirring time and speed.

Microstructural analysis showed that support nano-particles were equitably conveyed in the composite materials and no interface responses were seen at higher amplification. Specifically, mixing impact during cementing affected

DOI: 10.48175/IJARSCT-12722

ISSN 2581-9429 IJARSCT

microstructures. Likewise, expansion of SiC/Grimpacted the morphology of the Al combination. Microstructure of the composite material was better than that of the unreinforced Al alloy composites with even appropriation of SiC/Gr particles.

The ultimate tensile strength of composites enhanced from 2-8 wt. % of SiC/GrMMCs was 179.62, 194.39, 205.49, and 140.50 MPa, when compared to the unreinforced Al- based alloy 174.87 MPa.

Tensile strength was enhanced with the addition of SiC/Gr reinforcements up to 6weight %, after which they decreased due to the formation of agglomeration, by decreasing fluidity of Al-base alloy and also caused by an increase in the strain hardening effect resulting in the metal becoming brittle. By increasing the content of reinforcement ductility was decreased. Hence, it is seen from the above investigation that 8 weight % of SiC/Gr composite can be considered as optimum.

The hardness of composites from 2-8 wt. % of SiC/Gr MMCs was increased by 3.3%, 5.7%, 8.15% and 21.2% respectively, when compared to the Al- based alloy.

The obtained result showed that the composite had greater hardness when compared to the Al-based alloy while the Al alloy + 8 % SiC/Grcomposite exhibited high hardness when compared to other composites. Thus, composite strength increased with the addition of SiCparticles.

REFERENCES

[1]. J. Kumaraswamy, V. Kumar and G. Purushotham, A review on mechanical and wear properties of ASTM a 494 M grade nickel-based alloy metal matrix composites, Materials Today: Proceedings, Vol 37, 2021, pp 2027–2032,https://doi.org/10.1016/j.matpr.2020.07.499.

[2]. K. Jayappa, V. Kumar, and G. G. Purushotham, "Effect of reinforcements on mechanical properties of nickel alloy hybrid metal matrix composites processed by sand mold technique," Applied Science and Engineering Progress, Vol. 14, no. 1, pp. 44–51, Jan.–Mar. 2021, http://dx.doi.org/10.14416/j.asep.2020.11.001

[3]. J. Kumaraswamy, V. Kumar and G. Purushotham, Thermal analysis of nickel alloy/Al_2O_3/TiO_2 hybrid metal matrix composite in automotive engine exhaust valve using FEA method,Journal of Thermal Engineering, Vol. 7, No. 3, March, 2021, pp. 415-428. https://dx.doi.org/10.18186/thermal.882965.

[4].J Kumaraswamy, Vijaya Kumar, G Purushotham, Evaluation of the microstructure and thermal properties of (ASTM A 494 M grade) nickel alloy hybrid metal matrix composites processed by sand mold casting, International Journal of Ambient Energy, Vol. 43, pp. 4899–4908.https://www.tandfonline.com/doi/abs/10.1080/01430750.2021.1927836.

[5]. Sandeep Khelge, Vijaya Kumar, Vidyasagar Shetty and Kumaraswamy J,Effect of reinforcement particles on the mechanical and wear properties of aluminium alloy composites: Review, Materials Today: Proceedings, Vol. 52, Part 3, pp. 571-576, 2022. https://doi.org/10.1016/j.matpr.2021.09.525

[6]. Sandeep Khelge, Vijaya Kumar and Kumaraswamy J, Optimization of wear properties on aluminum alloy (LM22) hybrid composite, Materials Today: Proceedings, Vol. 52, Part 3, pp. 565--570, 2022.https://doi.org/10.1016/j.matpr.2021.09.518

[7]. Vidyasagar Shetty, Shabari Shedthi B and Kumaraswamy J, Predicting the thermodynamic stability of perovskite oxides using multiple machine learning techniques, Materials Today: Proceedings, Vol. 52, Part 3, pp. **457-461**, 2022. https://doi.org/10.1016/j.matpr.2021.09.208

[8]. Kumaraswamy J, Anil K. C., Vidyasagar Shetty and C Shashishekar. Wear behaviour of the Ni-Cu alloy hybrid composites processed by sand mold casting,Advances in Materials and Processing Technologies, Vol. 2, pp. 1-17. https://doi.org/10.1080/2374068X.2022.2092684

[9]. Harish R S, Sreenivasa Reddy M, Kumaraswamy J, Wear characterization of Al7075 Alloy hybrid composites, Journal of Metallurgical and Materials Engineering, Vol. 28 (2), pp. 291-303. https://doi.org/10.30544/821.

[10]. K.C. Anil, J. Kumaraswamy, Akash et al., Experimental arrangement for estimation of metal-mold boundary heat flux during gravity chill casting, Materials Today: Proceedings, Volume 72, Part 4, 2023, Pages 2013-2020. https://doi.org/10.1016/j.matpr.2022.07.399

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 2, August 2023

[11]. J. Kumaraswamy et al., "Thermal Analysis of Ni-Cu Alloy Nanocomposites Processed by Sand Mold Casting," Advances in Materials Science and Engineering, vol. 2022, Article ID 2530707, 11 pages, 2022. https://doi.org/10.1155/2022/2530707.

[12] R.S. Harish, M. Sreenivasa Reddy and J. Kumaraswamy, Mechanical behaviour of Al7075 alloy Al2O3/E-Glass hybrid composites for automobile applications, Materials Today: Proceedings, Volume 72, Part 4, 2023, Pages 2186-2192. https://doi.org/10.1016/j.matpr.2022.08.460

[13] J. Kumaraswamy, K.C. Anil and V. Shetty, Development of Ni-Cu based alloy hybrid composites through induction furnace casting, Materials Today: Proceedings, Vol. 72, pp. 2268-2274. https://doi.org/10.1016/j.matpr.2022.09.215

[14] Anil, K.C., Kumarswamy, J., Reddy, M., Prakash, B., Mechanical Behaviour and Fractured Surface Analysis of Bauxite Residue & Graphite Reinforced Aluminium Hybrid Composites, Frattura ed IntegritàStrutturale, 16 (62) (2022) 168-179. DOI: 10.3221/IGF-ESIS.62.12

[15] Anil K C, Kumaraswamy J, Mahadeva Reddy , Mamatha K M, Air Jet Erosion studies on Aluminum - Red Mud Composites using Taguchi Design, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 10, Issue 01, pp130-138, March 2023. https://doi.org/10.5109/6781059

[16] Sharan kumar, Akash, Anil K C, Kumaraswamy J,Solid Particle Erosion Performance of Multi-layered Carbide Coatings (WC-SiC-Cr3C2), EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 10, Issue 02, pp 813-819, June 2023. https://doi.org/10.5109/6792833