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Fabrication and Estimation of Mechanical Properties of Aa6061 Matrix Reinforced with Al_2O_3 and Stainless Steel 316 Powder

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Abstract: ***The necessity and the importance of the new materials with superior properties in the modern and hi-tech industries have become inevitable. For many industrial applications and particularly in nuclear applications, a wide range of materials is being adopted. The selected materials should have high strength, low density and high hardness with better machinability. The present work is focused on the evaluation of properties of AA (6061)- Al_2O_3 - Stainless Steel 316 powder composite. The composite is fabricated through Stir casting. The mechanical properties such as hardness, yield strength, tensile strength are determined. The uniform dispersion of the reinforcement particles in the matrix is ensured through scanning electron microscopic image. Tribological properties such as coefficient of friction and wear rate are determined. Influence of Al_2O_3 and Stainless Steel 316 powder weight percentage is considered for the evaluation in order to identify its influence on mechanical and Tribological properties.***

1. Introduction

A material is a substance or blend of constituents to be utilized for various applications. For the most part, materials can be isolated into two classes. They are crystalline and non-crystalline in nature. Models are metals, polymers and pottery. Propelled materials are being created incorporate nano materials, semiconductors, biomaterials and so forth.

1.1 Composite material

Composite material is mix of at least two synthetically and physically divergent components orchestrated appropriately and it has novel properties concerning diverse consolidated components. In our industry, composites are materials made by joining or progressively regular or fake components that are more grounded as a group than as individual players. The segment materials don't totally lose their individual personalities; they consolidate and contribute their most valuable qualities to improve the result or last item. Composites are commonly planned in view of a specific use, for example, included quality, proficiency or toughness.

The for the most part caused composites to can be separated into three gatherings: Polymer Matrix Composites (PMCs), Metal Matrix Composites (MMCs), and Ceramic Matrix Composites (CMCs).

Specifically, the MMC's assume significant jobs in the building and advance assembling fields. The improvements in the zone of aviation, propelling exercises in flying machines field and car industry rises such an interest. Further, MMCs have low thickness relatively, which plan their prevalent properties especially in modulus and quality, to numerous regular designing materials. Because of this exhaustive examination about the essential conduct of materials and better comprehension of their property, presently it is conceivable to plan another composite material with upgraded mechanical and physical properties. The propelled material comprises of composites gives better execution. The nonstop requests raised by the creating innovation have prompted utilize composite materials in different basic and mechanical applications and furthermore in airplanes field. A literature survey is done in order to understand the basics and importance of the research work held related to the proposed work. [1] Ashok Kumar and Murugan (2012) observed the metallurgical behaviour of stir cast Aluminium alloy 6061-T6 - AINp composite and concluded that by adding 2% magnesium to Al matrix, the wettability was improved. [2] Hamid Reza Ezatpour (2017) et al. have examined the influence of adding nano alumina particles to AA6061 alloy produced by stir casting process with an objective to improve the mechanical properties of the composites and reported that the nano composites present a fine grain microstructure with high porosity.[3] Mahendra and Radhakrishna (2018) have investigated the characterization of stir cast Al— (fly ash + SiC)-Cu hybrid metal matrix composites and found that the mechanical properties of the prepared composite are improved. [4] Sahraeinejad et al. have examined the effect of Al_2O_3, B_4C and Sic particle sizes from 130 nm to 4.3 µm on AA 5059 matrix, and with different process parameters to obtain a uniform distribution of particles within the stir zone. They reported that Nano-scale particles seem to be more effective to increase hardness by increasing the particle fraction in the produced composites. [5] Sajjadi et al. (2011) have examnied the outcome of inclusion of reinforcements on the micro structural and mechanical properties of A356_Al_2O_3 composites. The micro structural analysis shows the uniform distribution and low porosity in composite specimen and the mechanical results reveal that the inclusion of alumina in the matrix has led to increase the hardness, compression strength, the yield strength and ultimate tensile strength. [6] Arun Premnath (2013) et al. studied the mechanical properties of Al_2O_3 reinforced at different weight fractions (5, 10 and 15%) in aluminum based composites. They found that the density and the hardness were increased with the increase in Al_2O_3 content. [7] H.C. Anilkumar etc al (2011). Study the Mechanical properties of fly ash reinforced AA6061 composites. stir casting method used to prepare the composites could produce uniform distribution of the reinforced fly ash particles. The experimental result reveals that the Tensile Strength, Compression Strength and Hardness increased with the increase in the weight fraction of reinforced fly ash and decreased with increase in particle size of the fly ash.[8] Kumar et.al (2009) performed analysis on a press extruded AA6061/fly ash composite and investigated the dry sliding wear behaviour using the pin-on-disc method. They found that the composite showed a mild to severe wear at higher temperatures due to the formation of protective layer of reinforced materials at the high temperatures.[9] Kalaiselvan et al. (2011) have studied the production and characterization of boron carbide reinforced aluminum alloy based composite. The MMCs are fabricated by various techniques namely, squeeze casting, stir casting, and spray deposition, pressure infiltration, liquid infiltration and powder metallurgy. Among all the manufacturing process, conventional stir casting is an attractive fabrication method, as it is relatively cheap and provides wide selection of materials.[10] Valibeygloo et al. (2013) have fabricated the Al-4.5wt. % Cu alloy reinforced with varying volume fractions of alumina nano particles through the stir casting process and observed a uniform dispersion of reinforcements in the matrix. An outstanding improvement in compression strength and hardness is observed, due to the effect of nano particle addition.[11] Hossein Abdizadeh et al. (2012) have investigated the microstructure and mechanical properties of MgO reinforced Al based composites which are fabricated through the stir casting and powder metallurgy technique. The analysis reveals that the casting samples show higher density, compressive strength and improved mechanical properties with low porosity in the composite. [12] C H Hima Gireesh etc. al, (2018) his experimental study aimed at preparing an AA6061 hybrid metal matrix composite (AHMMC) with the non-metallic ceramic reinforcement materials SiC, Al_2O_3, and fly ash using the stir-casting technique and to explore its mechanical characterization. on comparison to the base metal AA6061, the proposed composite exhibits a good improvement in tensile strength, yield strength, and hardness. However, no significant change is observed in impact strength.

2. Matrix and Reinforcement Materials

2.1 Aluminium alloy (AA6061)

The effective way to reduce the weight of any structure is to build it with the materials of low specific weight. Aluminium alloys are metallic materials. As they provide a various number of interesting mechanical and thermal properties, they are mostly used in various applications. In addition, shaping of aluminium is easy, especially in material removal, such as machining. In other words, aluminium alloys are considered as the group of materials which offers the highest levels of machinability, while comparing with other lightweight metal like magnesium and titanium alloys.

Table 2.1: Chemical composition of AA6061

Material	Mg	Si	Fe	Cu	Cr	Mn	Zn	Ti	Al
%	0.9	0.62	0.33	0.28	0.17	0.06	0.02	0.02	Balance

The selection of right alloy for a certain purpose is based on the following considerations; density, tensile strength, yields strength, weldability, ductility, formability, workability and corrosion resistance. It is also used in the field of ship manufacturing, due to its higher strength and improved bearing capacity to sea atmosphere. Moreover, due to its high strength and increased mechanical properties, it is used in nuclear industries.

2.2 Alumina (Al_2O_3)

Aluminium oxide exists in several different crystallographic forms, of which corundum is most common. Corundum is characterized by a high specific gravity (4.0), a high melting point (about 2,050 °C), great insolubility, and hardness.

Aluminium oxide is the major ingredient in the commercial chemicals known as alumina. Of the pure, inorganic chemicals, alumina are among the largest volume produced in the world today. Rubies and sapphires are crystalline, nearly pure varieties of alumina, coloured by small amounts of impurities. Synthetic rubies and sapphires are made commercially by fusing a mixture of high-purity aluminium oxide with colouring agents in an oxy hydrogen blowpipe flame.

6061Aluminium alloy was selected as the matrix material for the present investigation and it was purchased from Vision castings, Hyderabad, India. Composition of 6061Al alloy is as shown in Table 2.1. The Particulates of Al_2O_3 with 40 micro meter size were purchased from vision castings, Hyderabad, India.

2.3 Stainless Steel 316 powder

Stainless steels are iron based alloys containing at least 10.5% Chromium. They achieve their stainless characteristics through the formation of an invisible and adherent Chromium rich oxide film. Alloy 316 is a general purpose austenitic stainless steel with a face centred cubic structure. It is essentially non-magnetic in the annealed condition and can only be hardened by cold working. Molybdenum has been added to increase corrosion resistance particularly in chloride containing environment, and the lower Carbon content of alloy 316L gives even better corrosion resistance in welded structures.

Figure 2.1: Stainless Steel 316 Powder (45 micron)

The new composite material reinforced with SS powder particles is being developed for the usage in the structural engineering and wear applications.

3. Fabrication of the Composite

Composition of proposed metal matrix composite for different specimens as per below table:

Table 3.1: Weight percentage of reinforcements of different samples

Specimen	Composition (weight%)		
	AL 6061	Stainless steel 304 powder	Al_2O_3
Sample A	95	5	-
Sample B	90	5	5
Sample C	87	8	5
Sample D	85	5	10
Sample E	80	8	12
Sample F	82	8	10

3.1 Stir Casting

The composite consists of aluminium alloy 6061 cast as matrix and Al_2O_3 and Stainless Steel powder 316L as reinforcement materials. The suitable fabrication technique for particle reinforced metal matrix composite is conventional stir casting route. As it is low-cost comparably and also offers wide selection of materials. Further, it produces better bonding of reinforcements with the matrix, due to the uniform stirring action.

Figure 3.1: Heating aluminium alloy 6061 in furnace

Figure 3.2: The die use for making casting materials

The Aluminium alloy 6061 kept in a crucible is heated in a resistance furnace at around 600°C for 2 to 3 hours before melting. In order to oxidize the surface of the reinforcements, and Al_2O_3 and SS Powder particles are preheated. The average reinforcement particle sizes of the and Al_2O_3 and SS powder are 30μm and 45μm, respectively. The preheated aluminium alloy is further heated above its liquidus temperature to melt the alloy completely. They are then slightly cooled below its liquidus to keep the slurry in the semisolid state. The heated particles are added gradually and mixed partially by manual and motorized stirring at an average speed of 600 rpm for the duration of 5-10 minutes. The melt is maintained at 650^0C ±10°C temperature range and the pouring temperature is around 620°C. The uniformly mixed molten state of metal is poured into steel mould and allowed to cool to obtain the product. By this process the amount of reinforcement materials are varied to get the required composition of the samples. Thus, the composite materials with different composition were achieved in the form of cylindrical shaped rods with 20 mm diameter and 160 mm length.

4. Experimentation

4.1 Tribological properties

4.1.1 Wear Testing

Wear testing is a method for assessing erosion or sideways displacement of material from its "derivative" and original position on a solid surface performed by the action of another surface. This test is commonly used as a simple measure of workability of material in service. Materials behave differently in friction state so it may be important to perform mechanical tests which simulate the condition of the material will experience in actual use. Wear testing is typically carried out on the AA6061 alloy. Wear tests of the selected alloy is a critical parameter for determining the quality of these materials. The loads and forces acting on these materials while in service are compressive in nature and their ability to withstand such loads and forces without failure is a measure of their reliability.

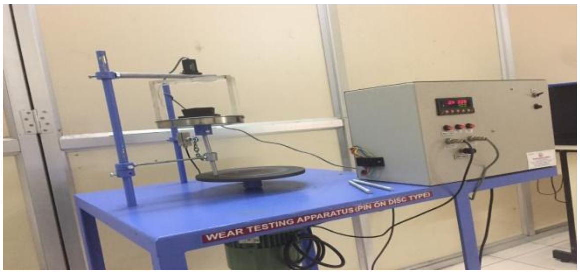


Figure 4.1: Wear testing apparatus (pin on disc)

4.2 Mechanical Properties

4.2.1 Hardness Test

To evalute Brinell hardness of the prepared composites, the diamond indenter of 1/16 diameter and load of 100kg is specified for the measurement. Red dial on scale B is used for measuring the readings.

Figure 4.2: Brinell hardness testing machine.

Figure 4.3: The Specimens prepared for Hardness test

The properties of the fabricated materials are measured by using ASTM B557M– 10. The result shows the presence of hard reinforcements in the matrix which improves the hardness to a considerable amount.

4.3 Tensile Test

The properties of the fabricated materials are measured by using M-30. The result shows the presence of hard reinforcements in the matrix which improves the tensile strength and yield strength to considerable amount.

4.3.1 Specimen Dimensions

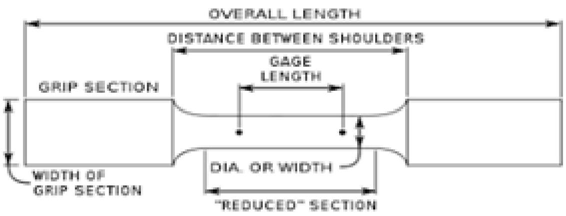


Figure 4.4: Tensile test specimen standard (ASTM E 8M).

Table 4.1: Specimen dimensions

Dimension	All dimensions are in mm
Length of reduced section	90
Gauge length	*80±0. 1*
Diameter	10± 0.1
Overall length	150

Figure 4.5: Specimens after machining on lathe

Figure 4.6: The breakage specimens after tensile testing

5. Results and Discussions

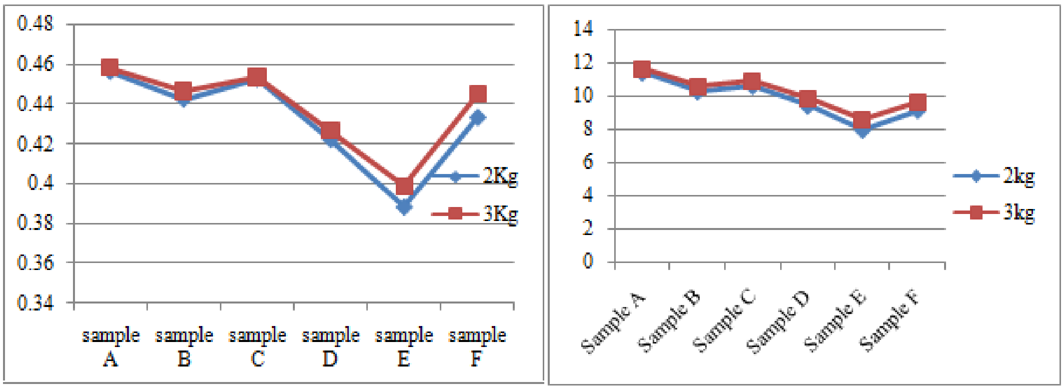
The values of wear rate and mechanical properties of the AA6061 hybrid metal matrix composite obtained through the experimentation are showed in table.

Table 5.1: Mechanical and Tribological properties of the hybrid composites

	Sample	Wear rate		Coefficient of friction	Hardness (BHN)	Ultimate tensile strength (MPa)	Yield strength (MPa)
		kg	(micron /minute)				
1	A	2	11.466	0.4561	71	186	170
		3	11.667	0.4582			
2	B	2	10.334	0.4423	73	192	158
		3	10.6	0.4465			
3	C	2	10.67	0.4524	81	170	153
		3	10.934	0.4536			
4	D	2	9.467	0.4221	86	212	206
		3	9.867	0.4267			
5	E	2	8	0.3882	82	229	213
		3	8.6	0.3990			
6	F	2	9.2	0.4331	72	183	168
		3	9.67	0.4452			

5.1.1 Influence of percentage of reinforcement on Tribological properties

The graphs show the sample from sample A to E the coefficient of friction and wear rate decreases while increasing the percentage of reinforcements Al_2O_3 and SS 316 powder. After that coefficient of friction of sample F increased suddenly due to increase in reinforcement percentage, pours and voids are formed in composite. Lowest coefficient friction is observed for sample E with the value 0.3882 &0.3990 for 2kg and 3kg respectively. From the above results less wear was take place at Sample E. For 2Kg&3Kg load on pan the wear rate is 8 and 8.6 respectively.

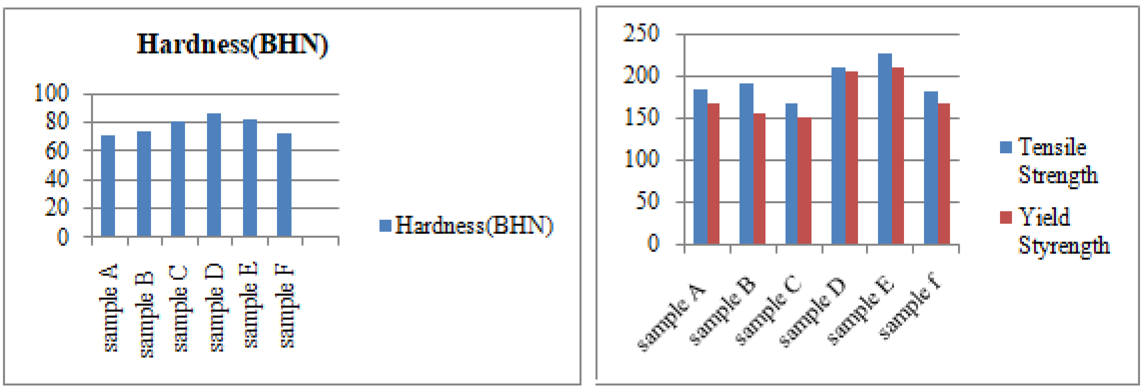


%percentages variation of reinforced materials Alumina and SS 316 powder

Graph 5.1: (a) The coefficient of friction in different samples for different weights, (b) The coefficient wear rate in different samples for different weights

5.2 Hardness of the different samples

In sample a aluminium matrix is reinforced only with SS 316 powder for further sample Al_2O_3 also added so that hardness value increased it is observed that while increasing the percentage of SS 316l powder the hardness value of the composite increased best result obtained at AA-85% SS316-5% Al_2O_3-10% with hardness 86 BHN. Further increase in reinforcement the hardness number decreases due to blow holes of the sample F.



(a) (b)

Graph 5.2: Shows the hardness value of the different specimens, (b) shows The Tensile Strength and Yield Strength of the composites

5.3 Influence of percentage of reinforcements on tensile strength and yield strength of the samples

From the graph it is shows that high tensile and yield strength is obtained at sample E with the values of 229 MPa and 213 MPa respectively.

5.4 Morphology

To study the particle reinforcement distribution in composite micro structure was observed from different locations of samples. The distribution of the reinforcements Al_2O_3 and stainless steel powder is uniformly distributed in sample E, hence it has high percentage of hard particles so it has good mechanical properties compared to the other fabricated samples. In Sample F due to addition of more percentage of reinforcements proper mixing is not done. So, that blow holes are formed, due to that properties are worsen.

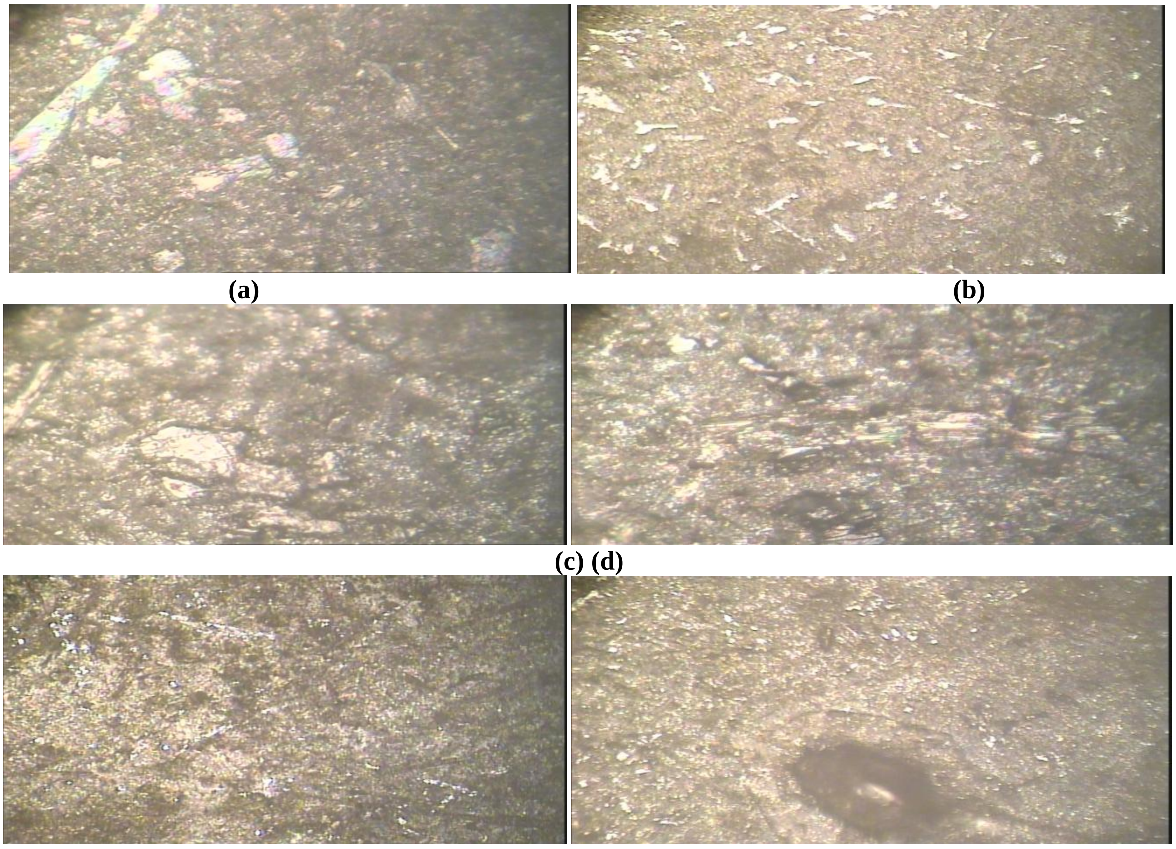


Figure 5.1: (a) micro structure (100x) for Sample, (b) Micro structure (100x) for Sample, (c) Micro structure (100x) for Sample C, (d) Microstructure (100x) for Sample, (e) Micro structure (100x) for Sample E uniform distribution of reinforcement, (f) Micro structure (100x) for Sample F blow holes are formed due to improper mixing.

6. Conclusion

1) The composite is successfully prepared through stir casting process and the uniform dispersion is verified through the optical microscopic image. The increase in the mechanical property is observed, as the wt. % Al_2O_3 of particles increase in the composite.
2) Wear test results shows that up to certain increase in reinforcements weight percentages of Al_2O_3 and Stainless Steel 316 powder, the wear rate is decreased but further increase in weight percentages wear rate is increased. Optimum wear rate is observed at a composition of (AA-80%, SS 316-8%, Al_2O_3-12%) for loads 2kg &3kg is 8 micron /minute and 8.6 micron/minute respectively.
3) It has been concluded from hardness measurement that, addition of Al_2O_3 and Stainless Steel 316 powder reinforcements the hardness value increases. However addition of reinforcements above certain limit the hardness is value decreases. Highest hardness value obtained for sample D (AA-85% SS316-5% Al_2O_3-10%) is 86BHN. Further increase in weight percentage of reinforcements hardness value decreases due to porosity and voids.
4) From Tensile Strength results, it is concluded that which increase in Stainless Steel 316 powder percentage the tensile strength is decreased due to low bond strength. However addition of Al_2O_3 increased the tensile strength of the samples. Highest tensile and yield strength is observed at a composition of (AA-80% SS 316- 8% Al_2O_3-12%) is 229 MPa and 213 MPa respectively.

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