Experimental Investigation of Mechanical And Tribological Behavior of Al7075 With Reinforced Sic And B4C For Chain Sprocket

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Abstract- *Aluminum based metal matrix composites (AMMCs) are appropriate materials for structural applications in the aircraft and automotive applications such as (All Terrain Vehicle) chain sprocket, vehicle frames and crank case. In this experimental work Al7075 is reinforced with the Silicon Carbide (SiC) and Boron Carbide (B4C) through stir casting process. Mechanical and wear behavior of this composite material were investigated for tribological behavior and morphology of the reinforced composite particle distribution were analyzed by optical microscopy. Ultimate Tensile test is performed to evaluate the tensile yield strength of the composite material and hardness test is performed to investigate the hardness range and the effect of wear resistance. Stress deformation of the chain sprocket with Al7075 material were designed and analyzed by using SOLIDWORKS and ANSYS. Experimental results of the mechanical properties, wear behavior and stress deformation were investigated. The reinforcement of Silicon Carbide and Boron Carbide improved the strength and wear resistance of the Al7075.*

Keywords- B_4C and SiC reinforcement, Stir casting, experimental testing, Chain sprocket Analysis.

I. INTRODUCTION

Metal matrix composites are most promising materials in achieving enhanced mechanical properties such as hardness, Young's modulus, yield strength and ultimate tensile strength due to the presence of micro sized reinforcement particles into the matrix. Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement or reinforcing material, whereas the continuous phase is termed as the matrix. Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them.

In this experimental work Al7075 is reinforced with the Silicon Carbide (SiC) and Boron Carbide (B4C) through stir casting process. Mechanical and wear behavior of this composite material were investigated for tribological behavior and morphology of the reinforced composite particle distribution were analyzed by optical microscopy. Ultimate Tensile test is performed to evaluate the tensile yield strength of the composite material and hardness test is performed to investigate the hardness range and the effect of wear resistance, where the analysis of chain sprocket designed and evaluated in SOLIDWORKS and ANSYS workbench.

Inclusion of SiC and Graphite particulate reinforcement content in Aluminum MMC improves the mechanical properties of the composite material like tensile strength, hardness, and compression strength [1].Mechanical behavior of AL-7075 matrix composite observed that the reinforcement of Boron Carbide increase the ultimate tensile strength, compressive strength and the hardness of the composite increased linearly with increase in volume percentage of Boron Carbide [2]. Density of the HAMC increases with increasing contents of ceramic reinforcement .Complementary reinforcement of Silicon Carbide with Boron carbide on AL7075 matrix improves the hardness level of the composite [3] .Silicon Carbide reinforcement contributed significantly improving the wear resistance of the material. It exhibits superior strength and the tribological properties of aluminum MMC reinforced at higher 6 wt. % of SiC compared to that of the 2wt% and 3wt % of SiC.Kammuluri [4]. Combination of reinforcing particulates have been conceptualized in the design of aluminum hybrid composites. The double synthetic ceramics reinforced hybrid AMCs despite showing good mechanical and tribological properties over the unreinforced alloys still need to be subjected to test under different corrosion media to ascertain its corrosion behavior [5].Processing variables such as holding temperature, stirring speed, size of the impeller and the position of the impeller in the melt are among the important factors to be considered in the production of cast metal matrix composites as these have an impact on mechanical properties [6]. Atuanya

[7] says that the incorporation of breadfruit seed hull ash particles in aluminum matrix can lead to the production of low cost aluminum composites with improved hardness and strength, these are light weight with good stiffness and strength. Hardness and tensile properties of the composites are higher as compared to the unreinforced base Aluminium matrix, addition level of reinforcement has resulted in further increase in both hardness and tensile strength [8]. Jaya Prasad V et al., [9] stated the reinforcement of particles has enhanced the wear resistance of aluminum matrix and composites. It is observed that increase in percentage of SiC improves wear resistance. Reinforcing Aluminum and its alloys with ceramics particles has shown an appreciable increase in its mechanical properties.Kalyan Kumar Singh et al. [10] stated that silicon carbide based aluminum metal matrix composites and aluminum matrix alloys possesses better properties at low sliding distance and at lower load also. Although silicon carbide based aluminum metal matrix composites shows better properties compared with aluminum matrix alloy at lower as well as at increased sliding distance under dry condition.

II. EXPERIMENTAL WORK

A. Material

Aluminium is selected as the base metal matrix it is relatively soft, durable, light weight, ductile, malleable metal and has high corrosion resistance, excellent heat conductivity. The selected aluminum alloy bears excellent characteristics for structural and automotive applications. It has major alloying elements Silicon, Copper which contributes for better strength, machinability and cast ability.

Table 1. Chemical composition of Al 7075 alloy

Material	Composition
Mg	2.1 - 25
Cr	0.05
Cu	1.2-1.6
Fe	0.05
Mn	0.05
Si	0.05
Zn	5.6-6.1
Ti	0.05
Others	0.05
Al	balance

Silicon carbide is taken as the reinforcement phase due to the fact that SiC has good strength and wear resistance when it reinforced with Aluminium produce high hardness, and high temperature stability. Combination of Boron carbide with the SiC enhances the hardness of reinforcement composite and then both combined and un-combinational SiC, B4C reinforcement compared and evaluated.A property of Aluminium7075 has shown in table 2. .Silicon and Boron carbide are the higher hardness ceramic reinforcements, silicon carbide is widely used because of its effective properties and boron carbide selected for its efficient and greatest strength, boron carbide is the second hardest known material and therefore it is selected to achieve higher hardness.Based on the chemical composition and material properties Aluminium 7075 is selected for the chain sprocket and in order to increase the wear resistance and hardness range silicon carbide and boron carbide reinforcement added to the base alloy which improves the mechanical and tribological behavior of the aluminium 7075 for chain sprocket.Material selection is one of the important factors that need to be selected for the suitable application, wrong selection may lead to a loss in performance or any serious hazard while it is in use. Hence before designing a product an engineer or technician should have a broad material knowledge for the required application.

Table 2. Al 7075 properties

PROPERTIES	VALUES
Density	2.81 g/cm^3
Elastic Modulus	71.7 Gpa
Melting Point	635 °C
Specific Heat Capacity	880 J/Kg-K
Tensile Strength: Ultimate (UTS)	572 Mpa
Rockwell Hardness	50,53 HRC
Thermal Conductivity	143 W/Mk
Elongation	11max

B. Composite Preparation

A recent development in stir casting process is a double stir casting or two-step mixing process. In this process, first the matrix material is heated to above its liquidus temperature. The melt is then cooled down to a temperature between the liquidus and solidus points to a semi-solid state. At this point the preheated reinforcement particles are added and mixed. Again the slurry is heated to a fully liquid state and mixed thoroughly. In double stir casting the resulting microstructure has been found to be more uniform as compared with conventional stirring. Aluminium can melt at a temperature of 635 degree Celsius and therefore the stir casting chamber maintains at about 700 degree Celsius and the reinforcements are preheated to 400 degree Celsius for better mixing and good reinforcement to the base alloy. Su et al (2012) designed a new three step stir casting methods for fabrication of nanoparticle reinforced composite. First the reinforcement and Al particles are mixed using ball mills to break the initial clustering of Nano particles.

Prepared composites in stir casting process shown in figure 1 and 2.The major advantage of stir casting process is its applicability to mass production. Compared to other fabrication methods, stir casting process costs as low as 1/3rd to 1/10th for mass production of metal matrix composites. Because of the above reasons, stir casting is the most widely used commercial method of producing aluminum based composites.

Fig 1: Stir casting process

Fig 2:Obtained composite from mould

C. Testing of composites

The tensile test was conducted in accordance with ASTM E8-95 standards at room temperature using a universal testing machine. The tensile test specimens of nominal diameter 12.5mm and gauge length of 62.5mm was machined from cast composites with the gauge length of the specimen parallel to the longitudinal axis of the casting. Tensile test was conducted for theproduced combinational reinforcement specimen1 (silicon carbide 3% and Boron carbide 2%), specimen2 (Silicon carbide 2% and Boron carbide 3%) and un-combinational specimen3 (silicon carbide 5%) aluminium metal matrix composites.

Microstructure of the composite was tested with optical microscope.Hardness test of the samples are conducted as per ASTM-E-10 standards, test conducted with the Automated Hardness Tester. The hardness range was taken for each specimen at different locations to circumvent the possible effects of particle segregation and the average readings are noted.

To investigate the tribological behavior of specimen Pin OnDisktest was conducted with ASTM G99 standards sliding speed range 0.26-10metre/sec, disc rotation speed 100-600 rpm, maximumnormal load 200 N, frictional force 0-200 N, pin size 3-12 mm, disk size 160 mm and wear track diameter 10-140 mm are taken for wear measurement up to 4mm.

Modeling of chain sprocket was designed with solid works and the stress deformation of the chain sprocket was analyzed by ANSYS workbench with respect to the applied load on each consecutive tooth of the chain sprocket.

D. Results

1. Tensile test

Ultimate tensile strength of a un- combinational reinforcement silicon carbide is higher than the combinational reinforcement of silicon carbide and boron carbide with aluminium7075.Experimental values of the reinforcement samples are listed in the table 3. Bar chart has been plotted to show the tensile strength of the prepared metal matrix composites in figure 3. Complementary reinforcement of the boron carbide with the silicon carbide reduces the tensile strength, where the addition of the more number of composites reduces the tensile strength of the composite.

Table 3. Tensile strength of the samples

Samples	Material reinforcement with Al7075	Tensile strength Values N/mm^2
1	$B_4C3\%$,SiC2%	317.520
2	$B_4C2\%$,SiC3%	320.624
3	SiC5%	358.052

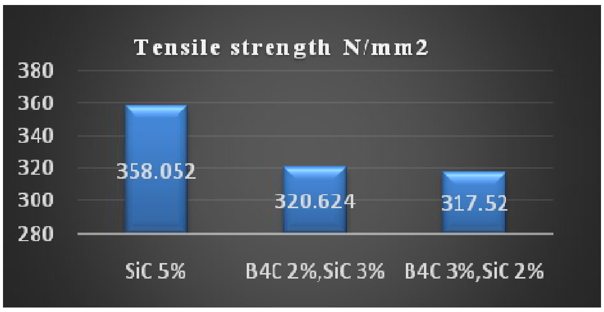

Fig 3: Tensile strength of reinforced composite

2. Microstructure

The microstructure of base alloy specimen and HAMMC specimen were examined with optical microscopy. Before polishing, we may use the abrasive paper or different emery sheet grades such as 400, 600, 800 and 1200. After polishing the specimens were etched by immersing in a solution of 1 ml HF, 2.5 ml HNO_3, 1.5ml HCl and 95 ml H_2O as used as an etchant for 15s. The microstructures were photographed using Envision 3.0 software and Image Analyzer software.

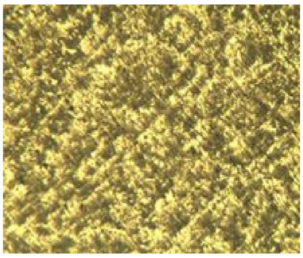
Fig 4:SiC and B4C MMC

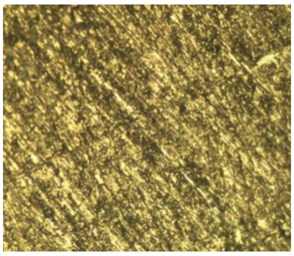
Fig 5: SiC MMC

3. Hardness test

Micro hardness test at various locations was carried out to know the effect of reinforced particulates on the alloy matrix as given in Table 4. Brinell hardness measurement has been carried out on the embedded reinforcement particles as well as in the locality of particles and matrix.

Table 4. Hardness range

Sample	Trial1	Trial2	Average BHN
Base alloy	137	143	140
SiC 5%	156	154	155
SiC3%, B4C2%	210	205	207
SiC2%, B4C3%	212	210	211

Hardness test results compared in figure 6.indicate that the variation of hardness in the locations due to the uncertainty of reinforcement particles presence at the indentation location. The samples with combination of silicon carbide and boron carbide with Al 7075 is having higher hardness and base alloy has the lower hardness because of the absence of reinforcement particulates.

4. Wear test

The wear rates were determined using the weight loss method. In the wear test the pin was pressed against the counterpart rotating against EN32 steel disc with hardness 65HRC by applying the load. An approximately strain-gauged friction detecting arm holds and loads the pin specimen vertically in to a rotating hardened steel disc. After running through a fixed sliding distance at specific time, the specimen was removed, cleaned and weighed to determine the weight loss due to wear. Table 5 shows the difference in weight measured before and after the test gives the wear of the specimen. The volume losses were determined using the weight loss method.

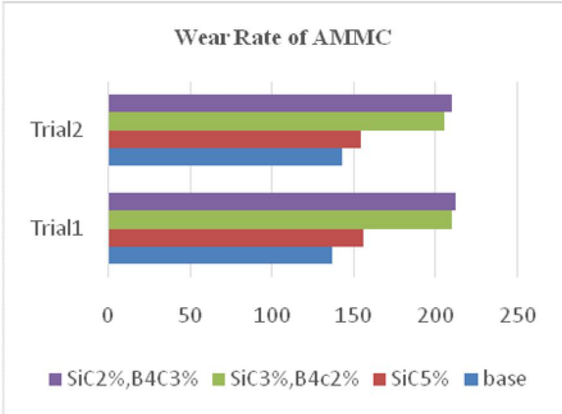

Fig 6:Wear rate variation of reinforcements

Table 5. Weight loss of composites for applied 1kg and 2 kg load in POD

Sample	Load (Kg)	Initial Weight (gms)	Initial Weight (gms)	Change in Weight (gms)
SiC 5%	1	9.7196	9.7171	0.025
SiC 5%	2	9.7171	9.7145	0.026
SiC3%,B_4C 2%	1	8.9795	8.9773	0.022
SiC3%,B_4C 2%	2	8.9773	8.9749	0.024
SiC2%,B_4C 3%	1	8.3280	8.3265	0.015
SiC2%,B_4C 3%	2	8.3265	8.3248	0.017

Table 6.Wear rate of the component

Sample	Wear rate at 1Kg (mm/min)	Wear rate at 1Kg (mm/min)
SiC 5%	44	45
SiC 3%,B_4C 2%	38	39
SiC 2%,B_4C 3%	40	42

From the table 6. Because of the wear rate of the reinforcement (SiC3%, B_4C2%) combination exhibits low wear rate comparing to the other reinforcement combinations. Experimental tests are conducted and the mechanical and tribological properties of the selected material with composite reinforcement were investigated and the results are discussed above and the design of chain sprocket analyzed using ANSYS workbench

5. Design and Analysis

As per von-mises stress theory:
Von-mises stress <= UTS/ F.O.S
Ultimate tensile stress of Aluminium 7075 = 570Mpa.
Obtained von-mises stress in ANSYS workbench =162 Mpa.
Fixed Factor of safety = 2.
Obtained:162 <= (570/2) = 285Mpa.
Obtained value ≤ calculated value, therefore design is safe.

Force for consecutive tooth calculated as per reference [11]
$T_k = T0 * (\sin\varphi / \sin(\varphi + 2))$ ^k-1
Where:
T_k= Back tension at tooth k,
T0 = Chain tension = 6572.68N
φ = Sprocket minimum pressure angle (17 – 64/N) = 15.57degree
N = Number of teeth on driven sprocket = 45,
2β = Sprocket tooth angle (360/N) = 8
K = the number of engaged teeth= (ϴ *N/360) = 15,
ϴ =Angle of wrap of chain oversprocket = 120

Table 7. Force for the sprocket tooth

TOOTH	FORCE N/mm^2
T1	1777.59
T2	1251.9
T3	846.16
T4	567.99
T5	381.27
T6	255.9
T7	171.9
T8	115.31
T9	77.4
T10	51.96

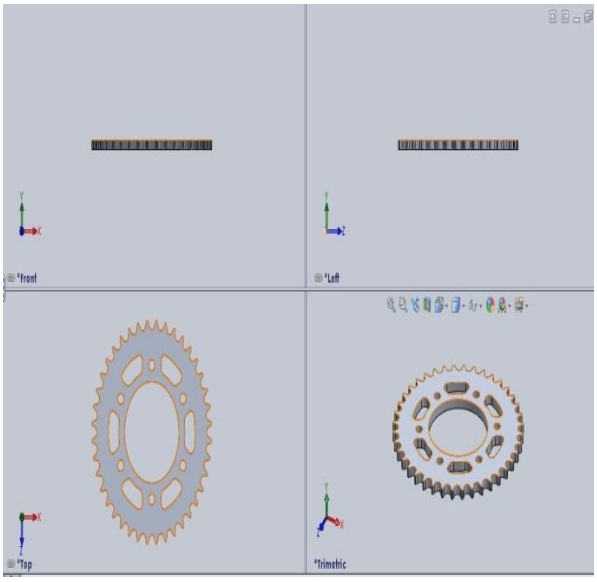

Fig 7: Sprocket modeling in Solid works

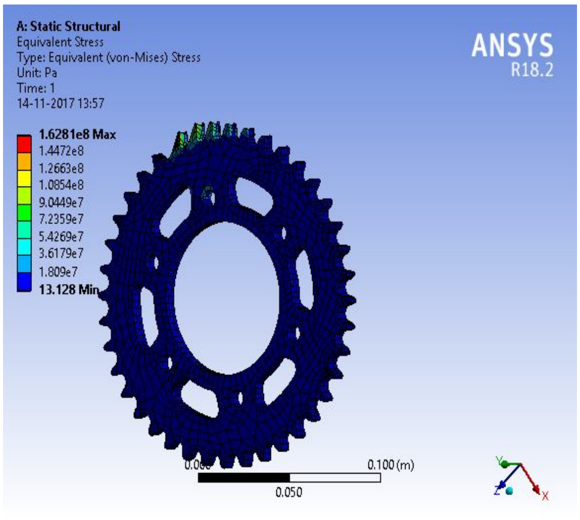

Fig 8: Equivalent von – mises stress

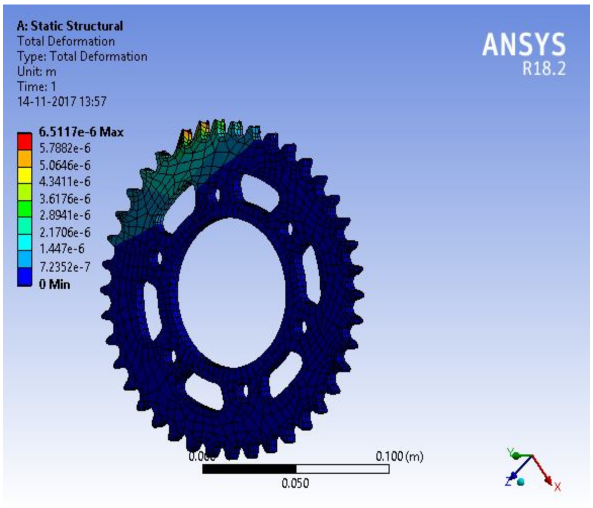

Fig 9: Total deformation

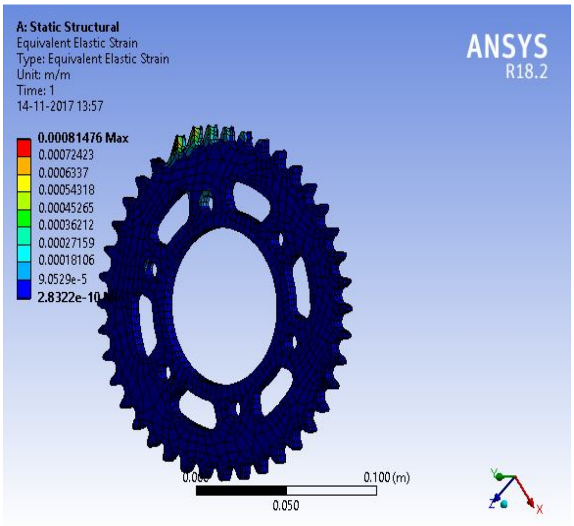

Fig 10: Equivalent elastic strain

The chain sprocket design was modeled by using Solid works, force for the consecutive teeth calculated [11] by the back tension formula which is applied to the chain sprocket and analyzed by ANSYS workbench. Von mises stress is less than the preliminary design hence the design is safe with little increase in deformation.

III. CONCLUSION

The hybrid composite samples of Al 7075 as matrix, SiC and B_4C particulates as reinforcements were fabricated using stir casting process. The mechanical properties such as hardness, wear, tensile and microstructure were investigated from the fabricated samples. From the results it is observed that the microstructure of the dual particulate reinforcements has shown an impact in hardness and wear rate of composite combinations. The microstructure analysis shows fairly even distribution of particles with some agglomerations of SiC and B_4C.The hybrid composite of SiC exhibited superior wear resistance and strength when compared with the combination of B_4C and SiC reinforcement with base alloy and in the combination reinforcement minimum percentage addition of Boron carbide sample wear resistance and hardness strength is better than the maximum boron addition. Composite having (5%SiC),(3% SiC and 2% B_4C) with 95% Al 7075 combination fabricated has higher hardness and superior wear resistance compared to the other combination. This hybrid composite can be explored for use in automotive chain sprockets applications.

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