# Investigation of wear resistance and mechanical properties of CNT reinforced aluminium 7075 alloy for gear applications

**Manikandan.K, Jeeva.S, Gokul Santhosh.V, Gokul.K**

**Abstract**— This project is based on the investigation of aluminium matrix reinforced with carbon nanotube particles. The investigation involves the analysis of wear resistance and the mechanical properties of the composite. The composite can be either ceramic matrix composite or metal matrix composite. This project is based on the metal matrix composite as we have decided to analyse the carbon nanotube reinforced aluminium. The aluminium 7075 alloy is selected because of its excellent resistance to fatigue, high strength and toughness. On the other hand, carbon nanotube particles offer excellent tensile strength and hardness to materials due to their nano structure and strength of the bonds between carbon atoms. The carbon nanotube particles are reinforced with aluminium 7075 by the stir casting process. The stir casting process is the most suitable way to reinforce because only then the carbon nanotube particles mix in correct proportions. Then the casted product is tested for wear resistance and the mechanical properties. The casting is done by adding appropriate proportion of carbon nanotube particles. Here, the 2wt% of carbon nanotube is used. For doing the wear test, a pin of 8mm diameter and 23 mm length of the casted portion is taken. The pin is then analysed for wear characteristics using pin-on-disc tribometer. The mechanical tests such as hardness tests, tensile tests and impact tests are performed on the casted product and the results are recorded. The traditionally used metals may not satisfy the vast engineering application. The metals cannot be used in all the applications considering the weight, strength and durability. In this regard, the composite materials can be replaced for the traditionally used metals. The composite material has good versatility properties which can be used in various applications. For each application, we can select the appropriate composite. Some of the properties of the composite materials include light weight, high strength etc. The results recorded in pin-on-disc tribometer test is used to draw graphs explaining the wear characteristics and the wear rate value for the composite is determined. The readings taken from material testing are used to find the strength of the material.

**Index Terms**— Aluminium 7075 alloy, carbon nanotube particles, stir casting process, pin-on-disc tribometer, strength, composite material.

## 1 INTRODUCTION

The metal matrix composites are composites made from atleast two different materials. One of the materials should be a metal while the other material can be either metal or ceramic and organic compounds. In this project, the carbon nanotube particles are reinforced into aluminium metal matrix. This is done to improve the wear resistance, friction co-efficient and thermal conductivity of the material. The traditionally used metals may not satisfy the vast engineering application. In this regard, the composite materials can be replaced for the traditionally used metals. The composite material has good versatility properties which can be used in various applications[2] . The aluminium 7075 alloy is selected because of its excellent resistance to fatigue, high strength and toughness. On the other hand, carbon nanotube particles offer excellent tensile strength and hardness[6]. The manufacturing of the metal matrix composites can be done by solid state method, liquid state method and semi-solid state method. Of these three methods, we have selected liquid state method. The reason to select liquid state method is due to the ease of forming of the composite at low viscosity. In liquid state methods, there are many ways to produce a composite. In that regard, we select stir casting technique to reinforce carbon nanotube particles into aluminium particles. Only in stir casting method, the carbon nanotube particles mix well with the aluminium matrix[1]. The aluminium 7075 alloy has good tensile strength and fatigue strength. So, reinforcing the carbon nanotube particles with aluminium 7075 alloy will help to manufacture a composite with good excellent tensile strength corrosion resistant and wear resistant properties. The mechanical tests such as hardness tests, tensile tests, compressive tests and impact tests are performed on the casted product then the strength and hardness of the composite is determined. The results recorded in pin-on-disc tribometer test is used to draw graphs explaining the wear characteristics and the wear rate value for the composite is determined[13].


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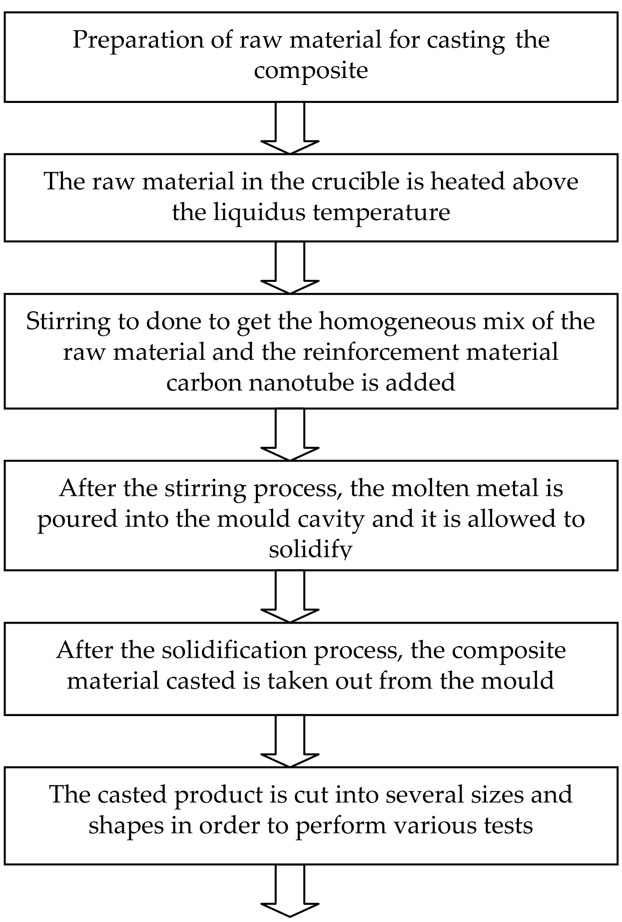
## 2 PROBLEM IDENTIFICATION

The traditionally used aluminium metals may not have appropriate properties for various applications. In other words, the versatility of those metals may not be sufficient for wide variety of applications. In such cases, it is necessary to come up with different materials with different composition. In that regard, the metal matrix composites can be an ideal one. So, in this project aluminum metal matrix composite is prepared and tested. The reason for giving importance to aluminium matrix is due to its good strength and light weight. The wear resistant and corrosion resistant of aluminium metals may not be appropriate for some aerospace and engineering applications. So, manufacturing a composite with aluminium and carbon nanotube will increase the strength, hardness, corrosion resistant and wear resistant properties than ever before[3]. The manufactured composite can be used for variety of applications because of its improved properties. Also, the normal aluminium material may have high wear rate when subjected to different loads[4]. So, using an aluminium matrix composite can result in decreased wear rate and so it can be used for many applications[12].

## 3 OBJECTIVES

- The main objective of the project is to measure the wear characteristics of the carbon nanotube reinforced aluminium material.
- To manufacture the composite with correct proportion of carbon nanotube and aluminium.
- To measure the wear rate of the produced composite by performing the wear test.
- To manufacture the composite material by stir casting method without any defects.
- To perform the hardness test, tensile test, impact and compressive tests on the manufactured composite.

## 4 PROPOSED METHODOLOGY



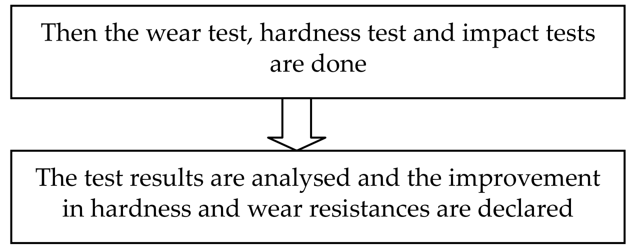




***Figure 1*** *Flow chart of the proposed methodology*

## 5 MANUFACTURING OF THE COMPOSITE

From the literatures, the composition of Al, Si, CNT was determined. Al=98%, SiC =0.5%, CNT=1.5% was determined to make the composite material. Both aluminium 7075 alloy particles and carbon nanotube particles gives abundant strength and hardness. For this, the stir casting process was selected. Here, the aluminium 7075 is used instead of pure aluminium. CNT % is lower because at higher percentages it may deposit on one side of the casted product. Also, only in stir casting process, the aluminium and carbon nanotube particles mix well together. SiC is used to increase the mechanical properties like strength, hardness etc.

### 5.1 Stir casting process

Stir casting process is a liquid state method commonly used for the production of composites. The metal matrix composites can be easily manufactured by stir casting method. Stir casting plays a vital role in giving uniform distribution of reinforced particles[5]. So, this is the most suitable process compared to any other. The stir casting process uses furnace, reinforcement feeder and mechanical stirrer. The raw materials are heated and melted in the furnace. After some time, the reinforcements such as carbon nanotube particles, silicon carbide particles and aluminium 7075 alloy particles are introduced into the furnace[10]. The mechanical stirrer is used to get the homogeneous mixture of the aluminum and carbon nanotube particles[8]. The mechanical stirrer usually has an impeller blade fitted with the stirrer rod. The number of impeller blades can be one, two or three. For making of any metal matrix composites, the single impeller setup is used to avoid excessive vortex flow. By considering all these parameters, the casting is done to produce the required composite material. Initially, the matrix material is heated in the furnace at a definite temperature. Then, the mechanical stirring is initiated for good mix. Now the silicon carbide of 0.5wt%, carbon nanotube 1.5wt% and aluminium 7075 alloy 98% are added as reinforcements. The stirring is continued for few more minutes. Then, the molten mixture is poured inti the mould cavity and allowed for solidification. The solidified product is then taken out from the mould. Thus, the casted product is the required composite material.

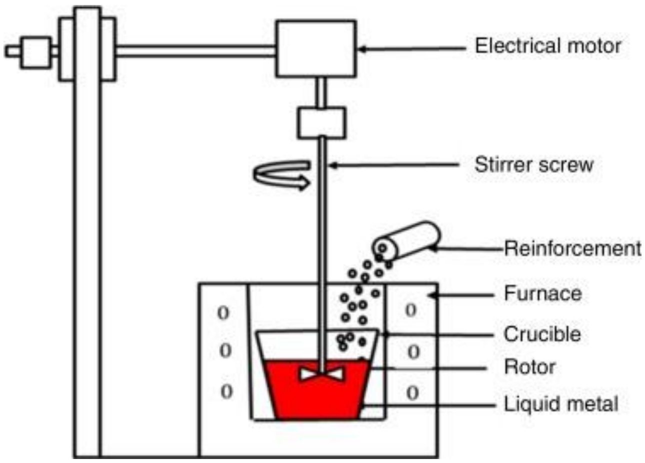



***Figure 2*** *Stir casting*

The above figure 2 shows the experimental setup for performing the stir casting process. The stirrer uses the power form the electrical motor for stirring operation. It has a single impeller blade for the stirring operation.

## 6 TESTING OF THE COMPOSITE MATERIAL

The composite material made from aluminium 7075 alloy particles and carbon nanotube particles is tested for wear rate, hardness and impact strength. Also, the analysis of the manufactured composite material is done in ANSYS 18.1 platform. The analysis is done to compare the displacement and von mises stress of the composite material. Then, the results are compared with the results of aluminium 7075 alloy. The pin-on-disc tribometer test is done to determine the wear rate of the composite material[9]. Rockwell hardness and Brinell hardness tests are done to determine the hardness of the manufactured composite. Charpy test is done to identify the impact strength of the composite material.

### 6.1 Pin-on-disc tribometer test

A tribometer is a device which is used to measure the wear rate, co-efficient of friction and frictional force between the worn surfaces in contact[13]. These are called the tribological parameters of the material. In this project, pin-on-disc type of tribometer is used. This type of tribometer uses a stationary pin pressed against the rotating disc. The pressing is the direct measure of the load applied[7]. The pin can be of 8mm to 12 mm diameter. Its length can be upto 35 mm. Before, performing the test, the pin should be checked for fine finish[11].

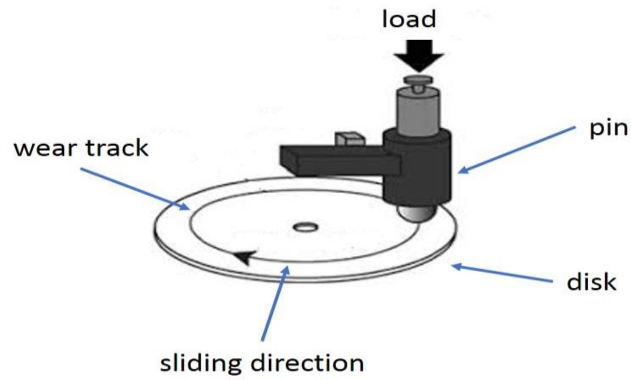



***Figure 3*** *Working of pin-on-disc tribometer.*

### 6.2 Input parameters

- From the manufactured composite, a pin of 8mm diameter and 25 mm length is made and subjected to pin-on-disc tribometer test.
- The input parameters are load= 50N, sliding speed=500 rpm, sliding distance= 1000m, sliding velocity=2.09m/s.
- Initial weight of the specimen, Mi= 3.3933g, final weight of the specimen, Mf= 3.3418g.
- Testing time= 8 minutes

***Figure 4*** *Experimental setup of pin-on-disc tribometer*

The above figure 4 represents the experimental setup of the pin-on-disc tribometer. The pin is made to press against the rotary disc of the tribometer.

### 6.3 Wear rate calculation

- Wear rate = (volume loss)/(applied load*sliding distance) [13]
- Volume loss = (Mi-Mf) /density
  where density, ϱ= 2.810g/cm^3
  Mi-Mf= 3.3933-3.3418 = 0.0515g
  Volume loss= (0.0515)/(2.810*10^-3)
  = 18.32mm^3
- Wear rate = (18.32)/(50*1000)
  = 3.664*10^-4 mm^3/Nm

The wear rate for the composite material prepared is 3.664*10^-3 mm^3/Nm.

The following graphs are used to study the wear characteristics of the composite material.

- Wear vs time
- Coefficient of friction vs time
- Frictional force vs time
- Frictional force vs wear
- Coefficient of friction vs wear
- Coefficient of friction vs Frictional force
- Temperature vs wear

The following graphs shows the wear characteristics at the load of 50N, sliding distance of 1000m and sliding velocity of 500 rpm. [15]

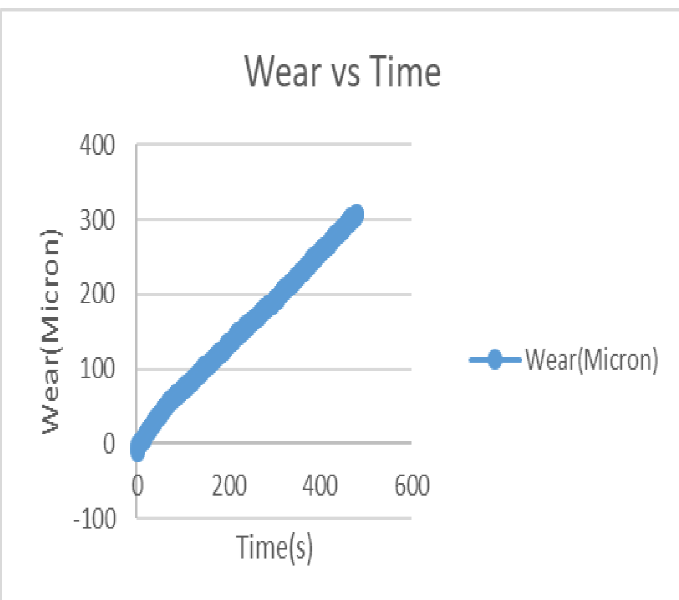



***Figure 5*** *Wear vs time*

The figure 5 shows the wear of the composite material with respect to the time of 8 minutes. The wear is measured in micron. The wear linearly increases with the increase in time.

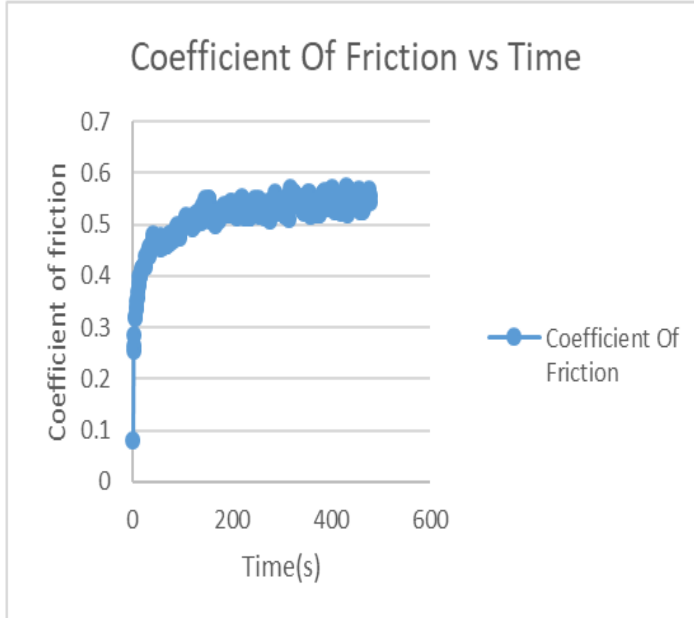



***Figure 6*** *Coefficient of friction vs time*

The above figure 6 shows the coefficient of friction with respect to time. The coefficient of friction is initially 0.1 and it increases gradually. The final coefficient of friction is 0.515.

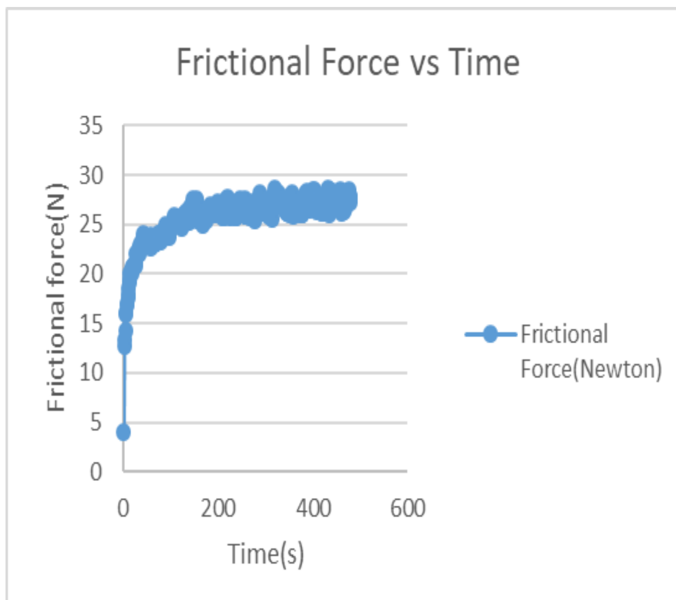



***Figure 7*** *Frictional force vs time*

The above figure 7 shows the frictional force values of the composite with respect to time. The frictional force is initially 5N to 10N. After about 2-3 minutes, the frictional force increases with increase in time.

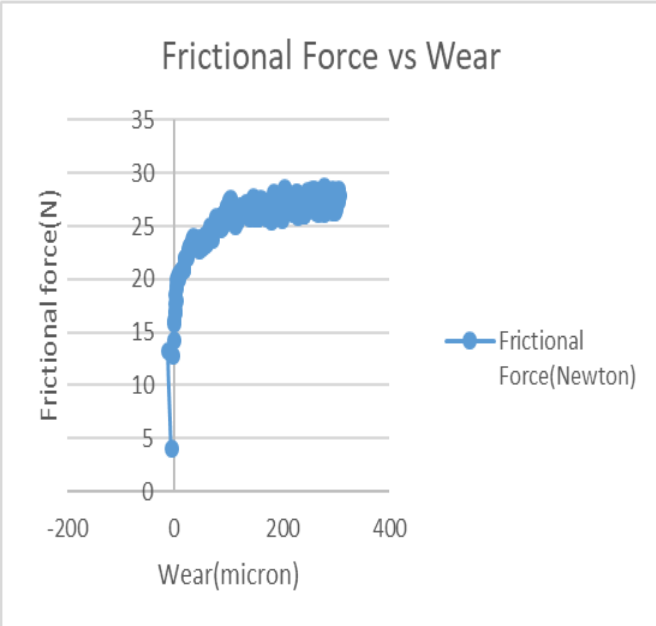



***Figure 8*** *Frictional force vs wear*

The above figure 8 shows the relation between the frictional force and the wear. Initially, for about 12.5N frictional force, the wear rate is very minimum. As the frictional force increases, the wear rate also increases. The maximum wear is obtained at the frictional force of 28N.

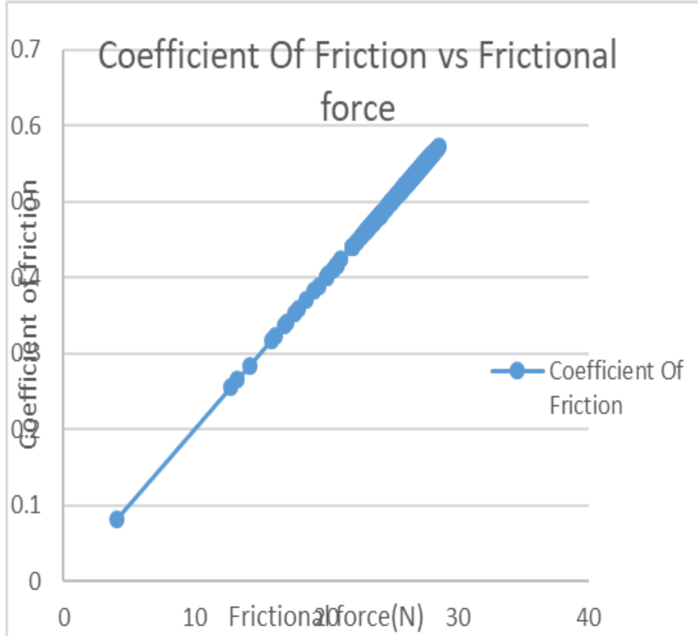



***Figure 10*** *Coefficient of friction vs Frictional force*

The above figure 10 shows the relation between the coefficient of friction and frictional force. The coefficient of friction increases linearly with the frictional force. The coefficient of friction is maximum at the frictional force of 30N.

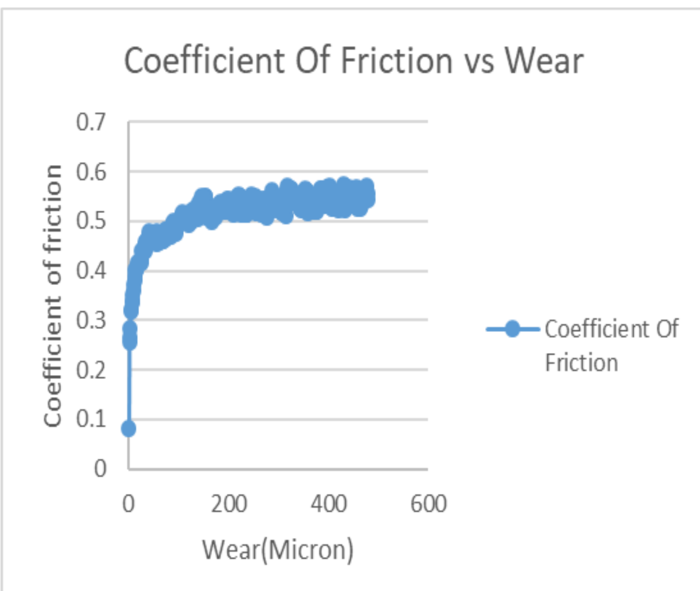



***Figure 9*** *Coefficient of friction vs wear*

The above figure 9 shows the relation between the coefficient of friction and wear rate. Upto to 0.3 coefficient of friction, no wear is recorded. Then, the wear increases gradually. The maximum wear rate recorded is 400 micron at o.6 coefficient of friction.

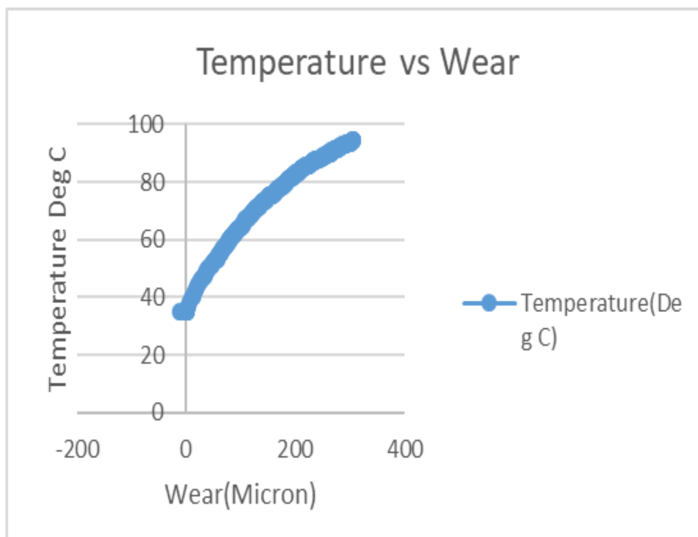



***Figure 11*** *Temperature vs wear*

The above figure 11 represents the relationship between the temperature and wear of the composite material at the load of 50N. The wear is initially minimum at the temperature of nearly 35 degree celcius. Then the wear rate increases gradually with the temperature.

### 6.4 Rockwell Hardness Test

The Rockwell hardness test is a method for measuring the hardness of any material based on the indentation of that particular material. The hardness value is obtained due to the indenter's depth of penetration. It is actually taken at the respective loads. Rockwell hardness indicates the hardness values in A scale and B scale. Here, the hardness value is measured in B scale. The casted composite is cut into pieces and tested for harness. The readings are taken at the load of 100kg. 1/16'' indenter is commonly used for aluminium materials. So, the same indenter is used for carbon nanotube and aluminium 7075 composite. Three readings are taken at different points and the average value is calculated. The average value indicates the hardness value of the composite material.

***Table 1*** *Rockwell hardness test results*

| Type of indenter | Readings | | | Rockwell Harness Number |
|---|---|---|---|---|
| | I | II | II | |
| 1/16'' | 64 | 63 | 65 | 64 |

The above table 1 shows the readings of the hardness at three different points on the composite material. The first reading shows a hardness of 64. Second reading shows hardness of 63 and the third reading shows a hardness value of 65. On taking the average for these hardness values, a value of 64 is obtained. Thus the Rockwell hardness of the composite is 64.

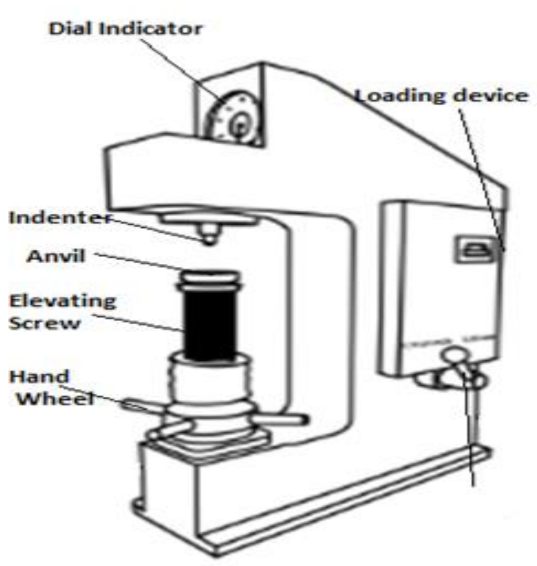



***Figure 12*** *Rockwell hardness tester*

The above figure 12 shows the Rockwell hardness machine setup. It also shows basic concept behind the working of the tester.

### 6.5 Brinell Hardness Test

The hardness measurement by brinell harness test is usually different from Rockwell hardness test. In rockwell hardness test, the indenter's depth of penetration is used to measure the hardness value. While in brinell hardness test, the impression made by the indenter is used to find the hardness of the material. So, by varying the size and type of the indenters, brinell hardness tests can be used for vast variety of materials. The microscope is used to measure the size of the indentation. The test is actually carried at the load of 187.5 kg. The diameter of the indenter used is 2.5mm. After performing the tests, the diameter of the indentation is measured and substituted in the following formula.

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

Where P= load applied (here 187.5kg)
D= diameter of indenter in mm (here 2.5mm)
d= diameter of indentation in mm

***Table 2*** *Brinell hardness test results*

| Diameter of indener (mm) | Load (kg) | Diameter of indentation (mm) | Brinell Hardness Number (BHN) |
|---|---|---|---|
| 2.5 | 187.5 | 1.4 | 111.4 |

The above table 2 shows the readings of hardness of the composite material taken from brinell hardness test. The diameter of indentation on measuring with the microscope is 1.4mm. By substituting this value in brinell hardness formula, the brinell hardness value of 111.4 is obtained.

**Brinell Hardness Number(BHN) calculation**

Diameter of indentation,d = 1.4 mm
BHN= 2P/(πD( D- square root of(D^2-d^2)))
= (2*187.5)/(3.14*2.5*(2.5- square root of(2.5^2-1.4^2)))
= (2*187.5)/(1.6829)
= 111.4

### 6.6 Impact test

The impact test is usually done to identify the ability of the material to withstand shock or impact loads. In other words, the impact test reveals the energy absorbing capacity of the material when subjected to shock loads. By, doing this test we can determine the impact strength of any material. Impacts can be of two types. One is Izod impact test and the other is Charpy impact test. In this project, Charpy test is preferred. In Charpy test, the pendulum is fixed in a way that it makes 135 degree with the specimen to be tested. The aluminium7075 and carbon nanotube composite is cut into a length of 55mm. A square specimen of 10mm*10mm is used in this project. A V-notch of 2mm deep is provided on the specimen. So, the area of cross-section at notch point is 7.2 mm^2. The energy required to break the specimen is measured in joules.

***Figure 13*** *Experimental setup of Charpy test*

The above figure 13 shows the experimental setup of the Charpy test before taking the readings. As, mentioned earlier, the angle between the test specimen and the pendulum is 135 degree. In this way, the impact strength of the specimen is tested. The impact strength is usually measured in J/mm^2.


***Figure 14*** *Way of holding the workpiece horizontally*

The figure 14 shows the mounting of the specimen horizontally. In Charpy test, the test specimen should be kept horizontally.

***Table 3*** *Impact test results*

| Loss of energy due to friction(J) | Energy required to break the specimen(J) | Actual energy required (J) | Impact strength (J/mm^2) |
|---|---|---|---|
| 0 | 4 | 4 | 0.55 |

The above table 3 shows the results of the impact test. Here, there is no loss of energy due to friction. The energy to break the specimen is 4J. Now the impact strength of the specimen is calculated in the following formula:

Impact strength of the specimen= (Energy required to break the specimen/Area of cross section at notch point.)

Impact strength= 4/7.2

= 0.55 J/mm^2

## 7 ANALYSIS OF THE COMPOSITE MATERIAL

The composite material prepared from the reinforcement of carbon nanotube particles is analysed on ANSYS 18.1 platform. The analysis for composite material is done and it is compared with analysis of the aluminium 7075 alloy[17]. The analysis usually done by comparing the displacement vector sum and von mises stresses of the specimen under loads. The load is applied at the edge of material. Here, the analysis done by applying a load of 1000n. To analyse a square matrix of 20mm*20mm is considered. After performing the analysis, the material which has least displacement and von mises stress value is considered as the good one.

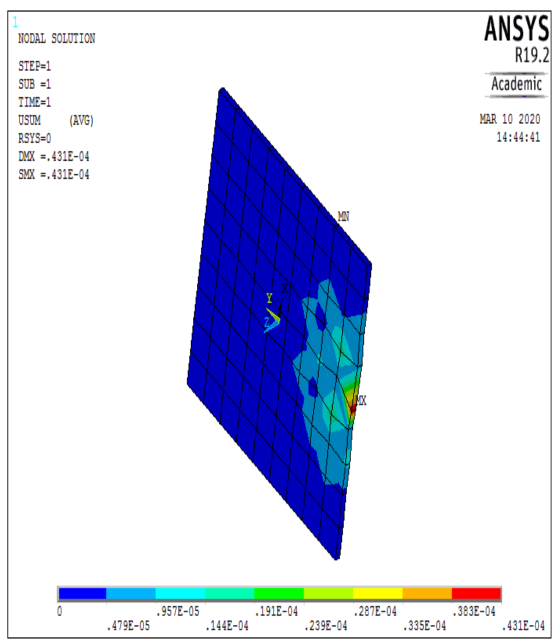



***Figure 15*** *Displacent vector sum of Al 7075 alloy*

The above figure 15 shows the displacement vector sum of the aluminium 7075 alloy at the load of 1000N. The displacement of the alloy is measured as 0.41E-04.

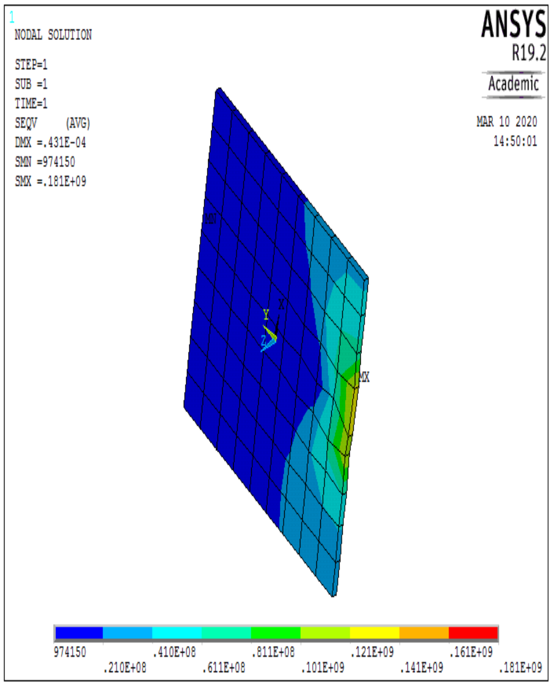



***Figure 16*** *Von mises stress of Al 7075 alloy*

The above figure 16 shows the von mises stress of the aluminium7075 alloy at the load of 1000N. The von mises stress is 0.181E+09.

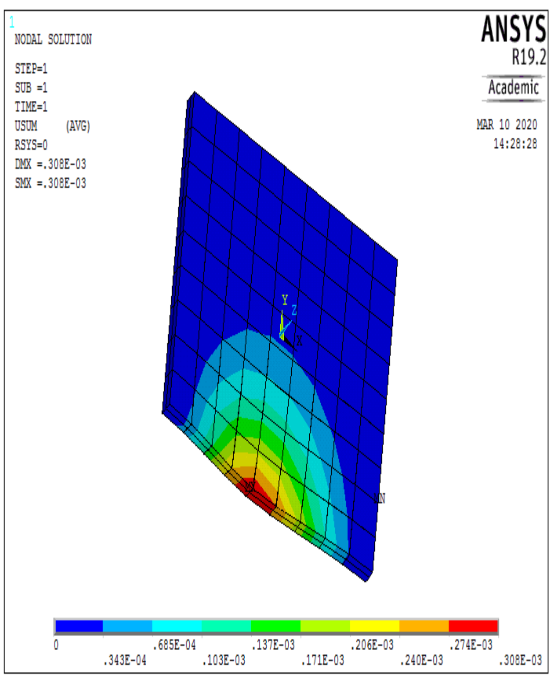



***Figure 17*** *Displacement Vector sum of Al 7075 and carbon nanotube composite*

The above figure 17 shows the displacement of aluminium 7075 and carbon nanotube composite. The displacement of the alloy is 0.3E-04 AT 100N. Thus the displacement of the composite is lower than the displacement in aluminium7075 composite.

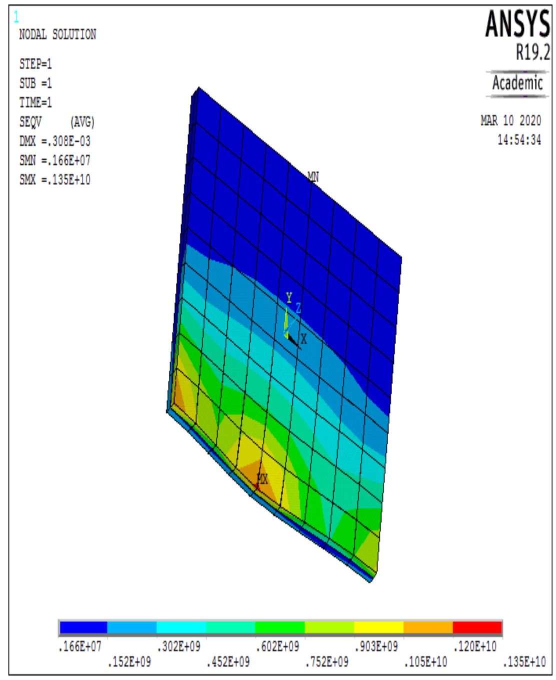



***Figure 18*** *Von mises stress of the Al 7075 and carbon nanotube composite*

The above figure 18 shows the von mises stress of the aluminium 7075 and carbon nanotube composite. The von mises stress is 0.135E+09 at 1000N. Thus the von mises stress of the composite is lower than the von mises stress of aluminium 7075 alloy.

## 8 CONCLUSION AND RESULTS

The aluminium 7075 and carbon nanotube composite manufactured is tested for wear rate, hardness and impact strengths. The wear rate done by pin-on-disc tribometer shows that wear rate of the composite is 3.664*10^-4 mm^3/Nm[16]. Thus, the resistance of the composite is low and this material can be used for gear applications. By using this material in gears, the life of a gear will be increased[18]. Also, the hardness value obtained from Rockwell hardness test is 64. For other aluminium materials, the Rockwell hardness will be around 58 to 62. So, the hardness of the material has increased to a good account. The Rockwell hardness of 64 shows that the composite can be good for gear applications. The Brinell hardness value obtained by measuring the size of indenter impression is 111.4. Usually the Brinell hardness values of aluminium materials lie between 90 to 110. A Brinell hardness value of 111.4 shows that the material can be used for era applications. The impact strength of the composite material is 0.55 J/mm^2. From the literatures referred, the impact strength of the aluminium 7075 alloy is 0.15 J/mm^2. Thus the impact strength has increased significantly. So it can be used for gear applications. The analysis was done on the aluminium 7075- carbon nanotube composite and on the aluminium alloy. The results showed that the displacement and von mises stress of the composite prepared was lower than that of the aluminium 7075 alloy. Thus, by considering all these results, it can be concluded that the aluminium 7075-carbon nanotube composite has improved hardness and strengths. So, this material can be used for gear applications.

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