EasyChair Preprint

№ 8241

Experimental Investigation of Tribological Characteristics of Aluminum - 7 Series Alloy (Al7075) Reinforced with Tungsten Carbide (WC)

Tirumani Srilakshmi, B Omprakash and S Md Gouse

June 10, 2022

EXPERIMENTAL INVESTIGATION OF TRIBOLOGICAL CHARACTERISTICS OF ALUMINUM - 7 SERIES ALLOY (Al7075) REINFORCED WITH TUNGSTEN CARBIDE (WC)

Titumani Shanmuka Srilakshmi
Department of Mechanical Engineering, JNTUA College of Engineering, Anantapuramu
tirumani05@gmail.com

Dr. B. Omprakash
Assistant Professor, Department of Mechanical Engineering, JNTUA College of Engineering, Anantapuramu
omprakash1715@gmail.com

S Md Gouse
M.Tech (R&AC) Lecturer in Mechanical engineering Government polytechnic jammalamadugu

ABSTRACT

The demand for high quality materials are increased, the development of light-weight aluminium (Al) also increased especially in aerospace and automotive industries. In order to combine all their properties, MMC's have become a very attractive method for various industrial applications. MMC'S are bringing extremely good thermal energy associated with high impact, ductility and toughness at higher temperature. The aim of this investigation is to study the microstructures and mechanical properties of Al7075 with tungsten carbide (WC) reinforced matrix composite. By varying weight % of WC content (1%, 2%, 3%) with Al7075, composite preparation by stir casting process and comparing the results with Al7075.

Metal matrix composites are mostly used in components of various parts of industrial equipment because of their excellent properties like high strength to weight ratio and high impact value and fracture toughness while compared to the conventional material. Due to the concepts of high strength to low weight ratio, the aluminum primarily based composites are gradually being applied as a part of the transport, aerospace, marine, automobile industries. The usually applied reinforcing materials for those composites are silicon carbide, tungsten carbide, aluminum oxide and graphite as particles. Tungsten carbide is attractive as reinforcement because it has high hardness, high modulus of elasticity and excellent thermal stability. This project mainly focuses on investigating their contribution to the enhancement of the mechanical performance of the composites

Keywords: Aluminum, Thermal Expansion, MMC, High Impact, Tungsten Carbide, Reinforced Matrix, Stir Casting, Microstructure, Optical microscope, Brinell hardnes

I. INTRODUCTION

The word Tribology is derived from two Greek words tribo meaning rubbing and the - logy element basically means the study of. Tribology is concerned with the science and the technology of the interface between two or more bodies in relative motion. Today we define tribology as the science of interacting surfaces, which are having relative motion with respect to each other. Tribology is the art of applying operational analysis to problems of great economic significance, namely, reliability, maintenance, and wear of technical equipment that ranges from spacecraft to household appliances. Tribology is crucial to modern machinery that uses sliding and rolling surfaces such as brakes, gears, clutches, driving wheels on trains and automobiles, bolts, and nuts. It is in most areas of engineering and industry such as aerospace and agriculture, even to such unlikely areas as cosmetics, medical implants and shoe manufacturing. Tribology plays an important role in manufacturing as well. In metal-forming operations, friction increases tool wear and the power required to work a piece.

Friction is the resistance to motion during sliding or rolling, experienced when one solid body moves tangentially over another. The resistive tangential force acts in a direction directly opposite to the direction of motion. Friction is not a material property; rather it is a system response. If two solid surfaces are clean without chemical films and adsorbents, high friction occurs. Surface contaminants or thin films affect friction. With well-lubricated surfaces, weak adhesion and friction are generally observed. However interface results in liquid-mediated adhesion, which may result in high friction, especially between two smooth surfaces. Dry friction, also called "Coulomb" friction, describes the tangential component of the contact force that exists when two dry surfaces move or tend to move relative to one another a wide range of applications.

The following section describes in brief the effect of various environmental parameter and material properties on friction and wear. The studies done are so vast that there is still a high level of difficulty in getting a clear understanding of tribological phenomena. Meng and Ludema [9] did point out more than 20 years back on the status of tribology and one can safely say that the situation is not very different today, though with the advent of sophisticated equipment the clarity is better. However, it is important to note that the statements made of friction and wear hold true for the experimental range in which the experiments are conducted. Effect of normal force It has been found that the friction coefficient of metallic pairs increases with an increase in load at low loads because of the oxide film breakdown and begin to drop at high loads because of interfacial changes caused by the wear particles. Considering the effect of normal load on the friction coefficient for copper sliding on copper shows lower friction at low loads as a result of oxide formation that effectively separates the two metal surfaces, and exhibits high friction at high loads due to break down of the oxide film [11]. This trend however is not always true, for example in the friction experiments carried out for stainless steels at very high loads it has been proposed that a large quantity of wear debris at the interface is responsible for the lower friction coefficient.

The composite materials consist of two constituents such as reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase, e.g., polymer matrix, metal-matrix and ceramic composites. In addition there are some reports to indicate the emergence of Inter metallicmatrix and carbon-matrix composites. Composites are being commercialized in three major fields polymer-matrix composites (PMCs), metal matrix composites (MMCs), and ceramicmatrix composites (CMCs).Other classification schemes based on a matrix/ fiber notation, such as Al/WC and 6061/WC T6 for aluminium reinforced with silicon carbide and boron and carbon-fiber reinforced polymers (BFRP or CFRP),are also being used.

Hari Prasada Rao Pydi, Balamurugan Adhithan, A.Syed Bava Bakrudeen reported that Miniature construction examination shows the uniform circulation of tungsten carbide particles in the Aluminum. The microstructure likewise uncovered great interfacial bond among lattice and tungsten carbide particles. Composite Al/Wc Material Powders that we have manufactured shows the prong Grain Structure when contrasted with Unadulterated Aluminum. The expansion of tungsten carbide with Al, builds the sway opposition of the built up Al by diminishing the breaks and voids in the precious stone grid which was noticed in the XRD investigation.

A Anish and M Ananth Kumar reported that The Al7075–WC–MoS2 composites is prepared by stir casting process. The mechanical properties of base metal and samples were assessed and compared. The conclusions made from the study are as follows: Aluminium composite is successfully fabricated by stir casting technique with fairly uniform distribution of WC & MoS2. Maximum tensile strength in the aluminium metal matrix is observed at 6% WC & 4% MoS2. Maximum hardness in the aluminium metal matrix is observed at 6% WC & 4% MoS2.

Santhosh Kumar B M, Girish D. P reported that the hardness increases with increasing wt. % of reinforcement for the MMCs. Important micro-structural changes occur during initial addition of reinforcement. The mechanical properties such as UTS, yield strength and hardness increase with increasing wt. % of reinforcement for the MMCs.

Meenakshi Kushal et al, conducts an experiment to optimize the design of drum brake (through reverse engineering approach). From the analysis, it is observed that the deformation in CE (Control expansion) alloy brake is considerably less than the Nickel alloy drum brake. Also, the temperature rise in CE alloy brake drum surface is less than the AL alloy brake drums; it increases the life of lining material and also increases braking performance. It is also found that due to instant breaking the temperature rise in drum brake is 65% to 66% more compared to gradual braking. Hence it is concluded that due to lighter weight, less deformation, and less temperature rise, the CE alloy material is better for drum brake application for the light commercial vehicle.

In stir casting method the difference in density of matrix and reinforcement material will not give the homogenous distribution of the particles and under dry wear and abrasive wear conditions SiC reinforced composites will shows the better properties [30],[31] but this 12 problem can be avoided or minimized in friction stir processing. Many works had been done on the reinforcement of solid lubricants which increases the resistance to wear, solid lubricants are the materials which increases the wear resistance property because of crystal structure and nature. Graphite, hexagonal boron nitride, zinc oxide, molybdenum disulfide, titanium dioxide etc., are some of the examples of solid lubricants, most of the solid lubricants has hexagonal crystal structure with Van der waals force between the layers, which slides the layers and acts as a solid lubricant.

Sayed et al and his co-author studied that Graphite predominantly acts as solid lubricant and by reinforcing in aluminium metal matrix makes it good lubricating material. Aluminium reinforced with graphite are emerging as feasible structural materials for aerospace applications and their predominant mechanical properties are feasible to use in naval technology.

Sharma et al studied that Aluminium metal matrix reinforced with Gr are known as potential materials for tribology applications. The reason for the outstanding tribological properties of graphite reinforced with aluminium is that aluminium alloy yields at low shear stresses and deforms rapidly.

Ulhas .K. Annigeria* G.B. Veeresh Kumar reported that The stir casting method generally involves the heating of the matrix material to a melting temperature in a crucible which is chemically inert to the materials that are going to be charged into it. The crucible can be of various types and the most basic type being the coke fired. The furnace generally being used is the electric resistance furnace. The particulates are preheated in order to improve its mixing with the matrix material also to avoid thermal mis-match.

The melt may or may not be stirred prior to mixing the particulates. The temperature of the crucible depends on the alloy material being melted. The mixing of the particulates can be two-step or three-step which is a variation depending on the weight percentages of the reinforcement. The mixing can be in semi-solid state or above liquidus state. There have to be variations in the geometry of the stirrer and feeding mechanism to get a homogenised material. An inert atmosphere may be maintained during stirring and pouring the melt into the mold in order to avoid defects in the cast product. The problem of gas entrapment due to vortex creation may be avoided by introducing the particulates by means of an injection gun with an inert gas carrying it. The wettability between the matrix and the reinforcement has to be appropriate in order to get a homogenised composite. The overall conclusion is that the microstructure of the 13 so produced composite has a fairly good distribution of the particulates in the matrix material. The properties obtained have achieved the tailor able characteristic of the composite material.

The automotive parts consists mainly of moving parts where effective wear is seen such as piston rings, bearings, compressors, cylinder walls because of this the reliability, durability of the material is reduced hence to overcome this criteria. Wear is the damaging, gradual removal or deformation of material at solid surfaces. Causes of wear can be mechanical also called as erosion. However, taking appropriate action is almost impossible if you don't know what the root cause of the failure is. Generally speaking, there are a handful of causes that are found to be responsible for most of the damage to – and failure of – industrial machinery. Wear of metals occurs by plastic displacement of surface and near-surface material and by detachment of particles that form wear debris. Aluminium is reinforced with composite called tungsten carbide which is of very hard reduces the wear rate and hardness of the parent material increases. So it can be effectively used in the moving parts.

Fig: 1. some of the eroded material due to wear

II. MATERIALS AND METHODOLOGY

2.1. Aluminum as Base Metal

Aluminum (Al) is the third most abundant metal in the earth's crust and in its natural form is combined with oxygen and other elements. It has a face-centered cubic (FCC) structure, has high ductility at ambient temperature, and is relatively easy to machine .Compared to other engineering metals; Aluminum has a low melting temperature about 660 °C. Since around 1886, when Al alloy was first produced by the Hall-Heroult method of electrolytic reduction, aluminum production rose from just over 45,000 tons to more than 25 million tons today. A good reference of the growth of Aluminum alloys are divided into workable alloys, i.e., those that undergo hot or cold mechanical working process, and cast alloys, i.e., where the final shape of the part is obtained by casting process. To classify workable and cast alloys, the Aluminum Association uses numerical designations that identify the class, the main alloying element, and modifications of the alloy within the class. The designation system adopted for workable aluminum alloys. Cast aluminum alloys are classified by a similar process. Compared to ferrous alloys, aluminum alloys are generally considered to have good machinability. However, their ductility is responsible for increasing the machining forces, for poor surface finish and difficult chip control, while the high contents of silicon in aluminum-silicon alloys are responsible for the high wear rates of cutting tools aluminum production is its application in the automotive industry.

2.2. Aluminium 7075

Presently engineering materials are developed with high specific strength at lesser cost. One of the typical example is the development of composite materials for automotive applications which improves the fuel economy as well as engine performance. Modern engineering systems demands materials with wide spectrum of properties which are not 20 achievable through the usage of homogenous materials. Hybrid Aluminium composites fulfils the demand such as ease of processing, reduction in cost and improved mechanical properties. The reliability and the performance of these composites depend on the right choice of reinforcing materials, weight percentage and processing conditions of the materials.

Fig: 2. Aluminium 7075

Aluminum alloys are ideal engineering material for automobile, aerospace and mineral processing industries for various high performing components and are being used for these diverse applications due to their lesser weight, exceptional thermal conductivity properties. Aluminum 7075 series alloy materials used for the construction of desirable components of automobile, aerospace and marine applications are in line skating-frames, shafts for lacrosse sticks, hang glider air-frames, rifles for the American military, camping knife and fork sets, fuselage, turbine casing, missile tail cone, bicycle components, automobile engine casing, etc.. These materials possess high strength/weight ratio also desirable lightweight and strength. In other fields, global needs are high performance rate, low cost and better quality materials have been made by researchers which transfer from monolithic to composite materials

Aluminum 7075	
Density	2810 kg/m3
Hardness, Vickers	175
Ultimate Tensile Strength	572 Mpa
Young's modulus	71.7 Gpa
Poisons ratio	0.33

Table: 1. Properties of 7075

2.3. Tungsten Carbide

Tungsten Carbide is a chemical compound containing equal parts of tungsten and carbon atoms. Tungsten carbide is approximately twice as stiff as steel. It is comparable with corundum in hardness and can only be polished and finished with abrasives of superior hardness such as cubic boron nitride and diamond powder, wheels, and compounds

Tungsten Carbide (WC)	
Density	14500 kg/m^3
Hardness, Vickers	1300
Ultimate Tensile Strength	370 Mpa
Young's modulus	669-696 Gpa
Poisons ratio	0.2

Fig: 3. (a) Tungsten Carbide (b) Properties of Tungsten carbide

2.4. Stir Casting

Stir casting process involves stirring of melted compound at the melting point of the base metal, in which the melt is stirred continuously which exposes the melt surface to the atmosphere which tend to continuous oxidation of aluminum melt. As a result of continuous oxidation, the wettability of the aluminum reduces and the reinforcement particles remain unmixed. Al2O3 is a very stable chemical compound, which cannot be reduced under normal conditions and the wettability of melt remains unchanged. In this research Al7075 with varying WC has taken for the wear test followed by the different test methods. It is a type of casting process in which a mechanical stirrer is introduced to form vortex to mix reinforcement in the matrix material. It is a suitable process for production of metal matrix composites due to its cost effectiveness, applicability to mass production, simplicity, almost net shaping and easier control of composite structure. Stir Casting is the simple stand the most cost effective method of liquid state fabrication. Stir casting is a liquid state method for the fabrication of composite materials, in which a disperse phase is mixed with a molten matrix metal by means of mechanical stirring.

A thermocouple has inserted and it gives the feedback of the temperature inside the furnace. The temperature inside the furnace is controlled about to 7500°C in order to minimize the chemical reaction between the substances. The temperature is controlled by connecting the relay from the furnace and thermocouple. The function of relay is to cut off the power supply when temperature goes beyond the 700°C. The mechanical stirring which is carried out using a stirrer driven by electric motor is used to disperse the tungsten carbide particles in matrix alloy. The preheated particles of reinforcement is added to the melt and stirred at 650 rpm for 10 minutes. The stirring is continued before the composite is not reached in mushy zone. The cooling is done in the furnace. Here the WC is taken in there concentrations i.e., 1%, 2%, 3%.

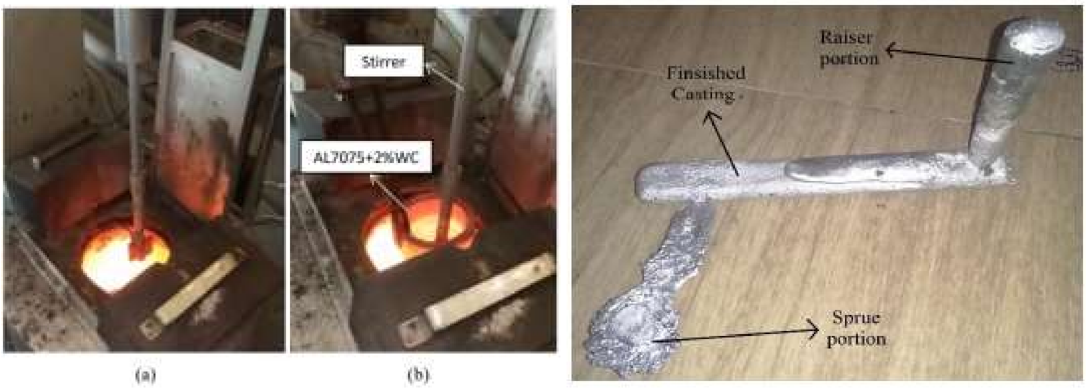


Fig: 4. (a) Stir casting setup at specific temperature (b) mixing of molten metal of Al7075 with Tungsten carbide (WC)

III. RESULTS AND DISCUSSION

3.1 Wear Test – Pin on Disc

A Pin on Disc machine was utilized to reproduce the sliding piece of the stuff contact. A schematic of the pin-on-circle machine. The pin-on-circle machine involved an even pivoting circle and an adjusted extra weight stacked pin. In the current testing, the tip of the pin was as a non-pivoting half circle. The encompassing climate was almost something similar for each test. The grating power and vertical removal of pin were consequently estimated in the pin-on plate machine utilizing a heap cell and a straight factor differential transformer (LVDT). The test conditions are introduced in. For all tests, the ordinary burden on the pin was something similar and was set to 7 N. Prior to the test, all examples were cleaned in an ultrasonic shower, first washed in heptane, then, at that point flushed in methanol, lastly dried in a broiler. A needle with a brush ceaselessly applied the sifted surrounding temperature grease with the guide of a pneumatic framework.

Fig: 5. Pin on Disc Tribometer

Initially after casting the material is machined under wire EDM to make pins for POD. The pins are machined with the radius of 1.5cm. i.e., 3cm Diameter. Here the counter part is Gray cast iron with radius 8cm because of its tough and vibration absorbing capability and usage of this helps in determining the application associated with it. Before starting the experiment the material and plate is cleaned with ethanol to remove any Excess oxidation layer. The weight of pin is calculated before Test and after and noted down. The sliding displacement is kept constant i.e., 1000m. The sliding speed is taken as 0.5m/s as literature

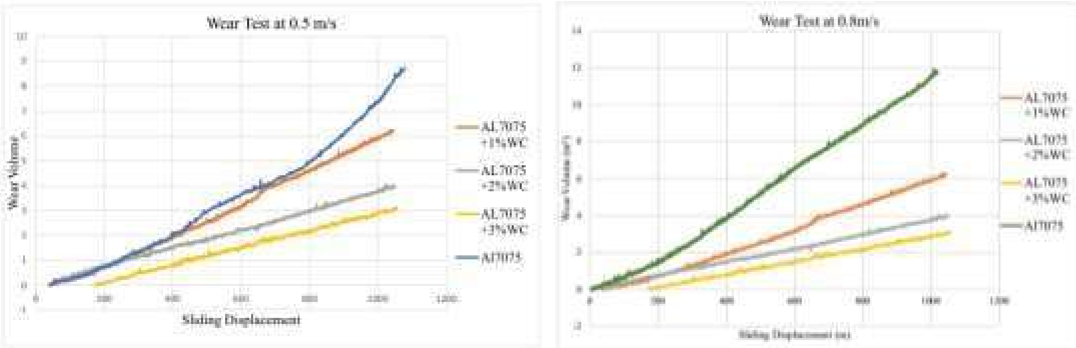
Time	COF	Friction Force	Displacement	Disc Speed	Sliding Displacement	Wear Volume
1	0.008	0	0	0	0.5	0
2	-0.134	-4	-2	0	1	-0.014137
3	-0.252	-8	12	0.024	1.5	0.084822
4	-0.055	-2	33	0.024	2	0
5	0.339	10	23	0.047	2.5	0.1625755
6	-0.205	-6	31	0.047	3	0.2191235
7	-0.024	-1	33	0.047	3.5	0.2332605
8	-0.079	-2	29	0.071	4	0.2049865
9	-0.079	-2	37	0.047	4.5	0.2615345
10	-0.055	-2	29	0.071	5	0.2049865
11	-0.032	-1	39	0.047	5.5	0.2756715
12	-0.071	-2	33	0.071	6	0.2332605
13	0.071	2	33	0.094	6.5	0.2332605
14	-0.024	-1	39	0.094	7	0.2756715
15	-0.102	-3	33	0.094	7.5	0.2332605
16	0.181	6	37	0.094	8	0.2615345
17	0.039	1	39	0.094	8.5	0.2756715
18	-0.118	-4	37	0.094	9	0.2615345

Table: 3. Wear results at 0.8m/s for Al7075

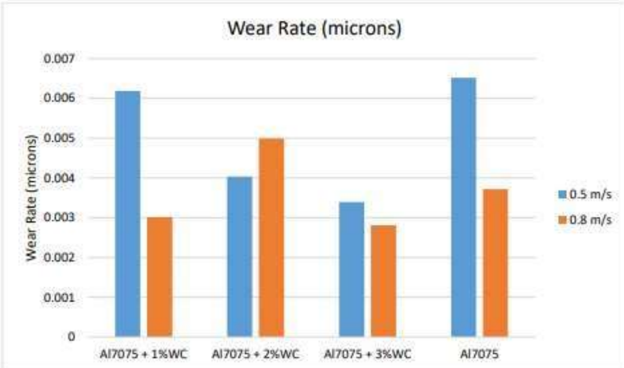
3.3. Wear Rate

Volume of Reinforcement	Wear Rate at 0.5 m/s (microns)	Wear Rate at 0.8 m/s (microns)
Al7075 + 1%WC	0.006183408	0.003015299
Al7075 + 2%WC	0.004031108	0.004987754
Al7075 + 3%WC	0.003391526	0.002807714
Al7075	0.006514966	0.003715465

Table: 4. Wear rate at different Sliding speeds and varying WC



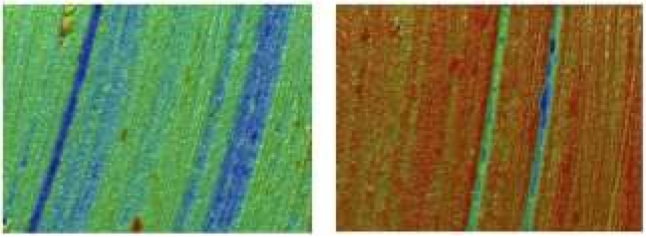
Graph: 1. Wear Rate at 0.5 and 0.8 m/s



Graph: 2. Comparison of Wear results at 0.5 m/s and 0.8 m/s

3.4. Surface Roughness Characterization

The surface roughness increases the friction coefficient and for all the loads that the coefficient of friction represents the percentage of friction force to the load hanging and that the increase in load lead to the flow of plastic the protrusions surfaces slippery and then an increase in the area of contact of real and this increases the area of connections and therefore we need to force cut is bigger than lead to increased friction force overtime increase the temperature of the surfaces and increase the flow of plastic to the protrusions, leading to flattening gradually protrusions become surfaces smooth and for the case become surfaces smooth and obtain steady-state and that higher speed leads to high temperature instant during the slide, leading to softer bumps, which reduces the shear force required to cut the connections and this leads to reduce the friction coefficient and when the test with a lubricant and all forms of the results were better and dropped all values for the wear rate and volumetric and weighted as well as specific addition to the coefficient of friction and be because they are to the layer of film between the surfaces reduces the contact between them, leading to lower the temperature. While Low coefficient of friction with increasing load and sliding speed of the lubrication situation, compared with the dry state when test conditions similar. The micrographs wear surface increases with increasing sliding velocity It is observed for the same velocity, the wear rate on the surface is increased as load increases.

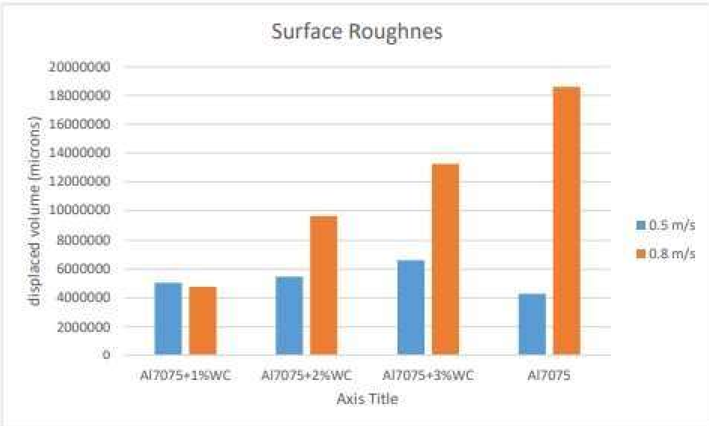


	Al7075+1%WC			Al7075+2%WC		
Sliding Velocity	NV (µm)	VD (µm)	%VD	NV (µm)	VD (µm)	%VD
0.5 m/s	6917310	1857773	26.8	8346334	2874984	34.44
0.8 m/s	8421653	3648149	43.31	12176089	2513544	20.64

Table: 5.11. Surface roughness Results of Al7075 and Al7075 with WC

	Al7075+3%WC			Al7075		
Sliding Velocity	NV (µm)	VD (µm)	%VD	NV (µm)	VD (µm)	%VD
0.5 m/s	8405188	1786542	21.25	7709746	3417751	44.33
0.8 m/s	15438719	2198649	14.24	23689832	5088413	21.4

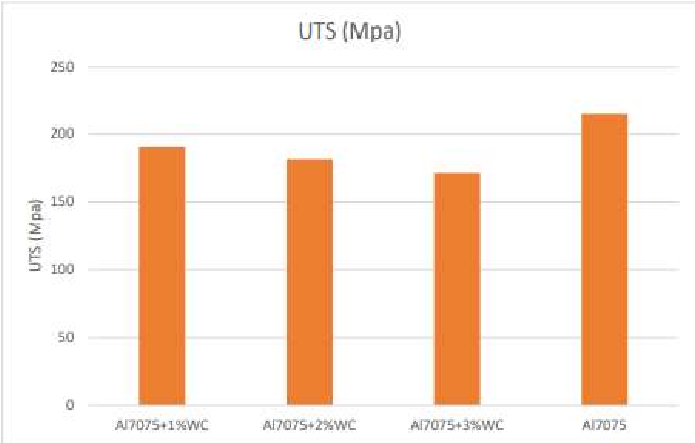
Table: 5.12. Surface roughness Results of Al7075 and Al7075 with WC



Graph: 3. Surface roughness Results of Al7075 and Al7075 with increase in WC

3.5. Tensile Strength

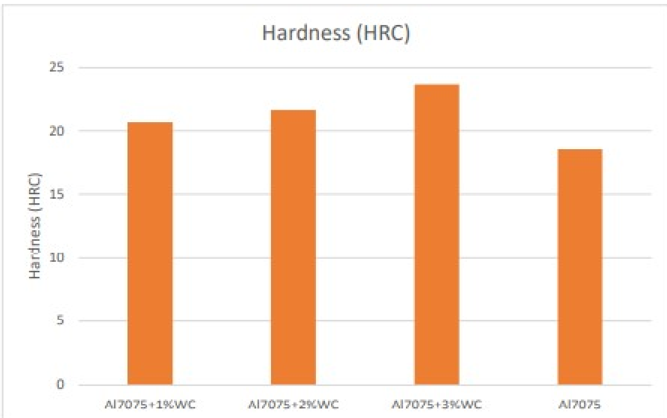
Tensile strength refers to the amount of stress a material can handle before it breaks, cracks, becomes deformed or otherwise fails. One measure of tensile strength is flexural strength. It can be observed that the tensile strength of the composites are higher than that of their base matrix also it can be observed that the increase in the filler content contributes in increasing the tensile strength of the composite. It can be observed that the tensile strength of the Al7075 increases with increase in the composite percentage.



Graph: 4. Tensile strength

3.6. Hardness Test

Rockwell hardness tester machine used for the hardness measurement. The surface being tested generally requires a metallographic finish and it was done with the help of 100, 220, 400, 600 and 1000 grit size emery paper. Load used on Rockwell's hardness tester was 200 grams at dwell time 20 seconds for each sample.



Graph: 5. Hardness Test

IV. CONCLUSION

The primary target of the current work is the relative investigation of AL7075 with varying Tungsten carbide. For this three composites Al7075+1%WC, Al7075+2%WC, Al7075+3%WC were prepared and tested. The obtained results were compared with the conventional applications. All the observations are drawn from experimental results corresponding to the variation from 0.5 to 0.8 m/s sliding speed. The comparison of these observations is done based on the Wear Characteristics, Surface

Characterization. Al7075 with varying Tungsten Carbide from 1% to 3% using stir casting methodology. The Mechanical properties has been characterized Tensile strength, wear and Surface roughness has been measured. The properties such as wear rate, surface roughness, COF and Hardness has greatly increased than that of Al7075 than that of Al7075 with WC. The Tensile strength is reduced due to addition of Tungsten carbide.

The Wear Test has been conducted for AL7075 with varying WC for two speeds based on the application chosen i.e., 0.5 m/s, 0.8 m/s. There is formation of protective oxide layer is seen on the aluminum which serves as resistance towards wear in Pin On Disc. With increase in the % of WC there is decreasing in COF is observed. The Surface roughness values has been drastically increased from 1%WC to 3%WC after wear test Surface roughness. It is observed that the sliding speed of 0.5 m/s material removal rate is less than that of 0.8 m/s because of WC tends to breakage of the Oxide layer of aluminium. Aluminium composites are termed as advanced materials due to their enhanced mechanical, electrical, thermal properties and cost effectiveness as compared to other engineering materials. Finally there is immense potential, scope and opportunities for research in the field of prediction on tribological and mechanical properties of the Aluminium alloys by reinforcing with different reinforcements. As indicated by the above outcomes, Al7075 from 2 to 3% shows better surface characteristics. It tends to be inferred that the Al+2-3%WC shows promising outcomes on various applications on execution and outflow and execution qualities.

REFERENCES

1. Microstructure Exploration of the Aluminum-Tungsten Carbide Composite with different Manufacturing circumstances by Hari Prasada Rao Pydi, Balamurugan Adhithan, A.Syed Bava Bakrudeen
2. Characterization of aluminium matrix reinforced with tungsten carbide and molybdenum disulphide hybrid composite by A Anish and M Ananth Kumar
3. Assessment of Mechanical Properties of Aluminium 7075 based Metal Matrix Composite by Santhosh Kumar B M, Dr. Girish D. P
4. Micro Structure and Mechanical Behavior of AL-7075-T6 and Fly Ash Metal Matrix Composite Produced by Stir Casting Process by F. Anand Raju and 2Dr. M.L.S. Deva Kumar
5. Enhancement of wear and ballistic resistance of armour grade AA7075 aluminium alloy using friction stir processing by SUDHAKAR, V. MADHU , G. MADHUSUDHAN REDDY b , K. SRINIVASA RAO
6. A study of sliding wear behaviors of Al-7075 alloy and Al-7075 hybrid composite by response surface methodology analysis Ravinder Kumar, Suresh Dhiman
7. Latest Research Development in Aluminum Matrix with Particulate Reinforcement Composites – A Review by A.Thirumoorthya , T. V. Arjunanb , K. L. Senthil Kumarc
8. Process Parameter optimization For Producing AA7075/WC composites by Friction stir welding by N. Arun Babu, B.Balu naik, B.Ravi , G.Rajkumar
9. Microstructure and Mechanical properties of As-cast Al7075-Tungsten carbide metal matrix composites by N. Arun Babu, B. Balu naik, B. Ravi
10. Characterization of mechanical properties of Aluminium/ Tungsten Carbide composites by K.Ravikumar
11. Friction and Wear Behaviour of Tungsten Carbide and E Glass Fibre reinforced Al7075 based Hybrid composites by Santhosh Kumar.B.M1 , D.P.Girish