

DEVELOPMENT AND WEAR CHARACTERIZATION OF AL7075/AL₂O₃/SiC HYBRID PARTICULATE METAL MATRIX COMPOSITE DEVELOPED BY STIR CASTING

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Abstract

In this work Hybrid Metal Matrix Composite have been developed using stir casting process for improving the Wear Behavior at lower cost. The silicon carbide (SiC) as one of the reinforcement used with 3% weight fraction and Alumina (Al₂O₃) as the major reinforcement in 3%, 6%, 9% & 12% weight fraction. Al-7075 has been considered as the matrix material. The low cost stir casting process has been used for the development of the composite system. The matrix material was melted in electric furnace and the heat treated reinforcement in the desired weight fraction have been added followed by constant stirring the melt. The temperature of the melt held at 750°C. The pouring temperature was recorded which has relation to quality of the casting. The casted specimen have been obtained in the form of cylindrical rod of 20mm diameter and 200mm length for carrying out tribological tests. Microstructure analysis reveals the uniform distribution of reinforcements in the aluminum matrix. The density of the composite increases with the increase in weight fraction. The composite density found to lie in between the density range of matrix and the reinforcement. The pin on disc wear test carried on all the samples at various speeds of 300, 600, 900 and 1200 rpm, varying load of 1kg, 2kg, 3kg & 4kg and varying sliding distances of 1km, 2km, 3km & 4km. These test reveals that the wear resistance increases with the increase in the reinforcement weight fraction. The increase in the speed reduces the wear rate and wear rate increases in with increase in sliding distance. The wear rate and coefficient of the composite reduces for higher volume fraction. The addition of SiC apart from improving the wear rate reduces the noise and vibration at higher speed and load condition. The overall tribological property improves due to addition of the two reinforcement.

KeyWords: Hybrid composite, SiC, Al₂O₃, Stir casting, Noise and vibration.

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1. INTRODUCTION

Light weight, high strength and wear resistant material are the need for the automobile and aircraft industries. The regulations and norms related to environment requires less fuel consumption requirement in vehicles to reduce the pollution which ultimately requires lightweight materials. The light weight alloys like aluminum, titanium, magnesium and copper can be used for automobile and aircraft parts. The alloy cannot be used alone due to its low strength and poor mechanical property. The ceramic materials are reinforced with the alloy for improved strength and wear resistance. The light weight metal alloy reinforced with hard ceramic material will improve the property of the material and at the same time light weight was retained.

The composite material have proven universally a saving of at least 20% of cost over metal counter parts. It has lower operational and maintainance cost. They are durable, resists fatigue loading, wear, dimensional integrity and easily maintainable and repairable. The cost of the composite depends on raw material cost and processing cost by 40% and 30% .By selecting the suitable process and

reinforcement having low cost can reduce the final material cost. The stir casting process and the particulate form of reinforcement reduces the final material cost and suitable for mass production. The particulate composite fabricated by stir casting route will provide uniform distribution of the reinforcement. The stir casting process will be affected by stirring speed, melt temperature, pouring temperature and blade geometry and its height. The melt temperature should be optimum to have the required viscosity thereby allowing the particles to be suspended in the matrix without sinking to bottom or floating at the top.

The conventional ceramic material used in development of composite will not provide the desired property if used alone. The combination of oxides or borides or carbides of ceramics can effectively enhance the property. The graphite or MSO₂ used with the hard ceramics improves the lubricating effect of the composite. The ceramics used are soft and hard nature, the hard ceramics increases the wear resistance and strength whereas the soft ceramics increases the lubrication effect, reduces the noise and vibration etc. The SiC ceramic reduces the noise and reduces the thermal expansion coefficient. It also conducts heat three times more

effectively. These requirements of ceramics are used in developing the hybrid metal matrix composites.

The Al -7075 alloy has been selected as the matrix material due to its high strength and light weight property. It is also having good heat treatable and age hardenable response compared to 6061 and 2024 series alloys. The secondary process such as age hardening, solutionising and precipitation hardening can be carried out on this type of composite materials which further enhances the wear resistance and strength.

Tribological characterization of the composite will be carried out to study the variation of the wear rate and its coefficient of friction .The wear is progressive loss of the material which alters the dimension and reduces the strength of the component. The coefficient of friction influences the noise, surface finish and vibration of the interacting parts. The automobile parts like disc brake, cylinder liner, piston and drive shaft are the some of the parts which experiences Sevier wear during its functioning. The high wear resistant materials like steel, cast iron or metal matrix composite to be used for such parts.

The composite material with proper weight fraction of the reinforcement, size, shape, coating and orientation will develop essential property. The Wettability of the melt, interface bond strength also influences the property. The microstructure of the composite was considered as the general parameter controlling the wear but with the availability of large variation in the materials, ceramics and composite materials the wear of material rather than system property it is of material characteristics. Over 300 equations for wear and friction can be found and these empirical equations are used for wear before 1970 .The contact mechanics based equations are used in 1970 to 1980.The wear map developed for the estimation of the wear of material over the range of parameter. The wear can also be evaluated on the basis of strength and hardness of the material. Considering all the above methods for determination of wear the experimental method of estimation of wear will be universally accepted and the established standards are included in ASTM .In this wok the essential parameter influencing the wear and friction behavior of material such as weight fraction, speed, load and sliding distance was evaluated for the developed hybrid metal matrix composites.

2. EXPERIMENT

Many interdependent variables has to be considered in design and development of the composite material. The performance of the composite material depends on the matrix and reinforcement hence careful selection of these materials is based on literature and the research data. The chemical compatibility of the reinforcement with matrix material has to be considered in designing the composite system. The excessive reaction of the reinforcement with the matrix will yield poor mechanical property. The composition and properties of the Al-7075 matrix is as shown in table 1&2.

The aluminum alloy Al-7075 has been selected as the matrix material is more compatible with the reinforcement and has good mechanical property and castabilityat the alloy level itself. The application of the alloy in automobile and aircraft application itself indicated that it is the proper selection. The material is also having good response to age hardening, heat treatment process and precipitation hardening.

Table -1: Composition of AL-7075

| Element | Weight % |
|-----------|----------|
| Silicon | 0.4 |
| Ferrous | 0.5 |
| Manganese | 0.3 |
| Magnesium | 2.9 |
| Copper | 2 |
| Zinc | 6.1 |
| Titanium | 0.2 |
| Aluminum | 87.60 |

Table -2: Properties of AL-7075

| Mechanical properties | |
|------------------------|---------|
| Hardness –Brinell | 150 |
| Tensile yield strength | 503MPa |
| Elongation at beak | 11% |
| Modulus of Elasticity | 71.7GPa |
| Poission'sRatio | 0.33 |
| Machinability | 70% |
| Shear modulus | 26.9GPa |
| Shear strength | 331Mpa |

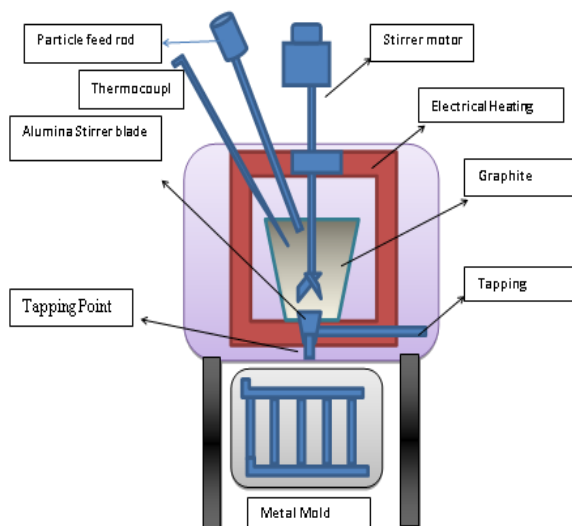
The reinforcement selected as alumina (Al_2O_3) in the form of particle size 50 micron to 150 micron. It is more stable with aluminum and withstands high temperature. It is an oxide ceramic having low affinity for the oxygen to for oxides. The particulate form of the reinforcement has better distribution in the matrix to provide isotropic property for the composite. The properties of the alumina is as shown in table 3.The Silicon carbide has been selected as the next ceramic which is a carbide type of ceramic. The SiC has good lubricating effect along with it reduces the noise and vibration during the relative motion. The properties of silicon carbide is shown in table 3.

Table -3: Properties of Al_2O_3 & SiC

| Property | Al_2O_3 | SiC |
|---|-----------|-------|
| Melting Point $^{\circ}C$ | 2072 | 2200 |
| Hardness(kg/mm 2) | 1175 | 2800 |
| Density(g/cm 3) | 3.69 | 3.1 |
| Coefficient of thermal expansion(micron/m $^{\circ}C$) | 8.1 | 4.0 |
| Fracture Toughness | 3.5 | 4.6 |
| Poisson's ratio | 0.21 | 0.14 |
| Colour | White | Black |

The matrix material Al-7075 T6 obtained in the form of square rod of 20mm X 20mm and length 100mm. The bars are cleaned to remove the impurity, dust and oil and heated in graphite crucible in electric furnace. The quantity of alumina and the reinforcement are shown in table 4.

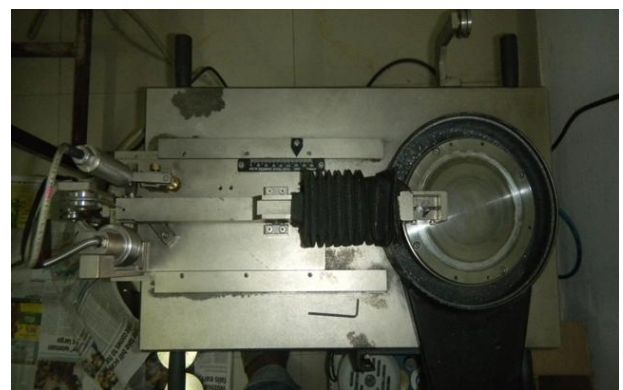
The melting temperature was held at 750 $^{\circ}C$ and the reinforcement heated separately to 450 $^{\circ}C$ being added to the melt. The constant stirring of the melt carried out with alumina stirrer to get uniform distribution of the ceramic particles. The stirring was carried out for 10 minutes and the melt was poured in to sand mold. The stir casting process is shown in fig 1

**Fig -1:** Stir casting Furnace set up

The castings of circular cross section of 20mm diameter and 200mm length has been casted. The specimens were machined to reduce the diameter to 16 mm and length to 30 mm for microstructure characterization and hardness test. The specimen in the form of pin of diameter 12mm and length 25mm have been machined for wear and friction test. Microstructure analysis has been carried out as per ASTM

E407 standards. The Specimens were grinded and polished with 300,600,900,1000 and 1200 grit emery paper followed by polishing with diamond paste in polishing machine. The keller's etchant has been used for etching. The optical micrograph has been obtained at 100x and 50X.

Wear test carried out on 'wear and friction monitor TR-20' supplied by DUCOM, Bangalore. Rotating disc against the loaded pin was used to determine the wear loss of the material at various conditions. The wear simulations confirms to ASTM G99 standards. Tests are conducted in dry conditions and with rotating motion. The test parameter includes load, speed, temperature, roughness, shape and wear track etc. The variation of coefficient friction also noted during the wear test which will be influenced due to addition of the SiC. The wear and friction monitor used in present investigation is shown in fig 2.

**Fig -2:** Pin on Disc Wear Tester

The disc material includes EN32 Steel, hardened to 60HRC and roughness was 1.6Ra. The wear track diameter of 120mm was selected. The surface of the specimen used are flat and cleaned after each test. The wear test was carried out in three phases on all the four types of specimen having the varying weight percentage.

The first phase involves the variation of load on the pin as 1kg, 2kg, 3kg and 4kg. The wear in micron and the average friction force in Newton were noted. In the second phase the speed of the disc were varied from 300, 600, 900, 1200 rpm. The corresponding wear and friction force were noted. In the third phase the sliding distance of the specimen was varied as 1km, 2km, 3km and 4km.

3. RESULTS AND DISCUSSION

The hybrid metal matrix composite was developed using stir casting furnace satisfactorily. The distribution of the particles are uniform without any interface reaction. The particle dispersion in the melt was achieved through stirring and maintain the melting temperature at 750 $^{\circ}C$.

The density of the composite measured experimentally shows that 3% to 4% variation as compared to theoretical density. The density increases as the weight fraction increases. Density of the developed composite found to be less than the density of the conventional material like steel

and cast iron. The porosity found to reduce to 3% due to sand casting.

The micro hardness values indicates that addition of reinforcement increases the hardness of the composite. This is due to more amount of ceramic particles in the vicinity of the indentation resists the deformation and induces hardness due to strong interface bonding.

Optical micrograph of unreinforced and reinforced composite shown in fig 3 indicates the presence of Al₂O₃ and SiC ceramic particles in the matrix. The amount of particles increases with increase in weight fraction. This gives the indication of the ceramic particles and their distribution in the composite. The micrograph indicates the presence of reinforcements in the Al matrix. The degree of clusters are little higher at higher weight fraction. Hardness was found to increase with increase in weight fraction.

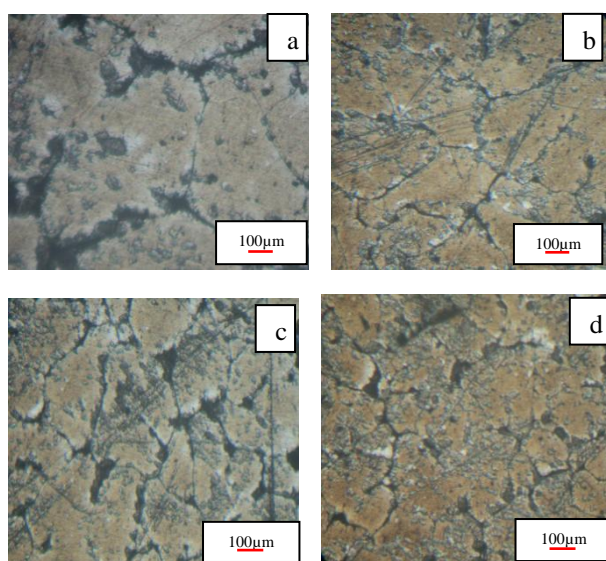


Fig -3: Optical micrograph of Hybrid composite at various weight fractions of reinforcement a) Al7075 + 3% Al₂O₃+3% SiC b) Al7075 + 6% Al₂O₃+3% SiC , c) Al7075 + 9% Al₂O₃+3% SiC , d) Al7075 + 12% Al₂O₃+3% SiC

| | | | |
|--|--|--|---|
| | | | Al7075 + 3%Al ₂ O ₃ +3% SiC |
| | | | Al7075 +6%Al ₂ O ₃ +3% SiC |
| | | | Al7075 +9%Al ₂ O ₃ +3% SiC |
| | | | Al7075 +12%Al ₂ O ₃ +3% SiC |

Fig -4: Vickers Micro hardness Indentation

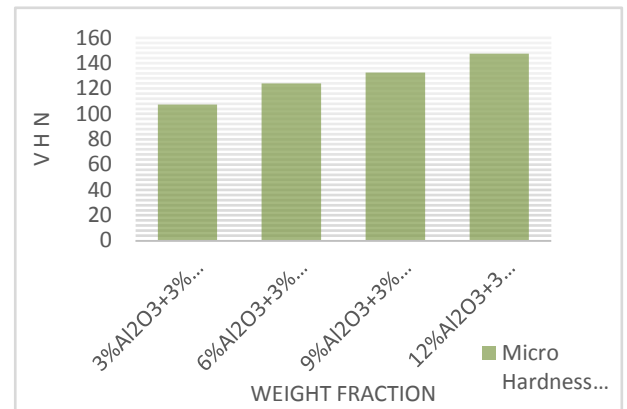


Fig -5: Vickers Micro hardness

The wear rate was estimated by $\Delta v/w$ s, the change in volume is estimated by knowing the wear length in micron .The coefficient of friction plot was obtained winducom software. The variation of the speed load and sliding distance vs wear rate with respect to weight fraction are shown in fig 6, 7, &8.

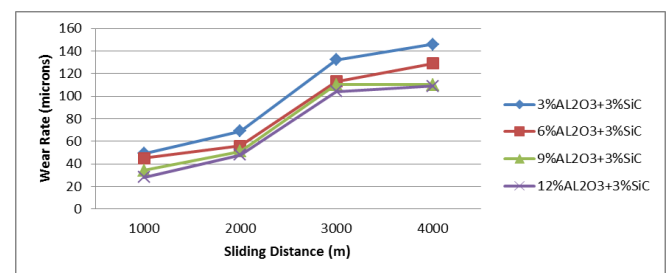


Fig -6: The variation of the sliding distance Vs wear with respect to weight fraction

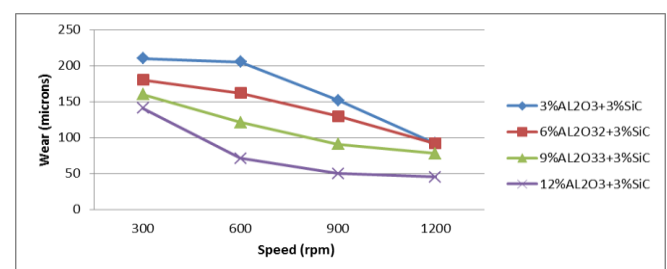


Fig -7: The variation of the speed vs wear with respect to weight fraction

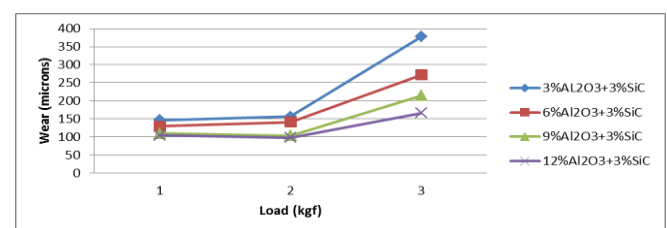


Fig -8: The variation of the load vs wear with respect to weight fraction

The coefficients of friction recorded by the device are shown in fig 9, 10&11.

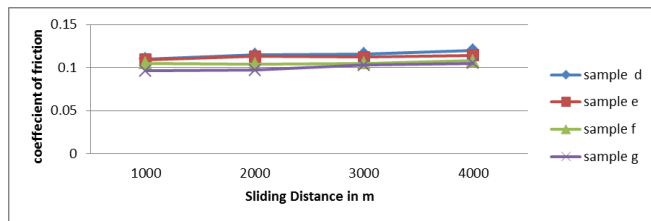


Fig 9:The variation of the coefficient of friction vs Sliding Distance Variation of 1000m,2000m,3000m& 4000m, Speed 600rpm, Load 2kgf, and Track Diameter 120mm.

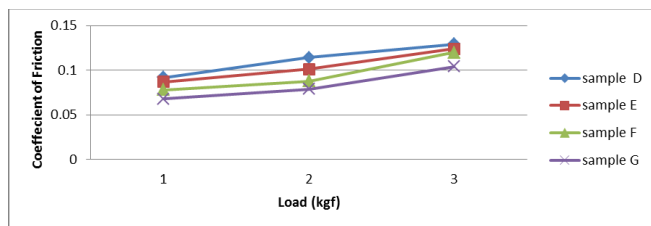


Fig -10:The variation of the coefficient of friction vs load of 1kg,2kg,3kg & 4kg for varying weight fractions , Sliding Distance 2000m, Speed 600rpm, and Track Diameter 120mm.

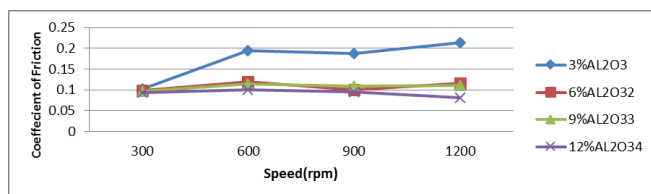


Fig -11: The variation of the coefficient of friction vs speed of 300rpm,600rpm,900 rpm & 1200rpm for varying weight fractions , Sliding Distance 2000m, load 2kg and Track Diameter 120mm.

The wear rate reduces with increase in speed, improved wear resistance of Al7075 / Al₂O₃/ SiC was observed at high speed. The transition from severe wear to mild wear was noticed as the speed varies from low to high value. The wear rate found to be inversely proportional to speed. With increase in speed the hardness increases and lower wear rate. Also at higher speed the temperature increases which will soften the material hence lower wear.

Wear rate was found to increase with increase in sliding distance and the highest percentage reinforcement of the composite possess the lowest wear rate at all sliding distance. The interfacial strength and the shape of the particulate will enhance the wear resistance at higher sliding distance. The improvement of the wear resistance is due to welding of the ferrous particle from the counter body at high sliding speed.

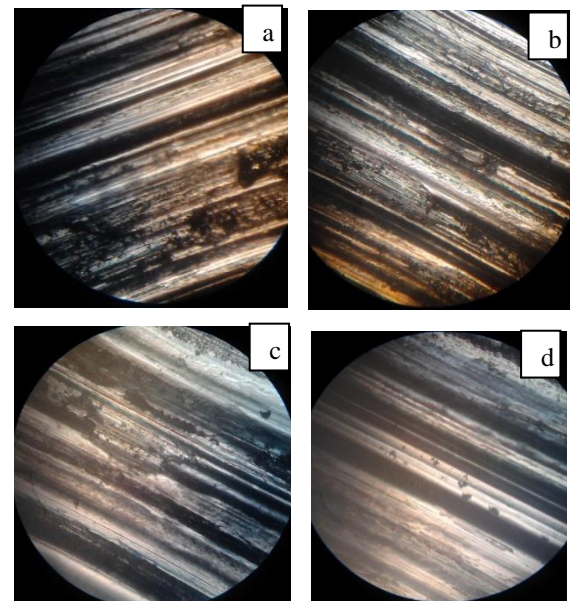


Fig-12: optical micrograph indicating the magnitude of delamination wear on test specimens at a) Al7075 + 3% Al₂O₃+3% SiC b) Al7075 + 6% Al₂O₃+3% SiC , c) Al7075 + 9% Al₂O₃+3% SiC , d) Al7075 + 12% Al₂O₃+3% SiC

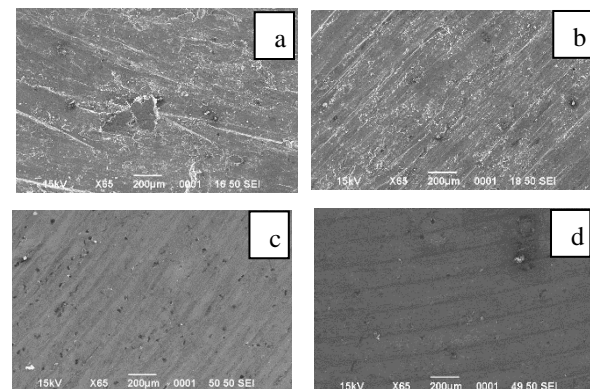


Fig-13: SEM indicating the magnitude of delamination wear on the wear test specimens at a) Al7075 + 3% Al₂O₃+ 3% SiC b) Al7075 + 6% Al₂O₃+3% SiC , c) Al7075 + 9% Al₂O₃+3% SiC , d) Al7075 + 12% Al₂O₃+3% SiC

The wear rate increases with increase in load on the pin, this behavior is due to wear of the ceramic particles at higher load or due to the fracture of the particles. The surface was covered with the transferred material layer which increases the wear. The detachment of the particles from the matrix was noticed at higher load and results in the increase in contact area of matrix and the disc which further increases the wear.

Tribological study involves the coefficient of friction and its effect of the wear of the material. It is essential to monitor the variation of the coefficient of friction along with the wear for a given speed, load and duration of experiment. The coefficient of friction was observed to be lower due to addition of SiC in the matrix. The coefficient of friction

reduces for the composite with highest weight fraction. The reduction in the coefficient of friction is related to noise and vibration of during the test. It was noticed that considerable amount of noise level found to reduce for all the specimens as the SiC content in the matrix found responsible for this behavior. The graphite in the silicon carbide induces the lubrication effect for the composite.

The fig 12 &13 shows the optical and SEM wear track micrographs obtained for the different weight fraction of the reinforcements. It can be seen in the optical wear track micrograph that at the lower weight fraction of reinforcement the wear track has more delamination of the layers indicating severe wear due to presence of small traces of hard Al_2O_3 particles. At lower weight percentage adhesive wear is large as seen from the presence of large craters in fig 12(a). The size of craters reduces to large smooth patches as the weight fraction increases. With the lower particle size the craters reduces with limited wear of material. With the increase in load the size of craters found to increase due to transition from mild wear to sever wear. With increase in speed the craters reduce in size due to Mild wear and long tracks appears on the wear surface this is due to increase in temperature of the pin which makes worn material to adhere to the disc resulting in reduction in wear rate fig 13 (d). The severity of wear reduces due to rise in temperature at higher speed and higher load, the wear debris get adhered either to the specimen or the disc which produce the smooth surface.

CONCLUSION

- By stir casting process the Particulate hybrid metal matrix composite can be developed effectively.
- The porosity can be reduced by constant stirring, maintaining the optimum melt temperature and using sand mold.
- Uniform distribution of the particulate and isotropic property of the composite can be obtained my melt temperature of $750^\circ C$ and stirring by the alumina stirrer until pouring the melt.
- The density of the composite material is half of the conventional material and it increases with addition of ceramic material.
- Wear rate found to increase with increase in load and sliding distance. Amount of wear reduces at higher speed than at lower speed of the disc.
- The weight fraction of the composite influences the wear resistance as the weight fraction increases the wear reduces.
- The addition of SiC as secondary ceramic reduces the coefficient of friction there by reduction in the noise and vibration during the motion.

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