**Optimization of Dry Sliding Wear on Vermiculite reinforced Al6061 composite using Response surface methodology and Promethee-II technique**

**Abstract**

In the current work, vermiculite, a natural mineral(Mg-Al Silicate), is used as reinforcement for Al6061 composite fabrication. Vermiculite (Mg-Al silicate), a naturally occurring mineral belonging to the phyllosilicate group found in Andhra Pradesh, is used in the study. Optimization of the wear and coefficient of friction on Al6061 filled with low-cost exfoliated vermiculite(EV) particulate composite. The stir cast route is used to fabricate the composite by varying the EV weight percentages of 2, 4, and 6% reinforcement. Speed, load and distance are chosen as input parameters to optimize wear and coefficient of friction. Design of Experiments is carried out based on Response Surface Method (RSM) and Analysis Of Variance (ANOVA) is performed to determine the significant factors that affect the wear behavior. PROMETHEE II technique has been adopted to convert the multi-objective criterion of optimizing wear and COF (Coefficient of Friction) into an equivalent single objective function, which has been optimized based on ranking. The addition of Vermiculite reinforcement has decreased the wear of composite. Compared to unreinforced Al6061 alloy, hardness increased by 41% with an increased reinforcement up to 4% by weight and decreased thereof. Wear decreases when the reinforcement is increased upto 4% and then increases at any given load and speed,of vermiculite wear resistance of LM13-10ZrB2-5TiC hybrid composite increased up to 63%, 49% and 69% respectively. FESEM worn surface analysis results indicated the transition of wear mechanism from mild abrasive wear to severe delamination with increasing load. ZrB2 and TiC particle reinforced hybrid composites offered better mechanical and tribological properties than TiC reinforced composite and LM13 alloy.

**Introduction**

**Light weight aluminum composite materials find numerous applications in various fields due to high strength to weight ratio and high thermal conductivity. Aluminum metal matrix composites (MMC) find numerous applications in field of shipping, aviation, packaging, transportation and automobile industries. The physical, mechanical and tribological properties of the composites depend on the type, size and quantity of reinforcement materials used in synthesis of the metal matrix composite. Many filler materials have been used as reinforcement in aluminum MMC to improve the wear and physical properties. Many studies have been conducted in recent times on wear behavior of aluminum composites.** G.Bala Narasimha (2014) et.al., investigation focused on hybrid MMC of AlMg1SiCu alloy as base material and 9% SiC and varying 3 to 9 % of graphite particulates varying insteps of 3 by vortex method. The wear resistance of the composites increased with addition of the SiC and Gr particle content. The wear rate is significantly less for the composites compared to pure matrix material. N. Radhika (2014) et.al., conducted study on the influence of wear test parameters like applied load, sliding velocity and temperature on wear rate of AlSi10Mg alloy reinforced with 3 wt‐ % graphite and 9 wt‐% alumina which was fabricated through liquid metallurgy route. They reported wear rate increases with load and temperature and decrease with increase in sliding velocity. P. Rajasekhar (2014) et.al., study the Determination of optimum variables, during the wear test on polymer matrix composites (PMC), is an important issue for nowadays specifically, the wear rate (WR) and coefficient of friction (COF) needs to be minimized. Despite extensive research on wear process, influential the indented operating conditions in industrial arena needs skilled operators. The purpose of this study is to optimize the process variables such as normal force, sliding velocity and reinforcement to minimize wear rate and friction coefficient. Central Composite Rotatable Design (CCD) was selected to conduct the experiments. The empirical models were developed using nonlinear regression analysis. The worn out morphology of the surfaces were observed through scanning electron microscope (SEM). The input variables were optimized using RSM Ravindra Singh Rana, Rajesh Purohit (2014) et.al., deals with the study of dry sliding wear performance of Al5083-10 wt. % SiC composites fabricated by Ultrasonic assisted stir casting process. Dry sliding wear tests have been carried out by using Pin-on-Disk wear test rate with normal loads of 10N, 20N, 30N, sliding distance 754 m, 1131 m, 1508 m and sliding velocity 0.42 m/s, 0.63 m/s, 0.84 m/s at constant time 30 minutes. Applied load has the highest influence on wear rate followed by sliding distance and sliding speed for Al- 5083/10% SiC composites. R. Venkatesh, Dr.V. Seahagiri Rao (2014) et.al., focuses on the influence of Silicon Carbide nanocoating on the HSS tool material. Silicon carbide powder was coated on the high speed steel pin by using physical vapour deposition (PVD) technique. The performance parameters like volume loss, wear rate, stresses developed and temperature rise were compared between coated high speed steel pin and uncoated high speed steel pin. Wear rate of the coated and uncoated pin are 3.289\*10-14 mm/Nm and 2.192\*10-14 mm/Nm respectively. We could conclude that the wear rate is less for coated pin. Riyadh A. Al-Samarai (2014) et.al., study the effect of load and speed on sliding friction coefficient and performance tribology of aluminum–silicon casting alloy was evaluated using a pin-on-disc with three different loads (10, 20, and 30 N) at three speeds (200, 300, and400 r/min) and relative humidity of 70%. Factors and conditions that had significant effect were identified. Experiments showed that the load and the speed affect the coefficient of friction and wear rate of the alloy. The results showed that the wear rate increased with increasing load and decreased with increasing sliding distance, whereas the friction coefficient decreased with increasing sliding speed before a stable state was reached. The friction coefficient also decreased with increasing load. S. Rajesh (2014) et.al., investigates the dry sliding wear behavior of graphite reinforced aluminum composites produced by the molten metal mixing method by means of a pin on disc type wear set up. Based on the ANOVA results, it is observed that the sliding distance (74.65 %) has highest significant effect on wear volume loss followed by sliding velocity (11.37%), contact stress (9.19%) and reinforcement percentage (1.33 %). Whereas sliding distance (49.56 %), reinforcement percentage (45.59%), contact stress (0.85%) and sliding velocity (0.46%) has significant influence on coefficient of friction respectively. Vijayanand Dharanikota (2014), investigated the optimization of dry sliding performances on the aluminum hybrid metal matrix composite was done using grey relational analysis in the Taguchi method. Different loads, sliding speeds, sliding distances and varying percentage of Silicon Carbide are selected as control factors. The multiple responses to evaluate the dry sliding performances are specific wear rate and coefficient of friction. A series of L27 orthogonal array of experiments for three different samples of Al-6082 SiC MMCs have been conducted on pin-on-disc wear tester apparatus, the volume loss and frictional force are measured. Based on grey relational analysis, the optimum level parameters for specific wear rate and coefficient of friction have been identified. Analysis of Variance (ANOVA) had given the impact of individual factors on the specific wear rate as well as the coefficient of friction. The results indicated that the four test parameters had a significant role in controlling the friction and wear behavior of composites out of which %vol. was identified as most influential parameter followed by load for specific wear rate and load for coefficient of friction. Kadir Gungora (2015) et.al., optimizes the effect of wear test parameters on the wear behaviour properties of sintered bronze based materials. Particle sizes, compaction pressure and test sliding speed are investigated to study their effects on the wear behaviour of test specimens. Taguchi's L27 (313) orthogonal array design is employed for the experimental plan. Friction coefficient and weight loss of the specimens are measured. Signal to noise ratio for wear properties of sintered bronze based materials using Taguchi method is calculated and effect of the test parameters such as particle size, compaction pressure and sliding speed on wear behaviour is determined using the analysis of variance (ANOVA).

Kiran Deore (2015) et.al., study of wear rate, friction force and coefficient of friction of different materials with same parameters. The materials being tested are SS316, SS304, SS410, Copper, Aluminum and Brass widely used in various implications and applications in industries throughout. With regard to the various industrial development fields there is nevertheless requirement of Mild steel, copper, aluminum and brass; hence it is a clear necessity to compute wear rate, friction force and coefficient of friction. It is a general observation that wear resistance is the key factor governing the applicability of the material as per various requirements. There have been a number of attempts to standardize the friction force and coefficient of friction by various committees. The tests were conducted on pin on disk apparatus with a spherical pin with flat circular disk placed perpendicular to the surface of the spherical pin end.

R.K Singh, D. Kumar and A. Kumar (2015), deals with the study of wear behavior of Al-SiC-Cu M.M.C.s for varying reinforcement content, applied load, sliding speed, and distance. Aluminium MMCs reinforced with three different percentage of reinforcement 3, 6, 9% wt. SiC and 0.5, 0.75, 1.00% wt. Cu prepared by stir casting method. Wear test was performed by using “pin on disk” apparatus. A plan of experiment based on L27 Taguchi orthogonal array is used to acquire the wear data. An analysis of variance is employed to investigate the influence of four controlling parameters, SiC content, Normal load, sliding speed and sliding distance on dry sliding wear of the composites. It is observed that SiC content, sliding speed and normal load significantly affect the dry sliding wear. The optimal combination of the four controlling parameters is also obtained for minimum wear. The microstructure study of worn surface indicates nature of wear to be mostly abrasive.

Sundaravadivelu and Mujiburrahman.K (2015), optimise the wear parameters of gray cast iron under high sliding and high contact pressure conditions and to coat with different kind of materials. In this proposed concept, we are coating with Nickel-Chromium-Aluminium with micro-coating. It was prepared as a normal disc and different methods were adopted into it. The friction tests and wear tests are carried out in originally designed pin-on-disk type test rig. The coefficient of friction of cast iron converged to some constant value with the increment of sliding distance and this converged value was independent of the contact and decreased with the increment of sliding speed. A statistical analysis of wear tests was conducted using Response Surface Methodology, Taguchi Technique with different experiments by using MINITAB software. These were evaluated and the optimum controlling parameters were examined on the basis of “smaller the best”. It was also analysed by ANOVA and S/N ratio respectively.

Veerabhadrappa Algur (2015) et.al., investigated the dry sliding wear behavior of Modified ZA-27 alloy was prepared by gravity die casting. The specific wear rate and frictional force of Modified ZA-27 alloy was studied by performing wear test using a pin-on-disc wear tester. Experiments were conducted according to plan of experiments generated using taguchi method. A L25 orthogonal array was used for analysis of data. ANOVA is used to study the influence of process parameters such as Normal load and sliding speed on specific wear rate and frictional force. Regression analyses are employed to find the optimal process parameter levels and to analyze the effect of these parameters on Modified ZA-27 alloy. The result reveals that Normal load and sliding speed were the more sensitive parameters.

Vemuri Lakshminarayana and Vincent Balu (2015) study the influence of varying load on EN8alloy steel when it is sliding against EN31alloy steel. The wear test was carried out by using Pin on Disc apparatus. The counter face discs were machined from theEN31 steel composition and the test was carried at low loads and high loads. Variations of friction coefficient and the wear rate at different normal loads and high load were investigated. The result shows that the wear rate increases when the load increases. An interesting result showed that the Co-efficient of Friction decreases at normal loading conditions and when the load increases from 125N, the Co-efficient of Friction increases till 175N.The Scanning Electron Microscopy (SEM) image of the worn out specimen reveals that the formation of groove lines on the sliding surface due to adhesion strength of the material is very less when it subjected to higher loads.

Gurpreet Singh and Sanjeev Goyal (2016), dry sliding wear behaviour of hybrid aluminum metal matrix composites is carried out. A mixture of silicon carbide and boron carbide is used in equal fraction as reinforcement with base material AA6082-T6 to prepareAA6082-T6/SiC/B4C hybrid metal matrix composites using stir casting technique. The weight percentage of silicon carbide and boron carbide mixture taken to prepare hybrid composites is 5, 10, 15 and 20. The wear behaviour of Al-SiC-B4C composites is investigated using a pin-on-disc apparatus at room temperature, and optimization of process parameters is done using response surface methodology. The weight percentage of reinforcement, sliding speed, load and sliding distance are selected as process parameters with five levels of each. Analysis of variance shows that wear increases with increase of load or sliding distance and decreases with an increase in reinforcement or sliding speed. The experimental results revealed that the wear of Al-SiC-B4C hybrid composites has been influenced most by the sliding distance and least by weight percentage of reinforcement. The interaction between load–sliding speed is the only significant two-factor interaction in the present model which increases wear rate in fabricated hybrid composites. Further, the experimental results obtained are verified by conducting confirmation tests, and the errors found are within 3 to 7%.

Prashant Mittal, Dr. Gajendra Dixit (2016), evaluated the sliding wear rate and micro structural observations of Sic particulate reinforced Al matrix composites as a function of volume of SiC. The gradient in wear behavior as a function of infiltration length was evaluated using a pin-on-ring device varying load and sliding speed. Towards this purpose, aluminium with 10 & 20 vol.% of Sic and Al, in the form of pins, have been wear tested against a hardened steel disc(EN31 steel disc hardened to 60HRc, grounded to 1.6Rasurface roughness) at different test loads (20N,30N,50N &70N) and with different sliding velocities (1m/s,3m/s,5m/s &7m/s). The results indicate that while the wear rate of Al-SIC decreases with increasing fraction of SiC, the corresponding effect on coefficient of friction is only marginal. An addition of even 10% Sic to Al, is shown to prevent the transition from mild to severe wear in the load range used in the present experiments. Experiments have been conducted under laboratory condition to assess the wear characteristics of the aluminium SiC composite using a pin-on disc wear test apparatus at different loads, speeds and constant sliding distances and track diameter under dry condition. The worn surfaces of the wear out samples were studied under SEM to get an idea about the effect of particulate reinforcement on the wear behavior of the composite.

V. Ramakoteswara Rao (2016) et.al., Aluminum Metal Matrix Composites (AMMCs), reinforced with particulates, have marked their importance in many engineering applications because of low wear rate and a significant hardness. In this work, AA7075 metal matrix composite materials, varying in the particle percentage of TiC reinforcement, were prepared by stir casting procedure and optimized volumetric wear at different parameters such as particle percentage of TiC, sliding speed and sliding distance. The specimens were examined Scanning Electron Microscope (SEM). Through Taguchi’s technique, a plan of experiment generated and it is used to conduct experiments based on L27 orthogonal array. The developed ANOVA used to find the optimum wear under the influence of percentage of TiC, sliding speed, sliding distance. In all the cases, matrix material shows a higher volumetric wear rate than composites. 8 wt % of TiC composites show a lower volumetric wear rate (535.58 mm3/sec) at minimum sliding distance and maximum sliding velocity of 1Km 2.61m/s, respectively.

Hiral H. PARIKH (2017) et.al., study the effect of the weight percentage of graphite content on the dry sliding wear behavior of cotton fiber polyester composite (CFPC) was examined by considering the effect of operating parameters like load, speed, and sliding distance. The cotton fiber reinforced polyester composites were fabricated with varying amount of graphite fillers (0, 3, 5 wt %) with a hand lay-up technique. Wear tests were planned by using a response surface (Box Behnken method) design of experiments and conducted on a pin-on-disc machine (POD) test setup. The experimental results indicated that proper wt.% fillers had a considerable effect on controlling the wear rate of the material. wear test results showed the inclusion of 5 wt.% of graphite as fillers in CFPC increase wear resistance compared to 3 wt.% of graphite fillers. The graphite fillers were recommended for CFPC to increase the wear resistance of the material.

Pushkar (2017) et.al., This study synthesized Cu–4 wt% Ni matrix composites reinforced with different percentages of TiC (0, 2, 4, 6, and 8 wt%) through high-energy ball milling, followed by compaction and sintering. The friction and wear behavior was examined at four different normal loads of 5, 10, 15, and 20 N. A constant sliding speed of 1.25 m/s was maintained while sliding against a hardened counterface made of EN31 steel (HRC 60) under ambient conditions using a pin-on-disk test rig. The wear rate for the composites and the Cu4Ni matrix alloy increased linearly with the load. However, the composites showed a lower wear rate than the matrix alloy.The average friction coefficient increased with the increasing load. However, the Cu4Ni matrix alloy exhibited the minimum value of the friction coefficient among all the materials investigated because of its relatively soft nature compared to the composites.

Rajesh S. Godse (2017) et.al., investigates the coefficient of friction and wear rate of different steel materials and compared. Experiments are conducted on a pin-on-disk apparatus on different types of pin materials such as stainless steel SS304, stainless steel SS316, stainless steel SS202, and mild steel sliding against EN-31 disk. The experiments are performed on a group of specimens for duration of 10 min for various loads of 8, 12, and 16 kg in magnitude with disk speed of 380 rpm. The results show that the coefficient of friction varies with duration of rubbing and normal load at constant sliding velocity. In general, coefficient of friction increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. The results obtained reveal that the coefficient of friction increases with the increase in normal load for all the tested materials. For the same operating condition, the magnitudes of the coefficient of friction and wear rate are different for different materials depending on normal load. The performance of steel with respect to wear is significantly governed by the chemical composition of material. Wear rate increases with the increase in normal load. Results have also shown that the wear of carbon steel is significantly reduced by adding more carbon content. Hence, it becomes imperative to analyze the wear characteristics of different types of steel materials, particularly SS304, SS316, SS202 and mild steel, sliding against EN-31 on a case-to-case basis in order to arrive at a more realistic assessment of wear performance.

V V K Lakshmi (2017) et.al., Study the Mechanical Properties and Wear Behaviour of Sugarcane Ash Reinforced Aluminium Composite. In this study Industrial waste sugarcane bagasse fly ash used as a reinforcement to cast a Metal Matrix Composite via liquid metallurgy route. AA 6061 is used as matrix material. Sub micron size of 0.165 *μ*m and percent reinforcement varying from 0% to 2.5% weight percentage were used in fabrication of MMC’s via double stir casting technique. The effect of low particle size on the dispersion and strength of MMC studied. Composites were characterized for mechanical properties such as hardness and tensile strength. The micro structures were examined with optical micrograph of 100x magnification for agglomerations. The dry sliding wear of the composites in the cast conditions were studied using pin on disc apparatus. Experiments were conducted varying the loads from 10N to 30N, for a constant distance of 5000m and constant sliding speed of 500 rpm. It is observed that mechanical and wear resistance increased in reinforcement content as compared to AA6061 alloy. Corrosion wear of MMC in NaCl solution was studied using potentiostatically polarization measurements. It was found that adding of ash particles to the aluminium alloy matrix decreased corrosion till 1.5% and further addition has increased the corrosion wear.

Exfoliated Vermiculite particles are chosen as filler material due to its very less density (0.64-1.12 g/cc). Exfoliated vermiculite (EV) is hydrate Mg Silicate and stable at elevated temperatures and inert. EV has lamellar structure due to which it has good lubricating properties.

Materials and Methods

Measurement

Characterization of mechanical properties of aluminium/tungsten carbide composites

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# Tribological Characterization of Stir-cast Aluminium-TiB2 Metal Matrix Composites

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## Abstract

The present study considers friction and wear of aluminium matrix composites reinforced with TiB2 micro particles processed through the stir casting method rather than in-situ techniques adopted by earlier studies. Different weight percentages of TiB2 powders having average sizes of 5 - 40 micron were incorporated into molten LM4 aluminium matrix by stir casting method. The friction and wear behavior were studied for Al-TiB2 composites prepared according to specific dimensions by using a block-on-roller type multi-tribotester at room temperature. Normal loads of 25 - 75 N and rotational speed of 400 – 600 rpm were used for determination of friction and wear behavior. It is found that friction and wear decrease with increase in percentage of TiB2 reinforcement in the composite, while friction and wear increase with applied load and speed. Scanning electron microscopy studies the reveal presence of both abrasive and adhesive wear mechanisms with abrasive wear being predominant.

# Dry Sliding Friction and Wear Behavior of AA7075-Si3N4Composite

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## Abstract

The present investigation is aimed at identifying the influence of Si3N4 reinforcement on the mechanical and tribological behavior of AA7075-Si3N4 composite. Five different composites of AA7075 aluminum alloy reinforced by silicon nitride particles have been fabricated by the stir casting route. The percentage of silicon nitride was varied from 0-8 wt%. The cast composites were tested for hardness, density and compression strength. Unidirectional friction and wear testing was carried out for all compositions under five different loading conditions (10 N, 20 N, 30 N, 40 N and 50 N) at a constant sliding speed of 1 m/s. SEM and EDS analysis was also carried out for worn surface analysis and elemental analysis of the composites. The hardness and compression strength of the composites exhibited an increasing trend with an increase in wt% of reinforcement in the base alloy, showing 20% improvement in hardness and around 50% improvement in compression strength for 8 wt% Si3N4 addition. The addition of Si3N4particles led to an improvement in the wear resistance by 37% at low loads (10 N) and 61% at higher loads (50 N). The COF for all varied compositions at low load (10 N) and high load (50 N) ranges from 0.10 to 0.20 and 0.25 to 0.30 respectively. Moreover, the COF is observed to increase until 4 wt% and beyond it decreases. Microscopic studies of worn surfaces revealed a dominance of delamination wear at lower concentrations (0 wt% and 2 wt%) and ploughing at higher concentrations (6 wt% and 8 wt%). The developed composites exhibited better mechanical and anti-wear properties and could serve as potential candidates in sliding applications such as bearings, brake drums, gears, sprockets and brake rotors.

# Study on Mechanical and Tribological Characterization of Al2O3/SiCp Reinforced Aluminum Metal Matrix Composite

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## Abstract

In this investigation, an attempt has been made to hardness and wear rate of Al7075 hybrid metal matrix composite reinforced with the hard ceramics like alumina (2, 4, and 6 wt.% of Al2O3) and silicon carbide (3, 6, and 9 wt.% of SiC) is fabricated by using stir casting method. The samples were aging at temperature of 140 ∘C, 160 ∘C and 180 ∘C and monitored by hardness test. Taguchi’s L27 Orthogonal array was used for optimizing the process parameters. The obtained results indicated that hardness increased with increasing reinforcement. A wear test was performed using pin-on disk apparatus at room temperature for constant load of 30N, at a fixed sliding speed of 1.66 m/s and wear resistance increased as the weight percentage of reinforcement increased. Scanning electron microscope (SEM) studies were carried out to evaluate the worn surface. From the analysis of variance (ANOVA), Al2O3 is the significant factor that affects the hardness and wear loss of hybrid composites followed by SiCp and heat treatment. Confirmatory test was performed for the optimized parameters and these results were within the acceptable range when compared with the experimental results.

## [Transactions of Nonferrous Metals Society of China](https://www.sciencedirect.com/science/journal/10036326)

[Volume 27, Issue 3](https://www.sciencedirect.com/science/journal/10036326/27/3), March 2017, Pages 627-637

# Parametric optimization of dry sliding wear loss of copper–MWCNT composites

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## Abstract

The wear behavior of multi-walled carbon nano-tubes (MWCNTs) reinforced copper metal matrix composites (MMCs) processed through powder metallurgy (PM) route was focused on and further investigated for varying MWCNT quantity via experimental, statistical and artificial neural network (ANN) techniques. Microhardness increases with increment in MWCNT quantity. Wear loss against varying load and sliding distance was analyzed as per L16 orthogonal array using a pin-on-disc tribometer. Process parameter optimization by Taguchi's method revealed that wear loss was affected to a greater extent by the introduction of MWCNT; this wear resistant property of newer composite was further analyzed and confirmed through analysis of variance (ANOVA). MWCNT content (76.48%) is the most influencing factor on wear loss followed by applied load (12.18%) and sliding distance (9.91%). ANN model simulations for varying hidden nodes were tried out and the model yielding lower MAE value with 3-7-1 network topology is identified to be reliable. ANN model predictions with R value of 99.5% which highly correlated with the outcomes of ANOVA were successfully employed to investigate individual parameter's effect on wear loss of Cu–MWCNT MMCs.

## [Tribology International](https://www.sciencedirect.com/science/journal/0301679X)

[Volume 98](https://www.sciencedirect.com/science/journal/0301679X/98/supp/C), June 2016, Pages 41-47

# Mechanical properties and tribological behavior of aluminum matrix composites reinforced with in-situ AlB2particles

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## Highlights

•

Under the present scratch test conditions, the wear resistance of the pure Al is improved significantly due to the formation of in situ AlB2particles.

•

The wear area and friction coefficient of the samples also increase almost linearly with the increase in the applied load.

•

Aluminum matrix composites reinforced with in-situ AlB2 particles are processed using powder metallurgy followed by hot rolling.

## Abstract

Aluminum matrix composites (AMCs) reinforced with in-situ AlB2 particles have been fabricated using a combination of powder metallurgy, hot rolling and solution treatment. The effects of boron content (7 and 12 wt%), hot rolling and heat treatment parameters on the microstructures and mechanical properties of the composites were investigated by means of scanning electron microscopy (SEM), tensile test and micro-hardness measurements. The friction coefficient, wear behavior and scratch morphology of the AMCs and pure aluminum were also studied using scratch tests. The hardness and wear properties are higher in a case of composites when compared to unreinforced matrix material.

# Synthesis and tribological investigation of Al-SiC based nano hybrid composite

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## Abstract

In this study, a novel self lubricating nano-composite Al-SiC-nAl2O3-WS2 has been synthesized via powder metallurgy method. Nano-Al2O3 has been prepared via combustion synthesis. Three different compositions by varying the amount of solid lubricant, WS2 (0, 5, 9) wt.% were synthesized and analyzed. The density measurements of composites were carried out by using Archimedes Principle. The micro hardness value of every composition was obtained by using micro hardness tester. The tribological properties were investigated under dry and unidirectional sliding conditions on a pin on disk tribometer. Taguchi L9 orthogonal array was used to study the effects of various parameters like load, content, speed and sliding distance on wear and frictional behavior of the composites. Analysis of variance (ANOVA) was used to investigate the percentage contribution of various parameters on the wear and friction behavior. It was observed that composite with 5 wt.% of WS2exhibited lower friction and wear. SEM images obtained therein revealed that ploughing and abrasion are the two dominant mechanisms of wear.

## [Materials & Design](https://www.sciencedirect.com/science/journal/02613069)

[Volume 63](https://www.sciencedirect.com/science/journal/02613069/63/supp/C), November 2014, Pages 620-632

# Experimental investigation on mechanical behaviour, modelling and optimization of wear parameters of B4C and graphite reinforced aluminium hybrid composites

Author links open overlay panel[A.Baradeswarana1](https://www.sciencedirect.com/science/article/pii/S0261306914005032#!)[S.C.Vettivel](https://www.sciencedirect.com/science/article/pii/S0261306914005032" \l "!)[b](https://www.sciencedirect.com/science/article/pii/S0261306914005032" \l "!)[A.Elaya Perumal](https://www.sciencedirect.com/science/article/pii/S0261306914005032" \l "!)[c2](https://www.sciencedirect.com/science/article/pii/S0261306914005032" \l "!)[N.Selvakumar](https://www.sciencedirect.com/science/article/pii/S0261306914005032" \l "!)[d3](https://www.sciencedirect.com/science/article/pii/S0261306914005032" \l "!)[R.Franklin Issac](https://www.sciencedirect.com/science/article/pii/S0261306914005032" \l "!)[a4](https://www.sciencedirect.com/science/article/pii/S0261306914005032" \l "!)

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## Highlights

•

Aluminium alloy reinforced with boron carbide and graphite through liquid casting.

•

The high hardness and elongation obtained in the AA 7075 hybrid composite.

•

SEM, EDS observations were used to evaluate the worn surface.

•

MINITAB software was used to analyse the wear rate and develop the map.

## Abstract

Aluminium alloy (AA) 6061 and 7075 were reinforced with 10 wt.% of boron carbide (B4C) and 5 wt.% of graphite through liquid casting technique. The Scanning Electron Microscope (SEM) and Energy Dispersive Spectrum (EDS) were used for the characterization of composites. The wear experiment was carried out by using a pin-on-disc apparatus with various input parameters like applied load (10, 20, and 30 N), sliding speed (0.6, 0.8, and 1.0 m/s) and sliding distance (1000, 1500, and 2000 m). Response Surface Methodology (RSM) using MINITAB 14 software was used to analyse the wear rate of hybrid composites and aluminium alloys. The worn surfaces of hybrid composites and base alloys were studied through SEM and EDS systems and some useful conclusions were made.

# Investigations on dry sliding wear behavior of in situ casted AA7075–TiC metal matrix composites by using Taguchi technique

Author links open overlay panel[S.BaskaranV.AnandakrishnanMuthukannanDuraiselvam](https://www.sciencedirect.com/science/article/pii/S0261306914002672#!)

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## Highlights

•

The AA7075–TiC metal matrix composites were produced by in situ casting technique.

•

The produced composites were characterized by XRD analysis and SEM.

•

The dry sliding wear behavior of composites was investigated by Taguchi technique.

•

The significant factors and their contribution in wear rate identified by ANOVA.

•

The formation of oxidation at high sliding velocity was verified by EDS.

## Abstract

High strength 7075 aluminum matrix composites with 4 and 8 wt.% of TiC particulate reinforcement was synthesized by reactive in situ casting technique. X-ray diffraction analysis and scanning electron microscopy were used to confirm the presence of TiC particles and its uniform distribution over the aluminum matrix. The dry sliding wear behavior of the as-casted composites was investigated based on Taguchi L27orthogonal array experimental design to examine the significance of reinforcement quantity, load, sliding velocity and sliding distance on wear rate. The combination of 4 wt.% of TiC, 9.81 N load, 3 m/s sliding velocity and 1500 m sliding distance was identified as the optimum blend for minimum wear rate using the main effect plot. Load and sliding velocity were identified as the highly contributing significant parameters on the wear rate using ANOVA analysis. Further a confirmation test was also conducted with the optimum parameter combination for validation of the Taguchi results.

**Desirability based multi-objective optimisation of abrasive wear and frictional behaviour of aluminium (Al/3.25Cu/8.5Si)/fly ash composites**

[**K. Ravi Kumar**](https://www.tandfonline.com/author/Kumar%2C+K+Ravi) &[V. S. Sreebalaji](https://www.tandfonline.com/author/Sreebalaji%2C+V+S)

Pages 128-136 | Received 24 Mar 2015, Accepted 27 May 2015, Published online: 19 Jun 2015

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**Abstract**

Aluminium alloy (Al/3.25Cu/8.5Si) composites reinforced with fly ash particles of three different size ranges (53–75 μm, 75–103 μm and 103–125 μm) in 3, 6 and 9 wt-% were fabricated using liquid metallurgy technique. Pin on disc abrasive wear tests were carried against the disc surface fixed with SiC emery paper (120 grades). A mathematical model was developed to predict the abrasive wear and coefficient of friction of the composites. Analysis of variance technique was used to check the validity of the developed model. Composites reinforced with coarse fly ash particles exhibited better abrasive wear resistance than those reinforced with fine fly ash particles. Abrasive wear in composites with fine fly ash particles is a combination of adhesive wear and abrasive wear. Larger fly ash particles present in composites gets fractured into fine particles and entrapped between the composite pin and the disc, thereby decreasing the wear rate. Worn surfaces of the pins were then analysed using scanning electron microscopy to study the wear mechanisms of the composites. The abrasive wear was optimised using desirability based multi-objective optimisation technique.

## [Tribology International](https://www.sciencedirect.com/science/journal/0301679X)

[Volume 116](https://www.sciencedirect.com/science/journal/0301679X/116/supp/C), December 2017, Pages 338-350

# Effect of weight fraction and particle size of CRT glass on the tribological behaviour of Mg-CRT-BN hybrid composites

Author links open overlay panel[P.M.Gopal](https://www.sciencedirect.com/science/article/pii/S0301679X17303717" \l "!)[a](https://www.sciencedirect.com/science/article/pii/S0301679X17303717" \l "!)[K.Soorya Prakash](https://www.sciencedirect.com/science/article/pii/S0301679X17303717" \l "!)[a](https://www.sciencedirect.com/science/article/pii/S0301679X17303717" \l "!)[S.Nagaraja](https://www.sciencedirect.com/science/article/pii/S0301679X17303717" \l "!)[b](https://www.sciencedirect.com/science/article/pii/S0301679X17303717" \l "!)[N.Kishore Aravinth](https://www.sciencedirect.com/science/article/pii/S0301679X17303717" \l "!)[a](https://www.sciencedirect.com/science/article/pii/S0301679X17303717" \l "!)

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## Highlights

•

Development of novel Hybrid Mg MMC with E waste CRT panel glass reinforcement.

•

Effect of reinforcement size and percentage over wear behavior is analyzed.

•

Multi objective optimization though Grey Relational Analysis.

•

Detailed worn out surface analysis through Scanning Electron Microscope.

## Abstract

The current research focuses on dry sliding wear behaviour of end of life CRT panel glass and BN reinforced hybrid magnesium matrix composite fabricated through powder metallurgy route. CRT panel glass percentage (5, 10 & 15 wt %) and particle size (10, 30 & 50 μm) are varied to find its effect on wear performance and BN solid lubricant is added at a fixed level of 2%. Increase in reinforcement content and particle size decreases the wear rate whereas the opposite trend is found for coefficient of friction. ANOVA results reveal that all of the considered parameters significantly influence the response parameters. Taguchi based GRA is used for multi objective optimization and the worn surface SEM analysis is also performed

## [Engineering Science and Technology, an International Journal](https://www.sciencedirect.com/science/journal/22150986)

[Volume 19, Issue 2](https://www.sciencedirect.com/science/journal/22150986/19/2), June 2016, Pages 710-716

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# Full Length Article

# Dry sliding wear behavior of epoxy fly ash composite with Taguchi optimization

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Received 9 October 2015, Revised 13 November 2015, Accepted 17 November 2015, Available online 10 December 2015.

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<https://doi.org/10.1016/j.jestch.2015.11.010>[Get rights and content](https://s100.copyright.com/AppDispatchServlet?publisherName=ELS&contentID=S2215098615301658&orderBeanReset=true)

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## Abstract

Epoxy resin matrix composite reinforced with fly ash particles was prepared by ultrasonic stirring method. Pin-on-disc wear test of the composite was carried out and compared according to Taguchi design-of-experiment. An orthogonal array exhibited and examined the influencing parameters like % of fly ash debris, typical load, sliding speed and track distance on the composite. Signal to noise ratio analysis optimizes the parametric condition that yields minimum wear rate, minimum frictional force and minimum coefficient of friction. A multi-criteria decision analysis method, TOPSIS is used to optimize the output, and confirmation test has been done to verify the projected model. ANOVA shows that applied normal load plays a vital role in increasing dry sliding wear of epoxy composites

# Dry sliding wear investigation of Al6082/Gr metal matrix composites by response surface methodology

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Received 2 December 2014, Accepted 5 May 2015, Available online 10 June 2015.

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<https://doi.org/10.1016/j.jmrt.2015.05.001>[Get rights and content](https://s100.copyright.com/AppDispatchServlet?publisherName=ELS&contentID=S2238785415000678&orderBeanReset=true)

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Materials and Methods

**3.1 Materials and Methodology**

* 1. Fabrication of Al 6061/EVcomposite using stir cast technique.
  2. Selection of process parameters for wear test and their levels.
  3. Selection of quality characteristics for each response characteristic.
  4. RSM Design of Experiments.
  5. Experimentation as per the RSM DOE.
  6. RSM analysis and ANOVA for responses to find the significance and effect of process parameters on responses
  7. PROMETHEE II analysis used for converting multi objective function into a single objective function to obtain optimal process parameter for both WEAR and Coefficient of Friction.
  8. Determining the results at optimum condition.

The composite is fabricated with Al6061 and EV particles as filler materials as described in paper. 2, 4, 6 weight percent EV particles are added to Aluminum6061 alloy as it has good properties and applications in engineering field. EV used as a reinforcement to improve strength and wear resistance. Figure 4.2 shows the specimens of composites after casting

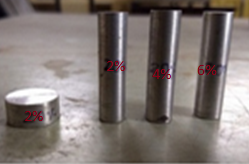


Fig Al6063+EV composite Fig Pin on disc Specimen test pieces

From the fabricated composite e cylindrical piece of ϕ10 mm diameter and 33 mm length work pieces are made by using lathe machine for all reinforcements. And these work pieces are used for wear test on Pin on Disc apparatus. Figure 4.3 shows the photographic view of the machined work piece for wear.

**EXPERIMENTAL PROCEDURE**

A series of experiments are planned to conduct, to study the effects of various process parameters on responses (WEAR and COF).The setup of the method comprises of a pin with flat surface and a circular rotating disk which is placed at a perpendicular with respect to the pin surface. The diameter of the pin is 10mm and the length is 33mm.The disk is made of hardened steel on which the pin is held with a jaw in the apparatus and rotation is provided to disk which causes wear of the pin on a fixed path on disk. The pin is pressed against the surface of the disk with load being applied with the arm attachment provided to the apparatus. Machine is attached with a data acquisition system and WINDUCOM 2010 software which gives result values and graphs. After every experimentation wear and frictional force are set to zero. Figure 4.5 shows the Wear and Friction Monitor. In the present research one of the commonest and simplest methods to test for wear rate was by using a pin-on-disc wear tester (Model: TR-20, DUCOM) as per ASTM: G99 – 05 as shown in Fig 4.1. The counterpart disc was made of quenched and tempered EN-32 steel having a surface hardness of 65 HRC. The specimens of size Ø10×33 mm were machined out from all the casting specimens. The track diameter of 100mm enabled the rotational speeds of 191, 382, and 573 rpm to attain linear sliding speeds of 1.0, 2.0 and 3.0 m/s respectively. Wear tests were carried out up to a sliding distance 1500m. The fictional traction experienced by the pin during sliding is measured continuously by PC-based data logging system.

The specification of the DUCOM Friction and Wear Tester used in the present investigation are shown Table 4.1



**SELECTION OF WEAR PROCESS PARAMETERS AND THEIR LEVELS**

Selection of right combination of process parameters and setting the range of the process parameters is very important step in unconventional process. In the present work process parameters are taken as follows

**Table 3.1: Process Parameters and their levels**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Process Parameters | Notation | Unit | Levels | | |
| I | II | III |
| Reinforcement | REF | Weight % | 2 | 4 | 6 |
| Speed | Speed | m/s | 1 | 2 | 3 |
| Load | Load | N | 10 | 20 | 30 |
| Distance | Distance | m | 500 | 1000 | 1500 |

**Table 3.2: RSM Design L27 orthogonal Array**

By using the processes parameters arranged in L27 orthogonal array experiments are done on the Pin on Disc apparatus, and the result in terms of Wear and Coefficient Of Friction are recorded to obtain an optimal solutions.

**RESULTS AND DISCUSSION**

After fabrication of Aluminium Composites micro structure and hardness values are evaluated. A series of experiments are conducted on aluminum composite to evaluate Wear and Coefficient of Friction.

The micro hardness of the composites was evaluated on the Vickers hardness tester. A load of 1000 g has been implemented for 15 s on all the specimens. Each specimen was tested three times, and average value has been taken. Table 5.1 shows the Vickers hardness of all the samples with different vol% of reinforcement mixture.

**Table 5.1: Results of micro Hardness tests**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| S.No. | Reinforcement | HV 1 | HV 2 | HV 3 | HV average |
| 1 | Pure (0%) | 62 | 60 | 61 | 61 |
| 2 | 20% | 80 | 79 | 80 | 80 |
| 3 | 40% | 88 | 87 | 88 | 88 |
| 4 | 60% | 68 | 69 | 68 | 68 |

The results obtained from wear test of all the specimens along with the analysis made for the aluminum composite material are presented as follows, a total 27 experiments are conducted on Pin on Disc apparatus for aluminum composite material. The test results for WEAR and COF of aluminum composite specimens after experimenting are analyzed to get an optimized solution. Table 5.2 shows the Design layout for conducting the experiments and Table 5.3 shows the process responses of WEAR and COF‘ **MINITAB’** software is used as statistical tool for RSM Design and ANOVA to find the effect of process parameters. PROMETHEE – II methodology was used to find single optimal solution for both WEAR and COF, and Net out ranking flow is calculated for each individual experimental trail as explained in the chapter 5. To find the optimal process parameters ranking was given. And finally a single optimal solution for both WEAR and COF is obtained.

The DOE, ANOVA for WEAR and COF, Regression Analysis are carried out using the software MINITAB 16.0.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Experiment Number | Processes Parameters | | |  | Responses | |
| Reinforcement % | Speed | Load | Distance | WEAR(Microns) | COF |
| 1 | 2 | 1 | 20 | 1000 | 95.77 | 0.306950 |
| 2 | 6 | 1 | 20 | 1000 | 99.73 | 0.307450 |
| 3 | 2 | 3 | 20 | 1000 | 41.35 | 0.236700 |
| 4 | 6 | 3 | 20 | 1000 | 38.31 | 0.192450 |
| 5 | 4 | 2 | 10 | 500 | 34.32 | 0.215300 |
| 6 | 4 | 2 | 30 | 500 | 36.12 | 0.175467 |
| 7 | 4 | 2 | 10 | 1500 | 59.96 | 0.214800 |
| 8 | 4 | 2 | 30 | 1500 | 87.19 | 0.175400 |
| 9 | 2 | 2 | 20 | 500 | 41.87 | 0.266100 |
| 10 | 6 | 2 | 20 | 500 | 70.35 | 0.230100 |
| 11 | 2 | 2 | 20 | 1500 | 79.07 | 0.263500 |
| 12 | 6 | 2 | 20 | 1500 | 98.30 | 0.228300 |
| 13 | 4 | 1 | 10 | 1000 | 50.26 | 0.268200 |
| 14 | 4 | 3 | 10 | 1000 | 25.68 | 0.168200 |
| 15 | 4 | 1 | 30 | 1000 | 105.29 | 0.198100 |
| 16 | 4 | 3 | 30 | 1000 | 45.89 | 0.137500 |
| 17 | 2 | 2 | 10 | 1000 | 50.39 | 0.323800 |
| 18 | 6 | 2 | 10 | 1000 | 65.59 | 0.264800 |
| 19 | 2 | 2 | 30 | 1000 | 99.26 | 0.239000 |
| 20 | 6 | 2 | 30 | 1000 | 119.26 | 0.200867 |
| 21 | 4 | 1 | 20 | 500 | 75.28 | 0.257450 |
| 22 | 4 | 3 | 20 | 500 | 20.65 | 0.152500 |
| 23 | 4 | 1 | 20 | 1500 | 110.58 | 0.257150 |
| 24 | 4 | 3 | 20 | 1500 | 36.62 | 0.150000 |
| 25 | 4 | 2 | 20 | 1000 | 49.58 | 0.193500 |
| 26 | 4 | 2 | 20 | 1000 | 49.54 | 0.193000 |
| 27 | 4 | 2 | 20 | 1000 | 49.60 | 0.194000 |

|  |  |  |
| --- | --- | --- |
|  |  |  |
| Fig :Effect of Reinforcement % on wear : Wear Vs Distance for Different Loads at 2m/S | | |
|  |  |  |
| FIG Effect of Load : Wear Vs Distance for different reinforcement at 2m/s speed | | |
|  |  |  |
| Fig Effect of Speed : Wear Vs Distance at 20N Load | | |

|  |  |  |
| --- | --- | --- |
|  |  |  |
| FIG : Effect of reinforcement on COF COF Vs Distance at varying Loads and 2m/s speed | | |
|  |  |  |
| FIG : Effect of Load on COF at different reinforcement and 2m/s speed | | |
|  |  |  |
| FIG Effect of speed on COF at varying reinforcement percent at 20N load | | |

**RESPONSE SURFACE RESULTS**

**Table 5.4: Analysis of Variance for Wear**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | DF | Adj SS | Adj MS | F- Value | P- Value |
| Regression | 14 | 19520.0 | 1394.28 | 9.26 | 0.000 |
| Linear | 4 | 16245.8 | 4061.46 | 26.96 | 0.000 |
| REF(A) | 1 | 585.6 | 585.62 | 3.89 | 0.072 |
| Speed(B) | 1 | 8987.8 | 8987.76 | 59.67 | 0.000 |
| load(C) | 1 | 3564.2 | 3564.20 | 23.66 | 0.000 |
| distance(D) | 1 | 3108.3 | 3108.27 | 20.63 | 0.001 |
| Square | 4 | 2676.5 | 669.14 | 4.44 | 0.020 |
| REF\*REF(A\*A) | 1 | 2463.2 | 2463.23 | 16.35 | 0.002 |
| Speed\*Speed(B\*B) | 1 | 27.3 | 27.26 | 0.18 | 0.678 |
| Load\*Load(C\*C) | 1 | 224.4 | 224.35 | 1.49 | 0.246 |
| Distance\*Distance(D\*D) | 1 | 44.0 | 44.03 | 0.29 | 0.599 |
| Interaction | 6 | 597.6 | 99.60 | 0.66 | 0.682 |
| REF\*Speed(A\*B) | 1 | 12.3 | 12.25 | 0.08 | 0.780 |
| REF \*Load(A\*C) | 1 | 5.8 | 5.76 | 0.04 | 0.848 |
| REF \*Distance(A\*D) | 1 | 21.4 | 21.39 | 0.14 | 0.713 |
| Speed\*Load(B\*C) | 1 | 303.1 | 303.11 | 2.01 | 0.181 |
| Speed\*Distance(B\*D) | 1 | 93.4 | 93.41 | 0.62 | 0.446 |
| Load\*Distance(C\*D) | 1 | 161.7 | 161.67 | 1.07 | 0.321 |
| Error | 12 | 1807.6 | 150.64 |  |  |
| Total | 26 | 21327.6 |  |  |  |

**Model Summary:**

S = 12.2733 R-Sq = 91.52% R-Sq(adj) = 81.64%

**Estimated Regression Equation:**

WEAR = 115.953 - 3.66262\*A - 5.83583\*B - 0.641417\*C + 0.0123517\*D + 0.0537271\*A\*A + 2.26083\*B\*B + 0.0648583\*C\*C + 1.14933E-05\*D\*D - 0.0875000\*A\*B + 0.00600000\*A\*C - 2.31250E-04\*A\*D - 0.870500\*B\*C - 0.00966500\*B\*D + 0.00127150\*C\*D

From the ANOVA table 5.4, it is concluded that speed, load and distance are most significant parameters that affect the wear.

**Table 5.5: Analysis of Variance for COF**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | DF | Adj SS | Adj MS | F- Value | P- Value |
| Regression | 14 | 0.062598 | 0.004471 | 29.48 | 0.000 |
| Linear | 4 | 0.038703 | 0.009676 | 63.79 | 0.000 |
| REF(A) | 1 | 0.003748 | 0.003748 | 24.71 | 0.000 |
| Speed(B) | 1 | 0.025942 | 0.025942 | 171.04 | 0.000 |
| load(C) | 1 | 0.009007 | 0.009007 | 59.38 | 0.000 |
| distance(D) | 1 | 0.000005 | 0.000005 | 0.03 | 0.859 |
| Square | 4 | 0.022896 | 0.005724 | 37.74 | 0.000 |
| REF\*REF(A\*A) | 1 | 0.018880 | 0.018880 | 124.48 | 0.000 |
| Speed\*Speed(B\*B) | 1 | 0.000197 | 0.000197 | 1.30 | 0.277 |
| Load\*Load(C\*C) | 1 | 0.000001 | 0.000001 | 0.00 | 0.953 |
| Distance\*Distance(D\*D) | 1 | 0.000000 | 0.000000 | 0.00 | 0.963 |
| Interaction | 6 | 0.000999 | 0.000167 | 1.10 | 0.417 |
| REF\*Speed(A\*B) | 1 | 0.000501 | 0.000501 | 3.30 | 0.094 |
| REF \*Load(A\*C) | 1 | 0.000109 | 0.000109 | 0.72 | 0.413 |
| REF \*Distance(A\*D) | 1 | 0.000000 | 0.000000 | 0.00 | 0.975 |
| Speed\*Load(B\*C) | 1 | 0.000388 | 0.000388 | 2.56 | 0.136 |
| Speed\*Distance(B\*D) | 1 | 0.000001 | 0.000001 | 0.01 | 0.930 |
| Load\*Distance(C\*D) | 1 | 0.000000 | 0.000000 | 0.00 | 0.986 |
| Error | 12 | 0.001820 | 0.001820 |  |  |
| Total | 26 | 0.064418 |  |  |  |

**Model Summary:**

S = 0.0123157 R-Sq = 97.17% R-Sq(adj) = 93.88%

**Estimated Regression Equation:**

COF = 0.654506 - 0.0122063\*A - 0.0670319\*B - 0.00564500\*C - 2.36667E-06\*D + 0.000148747\*A\*A + 0.00607778\*B\*B - 3.24306E-06\*C\*C + 1.01944E-09\*D\*D - 5.59375E-04\*A\*B + 2.60833E-05\*A\*C + 2.000E-08\*A\*D + 0.000985000\*B\*C - 1.10000E-06\*B\*D + 2.16667E-08\*C\*D

From the ANOVA table 5.5, it is concluded that reinforcement, speed and load are most significant parameters that affect the Coefficient of Friction.

**1 Analysis of Response Surface Plots**

Figure 5.19 to figure 5.24 presents the three-dimensional response surface plots of wear in relation to the reinforcement, speed, load and distance. It can be observed from response surface plots that the Wear of AA6061/Bagasse Composite decreases when the speed is increased at any given reinforcement and load. Wear decreases when the reinforcement is increased up to 40% and then increases at any given load and speed. However, Wear increases when the load is increased at any given reinforcement and speed. It can be inferred from the plots figure 5.25 to figure 5.30 that as the load and speed increases, Coefficient of Friction decreases. And also Coefficient of Friction decreases with increasing reinforcement up to 40% and then increases. The optimum Wear and Coefficient of Friction is exhibited by the apex of the response surfaces.

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**PROMETHEE II**

This is one approach of multi criteria decision making method. This method can convert several objective functions into single objective function. In this present work we optimize the both Wear and Coefficient of Friction as a single objective. Calculations are carried as explained in the chapter 3. Table 5.6 shows the responses of experimental trails.

Step 1: The obtained responses are normalized in this step using the formula as shown below. Table 5.7 shows the normalized decision matrix.

Rij =

**Table 5.7: Normalized Decision Matrix for L27 Design**

|  |  |  |
| --- | --- | --- |
|  | C1 | C2 |
| A1 | 0.238211135 | 0.090445518 |
| A2 | 0.198052936 | 0.087761675 |
| A3 | 0.790082142 | 0.467525497 |
| A4 | 0.820910658 | 0.705045625 |
| A5 | 0.861373086 | 0.582393988 |
| A6 | 0.843119359 | 0.796206835 |
| A7 | 0.601358889 | 0.585077831 |
| A8 | 0.325220566 | 0.796564681 |
| A9 | 0.784808843 | 0.309715513 |
| A10 | 0.495994321 | 0.502952228 |
| A11 | 0.407565156 | 0.323671498 |
| A12 | 0.212554508 | 0.512614063 |
| A13 | 0.699726194 | 0.298443371 |
| A14 | 0.948990975 | 0.835212024 |
| A15 | 0.141669202 | 0.674718196 |
| A16 | 0.744042186 | 1 |
| A17 | 0.698407869 | 0 |
| A18 | 0.544265287 | 0.316693505 |
| A19 | 0.202819187 | 0.455179817 |
| A20 | 0 | 0.659867597 |
| A21 | 0.445999392 | 0.356146001 |
| A22 | 1 | 0.919484702 |
| A23 | 0.088023527 | 0.357756307 |
| A24 | 0.838048879 | 0.932903918 |
| A25 | 0.706622046 | 0.699409554 |
| A26 | 0.707027685 | 0.702093398 |
| A27 | 0.706419227 | 0.696725711 |

Step 2: By using normalized values, calculate the evaluative differences of each alternative with respect to other alternatives. This step involves the calculation of differences in criteria values between different alternatives pairwise.

Step 3: Preference functions are computed for all the pairs using below formulae

Pj (a, b) = 0 if Raj ≤ Rbj

Pj (a, b) = Raj - Rbj if Raj > Rbj

Step 4: Aggregated preference function values for all the pairs are calculated using the formula shown below. Equal weightages are given for both criteria’s (w1 =0.5, w2 = 0.5). Aggregated preference function values are shown in the Table 5.8

Π (a,b) =

**Table 5.8: Aggregate Preference Matrix For L27 Design**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | A12 | A13 |
| A1 | 0 | 0 | 0.46 | 0.6 | 0.6 | 0.66 | 0.43 | 0.4 | 0.38 | 0.34 | 0.2 | 0.21 | 0.33 |
| A2 | 0.02 | 0 | 0.49 | 0.62 | 0.6 | 0.68 | 0.45 | 0.4 | 0.4 | 0.36 | 0.22 | 0.22 | 0.36 |
| A3 | 0 | 0 | 0 | 0.13 | 0.1 | 0.19 | 0.06 | 0.2 | 0 | 0.02 | 0 | 0.02 | 0 |
| A4 | 0 | 0 | 0 | 0 | 0 | 0.06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A5 | 0 | 0 | 0 | 0.06 | 0 | 0.11 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| A6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A7 | 0 | 0 | 0.09 | 0.17 | 0.1 | 0.23 | 0 | 0.1 | 0.09 | 0 | 0 | 0 | 0.05 |
| A8 | 0 | 0 | 0.23 | 0.25 | 0.3 | 0.26 | 0.14 | 0 | 0.23 | 0.09 | 0.04 | 0 | 0.19 |
| A9 | 0 | 0 | 0.08 | 0.22 | 0.2 | 0.27 | 0.14 | 0.2 | 0 | 0.1 | 0.01 | 0.1 | 0 |
| A10 | 0 | 0 | 0.15 | 0.26 | 0.2 | 0.32 | 0.09 | 0.1 | 0.14 | 0 | 0 | 0 | 0.1 |
| A11 | 0 | 0 | 0.26 | 0.4 | 0.4 | 0.45 | 0.23 | 0.2 | 0.19 | 0.13 | 0 | 0.09 | 0.15 |
| A12 | 0.01 | 0 | 0.29 | 0.4 | 0.4 | 0.46 | 0.23 | 0.2 | 0.29 | 0.14 | 0.1 | 0 | 0.24 |
| A13 | 0 | 0 | 0.13 | 0.26 | 0.2 | 0.32 | 0.14 | 0.2 | 0.05 | 0.1 | 0.01 | 0.11 | 0 |
| A14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A15 | 0.05 | 0.03 | 0.32 | 0.35 | 0.4 | 0.41 | 0.23 | 0.2 | 0.32 | 0.18 | 0.13 | 0.04 | 0.28 |
| A16 | 0 | 0 | 0.02 | 0.04 | 0.1 | 0.05 | 0 | 0 | 0.02 | 0 | 0 | 0 | 0 |
| A17 | 0.05 | 0.04 | 0.28 | 0.41 | 0.4 | 0.47 | 0.29 | 0.4 | 0.2 | 0.25 | 0.16 | 0.26 | 0.15 |
| A18 | 0 | 0 | 0.2 | 0.33 | 0.3 | 0.39 | 0.16 | 0.2 | 0.12 | 0.09 | 0 | 0.1 | 0.08 |
| A19 | 0.02 | 0 | 0.3 | 0.43 | 0.4 | 0.49 | 0.26 | 0.2 | 0.29 | 0.17 | 0.1 | 0.03 | 0.25 |
| A20 | 0.12 | 0.1 | 0.4 | 0.43 | 0.4 | 0.49 | 0.3 | 0.2 | 0.39 | 0.25 | 0.2 | 0.11 | 0.35 |
| A21 | 0 | 0 | 0.23 | 0.36 | 0.3 | 0.42 | 0.19 | 0.2 | 0.17 | 0.1 | 0 | 0.08 | 0.13 |
| A22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A23 | 0.08 | 0.06 | 0.41 | 0.54 | 0.5 | 0.6 | 0.37 | 0.3 | 0.35 | 0.28 | 0.16 | 0.14 | 0.31 |
| A24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A25 | 0 | 0 | 0.04 | 0.06 | 0.1 | 0.12 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 |
| A26 | 0 | 0 | 0.04 | 0.06 | 0.1 | 0.12 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 |
| A27 | 0 | 0 | 0.04 | 0.06 | 0.1 | 0.12 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 |

**Table 5.8: Aggregate Preference Matrix for L27 Design**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A14 | A15 | A16 | A17 | A18 | A19 | A20 | A21 | A22 | A23 | A24 | A25 | A26 | A27 |
| A1 | 0.73 | 0.29 | 0.71 | 0.23 | 0.27 | 0.18 | 0.28 | 0.24 | 0.79 | 0.13 | 0.72 | 0.54 | 0.54 | 0.54 |
| A2 | 0.75 | 0.29 | 0.73 | 0.25 | 0.29 | 0.19 | 0.29 | 0.26 | 0.82 | 0.13 | 0.74 | 0.56 | 0.56 | 0.56 |
| A3 | 0.26 | 0.1 | 0.27 | 0 | 0 | 0 | 0.1 | 0 | 0.33 | 0 | 0.26 | 0.12 | 0.12 | 0.11 |
| A4 | 0.13 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0.20 | 0 | 0.12 | 0 | 0 | 0 |
| A5 | 0.17 | 0.05 | 0.21 | 0 | 0 | 0 | 0.04 | 0 | 0.24 | 0 | 0.18 | 0.06 | 0.06 | 0.06 |
| A6 | 0.07 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0.14 | 0 | 0.07 | 0 | 0 | 0 |
| A7 | 0.3 | 0.04 | 0.28 | 0.05 | 0 | 0 | 0.04 | 0 | 0.37 | 0 | 0.29 | 0.11 | 0.11 | 0.11 |
| A8 | 0.33 | 0 | 0.31 | 0.19 | 0.11 | 0 | 0 | 0.06 | 0.40 | 0 | 0.32 | 0.19 | 0.19 | 0.19 |
| A9 | 0.35 | 0.18 | 0.35 | 0 | 0 | 0.07 | 0.18 | 0.02 | 0.41 | 0.02 | 0.34 | 0.19 | 0.2 | 0.19 |
| A10 | 0.39 | 0.09 | 0.37 | 0.1 | 0.02 | 0 | 0.08 | 0 | 0.46 | 0 | 0.39 | 0.2 | 0.21 | 0.2 |
| A11 | 0.53 | 0.18 | 0.51 | 0.15 | 0.07 | 0.07 | 0.17 | 0.04 | 0.59 | 0.02 | 0.52 | 0.34 | 0.34 | 0.34 |
| A12 | 0.53 | 0.08 | 0.51 | 0.24 | 0.17 | 0 | 0.07 | 0.12 | 0.6 | 0 | 0.52 | 0.34 | 0.34 | 0.34 |
| A13 | 0.39 | 0.19 | 0.37 | 0 | 0.01 | 0.08 | 0.18 | 0.03 | 0.46 | 0.03 | 0.39 | 0.2 | 0.21 | 0.2 |
| A14 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0.07 | 0 | 0.05 | 0 | 0 | 0 |
| A15 | 0.48 | 0 | 0.46 | 0.28 | 0.2 | 0.03 | 0 | 0.15 | 0.55 | 0 | 0.48 | 0.29 | 0.3 | 0.29 |
| A16 | 0.10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.13 | 0 | 0.05 | 0 | 0 | 0 |
| A17 | 0.54 | 0.34 | 0.52 | 0 | 0.16 | 0.23 | 0.33 | 0.18 | 0.61 | 0.18 | 0.54 | 0.35 | 0.36 | 0.35 |
| A18 | 0.46 | 0.18 | 0.44 | 0.08 | 0 | 0.07 | 0.17 | 0.02 | 0.53 | 0.02 | 0.45 | 0.27 | 0.27 | 0.27 |
| A19 | 0.56 | 0.11 | 0.54 | 0.25 | 0.17 | 0 | 0.1 | 0.12 | 0.63 | 0 | 0.56 | 0.37 | 0.38 | 0.37 |
| A20 | 0.56 | 0.08 | 0.54 | 0.35 | 0.27 | 0.1 | 0 | 0.22 | 0.63 | 0.04 | 0.56 | 0.37 | 0.37 | 0.37 |
| A21 | 0.49 | 0.16 | 0.47 | 0.13 | 0.05 | 0.05 | 0.15 | 0 | 0.56 | 0 | 0.48 | 0.3 | 0.3 | 0.3 |
| A22 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 |
| A23 | 0.67 | 0.19 | 0.65 | 0.31 | 0.23 | 0.11 | 0.15 | 0.18 | 0.74 | 0 | 0.66 | 0.48 | 0.48 | 0.48 |
| A24 | 0.06 | 0 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 |
| A25 | 0.19 | 0 | 0.17 | 0 | 0 | 0 | 0 | 0 | 0.26 | 0 | 0.18 | 0 | 0 | 0 |
| A26 | 0.19 | 0 | 0.17 | 0 | 0 | 0 | 0 | 0 | 0.26 | 0 | 0.18 | 0 | 0 | 0 |
| A27 | 0.19 | 0 | 0.17 | 0 | 0 | 0 | 0 | 0 | 0.26 | 0 | 0.18 | 0 | 0 | 0 |

Step 5: Leaving and Entering outranking flows are calculated for the obtained aggregate preference values by using the formulae shown below. Results are shown in the table 5.9

Leaving (positive) flow for ath alternative;

φ+(a)= (a ≠ b)

Entering (negative) flow for ath alternative;

φ-(a)= (a ≠ b)

Step 6: Net outranking flow for each alternative is calculated using the leaving and entering outranking flow values by using formula shown below. Ranking was given for net outranking flow values. Results are shown in the table 5.9

φ(a) = φ+(a) – φ-(a)

**Table 5.9: Net Out Ranking Flow Values for L27 Design**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| EXP NO | LEAVINGFLOW | ENTER FLOW | NETFLOW | RANKING |
| 1 | 0.013063 | 0.4138744 | -0.40081 | 26 |
| 2 | 0.008697 | 0.431753 | -0.42306 | 27 |
| 3 | 0.171775 | 0.0902464 | 0.081529 | 11 |
| 4 | 0.2485 | 0.0276361 | 0.220864 | 6 |
| 5 | 0.229312 | 0.0511237 | 0.178188 | 7 |
| 6 | 0.294808 | 0.0150796 | 0.279728 | 5 |
| 7 | 0.143187 | 0.0986126 | 0.044574 | 12 |
| 8 | 0.164215 | 0.1532099 | 0.011005 | 13 |
| 9 | 0.144415 | 0.1475647 | -0.00315 | 14 |
| 10 | 0.099403 | 0.1521794 | -0.05278 | 16 |
| 11 | 0.051787 | 0.2435668 | -0.19178 | 20 |
| 12 | 0.058025 | 0.2529549 | -0.19493 | 21 |
| 13 | 0.113714 | 0.1668941 | -0.05318 | 15 |
| 14 | 0.362602 | 0.0076493 | 0.354953 | 2 |
| 15 | 0.09778 | 0.2453466 | -0.14757 | 18 |
| 16 | 0.352081 | 0.0179807 | 0.3341 | 4 |
| 17 | 0.099569 | 0.3083938 | -0.20882 | 22 |
| 18 | 0.07746 | 0.2018835 | -0.12442 | 17 |
| 19 | 0.044991 | 0.2747974 | -0.22981 | 24 |
| 20 | 0.089455 | 0.318291 | -0.22884 | 23 |
| 21 | 0.062811 | 0.2177724 | -0.15496 | 19 |
| 22 | 0.427002 | 0.0018064 | 0.425196 | 1 |
| 23 | 0.022446 | 0.3624435 | -0.34 | 25 |
| 24 | 0.355157 | 0.0070843 | 0.348073 | 3 |
| 25 | 0.204064 | 0.0454696 | 0.158594 | 9 |
| 26 | 0.205178 | 0.0449787 | 0.160199 | 8 |
| 27 | 0.203073 | 0.045977 | 0.157096 | 10 |

Step 7: Determine the ranking of all the considered alternatives depending on the values of φ(a). The higher the value of φ(a), the better is the alternative. By observing the φ(a) values L22 level is best value. The corresponding process parameters and response values are shown below

**Process Parameters:**

Reinforcement – Level 2 – 4%

Speed – Level 3 – 3 m/s

Load – Level 2 – 20N

Distance – Level 1 – 500 m

**Responses:**

Wear – 20.65 microns

Coefficient of Friction – 0.1525

**CONCLUSIONS**

Based on the results obtained and discussion made in the earlier chapters the following conclusions are drawn:

* AA6061/Bagasse Composite is fabricated using Stir Casting Method. Micro Hardness Values are evaluated using Vickers Hardness Tester and as reinforcement percent increased micro hardness increased till 4% weight addition of EV particles.
* By using RSM Design of Experiments experimentation conducted on Pin on Disc apparatus
* Analysis of Variance conducted for both Wear and Coefficient of Friction and results are obtained as follows
* Speed, load and distance are most significant parameters affect the wear
* Reinforcement, speed and load are most significant parameters that affect the Coefficient of Friction.
* Wear of AA6061/Bagasse Composite decreases when the speed is increased at any given reinforcement and load. Wear decreases when the reinforcement is increased upto 40% and then increases at any given load and speed. However, Wear increases when the load is increased at any given reinforcement and speed.
* Load and speed increases, Coefficient of Friction decreases. And also Coefficient of Friction decreases with increasing reinforcement upto 40% and then increases but lower than 20%.

In the present work PROMETHEE II methodology was successfully implemented for converting multi objective criterion into a single objective function. By this method we get best rank for L22 level i.e., at 40% reinforcement, 3 m/s speed, 20N load and 500m distance, corresponding wear value is 20.65 microns and coefficient of friction value is 0.1525.