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Study of Mechanical and Tribo Logical Properties of Aa6351 Reinforced With B_4C & SIC

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Abstract: This work mainly focuses on increasing the mechanical strength and improving the wear resistance of an aluminum alloy hybrid matrix. The composites are prepared by the stir casting procedure. For this work, aluminum alloy 6351 is considered as a base material and titanium nitride and zirconium dioxide are utilized as reinforcement particles. Mechanical tests, such as the ultimate tensile strength, wear, impact and micro-hardness test, are conducted effectively in the fabricated AA6351/B_4C+SIC composites. Using the Technique for Order Preference by Similarity to Best Solution (TOPSIS), is executed to optimize the process parameters of the mechanical and wear tests. TOPSYS analysis defines the contribution and influence of each parameter. In the tensile, wear, hardness, impact tests parameters are chosen as % of reinforcement (2%, 4% and 7%), stirring speed (600, 650 and 700 rpm) and stirring time (20,25 and 30 min).The percentage of reinforcement highly influenced the wear and micro hardness test, while the stirring time parameter extremely influenced the ultimate tensile strength. From the corrosion test, the hang time influences the corrosion rate.

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I. INTRODUCTION

The stir casting process is a reliable process and it is used frequently for ferrous and non ferrous components. The stir casting process provides the homogeny, durability and strength of the mixed composite after it forms the solid shape. The powder is mixed well in the base materials to make up a rigid solid structure after solidification. The stirring parameters, such as stirring speed, stirring time and stirring temperature, are highly involve in altering the strength of the hybrid composites. This parameter acknowledges the uniform mixture obtained in the prepared composites. The stir casting parameters, such as stirring speed, stirring time and stirring temperature, were influenced to amend the strength of the casted samples. Stirring speed highly influenced the obtainment of the homogeneous mixture of the composites, and the stirring time increased the strength of the composites due to the longer duration resulting in the reinforced particles being well settled into the base materials .The stir casting temperature stimulated the high melting point of the composites, taking the minimum time to blend the particles in a good fashion. The ultimate tensile strength is one of the essential tests within the industry to evaluate the material strength and also find the failure of materials. There is several strength analyzing tests involved in industrial applications to maximize the strength of material which is to be used to fabricate components. In general, the tensile strength, compressive strength and shear strength tests are carried out by the way of using a universal testing machine. Numerous testing procedures have to be followed to conduct the strength analyzing test effectively. From the stir casting process, the tensile strength of the hybrid composites are increased by the influence of process parameters, particularly stir casting time .An increase in the stir casting time increases the tensile strength, as does increasing the percentage of reinforcement in the stir casting process. Hardness is one of the mechanical properties that offer a good material characteristic for the usage of industrial products. Different types of hardness tests are available to find the hardness of the material such as Rockwell hardness, Brinell hardness test and Vickers hardness. Normally, the Brinell hardness test is used for heavy applications, with a 5–10 mm hard steel ball used as the indenter. Accurate hardness measurement is also carried out by use of a micro-hardness test (Vickers hardness test), with a pyramid square diamond indenter used to measure the hardness of the material. In all the moving parts, the wear has to occur promptly to reduce the surface structure of the parts and also to encourage the failure of the materials. Normally the wear test is conducted through wet and dry conditions based on the test procedure and the materials .Dry sliding wear of Al8079–TiN/ZrO2 composites have high wear resistance compared to other combination composites. Wear rate can be dependent upon the various parameters, namely load, rpm, sliding distance and the adding of reinforcement. In industry, most machines suffer due to component wear. Use of loads and temperatures highly effect the wear rate of AMCs materials. In the Al8079–TiN/ZrO2 composites, lesser wear rates occurred with the applied load increases. When increasing the applied load, the wear and cracking resistance also increased. Similarly the wear rate was increased due to increase in the Al8079 temperature. The Al8079–TiN/ZrO2 composites had higher tension and wear properties due to the presence of both reinforced particles. These composites are widely used in aerospace and automotive industries for fabrication of components as well as structures. However, the potential for AlMMCs in this field is hardly explored and offers a big chance for significant development. Engineered materials that are lighter and perform better than current materials are being developed through research and development. The most potential replacement for steel and cast iron in the near future is thought to be for internal combustion engine applications as well as unsprung weight components, including the brake system.

II. LITERATURE REVIEW

Ravichandran et al [2]. Synthesized and studied the forming behavior of aluminium-based hybrid powder metallurgic composites. Aluminium-based metal matrix composites were synthesized from Al-TiO2-Gr powder mixtures using the powder metallurgy technique and their forming characteristics were studied during cold upsetting. The addition of both TiO2 and Gr reduces the

densification and deformation characteristics of the sintered preforms during cold upsetting.
Wiodarczyk-Fligier et al [3]. Fabricate the aluminium metal matrix composite material reinforced with Al2O3 particles. This manufacturing method shows the manufacturing of aluminium metal matrix composites with any reinforcement can be easily fabricated by powder metallurgy technique with required structure joining positive properties composite materials components.**Asif et al [4].** Development of aluminium based hybrid metal matrix composites for heavy duty applications. This paper shows the investigations on dry sliding wear behavior of aluminium based composites, reinforced with silicon carbide particles and solid lubricants such as graphite/antimony tri sulphide (Sb2S3). Both composites were mixed and fabricated by powder metallurgy technique. Final results shows that the proposed composites have lower friction coefficient, less temperature rise and low noise level; however they have little higher wear rate. **Mahboob et al [5]**. Investigates the influence of nanosized Al2O3 weight percentage on microstructure and mechanical properties of Al–matrix nano-composite by powder metallurgy technique. In their research, the morphological, micro structural and mechanical properties changes during nano-sized alumina increment to Al powder were studied. The process was carried out for different weight percentage Al–(0–20) wt-%Al2O3. Their results showed that the strength, ductility and hardness were increased by increasing the reinforcement nano particles weight percentage. **Shanta et al [6].** Investigates the processing, microstructure and properties of hybrid metallic and ceramic reinforced aluminium composites via P/M technique. In this work the combined Ti (micro) and Al2O3 (micro or nano) particles reinforced commercially with pure Al matrix composites have been developed via powder metallurgy route.A detailed microstructural characterization and the evaluation of mechanical properties including wear and corrosion behaviour have been carried out.The composites reinforced with the ceramic particles (micro or nano) alone exhibited higher hardness values. Micro structural characterization revealed that there is a uniform distribution in the composites. The hybrid composites exhibit a better wear resistance than the composite reinforced with individuals particles owing to their higher hardness as compared to that of the other composites. **Gokce et al [7].** Investigations on mechanical and physical properties of sintered aluminum powders through powder metallurgy route. In this study green and theoretical density increased with the increment of compaction pressure. The mechanical performance is very good for both pressures during the transverse rupture (three point bending test) owing to enhanced diffusion in the mentioned sintering process. **Sujit Das et al [8].** Experimental Analysis of Density of Sintered SiCp Reinforced AMMCS Using the Response Surface Method. The paper aim is to fabricate AlSiCp composites by powder metallurgy (P/M) processing route. An experimental investigation have been undertaken in order to understand the variation of density with respect to the variation of process parameters viz., variation of silicon carbide proportion, compacting pressure and sintering time. The relation among the various process parameters with density has been studied. A mathematical model has been developed using second order response surface model (RSM) with central composite design (CCD) considering the above mentioned process parameters. The model shows increase in density due to change in wt% of SiCp (x1) and sintering time for compaction load from 40-93.63586 Ton at a fixed sintering time of 40 minutes and for a fixed value of compacting pressure (x2). The response variable, density (R1) shows linear increase when it is plotted against sintering time (x3) and compacting pressure (x2) for a fixed value of wt% of SiCp (x1) and the prediction of density variation from the mathematical model developed in this study matches closely with the observed data (R2 = 89.8 %). The microstructure shows the uniform distribution of particles. **Dinesh Kumar Koli et al [9].** Properties and Characterization of Al-Al2O3 Composites Processed Powder Metallurgy Routes. This paper shows the characterization of mechanical properties with production routes of powder metallurgy for aluminium matrixAl2O3composites.A uniform distribution of the Al2O3reinforcement phase in the Al matrix can be obtained by high-energy ball milling of Al–Al2O3blends. Nearly 92% increase in the hardness and 57% increase in the tensile strength were obtained in the nano-composites as compared to the commercially pure aluminium. **R.Kartigeyan**

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et.al.[2012], has effectively developed Al 7075 alloy and Short Basalt Fibre composite through liquid metallurgy technique. The increase in short basalt fibre maximizes the ultimate tensile strength, yield strength and Hardness. The composite containing 6% wt of short basalt fibre signifies higher hardness value of 97.1 Mpa when compare to base matrix hardness 92Mpa. TheAl-7075/short basalt fibre reinforced 6 vol % maximizes the ultimate tensile strength by 65.51%. The distribution of reinforcements in metal matrix is genuinely uniform. From the above research paper I concluded that, under tension loading without affecting the tensile ductility, values of tensile strength increases. Experimental values of short basalt fiber gives the best result for the Al-MMC's.

Pradeep P et.al.[2017], has fabricated Al 7075 and Titanium DI Boride (Tib2) via the sir casting technique. The quantity fraction of TiB2 prompted are 4%, 6% and 8% . They evaluated the microstructure, wear, hardness properties. At 8% wt of TiB2 notices the maximum hardness of 126 VHN and strengthens the base matrix. Explicit wear rate diminishes as the sliding rate increments up to rotation speed (1.6 m/s) and weight, in light of work solidifying of the material surface. Minimal effect of the wear rate got from the 8 Wt. % of TiB2 fortified composite. The speed and the sliding distance are in most extreme with the insignificant weight. The micro image indicates the Aluminium debris are unvaryingly dispersed within the highest volume fraction of particulate matrix of 8Wt. %.

III. Theory of Metal Matrix Composites

A) B_4C: Carbides are prepared by adding carbon with similar or lower electronegativity elements, usually either a metal or a metal oxide, at temperatures of 1,000–2,800°C. Boron carbide (B_4C) is a covalently bonded solid and has a high melting point of about 2427°C. It is extremely hard, high neutron absorption capacity is highly inert, and is prepared by the reduction of boron oxide (B_2O_3) with carbon in an electric furnace. In B_4C, the carbon atoms occur in linear chains of three and the boron atoms occur in icosahedral groups of 12. The other form of boron carbide (BC_3), whose structure is like graphite, is produced from the reaction of boron tri-chloride (BCl_3) and benzene (C_6H_6) at about 800°C.

Boron Carbide

B) SIC: Silicon Carbide (SiC) is highly wear resistant and also has good mechanical properties, including high temperature strength and thermal shock resistance. Silicon Carbide (SiC), as a technical ceramic, is produced in two main ways. Reaction bonded SiC is made by infiltrating compacts made of mixtures of Silicon Carbide (SiC) and Carbon with liquid Silicon. The Silicon reacts with the Carbon forming Silicon Carbide (SiC). The reaction product bonds the SiC particles. Sintered SiC is produced from pure SiC powder with non-oxide sintering aids. Conventional ceramic forming processes are used and the material is sintered in an inert atmosphere at temperatures up to 2000°C or higher. Silicon Carbide (SiC) maintains its high mechanical strength in temperatures as high as 1,400. It has higher chemical corrosion resistance than other ceramics.

Silicon carbide

Table 3 Reinforcement materials properties

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Properties	B_4C	SiC
Density(gm/cm3)	2.52	3.21
Tensile Strength(MPa)	210 MPa	390 MPa
Fracture Toughness((MPa√m)	4.7	2.5
Hardness (Mpa)	2560	2800

3.4 Process parameters and their levels of stir casting process.

Below table presents the process parameters of the stir casting process, namely: percentage of reinforcement, stirring time and stirring speed. All three factors are chosen based on the conducting of mechanical tests such as the tensile test and wear test with different levels of process parameters.

Table 4 Levels of reinforcement

s.no	Parameters	Level1	Level2	Level3
1	% of reinforcement	2	4	7
2	Stirring time (Min)	20	25	30
3	Stirring speed (RPM)	500	550	600

IV. FABRICATION OF COMPOSITES

The fabrication of composites is done at room temperature by the hand lay-up technique. This method requires few materials and the apparatus for the fabrication of the composite.

Stir casting method

Stir casting equipment in vision castings and alloys

Stir casting technique is simple and the most commercial method of production of metal matrix composites. In preparing metal matrix composites by the stir casting method, there are several factors that need to be considered including

- Difficulty in uniform distribution of the reinforcement material.
- Wettability between the two main substances.
- Porosity in the cast metal matrix composites
- Chemical reactions between the reinforcement material and the matrix alloy

In conventional stir casting method, reinforced particulate is mixed into the aluminium melt by mechanical stirring. Mechanical stirring is the most important element of this process. After the mechanical mixing, the molten metal is directly transferred to a shaped mould prior to complete solidification. The essential thing is to create the good wetting between particulate reinforcement and aluminium melt. The distribution of the reinforcement in the final solid depends on the wetting condition of the reinforcement with the melt, relative density, rate of solidification etc. Distribution of reinforcement depends on the geometry of the stirrer, melt temperature and the position of the stirrer in the melt. Figure 1 shows a schematic diagram of stir casting process. An improvement in conventional stir casting is a double stir casting method or two-step casting process. In the first stage, the matrix material is heated to above its liquidus temperature and then cooled down to a temperature to keep in a semi-solid state. At this stage, the preheated reinforcement materials are added and mixed with a mechanical stirrer. Again the slurry is heated to a liquidus state and mixed thoroughly. Nowadays, this twostep mixing process has used in the fabrication of aluminium because of more uniform microstructure as compared of conventional stirring. A recent development in stir casting is three step stir casting for the fabrication of nanoparticle reinforced composite. In this method, first, the Al particles and reinforcement are mixed using ball milling process to break down the initial clustering of nanoparticles. Then the composite powder is mixed with melt by mechanical stirring.n The present study deals with the stir cast aluminium matrix composite regarding their enhanced properties such as mechanical, tribological.

During Stir casting process

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Pouring molten metal in mould cavity

Poured composite in the mould cavity

Fabricated composite samples by stir casting method

Total fabricated composite samples

Table: 4.3 Design of experiments for sample preparation

s.no	AA-6351 (wt%)	B_4C (wt%)	SIC (wt%)	Stirring time (Min)	Stirring speed (RPM)
1	96	2	2	20	600
2	96	2	2	25	650
3	96	2	2	30	700
4	92	4	4	20	600
5	92	4	4	25	650
6	92	4	4	30	700
7	86	7	7	20	600
8	86	7	7	25	650
9	86	7	7	30	700

4.1 Mechanical Properties Evaluation Methods:

- Tensile Test:
- Charpy Impact Test:
- Wear Test
- Hardness Test

V. RESULTS AND DISCUSSIONS

With varying B_4C, SiC weight percentages, stirring time, stirring speed the mechanical characteristics of AA-6351 with these varying parameters are investigated. Here, the findings of several characterisation experiments are provided. In relation to these reinforcements, relative impacts of B_4C, SiC concentration on various mechanical properties of composites are described.

Effect of reinforcement on Tensile Strength results

Table 6 presents the experimental summary of ultimate tensile strength; three factors contributed their influence and produced a different range of ultimate tensile strengths. The maximum ultimate tensile strength was obtained as 198.43 MPa from the fifth experimental runs. It is achieved by the influence of 7% of reinforcement, 25 min of stirring time and 550 rpm of stirring speed. The minimum ultimate tensile strength was observed as 150.0 MPa.

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Effect of reinforcement on impact strength

Table 6 presents the experimental summary of impact strength; three factors contributed their influence and produced a different range of impact strengths. The maximum impact strength was obtained as 32 Joules from the fifth experimental runs. It is achieved by the influence of 7% of reinforcement, 25 min of stirring time and 550 rpm of stirring speed. The minimum ultimate tensile strength was observed as 19 joules.

Effect of reinforcements on wear rate

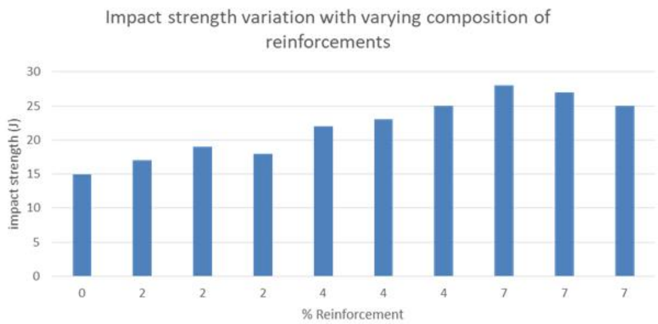
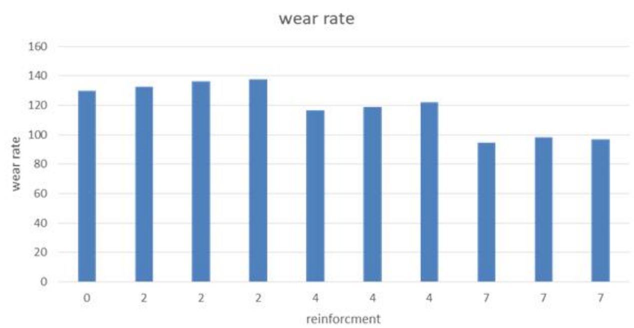
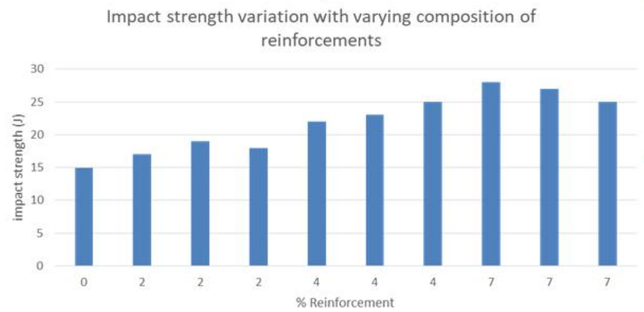


Table 6 presents the experimental summary of wear rate; three factors contributed their influence and produced a different range of wear rate. The minimum wear rate was obtained as 138.28µm from the fifth experimental runs. It is achieved by the influence of 4% of reinforcement, 25 min of stirring time and 550 rpm of stirring speed. The maximum wear rate obtained



Effect of reinforcement on impact strength

Table 6 presents the experimental summary of impact strength; three factors contributed their influence and produced a different range of impact strengths. The maximum impact strength was obtained as 28 Joules from the fifth experimental runs. It is achieved by the influence of 7% of reinforcement, 25 min of stirring time and 550 rpm of stirring speed. The minimum ultimate tensile strength was observed as 15 joules.



Sample	AL6351%	B4C %	SiC %	Melting temp	Stirring time	Linear wear(μm)	Energy (J)	RHN kgf
S1	96	2	2	680	10	132.42	18	65
S2	96	2	2	700	15	136.27	19	67
S3	96	2	2	720	20	137.78	17	64
S4	92	4	4	680	10	116.46	20	71
S5	92	4	4	700	15	119.23	23	73
S6	92	4	4	720	20	119.11	23	70
S7	86	7	7	680	10	93.67	27	82
S8	86	7	7	700	15	96.66	28	84
S9	86	7	7	720	20	97.00	24	88

Top sis-based ranking of composite samples

The Algorithm which is explained in Section 3.5 of Chapter 3 was used to obtain the Ranking of the Composite Samples by considering the Tabulated results shown in Table 5.1 as the Decision Matrix (DM). Later on, the Normalized Decision Matrix (B) and the Weighted Normalized Decision Matrix (T) was obtained. Tensile Strength, Flexural Strength, Impact Strength and Compressive Strength were assigned weight of 0.33, 0.34, 0.33 respectively. The Best (Positive Ideal) and the Worst (Negative Ideal) Solution i.e., A+ and A-were obtained and the Separation measures which is represented by the Closeness Coefficient (Pi*) was calculated for all the 10 samples. The ranking was given based on the descending order of Closeness values of (Pi*) to the Solution.

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Decision matrix

Samples	Tensile Strength (N/mm^2)	Wear rate (µm)	Impact Strength (J)	Hardness value (BHN)
S1	168.21	132.34	18	65
S2	178.54	136.67	19	67
S3	175.32	137.86	17	64
S4	182.21	116.12	20	71
S5	196.23	119.28	23	73
S6	198.43	119.2	23	70
S7	192.34	93.39	29	88
S8	184.37	96.69	28	82
S9	179.34	97.9	24	84

Normalized Decision Matrix

Samples	Tensile Strength (N/mm^2)	Wear rate (µm)	Impact Strength (J)	Hardness value (RHN)
S1	0.304515	0.33476	0.266787	0.316244
S2	0.323215	0.34312	0.308911	0.325688
S3	0.317386	0.358609	0.254869	0.305966
S4	0.329859	0.329288	0.393159	0.345132
S5	0.359223	0.314763	0.349325	0.354854
S6	0.355204	0.317026	0.379118	0.344576
S7	0.348198	0.302484	0.404911	0.369993
S8	0.33377	0.338185	0.294869	0.325688
S9	0.324664	0.348678	0.272745	0.306244

Weighted Normal Decision Matrix

Samples	Tensile Strength (N/mm^2)	Wear rate (µm)	Impact Strength (J/mm^2)	Hardness value (BHN)
S2	0.080804	0.08578	0.077228	0.081422
S3	0.079347	0.084652	0.073717	0.078992
S4	0.082465	0.082322	0.09829	0.086283
S5	0.088706	0.076191	0.112331	0.088714
S6	0.089801	0.079256	0.094779	0.091144
S7	0.087049	0.080621	0.077228	0.087498
S8	0.083442	0.084546	0.073717	0.081422
S9	0.081166	0.08717	0.063186	0.076561
Weightage	**0.25**	**0.25**	**0.25**	**0.25**

Best (Positive Ideal) Solution and Worst (Negative ideal) Solution

A+ (Ideal Solution)	0.08981	0.08869	0.09114	0.11233
A- (Ideal Solution)	0.07613	0.07619	0.07656	0.06319

Separation measures for each characteristic

Samples	Si+	Si-
S1	0.049822	0.013
S2	0.037633	0.0183
S3	0.042005	0.0141
S4	0.017755	0.0375
S5	0.036733	0.0344
S6	0.019952	0.0372
S7	0.012308	0.0523
S8	0.040536	0.0161
S9	0.052008	0.0121

Relative Closeness (Pi)

Samples	Tensile Strength (N/mm^2)	Wear rate (µm)	Impact Strength (J)	Hardness value (RHN)	Relative Closeness (Pi*)	Rank of Samples
S1	168.21	142.34	18	65	0.53182	8
S2	178.54	137.67	19	67	0.617088	5
S3	175.32	135.86	17	65	0.469428	7
S4	182.21	132.12	20	71	0.409958	2
S5	192.43	122.28	23	73	0.48423	4
S6	196.21	127.2	25	70	0.906657	3
S7	198.34	93.39	28	82	0.315382	1
S8	184.37	96.69	27	84	0.48809	6
S9	179.34	97.9	24	88	0.348784	9

VI. CONCLUSIONS AND FUTURE SCOPE

hybrid composites were prepared through the stir casting methodology, and the composites In this work, aluminum alloy with the addition of titanium nitride and zirconium oxide were tested by the tensile test, wear test, corrosion test and microhardness test. All the test parameters were optimized and the result of this work was summarized as follows: From the ultimate tensile strength the maximum ultimate tensile strength was ob-served as 198.43MPa from the fifth experimental runs. It was achieved by the influence of 7% of reinforcement, 25 min of stirring time and 550 rpm of stirring speed. Reinforcement led to increase the ultimate tensile strength due to the higher strength of the reinforced particles used in the composite preparation. Uniform mixing also provided an increase in the ultimate tensile strength of the specimen. The optimal parameters of the tensile test were found as 4% of reinforcement, 30 min of stirring time and 600 rpm of stirring speed. In the wear test, the minimum wear value was found to be 122.28 µm, as observed in the fifth experimental run. This minimum wear value was observed by the influence of 7% of reinforcement, 25 min of stirring time and 550 rpm of stirring speed. By contrast, the maximum wear was recorded at 142.34 µm. High stirring speed and stirring time was influenced to form a homogeneous mixture of the composites, causing the minimum wear of the specimen. The higher stirring speed offered a uniform and extreme blending of the reinforced particles with the base materials. In the wear test, the optimum parameters were concluded as 9% of reinforcement, 25 min of stirring time and 550 rpm of stirring speed. From the analysis, the maximum microhardness value was obtained as 75 HV from the sixth experimental runs. It was accomplished by the influence of 7% of reinforcement. The minimum microhardness value was observed as 63 HV. The optimal parameters of the microhardness test were registered as 7% of reinforcement. A moderate range obtained 9% of reinforcement.

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