Study of Wear Behavior and Microstructure of Al7075 with Al7075 Reinforced with Nano and Micro Particles of Al_2O_3 at Varying Percentage via Stir Casting Route

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***Abstract*: Two and more materials with significantly different physical and chemical properties are engineered to form a composite material. The properties of these materials remain separate at microscopic or macroscopic scale even when the structure gets finished. The materials we get after finalizing the composite have high density and high strength. They are used when we need light weight and high strength materials such as in the aspects of industrial and commercial fields in aircrafts, ships , common vehicles and different other engineering applications. Such type of materials are formed by adopting stir casting technique on Al7075 by adding reinforcements of Al_2O_3 in the form of nano and micro particles at varying wt. %. In present study Al7075-Al_2O_3 metal matix composite developed in three different compositions of micro and nano particles. The Fabrication of composite are carried out by liquid metallurgy route via stir casting technique. Casted composites machined to make the samples microstructure analysis and sample for pin-on-disc machine according to ASTM standard. This paper also includes information about tribological tests. These tests were carried out following Taguchi Method for different combinations and sizes of reinforcements, the various parameters used are Load, Sliding distance, Sliding velocity. Mechanical testing of composites are also done on various machine and equipments to find the effects of reinforcement weight percentage and size of reinforcements. It is found that density of the composites improved than the matrix alloy as the percentage filler contents increased the improved of density of composite. SEM images of micro and nano composites reveal that agglomeration of particles increases with increasing wt. %age. . In future scope some MMCs can be manufactured by using diffrent manufacturing techniques like powder metallurgy etc. and results can be compared with stir casting technique and with the base alloy.**

***Keywords*: Specific Wear Rate, Aluminum, Alumina, pin-on-disc, Orthogonal array, Scanning Electron Microscopy, Analysis of Variance (ANOVA).**

Introduction: Now a days,thedemandforlightweight,lowcostandhighquality performance materials has increased. One of the newly developed materials is Aluminium metal-matrix composites (AI-MMCs) which satisfy all of the above demands. Basically, there are three types of MMCs: particle reinforced, whisker reinforced and continuous fiber MMCs.

Metal-matrixcomposite(MMCs)arewidelyusedinindustrybecauseoftheir excellent mechanical properties. There are various MMCs used especially for automotive and engineering applications. This is because of their high strength, high elastic modulus, low co-efficient of thermal expansion, light weight, low thermal shock, good wear resistance and many more advantages. This combination of these properties is not available in a conventional material. These mechanical properties also depend on the composite particles for the reinforcement of the Aluminium.

Aluminium Alloys

Aluminium became a common structural material because of its attractive properties like its light weight, ease of fabrication and machinability, high resistance to atmospheric corrosion, good thermal conductivity, high metallic luster and nonmagnetic and non-sparking properties. Selecting the right alloy for a given application entailsconsiderationsofitstensilestrength,density,ductility,formability, workability, weld ability andcorrosion resistance. Aluminium alloys are alloys in which Aluminium (Al) is the predominant metal. The typical alloying elements are Copper, Magnesium, Manganese, Silicon andZinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of Aluminiumisusedforwroughtproducts,forexamplerolledplate,foilsand extrusions. Cast Aluminium alloys yield cost effective products due to its low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast Aluminium alloy system is Al-Si, where the high levels of Silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Wrought Aluminium alloys are used in the shaping processes: rolling, forging, extrusion, pressing, stamping. Cast Aluminium alloys are come after sand casting, permanent mould casting, die casting, investment casting, centrifugalcasting, squeeze casting and continuous casting. Aluminium alloys are classified as shown in Figure 1.

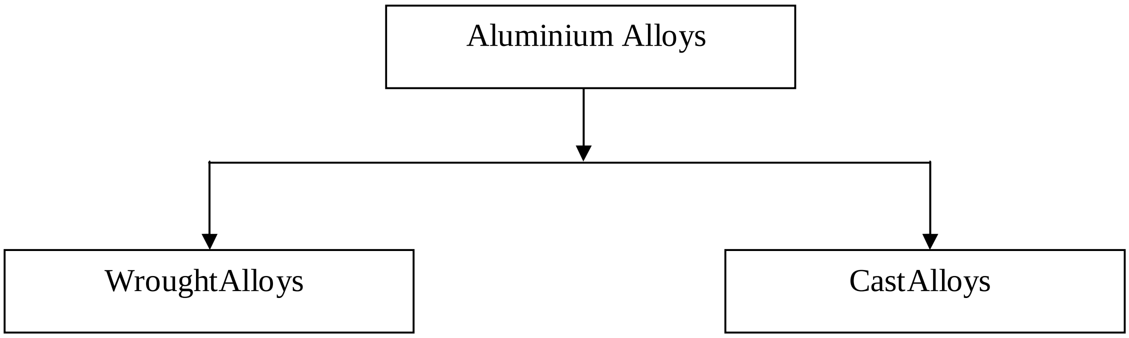

Figure 1 Classification of Aluminium Alloy

Cast Aluminium alloys

Aluminium and its alloys are used in a variety of cast and wrought form and conditions of heat treatment. Forgings, sections, extrusions, sheets, plates, strips, foils and wires are some of the examples of wrought form while castings are available as sand, pressure and gravity die-castings e.g. Al-Si and Al-Mg alloys. The designation of Cast Aluminium alloy is shown in Table 1

Table 1 Designation of Cast Aluminium alloys

Alloy Designation	Details
1XX.X	99% pure Aluminium
2XX.X	Cu containing alloy
3XX.X	Sic/Mg containing alloy
4XX.X	Si containing alloy
5XX.X	Mg containing alloy
6XX.X	Zn containing alloy

Wrought Aluminium alloys

To meet various requirements, Aluminium is alloyed with Copper, Manganese, Magnesium, Zinc andSilicon as major alloying elements. The designation of wrought Aluminium alloy is shown in Table 2.

Table 2 Designation of Wrought Aluminium alloys

Alloy designation	Details
1XXX	99% pure Aluminium
2XXX	Cu containing alloy
3XXX	Mn containing alloy
4XXX	Si containing alloy
5XXX	Mg containing alloy
6XXX	Mg and Si containing alloy
7XXX	Zn containing alloy
8XXX	Other alloys

Designation of Aluminium alloys

The Aluminium Association of America has classified the wrought Aluminium alloys according to a four-digit system. The classification is adopted by the International Alloy Development System (IADS). Table 3 gives the basis of designation of wrought and cast Aluminium alloys in the four-digit system. The first digit identifies the alloy type the second digit shows the specific alloy modification. The last two digits indicate the specific Aluminium.

Table 3 Temper designation system

Letter	Condition of alloy
F	As-fabricated
O	Annealed
T4	Solution treated
T6	Solution treated and aged

Table 4 Alloys conforming to British Standards 1490 LM6 Cast Aluminium.

Chemical composition	Weight percentage
Silicon	0.62
Iron	0.23
Copper	0.22
Manganese	0.03
Magnesium	0.84
Chromium	0.22
Zinc	0.10
Titanium	0.10
Aluminium	97.64

Physical and thermal properties of Aluminium alloy 7075

Table 5Physical properties of Aluminium alloy 7075

Physical properties	Unit
Melting Point	Approx. 635°C
Modulus of Elasticity	70-80 GPa
Poisson's Ratio	0.33
Density	2.81 gm/cm^3

Thermal properties

Co-efficient of Thermal Expansion (250°C) is 25.2µm/m°C
Thermal Conductivity: 130W/Mk

Stir casting

Stir casting set-up mainly consists a furnace and a stirring assembly. In general,thesolidificationsynthesisofmetalmatrixcomposites involvesameltof the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. The next step is the solidification of the melt containing suspended dispersions under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix. In preparing metal matrix composites by the stir casting method, there are several factors that need considerable attention, including the difficulty in achieving a 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 order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcementmaterialinthematrixalloymustbeuniform and thewettabilityorbonding between these substances should be optimized. The porosity levels need to be minimized.

Characterization of Stir Casting

1. Contents of dispersed phase are limited (usually not more than 30% by volume).

2. Distribution of dispersed phase throughout the matrix is not perfectly homogeneous:

- There are local clouds (clusters) of the dispersed particles (fibers).
- Theremaybegravity segregation of thedispersedphasedue toa difference in the densities of the dispersed and matrix phase.

3. The technology is relatively simple and low cost.

Alumina as reinforcement

Aluminium oxide, commonly referred to as alumina, possesses strong ionic inter atomic bonding giving rise to its desirable material characteristics. It can exist in several crystalline phases which all revert to the most stable hexagonal alpha phase at elevated temperature.This is the phase of particular interestfor structural applications and the material available from accurate alpha phase alumina is the strongest and stiffest of the oxide ceramics. Its high hardness, excellent dielectric properties, refractoriness and good thermal properties make it the material of choice for a wide range of applications. High purity alumina is usable in both oxidizing andreducing atmospheres to 1925°C. Weight loss in vacuum ranges from $10^{-7}$to 10^{-6}gm/cm^{2}/sec over a temperature range of 1700° to 2000°C. It resists attack by all gases except wet fluorine and is resistant to all common reagents except hydrofluoric acid and phosphoric acid. The composition of the ceramic body can be changed to enhance particular desirable material characteristics. An example would be additionsof chromeoxideor Manganese oxidetoimprovehardnessandchangecolor. Other additions can be made to improve the ease and consistency of metal films fired to the ceramic for subsequent brazed and soldered assembly. Alumina particles are shown in Figure 3

Figure 3Aluminia (Al_2O_3)

Characteristics of Aluminium oxide (Alumina)

The following are the characteristics of Aluminium oxide:

- Hard and wear-resistant.
- Resists strong acid and alkali attack at elevated temperatures.
- Good thermal conductivity.
- Excellent size and shape capability.
- High strength and stiffness.

Objective: Study of Wear Behavior and Microstructure of Al7075 with Al7075 Reinforced with Nano and Micro Particles of Al_2O_3 at Varying Percentage Via Stir Casting Route.

Methodology:

Wear test measurement

The experiments are carried out on pin-on-disc apparatus, where we can find the wear volume and coefficient of friction. The diameter of the bar is ϕ12 mm and length is 30 mm.

Experimental procedure of wear test

Dry sliding wear tests are conducted on a pin-on-disc friction and wear monitoring test rig (DUCOM) as per ASTM G 99 as shown in Figure 4 and 5.

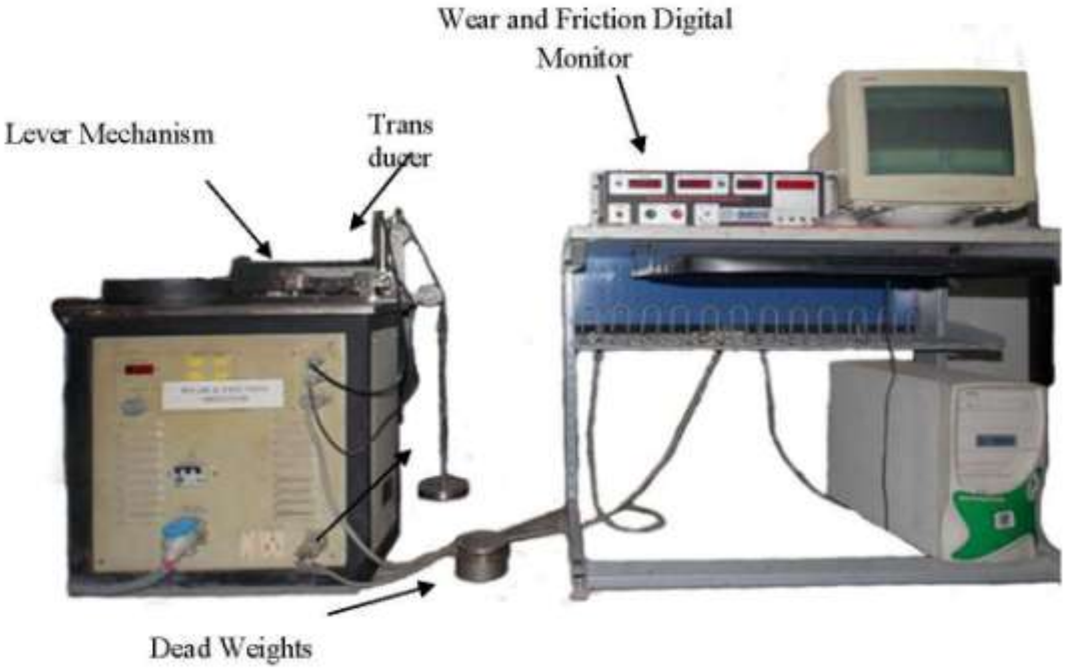

Figure 4Wear Testing Machine

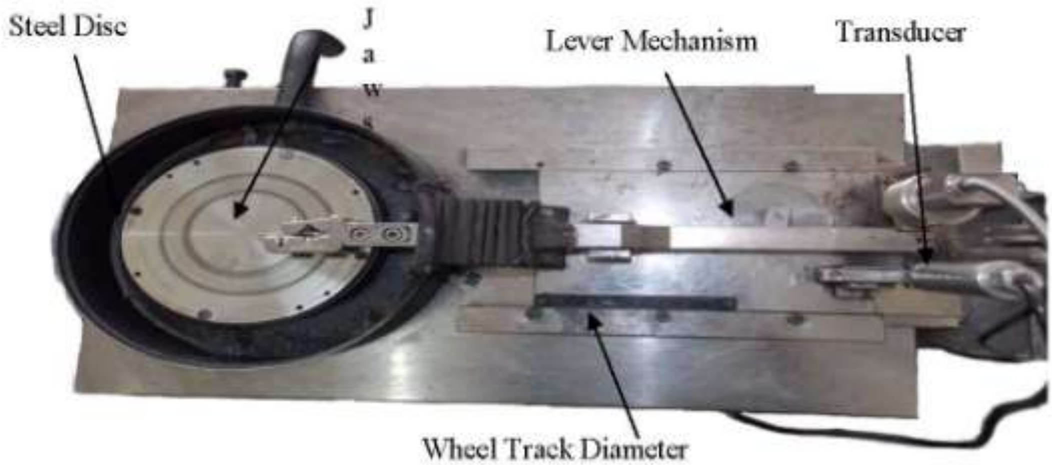

Figure 5Top view of wear testing machine

The pin is held against the counter face of a rotating disc of hardened ground steel with wear track diameter Φ80mm. The cylindrical pin of diameter Φ12mm and length 30mm isloadedagainstthediscthrough adeadweightloadingsystem. The specimen isheld stationary and the disc is rotated while a normal force is applied through a lever mechanism. The schematic diagram of the pin-on-disc apparatus is shown in the Figure 4 and 5. During the test, frictional force is measured by the transducer mounted on the loading arm. The frictional force readings are taken as the average of 100 readings of every 40 seconds for the required time period. For this purpose a microprocessor controlled data acquisition system is used. The wear test for all specimens are conducted under the normal load (10N,20N,30N),slidingdistance(1000m,2000m,3000m) and sliding velocity(1.57m/sec, 2.62m/sec and 3.66m/sec). The samples are weighed (up to an accuracyof0.0001gm usingmicrobalance)priortoandaftereachtestandthe difference between these two data is used as weight loss. The wear of the composite isstudiedasafunction of theslidingdistance,appliedload and thesliding velocity. The surface of the pin samples rubbed using emery paper (400 grit size) prior to test in ordered to ensure effective contact of fresh and flat surface with the steel disc.

The experimentation is carried out with the following parameters:

(1) Load.
(2) Sliding distance.
(3) Sliding velocity.

Table 6Parameter setting and levels for various control factors for wear test

Control factors	Units	Level		
		I	II	III
Load	Newton	10	20	30
Sliding distance	Meter	1000	2000	3000
Sliding velocity	m/sec	1.57	2.62	3.66

Pin-on-Disc Test

Pin-on-Disc testing method is used for tribological characterization. The test procedure is as follows:

- Initially,pinsurface is madeflatsuchthatitwillsupportloadover itsentirecross-sectioncalledFirstStage.This isachievedbythe surfaces of thepinsampleground using emery paper (400 grit size) prior to test.
- Run-in-wear is performed in the Second stage. This stage avoids initial turbulent period associated with friction and wear curves.
- Third stage is the actual testing called constant/ steady state wear. This stage is the dynamic competition between material transfer processes (transfer of material from pin to disc and formation of wear debris and their subsequent removal). Before the test, both the pin and disc are cleaned with ethanol soaked cotton.
- Precautionary steps are taken before experiment start to make sure that the load applied in normal direction. Figure 6 represents the schematic view of Pin-on-disc test set up.

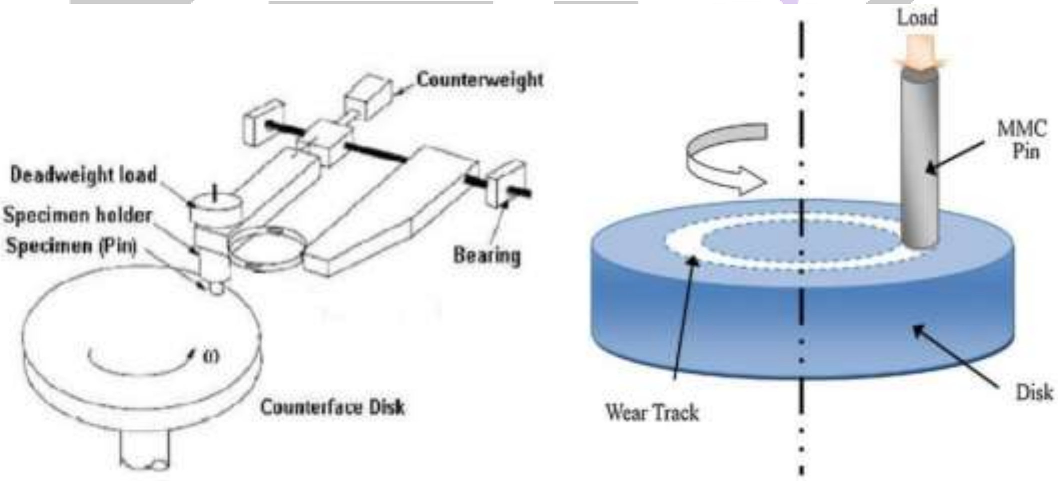

Figure 6Schematic views of the pin-on-disc apparatus.

Methodology for Finding Specific Wear Rate

Forfinding specificwearrate, theweightlossmethod is used forcalculating specific wear rate during the experiments. Before experiment performing on the pin-on-disc apparatus, initial weight of specimen is measured and after the completion of experiment again final weight of specimen is measured. Then weight loss is finding by subtracting initial and final weight of specimen.

$$K_s = \frac{\Delta m}{\rho \times F \times L}$$

Where K_s is specific wear rate (mm^3/Nm), Δm is the mass loss in the test duration(gm), ρ is the density of the composite (gm/cm^3) and F is the load (N), L is sliding distance (m).

- **Mass loss (Δm)** Weighing machine is used to find the weight of the sample up to high fractional value. It consists of a digital display monitor which gives the desired weight of the sample. By using this machine we can find the volume or mass loss during sliding wear (Δm) during the test.
- **Density calculation** the density of MMCs, which is ratio of weight to volume, obtained by accurately measuring the weight and the volume of the MMCs. The average of five reading of diameter and length of sample are taken for calculating the volume and mass is calculated by the weighting machine.
- **Sliding Distance (L)** Distance for that the sample has to cover on pin-on-disc machine for given sample. Three different values sliding distance are taken for experimentation.
- **Normal load (F)** Load applied on the sample by the dead weights on pin-on-disc machine. Three values of normal load are taken.

DesignofExperimentalTechnique

Taguchi design ofexperiment is a powerfulanalysis toolwhich is adopted for optimizing design parameters. Taguchi method provides the designer with a systematicandefficientapproachforexperimentation todeterminenearoptimum settingsof design parametersforperformance,quality andcost.Themostimportant stageinthedesignofexperimentliesintheselectionofthecontrolfactors.In the presentwork,theimpactofthethreesuchfactorsisstudiedusingL9orthogonal

arraywhichhas9rowscorrespondingtothenumberoftests.Inconventionalfull factorialexperimentaldesign,itwould require3^3=27 runstostudythreefactorseach atthreelevelswhereas,Taguchi'sfactorial experiment approach reducesittoonly9 runsofferingagreatadvantageintermsofexperimentaltimeandcost. The operating conditions underwhichsliding weartestscarriedoutaregivenintheTable6.The experimentalobservationsare transformed intoasignal-to-noise(S/N)ratio.There are threeS/Nratiosavailabledependingupon thetypeofcharacteristics(smaller-the- better,larger-the-better,nominal-thebetter).TheS/Nratioforminimum(friction and wearrate)comingundersmallerisbettercharacteristic,whichcanbecalculatedas logarithmictransformationofthelossfunctionasshownbelow

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\left(y_1^2 + y_2^2 + y_3^2 + ... + y_n^2\right)\right]$$

Where'n'istherepeatednumbertrialconditionsandy_1, y_2 ……$y_n$aretheresponse of thefrictionandslidingwearcharacteristics."Smallerisbetter" (LB)characteristic, withtheaboveS/N ratiotransformationissuitableforminimizationsof coefficientof friction andspecificwearrate.Thestandardlineargraphisusedtoassign thefactors andinteractionstovariouscolumnsofthe orthogonalarray(OA).

Scanning Electron Microscopy (SEM)

An SEM is to analyze the surface of specimen of the composite. The composite sample with diameter ϕ12mmand thickness 5mm is mounted on stubs with silver paste. To enhance the conductivity of the sample, a film of platinum is vacuum evaporate onto them before the photomicrograph are taken.

Figure 7 Scanning Electron Microscope

Results and Discussions

The characterization of the composites reveals that inclusion of reinforcement particles have strong influence not only on the mechanical properties of composites but also on their dry sliding wear. Incorporating micro and nano particles separately in Al7075 reveals modified mechanical properties and improved sliding wear resistance. A comparative study of modified behavior of the composites against the three different Wt. % reinforcements of nano and micro particles is discussed separately as follow.

Effect on specific wear rate of different reinforcements of MMCs under dry sliding condition

Conventional Pin-on-disc machine is used under dry sliding conditions specimens to monitor specific wear rate. The wear track and specimen cleaned before performing experiment. A micro balance of accuracy ±0.0001gmis used for weighting of

Specimens. After that the specimen is mounted in the jaws of wear machine which held the specimen against the disc. For all experiments, the track diameter is kept 100 mm and the experiment have been performed accordingly Taughi design using L9 array.

Table 7 Experimental design for Al7075 using L9 array

Load (N)	Sliding Distance (m)	Sliding Velocity (m/sec)	SWR (mm^3/Nm)	Mean	S/N Ratio
10	1000	1.57	0.00006147	0.0000615	84.2262
10	2000	2.62	0.00006690	0.0000669	83.4917
10	3000	3.66	0.00006990	0.0000699	83.1099
20	1000	2.62	0.00005786	0.0000579	84.7528
20	2000	3.66	0.00006780	0.0000678	83.3751
20	3000	1.57	0.00008197	0.0000820	81.7272
30	1000	3.66	0.00006388	0.0000639	83.8929
30	2000	1.57	0.00007715	0.0000771	82.2538
30	3000	2.62	0.00008277	0.0000828	81.6428

Table 8 ANOVA Table for specific wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
Load	2	1.6049	1.6049	0.80245	8.08	16.810
Sliding Distance	2	6.8781	6.8781	3.43905	34.63	72.049
Velocity	2	0.8639	0.8639	0.43196	4.35	9.050
Residual error	2	0.1986	0.1986	0.09932		2.080
Total	8	9.5456				100

Table 9 Response Table for specific wear rate

Level	Load	Sliding Distance	Velocity
1	0.000066	0.000061	0.000074
2	0.000069	0.000071	0.000069
3	0.000075	0.000078	0.000067
Delta	0.000009	0.000017	0.000008
Rank	2	1	3

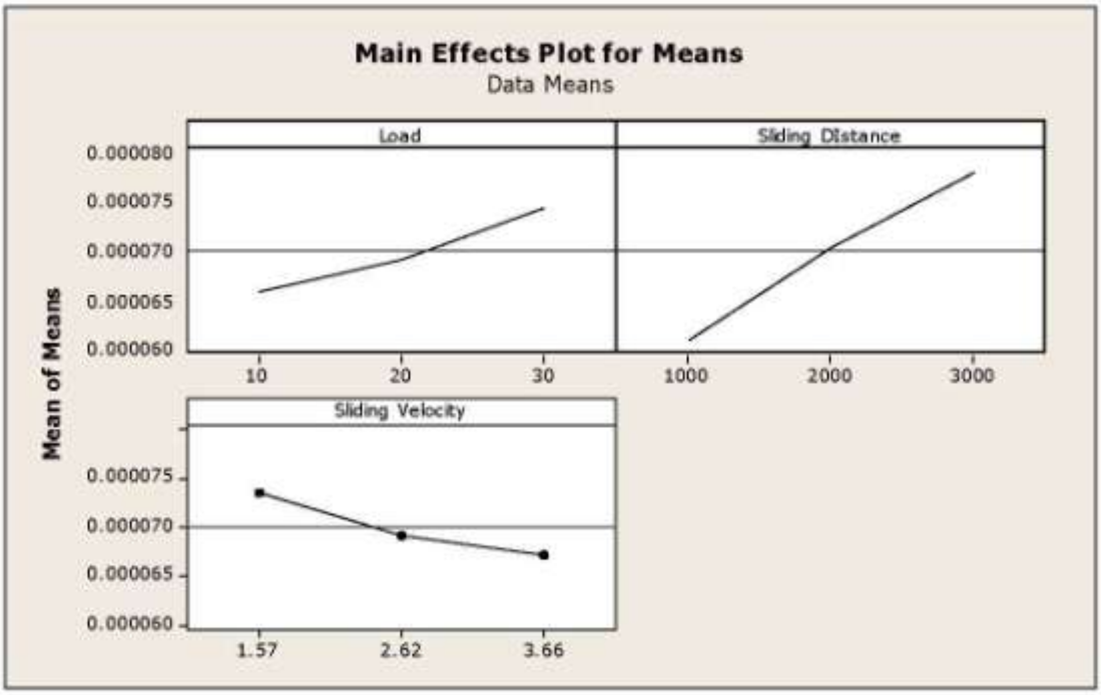

Figure 8 Effects of mean factors on specific war rate of Al7075

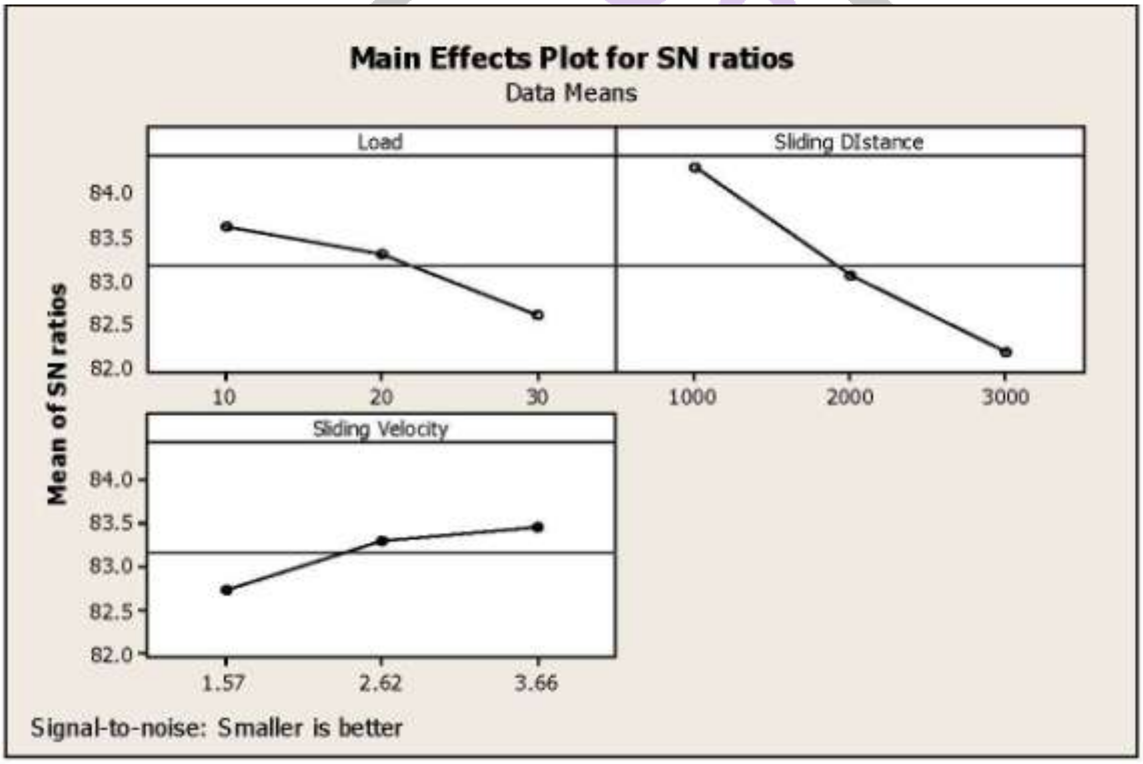

Figure 9 Effect of control factors on specific wear rate for Al7075

Table 10 Experimental design for Al7075 reinforced with 1.5Wt. % of micro particles of Al_2O_3 using L9 array

Load(N)	SlidingDistance (m)	SlidingVelocity(m/sec)	SWR(mm^3/Nm)	Mean	S/N Ratio
10	1000	1.57	0.00005769	0.00005769	84.77816
10	2000	2.62	0.00005589	0.00005589	85.05393
10	3000	3.66	0.00006129	0.00006129	84.25245
20	1000	2.62	0.00005048	0.00005048	85.93800
20	2000	3.66	0.00006129	0.00006129	84.25158

20	3000	1.57	0.00007872	0.00007872	82.07799
30	1000	3.66	0.00005768	0.00005768	84.77903
30	2000	1.57	0.00007211	0.00007211	82.83979
30	3000	2.62	0.00007972	0.00007972	81.96844

Table 11 ANOVA Table for specific wear rate

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P(%)**
Load	2	3.4123	3.4123	1.7062	4.94	22.193
Sliding Distance	2	8.6449	8.6449	4.3224	12.52	56.244
Velocity	2	2.6253	2.6253	1.3127	3.80	17.071
Residual error	2	0.6906	0.6906	0.3453		4.492
Total	8	15.3731				100

Table 12 Response Table for specific wear rate

Level	**Load**	**Sliding Distance**	**Velocity**
1	0.000058	0.000055	0.000070
2	0.000063	0.000063	0.000062
3	0.000070	0.000073	0.000060
Delta	0.000012	0.000018	0.000009
Rank	2	1	3

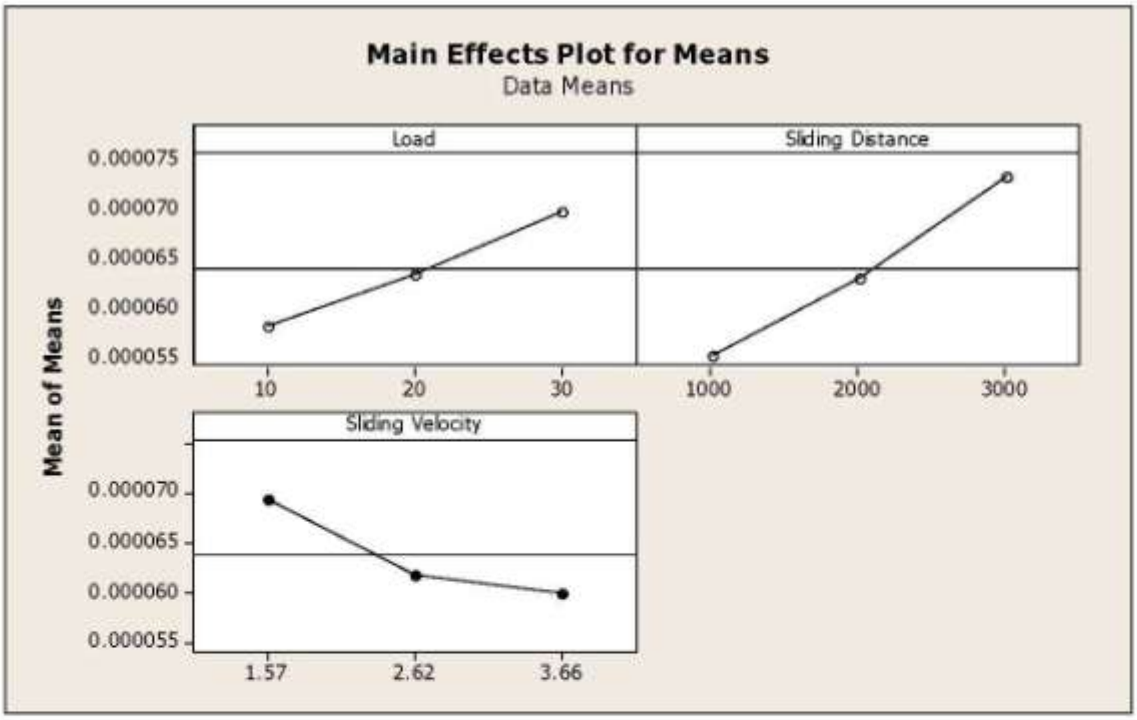

Figure 10Effect of mean factors on specific wear rate for micro composite sample

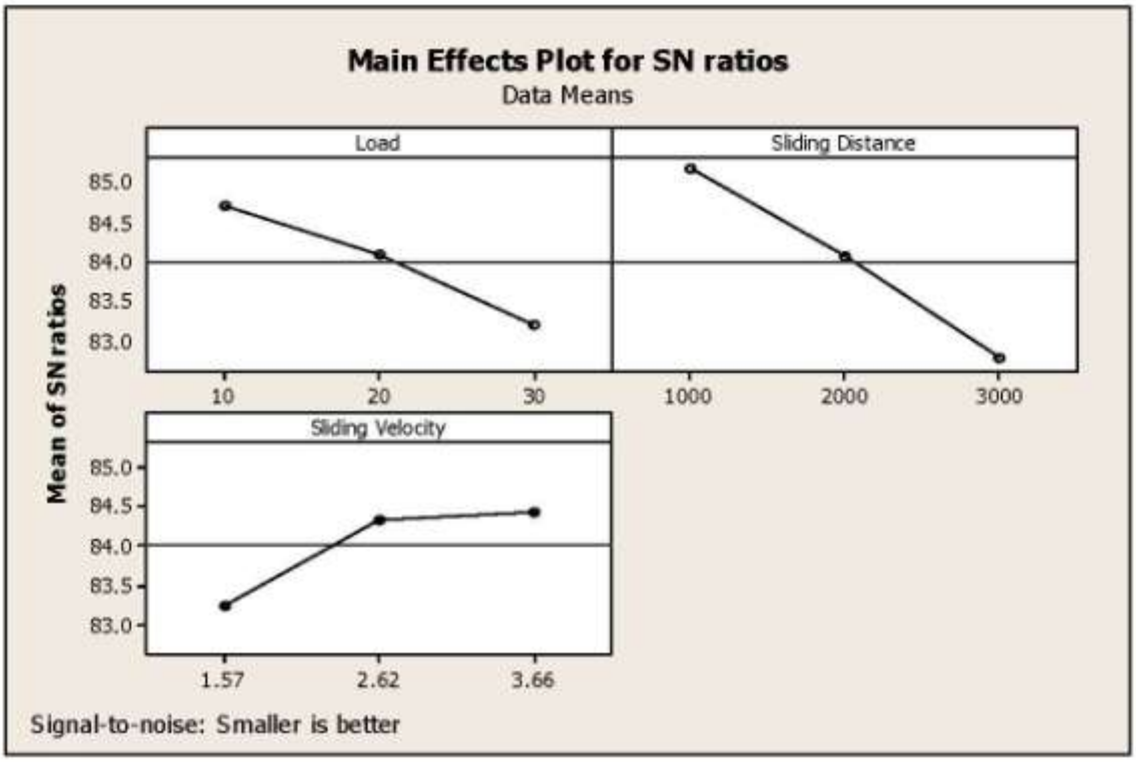

Figure 11Effect of control factors on specific wear rate for micro composite sample

Table 13 Experimental design for Al7075 reinforced with 3Wt.% of micro particles of Al_2O_3 using L9 array

Load(N)	SlidingDistance(m)	SlidingVelocity(m/sec)	SWR(mm^3/Nm)	Mean	S/N Ratio
10	1000	1.57	0.00004676	0.0000468	86.6030
10	2000	2.62	0.00004496	0.0000450	86.9436
10	3000	3.66	0.00005755	0.0000575	84.7994
20	1000	2.62	0.00004856	0.0000486	86.2752
20	2000	3.66	0.00005485	0.0000549	85.2164
20	3000	1.57	0.00006534	0.0000653	83.6963
30	1000	3.66	0.00005515	0.0000551	85.1691
30	2000	1.57	0.00006354	0.0000635	83.9387
30	3000	2.62	0.00007713	0.0000771	82.2555

Table 14 ANOVA Table for specific wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
Load	2	8.1509	8.1509	4.0755	16.23	44.198
Sliding Distance	2	9.5136	9.5136	4.7568	18.94	51.580
Velocity	2	0.2788	0.2788	0.1394	0.55	1.499
Residual error	2	0.5023	0.5023	0.2512		2.723
Total	8	18.4456				100

Table 15 Response Table for specific wear rate

Level	Load	Sliding Distance	Velocity
1	0.000050	0.000050	0.000059
2	0.000056	0.000054	0.000057
3	0.000065	0.000067	0.000056
Delta	0.000016	0.000017	0.000003
Rank	2	1	3

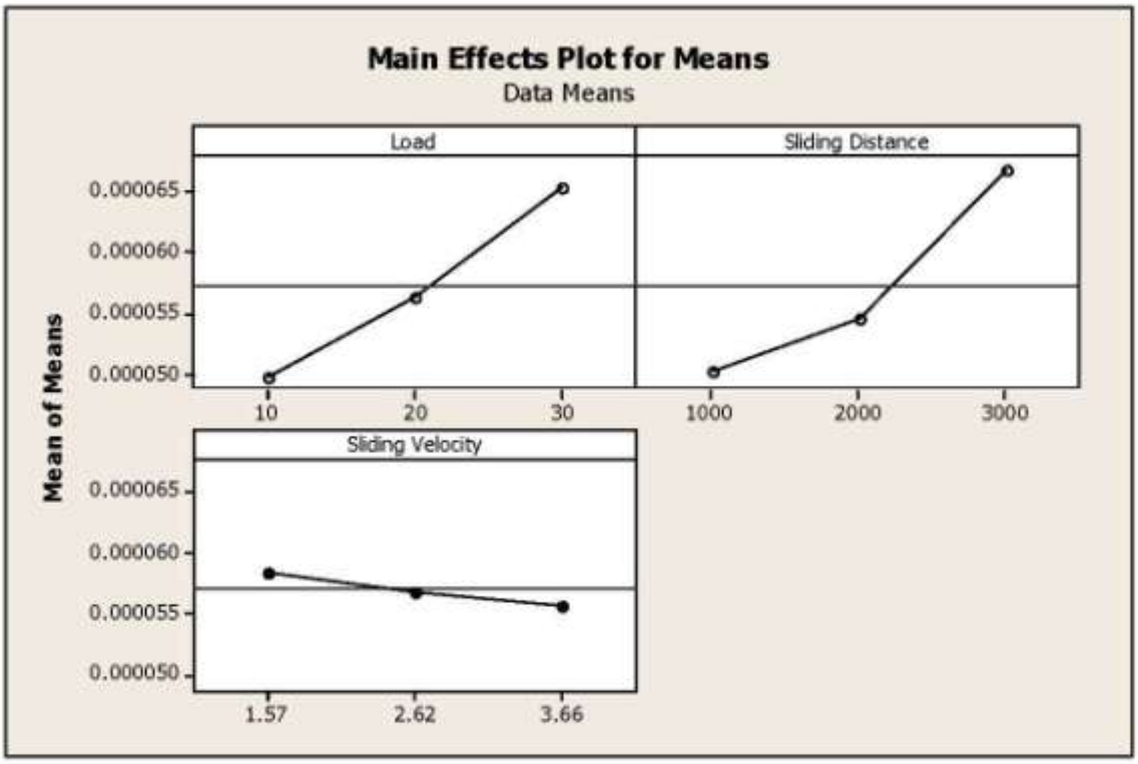

Figure 12Effect of mean factors on specific wear rate for micro composite sample

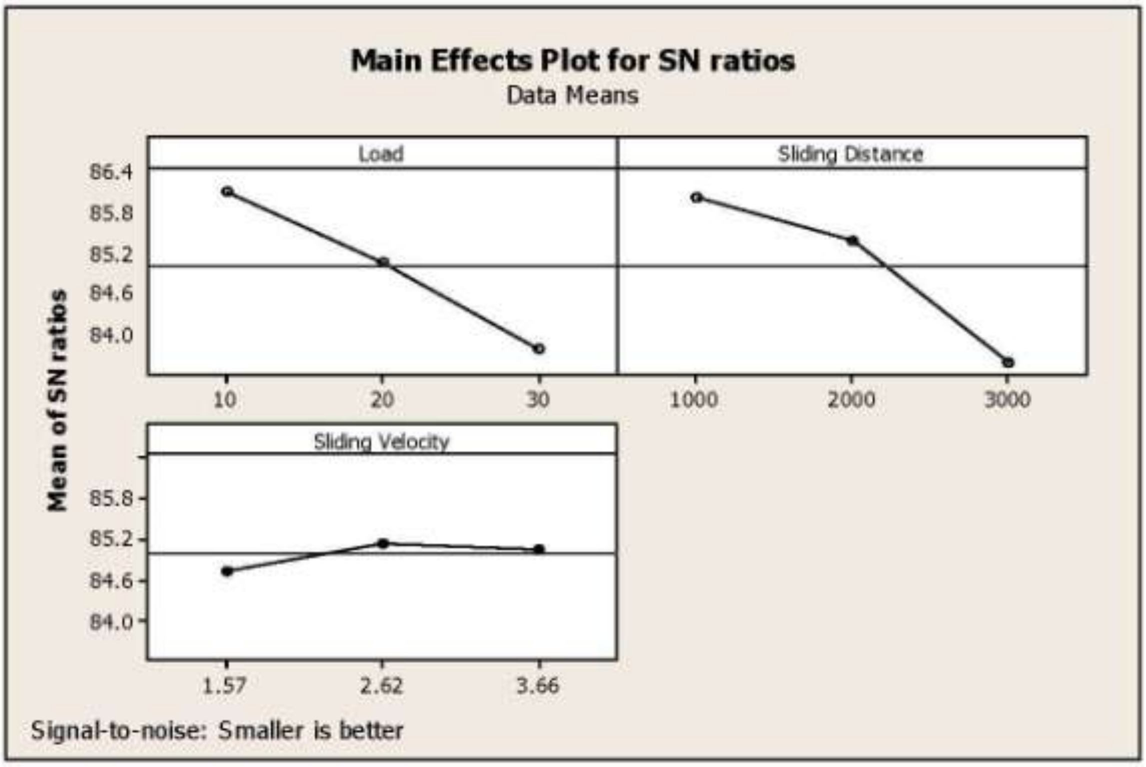

Figure 13Effect of control factors on specific wear rate for micro composite sample

Table 23 Experimental design for Al7075 reinforced with 4.5Wt. % of micro particles of Al_2O_3 using L9 array

Load(N)	SlidingDistance(m)	SlidingVelocity(m/sec)	SWR(mm^3/Nm)	SN ratio	Mean
10	1000	1.57	0.00003579	88.92577	0.00003579
10	2000	2.62	0.00004473	86.98757	0.00004473
10	3000	3.66	0.00004771	86.42787	0.00004771
20	1000	2.62	0.00004473	86.98757	0.00004473
20	2000	3.66	0.00005010	86.00321	0.00005010
20	3000	1.57	0.00006084	84.31662	0.00006084
30	1000	3.66	0.00005129	85.7997	0.00005129
30	2000	1.57	0.00005964	84.48862	0.00005964
30	3000	2.62	0.00006203	84.14822	0.00006203

Table 17 ANOVA Table for specific wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
Load	2	10.6739	10.6739	5.33694	16.25	55.360
Sliding Distance	2	7.9035	7.9035	3.95176	12.03	40.986
Velocity	2	0.0461	0.0461	0.02307	.07	0.248
Residual error	2	0.6567	0.6567	0.32836		3.406
Total	8	19.2803				100

Table 18 Response Table for specific wear rate

Level	Load	Sliding Distance	Velocity
1	0.000043	0.000044	0.000052
2	0.000052	0.000051	0.000050
3	0.000058	0.000057	0.000050
Delta	0.000015	0.000013	0.000002
Rank	1	2	3

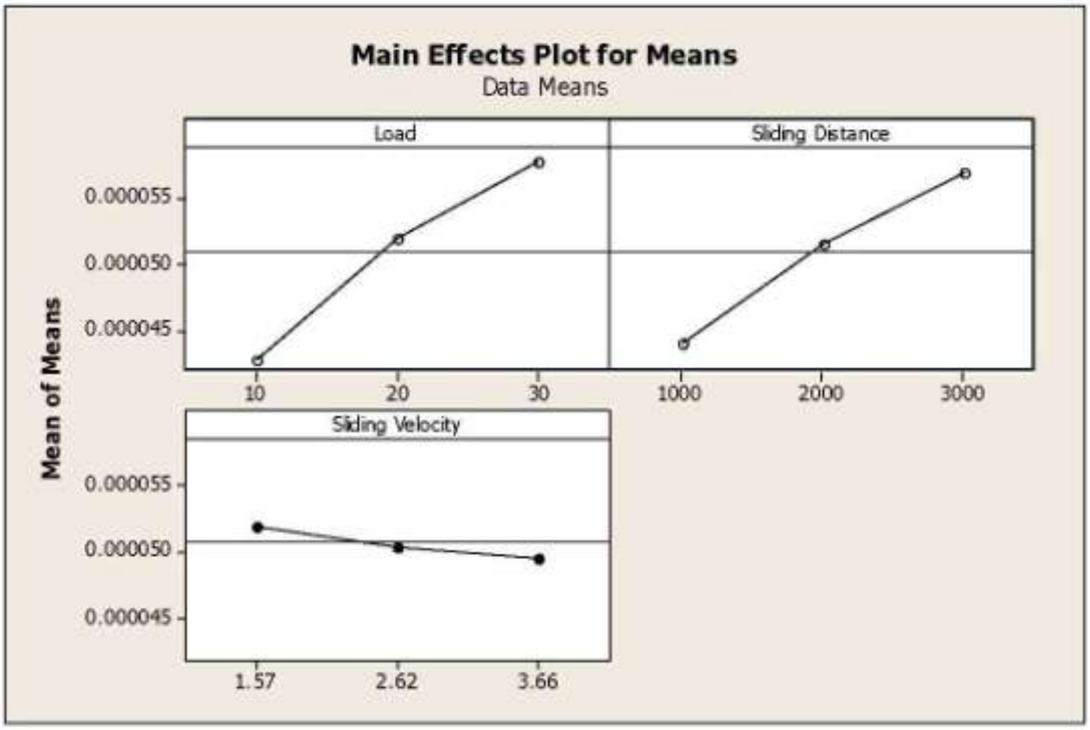

Figure 14Effect of mean factors on specific wear rate for micro composite sample

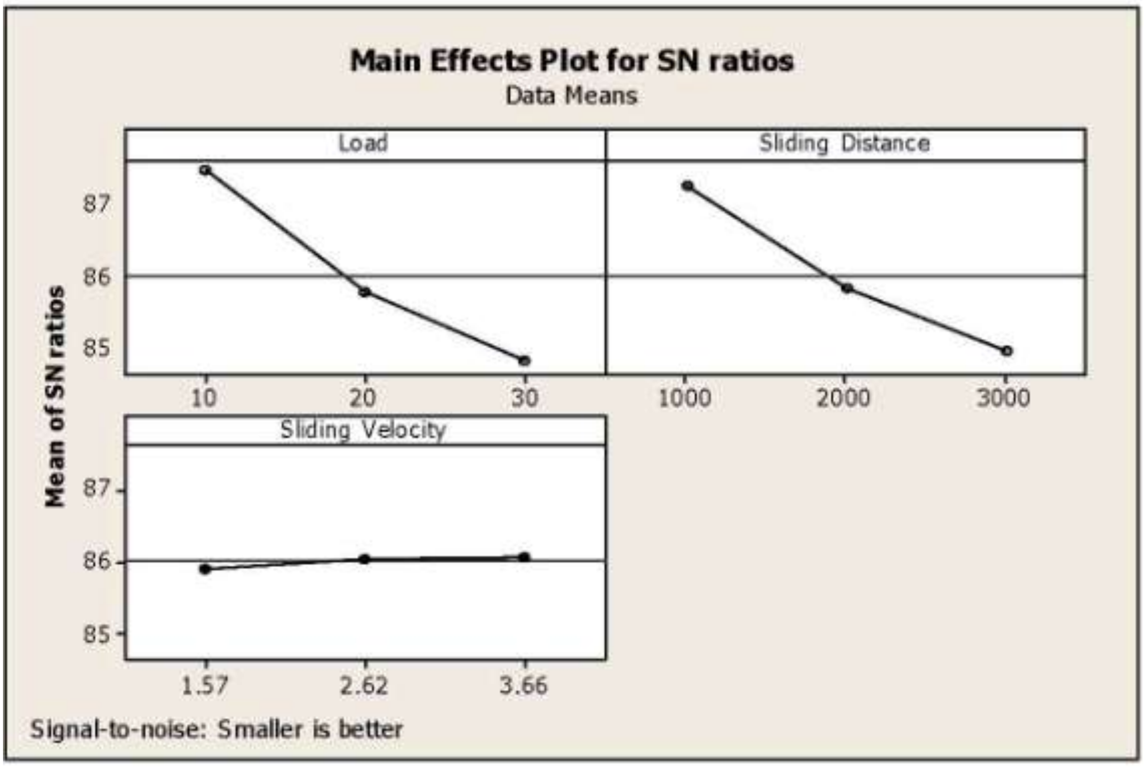

Figure 15Effect of control factors on specific wear rate for micro composite sample

Table 19 Experimental design for Al7075 reinforced with 1.5Wt.% of nano particles of Al_2O_3 using L9 array

Load(N)	Slidingdistance(m)	SlidingVelocity(m/sec)	SWR(mm^3/Nm)	SN ratio	Mean
10	1000	1.57	0.00003963	88.04054	0.0000396
10	2000	2.62	0.00004323	87.28476	0.0000432
10	3000	3.66	0.00004803	86.37048	0.0000480
20	1000	2.62	0.00004323	87.28476	0.0000432
20	2000	3.66	0.00005043	85.94583	0.0000504
20	3000	1.57	0.00006484	83.76277	0.0000648
30	1000	3.66	0.00004803	86.37048	0.0000480
30	2000	1.57	0.00006124	84.25924	0.0000612
30	3000	2.62	0.00006564	83.65645	0.0000656

Table 20 ANOVATable for Specific wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
Load	2	9.3716	9.3716	4.68578	227.45	44.299
Sliding Distance	2	10.4319	10.4319	5.21596	253.18	48.311
Velocity	2	1.3088	1.3088	0.65442	31.77	6.187
Residual error	2	0.0412	0.0412	0.02060		0.194
Total	8	21.1535				100

Table 21 Response Table for specific wear rate

Level	Load	Sliding Distance	Velocity
1	0.000044	0.000044	0.000055
2	0.000053	0.000052	0.000051
3	0.000058	0.000060	0.000049
Delta	0.000015	0.000016	0.000006
Rank	2	1	3

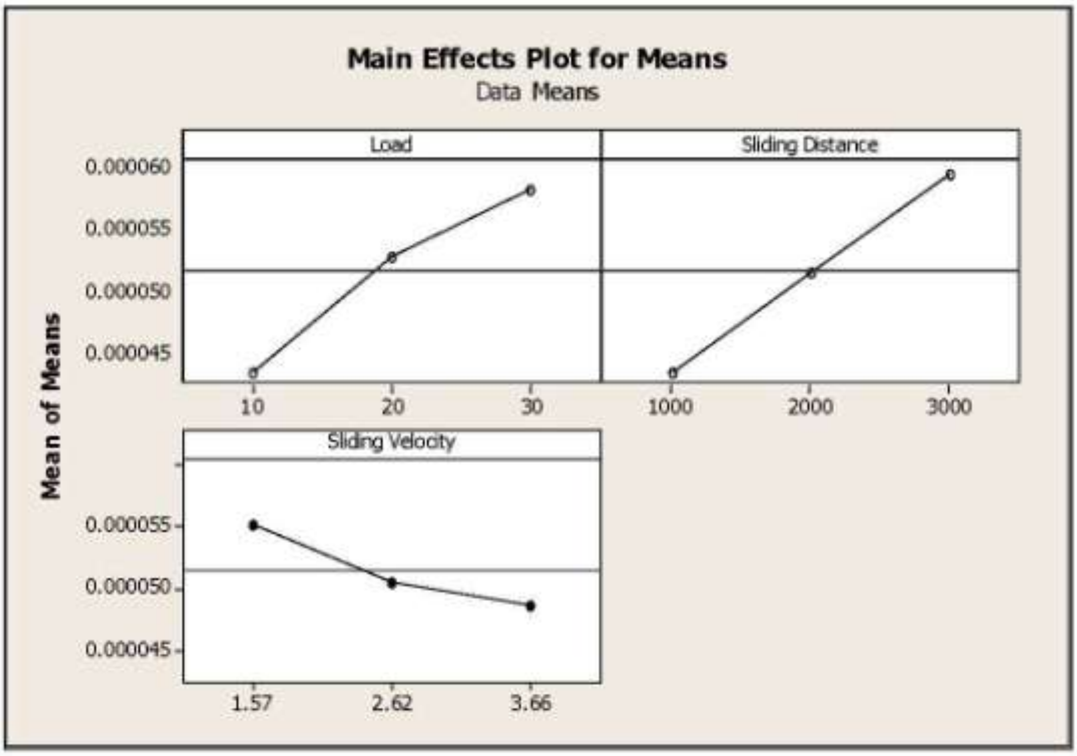

Figure 16Effect of mean factors on specific wear rate for nano composite sample

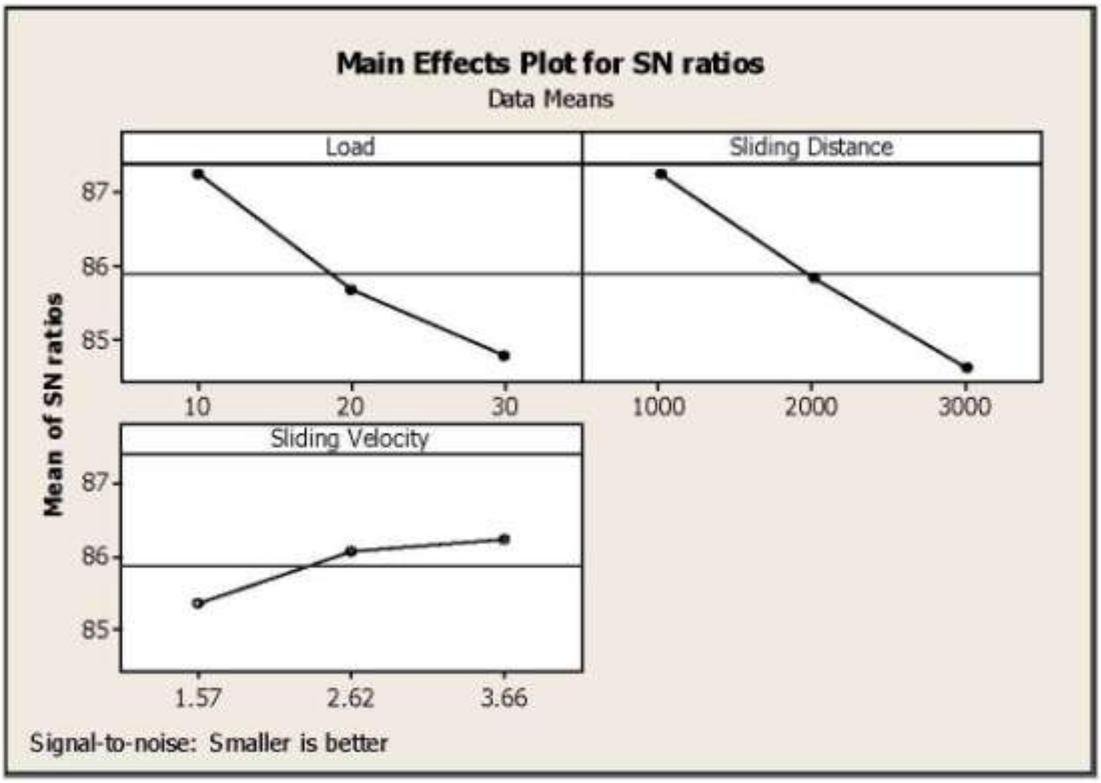

Figure 17Effect of control factors on specific wear rate for nano composite sample

Table 22Experimental design for Al7075 reinforced with 3 Wt. % of nano particles of Al_2O_3 using L9 array

Load(N)	SlidingDistance(m)	SlidingVelocity(m/sec)	SWR(mm^3/Nm)	SN Ratio	Mean
10	1000	1.57	0.00003609	88.85116	0.0000361
10	2000	2.62	0.00003790	88.42738	0.0000379
10	3000	3.66	0.00004572	86.79878	0.0000457
20	1000	2.62	0.00004512	86.91296	0.0000451
20	2000	3.66	0.00004512	86.91296	0.0000451
20	3000	1.57	0.00006136	84.24201	0.0000614
30	1000	3.66	0.00004331	87.26841	0.0000433
30	2000	1.57	0.00005775	84.76859	0.0000578
30	3000	2.62	0.00006216	84.12947	0.0000622

Table 23 ANOVA Table for specific Wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
Load	2	11.3678	11.3678	5.6839	24.81	47.415
Sliding Distance	2	10.5281	10.5281	5.2641	22.98	43.917
Velocity	2	1.6213	1.6213	0.8106	3.54	6.765
Residual error	2	0.4582	0.4582	0.2291		1.911
Total	8	23.9753				100

Table 24 Response Table for specific Wear rate

Level	Load	Sliding Distance	Velocity
1	0.000040	0.000042	0.000052
2	0.000051	0.000047	0.000048
3	0.000054	0.000056	0.000045
Delta	0.000015	0.000015	0.000007
Rank	2	1	3

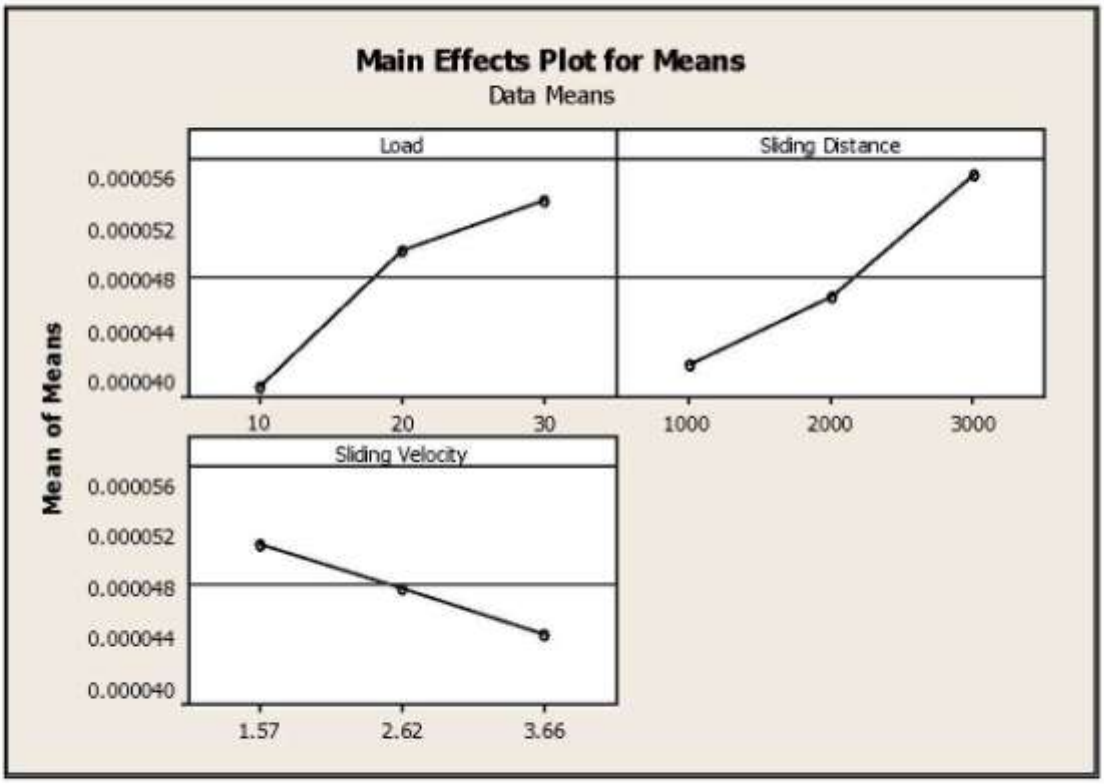

Figure 18Effect of mean factors on specific wear rate for nano composite sample

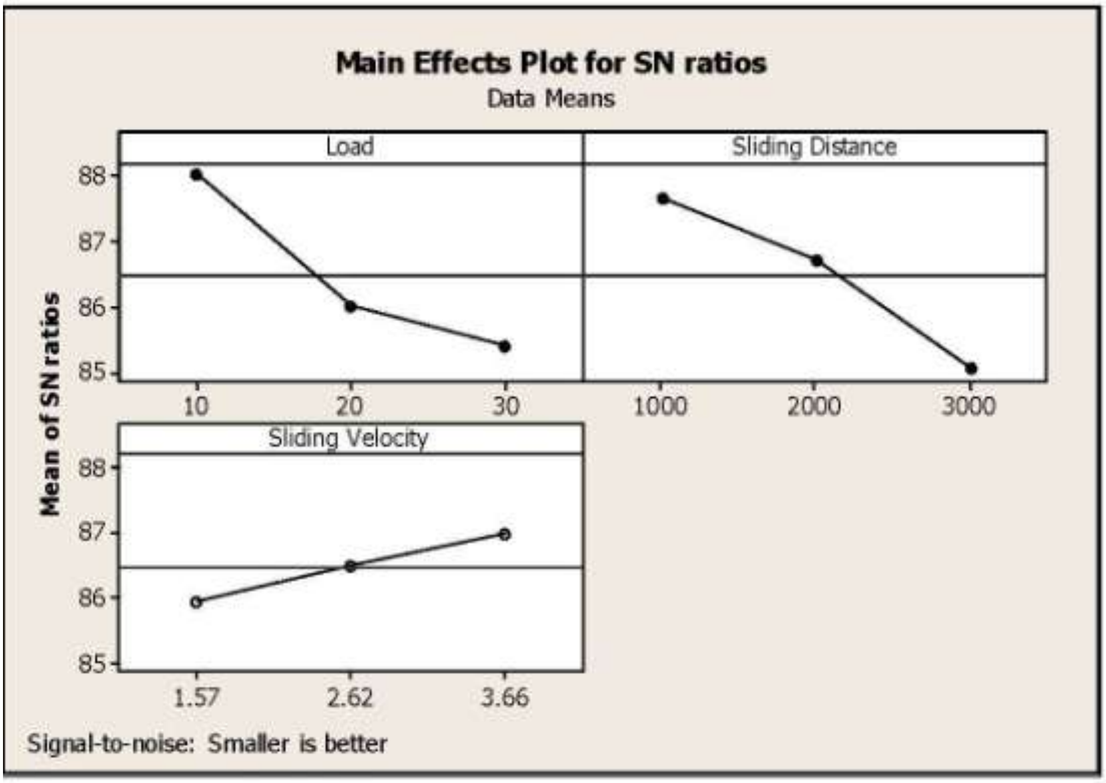

Figure 19Effect of control factors on specific wear rate for nano composite sample

Table 25Experimental design for Al7075 reinforced with 4.5Wt. % of nano particles of Al_2O_3 using L9 array

Load(N)	SlidingDistance(m)	SlidingVelocity (m/sec)	SWR(mm^3/Nm)	SN ratio	Mean
10	1000	1.57	0.00002890	90.7828	0.0000289
10	2000	2.62	0.00003251	89.7597	0.0000325
10	3000	3.66	0.00004455	87.0238	0.0000445
20	1000	2.62	0.00004335	87.2610	0.0000433
20	2000	3.66	0.00004786	86.4003	0.0000479
20	3000	1.57	0.00005840	84.6720	0.0000584
30	1000	3.66	0.00004214	87.5065	0.0000421
30	2000	1.57	0.00005719	84.8530	0.0000572
30	3000	2.62	0.00006020	84.4077	0.0000602

Table 26ANOVA Table for specific wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
Load	2	22.7029	22.7029	11.3514	14.61	57.678
Sliding Distance	2	14.8811	14.8811	7.4406	9.58	37.820
Velocity	2	0.2102	0.2102	0.1051	0.14	0.552
Residual error	2	1.5534	1.5534	0.7767		3.947
Total	8	39.3475				100

Table 27 Response Table for specific wear rate

Level	Load	Sliding Distance	Velocity
1	0.000035	0.000038	0.000048
2	0.000050	0.000046	0.000045
3	0.000053	0.000054	0.000045
Delta	0.000018	0.000016	0.000003
Rank	1	2	3

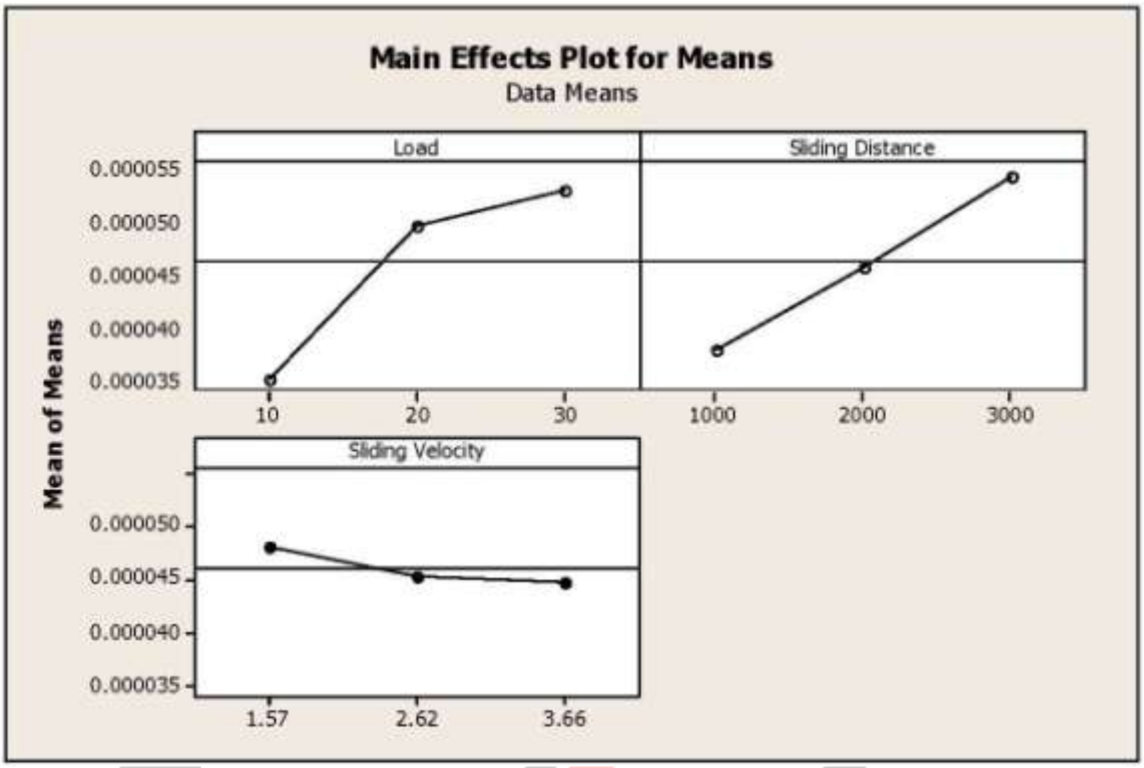

Figure 20Effect of mean factors on specific wear rate for nano composite sample

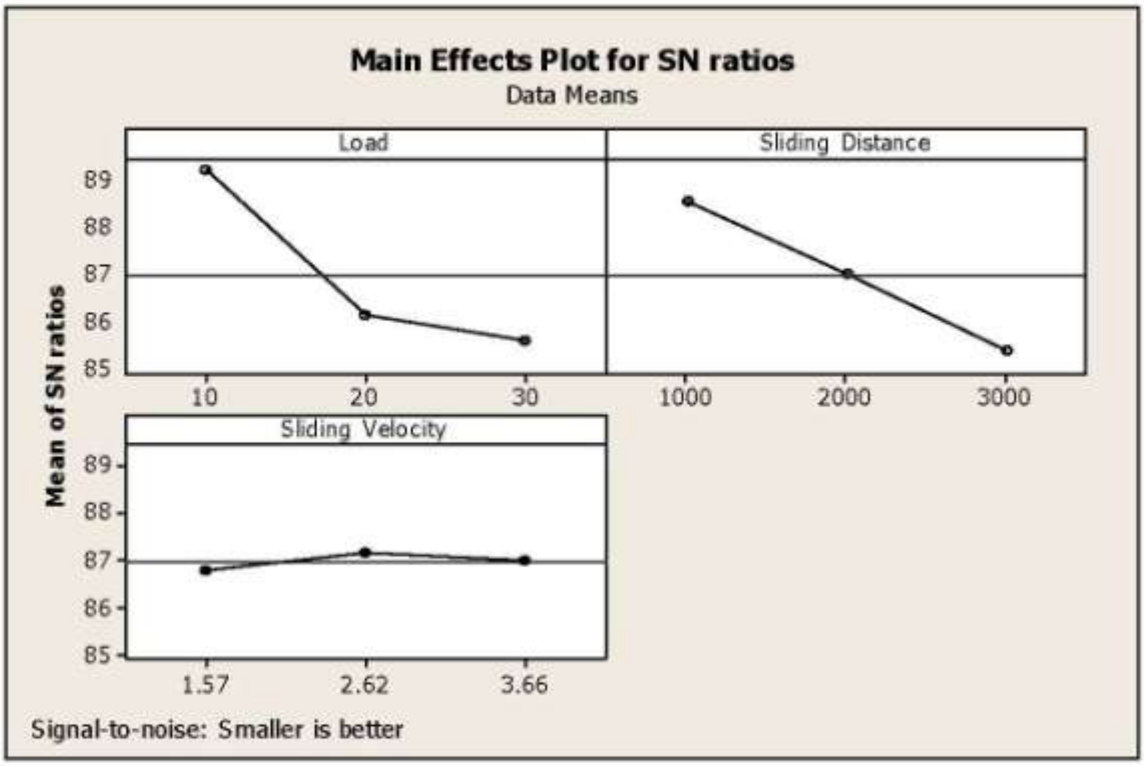

Figure 21Effect of control factors on specific wear rate for nano composite sample

ANOVA and effect of factors

Forunderstanding theeffectof variouscontrolfactors likenormalload,sliding distance and sliding velocity on the response of experimental data it is necessary to develop the Analysis of Variance (ANOVA) to find the significant factors. ANOVA is used to analyze the impact of each variable on the variation of the results. For Al7075 Table 8 shows the results of ANOVA for the specific wear rate. In this Table, the column shows the percentage contribution (P) of each variable in the total variation indicating the influence of specific wear rate. For pure Al7075, it can be observed from the Table 8 for specific wear rate that the sliding distance (L=72.049), load (P=16.810) and the sliding velocity (V=9.050) has significant influence on the specific wearrate. It is clearthat thecontrol factor slidingvelocity ishavingleast influence on the specific wear rate. From the ANOVA and response Table 9 of the mean of specific wear rate, it is seen that sliding distance has major impact on the specific wear rate followed by load and velocity.

Similarly Taguchi analysis is done for other micro and nano composites samples and response Table for mean revealed that sliding distance is most dominating factor which was assigned rank 1, followed by load (rank 2) and velocity (rank 3). Also from the ANOVA Tables it is clear that Sliding distance most is the significant factor.

Effect of sliding distance on specific wear rate

Figures 22 and 23 show the relationship between specific wear rate and sliding distance, with increase in sliding distance, there is higher specific wear rate for pure Al7075 and its Al_2O_3 reinforced composites. At larger sliding distance, rise of temperature of theslidingsurfaces areunavoidable. Thisresults in softening of thematrix and composite pin surfaces leading to heavy deformation at higher sliding distances. This contributes to higher wear of matrix and the composite.

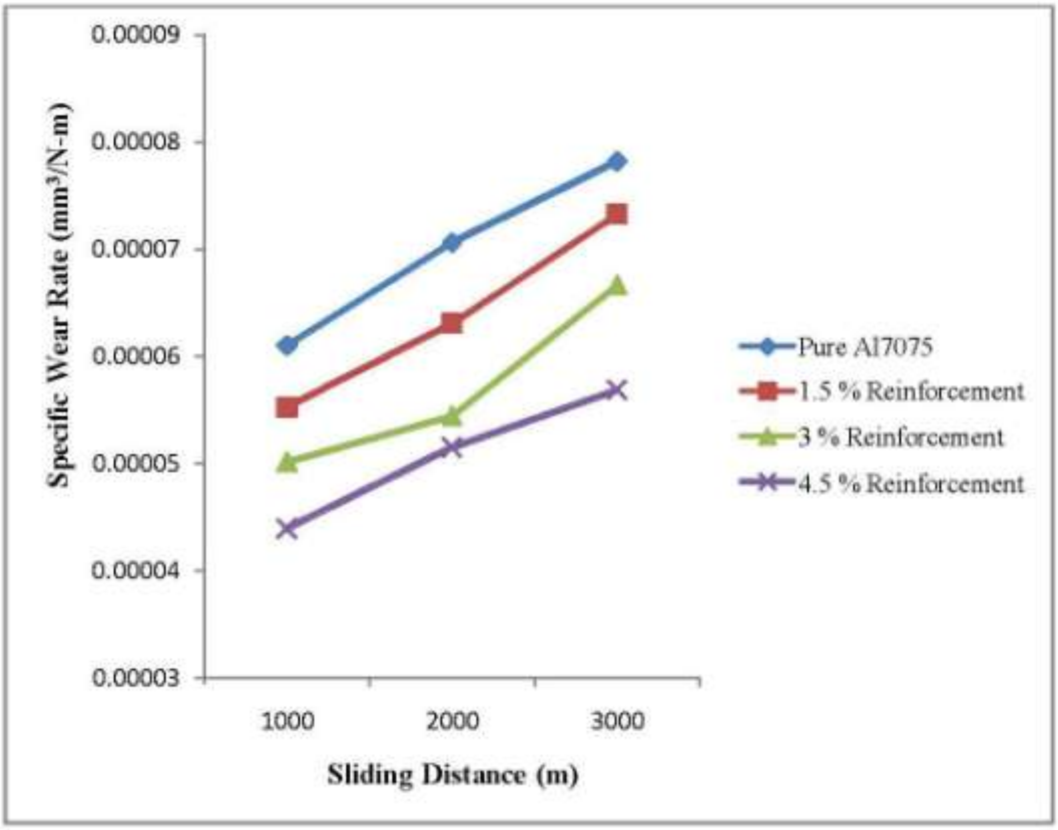

Figure 22Comparison of sliding distance and specific wear rate for micro particles reinforced in Al7075

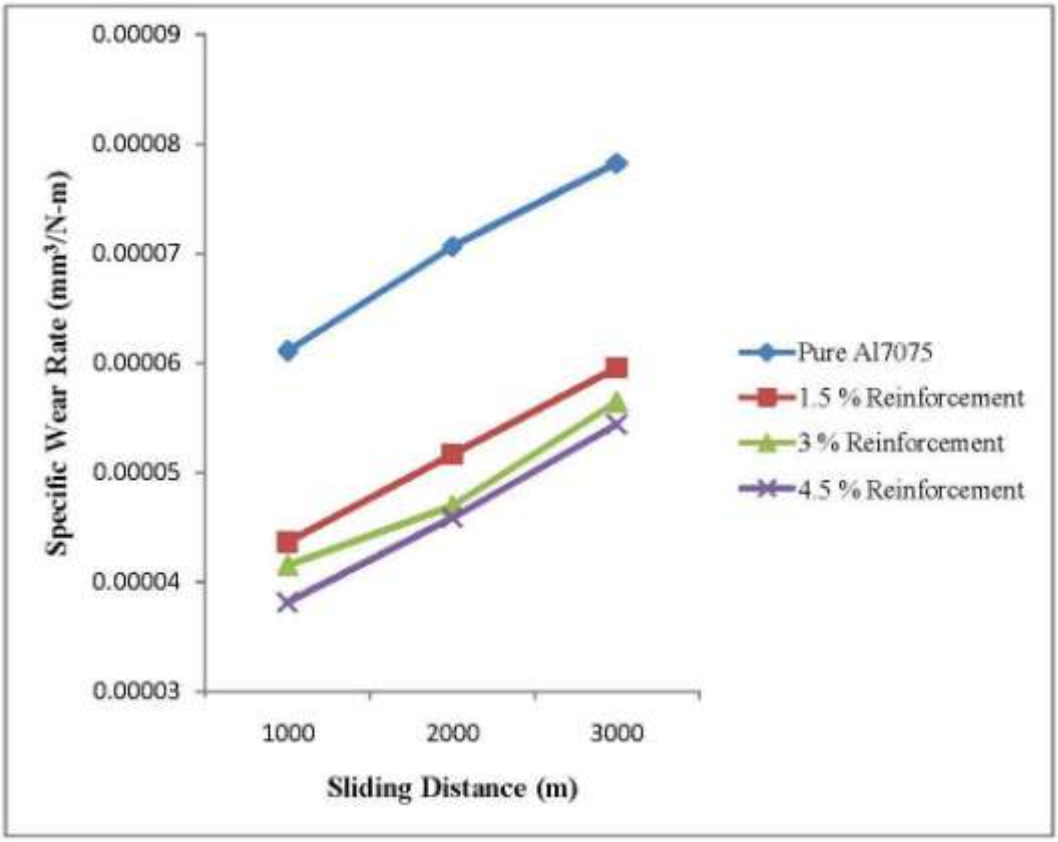

Figure 23 Comparison of sliding distance and specific wear rate for nano particles reinforced in Al7075

A close comparison of different graphs shown in Figure 22 and 23 reveals that specific wear rate of the composites was much lower when compared with the matrix alloyandreducedwithincreasedcontent$Al_2O_3$of thecomposites.This is attributed to enhancement in hardness of the composites. Increase in hardness results in improvement of wear and seizure resistance of materials. Among many ceramic materials, SiC and Al_2O_3 are widely in use, due to their favorable combination of density, hardness and cost effectiveness. When these reinforcements are combined with Aluminium, the resulting material exhibits significant increase in its elastic modulus, hardness, strength and wear resistance.

Effect of sliding velocity on specific wear rate

Figure 24 and 25 show the relation between the specific wear rate and sliding velocity, it is seen that the specific wear rate decreases with the increase velocity increase. It is attributed the fact that as low sliding velocity, the reinforcement does not appear on the surface and the specific wear rate of the matrix and composites is not much different.

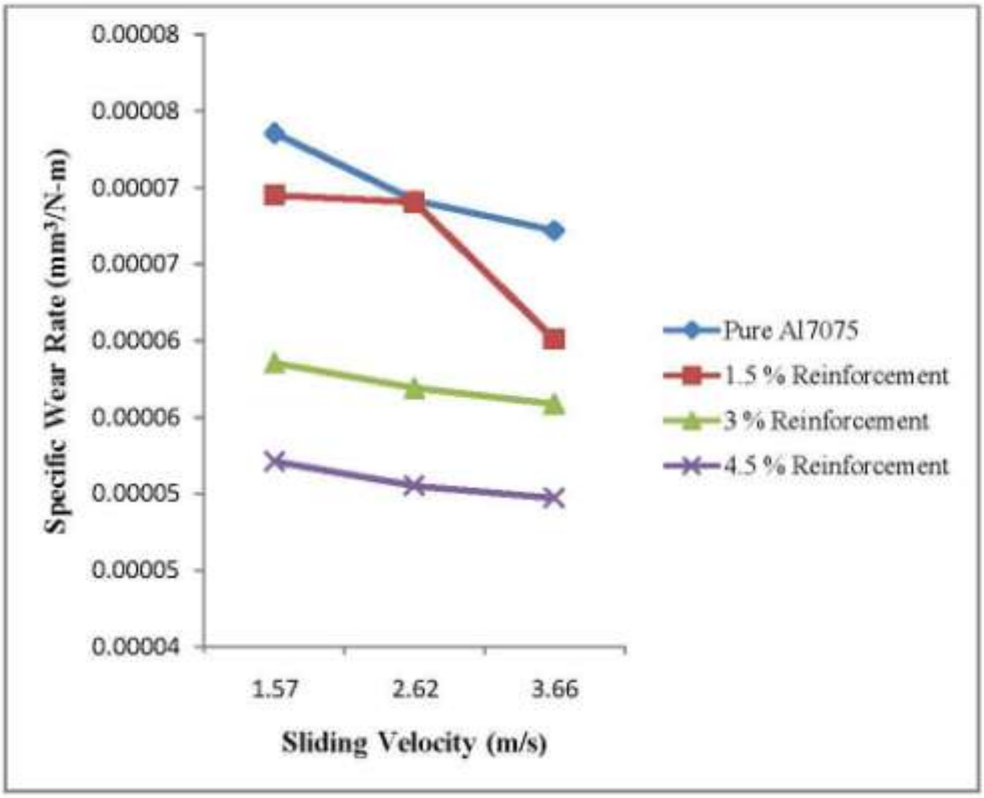

Figure 24 Comparison of sliding velocity and specific wear rate for micro particles reinforced in Al7075

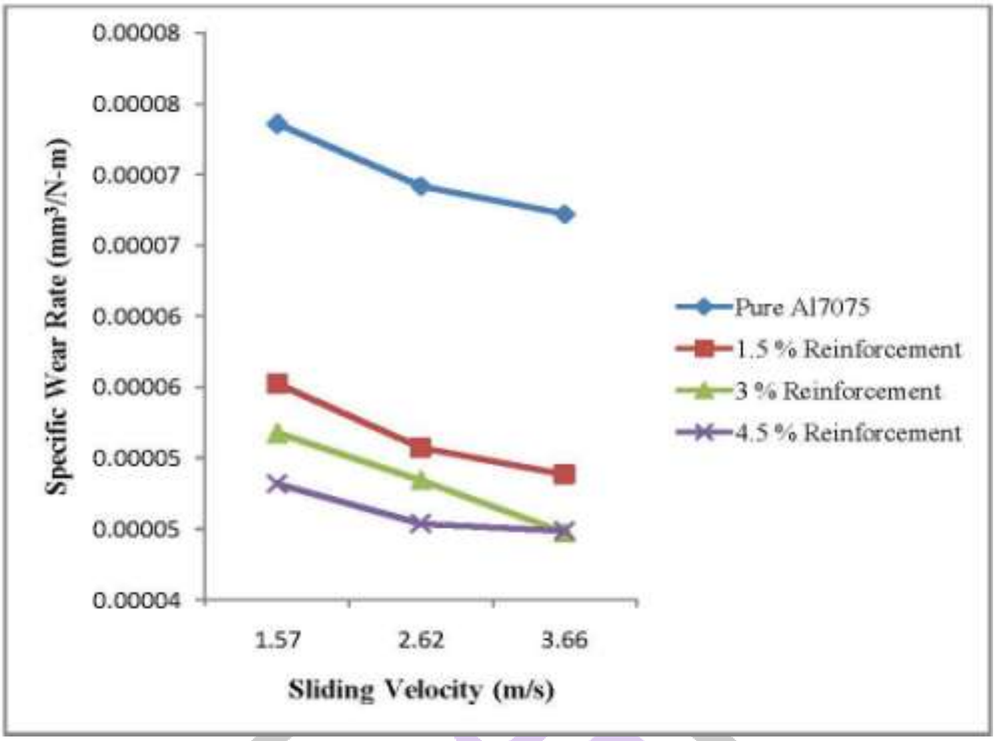

Figure 25Comparison of sliding velocity and specific wear rate for nano particles reinforced in Al7075

At a low sliding velocity the wearing surface is covered with a transferred material layer.Athigherspeedsanoxide-liketransferredlayerisformedatthesliding interface and reduced direct metallic contacts. This results in lower specific wear rate. At very high speeds thermal softening of the matrix is reported. The oxide layer is observed to break down and allow greater direct metallic contact during sliding and Al_2O_3 particles become dislodged and three body-body abrasive wear is predominated.

Effect of normal load on specific wear rate

Figure 26 and 27 shows the relation between the specific wear rate and load applied, it is seen that specific wear rate increase with applied load. The specific wear rate varieswiththenormalload,whichisanindicativeofArchard'slaw and is significantly lower in case of composites. With increase in loads, there is higher specific wear rate for matrix alloy and the composites. However, at all the loads considered, wear resistance of the composites were superior to the matrix alloy.

Alpas and Zhang [37] indicated that under different applied load conditions identified three different wear regimes. At low load (regime I), the particles support the applied load in which the wear resistances of MMCs are in the order of magnitude better than Al-alloy. At regime II, wear rates of MMCs and Al-alloy were similar. At high load and the transition to severe wear (regime III), the surface temperatures exceed a critical value. It is observed that the specific wear rate of the composites decreases with increased contents of Al_2O_3.

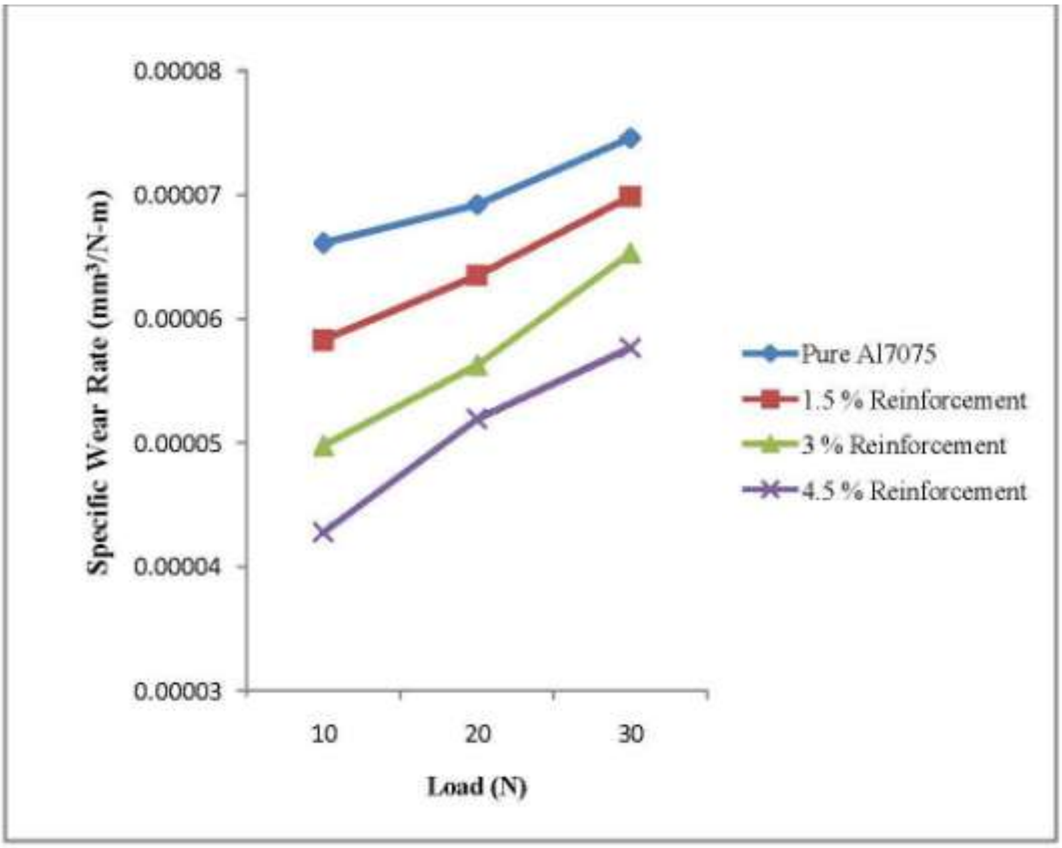

Figure 26Comparison of load and specific wear rate for micro particles reinforced in Al7075

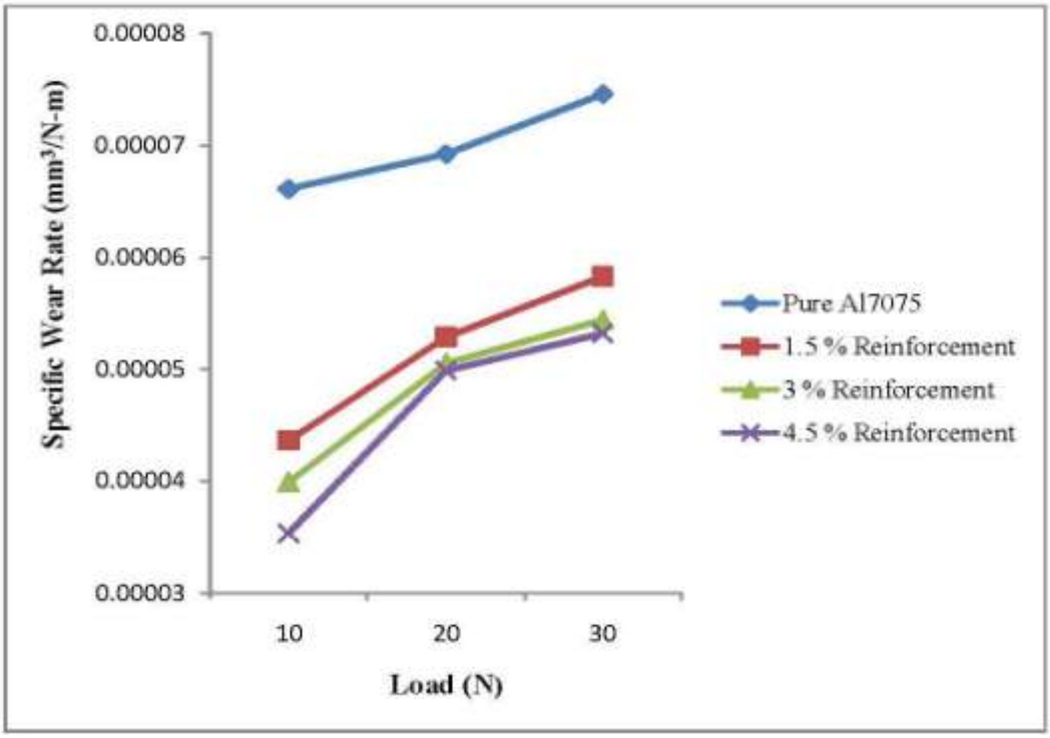

Figure 27Comparison of load and specific wear rate for nano particles reinforced in Al7075

Scanning electron microscopy (SEM) analysis

The cleaned, dried and etched specimens with diameter ϕ12mm and thickness 5mm is prepared and subsequently mounted on stubs with gold plating. The specimens thus mounted are viewed under FEI quanta FEG450 scanning electron microscope at an accelerating voltage of 20 kV. Figure 28-33 shows the SEM micrograph of the different Aluminium matrix composites at different magnifications (200X, 400X, 800X)). It is concluded from the SEM images that at low reinforcement percentage mixing of the Matrix and reinforcement is perfectly and it decreases with increase in the reinforcement percentage, also at higher reinforcement percentage agglomeration occurs which results in unequal distribution of particles in matrix, agglomeration found more in case of nano composites.

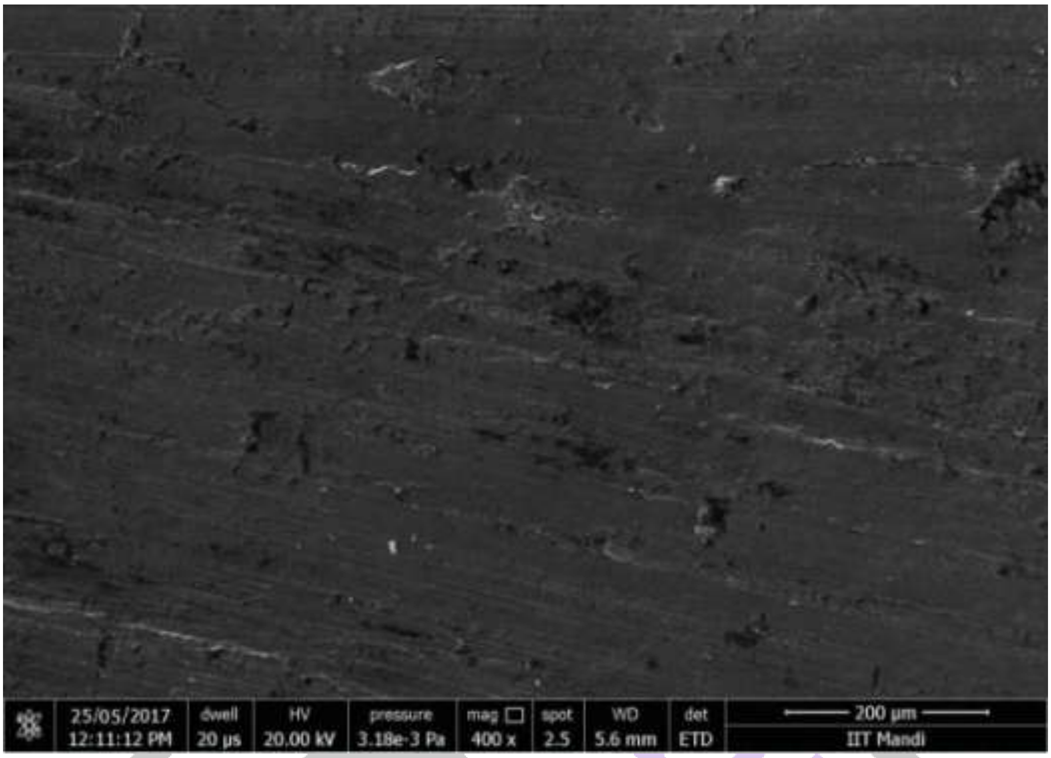

Figure 28SEM of MMCs with 1.5% micro Al_2O_3 (400×)

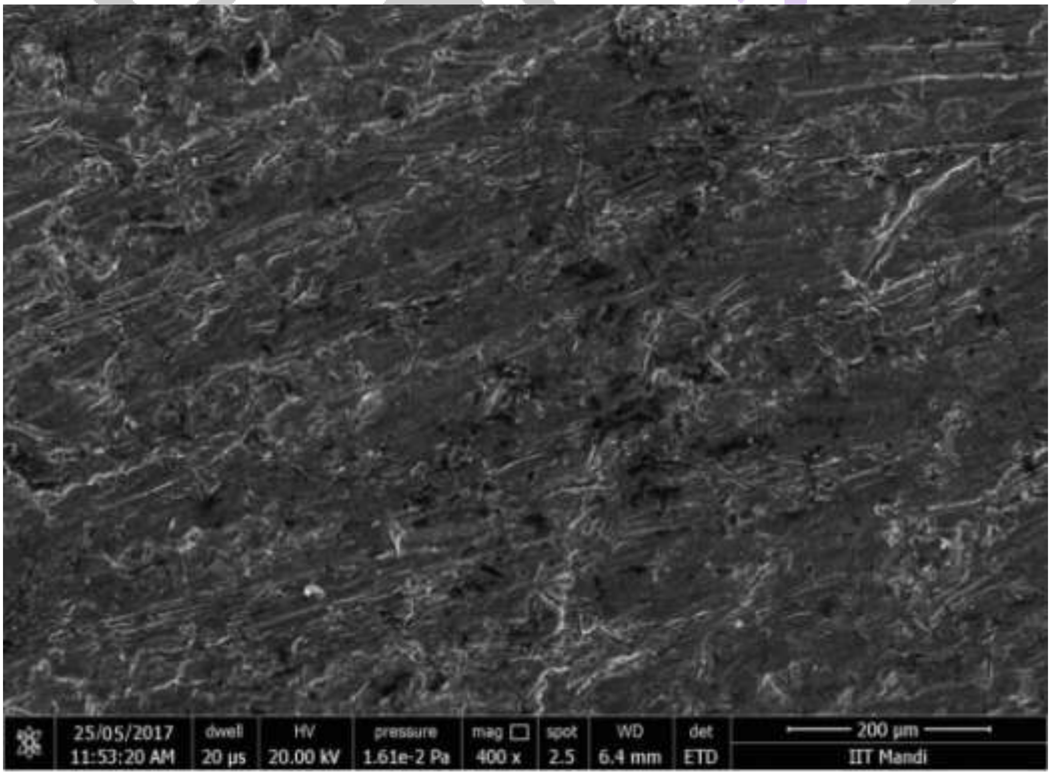

Figure 29SEM of MMCs with 3 % micro Al_2O_3 (400×)

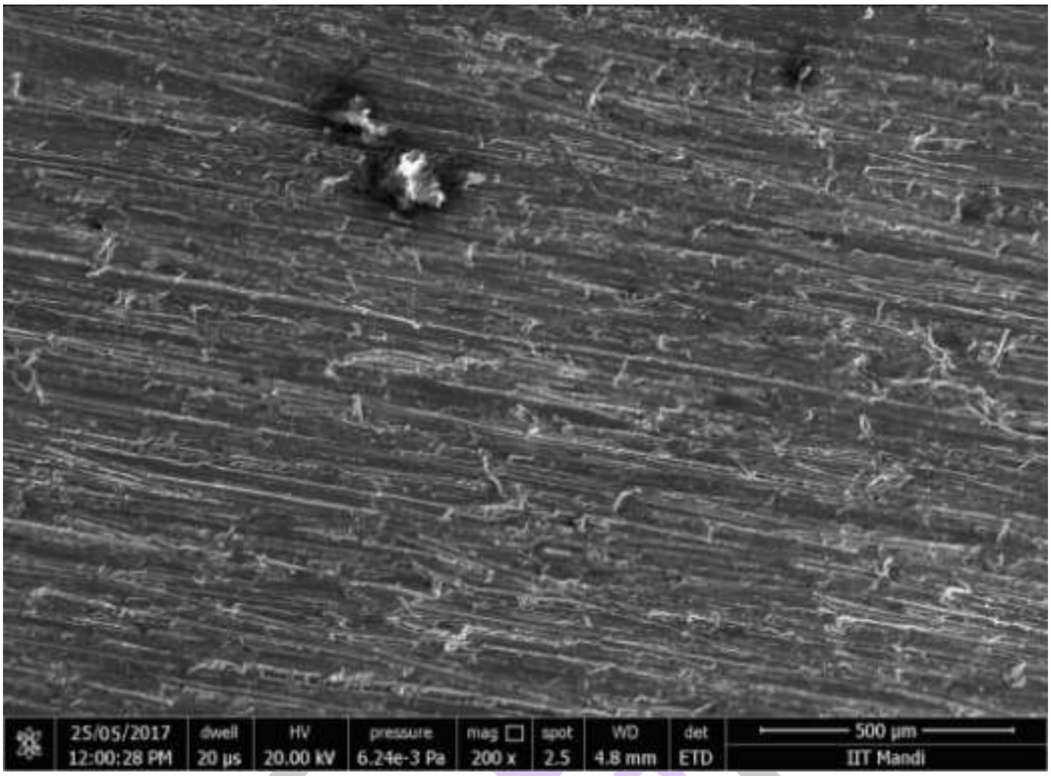

Figure 30SEM of MMCs with 4.5% micro Al_2O_3 (200×)

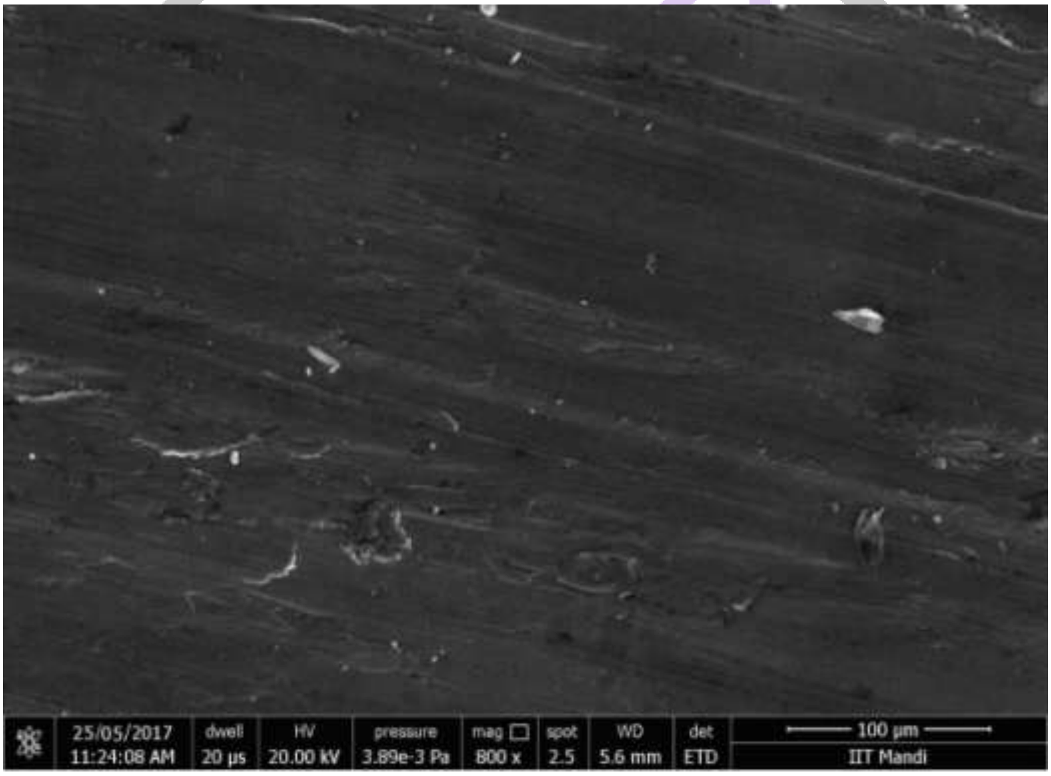

Figure 31 SEM of MMCs with 1.5% nano Al_2O_3 (800×)

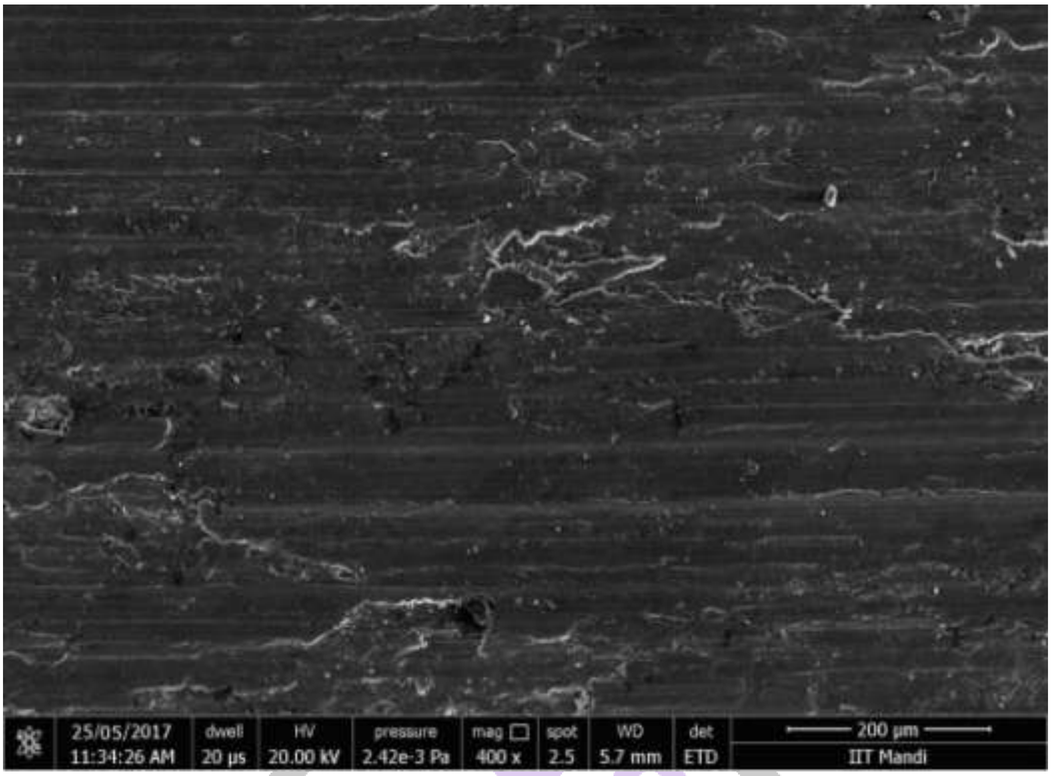

Figure 32SEM of MMCs with 3% nano Al_2O_3 (400×)

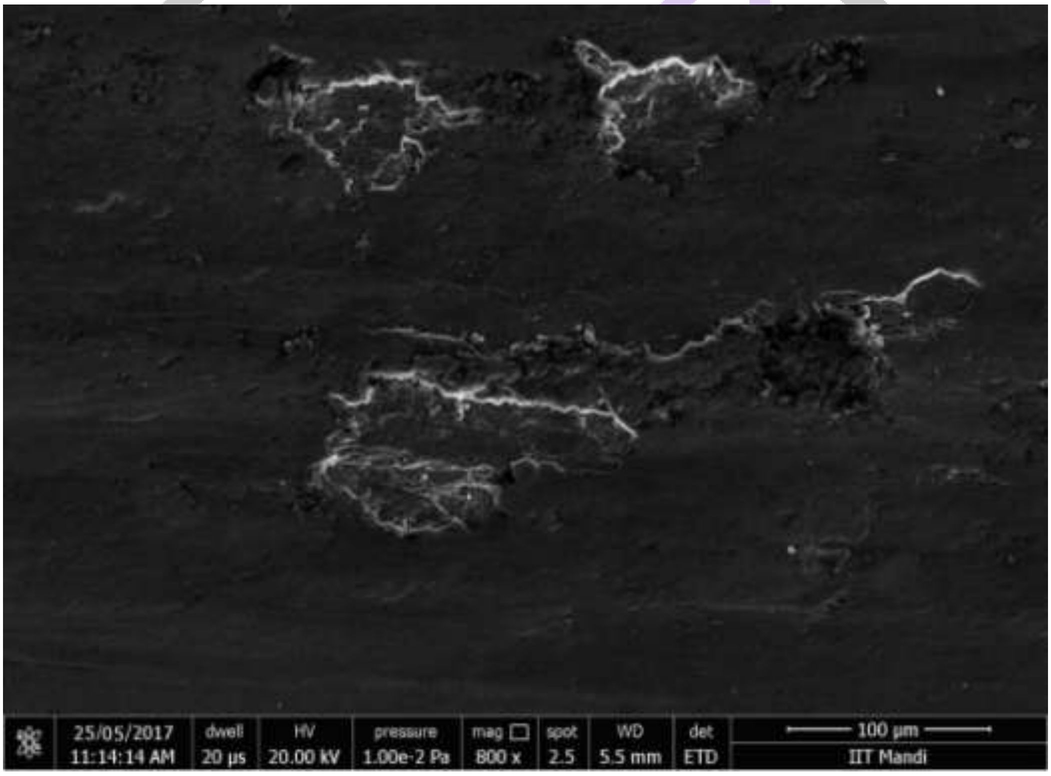

Figure 33 SEM of MMCs with 4.5% nano Al_2O_3 (800×)

Conclusions

1. For Al7075 alloys and fabricated composite specific wear rate increase with the increase in normal load and sliding distance while decreases with the increase in sliding velocity.
2. It is observed from the graphs that nano composite have better wear resistance than micro composites at different control factor.
3. SEM images of micro and nano composites reveal that agglomeration of particles increases with increasing wt. %age.

Scope for Future Works

1. Some MMCs can be manufactured by using other manufacturing techniques like powder metallurgy etc. and particles size can be further varied and wear can be calculate by other method and can be compared with above results.

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Though acknowledging is an endless task, I would like to express my sincere gratitude and thanks to all those who I might have inadvertently failed to mention here.

Needless to say, errors and omissions are mine.

Place: Solan (Er. Bhupender Pal)
Date: 15/08/2017

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