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Al-SiCp Nano Composite Material Experimental Investigation and Coated Carbide Insert Machining Process Analysis

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Abstract:
Al-SiCp Nano Composite Material with Ultrasonicator Development and Analysis are the topics of a recent paper. Aluminum serves as the matrix and SiCp serves as the reinforcement in this procedure. Three samples were created using an aluminium metal matrix and weight percentages of 1, 1.5, and 2 SiCp nanoparticles. The experiment revealed that a SiCp weight percentage of 2 in an aluminium matrix produces the optimum machining results. Three distinct parameters (speed, feed, and depth of cut) were used in four levels during the machining process on a CNC lathe with coated carbide inserts. PCA (principal component analysis) was utilised to optimise flank wear and surface roughness, while SEM (scanning electron microscope) was employed to determine the tool's condition. The ductility and hardness of the nano composite material were tested using chip morphology, and the influence of various machining operation parameters was determined using the ANOVA technique.

Keywords: Ultrasonicator; Scanning electron microscope; Ductility Flank wear; Chip morphology; Principal component analysis

1. Introduction

These days, the term "Al-SiCp nano composite material" is used to describe the fusion of two or more materials into a single nanomaterial with various chemical and physical properties. This particular composite material is created by the combining and development of properties that are not attainable with a single material. The composites may be designed and made to satisfy the requirements of the aerospace, medical, electronics, and other industries thanks to their excellent tailorability. Numerous composite materials, such as metal matrix composites, continuous fibre composites, carbon-carbon composites, cement matrix composites, ceramic matrix composites, and so on. The method utilised to combine the ingredients will determine how much the material for the composite will cost. Metal matrix composite, a form of composite material, is appropriate for the industrial sector. The main benefit of particle reinforced metal matrix composites, which have lower tensile strain than unreinforced metal matrix composites utilised in industrial applications and exhibit a wide range in fracture toughness.

2. Literature review

Li et al. [1] studied to disperse CNT into Al matrix by using SiCp as a carrier. They studied the fabrication of silicon carbide particles and its enhanced mechanical behaviour covered by in-situ carbon nanotubes reinforced 6061 AMMCs. Zhang et al. [2] experimentally analysed the mechanical properties and corrosion behaviour of Al/ SiC composites and fabricated by vaccum hot press sintering. They found that silicon has benificial effect to reduce the production of Al4C3. Bajpai et al. [3] tested Al-SiCp nano composites and investigated the mechanical properties by cold isostatic compaction process. They measured various properties like porosity, density, hardness, indirect tensile strength and compressive strength. Their investigations concluded, tensile strength, hardness and compressive strength of Al-SiCp nano composites initially increases up to 2 wt% SiCp and then decrease at 3 wt% of SiCp reinforcement. Du et al. [4] investigated and studied in-situ synthesis of SiCp and its strengthening effect on Al-Si -Cu-Ni-Mg piston alloy. They designed an in-situ 2% SiCp reinforced to Al-17.5Si-4.5 Cu-2 Ni0.65 Mg piston. They found some improvement in density, hardness, wear resistance and thermal expansion coefficients. Yashpal et al. [5] fabricated the Al-MMCs with particulate reinforcement. Their work reveals the increment in tensile strength as well as hardness of the composite due to increase in % of reinforcement and decrease in particle size. Wang et al. [6] analysed the tensile properties of Al-Cu/SiCp nanocomposites which are synthesized by semisolid stirring process using hot extrusion. The results showed that the a-Al dendrites were better formed and became finer with the formation of nano-sized SiCp in the a-Al grains. Reddy et al. [7] discussed the increase in performance of SiC nano size particle reinforced Al-MMNCs synthesized through hot extrusion techniques and microwave sintering. They fabricated aluminium MMNCs with SiCp nanp particle (0, 0.3, 0.5, 1.0 and 1.5% Vol.) reinforced and studied its thermal and mechanical properties. They observed that the ductility of Al-SiCp nano composites decreases by increasing in the vol. fraction of SiCp in Al-SiCp nano composites. Nandipati et al. [8] reviewed the mechanical properties of B4C nano-particles reinforced AA2024 Alloy and fabricated by ultrasonic cavitation method. In order to acquire uniform distribution ofB4C (nano-sized) particles in liquid Al alloy, they described a methodology for fabrication of bulk light-weight MMNC with superior properties and reproducible microstructures by the use of ultrasonic nonlinear effects i.e. acoustic streaming and transient cavitations. Their observations concluded that homogeneous microstructure and fine metal matrix composites were obtained with the gain in weight % of nano $_{B4Cp}$ content. The study also concluded that the ultrasonic nonlinear also affects the efficiently dispersed nano particles into molten alloy by increasing the wettability. Li et al. [9] studied the ultrasonic vibration and its effect on mechanical properties and microstructure of Al-5Cu compositesreinforced with nano-sized SiC particles. They synthesized the composites by using squeeze casting and high energy ball milling process. By applying the ultrasonic vibration, better scattering of SiCp was observed in microstructure observation. They also investigated some development in the properties of Al-alloy matrix with refinement of grains and proper nano particles distributions after the attribution of ultrasonic vibration. As magnesium is one of the promising metals due to its light weight and high performance, it can be used for the development of bulk magnesium composites. In order to fabricate the magnesium matrix nano composites, Sardar et al. [10] reviewed the fabrication and size of reinforcing particles of magnesium MC by ultrasonic assisted process. Kadivar et al. [11] investigated the ultrasonic-assisted vibration method and its effect on drilling of Al/SiCp MMC. They built two vibrations to vibrate the tool and excite the workpeice. They used 5 mm dia. HSS drill tools coated with TiN for drilling. They studied the parameters like cutting speed and feed rate and their effects are consideredon the drilling operation of Al/SiCp MMC. Their observations concluded that in case of ultrasonic vibration, the burr height, drilling force and surface roughness were reduced significantly as compared to conventional drilling.

It has been observed from the past literature review that a few studies have been conveyed so far in Al-SiCp metal matrix nano composite machined by coated carbide insert. So the research work is more concentrated on MMNC machined by coated carbide inserts. Experimentation

Aluminium material is very prevalent and has been widely used for its low melting point (630 CC), low density 2.7 g/cm^3 and its Rockwell hardness value 24HRB. The other property of aluminium is that it is light in weight but stiffness is high. Silicon Carbide Nano material (SiCp) is suitable for the fabrication process due to its high abrasive properties, high melting point (2730 CC) and also high strength. In the fabrication process, Aluminium powder is mixed with Silicon Carbide nano particle in the proper weight percentages. The experimental setup for Al-SiCp nano composite material as shown in Figure 1 consists of two chambers i.e. Primary chamber which consists of aluminium liquid metal pouring system, sieving system, feeder for SiCp Nano particle as well as high frequency mechanical vibrator and the Secondary chamber consisting of Ultrasonic generator and steel mold die for casting process. SiCp Nano particle is prepared by ball milling operation to make seize of nano particle 10–20 nm. These nano particle passes through various seize of sieves of the Primary chamber. The molten aluminium liquid metal is prepared in the furnaces and is entered through the pouring pipe and it is mixed with Silicon Carbide Nano particle in the primary chamber. The aluminium powder and Silicon Carbide Nano particle is completely mixed by a Mechanical vibrator (35KHz) in the primary chamber and that mixture entered in to the steel die which is surrounded by sufficient quantity of water in the Secondary chamber. Then, the ultrasonicator is started which generates ultrasonic waves at a frequency of 35–50 kHz. The high frequency of ultrasonic wave energy transfers to the steel mould die through the surrounded water in the ultrasonic chamber. The high energy of ultrasonic wave breaks the agglomeration of SiCp Nano particle to mix with aluminum liquid metal and AlSiCp nanocomposite casting ingot is formed in 4–5 min. Now, the casting ingot is prepared for samples.

3. Experimental methods

The lathe turning operation of Al-SiCp MMNC specimen is carried out by using CNC lathe machine. The specifications of CNC lathe machine are presented in Table 1.

Table 1: Specification of CNC lathe

Model	DX 200 4A
Motor Spindle Power	10.5 kW
Bed Swing	500 mm
Maximum Length of Turning	300 mm
Maximum Diameter of Turning	265 mm
Bore Spindle	50 mm
Nose Spindle	A25
Range of Chennai	50–4500 rpm

Positioning	0.007 mm
Repeatability	0.005 mm
Height of Machine	1780 mm

3.1 Parameter selection

The parameters selection is a vital point for machining operation. It should be noted that the parameters will lie within machining constraints and limit. Three parameters are selected i.e. feed (f) in mm/rev, depth of cut (d) in mm and cutting speed (v) in m/min are selected to conduct the experiment. Flank wear of tool (VBc) and surface roughness of work sample are considering for experimentation. Table 2 displays the process parameters and levels for the experimentation.

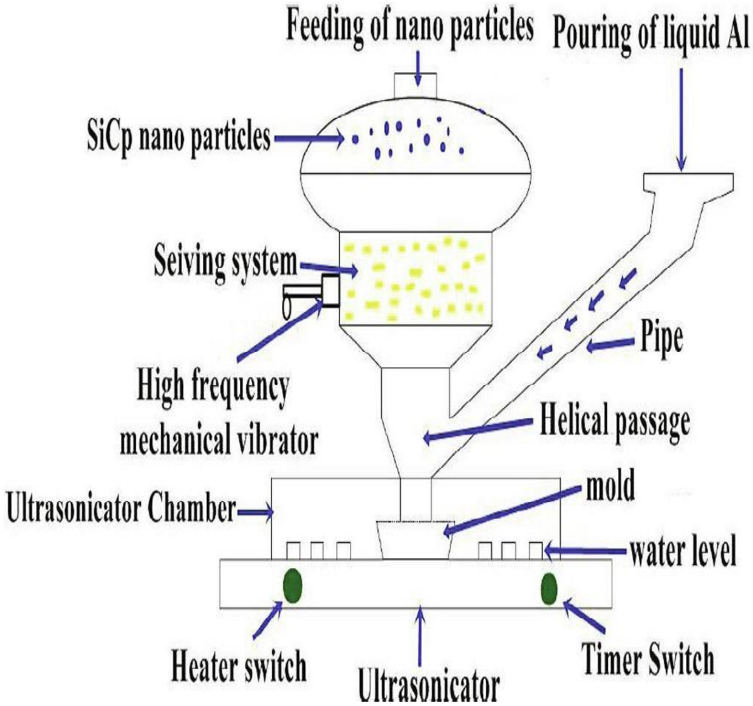

Figure 1: Schematic diagram of experimental setup.

Table 2: Ranges and levels for design of experimentation

Parameters/Levels	I	II	III	IV
v	70	140	210	280
f	0.05	0.10	0.15	0.2
d	0.1	0.2	0.3	0.4

3.2 Design setup using MINITAB

The Design of Experiment is conducted using MINITAB 17. The process parameters are selected at four different levels using Taguchi $_{L16}$ orthogonal array. Feed, depth of cut and cutting speed are considered as the three independent variables whereas flank wear of the tool and roughness of the work piece are taken as two dependent variables. This machining operation of Al-SiCp nano composite material involves of total 16 runs. The output of the experiment is evaluated for multilayer cutting carbide tool of AlSiCp nano composite materials during turning operations, which lies within the permissible ranges and it signifies the performance of the cutting insert. Analysis of Variance table indicates the importance of input parameters those are impacting the responses. The experimental table setup is presented in Table 3 having 16 numbers of runs.

Table 3: Design table of experimentation

Run No.	Process Parameters		
	Cutting Speed (v)	Feed (f) mm/rev	Depth of cut (d) mm
1	70	0.05	0.1
2	140	0.10	0.1
3	210	0.15	0.1
4	280	0.20	0.1
5	140	0.05	0.2
6	70	0.10	0.2
7	280	0.15	0.2
8	210	0.20	0.2
9	210	0.05	0.3
10	280	0.10	0.3
11	70	0.15	0.3
12	140	0.20	0.3
13	280	0.05	0.4
14	210	0.10	0.4
15	140	0.15	0.4
16	70	0.20	0.4

3.3 Experimental setup

Aluminium and silicon carbide Nano material Nano composite cast ingot is formed in rounded shape having 65 mm long and 44 mm diameter and is considered for dry turning operation in CNC lathe by coated carbide tool (CNMG 12040822 TN 6010). The machining operation is conducted on sample

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3 (2 wt%). When more than 2 wt% of SiCp is added to Aluminium matrix, it produces high viscosity, and that will not be convenient for machining operation [12].

As, tensile strength and hardness value of sample 3 is more than the corresponding value of sample 1 and 2, so sample 3 is considered for machining. Operation [12–15]. The cutting tool is taken and that was mounted on the tool holder. For each experimental run, 100 mm machining length is fixed and new cutting edge is used for each experimental run. A chip of the sample is collected for microstructural study. Table 4 displays the cutting conditions of CNMG 12040822 TN 6010.

Table 4: Cutting conditions of CNMG 12,040,822 TN 6010

Workpiece	Al-SiC_p metal matrix
Hardness	55 ± 1 HRC
Cutting environment	Dry
Tool holder	PCLNR2525M12
Responsesof workpiece	Flank wear of cutting insert and Surface roughness
Cutting tool insert geometry	CNMG 12,040,822 for coated carbide
Overhang length	30mm
Grade	HC S10 for coated

3.4 Assessment offlank wear and surface roughness of workpiece

The quality of the work piece depends on the roughness of its surfaces after machining process. If the deviation is more, then it is applicable for higher surface roughness whereas lesser deviation causes for smoother work surface. The measurement of surface roughness (Ra) of work piece is carried out by using Talysurf instrument and is expressed in micrometre (mm). Flank wear of the tool (VBc) in mm is obtained due to continuous contact of work material during machining operation. When the tool is eroded by continuous operation with finished part of work mate-rial, then failure of the tool takes place. Table 5 shows various input and output parameters for different experimental runs using Taguchi L16 orthogonal array.

Table 5: Experimental runs at different input parameters

Process Parameters			Response Parameters	
Cutting Speed (v)	Feed (f)	Depth of cut (d)	Ra (mm)	VBC (mm)
70	0.05	0.1	0.52	0.157
140	0.10	0.1	0.64	0.162
210	0.15	0.1	0.94	0.166
280	0.20	0.1	1.61	0.170
140	0.05	0.2	0.42	0.106

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70	0.10	0.2	0.67	0.078
280	0.15	0.2	0.74	0.189
210	0.20	0.2	1.53	0.184
210	0.05	0.3	0.68	0.146
280	0.10	0.3	0.59	0.198
70	0.15	0.3	0.96	0.217
140	0.20	0.3	1.18	0.208
280	0.05	0.4	1.01	0.130
210	0.10	0.4	0.74	0.226
140	0.15	0.4	1.06	0.200

3.5 *Optimization technique using principal component analysis*

PCA is a multivariate technique in which a linear composite of the original variables is formed by new uncorrelated variables [13–15]. In the current work PCA is used to optimize the process parameters in order to get an optimal setting. The objective of the optimization is to minimize the flank wear of the tool and roughness of the workpiece.

Table 6 displays the optimization of input parameters using PCA for coated carbide insert. It is observed that highest MPI (0.9010) occurs at experimental run 6 of the settings. Hence, the optimal condition for machining Al/SiCp MMNC's is Depth of cut 0.2- Cutting Speed 70- Feed 0.10.

Table 6: Optimization of input parameters using Principal Component Analysis

Sl. No.	R_a	V_{BC}	MPI
Ideal	1	1	1.0166
1	0.8076	0.4968	0.6013
2	0.6562	0.4814	0.5435
3	0.4468	0.4698	0.4663
4	0.2608	0.4588	0.4050
5	1	0.7358	0.8298
6	0.6268	1	0.9010
7	0.5675	0.4126	0.4674
8	0.2745	0.4239	0.3846
9	0.6176	0.5342	0.5689
10	0.7118	0.3939	0.4989
11	0.4375	0.3594	0.3895
12	0.3559	0.375	0.3753
13	0.4158	0.6	0.5529
14	0.5675	0.3451	0.4197

15	0.3962	0.39	0.3873
16	0.1900	0.3861	0.3317

4. Results and discussion

4.1 SEM analysis

The micro-structural analysis has been carried out for the tool insert. The tool after machining operation is placed under scanning electron microscope at 500x zoom. From Figure 2(a) it is noticed that some minute cracks and holes are formed on the tool surface at run no. 1 (70 m/min). Figure 2(b) captures the images of burrs on tool surface at run no. 4 (280 m/min) of the settings. This might be due to mismatch of ions between the workpiece and the tool materials during machining, resulting in the formation of holes. Further, high temperature is produced during machining of the tool and work-piece, resulting in the formation of cracks, holes and burrs on the tool surface.

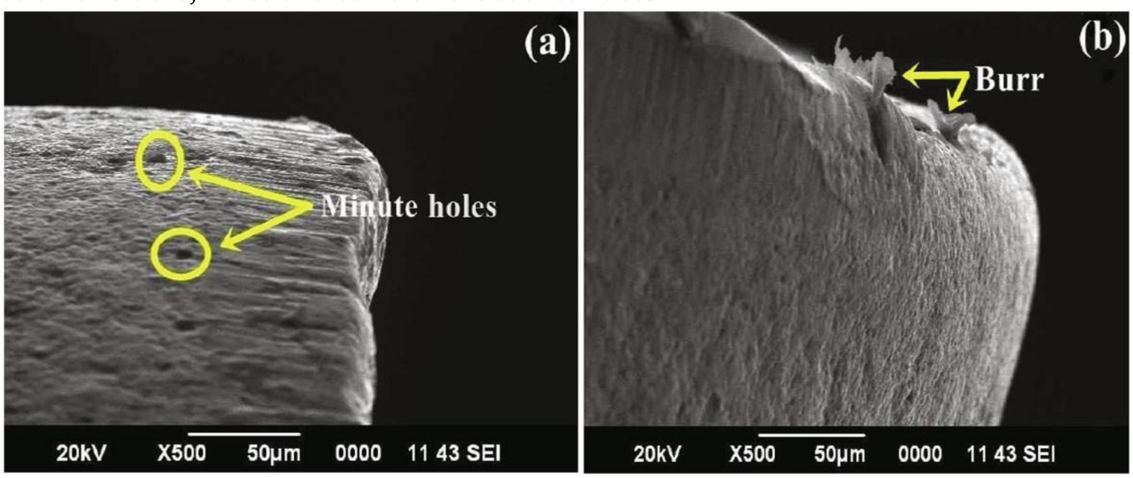

Figure 2: SEM view of tool insert after machining (a) minute holes at Run No. 1 (v = 70 m/min, f = 0.05 mm/revolution and d = 0.1 mm) and (b) burr at Run No. 4 (v = 280 m/min, f = 0.20 mm/revolution and d = 0.1 mm).

4.3 Main effect plot

Figure 3displays the main effect plot using Principal Component analysis. It is concluded that MPI decreases for the process parameters i.e. feed (f) and cutting speed (v). As the ductility property decreases, there is an increase in weight % of nano particles in the Al-metal matrix. As a result, with the rise in feed and cutting speed, MPI decreases. It is also observed that there is a gradual increase and sudden decrease in the MPI for depth of cut (d). This might be due to the development of vibration during dry turning machining operation.

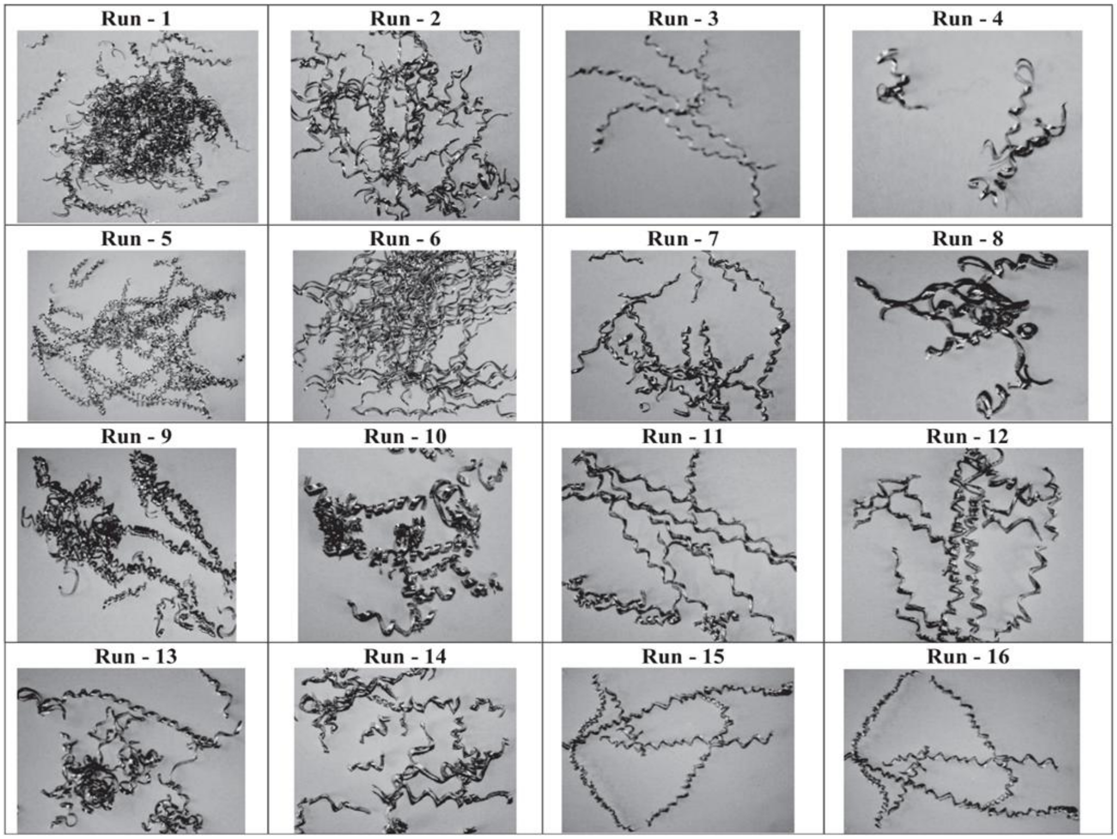

Figure 3: Main effect plot for Multiple Performance Index (MPI).

4.4 Analysis of Variance (ANOVA) for means

Analysis of variance signifies the most vital process parameters affecting the responses. Table 7 shows the ANOVA table for PCA. P denotes the probability test. The factor is said to be significant If the value of P is <0.05, [12–15]. It is noticed from table that the crucial parameters affecting the Multiple Performance Index is only feed.

Table 7:ANOVA table for means

Source	DF	Adj SS	Adj MS	F	P	Remarks
Regression	3	0.23752	0.07917	6.31	0.008	
Feed (f)	1	0.18255	0.18255	14.55	0.002	Significant
Depth of Cut (d)	1	0.03714	0.03714	2.96	0.111	
Cutting Speed (v)	1	0.01783	0.01783	1.42	0.256	
Error	12	0.15058	0.01255			
Total	15	0.38810				

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Table 8: Comparison of statistical and experimental model values of MPI

Experimental Run	Experimental Values	Statistical Values
1	0.4204	0.3707
2	0.2665	0.2412
3	0.3183	0.2881
4	0.3751	0.4044
5	0.3529	0.3135
6	0.7599	0.7381
7	0.3095	0.2686
8	0.3087	0.2699
9	0.4679	0.5095
10	0.3229	0.2718
11	0.2315	0.2022
12	0.2449	0.2162
13	0.2803	0.2412
14	0.3354	0.3766
15	0.3379	0.2958
16	0.2434	0.2249

4.5 Statistical model for MPI

The equation of regression is obtained by using MINITAB software by selecting proper input parameters to the model. Eq.(1) shows the equations of regression obtained from the model.

MPI = 0.929 - 1.911 * f - 0.431 * d - 0.000427 * v………………………………………… (1)

R2 = 95.2%, R^2 (predicted) = 93.29%, R^2 (adj) = 91.22%

Regression coefficients (R^2) of 95.2% indicate a good sign of predicted values with experimental runs.Figure 4displays the comparison of experimental and statistical model values for Multiple Performance Index. The graph also determines a good result confirming the model stability.Table 8 shows the comparison of statistical and experimental model values for all 16 numbers of runs.

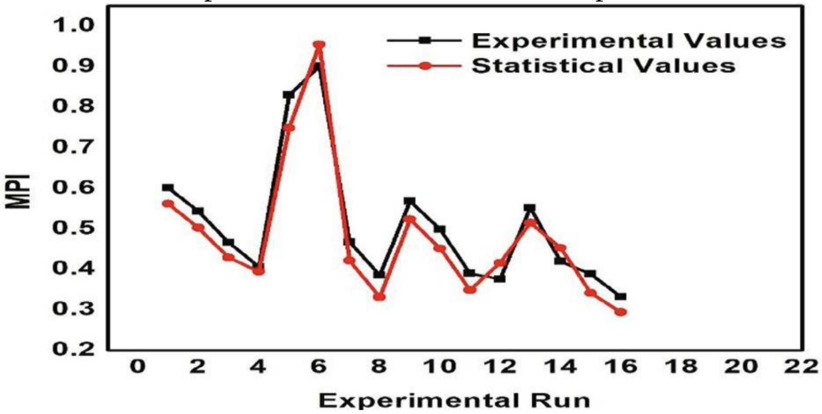

Figure 4: Comparison of MPI experimental and statistical values

5. Conclusions

The most recent study paper work supports the proper mixing of 2 weight percent of SiCp nanoparticle in the aluminium metal matrix using an ultrasonicator and a solidification casting method. Principle component analysis (PCA) was used to optimise the flank wear of the cutting insert and the work piece's surface roughness, which led to the best parameter settings and contributed to a secure machining process. The cutting tool's stability and compatibility for machining operations were observed from the experimental observation. As the ductility is decreased and the hardness is increased during the machining of Al + SiCp, long coiled and open helical chips can be seen clearly. Without undergoing any permanent distortion, tool wear growth decreases, allowing cutting tool sharpness. According to the primary effect plot, the Multiple Performance Index (MPI) lowers as a result of raising process parameters, however the MPI's decline shows a decrease in the material's ductility as a result of raising the weight percentage of nanoparticles in the aluminium metal matrix. The Multiple Performance Index is most significantly impacted by the ANOVA table results. The examination of the regression equations shows a strong correlation between the experimental and statistical models, demonstrating the applicability and stability of the model.

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