DEVELOPMENT OF Al-SiCp NANO COMPOSITE MATERIAL AND EXPERIMENTAL INVESTIGATION OF ITS MACHINING PROCESS BY COATED CARBIDE INSERT.

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ABSTRACT

This paper deals with development of Al-SiCp Nano Composite Material using ultrasonicator. In this process, aluminum is taken as matrix and SiCp nano material is taken as reinforcement. For experimental investigation three samples were prepared by 1,1.5 and 2 weight percentage of SiCp Nano Particle with aluminum metal matrix.It was observed that 2 weight percentage of SiCp in the aluminum matrix gives the best results for machining operation. In the machining process, CNC lathe machine and coated carbide inserts ware used and Taguchi L_{16} technique was used in three different parameters (speed, feed and depth of cut) in four levels. The flank wear and surface roughness of tool was optimized PCA (principal component of analysis) and SEM (scanning electron microscope) was used for finding out the status of tool. The chip morphology was conducted for ductility and hardness of the nano composite material and ANOVA technique was used for finding out the influence parameters during machining operation

Keywords: Ultrasonicator Scanning electron microscope Ductility Flank wear
Chip morphology

1. Introduction

Al-SiCp nano composite material is refer days combination of two or more material with one is nano material having different chemical and physical properties. This unique composite material is formed by the combination and characteristics developed by the materials which can't be possible by a single material. Because of the strong tailorability, the composites can be designed and fabricated to meet the demands of aerospace industries, medical sector, electronics, and other industries. Various composite materials like- continuous fibre composites, carbon-carbon composites, cement matrix composites, ceramic matrix composites, polymer matrix composites and metal matrix composites etc. The cost of the composite's material depends upon the technique used for combination of the materials. Among all type of composite materials, metal matrix composite is suitable for industrial section. The main advantage of metal matrix composites which pauses great variation in fracture toughness and particulate reinforced metal matrix composites have lower tensile strain then unreinforced metal matrix composites which are used for industrial applications.

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 behavior covered by in-situ carbon nanotubes reinforced 6061 AMMCs. Zhang et al. [2] experimentally analyzed the mechanical properties and corrosion behavior of Al/ SiC composites and fabricated by vacuum hot press sintering. They found that silicon has beneficial 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 nanoparticles 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 lightweight 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 composites reinforced 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 Orde 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 workpiece. 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 considered on 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.

3. Experimentation:

Aluminiu*m m*aterial 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 aluminum 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 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 Fig. 1 consists of two chambers i.e. Primary chamber which consists of aluminum 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 aluminum 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 aluminum powder and Silicon Carbide Nano particle is completely mixed by a Mechanical vibrator (35KHz) in the primary chamber and that mixture entered into 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 Al-SiCp nanocomposite casting ingot is formed in 4–5 min. Now, the casting ingot is prepared for samples.

4.Machining of Al-SiCp workpiece

4.1. 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.

4.2. Parameter selection

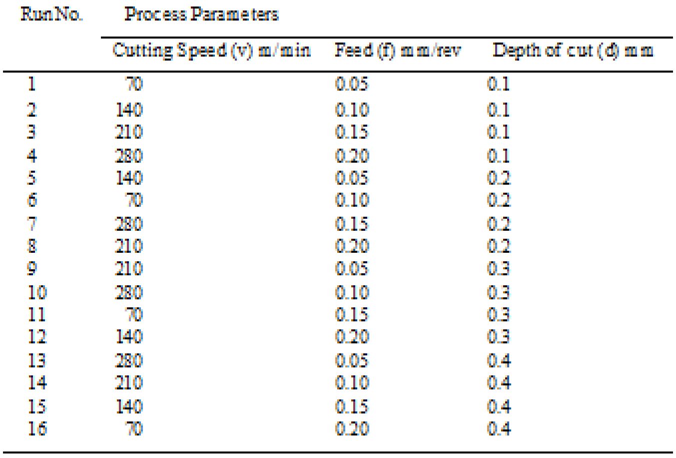
The parameters selection is a vital point for machining operation. It should be noted that the parameters will lie within machining constraints and limit. Three parameters are selected i.e. feed (f) in mm/rev, depth of cut (d) in mm and cutting speed (v) in m/min are selected to conduct the experiment. 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.

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

Table 2
Ranges and levels for design of experimentation.

4.3. Design setup using MINITAB.

The Design of Experiment is conducted using MINITAB 17. The process parameters are selected at four different levels using Taguchi L_{16} 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 number of runs.



Run No.	Process Parameters		
	Cutting Speed (v) m/min	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

Table 3

Design table of experimentation.

4.4. 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 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. Chips 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.

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

4.5. Assessment offlank wear and surface roughness of workpiece

The quality of the 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 material, 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)	R_a (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
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
70	0.20	0.4	2.21	0.202

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.	Normalized data		MPI
	Ra	VBC	
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

6. Results and discussion

6.1. 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 Fig. 2(a) it is noticed that some minute cracks and holes are formed on the tool surface at run no. 1 (70 m/min). Fig. 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.

6.2. Chip morphological analysis of cutting tool

The chip image analysis of cutting tool is presented in Fig. 3. Long coiled and open helical chips can be clearly visible while machining Al + SiCp with the reduction in the ductility and increase in the hardness. There are also occurrence of and close-coiled and highly segmented chips during machining. It is noticed that the chips are strained during breaking and cutting as there is an increase in hardness and reduction in ductility. There is also a reduction in cutting temperature and is due to the thermal barrier of the coated insert. The tool wear growth reduces without any permanent deformation enabling sharpness of the cutting tool. Further, due to the rise in the cutting temperature the chips are obtained at depth of cut 0.3 mm and 0.4 mm which accelerated the tool wear growth.

6.3. Main effect plot

Fig. 4 displays the main effect plot using Principal Component analysis. From Fig. 4 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 gradu

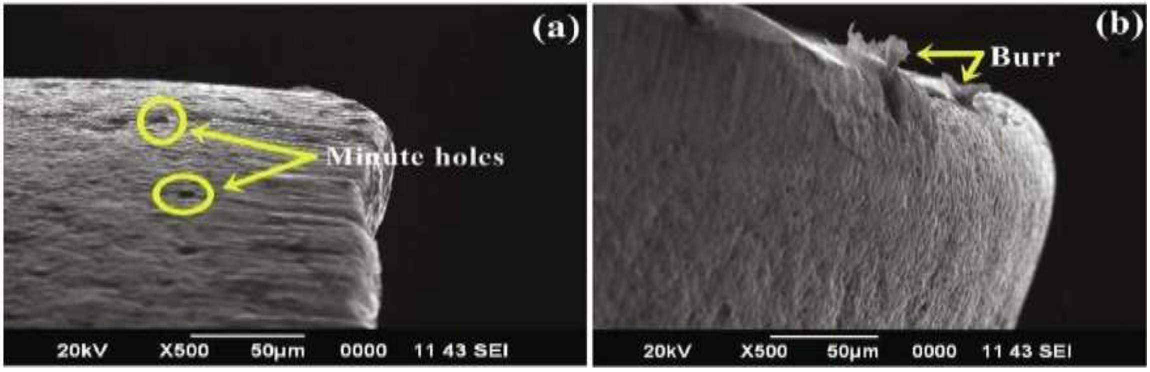
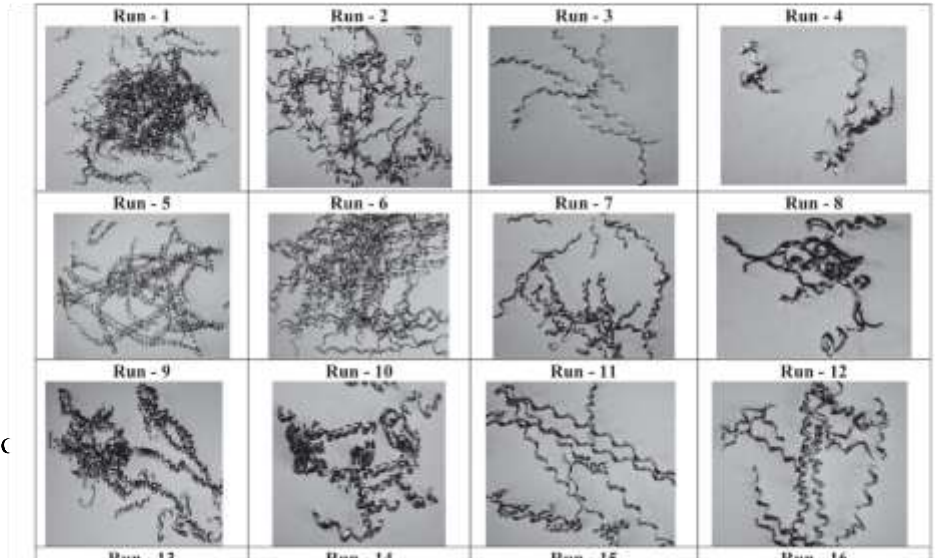


Fig. 2. SEM view of tool insert after machining (a) minute holes at Run No. 1 (v = 70 m/min, f = 0.05 mm/revolution and d = 0.1 mm) and (b) burr at Run No. 4 (v = 280 m/min, f = 0.20 mm/revolution and d = 0.1 mm).



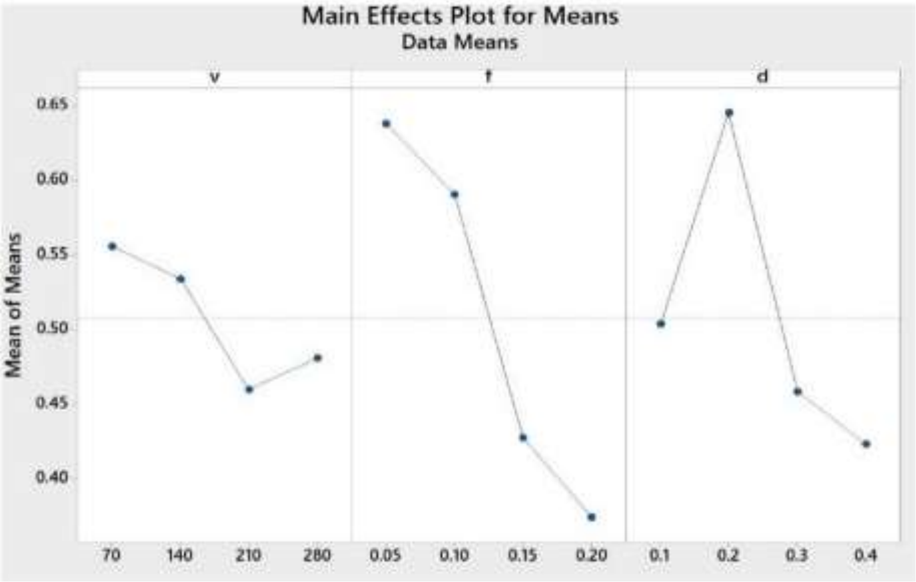


Table 7

ANOVA table for means.

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

(d). This might be due to the development of vibration during dry turning machining operation.

6.4. 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.

6.5. 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.

$$MPI = 0.929 - 1.911 * f - 0.431 * d - 0.000427 * v \quad (1)$$

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

Regression coefficients (R^2) of 95.2% indicates a good sign of predicted values with experimental runs. Fig. 5 displays 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 number of runs.

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

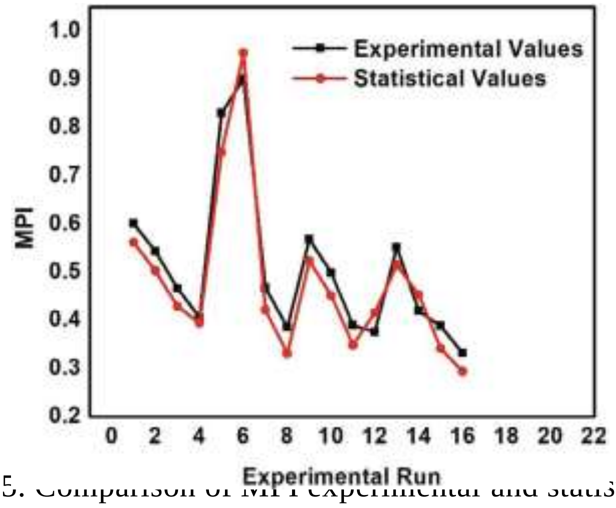


Fig. 5. Comparison of MPI experimental and statistical values.

7. Conclusions

The recent research paperwork justifies 2 wt% of SiCp nano particle mixes properly in the aluminium metal matrix by means of ultrasonicator with a solidification casting process. The flank wears. of the cutting insert and surface roughness of the work piece were optimized by using Principal component analysis (PCA) which results in the optimal setting of parameters and helps for a safe machining process. From the experimental observation, it was observed that the cutting tool proves its stability and suitability for machining operation. Long coiled and open helical chips can be clearly visible while machining Al + SiCp with the reduction in the ductility and increase in the hardness. The tool wear growth reduces without any permanent deformation enabling sharpness of the cutting tool. From the main effect plot, Multiple Performance Index (MPI) decreases due to increase of process parameters whereas decrease of MPI indicates the reduction of ductility of the material a with the increase in wt. % of nano particle in the aluminium metal matrix. ANOVA table results feed to be the most crucial parameters affecting the Multiple Performance Index. The regression equation analysis indicates a good result in between experimental and statistical models which proves the suitability and stability of the model.

Credit authorship contribution statement

Pradyut Kumar Swain: Conceptualization, Methodology, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The author declares that I have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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