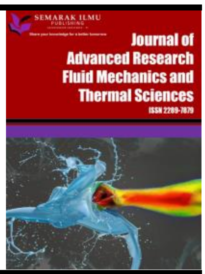
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Characterization and Machinability Studies of Aluminium-based Hybrid Metal Matrix Composites – A Critical Review

Suhas Prakashrao Patil[1], Sandeep Sadashiv Kore[1,*], Satish Suresh Chinchanikar[1], Shital Yashwant Waware[2]

[1] Department of Mechanical Engineering, Vishwakarma Institute of Information Technology, Pune, India
[2] Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Technology Pimpri, Pune, India

ARTICLE INFO

Article history:
Received 17 June 2022
Received in revised form 13 November 2022
Accepted 25 November 2022
Available online 15 December 2022

Keywords:
Hybrid metal matrix composite; machinability; turning; cutting parameters; optimization

ABSTRACT

Metal matrix composites (MMCs) are attracting automobile and aeronautical sector because of their superior mechanical and physical characteristics which ultimately reduce the weight of components and hence the energy requirements. These composites are prepared by adding various reinforcements into the base metal by the methods like stir casting, squeeze casting, stir and squeeze casting, sand casting, in-setu method, powder metallurgy etc. When more than one particle is added into the base metal; these composites are called as Hybrid Metal Matrix Composites (HMMCs). The machinability of these hard to cut materials is a challenging task in front of manufacturing industry. Present study considers turning operation of HMMC done on either lathe or CNC machine by using different cutting tool materials. This review focuses on effect of various cutting parameters like speed, depth of cut, feed and also the parameters like reinforcement particle type, particle size and weight percentage on the machinability issues like surface roughness, MRR, cutting forces, tool wear etc. Further the various optimization methods used to suggest the cutting parameters to obtain minimum surface roughness, minimum cutting forces, minimum tool wear and maximum Material Removal Rate (MRR) are addressed.

1. Introduction

Due to their superior characteristics, such as low density, stiffness and high specific strength as well as low coefficient of expansion, hybrid metal matrix composites (HMMCs) are being employed for a variety of applications in the automotive and aerospace sectors.

Composite materials are classified into two types. First type is based on matrix such as metal matrix, polymer matrix and ceramic matrix composite. Second type is based on reinforcement's type such as particulate, fibre or whiskers. Now-a-days; particulate metal matrix composite is widely used. Particulate metal matrix composite consists of a base metal and a reinforcement particle. Base metal may consist of aluminium, magnesium etc and the reinforcement may consist of particles like silicon

* *Corresponding author.*
E-mail address: sandeep.kore@viit.ac.in

https://doi.org/10.37934/arfmts.101.2.137163

carbide, graphene, boron carbide, alumina, carbon nano tubes, titanium boride or materials like rock dust, egg shell, fly ash, sugarcane ash or jute etc. Various preparation methods are used to add these reinforcements into the base metal but stir casting is the most suitable method as it evenly distributes the reinforcement particles into the base metal.

Due to improved mechanical characteristics; HMMCs are being challenging to cut. Hence there is need to work on machinability of these composites. Machinability is described in terms of response parameters like surface roughness, MRR, cutting forces, tool wear. Various cutting parameters are varied to obtain these response parameters. The cutting parameters include the cutting speed, interface temperature between tool and workpiece, feed rate, depth of cut, tool or workpiece material, etc.

Several researchers have applied Design of Experiment (DOE) to reduce the number, time and cost of the experiments. Enhancing the quality attributes of the responses requires the optimization of process parameters. Turning is most commonly used operation in the manufacturing industry; hence optimising it is critically needed. Industrial procedures can be made more efficient by various optimization techniques such as Taguchi method, Genetic algorithm, Fuzzy logic etc.

2. Machining of Aluminium-Based Metal Matrix Composites

Metal Matrix Composites are prepared by various researchers and machining of these MMCs is carried out. Details of preparation methods and machining of MMCs is reviewed as below:

i. Base material: Various researchers have used different aluminium alloys as base metal viz. AA7075, Al6063, Al6061, LM6, Al2024, LM25, A356, Al2124, 2009 Al alloy etc. From this study it comes to know that major research is done by taking either Al6061 or Al6063 as a base metal while relatively less focus is given to other alloys as mentioned above
ii. Addition of reinforcements in base metal: Different researchers have added various materials as reinforcements in the base metal as shown in Figure 1. In current review; 17 % literature considered only SiC as a reinforcement material; 11% used SiC with addition of other metals such as boron carbide, graphene, carbon nanotubes, titanium boride etc; 2% used SiC with addition of other metals such as rice husk ash, fly ash etc; 17 % literature considered the metals other than SiC such as titanium boride, Hexagonal boron nitride, boron carbide, Stainless steel 316L flakes, zircon boride, titanium carbide, aluminium oxide; 11% used only non-metals such as eggshell, rock dust, sugarcane ash, groundnut shell ash, jute ash, fly ash while 8% researchers not added any metal or non-metal as reinforcement in aluminium alloy.

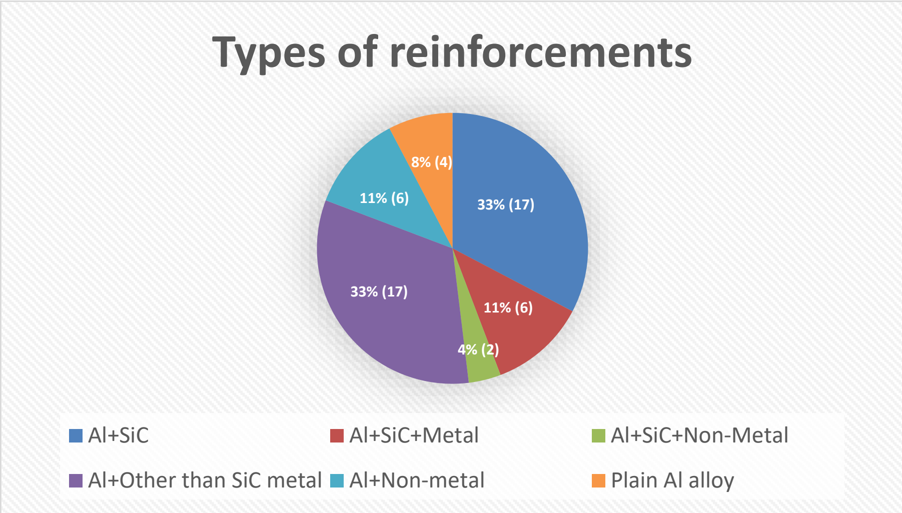


Fig. 1. Addition of reinforcements in base metal

iii. Preparation method: Various preparation methods like stir casting, stir and squeeze casting, sand casting, powder metallurgy is used by the researchers but stir casting is the most suitable method as it evenly distributes the reinforcement particles into the base metal.

iv. Machining processes: Different machining processes like turning, milling, grinding, drilling etc can be applied to MMCs depending upon its industrial application. As turning is most common machining technique in the industry; this review focusses on turning of MMCs.

v. Input parameters and responses: This review considers various machining parameters like depth of cut, cutting speed, feed with varying percentage of reinforcement material, cutting tool material etc as input parameters. The response parameters include 'SR', MRR, cutting forces, energy consumption, cutting temperature, hardness, tool life, tool wear, residual stresses, morphology, fatigue strength, tensile strength, compressive strength, percentage elongation, diffraction analysis etc.

vi. Methodology: Researchers have prepared the MMC by various preparation methods as mentioned above. Machining of these MMCs is carried out on CNC machine or conventional lathe machine. Number of experiments to be performed is decided by Design of Experiment (DOE) technique by using different orthogonal array, ANOVA is performed for statistical analysis and regression equations are formed. Optimisation of machining parameters is carried out by using different optimisation techniques such as Response surface methodology (RSM), Grey relational Analysis (GRA), TOPSIS etc.

MMCs categorised as shown in Figure 1 are reviewed in detail as follows.

2.1 MMCs having SiC as a Reinforcement Material (Al + SiC)

Nearly 33% researchers have added only SiC as a reinforcement material in varying proportions. Following are the details of it.

2.1.1 Base metal used

Various researchers have used different aluminium alloys as base metal viz. AA7075, Al6063, Al6061, LM6, Al2024, LM25, A356, Al2124, 2009 Al alloy.

2.1.2 Percentage and size of reinforcement particles

Researchers have added SiC as a reinforcement in various aluminium alloys as mentioned above in varying proportions from 1% to 25% by weight. While some researchers have added it in the proportion varying from 13% to 65% by volume. Size of these particles varied from 0.3 micron to 50 micron.

2.1.3 Range of input parameters

Machining parameters are varied by different researchers to get the values of responses. Cutting speed values are varied from 30 m/min to 900 m/min, feed values are varied from 0.04 mm/rev to 0.6 mm/rev and depth of cut values are varied from 0.15 mm to 2.5 mm.

2.1.4 Methodology used by different researchers

Ic *et al.,* [4] added 10 % SiC nanoparticles into the base metal of Al6063 by stir casting method. The cylindrical rods of this composite were turned on conventional lathe machine by taking input parameters as spindle speed as 900 RPM, 'Z' as 1 mm, cutting tool material as KNUX1605X. The performance parameters were ‘SR’, energy consumption, and hardness. To determine how many experiments would be conducted, the Design of Experiment was employed. ANOVA technique was applied, formed regression equations and Optimum machining parameters were achieved by Goal Programming method. At the end the authors came to know that ‘SR’ is increased when the depth of cut is increased and the spindle speed is increased

Balasubramanian *et al.,* [7] taken LM6 as a base metal and added SiC in various proportions as 8%, 10% and 12% respectively to form three separate samples by stir casting method. A little amount of magnesium has been added to the molten alloy to improve the wettability of SiC particles. Hexachloroethane-degassing tablets were gradually inserted in order to prevent the specimen's blowholes from forming in the molten metal. The rods of this composite were turned on CNC turning centre by taking input parameters as spindle speed, feed and depth of cut. Cutting temperature, cutting forces such tangential, axial, and radial forces, and acceleration of vibration, profile roughness were the performance metrics. The authors have achieved optimum parameters through the application of ANOVA and RSM. Regression analysis was used to develop mathematical model and the same was verified by practical tests. The authors came to the conclusion that the feed rate has the greatest impact on cutting temperature.

Bhushan *et al.,* [8] added 10 weight % SiC nanoparticles into the base metal of Al7075 by stir casting method. The cylindrical shaped rods of this composite were turned on CNC lathe machine by taking input parameters as ‘X’ (90, 150, 210) m/min, ‘Y’ (0.15, 0.20, 0.25) mm/rev, 'Z' (0.2, 0.4, 0.6) mm and nose radius (0.4, 0.8, 1.2) mm. The performance parameters were ‘SR’ and tool life. Impact of cutting parameters on response parameters was studied by applying RSM. The authors conducted thirty experiments at three levels. ANOVA was done and regression equations were formed. To obtain optimum values of either ‘SR’ or tool life separately; desirability analysis was used while to obtain optimum values of both the response parameters at a times; desirability approach was used.

Wang *et al.,* [20] had added 20% volume fraction of SiC into Al2024 base metal. The specimens of this composite were turned by taking input parameters as cutting speed and cutting depth - the 'X' was chosen as (250, 520, 780, and 1200) mm/s, while 'Z' was chosen from (20 to 110) µm with an interval of 30 µm. The performance parameters were cutting mechanism, cutting force, ‘SR’. After researching potential SiC particle fracture mechanisms during the turning process, the scientists have discovered three different types of fracture. Additionally, a link is shown between particle size and 'SR'. Additionally, the effects of machining settings on cutting force were investigated. The authors came to the conclusion that the relative position of the cutter in relation to the SiC particle affected the way the particles were removed. The particle size has a considerable impact on the machine surface quality of SiCp/Al MMCs.; the 'SR' was near to the particle radius. For this composite, the average cutting force decreased as the particle size increased, however the peak cutting force exhibited the opposite trend.

Aurich *et al.,* [21] used stir casting method to add 17% and 30% volume fraction of SiC having particle size of 0.6 micron and 3 microns by taking pure Aluminium as a base metal. The rods of this composite were turned on CNC lathe by taking input parameters as 'X', 'Y' and 'Z'. The performance parameters were workpiece roughness and residual stresses. The effects of the silicon reinforcements and the workpiece roughness were investigated experimentally in dry turning. Three composites of varying proportion of SiC reinforcements and their non-reinforced aluminium matrix alloy are considered as the workpiece. The authors came to the conclusion that the feed was the most significant cutting parameter for the 'SR'. When compared to low feeds, high feeds reduced the residual tension in the workpiece's surface. However, employing high feeds significantly reduces the surface quality.

Krishnamurthy *et al.,* [34] taken aluminium as base metal while SiC and graphite were taken as reinforcements in the proportions of 0%, 2.5%, 5.0%, 7.5% and 10% each. The mixing of these reinforcements was done by liquid metallurgy route. The cylindrical rods having 60 mm diameter and 180 mm length were turned by carbide tipped cutting tool on a centre lathe by taking machine parameters as 'X' (100,160,220,280,340) m/min, 'Y' rate (0.04, 0.06, 0.08, 0.1 and 0.12) mm/rev, 'Z' (0.15,0.30,0.45,0.6,0.75) mm and reinforcement (0, 2.5, 5, 7.5, 1) %. The performance parameters were Cutting forces and 'SR'. The machinability characteristics of composites made of aluminium, silicon carbide, and graphite have been studied by the authors. Regression machinability models have been constructed and the Design of Experiments technique is used to express how much the resultant force depends on the cutting parameters and the proportion of reinforcement. As shown in Figure 2; as percentage of SiC reinforcements increases; resultant force increases while graphite reinforcements show opposite trend.

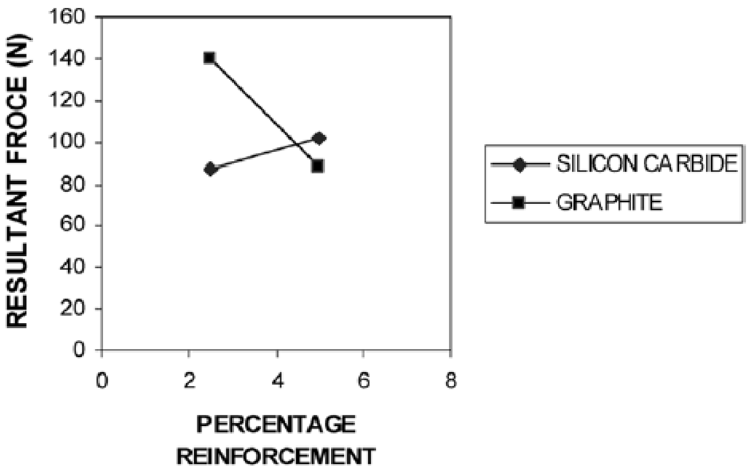


Fig. 2. Percentage reinforcement vs. resultant force [34]

Sahoo *et al.,* [35] taken AA6061 as base metal while 10% SiC was added as reinforcement by stir casting method. The composite rods were turned by multilayer coated carbide insert on CNC lathe of 16KW power. Machining parameters were taken as ‘X’s (60, 120, 180) rpm, ‘Y’ rate (0.05, 0.1, 0.15) mm/rev and ‘Z’ (0.2, 0.3, 0.4) mm while performance parameters were Flank wear and ‘SR’. Optimum machining parameters were found by Grey relational analysis method. In contrast to low ‘X’ (60 m/min), the authors found that flank wear increased at higher ‘X’ (180 m/min). Up until 0.1 mm/rev, ‘SR’ increases with feed increase, and above 0.15 mm/rev feed, surface quality declines. The multi-layer TiN coated carbide insert has also been found to have higher machining performance. TiN offers lubricity, which lowers friction, interface temperature, and wear rate.

Joardar *et al.,* [36] taken LM6 as base metal while 10% SiC was added as reinforcement by stir casting method. The composite rods of length 60 mm were turned by lathe machine. The machining parameters were ‘X’ (30, 60, 90) rpm, ‘Z’ (0.5, 1.0, 1.5) mm and weight % of SiC (7.5, 10.00, 12.5) while performance was cutting force (Tangential, Axial, Radial). Analysis of variance was used to create the mathematical models and assess their suitability. The outcomes demonstrated the accuracy of the mathematical models for the cutting forces

Palanikumar *et al.,* [37] taken LM25 as base metal while SiC (Particle size of 25 micron) was added as reinforcement in the varying proportions of 10%, 15% and 25%. The composite rods were turned by PSG 141 lathe using carbide tool insert. The machining parameters were % Volume fraction of SiC (10, 15, 25) %, ‘X’ (50 100, 150) m/min, ‘Y’ (0.20, 0.40, 0.60) mm/rev, ‘Z’ (0.5, 1.5, 2.5) mm and machining time (3 6, 9) min while performance parameters were MRR and ‘SR’. The authors came to the conclusion that the key criteria for ‘SR’ were feed and the percentage volume fraction of SiC.

Kremer *et al.,* [38] taken 2009 aluminium alloy as base metal while SiC was added as reinforcement in the varying proportions of 5% and 15% by powder metallurgy method. The cylindrical rods of composite material were turned by CNC lathe. The machining parameters were ‘X’ (400,500,600,700,800,900) m/min, ‘Y’ rate (0.1, 0.3) mm/rev while performance parameters were tool life and surface quality. Three various CVD diamond-coated tools were used to rotate the components. The authors came to the conclusion that the multilayer coating produced outcomes that were comparable to those of the monolayer coating.

Palanikumar *et al.,* [39] taken A356 as base metal while 20% SiC was added as reinforcement by stir casting method. The rods of 48 mm diameter and 175 mm length of composite material were turned by CNC lathe using PCD insert. ‘SR’ was a performance parameter whereas the machining parameters were ‘X’ (75, 125, 175) m/min, ‘Y’ (0.1, 0.2, 0.3 mm/rev) and depths of cut (0.50, 1.0, 1.5) mm. The empirical relation was used to optimise the cutting parameters. According to the article's conclusions, while ‘SR’ increases with increased feed, it decreases with increased cutting speed. The ideal outcome is achieved with a medium depth of cut.

Wanga *et al.,* [40] taken Al6063 as base metal while SiC with volume percentage of 65 was added as reinforcement by stir casting method. The milling operation was performed on DMU80 mono BLOCK (DMG). The machining parameters were milling speed (100, 400) m/min, ‘Y’ rate (0.02, 0.1) mm/rev and axial ‘Z’ (0.1, 0.3) mm while performance parameter were ‘SR’, residual stress and morphology. Experiments on the unreinforced aluminium material Al6063 were also conducted in order to compare it to the composite material.

Sudheer *et al.,* [41] taken Al6061 as base metal while 15% SiC with was added as reinforcement. Composite material was prepared in cylindrical shapes having diameter of 75 mm and length of 300 mm. The turning operation was performed on TMX-2030 engine lathe. The machining parameters were ‘X’ (34, 64, 94) m/min, ‘Y’ (0.113, 0.178, 0.249) mm/rev, ‘Z’ (0.25, 0.5,0.75) mm while performance parameters were ‘SR’ and MRR. In this research work, the effect on ‘SR’ due to carburising flame and oxidizing flame during turning of Al based composites is determined. The results achieved were examined with dry machining. Multiple regression was used to generate the mathematical models.

Kim *et al.,* [42] taken Al2124 as base metal while 17% volume fraction of SiC having particle size of less than 0.3 micron was added as reinforcement. Composite material was prepared in the cylindrical shapes having diameter of 75 mm and length of 2500 mm. The turning operation was performed on Universal lathe. Performance parameter were cutting forces and cutting temperature. In this study, four machining scenarios—conventional turning, ultrasonic-assisted turning, laser-assisted turning, and laser ultrasonic-assisted turning—were used to conduct dry turning operations.

Sharma *et al.,* [46] taken 7XXX series alloys as base metal while 13-15% volume fraction of SiC was added as reinforcement. On specimens with an axial fatigue cycle that had a constant amplitude, testing was done in tension. In compared to 7075-T6 and T7 alloys, it was found that the composite material's fatigue strength was exceptionally high.

Alam *et al.,* [49] taken A356 as base metal while SiC was added in different proportions ranging from 1% to 5% as reinforcement by stir casting method. Performance parameters were hardness, tensile strength, compressive strength, % elongation, forgeability, diffraction analysis and morphology. A 41% and 45% increase in yield tensile strength and ultimate tensile strength, respectively, was achieved. There was a 4% and a 5.45% reduction in toughness and elongation, respectively. Strength under compression increased from 311 MPa to 603 MPa.

Sankhla *et al.,* [50] taken aluminium powder as base metal while SiC having particle size of 50 micron was added as reinforcement in different proportions as 15%, 20% and 25% by powder metallurgy technique. The turning operation was performed on CNC lathe. Machining parameters were taken as ‘X’ (40,80,120) m/min, ‘Y’ (0.1,0.2,0.3) mm/rev while performance parameters were Tool wear and ‘SR’. The researchers came to the conclusion that hardness, tensile strength, and compressive strength all improved as SiC fraction increased.

2.1.5 Summary of machinability studies of SiC reinforced aluminium alloys

Following Table 1 includes Effect of addition of SiC reinforcement in varying proportion to different aluminium alloys.

Table 1
Effect of addition of SiC reinforcement in aluminium alloy

Ref.	Base metal	% of reinforcements	Input Parameters	Performance Parameters	Remarks
[4]	Al6063	SiC (10%)	Spindle Speed: 900 RPM, ‘Z’: 1 mm, cutting tool material: KNUX 1605X, Working material	‘SR’, energy consumption, and hardness	‘SR’ increases
[7]	LM6	SiC (8%, 10%, 12%)	‘X’, ‘Y’, ‘Z’	Cutting temperature (T), cutting forces, vibration in terms of acceleration, the profile roughness	Young's modulus increased to 10.9%, ultimate strength improved to 17.2%, hardness increased by 23.2%, and elongation decreased by 43.6%
[8]	AA7075	10 wt.% SiC (10-20 µm)	‘X’ (90, 150, 210 m/min), ‘Y’ (0.15, 0.20, 0.25 mm/rev), ‘Z’ (0.2, 0.4, 0.6 mm) and nose radius (0.4, 0.8, 1.2 mm)	‘SR’, Tool life	Tool life and ‘SR’ are reduced

[20]	Al2024	SiC (30% Volume fraction)	Cutting depth are selected from a range of 20 to 110 mm with a 30-mm interval. The cutting speeds are 250 mm/s, 520 mm/s, 780 mm/s, and 1200 mm/s.	Cutting mechanism, cutting force, 'SR'	'SR' increases as size of particles increases. The 'SR' is close to the particle radius
[21]	Al	SiC (17% and 30% Volume fraction) (Particle size: 0.6 micron and 3 micron)	Speed, feed and depth of cut	workpiece roughness and the surface layer of the workpiece, residual stresses	'SR' increases as particle size increases
[34]	Al	1.Al-SiC (0,2.5,5,7.5,10)% 2.Al-Gr (0,2.5,5,7.5,10 %)	'X': (100,160,220,280,340) m/min 'Y' : (0.04, 0.06, 0.08, 0.1 and 0.12) mm/rev 'Z': (0.15,0.30,0.45,0.6,0.75) mm Reinforcement (%): (0, 2.5, 5, 7.5, 10)	Cutting forces, 'SR'	The resultant force in Al-SiC composites increases with the proportion of reinforcement because the addition of silicon carbide particles makes the composite harder. Due to the lubricating qualities of graphite, the resultant force in MMCs decreases as the proportion of reinforcement increases
[35]	AA6061	SiC (10%)	'X' (60, 120, 180 rpm), 'Y'(0.05, 0.1, 0.15 mm/rev.), and depth of cut (0.2, 0.3, 0.4 mm)	Flank wear, 'SR'	Flank wear and 'SR' increases
[36]	LM6	SiC (10%)	'X' (30, 60, 90 rpm), depth of cut (0.5, 1.0, 1.5 mm), Weight % of SiC (7.5, 10.00, 12.5%)	Cutting force (Tangential, Axial, Radial)	Cutting forces increased
[37]	LM 25	SiC (10,15,25%) 25 microns	% Volume fraction of SiC: 10, 15, 25 % 'X': 50 100, 150 m/min 'Y': 0.20, 0.40, 0.60 mm/rev 'Z': 0.5, 1.5, 2.5 mm Machining time: ,3 6, 9 min	MRR, 'SR'	As the % reinforcement of SiC increases, 'SR' increases.
[38]	2009 Aluminium alloy	SiC (5 & 15 %)	'X': 400,500,600,700,800,900 m/min 'Y' : 0.1, 0.3 mm/rev	Tool life, surface quality	During turning operation; as the % reinforcement of SiC increases, tool life decreases.
[39]	A356	SiC (20%)	'X' (75, 125 and 175 m/min), 'Y' (0.1, 0.2 and 0.3 mm/rev) and depths of cut (0.50, 1.0 and 1.5 mm).	'SR'	'SR' is increased by SiC addition. Increased cutting speed reduces 'SR', but increased feed causes the surface to become rougher.
[40]	Al6063	SiC (65% by volume)	milling speed (100, 400m/min), 'Y' (0.02, 0.1 mm/rev) and axial 'Z' (0.1, 0.3 mm)	'SR', residual stress and morphology	Hardness and tensile strength increase upon addition of reinforcements.
[41]	Al6061	SiC (15%)	'X' (34, 64, 94), 'Y' (0.113, 0.178, 0.249), 'Z' (0.25, 0.5,0.75)	'SR', MRR	Hardness increases

[42]	Al2124	SiC (17% by volume), Particle size < 0.3 micron	NA	Cutting forces, cutting temperature	Cutting forces and cutting temperature increases.
[46]	7XXX series alloys	SiC (13-15 % by volume)	NA	Microstructure, fatigue strength	Fatigue strength gets increased.
[49]	A356	SiC (1,2,3,4,5 %)	NA	Hardness, tensile strength, compressive strength, % elongation, forgeability, diffraction analysis, morphology	Hardness, YTS and UTS increased by 125%, 41% and 45% respectively. Toughness, elongation and forgeability decreased
[50]	Al powder	SiC (15,20,25%) 50 microns	'X' (40,80,120) m/min, feed rate (0.1,0.2,0.3 mm/rev)	Tool wear, 'SR'	increases the hardness and compressive strength of materials but has been found to be damaging to the quality of the tools and surfaces

As per the current review; following is the tabular representation for effect of various input parameters on the responses (Table 2).

Table 2
Effect of machining parameters on responses

Reference	Input parameter	Effect on responses
[49,50]	Percentage of SiC	As Percentage of SiC increases; (Hardness, tensile strength, compressive strength) increases; (toughness and elongation) decreases
[39,50]	Cutting speed	As cutting speed increases; ('SR', tool wear) decreases
[7,50,21]	Feed	As feed decreases; (temperature, cutting forces, tool wear) increases, ('SR', residual stress) decreases
[4,7]	Depth of cut	As depth of cut increases; ('SR', machining forces) increases

From ANOVA technique; following are the details of most influencing factors for respective responses.

Table 3
Most influencing factor for responses

Reference	Response	Most influencing factor
[7], [37]	Cutting temperature, roughness	feed
[37]	'SR'	Percentage of SiC reinforcement

2.2 MMCs having SiC and Other Metal Particles as a Reinforcement Material (Al + SiC + Metal)

Nearly 11% researchers have added varying proportions of SiC and different metals such as boron carbide, graphene, caron nanotubes, titanium boride as a reinforcement material. Following are the details of it.

2.2.1 Base metal used

Various researchers have used different Aluminium alloys as base metal viz AA7075-T6, Al2219, Al6061, Al6061-T6.

2.2.2 Percentage and size of reinforcement particles

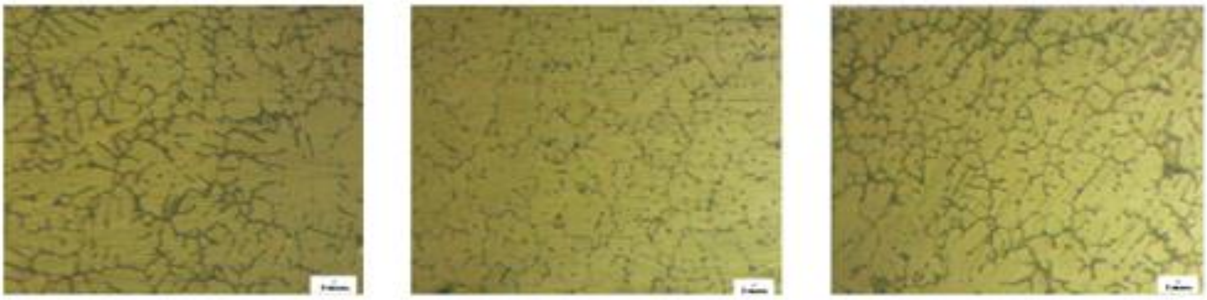
Researchers have added SiC as a reinforcement in various aluminium alloys as mentioned above in varying proportions from 5% to 15% by weight. Also, boron carbide particles are added in the proportion of 0.1% to 0.5%, graphene is added in the range of 0.1% to 7.5%, carbon nanotubes are added in the range of 0.1% while titanium boride is added in the range from 2.5% to 5%. Size of these particles varied from 25 micron to 50 micron.

2.2.3 Range of input parameters

Machining parameters are varied by different researchers to get the values of responses. Cutting speed values are taken in the range from 40 m/min to 500 m/min, 'Y' values are taken in the range from 0.04 mm/rev to 0.3 mm/rev and depth of cut values are taken in the range from 0.1 mm to 0.75 mm.

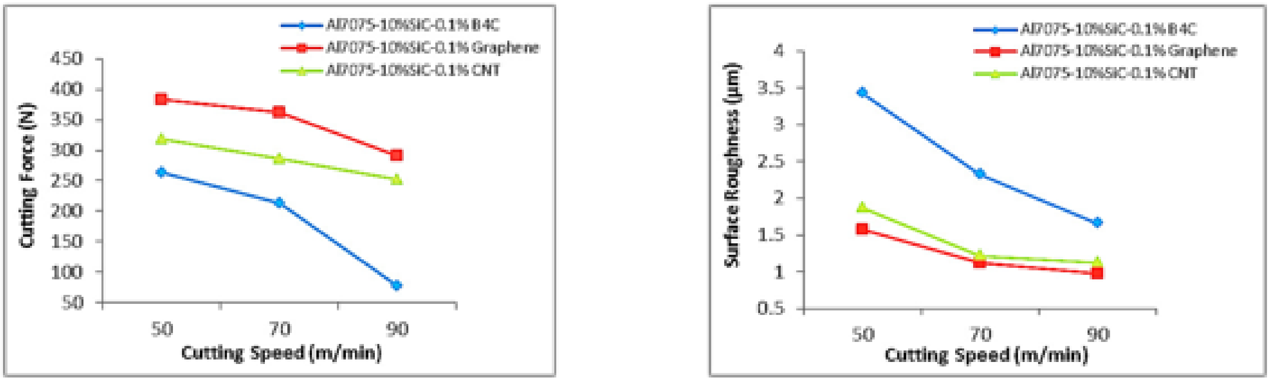
2.2.4 Methodology used by different researchers

Ajithkumar *et al.,* [1] taken Al7075-T6 as a base metal and prepared three different samples by varying the percentage of reinforcements. First sample was prepared by adding SiC (10%) and B_4C (0.1%), second sample was consisting of SiC (10%) and Graphene (0.1%) while the constituents of third sample were SiC (10%) and CNT (0.1%). These composites were made by using a combination of squeeze casting and stir casting. The cylindrical rods of this composite were turned on Turn 5075-SPM CNC lathe by taking input parameters as spindle speed, feed and depth of cut. The performance parameters were cutting force and 'SR'. Gray relational analysis was used by the authors and recommended optimum cutting parameters. According to the results of the experiment, the feed rate had the greatest influence on the 'SR', while the depth of cut had the greatest impact on the cutting forces. The authors came at the additional conclusion that the composites made from graphene and B_4C had surfaces that are, respectively, the least and most rough. They learned that adding a composite made of graphene resulted in a smoother surface than composites made of carbon nanotubes and B_4C. As shown in Figure 3; microstructure of composite having graphene content is observed to be very fine with relatively low dislocations. Hence as shown in Figure 4; 'SR' decreases as you increase cutting speed but it is relatively low than that of other two composites while cutting force of the composites having graphene content is relatively large than that of other two composites.



(a) (b) (c)

Fig. 3. (a) Al7075+10%SiC+0.1%B_4C (b) Al7075+10% SiC+0.1%Gr (c) Al7075+10%SiC+0.1%MWCNT [1]



(a) (b)

Fig. 4. The effect of cutting speed on (a) cutting force and (b) 'SR' (At 'Y' 0.3 mm/rev and 'Z' 1.5 mm using DLC coated carbide tool) [1]

Basavarajappa [22] taken Al2219 as a base metal and prepared two different samples by varying the percentage of reinforcements. First sample was prepared by adding 15 weights % of SiC while second sample was consisting of SiC (15%) and Graphite (3%). These composites were formed by combined stir casting method. The cylindrical rods of this composite having 25 mm diameter and 300 mm length were turned on CNC lathe with carbide, coated carbide, and polycrystalline diamond (PCD) tools. The input parameters were taken as speed (50,80,110) m/min, 'Y' (0.05,0.075,0.1) mm/rev, 'Z' (0.3) mm. The performance parameter was tool life. The impact of graphite incorporation in an Al 2219/15SiCp composite on tool wear has been investigated by the authors. For all cutting parameters, the flank wear of every tool used to machine Al2219/15SiCp-3Gr composite is lower than that of Al2219/15SiCp composite. This is because there are graphite particles present, which provide a thin lubricating coating. In terms of tool wear, PCD tools perform far better than conventional tools.

Kannan *et al.,* [23] taken Al7075 as a base metal and prepared three different samples by varying the percentage of reinforcements. First sample was prepared by adding 7 wt.% SiC and 3 wt.% graphite, second sample was consisting of 5 wt.% SiC + 5wt.% graphite while the constituents of third sample were 3 wt.% SiC + 7 wt.% Graphite. These composites were prepared by stir casting method. The cylindrical shaped rods having 30 mm diameter and 250 mm length were turned on centre lathe by taking input parameters as speed (40, 90, 140) m/min, 'Y' (0.075, 0.1, 0.125) mm, 'Z' (0.1,0.2, 0.3) mm. The performance parameters were cutting force, tool wear and 'SR'. The authors used DOE by Taguchi L27 orthogonal array and also ANOVA technique. Optimization was done by TOPSIS method. Validation was done by comparing analytical and experimental results. The results of the experiment showed that the addition of 7 weight % graphite significantly reduced the values of cutting force, tool wear, and 'SR' by 16%, 22%, and 32%, respectively.

Poovazhagan *et al.,* [26] taken Al6061 as a base metal and added fixed weight percentage of B_4C (0.5%) and varying percentage of SiC (0.5, 1.0 and 1.5 vol. %) by ultrasonic cavitation-based solidification process. The authors have done EDS analysis, hardness test, tension test and impact test of the composites. They conclude that as the percentage of reinforcements increases; hardness of the composites increases, tensile strength increases and impact energy gets decreased.

Johny *et al.,* [29] taken Al6061-T6 as a base metal and prepared three different samples by varying the percentage of reinforcements. First sample was prepared by adding SiC-10% and TiB_2-0%, second sample was consisting of SiC-10% and TiB_2-2.5% while the constituents of third sample were SiC-10% and TiB_2 -5%. These composites were prepared by stir casting method. The cylindrical shaped rods having 50 mm diameter and 300 mm length of this composite were turned on CNC lathe by taking input parameters as 'X' (60, 90, 120) m/min, 'Y' (0.1, 0.2, 0.3) mm/rev, 'Z' (0.50,0.75, 0.1) mm and % of TiB_2 (0, 2.5, 5). The performance parameters were hardness, tensile strength, 'SR', wear analysis (tool & workpiece). It has been noted that while the addition of TiB_2 reduced the composite's strength by 50–60%, the addition of SiC reinforcement increased the composite's strength by 20%.

Elango *et al.,* [51] taken Al6061 as a base metal and prepared three different samples by varying the percentage of reinforcements. First sample was prepared by adding 5% SiC and 2.5% graphene, second sample was consisting of 5% SiC and 5% graphene while the constituents of third sample were 5% SiC and 7.5% graphene. These composites were prepared by stir casting method. The cylindrical rods having 50 mm diameter and 300 mm length of this composite were turned on CNC lathe by taking input parameters as 'X': 300, 400 and 500 m/min, 'Y': 0.04, 0.08 and 0.12 mm/rev and 'Z': 0.1, 0.2 and 0.3 mm. The performance parameters were hardness and 'SR'. The hybrid composite's Vickers hardness value decreases as graphene material percentage increases. The 'SR' of the composite is decreased by the inclusion of graphene.

2.2.5 Summary of machinability studies of SiC reinforced aluminium alloys

Following Table 4 includes Effect of addition of SiC reinforcement in varying proportion to different aluminium alloys.

Table 4
Effect of addition of SiC and other metal particles reinforcement in aluminium alloy

Ref.	Base metal	% of reinforcements	Input Parameters	Performance Parameters	Remarks
[1]	Al7075-T6	1.SiC (10%), B_4C (0.1%) 2.SiC(10%),Graphene(0.1%) 3.SiC(10%),CNT(0.1%)	1. Cutting speed 2. Feed 3. Depth of cut	1.Cutting force 2. 'SR'	Microstructure, Hardness, tensile strength
[22]	Al2219	Al 2219/15%SiCp (Particle size: 25 micron) and Al 2219/15SiCp-3%%Gr (hybrid))	Speed (50,80,110), 'Y' (0.05,0.075,0.1), 'Z' (0.3) with carbide, coated carbide, and polycrystalline diamond (PCD) tools.	Tool life	Tool wear is lesser for the sample containing Graphite particles.

[23]	Al7075	(1)7wt.%SiC+3wt.% Gr, (2)5wt.%SiC +5wt.% Gr, (3) 3wt.%SiC +7 wt.% Gr [Particle size= 50 micron]	Speed (40, 90, 140), 'Y' (0.075, 0.1, 0.125), 'Z' (0.1,0.2, 0.3)	'SR', tool wear, cutting forces	Hardness
[26]	AA6061	SiC (0.5, 1.0 and 1.5 vol. %) and B_4C (fixed 0.5 vol. %)		EDS analysis, hardness test, tension test and impact test.	The hybrid composites' ductility and impact strength slightly decreased but their hardness and tensile strength greatly enhanced.
[29]	Al6061-T6	Al/SiC-10%/ TiB_2-0%, Al/SiC-10%/ TiB_2-2.5% and Al/SiC-10%/ TiB_2-5%	'X' (60, 90, 120), 'Y' (0.1, 0.2, 0.3), 'Z' (0.50,0.75, 0.1), % of TiB_2 (0, 2.5, 5)	hardness, tensile strength, 'SR', Wear analysis (tool & workpiece)	Hardness, As weight percentage of TiB_2 increases wear strength and porocity
[51]	Al6061	(Al 6061 + 5% SiC + 2.5% Gr, Al 6061 + 5% SiC + 5% Gr and Al6061 + 5% SiC + 7.5% Gr) Size of SiC and Gr - 40 micron	'X': (300, 400, 500) m/min Feed: (0.04, 0.08, 0.12) mm/rev 'Z': (0.1, 0.2, 0.3) mm	Hardness, 'SR'	Hardness increases, 'SR' decreases (On addition of graphene)

As per the current review; following is the tabular representation for effect of various input parameters on the responses (Table 5).

Table 5
Effect of machining parameters on responses

Reference	Input parameter	Effect on responses
[26]	Percentage of SiC and other metal particles	As Percentage of SiC increases; (Hardness, tensile strength) increases; (Ductility, impact energy) decreases
[22]	Cutting speed	As cutting speed increases; tool wear increases
[1]	Feed	As feed decreases; 'SR' decreases
[22]		As feed increases; tool wear increases

From ANOVA technique; following are the details of most influencing factors for respective responses.

Table 6
Most influencing factor for responses

Reference	Response	Most influencing factor
[1]	'SR'	Feed rate
[1]	Cutting forces	Depth of cut

2.3 MMCs having SiC and Other Non-Metal Particles as a Reinforcement (Al + SiC + Non-Metal)

Nearly 4% researchers have added varying proportions of SiC and different non-metals such as rice husk ash and fly ash as a reinforcement material. Following are the details of it.

2.3.1 Base metal used

Various researchers have used different Aluminium alloys as base metal viz. Al356.2 and commercial aluminium.

2.3.2 Percentage and size of reinforcement particles

Researchers have added SiC as a reinforcement in various aluminium alloys as mentioned above in varying proportions from 5% to 6% by weight. Also, rice husk ash particles are added in the proportion of 6%, fly ash is added in the range of 5%. Size of these particles varied from 25 micron to 35 micron.

2.3.3 Range of input parameters

Machining parameters are varied by different researchers to get the values of responses. Cutting speed values are taken in the range from 40 m/min to 200 m/min, feed values are taken in the range from 0.14 mm/rev to 0.25 mm/rev and depth of cut values are taken in the range from 0.5 mm to 2.0 mm.

2.3.4 Methodology used by different researchers

Chintada *et al.,* [6] taken Al356.2 as a base metal and added SiC (6%, 25 µm) and Rice Husk Ash (RHA) (6%, 35 µm) as reinforcements by stir casting method. The cylindrical rods of this composite were turned on lathe machine by taking input parameters as 'X' (40,60,100,150,200) m/min, 'Y' (0.14, 0.16, 0.2, 0.25) mm/rev, and 'Z' (0.5, 0.75, 1.0, 1.5, 2.0) mm. The performance parameters were 'SR', cutting forces and flank wear. In this research; authors have calculated the response parameters analytically and validated them experimentally. The authors have concluded that minimum 'SR' is observed in minimum range when feed is within 0.14–0.2 mm/rev. It is because the built-up edge's impact is reduced. While cutting depths between 0.5 and 1 mm provide the roughest surfaces. Due to the abrasion process, flank wear is also seen to be at its highest.

Baburaj *et al.,* [15] taken commercial aluminium (Grade: LM0) as a base metal and added 5% SiC and 5% fly ash as reinforcements by stir casting method. The cylindrical shapes of 100 mm length and 25 mm diameter this composite was turned on CNC Lathe (LMW smart junior) by using uncoated tungsten carbide insert. taking input parameters as cutting speed, feed rate, depth of cut and cutting tool nose radius. The performance parameter was 'SR'. Authors have done Design of Experiment by Taguchi L16 orthogonal array. Optimization is done by Taguchi method and Genetic Algorithm (GA). Validation is achieved by comparing analytical and experimental results. They concluded that results obtained from GA are better than that of Taguchi method.

2.3.5 Summary of machinability studies of SiC reinforced aluminium alloys

Following Table 7 includes Effect of addition of SiC reinforcement in varying proportion to different aluminium alloys.

Table 7
Effect of addition of SiC and other non-metal particles as reinforcement in aluminium alloy

Ref.	Base metal	% of reinforcements	Input Parameters	Performance Parameters	Remarks
[6]	Al356.2	SiC (6%, 25 µm) and RHA (6%, 35 µm)	'X' (40,60,100,150,200 m/min), 'Y' (0.14, 0.16, 0.2, 0.25 mm/rev), and 'Z' (0.5, 0.75, 1.0, 1.5, 2.0 mm)	'SR', cutting forces and flank wear	cutting forces increases
[15]	Commercial aluminium (Grade: LM0)	(5%wt SiCp-5%wt Fly ash)	cutting speed, feed rate, depth of cut and cutting tool nose radius	'SR'	'SR' increases

As per the current review; following is the tabular representation for effect of various input parameters on the responses (Table 8).

Table 8
Effect of machining parameters on responses

Reference	Input parameter	Effect on responses
[6]	Percentage of SiC and other non-metal particles	As Percentage of reinforcements increases; flank wear increases; cutting forces decreases
[6]	Depth of cut	As depth of cut increases; 'SR' increases

From ANOVA technique; following are the details of most influencing factors for respective responses.

Table 9
Most influencing factor for responses

Reference	Response	Most influencing factor
[15]	'SR'	Cutting speed

2.4 MMCs having Metal Particle Reinforcement Other than SiC Material (Al + Metal Other than SiC)

Nearly 33% researchers have added metal particles other than SiC such as titanium boride, boron carbide, hexagonal boron nitride, stainless steel, zircon boride, graphene, titanium carbide as a reinforcement material in varying proportions. Following are the details of it.

2.4.1 Base metal used

Various researchers have used different Aluminium alloys as base metal viz AA7075, Al6061, Al7050, Al2024, Al6063, Al2219, Al356.

2.4.2 Percentage and size of reinforcement particles

Researchers have added different reinforcement particles in various aluminium alloys as mentioned above in varying proportions. Titanium boride (0-12%), boron carbide (5-19% by volume), hexagonal boron nitride (10% by volume), stainless steel (0-25%), zircon boride (1%-6%), graphene (1%), titanium carbide (0-4%) were added by researchers. Size of these particles varied from 9.5 micron to 50 micron.

2.4.3 Range of input parameters

Machining parameters are varied by different researchers to get the values of responses. Cutting speed values are taken in the range from 24 m/min to 535 m/min, feed values are taken in the range from 0.04 mm/rev to 0.35 mm/rev and depth of cut values are taken in the range from 0.5 mm to 2.0 mm.

2.4.4 Methodology used by different researchers

Pugazhenthiet *et al.,* [5] taken AA7075 as a base metal and added TiB_2 in varying percentage (0, 3, 6, 9 and 12 %) as reinforcements by stir casting method. The rods of 450 mm length and 45 mm diameter of this composite were turned on Lathe machine by taking input parameters as cutting speed, feed rate, depth of cut and TiB_2 content. The performance parameters were cutting force and 'SR'. The authors came to the conclusion that cutting force decreased as cutting speed and TiB_2 particle content rose, whereas it increased when feed rate and depth of cut increased. Increases in feed rate and depth of cut result in a reduction in surface finish whereas increases in cutting speed result in an improvement.

Gnanavelbabu *et al.,* [9] taken AA6061 as a base metal and taken B_4C (5–15 vol.%) and hBN (10 vol.%) as reinforcements by two-stage stir casting method. The cylindrical rods of this composite were turned on CNC lathe. The input parameters were as speed (60,120,180) rpm, 'Y' (90.05, 0.1, 0.15) mm/rev, 'Z' (0.2, 0.4, 0.6) mm and volume percentage of boron carbide (5%, 10%, 15%). The performance parameters were tangential force, cutting force and tool wear. By using the grey-response surface methodology, the input parameters were optimised.

Lin *et al.,* [11] taken AA7075 as a base metal and added 6% of TiB_2 as reinforcements by In-setu method. The cylindrical rods of 60 mm length and 20 mm diameter of this composite were turned on Precision lathe machine by taking input parameters as tool nose radius (0.4, 0.6, 0.8, and 1.0) mm, tool wear (0.26 mm) VB. The performance parameters were Cutting force, Residual stress distribution. The researchers came to the conclusion that while there are TiB_2 particles present, the residual stress on the machined surface is still compressive in character.

Mahanta *et al.,* [17] taken AA7075 as a base metal and taken fixed quantity of boron carbide (1.5 wt. %) and varying wt. % of fly ash (0.5 wt.%, 1.0 wt.%, 1.5 wt.%) as reinforcements ultrasonic-assisted stir casting technique. The authors have tested various morphological, physical and mechanical properties like hardness, UTS, impact energy, density, porosity, % elongation of the composite material. As the percentage of fly ash reinforcements increases; properties like hardness, Ultimate Tensile Strength and impact strength increases maximum up to 32.93%, 31.25% and 9.31% respectively while properties like density, porosity and elongation get decreased.

Vaxevanidis *et al.,* [24] taken Al–Mn matrix alloy as a base metal and taken 0.25% stainless steel 316L flakes as reinforcements. The turning of this composite was done by lathe machine. Variable Speed and Feed with constant depth of cut were taken as input parameters while 'SR' was taken as performance parameter. The authors have done DOE by L9 orthogonal array and also done ANOVA. Validation was achieved by comparing it with experimental results.

Sivasankarana *et al.,* [25] taken three samples for their research work. First sample was consisting of only AA7075, second sample was comprising of AA 7075 and 3%ZrB_2 while third sample was comprising of AA 7075-3%ZrB_2-1%. These reinforcements were added by In-setu method. The cylindrical rods of 200 mm length and 30 mm diameter of this composite were turned on CNC lathe by taking input parameters as tool nose radius (0.4 mm and 0.8 mm), 'X' (between 125 mm/min to 300 mm/min), 'Y' (between 0.075 mm/rev to 0.225 mm/rev), 'Z' (between 0.5 mm to 1.5 mm). The performance parameters were MRR, ‘SR’. The authors came at the conclusion that the ‘SR’ of the workpiece decreased as the tool's nose radius grew.

Kishorea *et al.,* [27] taken AA6061 as base metal and varying percentage of TiC (0%, 2% & 4%) were added as reinforcement by In-setu method. The cylindrical rods of this composite were turned on Kirloskar made Turnmaster-35 lathe using uncoated tungsten carbide tool. The input parameters were ‘X’ (40,60,80,100,120) m/min, ‘Y’ (0.04,0.06,0.08,0.1,0.12) mm/rev and ‘Z’ (0.5,0.75,1.0,1.25,1.50) mm. The performance parameters were cutting force, ‘SR’ and flank wear. The authors came to the conclusion that while cutting force increased with an increase in feed rate and depth of cut, it dropped as cutting speed increased. As cutting speed increased, ‘SR’ decreased.

Sivasankarana *et al.,* [28] taken three samples for their research work. First sample was consisting of only AA7075, second sample was comprising of AA 7075 and 3%ZrB_2 while third sample was comprising of AA 7075-3% ZrB_2 -1%. These reinforcements were added by In-setu method. The cylindrical rods of 200 mm length and 30 mm diameter of this composite were turned on CNC turning centre by taking input parameters as Cutting speed, feed depth of cut. The performance parameter was ‘SR’. The authors came to the conclusion that when feed rate and cut depth increased, ‘SR’ similarly increased. The metal matrix composite forms an increasing number of discontinuous chips as a consequence of the addition of graphite.

Bansala *et al.,* [30, 52] taken Al2024 as a base metal and added Al_2O_3 in varying percentage (2, 4 and 6%) as reinforcements by sand casting method. The rods of 300 mm length and 45 mm diameter of this composite were turned on centre lathe by taking input parameters ‘X’ (265,400,535 rpm), ‘Y’ (0.29, 0.32, 0.35) mm/rev, and ‘Z’ (1.0, 1.5, 2.0) mm, % of concentration (2%, 4%, 6%). The performance parameters were hardness, tensile strength, tool wear, ‘SR’ and MRR. The authors came to the conclusion that surface finish enhanced with increasing cutting speed. The hardness, MRR and tensile strength of composite materials have been discovered to increase when the reinforcement ratio rises.

Saravanakumar *et al.,* [32] taken AA6063 as a base metal and prepared two different samples by stir casting method. First sample was consisting of Al6063 with 6% Al_2O_3 while second sample was consisting of Al6063 with 6% Al_2O_3p and 1% Graphite particles. The composite blocks having dimension of 130mm×25mm×10mm were prepared. Drilling operation with the help of drill bit of 10 mm diameter was done on this composite block by using CNC machining centre. Input parameters were taken as ‘X’ (1000, 3000) rpm, ‘Y’ (50, 150) mm/min, % of graphite particles (0, 1%) and Tool (Coated, uncoated). The performance parameters were burr height of exit hole, ‘SR’ of drilled hole and chip produced during drilling. Al_2O_3 reinforced composites benefit from the addition of a tiny amount of graphite because it lowers the burr height of the exit hole, improves surface quality, and facilitates easy shearing and the creation of discontinuous chips during drilling of the composites.

Mahamani [33] taken AA2219 as a base metal and added 6% TiB_2 as reinforcements by stir casting method. The cylindrical rods of this composite were turned on Turn master-35 lathe (Kirloskar make) with uncoated tungsten carbide insert by taking input parameters as ‘X’ (100, 125, 150) rpm, ‘Y’ (0.05, 0.1, 0.15) mm/min and ‘Z’ (0.5, 1.0, 1.5) mm. The performance parameters were cutting force and ‘SR’. Taguchi L27 orthogonal array was used for experimentation. The feed rate has the biggest influence on cutting force and ‘SR’, according to the authors' research.

Kannan *et al.,* [43-45] taken AA7075, Al6061 and A356 as a base metal and and prepared three different samples. First sample was consisting of Al7075 and 10% Al_2O_3 having particle size: 15-micron, second sample was comprising of Al6061 + (10% & 20% Al_2O_3) having particle size: 17 and 23 microns while third sample was comprising of Al6061+ (10% Al_2O_3) having particle size: 9.5 and 20 microns. The cylindrical rods of this composite were turned on lathe machine by taking input parameters as ‘X’ (24) m/min, ‘Y’ (60, 100) mm/rev, uncut chip thickness (0.1, 0.3) mm, width of cut

(3) mm and cutting environment (Dry and Wet). The performance parameters were cutting forces, 'SR' and flank wear. They found that there will be more microhardness changes below the machined surface as lower volume percentage and the course the particles. Additionally, machining forces rise as the volume proportion of particles and average particle size both rises. Additionally, tool wear and 'SR' increase with the addition of SiC particles.

Arunachalam *et al.,* [47] taken Scrap aluminium ca r alloy wheels (typically Al-Si7Mg) as a base metal and added Al_2O_3 having particle size of 50 Microns as reinforcement by combined stir-squeeze casting. The casting parameters were taken as squeeze pressure (75,100,125) MPa, squeeze pressure holding time (15,30,45) sec, stirrer speed (450,525,600) RPM and die preheating temperature (250,300,350) degree. The performance was measured in terms of porosity, hardness, ultimate tensile strength, ultimate compressive strength. The authors concluded that compressive strength get increased by 18.5% and porosity get reduced by 13.5%.

Hiremath *et al.,* [48] taken Al6061 as a base metal and added B_4C (0,5,7,9) wt% as reinforcements by stir casting method. The rods of 150 mm length and 35 mm diameter of this composite were turned on conventional lathe machine by taking input parameters as 'X' (29, 43 and 65) m/min, 'Y' (0.111, 0.222 and 0.333) mm/rev and 'Z' (0.5, 0.75 and 1.0) mm. The performance parameters were feed force, radial force, cutting force and 'SR'. The authors concluded that as the wt% of the B_4C particulates is reduced; surface finish improves.

2.4.5 Summary of machinability studies of SiC reinforced aluminium alloys

Following Table 10 includes Effect of addition of SiC reinforcement in varying proportion to different aluminium alloys.

Table 10
Effect of addition of metal particle reinforcement other than SiC material in aluminium alloy

Ref.	Base metal	% of reinforcements	Input Parameters	Performance Parameters	Remarks
[5]	AA7075	TiB_2 (0, 3, 6, 9 and 12 wt%)	cutting speed, feed rate, depth of cut and TiB_2 content	Cutting force, 'SR'	As % of TiB_2 increases; cutting forces decreased and 'SR' increased.
[9]	AA6061	B_4C (5–15 vol.%) and hBN (10 vol.%)	Speed (60,120,180 rpm), 'Y' 90.05, 0.1, 0.15 mm/rev, 'Z' (0.2, 0.4, 0.6 mm) and volume percentage of boron carbide (5%, 10%, 15%)	Tangential force, cutting force and tool wear.	Cutting force and tool wear increases
[11]	Al 7050	TiB_2 (6 wt %)	Tool nose radius (0.4, 0.6, 0.8, and 1.0 mm), Tool wear (0.26 mm VB) [Tool wear was measured by an Alicona IFG-G4 automatic tools scanner]	Cutting force, Residual stress distribution	Residual stresses and hence the cutting forces increases
[17]	Al7075	fixed quantity of boron carbide (B_4C) (1.5 wt. %) and varying wt. % of fly ash (0.5 wt.%, 1.0 wt.%, 1.5 wt.%)	NA	Morphological study, Hardness, UTS, Impact energy, Density, porosity, % elongation	(Hardness increased by 32.93%, UTS increased by 31.25%, Impact strength increased by 9.31%, Density decreased by 8.41%, also porosity and % elongation get decreased

[24]	Al–Mn matrix alloy	Stainless steel 316L flakes (SSF) (0.25%)	Variable Speed and Feed, constant depth of cut	'SR' (R_a, R_t, R_{sk} and R_{ku})	R_{sk} as well as R_{ku} remain uncorrelated
[25]	Al7075	(1) AA7075, (2) AA 7075-3% ZrB_2 and (3) AA 7075-3% ZrB_2-1%Gr	tool nose radius (0.4 mm and 0.8 mm), 'X' (between 125mm/min to 300mm/min), 'Y' (between 0.075mm/rev to 0.225mm/rev), 'Z' (between 0.5mm to 1.5mm)	MRR, 'SR'	ZrB_2 increases 'SR' while addition of graphite decreases it.
[27]	Al6061	TiC (0%, 2%, 4%)	'X' (40,60,80,100,120), 'Y' (0.04,0.06,0.08,0.1,0.12), 'Z' (0.5,0.75,1.0,1.25,1.50)	cutting force, 'SR' and flank wear	Hardness increases
[28]	AA7075	(1) AA7075, (2) AA 7075-3% ZrB_2 and (3) AA 7075-3% ZrB_2-1%Gr	Cutting speed, feed depth of cut	'SR'	Addition of Graphite cause better surface finish.
[30]	Al 2024	α Al_2O_3 (2%, 4%, 6%)	'X' (265, 400, 535 rpm), 'Y' (0.29, 0.32, 0.35 mm/rev.), and depth of cut (1.0, 1.5, 2.0 mm), % of concentration (2%, 4%, 6%)	hardness, tensile strength, Tool wear, 'SR', MRR	Hardness and tensile strength increases
[32]	Al6063	Al6063 with 6% Al_2O_3 and Al6063 with 6% Al_2O_3 and 1% Gr.	'X' (1000, 3000 rpm), 'Y' (50, 150 mm/min), % of graphite particles (0, 1%), Tool (Coated, uncoated)	burr height of hole, 'SR' and chip produced	Graphitic composites made of Al/ Al_2O_3p/Grp have greater surface finish than Al_2O_3p reinforced composites.
[33]	AA2219	AA2219-6% TiB_2/ ZrB_2 in-situ metal composites	'X' (100, 125, 150 rpm), 'Y' (0.05, 0.1, 0.15 mm/min), 'Z' (05, 1.0, 1.5 mm)	Cutting force, 'SR'	ANOVA results showed that feed rate significantly affects cutting force (50.78%) and 'SR' (76.44%).
[43]	Al7075, Al6061	1. Al7075 + (10% Al_2O_3), Particle size: 15 micron 2. Al6061 + (10% & 20% Al_2O_3), Particle size: 17 and 23 micron 3. Al6061+ (10% Al_2O_3), Particle size: 9.5 and 20 micron	'X'(24), 'Y' 60, 100), Uncut chip thickness(0.1, 0.3), Width of cut (3), Cutting environment (Dry and Wet)	Cutting forces, 'SR', Flank wear	As volume fraction increases and particle size decreases, uniformity in hardness value is obtained beneath the machined surface.
[44]	Al356, Al7075	1. Al356 + (20% SiC), Particle size: 12 micron 2. Al7075 + (10% Al_2O_3), Particle size: 15 microns	'X' (60, 120, 240), 'Y' (0.15), 'Z' (2), Tool nose radius (0.8), Cutting environment (Dry and Wet)	Cutting forces, 'SR', Flank wear	Tool wear and 'SR' increases.

[45]	Al7075, Al6061	1. Al7075 + (10% and 15% Al_2O_3) 2. Al6061 + (10% & 20% Al_2O_3) 3. Al6061 + (10% Al_2O_3), Particle size: 9.5, 20 and 25 microns	'X' (24), 'Y' (60, 100), Uncut chip thickness (0.1, 0.3), Width of cut (3), Cutting environment (Dry and Wet)	Line defects, cutting forces	Machining forces increase as average particle size and particle volume percentage rise.
[47]	Scrap aluminium car alloy wheels (typically Al-Si7Mg)	Al_2O_3 (50 Micron)	squeeze pressure (75,100,125 Mpa), squeeze pressure holding time (15,30,45 sec), stirrer speed (450,525,600 RPM) and die preheating temperature (250,300,350 Degree)	Porosity (%), Hardness (HRB), Ultimate Tensile Strength (MPa), Ultimate Comp. Strength (MPa)	Decreased porosity of 5.29% (13.5% less) and compressive strength of 433 MPa (18.5% more)
[48]	Al6061	B_4C (0,5,7,9 wt %)	cutting speeds (29, 43 and 65 m/min), 'Y' (0.111, 0.222 and 0.333) and 'Z' (0.5, 0.75 and 1.0 mm)	feed force, radial force, cutting force and surface roughness.	During turning operation; as % of B_4C increased, 'SR' gets increased. In all the examples examined, the surface quality is greatly enhanced by increasing cutting speed while lowering feed rate and depth of cut.
[52]	Al 2024	α Al_2O_3 (2%, 4%, 6%)	'X' (265,400,535 rpm), 'Y' (0.29, 0.32, 0.35 mm/rev.), and depth of cut (1.0, 1.5, 2.0 mm), % of concentration (2%, 4%, 6%)	tool wear, MRR and 'SR'	Hardness and tensile strength increase upon addition of reinforcements.

As per the current review; following is the tabular representation for effect of various input parameters on the responses (Table 11)

Table 11
Effect of machining parameters on responses

Reference	Input parameter	Effect on responses
[5]	Percentage of reinforcements	As Percentage of reinforcements increases; (tool wear, hardness, tensile strength) increases; (MRR) decreases
[5,27,30,52]	Cutting speed	As cutting speed increases, (flank wear) increases; (cutting forces, 'SR') decreases
[5,27,28,30,52]	Feed rate	As feed rate increases, (cutting forces, 'SR', flank wear) increases
[5,27,28,52]	Depth of cut	As depth of cut increases, (cutting forces, 'SR', flank wear) increases
[25]	Tool nose radius	As tool nose radius increases; 'SR' decreases

From ANOVA technique; following are the details of most influencing factors for respective responses.

Table 12
Most influencing factor for responses

Reference	Response	Most influencing factor
[9]	Tangential force, cutting force, tool wear, 'SR', MRR	Cutting speed
[13]	cutting force, 'SR'	Feed rate
[11]	Radial force	Tool nose radius

2.5 MMCs having Non-Metal Particle Reinforcement (Al + Non-Metal Particles)

Nearly 11% researchers have added non-metal particles such eggshell, boron carbide, rock dust, sugarcane ash, groundnut shell ash, jute ash, fly ash etc as a reinforcement material in varying proportions. Following are the details of it.

2.5.1 Base metal used

Various researchers have used different Aluminium alloys as base metal viz Al6063-T6, Al6061-T6, Al6063, LM6, Al6061

2.5.2 Percentage and size of reinforcement particles

Researchers have added different reinforcement particles in various aluminium alloys as mentioned above in varying proportions such as eggshell (6%), boron carbide (6%), rock dust (2 to 15%), sugarcane ash (3 to 9%), groundnut shell ash (3 to 9%), jute ash (3 to 9%), fly ash (10 to 20%) etc. Size of these particles varied from 10 micron to 600 micron.

2.5.3 Range of input parameters

Machining parameters are varied by different researchers to get the values of responses. Spindle speed values are taken in the range from 637 RPM to 1273 RPM, feed values are taken in the range from 0.1 mm/rev to 0.3 mm/rev and depth of cut values are taken in the range from 0.2 mm to 0.6 mm.

2.5.4 Methodology used by different researchers

Kesarwani *et al.,* [2] taken Al6063 T6 as a base metal and prepared three different samples. First sample was consisting of Al6063 T6 and Eggshell (6% wt, 104 µm), second sample was comprising of Al6063 T6 and boron carbide (6%wt, 104 µm) while third sample was comprising of Al6063 T6 and hybrid AMC (6%wt eggshell+6%wt B_4C, 104 µm). It is discovered after turning these composites that hybrid AMC has the highest MRR and the lowest 'SR' when compared to the other two samples.

Balachandhar *et al.,* [3] taken Al6061-T6 as a base metal and added AZ 31 (1%) and rock dust (2%) as reinforcements. After turning these composites, it was discovered that the surface quality was superior on the composite made up of 97% Al6061, 2% rock dust, and 1% AZ 31.

Butola *et al.,* [10] taken Al6063 as a base metal and prepared three different samples. First sample was consisting of Al6063 and sugarcane ash (3%, 6% and 9%), second sample was comprising of Al6063 and groundnut shell ash (3%, 6% and 9%) while third sample was comprising of Al6063 and jute ash (3%, 6% and 9%). Particle size of these added particulates was taken in the range from 53 micrometres to 600 micrometres. Researchers have optimised the input parameters after turning these composites and have determined the percentage contribution of each input parameter for all samples.

Nataraj *et al.,* [12] taken LM6 as a base metal and prepared three different samples. First sample was consisting of [LM6 - 80%, Fly ash - 10%, SiC - 10%], second sample was comprising of [LM6 - 77%, Fly ash - 15%, SiC - 8%] while third sample was comprising of [LM6 - 75%, Fly ash - 20%, SiC - 5%]. It has been discovered after turning these composites that a higher fly ash reinforcement reduces the ultimate tensile strength and elongation.

Prakash *et al.,* [14] taken Al6061 as a base metal and added rock dust (5, 10 & 15%) having particle size of (10, 20 & 30) microns as reinforcements. According to the study, MRR is directly correlated with the machining parameters and indirectly correlated with the material parameters taken into account [14].

Kirubadurai *et al.,* [16] taken Al6061 as a base metal and added (5%, 10% and 15% fly ash) as reinforcements. By maintaining the depth of cut constant, the authors examined the values of BUE and subsequently the 'SR' in relation to cutting speed and feed rate.

2.5.5 Summary of machinability studies of SiC reinforced aluminium alloys

Following Table 13 includes Effect of addition of SiC reinforcement in varying proportion to different aluminium alloys.

Table 13
Effect of addition of non-metal reinforcement in aluminium alloy

Ref.	Base metal	% of reinforcements	Input Parameters	Performance Parameters	Remarks
[2]	Al6063 T6	Eggshell (6% wt, 104 µm), boron carbide (6%wt, 104 µm) and hybrid AMC (6%wt egg	'X' 500 rpm, 'Y' 0.1 mm/rev and 'Z' 0.5 mm	MRR, 'SR', residual stress and interface temperature	AMC has the highest MRR and the lowest 'SR'
[3]	Al6061-T6	AZ 31(Mg) (1%) and rock dust (2%)	'X' 1000 – 1800 rpm, 'Y' 0.05 – 0.2 mm/min and 'Z' 0.2 – 0.7 mm	'SR'	Surface quality gets improved for 1% AZ31 and 2% rock dust
[10]	Al6063	Sugarcane ash (3%, 6% and 9%), groundnut shell ash (3%, 6% and 9%) and jute ash (3%, 6% and 9%) (Size 53 micrometres to 600 micrometres)	Speed (1000, 1500 rpm), 'Y' (0.15, 0.30 mm/rev), 'Z' (0.3, 0.6 mm)	'SR'	Percentage contribution of each input parameter is determined
[12]	LM6	Sample 1 [LM6 - 80%, Fly ash - 10%, SiC - 10%], Sample 2 [LM6 - 77%, Fly ash - 15%, SiC - 8%] Sample 3 [LM6 - 75% ,Fly ash - 20%, SiC - 5%]	Speed (125-175 m/min), 'Y' (0.05-1.00 mm/rev), 'Z' (0.25-0.75 mm)	work-tool interface temperature, 'SR' parameters such as Ra, Rq, and Rt and vibration in terms of acceleration in three directions Vx, Vy, and Vz	Higher fly ash reinforcement reduces the ultimate tensile strength and elongation.

[14]	Al6061	Rock dust (5, 10 & 15%) particle size (10, 20 & 30) microns	Reinforcement weight % (5,10,15 %) and particle size (10,20,30 micron), also the turning parameters viz. speed (637, 955, 1273 rpm), 'Y' (0.1, 0.2, 0.3 mm/rev) and 'Z' (0.2, 0.4, 0.6)	'SR' (Ra) and MRR	As machining parameters increase; MRR increases.
[16]	Al6061	(5%, 10% and 15% fly ash)	cutting speed, feed rate (By keeping depth of cut constant)	'SR'	Values of BUE and the 'SR' are determined with respect to machining parameters

As per the current review; following is the tabular representation for effect of various input parameters on the responses (Table 14).

Table 14
Effect of machining parameters on responses

Reference	Input parameter	Effect on responses
[12]	Percentage of reinforcements	As Percentage of reinforcements increases; (tensile strength, elongation, Youngs modulus) increases; (density) decreases
[14]	Cutting speed, Feed rate, Depth of cut	As input parameters increases, (MRR) increases

From ANOVA technique; following are the details of most influencing factors for respective responses.

Table 15
Most influencing factor for responses

Reference	Response	Most influencing factor
[3]	'SR'	Cutting speed
[14]	'SR'	Feed rate
[12]	Vibration	Feed rate

2.6 Turning of plain aluminium alloys

Researchers have also worked on machinability studies of various plain aluminium alloys like AA6026 - T9, Ti-6Al-4Valloy, Al1350-O, Al7075-T6, AA 6063 T6 etc. Against a number of machining parameters, various performance characteristics are calculated. Optimisation of machining parameters was also done by various techniques. But the values of desired responses which were obtained were considerably less than that in the case of machining of HMMCs.

3. Conclusion

i. Hybrid Metal Matrix Composites (HMMCs) are having better mechanical properties than that obtained by single Metal Matrix Composites (MMCs).
ii. Silicon Carbide (SiC) plays major role in adding strength to the MMCs. It can be added separately or along with any other metal or non-metal for improving the mechanical properties of MMCs.

iii. Graphene particles are giving better surface finish and also minimising flank wear due to its lubrication properties. It also helps to form discontinuous chips during turning operation.
iv. 'SR' rises in direct proportion to the size of the reinforcement material's particles.
v. Various optimization approaches, such as Taguchi method, Genetic algorithm, Fuzzy logic, TOPSIS, etc., can be used to optimise machining parameters including cutting speed, feed, and depth of cut for a superior surface finish, tool life, and minimal cutting forces.
vi. The main determinants of 'SR' are feed rate and the % volume fraction of SiC.
vii. Compared to frequently used cutting tools, the reinforcing particles added to metal matrix composites have a higher degree of hardness. Therefore, it is advised to use Polycrystalline Diamond (PCD) or Tungsten carbide tools for the machining of these MMCs, Coated tools gives better performance than that of uncoated tools.
viii. Stir casting was found to be an efficient casting technique as it uniformly distributes reinforcement particles into the base metal.

4. Future Scope

MMCs having aluminium alloys as base metal and various metal particles like SiC, TiB_2, B_4C, TiC etc as reinforcement materials are generally addressed by researchers. But the HMMCs having nanoparticles of graphene, carbon nanotubes, fly ash etc along with major proportions of SiC and other metals is not addressed adequately by the researchers.

Most of the research work is done by considering the Al6061, Al6063, LM6 etc as a base metal. There is scope to work on many other aluminium alloys.

References

[1] Ajithkumar, J. P., and M. Anthony Xavior. "Cutting force and surface roughness analysis during turning of Al 7075 based hybrid composites." *Procedia Manufacturing* 30 (2019): 180-187. https://doi.org/10.1016/j.promfg.2019.02.026
[2] Kesarwani, Soni, M. S. Niranjan, and Vibhu Singh. "To study the effect of different reinforcements on various parameters in aluminium matrix composite during CNC turning." *Composites Communications* 22 (2020): 100504. https://doi.org/10.1016/j.coco.2020.100504
[3] Balachandhar, R., R. Balasundaram, and M. Ravichandran. "Analysis of surface roughness of rock dust reinforced AA6061-Mg matrix composite in turning." *Journal of Magnesium and Alloys* 9, no. 5 (2021): 1669-1676. https://doi.org/10.1016/j.jma.2021.03.035
[4] Ic, Yusuf Tansel, Ebru Saraloğlu Güler, Büşra Sezer, Buğrahan Samed Taş, and Hazel Sultan Şahin. "Multi-objective Optimization of Turning Parameters for SiC-or Al2O3-Reinforced Aluminum Matrix Composites." *Process Integration and Optimization for Sustainability* 5, no. 3 (2021): 609-623. https://doi.org/10.1007/s41660-021-00169-4
[5] Pugazhenthi, A., I. Dinaharan, G. Kanagaraj, and J. Selvam. "Predicting the effect of machining parameters on turning characteristics of AA7075/TiB2 in situ aluminum matrix composites using empirical relationships." *Journal of the Brazilian Society of Mechanical Sciences and Engineering* 40, no. 12 (2018): 1-15. https://doi.org/10.1007/s40430-018-1480-2
[6] Chintada, Shoba, Siva Prasad Dora, and Raju Prathipati. "Investigations on the machinability of Al/SiC/RHA hybrid metal matrix composites." *Silicon* 11, no. 6 (2019): 2907-2918. https://doi.org/10.1007/s12633-019-0080-9
[7] Balasubramanian, K., M. Nataraj, and Palanisamy Duraisamy. "Machinability analysis and application of response surface approach on CNC turning of LM6/SiCp composites." *Materials and Manufacturing Processes* (2019). https://doi.org/10.1080/10426914.2019.1660787
[8] Bhushan, Rajesh Kumar. "Multi-response optimization of parameters during turning of AA7075/SiC composite for minimum surface roughness and maximum tool life." *Silicon* 13, no. 9 (2021): 2845-2856. https://doi.org/10.1007/s12633-020-00640-w

[9] Gnanavelbabu, A., V. Arunachalam, K. T. Sunu Surendran, R. Saranraj, and K. Rajkumar. "Turning Process Characteristics of Aluminium Matrix Hybrid Composite Using Grey Relational Surface Methodology." *Trends in Manufacturing and Engineering Management* (2021): 523-533. https://doi.org/10.1007/978-981-15-4745-4_46
[10] Butola, Ravi, Susheem Kanwar, Lakshay Tyagi, Ranganath M. Singari, and Mohit Tyagi. "Optimizing the machining variables in CNC turning of aluminum based hybrid metal matrix composites." *SN Applied Sciences* 2, no. 8 (2020): 1-9. https://doi.org/10.1007/s42452-020-3155-8
[11] Lin, Kunyang, Wenhu Wang, Ruisong Jiang, and Yifeng Xiong. "Effect of tool nose radius and tool wear on residual stresses distribution while turning in situ TiB2/7050 Al metal matrix composites." *The International Journal of Advanced Manufacturing Technology* 100, no. 1 (2019): 143-151. https://doi.org/10.1007/s00170-018-2742-y
[12] Nataraj, M., and K. Balasubramanian. "Parametric optimization of CNC turning process for hybrid metal matrix composite." *The International Journal of Advanced Manufacturing Technology* 93, no. 1 (2017): 215-224. https://doi.org/10.1007/s00170-016-8780-4
[13] Abas, Muhammad, Lal Sayd, Rehman Akhtar, Qazi Salman Khalid, Aqib Mashood Khan, and Catalin Iulian Pruncu. "Optimization of machining parameters of aluminum alloy 6026-T9 under MQL-assisted turning process." *Journal of Materials Research and Technology* 9, no. 5 (2020): 10916-10940. https://doi.org/10.1016/j.jmrt.2020.07.071
[14] Prakash, K. Soorya, P. M. Gopal, and S. Karthik. "Multi-objective optimization using Taguchi based grey relational analysis in turning of Rock dust reinforced Aluminum MMC." *Measurement* 157 (2020): 107664. https://doi.org/10.1016/j.measurement.2020.107664
[15] Baburaj, E., K. M. Mohana Sundaram, and P. Senthil. "Effect of high speed turning operation on surface roughness of hybrid metal matrix (Al-SiCp-fly ash) composite." *Journal of Mechanical Science and Technology* 30, no. 1 (2016): 89-95. https://doi.org/10.1007/s12206-015-1210-y
[16] Kirubadurai, B., K. Kanagaraja, and G. Jegadeeswari. "Impact of BUE on surface ruggedness for machining of aluminium matrix composites (6061/fly ash)." *Adv Mater Process Technol* (2020): 1-8. https://doi.org/10.1080/2374068X.2020.1823656
[17] Mahanta, Sweety, M. Chandrasekaran, and Sutanu Samanta. "New Emerging Al7075 Based Hybrid Nanocomposite for Automotive Applications: A Sustainability Approach." In *Key Engineering Materials*, vol. 856, pp. 29-35. Trans Tech Publications Ltd, 2020. https://doi.org/10.4028/www.scientific.net/KEM.856.29
[18] Mia, Mozammel, Md Awal Khan, Saadman Sakib Rahman, and Nikhil Ranjan Dhar. "Mono-objective and multi-objective optimization of performance parameters in high pressure coolant assisted turning of Ti-6Al-4V." *The International Journal of Advanced Manufacturing Technology* 90, no. 1 (2017): 109-118. https://doi.org/10.1007/s00170-016-9372-z
[19] Santos, M. C., A. R. Machado, M. A. S. Barrozo, M. J. Jackson, and E. O. Ezugwu. "Multi-objective optimization of cutting conditions when turning aluminum alloys (1350-O and 7075-T6 grades) using genetic algorithm." *The International Journal of Advanced Manufacturing Technology* 76, no. 5 (2015): 1123-1138. https://doi.org/10.1007/s00170-014-6314-5
[20] Wang, Yefu, Wenhe Liao, Kai Yang, Wanqun Chen, and Tingting Liu. "Investigation on cutting mechanism of SiCp/Al composites in precision turning." *The International Journal of Advanced Manufacturing Technology* 100, no. 1 (2019): 963-972. https://doi.org/10.1007/s00170-018-2650-1
[21] Aurich, Jan C., Marco Zimmermann, Stefan Schindler, and Paul Steinmann. "Turning of aluminum metal matrix composites: influence of the reinforcement and the cutting condition on the surface layer of the workpiece." *Advances in Manufacturing* 4, no. 3 (2016): 225-236. https://doi.org/10.1007/s40436-016-0152-7
[22] Basavarajappa, S. "Tool wear in turning of graphitic hybrid metal matrix composites." *Materials and Manufacturing Processes* 24, no. 4 (2009): 484-487. https://doi.org/10.1080/10426910802714431
[23] Kannan, A., R. Mohan, R. Viswanathan, and N. Sivashankar. "Experimental investigation on surface roughness, tool wear and cutting force in turning of hybrid (Al7075+ SiC+ Gr) metal matrix composites." *Journal of Materials Research and Technology* 9, no. 6 (2020): 16529-16540. https://doi.org/10.1016/j.jmrt.2020.11.074
[24] Vaxevanidis, N. M., N. A. Fountas, G. V. Seretis, C. G. Provatidis, and D. E. Manolakos. "A multi-parameter experimental and statistical analysis of surface texture in turning of a new aluminum matrix steel particulate composite." In *International Conference on Advanced Manufacturing Engineering and Technologies*, pp. 387-403. Springer, Cham, 2017. https://doi.org/10.1007/978-3-319-56430-2_29
[25] Sivasankaran, S., P. T. Harisagar, E. Saminathan, S. Siddharth, and P. Sasikumar. "Effect of nose radius and graphite addition on turning of AA 7075-ZrB2 in-situ composites." *Procedia Engineering* 97 (2014): 582-589. https://doi.org/10.1016/j.proeng.2014.12.286
[26] Poovazhagan, L., K. Kalaichelvan, A. Rajadurai, and V. Senthilvelan. "Characterization of hybrid silicon carbide and boron carbide nanoparticles-reinforced aluminum alloy composites." *Procedia Engineering* 64 (2013): 681-689. https://doi.org/10.1016/j.proeng.2013.09.143

[27] Kishore, D. Sai Chaitanya, K. Prahlada Rao, and A. Mahamani. "Investigation of cutting force, surface roughness and flank wear in turning of In-situ Al6061-TiC metal matrix composite." *Procedia materials science* 6 (2014): 1040-1050. https://doi.org/10.1016/j.mspro.2014.07.175
[28] Sivasankaran, S., E. Saminathan, S. Sidharth, P. T. Harisagar, and P. Sasikumar. "Effect of Graphite addition on surface roughness during turning of AA 7075-ZrB2 in-situ metal matrix composites." *Procedia Materials Science* 5 (2014): 2122-2131. https://doi.org/10.1016/j.mspro.2014.07.548
[29] James, S. Johny, Kb Venkatesan, Pc Kuppan, and R. Ramanujam. "Hybrid aluminium metal matrix composite reinforced with SiC and TiB2." *Procedia Engineering* 97 (2014): 1018-1026. https://doi.org/10.1016/j.proeng.2014.12.379
[30] Bansal, Puneet, and Lokesh Upadhyay. "Experimental investigations to study tool wear during turning of alumina reinforced aluminium composite." *Procedia Engineering* 51 (2013): 818-827. https://doi.org/10.1016/j.proeng.2013.01.117
[31] Jayaraman, P. "Multi-response optimization of machining parameters of turning AA6063 T6 aluminium alloy using grey relational analysis in Taguchi method." *Procedia Engineering* 97 (2014): 197-204. https://doi.org/10.1016/j.proeng.2014.12.242
[32] Saravanakumar, A., P. Sasikumar, and S. Sivasankaran. "Effect of graphite particles in drilling of hybrid aluminum matrix composite." *Procedia Engineering* 97 (2014): 495-504. https://doi.org/10.1016/j.proeng.2014.12.274
[33] Mahamani, A. "Influence of process parameters on cutting force and surface roughness during turning of AA2219-TiB2/ZrB2 in-situ metal matrix composites." *Procedia Materials Science* 6 (2014): 1178-1186. https://doi.org/10.1016/j.mspro.2014.07.191
[34] Krishnamurthy, L., B. K. Sridhara, and D. Abdul Budan. "Comparative study on the machinability aspects of aluminium silicon carbide and aluminium graphite composites." *Materials and Manufacturing Processes* 22, no. 7-8 (2007): 903-908. https://doi.org/10.1080/10426910701451754
[35] Sahoo, A. K., S. Pradhan, and A. K. Rout. "Development and machinability assessment in turning Al/SiCp-metal matrix composite with multilayer coated carbide insert using Taguchi and statistical techniques." *Archives of civil and mechanical engineering* 13, no. 1 (2013): 27-35. https://doi.org/10.1016/j.acme.2012.11.005
[36] Joardar, H., N. S. Das, G. Sutradhar, and S. Singh. "Application of response surface methodology for determining cutting force model in turning of LM6/SiCP metal matrix composite." *Measurement* 47 (2014): 452-464. https://doi.org/10.1016/j.measurement.2013.09.023
[37] Palanikumar, K., and R. Karthikeyan. "Optimal machining conditions for turning of particulate metal matrix composites using Taguchi and response surface methodologies." *Machining Science and Technology* 10, no. 4 (2006): 417-433. https://doi.org/10.1080/10910340600996068
[38] Kremer, A., A. Devillez, S. Dominiak, D. Dudzinski, and M. El Mansori. "Machinability of Al/SiC particulate metal-matrix composites under dry conditions with CVD diamond-coated carbide tools." *Machining Science and Technology* 12, no. 2 (2008): 214-233. https://doi.org/10.1080/10910340802067494
[39] Palanikumar, K., N. Muthukrishnan, and K. S. Hariprasad. "Surface roughness parameters optimization in machining A356/SiC/20p metal matrix composites by PCD tool using response surface methodology and desirability function." *Machining Science and Technology* 12, no. 4 (2008): 529-545. https://doi.org/10.1080/10910340802518850
[40] Wang, T., L. J. Xie, X. B. Wang, L. Jiao, J. W. Shen, H. Xu, and F. M. Nie. "Surface integrity of high speed milling of Al/SiC/65p aluminum matrix composites." *Procedia Cirp* 8 (2013): 475-480. https://doi.org/10.1016/j.procir.2013.06.136
[41] Sudheer, N. V. V. S., and K. Kateeka Pavan. "Effect of carburizing flame and oxidizing flame on surface roughness in turning of aluminium metal matrix composite and differential evolution optimization of process parameters." *Procedia materials science* 6 (2014): 840-850. https://doi.org/10.1016/j.mspro.2014.07.101
[42] Kim, Jin, Lorenzo Zani, Ahmad Abdul-Kadir, Lewis Jones, Anish Roy, Liguo Zhao, and Vadim V. Silberschmidt. "Hybrid-hybrid machining of SiC-reinforced aluminium metal matrix composite." *Manufacturing Letters* 32 (2022): 63-66. https://doi.org/10.1016/j.mfglet.2022.04.002
[43] Kannan, S., and H. A. Kishawy. "Surface characteristics of machined aluminium metal matrix composites." *International Journal of Machine Tools and Manufacture* 46, no. 15 (2006): 2017-2025. https://doi.org/10.1016/j.ijmachtools.2006.01.003
[44] Kannan, S., and H. A. Kishawy. "Tribological aspects of machining aluminium metal matrix composites." *Journal of materials processing technology* 198, no. 1-3 (2008): 399-406. https://doi.org/10.1016/j.jmatprotec.2007.07.021
[45] Kannan, S., H. A. Kishawy, and I. Deiab. "Cutting forces and TEM analysis of the generated surface during machining metal matrix composites." *Journal of materials processing technology* 209, no. 5 (2009): 2260-2269. https://doi.org/10.1016/j.jmatprotec.2008.05.025

[46] Sharma, M. M., C. W. Ziemian, and T. J. Eden. "Fatigue behavior of SiC particulate reinforced spray-formed 7XXX series Al-alloys." *Materials & Design* 32, no. 8-9 (2011): 4304-4309. https://doi.org/10.1016/j.matdes.2011.04.009

[47] Arunachalam, Ramanathan, Sujan Piya, Pradeep Kumar Krishnan, Rajaraman Muraliraja, John Victor Christy, Abdel-Hamid I. Mourad, and Majid Al-Maharbi. "Optimization of stir–squeeze casting parameters for production of metal matrix composites using a hybrid analytical hierarchy process–Taguchi-Grey approach." *Engineering Optimization* 52, no. 7 (2020): 1166-1183. https://doi.org/10.1080/0305215X.2019.1639693

[48] Hiremath, Vijaykumar, V. Auradi, and S. T. Dundur. "Experimental investigations on effect of ceramic B4C particulate addition on cutting forces and surface roughness during turning of 6061Al alloy." *Transactions of the Indian Ceramic Society* 75, no. 2 (2016): 126-132. https://doi.org/10.1080/0371750X.2016.1164626

[49] Alam, Md Tanwir, Akhter Husain Ansari, Sajjad Arif, and Md Naushad Alam. "Mechanical properties and morphology of aluminium metal matrix nanocomposites-stir cast products." *Advances in Materials and Processing Technologies* 3, no. 4 (2017): 600-615. https://doi.org/10.1080/2374068X.2017.1350543

[50] Sankhla, Arvind M., Kaushik M. Patel, Mayur A. Makhesana, Kuldeep K. Saxena, and Nakul Gupta. "Experimental Investigation of Tool Wear in Machining of SiC Based Al-MMC." *Advances in Materials and Processing Technologies* (2021): 1-20. https://doi.org/10.1080/2374068X.2021.1948710

[51] Elango, Mallichetty, and Krishnamoorthy Annamalai. "Machining parameter optimization of Al/SiC/Gr hybrid metal matrix composites using ANOVA and grey Relational analysis." *FME Transactions* 48, no. 1 (2020): 173-179. https://doi.org/10.1080/14484846.2020.1761587

[52] Bansal, Puneet, and Lokesh Upadhyay. "Effect of turning parameters on tool wear, surface roughness and metal removal rate of alumina reinforced aluminum composite." *Procedia Technology* 23 (2016): 304-310. https://doi.org/10.1016/j.protcy.2016.03.031

[53] Gudekote, Manjunatha, and Rajashekhar Choudhari. "Slip effects on peristaltic transport of Casson fluid in an inclined elastic tube with porous walls." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 43, no. 1 (2018): 67-80.

[54] Gudekote, Manjunatha, Rajashekhar Choudhari, Hanumesh Vaidya, and Kerehalli Vinayaka Prasad. "Peristaltic flow of Herschel-Bulkley fluid in an elastic tube with slip at porous walls." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 52, no. 1 (2018): 63-75.

[55] Gudekote, Manjunatha, Hanumesh Vaidya, Divya Baliga, Rajashekhar Choudhari, Kerehalli Vinayaka Prasad, and Viharika Viharika. "The effects of convective and porous conditions on peristaltic transport of non-Newtonian fluid through a non-uniform channel with wall properties." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 63, no. 1 (2019): 52-71.

[56] Baliga, Divya, Manjunatha Gudekote, Rajashekhar Choudhari, Hanumesh Vaidya, and Kerehalli Vinayaka Prasad. "Influence of velocity and thermal slip on the peristaltic transport of a herschel-bulkley fluid through an inclined porous tube." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 56, no. 2 (2019): 195-210.

[57] Divya, B. B., G. Manjunatha, C. Rajashekhar, Hanumesh Vaidya, and K. V. Prasad. "Analysis of temperature dependent properties of a peristaltic MHD flow in a non-uniform channel: A Casson fluid model." *Ain Shams Engineering Journal* 12, no. 2 (2021): 2181-2191. https://doi.org/10.1016/j.asej.2020.11.010

[58] Shivade, A., and S. Sapkal. "Selection of optimum plant layout using AHP-TOPSIS and WASPAS approaches coupled with Entropy method." *Decision Science Letters* 11, no. 4 (2022): 545-562. https://doi.org/10.5267/j.dsl.2022.5.002