Impact of TiB_2 Particles on Improving Processing Parameters of TiB_2/Al Metal Matrix Composites.

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Abstract. TiB2/Al MMCs, which are composite materials consisting of TiB2 particles embedded in an aluminium matrix, exhibit unique properties that make them very favourable for manufacturing high-performance aircraft blades. Nevertheless, the machinability of TiB2/Al MMCs continues to be a hurdle owing to the impact of TiB2 particles, hence restricting the extensive use of these materials. This research effectively examined the influence of TiB2 particles on processing parameters for TiB2/Al MMCs in order to meet manufacturing requirements. In addition, the research sought to determine the most favourable processing settings for these metal matrix composites, taking into account many considerations. The end-process variables, namely surface roughness and material removal rate (MRR), were assessed after the determination of the most favourable cutting velocity, feed rate, and depth of cut. The findings demonstrate substantial deviations from the strengthening of Metal Matrix Composites (MMCs) using titanium diboride (TiB2) nanoparticles. These results provide vital insights for enhancing the machining process of this material.

1 Introduction

Recognizing the superior attributes such as improved strength-to-weight ratios, enhanced elastic modulus, and increased resistance to wear, particle-reinforced composites produced from metal matrices (PRMMCs) have become a crucial class of materials in aviation and various industries[1-2]. PRMMCs were first produced utilising distinct methodologies,

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namely ex-situ and in-situ procedures, correspondingly. A reinforcement is produced using a stir-casting method and then incorporated into a substrate by a further stir-casting approach. The phenomenon of segregating positive reinforcement particles with poorer interfacial bonding is often found in stir-casting composite materials[3-4]. The in-situ nano-composite, on the other hand, is unique since it synthesises its reinforcing materials naturally over the substrate. This novel method improves surface adsorption, leading to enhanced stiffness properties. The rapid synthesis allows for improved integration, which adds to the composite's overall efficacy boost[5]. It is currently common practice for ongoing research projects to place equal emphasis on the steps required to prepare materials for evaluation[6]. Furthermore, research on the mechanical characteristics is ongoing[7,8].

Production of particle-reinforced metal matrix composites (MMCs) takes place in-house. Analysing the performance characteristics of these composites for different applications and understanding the complexities of manufacturing procedures are the main goals. Possessing sufficient expertise in machining high-performance materials is essential for engineering applications. Encased reinforcing elements inside the mould are known to be quite abrasive. This property causes problems when machining metal matrix composites (MMCs), the most common of which are increased tool wear and reduced surface quality[9]. Industry practice often employs ex-situ metal matrix composites (MMCs) reinforced with SiC particles because of how easy they are to prepare. Consequently, the majority of research studies have concentrated on investigating the active aspects of machining with silicon carbide additives in metal matrix composites[10-12], specifically examining cutting tool wear and surface integrity[13,14], as well as chip formation, to comprehensively understand their performance during machining processes15,16].

In fact, in-situ metal matrix composites (MMCs) machining has received little attention from academic investigations. Aluminium metal (AMC) matrix composites with in-situ ceramic reinforcement are novel materials. The newly developed AMC showed better machining performance than Al2O3 and Al_2O_3/SiC composites[17]. Metal matrix composites (MMCs), specifically PTMCs made of TiCp/Ti-6Al-4V, were the focus of the investigation. The results showed that PTMCs are more difficult to remove materials from than Ti-6Al-4V. An important factor in attaining better surface quality was the use of a short intensity of metal cutting in conjunction with specimen speed. We also evaluated the performance of electroplated CBN wheels to brazed CBN wheels. According to the experimental findings, the brazed CBN grinding disc has a better chance of quickly grinding PTMCs at high velocities[18,19]. The machinability of metal matrix composites (MMCs) made of in-situ Al-6061 and TiB_2 was the subject of another investigation. To find out what happens when you change the cutting settings, researchers looked at tool wear, cutting aggressiveness, and surface roughness. There was a correlation between tool wear, surface roughness, and cutting forces and the TiB_2 reinforcement ratio[20].

The potential of machining homogenised composite material matrix architectures using genuine Al-Cu/TiB_2 aluminium. The study's primary objective was to identify the variables that have the most influence on efficiency metrics taken during turning operations. Additionally, the research looked at how often chips and built-up edges develop during milling[21].Metal matrix composites (MMCs) containing TiB_2/Al were the subject of an experimental investigation to determine their productivity. The surface condition, tool wear and tear, and chipping were the primary areas of analysis in the exhaustive examination. In comparison to PCBN and coated carbide tools, PCD tools demonstrated the least amount of tool wear, according to the data[22]. Researchers looked examined TiB2/Al metal matrix composites (MMCs) to learn about tool wear and their inherent surface integrity. Tool damage most often manifested as bonding, cutting, and stripping deterioration. Uncoated carbide tools had a lifetime of 3–20 minutes, with milling speed being the main factor determining the exact value. Parameter selection for metal matrix composite slicing is an important part of machine tooling procedures in real-world engineering applications[23,24]. The effect of surface quality on turning LM23 Nano-particles with Al and SiC compositions as a function of machining settings. Finding the sweet spot for metal removal rate and surface roughness was the goal of the research, which used response surface methodology (RSM)[25].

Optimising machining conditions using the Taguchi process also helped reduce surface roughness[26]. To convert Al/SiCp metal matrix composites, we used an uncoated tungsten carbide insert in a dry environment and tested the effects of changing cutting speed, feed rate, and depth of cut on flank wear and surface roughness. Implementing the Taguchi technique allowed us to identify the optimal process parameters for lowering flank wear and improving surface roughness[27]. Additionally, certain analyses aimed at optimising cutting settings using soft computing approaches. Investigated were the effects of PCD inserts on Al-SiC(20p) surface roughness and machining conditions. We used an artificial neural network (ANN) and analysis of variance (ANOVA) to look at the data from the large investigations[28]. The procedure of turning Al/SiC MMCs with a PCD insert was the subject of an extensive exploratory study. Findings indicated relationships between cutting speed, feed rate, depth of cut, specific power, and workpiece surface quality.

Using Grey relational analysis, which is especially useful for stir casting particle-reinforced MMCs, we were able to establish the optimal machining settings[29]. For the purpose of this study, we turned in-situ Al606/TiC metal matrix composites and examined how various operational variables, such as feed rate, depth of cut, and cutting speed, affected cutting force, surface roughness, and flank wear[30]. In addition, we tested how different machine parameters, such as carriage travel rate, tool travel distance, and cutting speed, affected the cutting of the specimen and surface irregularities in the TiC aluminium alloy (Al-6061). To do this, we used analysis of variance (ANOVA) methods and the L-27 Taguchi orthogonal array to dissect the impact of each parameter[31].

According to the results of the aforementioned study, a lot of work has gone into developing and perfecting machine cutting settings for stir-casted metal matrix composites that have SiC particles reinforced. Nonetheless, physical properties differ between stir-casted and non-stir cast metal matrix composites due to the different microstructures linked with the two processes. Thus, stir-casting and non-stir-casting metal matrix composites are functionally different. However, research into the optimisation of cutting settings and detailed machinability of in-situ MMCs has been sparse. Additionally, as an important measure for appliance production, machining efficiency is significant. Among the many pressing issues with TiB2-particle-reinforced metal matrix composites (MMCs), this study intends to illuminate the ways in which reinforced particles impact machining forces, residual stress, and surface roughness. We look at the effects of different cutting settings. Furthermore, our experimental results inform the development of a multi-objective optimisation model that takes surface roughness and material removal rate into account. Here is a summary of the paper: I will explain the machining tests in detail in Section 2. In Section 3, we give and discuss the results of the experiments. Section 4 details the process of creating and refining a model for multi-objective optimisation using a genetic algorithm (GA). Section 5 presents the paper's concluding conclusions and suggests areas for further study to explore.

2 Experimental Procedure

2.1 Content as well as example

In this experiment, 7075 aluminium that was not reinforcing and standard comparable alloys that were were both used, with the addition of 6 vol% TiB2 particles with sizes varying from 50 to 200 nm. In its production, the substance made use of a mix of chemicals. Table 1 shows the chemical composition of the matrix alloy as a percentage of total weight. Figure 1 shows the microstructure of metal matrix composites containing 6% TiB2/Al, and Table 2 details the mechanical and physical properties of these composites. The specimens, which measure 20mm x 100mm, were made by turning rectangular blocks of 7075 aluminium alloy with TiB2/Al MMCs, as shown in Figure 2.

Table 1: Alloy 7050 Chemical Composition

Element	Cr	Cu	Fe	Mg	Mn	Si	Zn	Ti	Al
Content	0.8	1.35	0.3	2.21	0.08	0.4	5.67	0.06	Balance

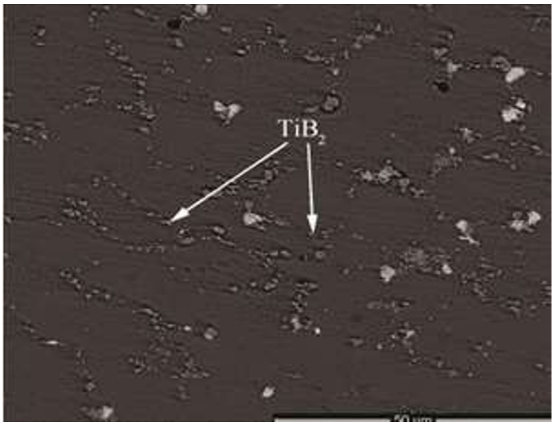

Fig.1. Al-TiB2 morphologies

Fig. 2. TiB2/Al MMCs specimens.

Table. 2. TiB2/Al metal matrix composites' physical and mechanical characteristics

property	Density (kg·m-3)	BHN	Elongation	Poisson ratio	Yield strength (MPa)	Elastic modulus (GPa)
Content	2980	220	6%	0.33	630	82

2.2 Experimental setup

The experiments in this study used a 2Y2K speed lathe turning centre and a bar turning process in a dry environment. The experiment used a cemented carbide tool to target the coarse impact of TiB_2 particles. In Table 3, you may see the specific turning circumstances, together with the cutting parameters. To further illustrate the experimental design, Fig. 3 shows the layout of the cutting apparatus.

The 2Y2K speed lathe turning centre was selected as the experimental platform for the investigation because it can provide accurate control and measurement while turning bars. In order to separate the impact of cutting settings on the materials' machining performance, it was decided to work in a dry environment. The goal of the study was to address the coarse properties of the material caused by the TiB_2 particles by using a cemented carbide tool that is recognised for its durability and resilience to abrasion.

Table 3 shows the exact turning settings used, including important factors like feed rate, cutting speed, and thickness per cutting. The machinability and surface quality of the turned components are greatly affected by these restrictions. Figure 3 shows the cutting setup in graphical form, providing information on the spatial arrangement and orientation of the tools, workpiece, and associated components as they are turned.

Table 3. Process consideration and their Levels

Feature	Level-I	Level-II	Levl-III
Cutting speed (rpm),	480	750	1145
Feed rate (mm/rev)	0.4	0.8	1.2
Depth of cut (mm)	0.2	0.4	0.6

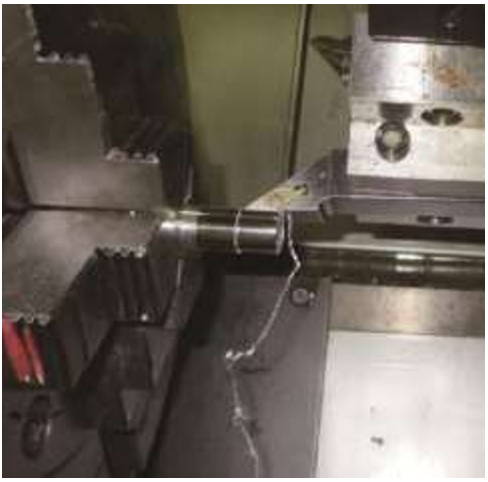

Fig. 3. Cutting setup.

2.3 Taking measurements

We used a surface roughness evaluator (SJ210) with a measurement of 20 millimetres and a cutoff length of 20 millimetres to determine the surface roughness. An average of the two measurements that were collected at each moment were recorded and reported for further study. The measurements were done twice. The material removal rate, which refers to the rate at which material is cut or removed during a machining process, is often quantified in terms of the volume or weight of material removed per unit of time. For example, cubic millimetres per second or grammes per minute are examples of units of measurement that are commonly used. Considering that the material removal rate is a statistic that acts as an indication of the efficiency and efficacy of a certain cutting process, it is an extremely important parameter. Although quicker machining times are often the result of greater material removal rates, it is vital to strike a balance between this and other considerations such as the life of the tool and the high quality of the surface.

3 Results And Discussions

3.1. Roughness of the exterior

Figure 4 clearly shows how cutting speed affects surface irregularity. At all tested cutting velocities, TiB2/Al metal matrix composites (MMCs) show less roughness than the non-reinforced AL-7075 alloy. Because of the reinforcing particles, Al MMCs/TiB2 have less ductility and crack more easily when turned, which is why this happens. Figure 4 also shows that surface irregularity improves as cutting speed increases; this may be because greater cutting speeds cause less material deformation.

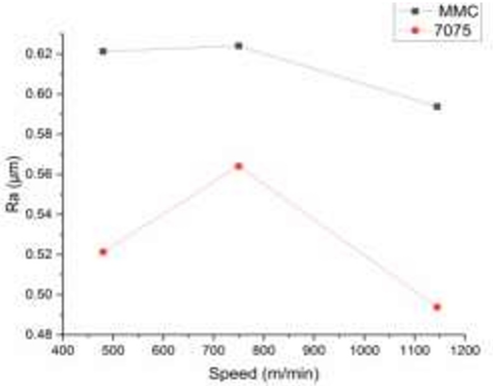

Fig.4. Machining intensifies and the texture

You can see the effect of feed rate on surface roughness in Figure 5. The surface roughness grows in direct proportion to the total feed rate. When compared to the non-reinforced alloy, Metal Matrix Composites (MMCs) exhibit reduced surface irregularity at lower feed rates. At greater feed rates, however, the MMCs start to seem rougher than the non-reinforced alloy, reversing the trend.

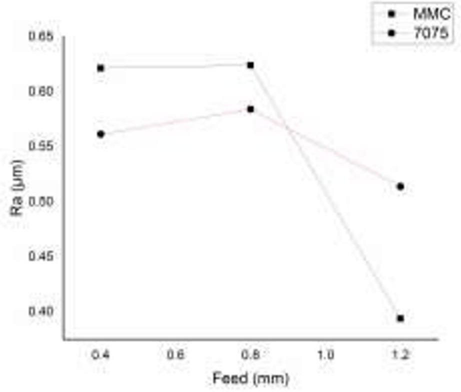

Fig.5. The rate of feed and texture

In addition, Figure 6 shows the machining surfaces of the non-reinforced Al-7075 composite, whereas Figure 7 shows the machining surfaces of the stir-casting (TiB2) particle-strengthened metal matrix composite, both under the same cutting circumstances. It is worth noting that the non-reinforced 7075 aluminium alloy has uneven feed marks on its surface. This is likely due to the material straightening out when cutting. The feed markings on the surface of MMCs, on the other hand, are noticeable and become worse as the cutting speed increases.

This study's findings on ex-situ SiC particle-reinforced MMCs are drastically at odds with the experimental data. The variation in the diameters of the reinforcing parts is likely to blame for this disparity. The produced layer is relatively unaffected by TiB2 particles since their size is less than a micrometre. So, unlike with bigger reinforcement particles, their effect on machining properties and surface quality is unique. If we want to know how in-situ TiB2 particles affect the machined surface of MMCs, we need to know the size of the reinforcement particles.

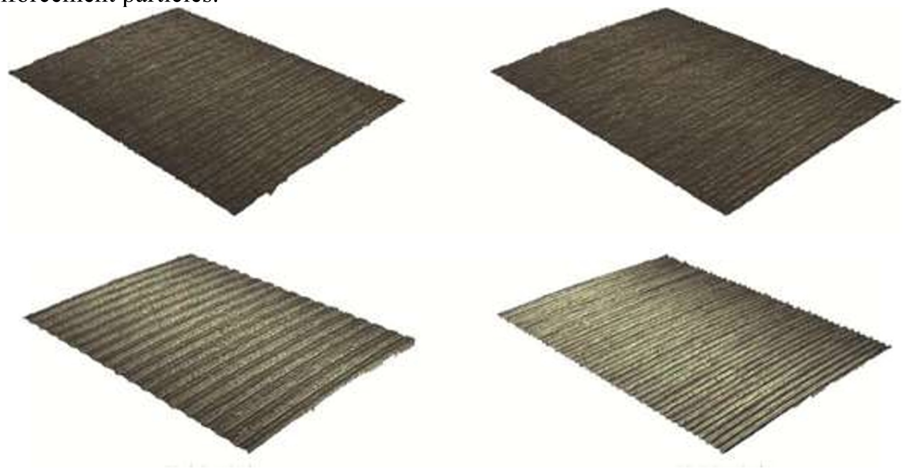

Fig. 6. metal matrix composites manufactured under various rates

3.2. Optimising rotational variables considering exterior irregularity with the MRR

Irregularities occurring at the interface have a substantial influence on the quality of components. This characteristic is of utmost importance as it has the capability to generate sites for the production of cracks or corrosion in the presence of imperfections[32]. This part is focused on doing experimental inquiries to examine the correlation between cutting parameters and surface roughness. In order to do a quantitative analysis of this correlation, the surface roughness was measured using RSM (Response Surface Methodology). This method is remarkable because it can accurately portray a two- or three-dimensional hypersurface, illustrating the real relationship between the inputs that govern parameters and the genuine average responses. Furthermore, the optimisation of machining variables took into consideration factors such as Material Removal Rate (MRR) and Surface Roughness (RA).

3.3 Making a framework for exterior irregularity

Experiments in this section used Box-Behnken designs because, in comparison to more complicated designs, they effectively estimate first- and second-order coefficients with a lower sample size. There were three tiers for every component in the Box-Behnken layout. Cutting speeds varied from 110 m/min to 300 m/min, depth of cut from 0.4 mm to 1.2 mm, and feed rate from 40 mm/min to 120 mm/min. Table 4 displays the experimental settings along with the responses for each[26,33]. Previous research has shown that a second-order quadratic model may approximate the optimal relationship between surface roughness (Ra) and the machining factors with the required degree of precision. Equation (1) provides a mathematical representation of this connection.

In Equation (1), Ra signifies surface irregularities of the specimen, the symbol **β** corresponds to its degradation coefficient, $\mathbf{x_i}$ denotes the levels of the $\mathbf{i^{th}}$ turning variables, and **ε** represents the experimental error associated with the investigation.

$$y = \beta + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i} \sum_{j} \beta_{ii} x_i x_j + \varepsilon \tag{1}$$

In order to validate the findings of previous studies, we used analysis of variance (ANOVA) to look at how different input parameters affected surface roughness. There was an evaluation of the linear, 2FI, and quadratic models' efficacy. Table 5 summarises the following metrics: mean, standard deviation, adjusted R2, projected R2, corrected R2, and coefficient of determination. Based on the data in Table 5, it seems that using a quadratic model as the response surface function yields the best results. To determine the correlation between surface roughness and machining parameters, the following second-order response surface model was constructed using data from Table 4 and RSM in uncoded units.

Table.4. Value of parameters suggested after optimisation

S.No	Speed	Feed	Depth of Cut	Rake Angle	MRR	Ra
1	480	0.4	0.2	2	240	0.6875
2	480	0.8	0.4	4	238	0.4603
3	480	1.2	0.6	6	237	0.7162
4	750	0.4	0.4	6	234	0.2268
5	750	0.8	0.6	2	233	0.5765

6	750	1.2	0.2	4	232	1.0689
7	1145	0.4	0.6	4	231	0.5336
8	1145	0.8	0.2	6	230	0.2024
9	1145	1.2	0.6	2	229	0.4454

$$Ra = 2.33 - 0.0044V + 0.091f + 1.26a_p - 0.00038Vf + 0.0026Va_p + 0.00062fa_p + 0.000048V^2 + 0.00016f^2 - 1.11a_p^2 \quad (2)$$

Table. 5. Process Variables Synopsis

Sources	Std. Dev	R2	Adj. R2	Pred. R2	Press
Linear	0.150961	0.9382	0.9254	0.9289	1.58674
2FI	0.126385	0.9504	0.9406	0.9452	1.17654
Quadratic	0.087173	0.9824	0.9857	0.9841	0.44706

A method for determining its sufficiency was to use the initial data set used to construct the regression model for validation. To further assess how well the response surface model worked, we used a second set of validation data that included one to three surface roughness assessments. In order to conduct a thorough evaluation of the model's correctness, the validation data shown in Table 6 were purposefully chosen from different places throughout the range of the cutting parameters. The highest inaccuracy is within 10%, as shown in Table 6. So, it's safe to say that the regression model passed the validation test.

Table. 6. An explanation of the Cutting parameter

Run	**Cutting parameter**		**αp(mm)**	**Measurement results**	**Surface roughness (μm) RS model**	**Error(%)**
	V(m/min)	f(mm/min)				
1	480	48	0.5	1.191	1.27210	6.809%
2	750	54	0.7	1.804	1.96562	8.959%
3	1150	60	1.1	0.477	0.45118	5.413%

3.4. Optimization problem formulation

It is necessary to consider other factors in order to reach a given surface roughness value, since surface roughness might vary depending on the kind and position of components. From a more pragmatic perspective, the Material Removal Rate (MRR) is a further critical component in turning processes. Consequently, we optimise both the surface roughness and the MRR. Using Eq. (3), we can get the Material Removal Rate in mm3/min.

$$\text{MRR} = 1000 \times V \times f \times \alpha p \quad (3)$$

It is possible to achieve high material removal rates (MRRs) by optimising the cutting conditions using the right mathematical approach, all while keeping surface roughness as a restriction. The next step is to formalise the multi-objective optimisation paradigm mathematically. In this context, MRR stands for the Material Removal Rate, which is described in Equation 3. Based on the instructions in the cutting guide, we have established the ranges of the cutting parameters for optimisation.

3.5. Outcomes of optimization while further conversation

All through the inquiry, there is a connection of trade-off between these two goals. An example would be the trade-off between surface roughness and material removal rate (MRR) caused by an increase in feed rate. Therefore, solely focusing on reducing surface roughness would hinder the achievement of another goal, which is escalating material removal rate. Therefore, it's critical to strike a balance between all objectives. As a solution, we apply a standard procedure for aggregating biassed aspects to deal with objective variables. It is common practice to utilise stabilisation influences, where the total of all effects is 1. Considering the trade-off between the goals, the optimisation process gives a single solution for each iteration.

Pareto optima are solutions to multi-objective issues where no one answer is better than the others. Reason being, surface roughness and other variables are part-specific, calling for individualised machining strategy. This research attempted to solve the optimisation problem by using a Pareto-based strategy. This strategy offers several options, so the user may choose the best one according to his methodological or financial needs. This study optimised using a Pareto-based genetic algorithm to do this.

Initialization, evaluation, crossover, mutation, selection, and other crucial operations are all part of the genetic algorithm (GA). This study used the following settings for the genetic algorithm: 100 individuals per population, a 0.8 crossover probability, a 0.05 mutation probability, and 300 generations altogether. The multi-objective optimisation model was fine-tuned using the commercial application MATLAB. For every objective, Figure 7 shows the Pareto optimal solution.

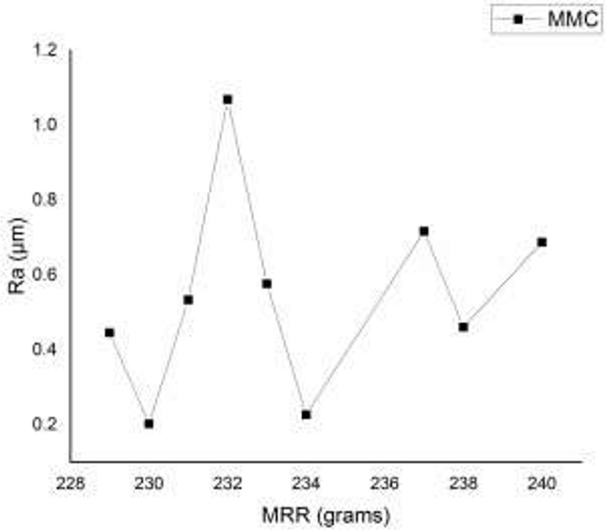

Fig. 7. Pareto optimal solutions.

Figure 7 analysis shows that surface roughness and MRR are trade-offs, with opposing ideal values for the two goals. For machining considerations with V = 480 m/min, f = 0.4 mm/min, and ap = 0.425mm, the configuration with the least surface roughness but a relatively low MRR is represented by point I. Meanwhile, point II shows a surface roughness of around 1.2µm and a moderately high MRR, which correspond to machining considerations of V = 750 m/min, f = 1.2 mm/min, and ap = 0.984mm. The research found that a middle ground between the two extremes, as shown in Figure 7, maximises RA and MRR. a similar experiment to confirm the ideal result we got. Use of both the study's optimum cutting settings and appropriate projected machining factors yielded the same rate of material removal. After cutting Al7075/TiB2 with these conditions, we measured and compared the specimens' RA. Table 7 displays the results. The table shows that when comparing the optimum machining considerations to the standard parameters, the former produced a better RA with the same MRR. This confirms what other studies have shown: that faster cutting speeds improve RA by facilitating a more uniform flow of material elevation. On the other hand, higher feed rates are associated with an increase in RA.

Table.7. Results of comparative experiment.

Machining type	*a*p(mm)	*V* (m/min)	Machining parameter *ƒ* (mm/min)	Ra (µm)	MRR (mm^3/min)
Predictable	0.8	480	0.4	0.85	140800
Optimal	0.8	750	0.8	0.593	141360

4 Summary as well as potential initiatives

We compared 6% TiB2/Al MMCs to non-reinforced Al-7075 to see how the stir-casted Al-7075/TiB2 machinability affected the results. Investigating how TiB2 particles affected surface roughness was the primary focus of the research. We created an RSM model just for Ra. Also, a genetic algorithm that takes surface roughness and material removal rate into account has a Pareto focus in order to maximise efficiency across a variety of goals. Following is a synopsis of the most important takeaways from this study:

➢ After a certain point, the surface roughness of both materials reached a plateau, even though it decreased significantly as cutting speed rose. When comparing Al-7075 and Al-7075/TiB2, the Ra for the latter was less substantial at low input rates. Ra for Al-7075/TiB2 MMCs increased more rapidly than Ra for 7075-aluminum alloy as feed rate increased. Additionally, the 7075-aluminum alloy showed chip formations that were not as apparent and prominent as those on the Al-7075/TiB2 MMCs. These results contradict those of previous studies, suggesting a discrepancy in the phenomena under study.

➢ In this work, we used independent checking data to validate the surface roughness RMS model. The Pareto-based genetic algorithm was an effective strategy for optimising the material removal rate and surface roughness, two objectives in a multi-objective optimisation issue. We found a number of Pareto solutions that gave us different optimum values for MRR and surface roughness.

A thorough comprehension of the machinability of this new material still needs more investigation. In order to better understand the machining properties of this novel material, future research will concentrate on delving further into several areas, including the mechanics of material removal and chip production.

References

1. Cui Y, Wang LF, Ren JY. Multi-functional SiC/Al composites for aerospace applications. *Chinese J Aeronaut* 2008; 21(6): 578-84.
2. Natarajan S, Naraynasamy R, Kumaresh B, Dinesh G, Kumar BA, Sivapradad K. Sliding wear behavior of Al 6063/TiB2 in situ composites at elevated temperatures .*Mater Design* 2009; 30(7): 2521-31.
3. Tham LM, Gupta M, Cheng L. Effect of limited matrix-reinforcement interfacial reaction on enhancing the mechanical properties of aluminium-silicon carbide composites. *Acta Mater* 2001; 49(16): 3243-53.
4. Irfan A, Zhang Q, Xiang M. Corrosion inhibition of SiCp/5A06 aluminum metal matrix composite by ceriumconversion treatment. *Chinese J Aeronaut* 2009; 22(6): 670-6.
5. Ai TT. Microstructure and mechanical properties of in-situ synthesized Al2O3/TiAl composites. *Chinese J Aeronaut* 2008; 21(6): 559-64.
6. Lu L, Lai MO, Su Y, Teo HL, Feng CF. In situ TiB2 reinforced Al alloy composites. *Scripta Mater* 2001; 45(9): 1017-23.
7. Tayeh T, Douin J, Jouannigot S, Zakhour M, Nakhl M, Silvain J, Bobet J. Hardness and Young's modulus behavior of Al composites renforced by nanometric TiB2 elaborated by mechanosysnthesis. *Mater Sci Eng A-Struct* 2014; 591: 1-8.
8. Wang M, Chen D, Chen Z, Wu Y, Wang F, Ma N, Wang H. Mechanical properties of in-situ TiB2/A356 composites. *Mater Sci Eng A-Struct* 2014; 590: 246-54.
9. Pramanik A, Zhang LC, Arsecularatne JA. An FEM investigation into the behavior of metal matrix composites: Tool-particle interaction during orthogonal cutting. *Int J Mach Tool Manu* 2007; 47(10): 1497-506.
10. El-Gallab M, Sklad M. Machining of Al/SiC particulate metal-matrix composites Part I: Tool performance. *J Mater Process Tech* 1998; 83(1-3): 151-8.
11. Ding X, Liew WYH, Liu XD. Evaluation of machining performance of MMC with PCBN and PCD tools. *Wear* 2005; 259(7-12): 1225-34.
12. Bhusham PK, Kumar S, Das S. Effect of machining parameters on surface roughness and tool wear for 7075 Alalloy SiC composite. *Int J Adv Manuf Tech* 2010; 50(5): 459-69.
13. El-Gallab M, Sklad M. Machining of Al/SiC particulate metal-matrix composites Part II: Workpiece surface integrity. *J Mater Process Tech* 1998; 83(1-3): 277- 85.
14. Muthukrishnan N, Murugan M, Rao KP. Machinability issues in turning of Al-SiC (10p) metal matrix composites. *J Mater Process Tech* 2008; 39(3): 211-8.
15. Joshi SS, Ramakrishnan N, Ramakrishnan P. Analysis of chip breaking during orthogonal machining of Al/SiCp composites. *J Mater Process Tech* 1999; 88(1-3): 90-6.
16. Pramanik A, Zhang LC, Arsecularatne JA. Machining of metal matrix composites: Effect of ceramic particles on residual stress, surface roughness and chip formation. *Int J Mach Tool Manu* 2008; 48(15): 1613-25.
17. Siva SBV, Ganguly RI, Srinivasarao G, Sahoo KL. Machinability of Aluminum metal matrix composite reinforced with in-situ ceramic composite developed from mines waste colliery shale. *Mater Manuf Process* 2013; 28(10): 1082-9.
18. Li Z, Ding WF, Shen L, Xi XX, Fu YC. Comparative investigation on high-speed grinding of TiCp/Ti-6Al-4V particulate reinforced titanium matrix composites with

single-layer electroplated and brazed CBN wheels. *Chinese J Aeronaut* 2016; 29(5): 1414-24.

19. Anandakrishnan V, Mahamani A. Investigations of flank wear, cutting force, and surface roughness in the machining of Al-6061-TiB2 in situ metal matrix composites produced by flux-assisted synthesis. *Int J Adv ManufTech* 2011; 55(1): 65-73.
20. Senthil P, Selvaraj T, Sivaprasad K. Influence of turning parameters on the machinability of homogenized Al-Cu/TiB2 in situ metal matrix composites. *Int J Adv Manuf Tech* 2013; 67(5): 1589-96.
21. Ding WF, Zhao B, Xu JH, Yang CY, Fu YC, Su HH. Grinding behavior and surface appearance of (TiCp+TiBw)/Ti-6Al-4V titanium matrix composites. *Chinese J Aeronaut* 2014; 27(5): 1334-42.
22. Jiang RS, Wang WH, Song GD, Wang ZQ. Experimental investigation on machinability of in situ formed TiB2 particles reinforced Al MMCs. *Journal of Manufacturing Processes* 2016; 23: 249-57.
23. Xiong YF, Wang WH, Jiang RS, Lin KY, Song GD. Tool wear mechanisms for milling in situ TiB2 particle-reinforced Al matrix composites. *Int J Adv Manuf Tech* 2016; 86(9): 3517-26.
24. Xiong YF, Wang WH, Jiang R, Lin KY, Song GD. Surface integrity of milling in-situ TiB2 particle reinforced Al matrix composites. *Int J Refract Met H* 2016; 54: 407-16.
25. Palanikumar K, Karthikeyan R. Optimal machining conditions for turning of particulate metal matrix composites using Taguchi and response surface methodologies. *Mach Sci Technol* 2006; 10(4): 417-33.
26. Palanikumar K, Muthukrishnan N, Hariprasad KS. Surface roughness parameters optimization in machining A356/SiC/20p metal matrix composites by PCD tool using response surface methodology and desirability function. *Mach Sci Technol* 2008; 12(4): 529-45.
27. Sahoo AK, Pradhan S. Modeling and optimization of Al/SiCp MMC machining using Taguchi approach. *Measurement* 2013; 46(9): 3064-72.
28. Muthukrishnan N, Davim JP. Optimization of machining parameters of Al/SiC-MMC with ANOVA and ANN analysis. *J Mater Process Tech* 2009; 209(1): 225-32.
29. Ramanujam R, Muthukrishnan N, Raju R. Optimization of cutting parameters for turning Al-SiC(10p) MMCusing ANOVA and grey relational analysis. *Int J Precis Eng Man* 2011; 12(4): 651-6.
30. Kishore DSC, Rao KP, Mahamani A. Investigation of cutting force, surface roughness and flank wear in turning of In-situ Al6061-TiC metal matrix composite. *Procedia Materials Science* 2014; 6: 1040-50.
31. Kishore DSC, Rao KP, Ramesh A. Optimization of machining parameters for improving cutting force and surface roughness in turning of Al6061-TiC in-situ metal matrix composites by using Taguchi method. *Mater Today* 2015; 2(4-5): 3075-83.
32. Xavior MA, Adithan M. Determining the influence of cutting fluids on tool wear and surface roughness duringturning of AISI 304 austenitic stainless steel. *J Mater Process Tech* 2009; 209(2): 900-9.
33. Makadia AJ, Nanavati JI. Optimisation of machining parameters for turning operations based on response surface methodology. *Measurement* 2013; 46(4): 1521-9.