Physical Mechanical and Wear Analysis of Titanium Reinforced

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Abstract — In order to evaluate its machining and mechanical capabilities, a hybrid aluminium metal matrix composite was created for this investigation. Composites made of an aluminium metal matrix are reinforced with silicon carbide and titanium di boride. The shape and structure of the composites and improved particle dispersion were thoroughly examined using optical microscopy. Using a Vickers hardness testing apparatus, the cast composite underwent the hardness test to assess its hardness. The results of the hardness tests show that the hardness value is increased by SiC and TiB2 reinforcing. The hardness rating decreases when the reinforcement is increased by up to 15%, though. Mechanical testing was done on tensile samples created from cast composite specimens of diverse compositions. According to the results of tensile tests, applying reinforcement SiC to the base metal provided the composite 20% more strength, however adding TiB2 decreased the strength by 50–60%. Wear test analysis was the method used to study the TiB2 wear resistance behaviour. The addition of TiB2 increased the composite's wear resistance, according to wear tests. The samples made of cast composite were carefully machined. The impact of machining parameters including cutting speed (s), feed rate (f), depth of cut (d), and TiB2 weight percentage on surface roughness (Ra) throughout a turning operation was investigated. The proportion of TiB2 reinforcement, having a contribution of 38.86%, is the single most important parameter impacting surface quality, according to the examination of variance approach. Research on tool wear was conducted to examine tool wear patterns, built-up edge formation, the impact of TiB2 on tool wear, and how these factors affect the surface's cast composite quality. Surface quality is affected by TiB2's increased tool wear, poor surface polish, and built-up edge formation.

Keywords: SiC, Surface Roughness, Tool Wear, Tib_2, Hybrid Metal Matrix Composite

I. INTRODUCTION

A number of its distinctive properties, including high specific strength, wear resistance, strength-to-weight, toughness-to-cost, and additional desired attributes, composites are widely employed in the aerospace, military, and automotive sectors. Incorporating hard ceramic particles like SiC, AL2O3, and B4C into an aluminum-based matrix has been attempted on many occasions. The scientific literature claims that SiC is chemically compatible with aluminium, forms a suitable bond with the matrix without forming an intermetallic phase, and offers additional advantages including excellent thermal conductivity, high workability, and low cost. The fabrication of metal matrix composites including SiC in varying quantities, in addition to the mechanical and machinability characteristics of these composites, have historically received the majority of attention.

In reaction to the requirement for materials for engineering with high strength, stronger wear resistance, and enhanced temperature efficiency, hybrid aluminium metal matrix composites were developed recently. A common second reinforcing material is Al2O3. It can have downsides, though, such poor wetting behavior with aluminium and higher porosity due to weight gain. In earlier research, we tried to create an Al/SiC/Al2O3 composite. The current effort is to create TiB2, which will outperform all already available reinforcements. The extraordinary properties of TiB2, such as its high melting point (2790° C), high hardness (86 HRA or 960 HV), high elastic modulus (530*103 GPa), and excellent thermal stability, are mostly to blame for this.

Brittle reaction byproducts are not produced inside the reinforcement-matrix contacts because TiB2 ceramic particles have no ability to interact with molten aluminium. TiB2 reinforced aluminium is renowned for having excellent wear resistance. In accordance with Khairaldien's research, when silicon carbide particles come into touch with one another, the strength of the material is reduced by around 15% to 20% of its weight percentage, while the likelihood of a number of particles clustering together rises. To produce high-strength and cost-effective combinations, the quantity of reinforcement in the current investigation was modified to a maximum of 15% (10% SiC and 0-5% TiB2).

The stir-cast aluminium matrix and its manufacturing factors were comprehensively studied by Pai et al., and the stir-casting process is employed for production. A Comparative Study on the Microstructures and Mechanical Properties of Al 6061 Alloy and the MMC Al 6061/TiB2/12P is the title of a piece of writing by T.V. Christy. The composite Al-6061/TiB2/12p was successfully created using the in-situ reaction process. Strings and particle agglomerates were discovered to be the composite's distinctive microstructural features. Al-TiB2 composite has higher hardness, tensile strength, and Young's modulus values than the parent alloy. However, machining is necessary for the ultimate conversion of raw materials into vital designed goods. Composites are typically challenging to treat due to their hardness and abrasiveness, which increases tool wear.

Sharp abrasives operate as tiny cutting edges once they come into interaction with tool edges. These minute particles act as abrasives between the cutting insert and the surface of the workpiece. Excessive tool wear and poor surface quality result from this. The present research examines how different machining parameters affect surface roughness.

II. MATERIALS AND METHODS

The original specimen was reinforced using silicon carbide particles with an average size of 25 microns. Titanium di boride particles having an average size of 10 microns were employed as reinforcements in the additional specimen. The metal matrix phase is aluminium (6061 T6). For the metal matrix phase of SiC and TiB2, the reinforcing weight percentage is 10%. For two hours at 1000 °C, SiC particles were warmed to increase wettability by evaporating absorbed hydroxide and other gases. TiB2 has been warmed up to 200 °C. To fully melt the matrix, the furnace's temperature needed to be raised to 750°C. At this time, the warmed SiC particles were added and mixed. 2 grammes of magnesium have been included to increase the capacity to retain moisture.

Using a standard stirring rate of 350 rpm, mechanical stirring was conducted for 15 minutes. Pouring molten metal over a mould is known as gravity casting. The second specimen is reinforced similarly with TiB2. The test specimens measured 300 mm length and 50 mm wide. The shape and structure of many specimens was examined using optical microscopy. The hardness test, which lasted 10 seconds, was conducted using the Vickers hardness machine (Matsuzawa MMT-X). Ten measurements were taken at a constant distance of around 0.5mm away from every depression to determine repeatability in the results. It uses a diamond indenter. Four samples were obtained from every specimen to guarantee that the results were as reliable as possible.

The tensile test was conducted using INSTRON tensile testing equipment. The samples were made in compliance with ASTM specifications. Utilising a wire EDM machine, the samples were cut according to requirements. The wear test experiment was carried out using a pin-on-disc reciprocating wear testing equipment. Specimens 10mm broad, 30mm long, and 30mm wide were cut using wire EDM, and they were subsequently machined and polished to have a surface roughness of a fraction of a micron. Pins are created from mild steel. With respect to 50N and 70N loads, wear tests were conducted. A mild steel pin may go over the prepared specimen's whole length for around 720 m. The temperature ranges between 35°C and 44°C, with a 10Hz frequency.

The cast specimens were painstakingly produced on a lathe. Tin-TiCN-Al2O3-TIN has been utilised to treat the multilayer insert that was used to manufacture the Al-SiC-TiB2 composite. Its ISO identification is CNMG 120408 - FR-TN8135. The surface quality of the machined element was evaluated using the Mahr instrument.

Fig. 1: Graphite crucible in sand casting process

III. Result and Discussion

A. *Physical Analysis*

1) *Density Analysis*

Optical micrographs of Al-SiC-TiB2 MMCs with varied compositions are produced using optical microscopy. Fig. 1(a,b,c) displays the micrographs of the Al/SiC-10%/TiB2-0%, Al/SiC-10%/TiB2-2.5%, and Al/SiC-10%/TiB2-5% composites. Micro structural investigation demonstrates the presence of SiC and TiB2 reinforcements as well as their homogenous distribution within the metal matrix. As seen in Fig. 1(d), clusters form around the Sic particle reinforcement. The main cause of these clusters is the increased percentage of TiB2 reinforcement. It's also important to remember that porosity is primarily concentrated in areas where clusters have developed. TiB2 weight% with the matrix structure is limited to 2.5% since a higher TiB2 weight percentage causes porosity and the development of clusters.

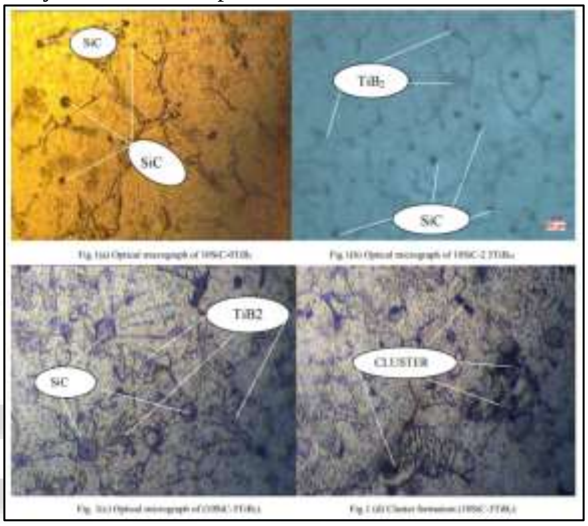
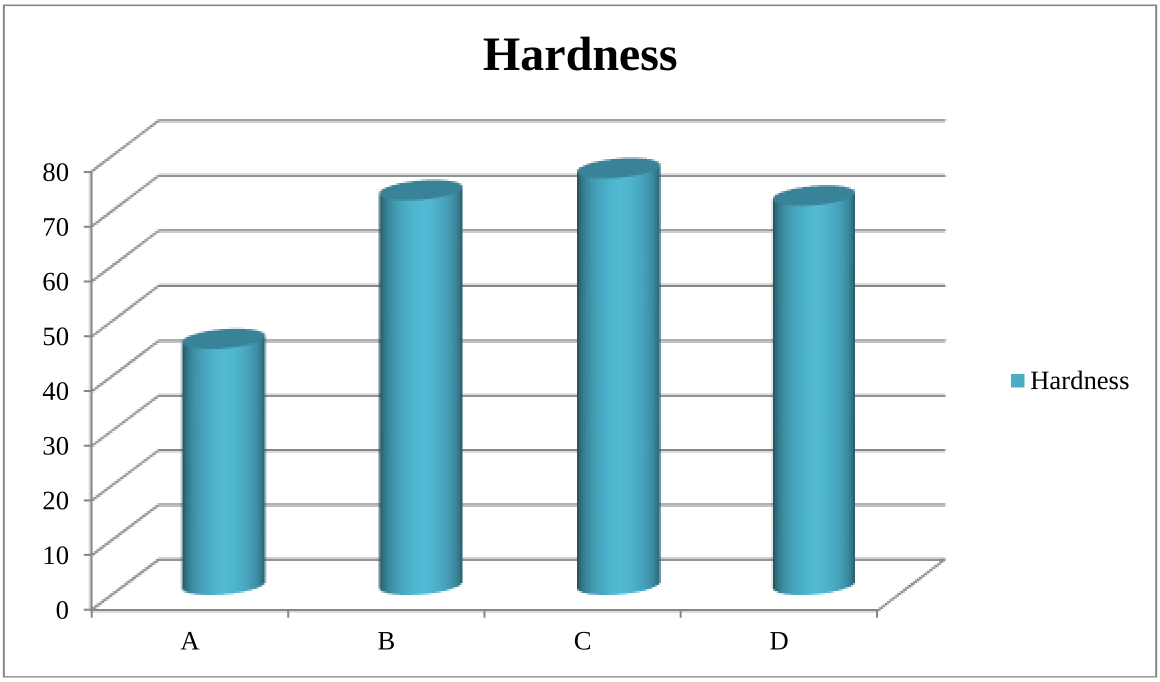


Fig. 2: Density analysis

2) *Hardness test of Al 6061 reinforced with SiC and TiB2*

The average outcomes are displayed in the graph of HV vs. kind of% of reinforcements. As observed in Fig. 2, adding TiB2 to an aluminium matrix increases the hardness value. Additionally, it has been shown that the hardness value rapidly declines when the amount of TiB2 increases up to 5%. Cluster formation, which leads to porosity, is to blame for this reduction in hardness. This investigation has led us to the conclusion that adding plenty of reinforcements reduces the toughness of a metal matrix composite. The proper proportion of TiB2 reinforcement is established at 2.5 based on the results of the trials.



Hardness value (a) Al 6061 (b) 10% SiC (c) Al/10% SiC/2.5% TiB_2 (d) Al/10% SiC/5% TiB_2
Fig. 3: Shows the micro hardness plot of specimens

IV. Mechanical Testing

The introduction of TiB2 particles, as seen in Table 1, results in a substantial decrease in tensile strength. Although TiB2 particles are praised for their high strength, the test findings show a reduction in strength. Excessive cluster development results in porosity. Micrographs of clusters in the metal matrix and the porosity brought on by cluster formation are shown in Figure 3 as well. The image makes it crystal clear that SiC particles are surrounded by TiB2 particles. Interfacial bonding is also absent because there isn't a metal matrix made of aluminium. This occurs as a result of the non-uniform reinforcement dispersion in the metal matrix phase. Cast metal matrix composites must be produced with consideration for operational aspects that impact tensile properties, such as holding temperature, stirring speed, impeller size, and location in the melt.

Weight % of reinforcements	Tensile strength (Mpa)
SiC 10% - TiB_2 0%	151.8
SiC 10% - TiB_2 2.5%	56.8
SiC 10% - TiB_2 5%	99.8

Table 1: Tensile test values

A. Fracture Analysis

A graph of Load (N) vs Elongation (mm) for tensile specimens with SiC-10% and 0% TiB2 is shown in Figure 4(a). This specimen is ductile and has a high tensile strength due to the fact that it only contains 10% SiC and 0% TiB2. The graph shows that the specimen breaks at a 0.75mm elongation and 3900N force.

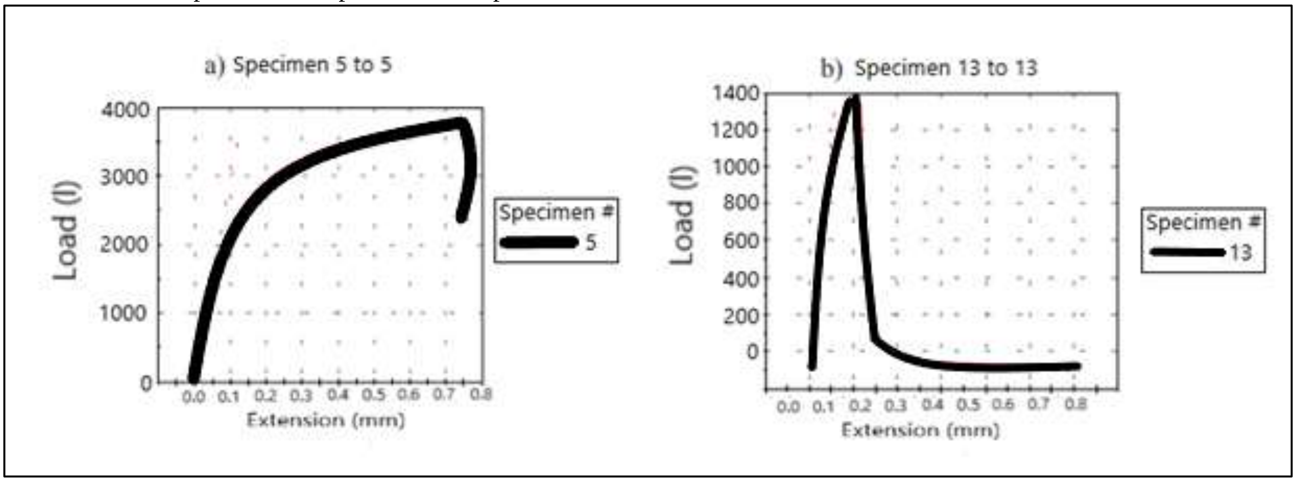


Fig. 4: Fracture analysis graph

Fig. 5(a) Tensile fracture macrograph

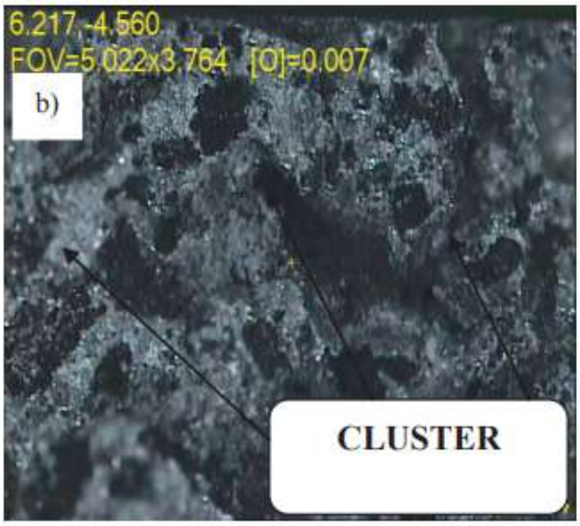


Fig. 5 (b) Tensile fracture macrograph

Fig. 5(a) depicts the fracture macrograph of a tensile specimen made of SiC-10% and TiB2. The graphic demonstrates how evenly distributed the reinforcement is throughout the continuous metal phase within the cast specimen. The metal's surface and the reinforcement phase also have a distinct and potent interfacial interaction. The composite's strength was increased above that of the parent metal alloy to 151.8 Mpa by this robust interfacial bonding. The macro graphing of the tensile specimen reveals that there are no clusters of reinforcement on the fracture surface.

Graph of Load (N) vs. Elongation (mm) for a tensile specimen made of Sic-10% and TiB2 is shown in Figure 4(b). As reinforcement (2.5% TiB2) is applied, ductility declines and elongation increases. According to the line graph, the specimen breaks at 1400N force and 0.1mm elongation. Figure 5(b) depicts the fracture macrograph of a tensile specimen made of Sic-10% and TiB2. As can be seen in the figure, the reinforcement from the continuous metal phase is not spread evenly. On the macrograph, the black areas represent clusters that reinforce one another. Together with TiB2 particles, SiC particles formed a reinforcing cluster. There is no interfacial connection between the cluster's surface and the aluminium matrix. The results of the tensile test are unfavourable, with a considerable reduction in composite strength to 56.8 Mpa due to porosity and poor interfacial bonding caused by this cluster formation.

B. Wear Test Analysis

The results of the experiment, which involved a wear test, were displayed on a graph. The line graph in Figure 6 shows how adding TiB2 improves the composite's ability to resist wear. After 60 minutes of testing, Sic-10% and 0% TiB2 have a wear value of 118.39 m, whereas Sic-10% and 2.5% TiB2 have a wear value of 93.96 m. By adding TiB2, the wear resistance property is increased by 20%. The outcomes also show that 5% TiB2 reduces wear resistance. This is more likely caused by the specimen's porosity than by the use of TiB2.

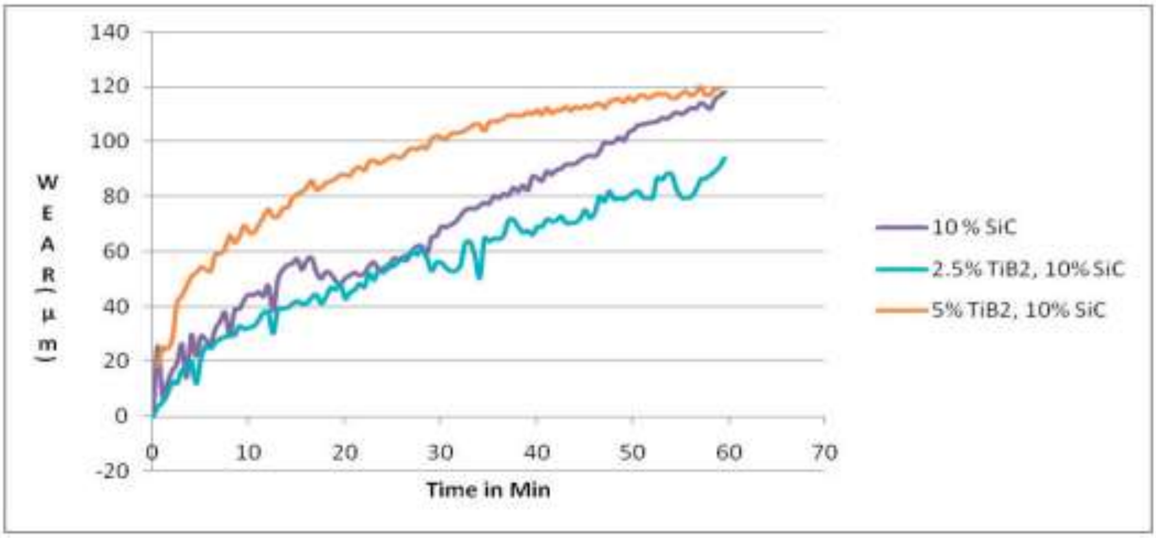


Fig. 6: Wear Vs Time

C. Analysis of Machining Parameters

The goal of the current study is to identify the optimal set of process parameters for enhancing the quality of machined components by examining the effects of various machining process variables on surface roughness. The Taguchi L27 orthogonal array was used for the turning operations investigations. Table 2 displays the machining variables and their levels.

Factors	Units	1	2	3
Cutting speed (A)	m/min	60	90	120
Feed rate (B)	mm/rev	0.1	0.2	0.3
Depth of cut (C)	mm	0.50	0.75	0.10
% Reinforcement of TiB_2(D)	%	0	2.5	5

Table 2: Wear mass loss of mild steel pins

Table 3 shows how different machining parameters interact with one another to affect surface roughness. The study showed that the percentage of TiB2 reinforcement, with an influence of 38.86%, is a highly important factor. This illustrates that surface roughness is significantly influenced by the type of material used for the work piece and its chemical makeup rather than cutting speed, feed rate, and depth of cut. According to the table, with contributions of 22.48 and 11.51%, respectively, cutting speed and feed rate have a significant impact on surface roughness as determined by $P<0.05$. The other factors and their interactions have very little impact.

Source	DF	SS	MS	F	P	% Contribution
Cutting Speed	2	2.312	1.1578	11.21	0.009	22.41
Feed rate	2	1.183	0.5951	5.75	0.039	11.51
Depth of cut	2	0.133	0.0649	0.69	0.581	1.39
% Reinforcement	2	3.982	1.9971	19.59	0.002	38.99
Cutting Speed*Feed rate	4	1.271	0.3182	3.20	0.110	12.49
Cutting Speed*Depth of cut	4	0.699	0.1689	1.71	0.271	06.62
Cutting Speed*% Reinforcement	4	0.081	0.0254	0.21	0.918	0.87
Error	6	0.635	0.1042			05.98
Total	26	10.296				

Table 3: Analysis of variance for surface roughness

D. S/N Ratio Analysis

The signal-to-noise ratio, in which the signal represents the desired value and the noise the unwanted value, is that. The smaller the better characteristic is used in this study. According to S/N ratio studies, the proportion of TiB2 reinforcement has the greatest impact on surface roughness, and increasing reinforcement percentage results in a worse surface finish. This is brought on by fractured abrasives that move with the workpiece during turning and abrasive particles that pull out during milling. Microstructural analysis reveals that increased porosity caused by a larger weight percentage of TiB2 abrasive particles eventually contributes to poor surfacefinish. The optimal machining settings for a suitable surface finish are 120 m/min cutting speed, 0.3 mm/rev feed rate, 0.5 mm of cut depth, and 0% TiB2 reinforcement, as shown in Fig. 7.

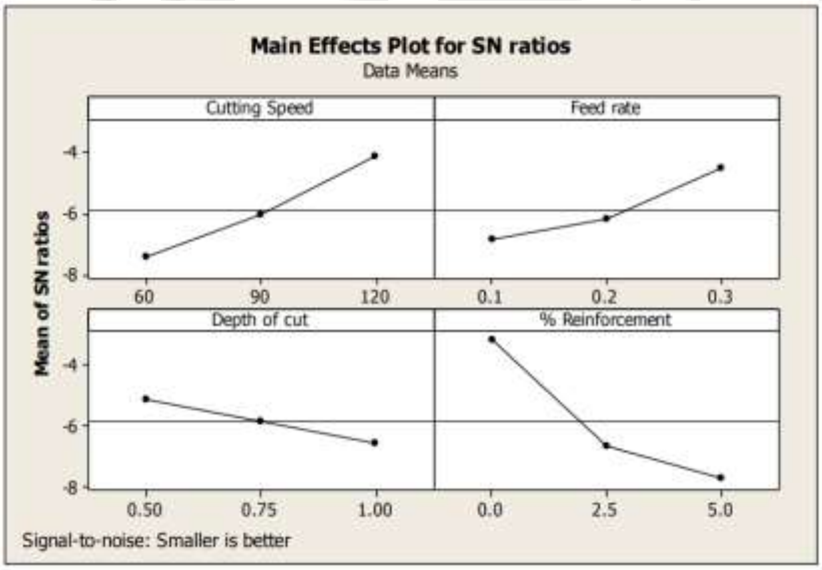


Fig. 7: Main effect plots for SN ratios

E. Tool Wear Analysis

Tool life is the single most important consideration for considering machinability. Tool wear is greatly influenced by the material of the tool, the composition of the workpiece, and the cutting parameters. Figure 8 shows a tiny optical view of the tool after machining. The specimen has the following cutting parameters: 120 m/min cutting speed, 1 mm depth of cut, and 0.1 mm/rev feed rate. Its material composition is 10% SiC and 2.5% TiB2. It has been observed that worn-out portions boost work piece material adhesion and, as a result, are commonly coated with an aluminium coating because of the high force applied at the tool-work piece interface in the third cutting zone. Then, this layer is removed by the abrasive SiC particles. A little amount of the tool material was usually removed along alongside the aluminium, causing tool wear.

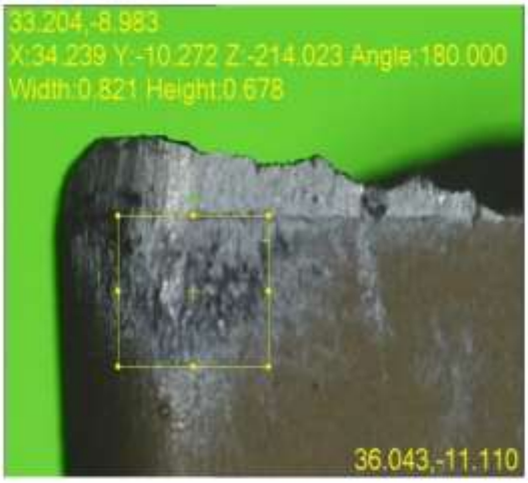


Fig. 8 Tool wear

Fig. 9 Built-up Edge

Figure 9 displays the optical microscopic picture of a tool with a built-up edge after machining. The aforementioned specimen has the following cutting parameters: cutting speed of 60 m/min, depth of cut of 1, and feed rate of 0.3 mm/rev. Its material composition is 10% SiC and 2.5% TiB2. Low cutting speed causes the cutting force to rise, which in turn raises the temperature. This is the case because aluminium has a propensity to stick to cutting edges of tools. According to the analysis, slow cutting speeds and deep cuts result in built-up edges.

V. Conclusion

1) A closer look at the metal matrix's microstructure reveals the presence and distribution of SiC and TiB2.
   The rise in the weight percentage of reinforcement (SiC 10% and TiB2 5%) leads to cluster development. The maximum amount of TiB2 that can be present in the matrix is therefore limited to 2.5% for 10% SiC.
2) With regard to measures of hardness, the presence of reinforcements affects the hardness value; nevertheless, the inclusion of TiB2 up to 5% results in porosity, which affects the hardness value.
3) Results of tensile tests reveal that adding reinforcement Sic to the base metal boosted the composite's strength by 20% while adding TiB2 decreased it by 50%–60%.
   Microstructure analysis and tensile specimen testing have shown that cluster formation causes porosity, as well as porosity results in lesser strength that the fundamental aluminum alloy.
4) Wear testing has revealed that TiB2 particles increase a hybrid aluminium metal matrix's wear resistance.
   According to the testing results, the Sic 10% - TiB2 0% specimen exhibited 20% more wear than the Sic 10% - TiB2 2.5% specimen.
5) The machining investigation showed that the proportion of TiB2 reinforcement, which accounts for 38.86% of the total, had the greatest impact on surface roughness. The importance of surface roughness is increased by the addition of TiB2 reinforcement.
6) Using Taguchi analysis, the following ideal machining parameters are derived for maximum surface roughness: 120 m/min cutting speed, 0.3 mm/rev feed rate, 0.5 mm depth of cut, and 0% TiB2 reinforcement.
7) A research investigation of tool wear found that high tool wear is caused by both abrasive and adhesive impacts.
   – High tool wear is caused by a low cutting speed, a deep cut, with an elevated wt% of TiB2 reinforcement.
   – Surface quality is influenced by built-up edge formation.

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3) Data Availability: The original data that support the findings of this study are included in the Article.
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