JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

SiC and TiB_2 Reinforced Hybrid Aluminium Metal Matrix Composite

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ABSTRACT:

An effort was put forth in this study to construct a hybrid aluminum metal matrix composite with the goal to test its machining and mechanical properties. Reinforcing Silicon carbide and Titanium di boride are used to create a hybrid aluminium metal matrix composites. Optical microscopy was used to investigate the morphology of the composites and strengthened particle dispersion in depth. The hardness test was performed on the cast composite to determine its hardness using a Vickers hardness testing device. The hardness test results demonstrate that adding reinforcement SiC and TiB_2 enhances the hardness value. However, increasing the reinforcement by up to 15% results in a decrease in hardness value. Tensile samples made from cast composite specimens of various compositions were mechanically tested. Tensile test findings show that adding reinforcement SiC to the base metal gave 20% strength to the composite, whereas adding TiB_2 reduced the strength by 50 - 60%. The wear resistance behavior of TiB_2 has been studied using wear test analysis. Wear testing revealed that the inclusion of TiB_2 improved the wear resistance of the composite. The cast composite examples were machined with care. During a turning operation, the influence of machining parameters such as cutting speed (s), feed rate (f), depth of cut (d), and TiB2 weight % on surface roughness (Ra) was examined. The analysis of variance approach reveals that the percentage of TiB_2 reinforcement is the single most significant parameter influencing surface quality, with a contribution of 38.86%. Tool wear research was performed to investigate tool wear pattern, built-up edge creation, the effect of TiB_2 on tool wear, and the way these variables impact cast composite quality of the surface. TiB_2 causes excessive tool wear, poor surface finish, and built-up edge development, all of which have an impact on surface quality.

Keywords: SiC, Surface roughness, Tool wear, TiB_2, Hybrid metal matrix composite.

INTRODUCTION:

Composites are widely used in the aerospace, defence, and automotive industries due to their unique qualities that include high specific strength, wear resistance, strength-to-weight, strength-to-cost, and furthermore are all desirable characteristics. There have been treated as several attempts at incorporating hard ceramic particles including SiC, AL_2O_3, and B_4C within an aluminum-based matrix. According to the literature, SiC is chemically compatible with aluminium and establishes an appropriate connection with the matrix without producing an intermetallic phase, as well as having additional benefits such as great thermal conductivity, good workability, and cheap cost. In the past, the primary focus has been on the creation of metal matrix composites containing SiC in various amounts, as well as the mechanical and machinability features of these composites.

In recent years, hybrid aluminium metal matrix composites have been created in response to the need for engineering materials having high strength, higher wear resistance, and improved temperature performance. Al_2O_3 is a popular second reinforcing material. However, it has drawbacks such as poor wetting behaviour with aluminium and increased weight % leads to increased porosity. In prior work, we attempted to synthesise an $Al/SiC/Al_2O_3$ composite. The present endeavour is to develop TiB_2, a superior reinforcement to every one of the existent reinforcements. This is primarily due to TiB_2's outstanding qualities, which include a high melting point (2790° C), high hardness (86 HRA or 960 HV), high elastic modulus (530*103 GPa), and great thermal stability.

Because TiB_2 ceramic particles are unable to interact with molten aluminium, the production of brittle reaction by-products within the reinforcement-matrix contacts is avoided. Aluminium reinforced with TiB_2 is also noted for its great wear resistance. According to Khairaldien's research, the strength of silicon carbide decreases around 15-20% weight percentage as a result of Sic particle contact with each other, and the chance of more than two particle clustering collectively increases. In the present study, the amount of reinforcement was adjusted to a maximum of 15% (10% SiC and 0-5% TiB2) with the goal to generate high-strength and cost-efficient combinations.

Pai et al. thoroughly investigated the stir-cast aluminum matrix and its manufacturing variables, and the stir-casting method is used for production. T.V. Christy's work titled "A Comparative Study on the Microstructures and Mechanical Properties of Al 6061 Alloy and the MMC Al 6061/TiB_2/12P". The in-situ reaction technique effectively generated the composite Al-6061/TiB_2/12p. As unique microstructural characteristics of the composite, strings and particle agglomerates were found. The hardness, tensile strength, and Young's modulus of the Al-TiB2 composite were greater than those of the parent alloy. Nevertheless, the final transformation of these materials into essential engineered products is linked to machining. Because of their hardness and abrasive nature, composites are usually difficult to process, resulting in increased tool wear.

When harsh abrasives make contact with tool edges, they behave as little cutting edges. Among the cutting insert and the workpiece, these tiny particles function as abrasives. This leads to increased tool wear and poor surface quality. The current study investigates the effect of machining settings on surface roughness.

MATERIALS AND METHODS

Regarding reinforcement for the initial specimen, silicon carbide particles with an average size of 25 microns were chosen. As reinforcements for the second specimen, titanium di boride particles with an average size of 10 microns were used. Aluminium (6061 T6) is the metal matrix phase. The weight percentage of reinforcement for the metal matrix phase of SiC and TiB_2 is 10%. SiC particles were preheated at 1000°C for 2 hours to improve wettability by removing absorbed hydroxide and other gases. TiB_2 is having been preheated to 200°C. The furnace temperature has been increased to 750°C in order to completely melt the matrix. The warmed SiC particles were introduced and blended at this point. To improve the moist ability, 2 grams of magnesium are added.

Mechanical stirring was performed for 15 minutes at an average stirring speed of 350rpm. Gravity casting is the process of pouring molten metal through a mould. Similarly, TiB2 is used to reinforce the second specimen. The specimens in question were 300 mm long and 50 mm across. Optical microscopy was used to examine the morphology of several specimens. The Vickers hardness machine (Matsuzawa MMT-X) was used for the hardness testing, which lasted 10 seconds. To establish repeatability in findings, ten measurements were collected with a consistent distance of approximately 0.5mm from each depression. A diamond indenter is employed. To ensure maximum dependability of results, four samples were taken from each specimen.

INSTRON tensile testing apparatus was used for the tensile test. The specimens were created in accordance with ASTM standards. The specimens were chopped to specifications using a wire EDM machine. A pin-on-disc reciprocating wear testing machine was employed to conduct the wear test experiment. Wire EDM was employed for cutting specimens 10mm wide, 30mm long, and 30mm wide, which were then machined and polished to a surface roughness of less than a micron. Mild steel is used to make the pins. Wear tests were performed using 50N and 70N loads, correspondingly. Upon the prepared specimen, the entire length traversed by a mild steel pin is approximately 720 m. Temperatures vary from 35°C to 44°C, with a frequency of 10Hz.

In a lathe, the cast specimens were meticulously machined. The multilayer insert used to machine the Al-SiC-TiB_2 composite has been treated with TIN-TiCN-Al_2O_3-TIN. It has the ISO code CNMG 120408 -FR-TN8135. The Mahr instrument was used to determine the surface quality of the machined component.

RESULT AND DISCUSSION

1. Physical Analysis

1.1. Density Analysis

Optical microscopy is used to create optical micrographs of Al-SiC-TiB2 MMCs of various compositions. The micrographs of Al/SiC-10%/TiB_2-0%, Al/SiC-10%/TiB_2-2.5%, and Al/SiC-10%/TiB_2-5% composites are shown in Fig. 1(a,b,c). The existence of SiC and TiB_2 reinforcements, as well as their homogeneous distribution in the metal matrix, is demonstrated by micro structural analysis. Clusters are generated around the Sic particle reinforcement, as seen in Fig. 1 (d). The higher weight % of TiB_2 reinforcement is primarily responsible for these clusters. It is also worth noting that porosity is concentrated mostly in cluster-formed locations. Because an increase in TiB_2 weight percentage leads to porosity and cluster formation, TiB_2 weight % with the structure of the matrix is limited to 2.5%.

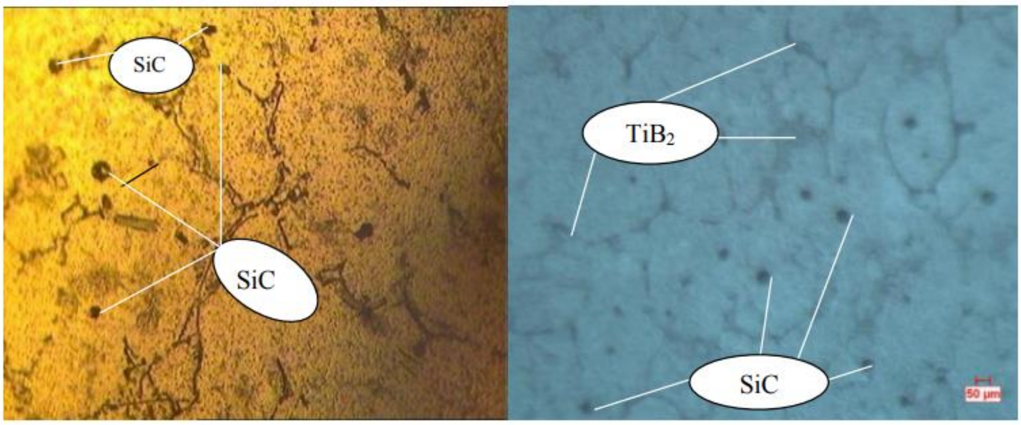


Fig.1(a) Optical micrograph of 10SiC-0TiB_2 Fig.1(b) Optical micrograph of 10SiC-2.5TiB_{29}

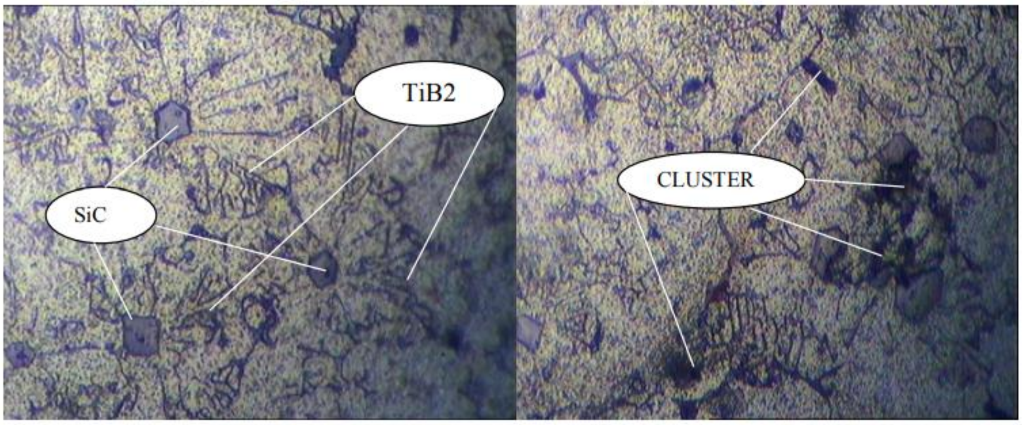


Fig. 1(c) Optical micrograph of (10SiC-5TiB_2). Fig.1 (d) Cluster formation (10SiC-5TiB_2)

1.2. Hardness test of Al 6061 reinforced with SiC and TiB2

In the graph HV vs type of % of reinforcements, the average results are plotted. The addition of TiB_2 to an aluminium matrix enhances the hardness value, as seen in Fig. 2. It has also been observed that as the percentage of TiB_2 grows up to 5%, the hardness value decreases abruptly. This loss in hardness is caused by cluster formation, which results in porosity. As a result of this experiment, we may deduce that a large number of reinforcements decrease the hardness value of a metal matrix composite. Based on the findings of the experiments, the appropriate percentage of TiB_2 reinforcement is set at 2.5.

Hardness value (a) Al 6061 (b) 10% SiC (c) Al/10% SiC/2.5% TiB_2 (d) Al/10% SiC/5% TiB_2

Fig. 2: Shows the micro hardness plot of specimens

2. Mechanical Testing

According to Table 1, there is a significant loss in tensile strength owing to the inclusion of TiB2 particles. Despite the fact that TiB_2 particles are called for their strong strength, the test results demonstrate a decrease in strength. Porosity is caused by an excess of cluster formation. Figure 3 depicts micrographs of clusters in the metal matrix as well as porosity caused by cluster formation. The picture plainly indicates that TiB2 particles surround the SiC particles. Furthermore, because there isn't an aluminium metal matrix, therefore is no interfacial bonding. This happens owing to the metal matrix phase's non-uniform reinforcement dispersion. Holding temperature, stirring speed, impeller size, and impeller placement in the melt are all operational factors are all critical parameters to take into account when producing cast metal matrix composites since they affect tensile characteristics.

Weight % of reinforcements	Tensile strength (Mpa)
SiC 10% - TiB_2 0%	149.8
SiC 10% - TiB_2 2.5%	54.2
SiC 10% - TiB_2 5%	98.1

Table 1: Tensile test values

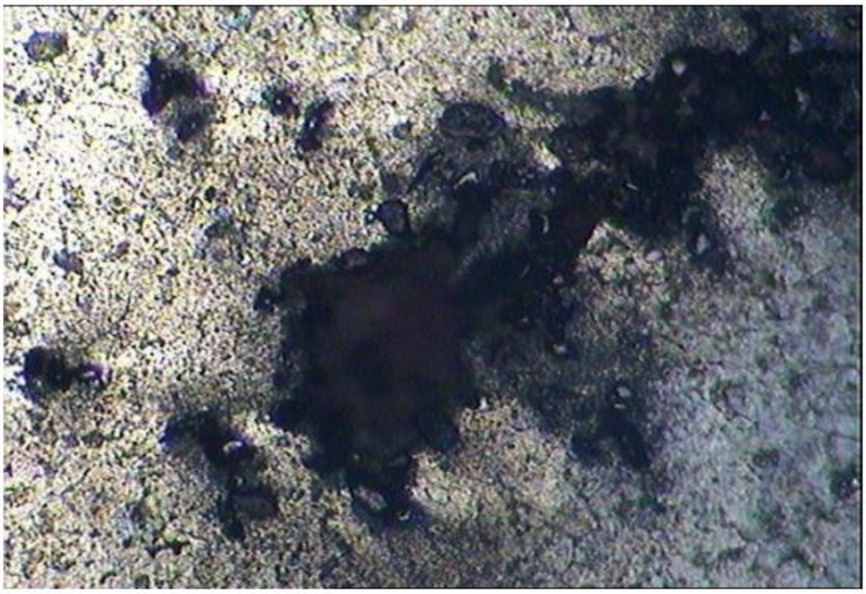
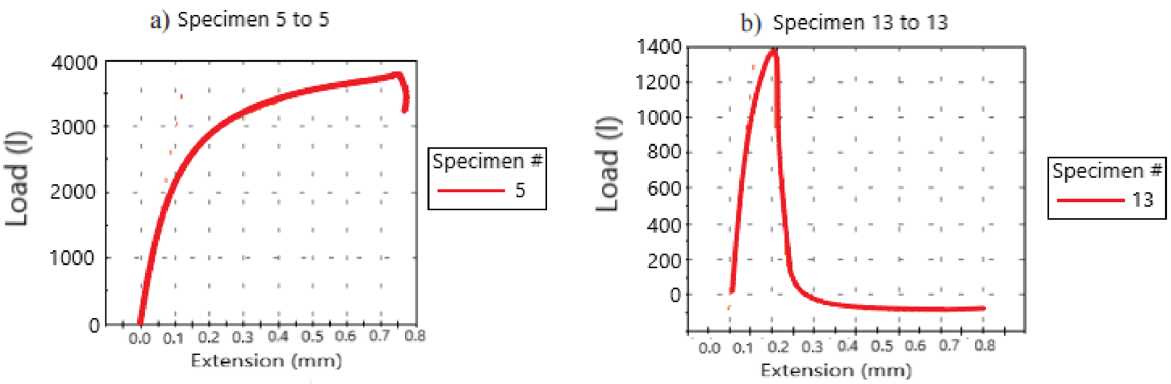


Fig. 3: Shows cluster formation

2.1. Fracture analysis

Figure 4 (a) depicts a graph of Load (N) versus Elongation (mm) for tensile specimens with SiC-10% and 0% TiB_2. Because it includes just 10% SiC and 0% TiB_2, this specimen is ductile and has a high tensile strength. The graph reveals that the specimen breaks at 3900N force with a 0.75mm elongation.



The fracture macrograph of a tensile specimen of SiC-10% and TiB_2 is shown in Fig. 5(a). The illustration shows that the reinforcement is uniformly distributed in the continuous metal phase of the cast specimen. Furthermore, there is a clear and strong interfacial relationship between the metal's surface and the reinforcement stage. This strong interfacial bonding boosted the composite's strength above the parent metal alloy to 149.8 Mpa. The fracture surface possesses no clusters of reinforcement, as seen by the Macro graph of tensile specimen.

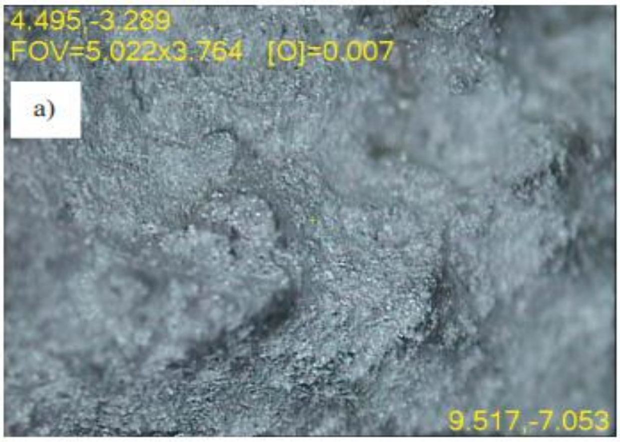


Fig. 5(a) Tensile fracture macrograph

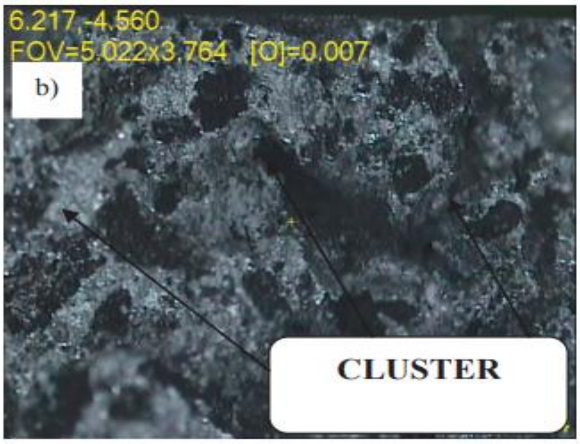


Fig. 5 (b) Tensile fracture macrograph

Figure

4 (b) depicts a graph of Load (N) vs. Elongation (mm) for a tensile specimen with a composition of Sic-10% and TiB_2. When reinforcement is increased (2.5% TiB_2), elongation decreases as ductility falls. The line graph demonstrates that the specimen breaks at 1400N load with a 0.1mm elongation. The fracture macrograph of a tensile specimen of Sic-10% and TiB_2 is shown in Fig. 5(b). From the continuous metal phase, the reinforcement is not distributed equally, as seen in the image. The black regions on the macrograph are reinforcing clusters. SiC particles joined forces with TiB2 particles and created a reinforcing cluster. The surface generated by the cluster lacks interfacial connection with the aluminium matrix. Because this cluster development causes porosity and weak interfacial bonding, the tensile test findings are negative, with a significant fall in composite strength to 54.2 Mpa.

2.2. Wear test analysis

A wear test was performed, and the findings of the experiment were presented in a graph. The line graph (Fig.6) demonstrates that the inclusion of TiB_2 boosts the wear resistance property of the composite. The wear value of Sic-10% and 0% TiB_2 is 118.39 m, whereas Sic-10% and 2.5% TiB_2 is 93.96 m after 60 minutes of testing. The inclusion of TiB_2 boosts the wear resistance characteristic by 20%. Furthermore, the results reveal that 5% TiB_2 decreases wear resistance. This is most likely attributable to the specimen's porosity rather than TiB_2 application.

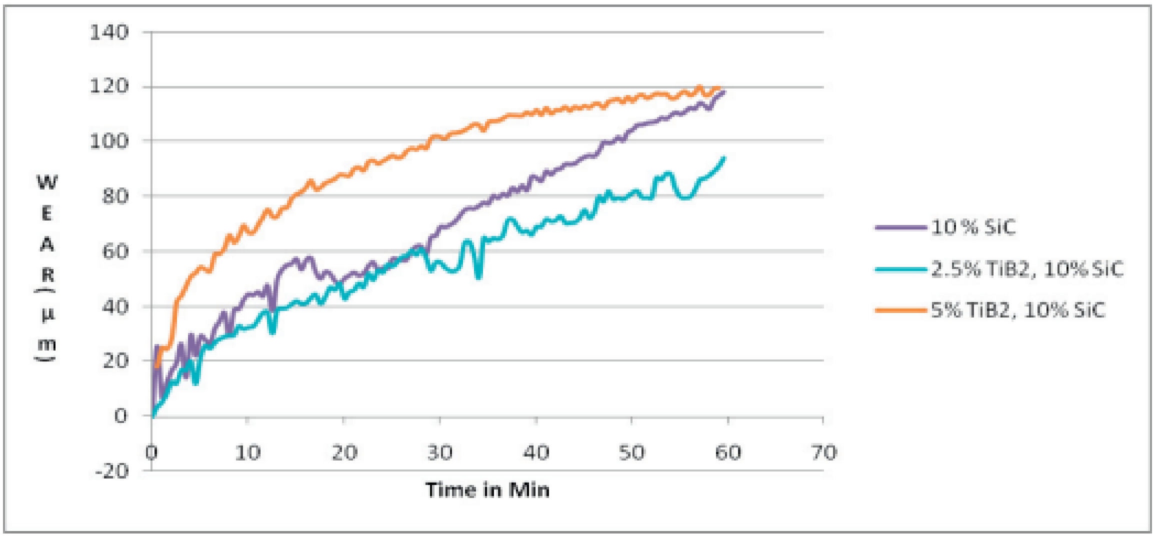


Fig. 6 Wear Vs Time

2.3.Analysis of machining parameters

The present study investigates the influence of multiple machining process factors on surface roughness in order to determine the ideal combination of process parameters for optimising the quality of machined components. The turning operations experiments were carried out using Taguchi's L_{27} orthogonal array. The machining factors and their levels are shown in Table 2.

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 depicts the influence of machining settings and their interplay on surface roughness. The experiment revealed that the very relevant element is the proportion of TiB_2 reinforcement, with a contribution of 38.86%. This demonstrates that the nature of the work piece material and its chemical composition, instead of cutting speed, feed rate, and depth of cut, has a substantial impact on surface roughness. The table reveals that cutting speed and feed rate have a substantial influence on surface roughness as $P<0.05$, with 22.48 and 11.51% contributions, respectively. The remaining factors and interaction effects are negligible.

Source	DF	SS	MS	F	P	% Contribution
Cutting Speed	2	2.309	1.1572	11.26	0.008	22.44
Feed rate	2	1.179	0.5928	5.79	0.041	11.55
Depth of cut	2	0.123	0.0631	0.67	0.577	1.33
% Reinforcement	2	3.998	1.9986	19.51	0.002	38.94
Cutting Speed*Feed rate	4	1.279	0.3195	3.16	0.105	12.59
Cutting Speed*Depth of cut	4	0.691	0.1698	1.67	0.278	06.69
Cutting Speed*% Reinforcement	4	0.086	0.0229	0.22	0.923	0.89
Error	6	0.619	0.1029			05.99
Total	26	10.284				

Table 3: Analysis of variance for surface roughness

2.4. S/N ratio analysis

That is the signal-to-noise ratio, wherein signal indicates the desired value and noise indicates the undesirable value. This analysis is performed by choosing the smaller the better attribute. S/N ratio research reveals that TiB_2 reinforcement percentage is the most significant element on surface roughness, and increasing reinforcement percentage contributes to poor finish on the surface. This is caused to abrasive particle pull out throughout machining and broken abrasives that slide along with the workpiece throughout the turning action. Higher porosity owing to higher weight % of TiB_2 abrasive particles ultimately contributes to poor surface finish, as revealed in microstructural examination. According to Fig. 7, the best machining parameters for a satisfactory surface finish are cutting speed 120m/min, feed rate 0.3mm/rev, depth of cut 0.5mm, and 0% TiB_2 reinforcement.

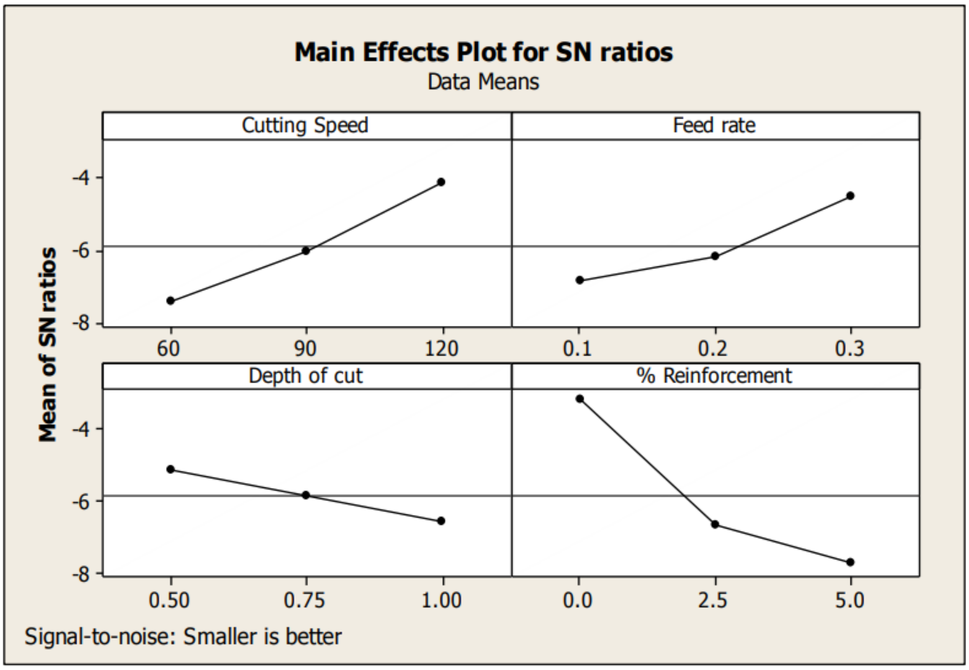


Fig. 7: Main effect plots for SN ratios

2.5. Tool wear analysis

The maximum amount that essential factor in determining machinability is tool life. Tool material, work piece material, and cutting settings all play a significant role in tool wear. Figure 8 depicts an optical microscopic image of the tool following machining. The specimen is composed of 10% SiC and 2.5% TiB_2, and its cutting parameters are as follows: cutting speed-120 m/min, depth of cut-1mm, and feed rate-0.1mm/rev. Because of the tremendous force exerted at the tertiary cutting zone (tool - work piece interface), it is being noticed that worn-out areas enhance work piece material adherence and consequently are frequently coated with an aluminium coating. The harsh abrasive SiC particles then remove this layer. Along with the aluminium, a tiny portion of the tool material was frequently taken away, resulting in tool wear. It has been determined that both abrasive and adhesion effects produce tool wear.

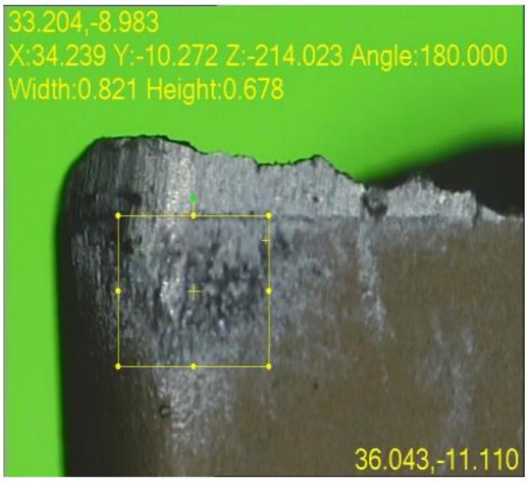


Fig. 8 Tool wear

Fig. 9 Built-up Edge

The optical microscopic image of a tool that has a built-up edge following machining is shown in Fig. 9. The above-mentioned specimen is composed of 10% SiC and 2.5% TiB_2, and it's cutting parameters are as follows: cutting speed-60m/min, depth of cut-1mm, and feed rate-0.3mm/rev. Low cutting speed results in increased cutting force, which raises the temperature. This is owing to aluminum's tendency to adhere to the tool's cutting edge. The investigation revealed that built-up edges are caused by a high depth of cut and a slow cutting speed.

CONCLUSION

1. Micro structural investigation reveals the existence and distribution of SiC and TiB_2 in the metal matrix.

   Cluster formation is caused by an increase in the weight percentage of reinforcement (SiC 10% and TiB_2 5%). As a result, the maximum percentage of TiB_2 in the matrix is restricted to 2.5% for 10% SiC.
2. According to hardness measurements, the addition of reinforcements has an influence on hardness value; however the addition of TiB_2 up to 5% causes porosity, which impacts hardness value.
3. Tensile test findings show that adding reinforcing Sic to the base metal increased 20% strength to the composite, whereas adding TiB_2 reduced the strength by 50-60%.
   It has been determined by microstructure analysis and tensile specimen testing that cluster development results in porosity and porosity leads to lower strength than the basic aluminium alloy.
4. Wear investigation has shown that TiB_2 particles improve the wear resistance of a hybrid aluminium metal matrix.
   The experimental findings shown that the Sic 10% - TiB_2 0% specimen had 20% greater wear compared to the Sic 10% - TiB_2 2.5% specimen.
5. The machining study revealed that the percentage of TiB_2 reinforcement is the most important effect on surface roughness, accounting for 38.86% of the total. The inclusion of TiB_2 reinforcement raises the significance of surface roughness.
6. The subsequent ideal machining settings for maximal surface roughness are calculated using Taguchi analysis: cutting speed 120m/min, feed rate 0.3mm/rev, depth of cut 0.5mm, with 0% TiB2 reinforcing.
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.

Acknowledgement: The authors are thankful to Department of Mechanical Engineering, NIU, Greater Noida for providing kind guidance and excellent opportunity as well as necessary facilities for the research.

Conflicts of Interest: The authors confirm that the content of the article has no conflict of interest.

Author's Contribution: Both the authors Mohd Suhail and Madhusmita Sahu have contributed equally in the paper.

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

Funding: This research paper received no external funding.

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