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Hybrid Aluminium Metal Matrix Composite Reinforced With SiC and TiB_2

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Abstract

In this research work an effort has been made to prepare hybrid aluminium metal matrix composite to study its machining and mechanical properties. Preparation of hybrid aluminium metal matrix composite is made by reinforcing Silicon carbide and Titanium di boride. Morphology of the composite and reinforced particle distribution were studied in detail by optical microscopy. The hardness test has been carried out to determine the hardness of the cast composite using Vickers hardness testing instrument. The hardness test shows addition of reinforcement SiC and TiB_2 increases hardness value. But increase in reinforcement up to 15 wt % reveals reduction in hardness value. Mechanical testing was carried out on the tensile samples prepared from the cast composite specimen of different compositions. From tensile test results it has been observed that addition of reinforcement SiC to base metal added 20% strength to the composite but addition of TiB_2 reduction in 50 - 60% strength is recorded. Wear test analysis has been carried out to study the wear resistance behaviour of TiB_2. Wear test analysis proved that the addition of TiB_2 increased the wear resistance behaviour of composite. The cast composite specimens were carefully machined. The effect of machining parameters like cutting speed (s), feed rate (f), depth of cut (d) and weight percentage of TiB_2 on surface roughness (Ra) were investigated during turning operation. The analysis of variance method shows that % of TiB_2 reinforcement is the most influential parameter which affects surface quality and its contribution is 38.86%. Tool wear analysis was carried out to study tool wear pattern, built-up edge formation, influence of TiB_2 on tool wear and how these factors affects surface quality of cast composite. Analysis proves TiB_2 cause high tool wear, poor surface finish and built-up edge formation affects surface quality.

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

1. Introduction

Composites have its wide application in aerospace, defense and it in automotive industries because of its unique properties such as high specific strength, wear resistance, strength-to-weight, strength-to-cost, etc. [1]. Various efforts have been taken to introduce hard ceramic particulates like SiC, AL_2O_3 and B_4C into aluminium based

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matrix. From the literature study reveals that among the reinforcements SiC is chemically compatible with aluminium and forms an adequate bond with the matrix without developing inter- metallic phase and has other advantages such as excellent thermal conductivity, good workability and low cost [2]. In past main focus is given for the development of metal matrix composite with SiC in various proportions and its mechanical and machinability properties have been studied. Recently due to the necessity of engineering materials with high strength, increased wear resistance and enhanced temperature performance hybrid aluminium metal matrix composites are developed. Al_2O_3 is one of the widely used second reinforcement. But it has its own demerits like poor wetting behaviour with aluminium and more weight percentage leads to increase in porosity [3]. An attempt has been made to fabricate $Al/SiC/Al_2O_3$ composite in our previous work. In this present work an attempt has been made to introduce TiB_2 an outstanding reinforcement among all the other reinforcements. This is due to the fact that TiB_2 reveals outstanding features such as high melting point (2790C) high hardness (86 HRA or 960 HV) and high elastic modulus ($530*10^3$ GPa) and good thermal stability. TiB_2 ceramic particle do not react with molten aluminium, thereby avoiding formation of brittle reaction products at the reinforcements-matrix interfaces. Also aluminium reinforced with TiB_2 is known for its high wear resistance property [4]. Khairaldien's research shows a drop of strength at 15-20% weight percentage of silicon carbide due to the contact of Sic particle with the other and the increase in chance of more than two particle cluster together. Considering this in this work % of reinforcement has been fixed (10% SiC and 0-5% TiB2) to maximum of 15 weight % to have high strength and cost effective composites. [5] The stir cast aluminium matrix and its process parameters were thoroughly investigated by Pai, et. Al [6] and stir casting method is used for fabrication T.V. Christy in his paper, "A Comparative Study on the Microstructures and Mechanical Properties of Al 6061 Alloy and the MMC Al 6061/TiB2/12_P" the composite Al-6061/TiB2/12p was successfully produced by the in-situ reaction procedure. Strings as well as particulate agglomerates were present as distinct micro structural features of the composite. The manufactured Al-TiB_2 composite exhibited higher values of hardness, tensile strength and Young's modulus than the base alloy [7]. However the final change of these composites into required engineering products is connected with machining. Composites are always hard to machine due to its hardness and abrasive nature this leads to increased tool wear [8,9]. The hard abrasives come in contact with tool edges and acts as small cutting edges. These particles act as abrasives between cutting insert and work piece. This results in elevated tool wear, poor surface finish [9]. This present work analyses the influence of machining parameters on surface roughness.

2. Experimental Procedure

Silicon carbide particles of average size of 25 microns were selected as reinforcement for the first specimen. Titanium di boride particles of average size of 10 microns were selected as reinforcement for the second specimen. The metal matrix phase is aluminum (6061 T6). The wt % of reinforcement both SiC and TiB_2 with metal matrix phase is 10%. SiC particles were preheated at 1000°C for 2 hours to improve the wettability by removing the absorbed hydroxide and other gases. TiB_2 is preheated up to 200°C. The furnace temperature was raised to 750°C to melt the matrix completely. At this stage the preheated SiC particles were added and mixed. 2 grams of magnesium is added in order to increase the wet ability. Mechanical stirring was carried out for 15min at 350rpm average stirring speed. The molten metal is poured into the mould by gravity casting. Similarly the second specimen reinforced with TiB2 is fabricated. The dimensions of the specimens were 300 mm in length and 50mm in diameter. Morphology of different specimens was studied by optical microscopy. The hardness testing was carried out using (Matsuzawa MMT-X) Vickers hardness machine with 200gf for 10 seconds. Ten readings were taken with standard distance of app 0.5mm from every indentation to achieve reliability in results. Diamond indenter is used. Four samples were made from each specimen to have high reliability in results. The tensile test was carried out using INSTRON tensile testing equipment. The specimens were made as per ASTM standards. A wire EDM machine was used to cut the specimens as per standards. The set up used to carry out wear test experiment was a pin-on-disc reciprocating wear testing machine. Specimens of 10mm width and 30mm length and breadth were cut by wire EDM, machined, and then polished to a surface roughness of less than one micron. The pins are made up of mild steel. Wear tests were conducted with a load of 50N and 70N respectively. The distance travelled by mild steel pin on the specimen prepared is around 720 m. The temperature range is from 35°C to 44°C with a frequency of 10Hz. The cast specimens were carefully machined in a lathe. The insert used for machining the Al-SiC-TiB2 composite was coated multilayer insert coated with TIN-TiCN-Al2O3-TIN. Its ISO code is CNMG 120408 –FR-TN8135.The surface finish of the machined component was measured using Mahr instrument.

3. Result And Discussion

3.1. Microstructure Analysis

The optical micrographs of Al-SiC-TiB_2 MMCs of different compositions are prepared using optical microscopy. Fig. 1(a,b,c) shows the micrographs of Al/SiC-10%/TiB_2-0%,Al/SiC-10%/TiB_2-2.5% and Al/SiC-10%/TiB_2-5% composites. Micro structural analysis proves the presence of SiC and TiB_2 reinforcements and its uniform distribution in the metal matrix. From Fig. 1 (d) it has been observed that clusters are formed around the Sic particle reinforcement. These clusters are mainly due to the increased weight percentage of TiB_2 reinforcement. It is also noted that porosity is mainly located around the cluster formed regions. As the increase in weight percentage of TiB_2 leads to porosity and cluster formation the weight percentage of TiB_2 with the matrix is limited to 2.5%.

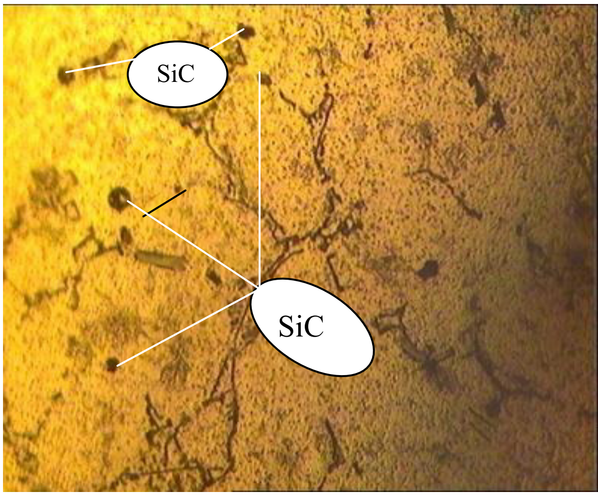

Fig.1(a) Optical micrograph of 10SiC-0TiB_2

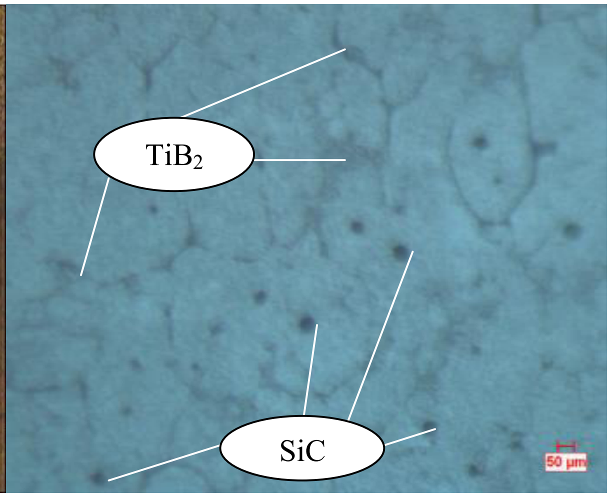

Fig.1(b) Optical micrograph of 10SiC-2.5TiB_{29}

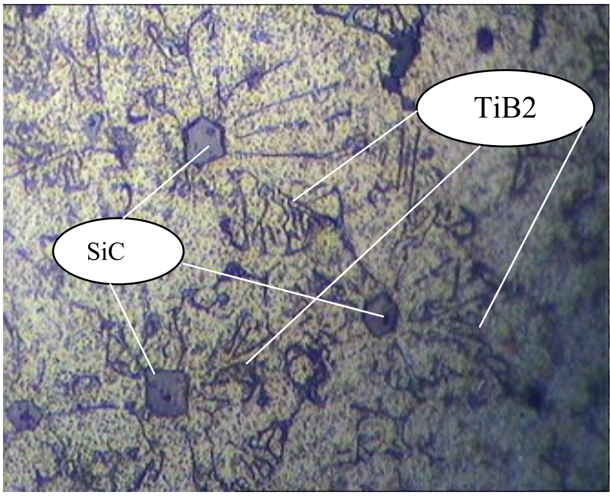

Fig. 1(c) Optical micrograph of (10SiC-5TiB_2).

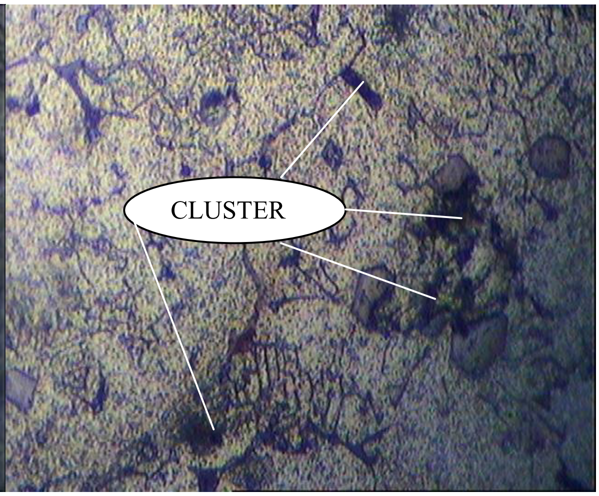

Fig.1 (d) Cluster formation (10SiC-5TiB_2)

3.2. Hardness test of Al 6061 reinforced with SiC and TiB_2

The average values are plotted in graph HV versus nature of % of reinforcements. From Fig. 2 it has been clearly proved that addition of TiB_2 with aluminium matrix increases the hardness value. It has bee also noted that when % of TiB_2 increases up to 5% there is a sudden decrease in hardness value. This decrease in hardness value is due to cluster formation which leads to porosity. So from this experiment we conclude that high amount of reinforcements reduces hardness value in metal matrix composite. From the experiment results the optimal % of reinforcement of TiB_2 is fixed as 2.5.

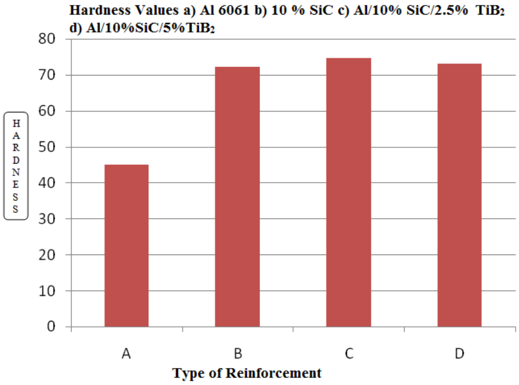

Fig. 2 Shows the micro hardness plot of specimens

Fig. 3 Shows cluster formation

3.3. Mechanical Testing

From the Table 1 it has been observed that there is a considerable reduction in tensile strength due to the addition of TiB_2 particles. Though TiB_2 particles are named for higher strength the test shows reduction in strength. It is due to the excess cluster formation which leads to porosity. Fig. 3 shows the micrographs of clusters in the metal matrix and porosity due to cluster formation. It has been clearly observed from the micrograph that the SiC particles are surrounded by TiB_2 particles. As there is lack of aluminium metal matrix there is no interfacial bonding. This is due to the non-uniform dispersion of reinforcement in the metal matrix phase. Processing variables such as holding temperature, stirring speed, size of the impeller, and the position of the impeller in the melt are among the important factors to be considered in the production of cast metal matrix composites as these have an impact on tensile properties.

Table 1. Tensile test values

Weight % of reinforcements	Tensile strength (Mpa)
SiC 10% - TiB_2 0%	150.1
SiC 10% - TiB_2 2.5%	54.8
SiC 10% - TiB_2 5%	97.9

3.4. Fracture analysis

Fig. 4 (a) shows the graph of Load (N) vs Elongation (mm) for the tensile specimen of composition SiC-10% and 0% of TiB_2. This specimen exhibits ductility and considerable tensile property as it contains only 10 wt % of SiC and 0% of TiB_2. Graph shows that the specimen fractures at 3900N load with an elongation of 0.75mm.

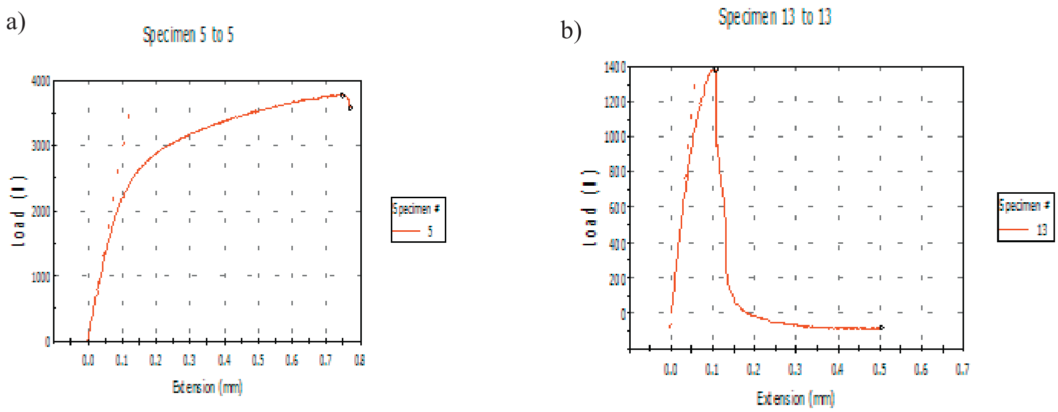

Fig..4. (a) Load (N) Vs Elongation (mm) for SiC 10% - TiB_2 0%; (b) Load (N) Vs Elongation (mm) for SiC 10% - TiB_2 2.5%

Fig. 5(a) Tensile fracture macrograph

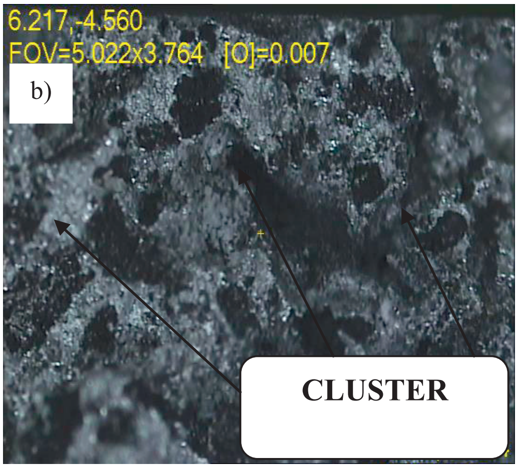

Fig. 5 (b) Tensile fracture macrograph

Fig. 5(a) shows the fracture macrograph of tensile specimen of SiC-10% and 0% of TiB_2. It has been observed from the figure the reinforcement is evenly distributed in the continuous metal phase of the cast specimen. Also a clear, strong interfacial bonding is seen in between metal and reinforcement phase. This strong interfacial bonding increased the strength of the composite than the parent metal alloy to 150.1 Mpa. It has been proved from Macro graph of tensile specimen that the fracture surface contains no clusters of reinforcement.

Fig. 4 (b) shows the graph of Load (N) Vs Elongation (mm) for the tensile specimen of composition Sic-10% and 2.5% of TiB_2. This shows reduction in elongation as ductility decreases when reinforcement increases (2.5% of TiB_2). Graph shows that the specimen fractures at 1400N load with an elongation of 0.1mm.Fig. 5(b) shows the fracture macrograph of tensile specimen of Sic-10% and 2.5% of TiB_2. Figure shows that the reinforcement is not evenly distributed in the continuous metal phase. The black spots seen in the macrograph are reinforcement clusters. The SiC particles mixed with TiB2 particles and formed cluster of reinforcement. The cluster formed surface lack interfacial bonding with aluminum matrix. As this cluster formation leads to porosity and poor interfacial bonding tensile test results are adverse and considerable reduction in strength of composite to 54.8 Mpa.

3.5. Wear test analysis

Wear test was carried out and a graph is plotted using experiment results. The graph (Fig.6) shows that wear resistance property of composite increases due to the addition of TiB_2. Test is carried out for 60 minutes and the wear value of Sic-10% and 0% of TiB_2 is 118.11µm whereas for Sic-10% and 2.5% of TiB_2 is 94.03 µm. This show wear resistance property increases by 20% due to addition of TiB_2. Also the results show that 5 % of TiB_2 reduces wear resistance property. This is probably not due to TiB_2 addition but porosity of the specimen.

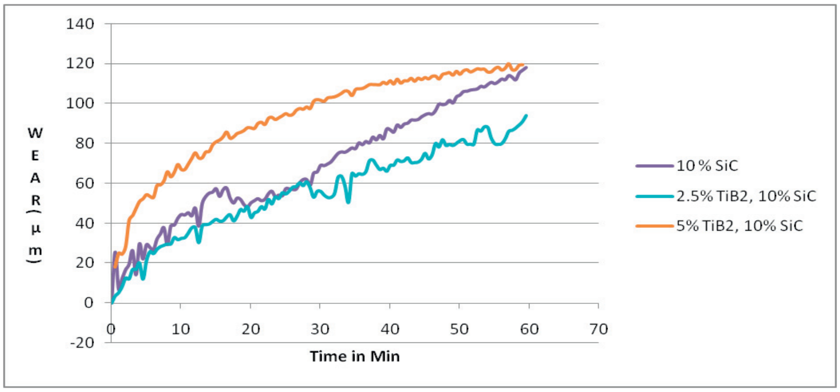

Fig. 6 Wear Vs Time

3.6. Analysis of machining parameters

This work examines the effect of various machining process parameters on surface roughness and to get the optimal sets of process parameters so that the quality of machined parts can be optimized. The experiments for turning operations were conducted according to the Taguchi's L_{27} orthogonal array. Table.2 shows the machining factors and their levels.

Table 2. Wear mass loss of mild steel pins

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 3 shows the contribution of machining parameters and interaction effect on surface roughness. It has been observed from the experiment that the highly influential factor is percentage of reinforcement of TiB_2 and its contribution is 38.86%. This shows nature of work piece material and its composition is a highly significant factor on surface roughness rather than cutting speed, feed rate and depth of cut. Table shows cutting speed and feed rate has significant effect on surface roughness as $P<0.05$ and its contribution is 22.48 and 11.51% respectively. Remaining parameters and interaction effects are insignificant.

3.6.1. S/N ratio analysis

This is the ratio of signal to noise where signal represents the desirable value while noise the undesirable value. This analysis is made by selecting smaller the better characteristic. S/N ratio analysis shows that % reinforcement of

TiB_2 is the highest influential factor on surface roughness and increase in weight percent of reinforcement leads to poor surface finish. This is due to pull out of abrasive particle during machining and the broken abrasives which slide along with work piece during turning operation. Also increased porosity due to increased weight percent of TIB_2 abrasive particles which has been also observed in micro structural analysis leads to poor surface finish. From Fig. 7 the optimal machining parameter for good surface finish is determined as cutting speed 120m/min, feed rate 0.3mm/rev, depth of cut 0.5mm and 0% of TiB_2 reinforcement

Table 3. Analysis of variance for surface roughness

Source	DF	SS	MS	F	P	% Contribution
Cutting Speed	2	2.314	1.1574	11.28	0.009	22.48
Feed rate	2	1.184	0.5921	5.77	0.040	11.51
Depth of cut	2	0.127	0.0635	0.62	0.570	01.23
% Reinforcement	2	3.995	1.9977	19.47	0.002	38.86
Cutting Speed*Feed rate	4	1.274	0.3187	3.11	0.104	12.39
Cutting Speed*Depth of cut	4	0.680	0.1701	1.66	0.276	06.61
Cutting Speed*% Reinforcement	4	0.088	0.0220	0.21	0.921	0.85
Error	6	0.615	0.1026			05.98
Total	26	10.280				

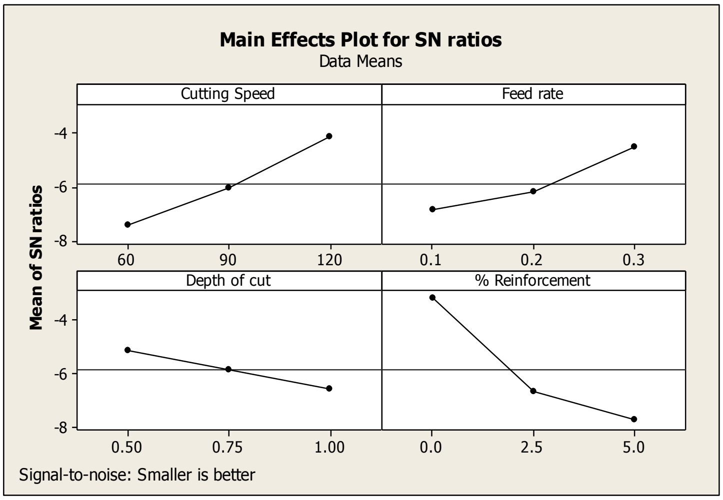

Fig. 7 Main effect plots for SN ratios.

3.6.2. Tool wear analysis

Tool life is the most important parameter to assess machinability. Tool material, work piece material and cutting parameters contribute much in tool wear. Fig. 8 shows the optical microscopic view of tool after machining. The composition of the specimen is 10% SiC and 2.5% TiB_2 and its cutting parameters are cutting speed-120 m/min, depth of cut-1mm and feed rate-0.1mm/rev respectively. It has been observed that worn out area encourages adhesion of work piece material and therefore often covered with an aluminum film due to the high pressure created at the tertiary cutting zone (tool – work piece interface). Then this film is stripped away by the hard abrasive SiC particles. Often along with the aluminum a small part of the tool material was also stripped away leading to tool wear. It has been concluded that the tool wear is caused by both abrasive and adhesion actions.

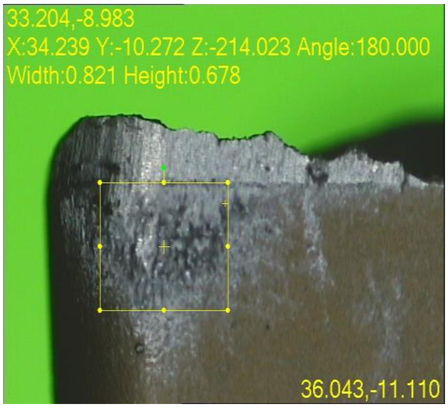

Fig. 8 Tool wear

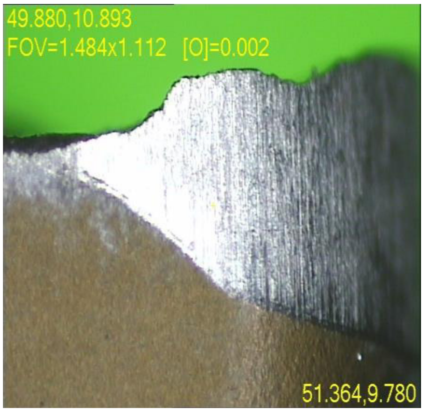

Fig. 9 Built-up Edge

Fig. 9 shows the optical microscopic view of tool with built-up edge after machining. The composition of the specimen above experiment is 10% SiC and 2.5% of TiB_2 and its cutting parameters are cutting speed-60m/min, depth of cut- 1mm and feed rate-0.3mm/rev respectively. Low cutting speed causes high cutting force which leads to rise in temperature. This is due to aluminium's affinity to stick to the cutting edge of the tool. It has been observed from the experiment that built up edges is due to high depth of cut and low cutting speed.

4. Conclusion

1. Micro structural analysis shows the presence of SiC and TiB2 and its distribution in the metal matrix.
   - Increase in weight percentage of reinforcement (SiC10%&$TiB_2$5%) leads to cluster formation. Hence the maximum % of TiB_2 into the matrix is limited to 2.5% for 10% SiC
2. It has been concluded from hardness measurement that, addition of reinforcements has effect on hardness value, but addition of TiB_2 up to 5% leads to porosity which affects hardness value.
3. From tensile test results it has been observed that addition of reinforcement Sic to base metal added 20% strength to the composite but addition of TiB_2 reduction in 50 -60% strength is recorded.
   - It has been analyzed from micro structure study and from tensile specimen after experiment that cluster formation leads to porosity and porosity leads to reduction in strength than base aluminium alloy
4. It has been proved from wear analysis that TiB_2 particles increase the wear resistance behavior of hybrid aluminum metal matrix.
   - Experimental results proved that the quantity of wear of Sic 10% - TiB_2 0% is 20% more than Sic 10% - TiB_2 2.5% specimen.
5. It has been observed from the machining analysis that % of reinforcement of TiB_2 is the most significant factor on surface roughness and its contribution is 38.86 %. The addition of TiB_2 reinforcement increases surface roughness value.
6. Using Taguchi analysis the below optimal machining parameters are tabulated for best surface roughness and its values are cutting speed 120m/min, feed rate 0.3mm/rev, depth of cut 0.5mm and 0% of reinforcement of TiB_2.
7. It has been concluded from tool wear analysis that
   - The high tool wear is caused due to both abrasive and adhesive actions.
   - Low cutting speed, high depth of cut and increased wt % of TiB_2 reinforcement causes as high tool wear.
   - Built-up edge formation affects surface quality.

Acknowledgements

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