Influence of machining parameters on cutting tool life while machining aluminum alloy fly ash composite

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Abstract. Metal matrix composites containing fly ash as reinforcement are primarily preferred because these materials possess lower density and higher strength to weight ratio. The metal matrix composites possess heterogeneous microstructure which is due to the presence of hard ceramic particles. While turning composites, the catastrophic failure of cutting tools is attributed to the presence of hard particles. Selection of optimal cutting conditions for a given machining process and grade of cutting tools are of utmost importance to enhance the tool life during turning operation. Thus the research work was aimed at the experimental investigation of the cutting tool life while machining aluminum alloy composite containing 0-15% fly-ash. The experiments carried out following ISO3685 standards. The carbide inserts of grade K10 and style CGGN120304 were the turning tools. The cutting speed selected was between 200m/min to 500m/min in step of 100m/min, feed of 0.08 & 0.16 mm/revolution and constant depth of cut of 1.0 mm. The experimental results revealed that the performance of K10 grade carbide insert found better while machining composite containing 5% filler, at all cutting speeds and 0.08mm/revolution feed. The failures of carbide tools are mainly due to notch wear followed by built up edge and edge chipping.

Key Words: Composite material, K10 carbide, turning, tool life, Notch wear, burr formation

1. Introduction
Aluminium metal matrix composites containing fly ash as the reinforcement which is obtained from the by products of thermal power plants, possess lower weight, higher wear resistance, tensile strength and thermal conductivity, hence they are preferred for the aviation, automobile and structural applications. The composites offer a unique balance of physical and mechanical properties. However, the cast composite parts have to be machined to meet the industrial requirement in order to obtain desired shape and size of the component with required quality at minimum cutting force. Hence extensive study was carried out on the behaviour of the cutting tools and failure mode while machining aluminum fly ash metal matrix composite using K10 grade carbide inserts. Thus, in the present experimental studies, it was aimed at the formulation of aluminum alloy-fly ash composites containing varied reinforcement and subjecting them for turning operation at varied cutting speeds and feeds using K10 grade tungsten carbide inserts.
2. Literature review
Manufacturing aspects of Aluminum composites containing fly ash has been investigated by numerous researchers and there are many published works related to this subject. According to the previous investigation like, S. Sarkar et al [1] demonstrated method of manufacturing Aluminum composites containing fly ash of 10%, 20% and 30% using stir casting method. In his research work the pre heated fly ash particles with different percentages were added to the vortex formed in the melt by stirring at 250-300RPM. Y.Sahin et al [2], carried research work on machining of Al₂O₃ particle reinforced aluminum (Al2024) metal matrix composites and found that the surface roughness increased with increase of volume fraction of the particles. S.Kannan et al. [3] observed accelerated tool wear of cutting tools due to abrasive wear mechanism while machining aluminum matrix composites. E.Kilickap et al [4], conducted experiments on machining aluminum metal matrix composites using Aluminum with 5% SiCp the results of the experiments shown that cutting speed was the most influential machining parameter on tool wear. M.El-Gallab et al [5], conducted experiments on machining aluminum metal matrix composites using Aluminum with 20% SiCp the results of the experiments shown that by increasing cutting speed, keeping feed rate and depth of cut low, leads to ductile tearing of chips. G.E.D’Errico et al [6], conducted experiments on machining composites and found that machining of silicon carbide reinforced MMC Al359/SiC/20P is more difficult than alumina reinforced MMC Al6061/Al₂O₃/10P. A.Toropov et al [7] found that during machining Al6061-T6 grade aluminum alloy the mechanism of burr formation generally takes place in the feed direction which depends on the tool geometry, work piece angle and feed. Metin Kok [8], carried research work on machinability of Al2024/ Al₂O₃ composites using coated and uncoated carbide cutting tools and he was observed that the BUE formation occurred at lower cutting speeds. K.B.Ahsan. et al [9] carried research work on study on carbide cutting tool life using various cutting speeds and they observed at higher cutting speeds surface roughness values decreases. Prakash Rao C.R. et al [10] carried research work on Machining behavior of Al6061 fly-ash composites using HSS M2 grade & Kennametal make CGGN120304 inserts of ISO K10 grade and they observed that while machining aluminum-fly ash composites the cutting tools fails mainly due to built up edge formation, however at higher cutting speed and feed the tendency of built up edge formation found lower. C.A.Brown et al [11] found that the machined surfaces of Al-Si alloy-graphite composites tend to be rougher than the surfaces machined at identical conditions on matrix material without reinforcement because of presence of deeper holes or valleys. Gurpreet Singh et al. [12] observed increase of surface roughness with the increase of feed rate and depth of cut while machining aluminum SiC-Graphite hybrid metal matrix composite (MMC). M.Ramalinga reddy et al. [13], conducted experiments on machining and they found that the effect of feed rate is very high on the surface roughness and very clearly observed on the roughness profile. Prakash Rao C.R. et al [14] carried research work on Effect of Machining Parameters on the Surface Roughness while Turning Particulate Composites and they observed that PCD inserts exhibits lower surface roughness while turning composites containing 10% filler material when compared with that of K10 grade tungsten carbide insert.

The above review revealed that a limited number of research works was done on the study of tool life while machining aluminum fly ash composites. The aim of the research work was therefore to investigate the tool life and hence study failure mode of K10 grade carbide inserts during turning of metal matrix composites at varied cutting speed using single point cutting tool.

3. Work material
3.1 Materials
The Aluminum alloy of grade Al6061 was the matrix material and the reinforcing phase for the present studies was fly ash, Table 1 and Table 2 are presented with the chemical composition of matrix material and reinforcing materials respectively.
Table 1. Composition of base matrix Al6061 alloy

| Parameter | Mg  | Si  | Fe  | Cu  | Cr  | Al  |
|-----------|-----|-----|-----|-----|-----|-----|
| Wt %      | 0.92| 0.58| 0.21| 0.23| 0.24| Rest|

Table 2. Composition of Fly ash

| Parameter | SiO₂ | Al₂O₃ | CaO | MgO | Fe₂O₃ | K₂O |
|-----------|------|-------|-----|-----|-------|-----|
| Wt %      | 58.32| 24.23 | 4.39| 1.20| 4.13  | 0.92|

3.2 Specimen Preparation & Characterization

The composite material was prepared using liquid metallurgy technique in which, the preheated fly ash particles were added as per rule of mixture to the molten metal and the temperature of molten metal was maintained between 720°C-730°C and simultaneously hexachloro ethane tablets were added to carry out degassing. The fly ash particles were preheated to a temperature of 100°C for two hours to remove the moisture content before being introduced into the vortex and stirring was carried out for duration of 60 minutes at 75 revolutions per minute. The slag inclusions thus formed after degassing were removed from the molten metal. The cast composites of Al6061 alloy and its composites containing fly ash of 0-15% in steps of 5% of diameter 120 mm and of length 300 mm were obtained and were the work materials for the continuous turning tests.

4. Cutting tool

Cutting tool used for the experiment is shown in Figure 1. Kennametal make positive rake angle tool was modified to obtain 10° positive side rake angle before conducting the experiment and nomenclature of cutting tool are presented in and Table 3.

![Figure 1. Cutting tool used for the experiment](image1)

Table 3. Nomenclature of cutting tool used for the experiment

| Carbide insert grade | K10          |
|----------------------|--------------|
| Back rake angle      | 15°          |
| Side rake angle      | 10°          |
| End cutting edge angle| 95°         |
| Side cutting edge angle| 95°         |
| End clearance angle  | 15°          |
| Side clearance angle | 15°          |
| Cutting tool type    | Throw away insert |
5. Machine tool
ACE Designers make JOBBER XL CNC lathe was the machine tool selected for the experimental studies, presented in Figure 2, and the specifications are tabulated in Table 4. The castings were held between hydraulic chuck and revolving centre and used for turning test on the CNC lathe.

![Figure 2. JOBBER XL CNC Lathe](image)

| Specification of JOBBER XL CNC lathe |
|-------------------------------------|
| Maximum turning diameter | 270 mm |
| Maximum turning length | 400 mm |
| R P M | 50-4000 |
| Clamping system | Hydraulic |
| Bar capacity | 36 mm |
| Dimension (m) | 2200X 1750X 1750 |

6. Turning tests
The turning tests were carried out with different cutting speeds and feeds whereas, depth of cut, cutting tool overhang and cutting tool geometry were kept constant following dry cutting conditions. The experimental studies carried out as per ISO 3685 standards. The cutting speeds were 200 m/min to 500 m/min in step of 100 m/min and the depth of cut of 1.0 mm. Built up edge and built up layer formation on the cutting edges were cleaned frequently. The carbide inserts were inspected for the nature of failure after every pass and average tool life of three consecutive readings was considered.

7. Results & discussion
7.1 Hardness test
The hardness test was carried out on KB3000H model Brinell hardness tester. The average hardness of the composite material measured is shown in the Table 5. From Figure 3, it is observed that addition of 5-15% fly ash to Al6061 matrix material resulted in increase of hardness from 21.68%-51.44%. The increase of hardness of MMC may be attributed to the presence of fly ash containing ceramic particles.

| Material       | BHN   | Density (g/cc) |
|----------------|-------|----------------|
|                |       | Predicted      | Experimental |
| Al6061         | 40.63 | 2.7            | 2.7          |
| Al6061+5% fly ash | 49.44 | 2.605          | 2.54         |
| Al6061+10% fly ash | 63.46 | 2.51           | 2.45         |
| Al6061+15% fly ash | 83.22 | 2.415          | 2.36         |
7.2 Density measurement
The density measurement values are compared with predicted density values by rule of mixture for cast Al6061 matrix and its composites containing varied percent fly-ash. The density of the composite material predicted and experimental values are shown in the Table 5. From Figure 4, it can also be observed that the difference between measured and predicted density values found lower and hence proves liquid metallurgy techniques followed for composite preparation. The increase in percent filler fly ash in the matrix resulted in 6-13% decrease in density of metal matrix composites, owing to the lower density of fly ash as compared to matrix Al-6061.

7.3 Scanning Electron microscope
The analysis of cast composites was carried out using JEOL make JSM-6380 model Scanning Electron microscope. Figure 5 to 8 presents the SEM microphotographs of cast Al6061 base matrix and its composites containing fly ash of 5 to15% in steps of 5. The SEM image confirms the presence of fly ash in the composites and suitability of the process adopted to manufacture aluminum flyash composites.

Figure 3. Comparison of hardness of composites

Figure 4. Comparison of experimental & predicted density of composites
7.4 Tool life test

The outside diameter turning test was carried out after skin turning of cast surface and K10 Grade carbide inserts were used for continuous turning experiment. The tool life of K10 Grade carbide inserts when continuous turning of composite materials, as a function of percentage filler were presented in Table 6 and Table 7. The cutting speed and feed per revolution was varied during the experiment by keeping depth of cut and cutting tool over hang constant.

| Percent fly ash | Tool life in minutes at feed of 0.08 mm/rev |
|-----------------|---------------------------------------------|
|                 | 200m/min | 300m/min | 400m/min | 500m/min |
| 0% fly ash      | 27.4     | 14.42     | 8.24     | 4.92     |
| 5% fly ash      | 25.62    | 13.33     | 7.11     | 4.01     |
| 10% fly ash     | 21.23    | 10.5      | 6.21     | 3.55     |
| 15% fly ash     | 17.22    | 7.8       | 4.65     | 2.37     |
Table 7. Tool life of K10 grade carbide inserts while machining Al6061 and its composites containing filler fly ash

| Percent fly ash | Tool life in minutes at feed of 0.16 mm/rev |
|----------------|------------------------------------------|
|                | 200m/min                   | 300m/min       | 400m/min       | 500m/min       |
| 0% fly ash     | 18.6                      | 8.8             | 5.26           | 3.24           |
| 5% fly ash     | 17.26                     | 8.3             | 4.94           | 2.84           |
| 10% fly ash    | 14.7                      | 7.6             | 4.41           | 2.46           |
| 15% fly ash    | 10.9                      | 6.1             | 3.38           | 1.62           |

Figure 9. Effect of percent fly ash and feed per revolution on tool life at 200m/min

Figure 10. Effect of percent fly ash and feed per revolution on tool life at 300m/min

Figure 11. Effect of percent fly ash and feed per revolution on tool life at 400m/min

Figure 12. Effect of percent fly ash and feed per revolution on tool life at 500m/min

From Figures 9 to 12, it can be observed that when composite material subjected to continuous turning application tool life reduces as the percent filler fly ash increases. It can also be observed that increased cutting speed leads to rapid reduction of tool life and as feed rate increases tool life reduces during continuous turning application.
Figure 13. Effect of percent filler and cutting speed on tool life at 0.08mm/revolution feed

Figure 14. Effect of percent filler and cutting speed on tool life at 0.16mm/revolution feed

From Figure 13 & 14, it can be observed that when composite material subjected to continuous turning application, tool life reduces as the cutting speed increases. The influence of cutting speed was found high on tool life when compared to percent filler fly ash, however feed per revolution was found significant. Failure of carbide inserts was mainly due to notch wear during machining composites. The criteria of changing cutting edge was failure of cutting tools due to built up edge formation followed by micro chipping, chipping of the cutting edge and notch wear. While machining composite material containing 10% reinforcement and 15% reinforcement, at 500 m/min cutting speed and feed of 0.16 mm/revolution, the cutting tool failed due to notch wear, high nose wear and spalling of cutting edge.

8. Conclusion

1. Hardness of the composite material increases with increase in percentage of fly ash.
2. Density of the composite material was found lower with higher percentage fly-ash.
3. While machining composite material containing 10% reinforcement and 15% reinforcement, at 500 m/min cutting speed and feed of 0.16 mm/revolution, the cutting tool failed due to notch wear, high nose wear and spalling of cutting edge.
4. During continuous turning of composite materials, the failure of cutting tools are mainly due to notch wear, which occurs at the end of radial depth, intersection of rake and flank surface.
5. The heterogeneous microstructure of the composite material containing filler fly ash consisting of hard ceramic particles was leading to notch wear during continuous turning experiment.
6. During continuous turning of composite material the tool life of K10 grade carbide insert reduces as the percent fly-ash increases.
7. During continuous turning of composite material the tool life of K10 grade carbide insert reduces as the cutting speed and the feed per revolution increases.
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