Performance Comparison of Al$_2$O$_3$ Cutting Tool with and without Reinforcement of Graphene Nanoplatelets

R Peddi Raju, A.Gopala Krishna

Abstract: *Al$_2$O$_3$ is a commonly used cutting tool material for machining cast iron and hard steels. However its low fracture toughness has been its potential drawback to use it for wider applications. In order to improve the fracture toughness, graphene nanoplatelets has been used as the reinforcement. The Al$_2$O$_3$-TiCN composite have been made by powder metallurgy. The present work compares the performance characteristics of Al$_2$O$_3$-TiCN with and without graphene nanoplatelets (GNP) in CNC machining. The machining performance of the prepared cutting tools is tested in terms of temperature generated, flank wear, cutting force and surface finish. It is observed that the prepared composite tool with GNP has much improved machining performance over the Al$_2$O$_3$ cutting tool that has no GNP reinforcement. The work has the unique novelty of using GNP as the reinforcement in Al$_2$O$_3$ cutting tool material.*

Keywords : Al$_2$O$_3$-TiC, Machining, Graphene nanoplatelets, Performance testing.

I. INTRODUCTION

These days, manufacturing industries are under continuous pressure to come up with the high quality cutting tools that cater to the ever increasing requirements of producing components with high production rate and quality. It is essential for a cutting tool to have good machining performance. It is note-worthy that the machining performance of cutting tool has significant influence on the unit cost of a component. As more and more exotic materials are being invented, industries are in continuous pressure to adopt the more efficient technologies to process them. Especially there is stringent requirement in defence and aerospace sector, to find the new materials that have high specific strength and specific stiffness. To machine them, efficient cutting tools need to be developed. Therefore the present work is taken up to compare the performance of new material that could machine the difficult-to-machine materials. Ceramic tool materials are widely used in industry because of their high hardness and wear resistance, high resistance to plastic deformation and chemical stability. Predominantly, alumina cutting tool inserts are widely used because of their strong ionic interatomic bonding. This bonding is much higher than the conventional carbide cutting tool materials. Therefore, Alumina cutting tools are considered in this work.

The present work compares the machining performance of

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Al$_2$O$_3$-TiCN cutting tool with and without graphene nanoplatelets prepared by powder metallurgy.

II. LITERATURE SURVEY

There have been some attempts in the literature where cutting tools with nano reinforcements are tested for their performance in machining. Zheng et al.[1] fabricated Sialon–Si3N4 graded nano-composite ceramic tool materials by using hot-pressing technique. The cutting performance and wear mechanisms of the graded tools were investigated via turning of Inconel 718 alloy. Zhao et al.[2] fabricated Al$_2$O$_3$-based composite ceramic tool material reinforced with WC microparticles and TiC nanoparticles by using hot-pressing technique. The cutting performance, failure modes and mechanisms of the Al$_2$O$_3$/WC/TiC ceramic tool were investigated via continuous and intermittent turning of hardened AISI 1045 steel. Wu el at.[3] deposited AlCrN coating and AlCrSiN multilayer and nanocomposite coatings on high speed steel (HSS) cutters. Their wear mechanisms were studied. Kursuncu et al.[4] deposited the nanocomposite TiAlSiN/TiSiN/TiAlN thin film on the cutting tools and then they were subjected to cryogenic heat treatment to increase the tool life of the used cutting tools.The present work has the unique novelty of comparing the machining performance of Al$_2$O$_3$-TiCN reinforced with GNP with conventional Al$_2$O$_3$-TiCN tool. Their performance is investigated in terms of temperature generated, surface finish, cutting force and flank wear.

III. EXPERIMENTATION

The turning experiments were performed on a two axis CNC lathe (LMW SMARTURN LT) shown in Fig.1 with the capacity of 10.5 kW maximum power and the maximum spindle speed of 4500 rpm.

Fig.1. CNC Turning machine used for experimentation

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An AISI 316L austenitic stainless steel was used as the workpiece material. AISI 316L has the Rockwell hardness of 95. AISI 316L is a low carbon chromium-nickel-molybdenum austenitic stainless steel which finds numerous applications in manufacturing industries because of its excellent resistance to corrosion and excellent creep resistance at elevated temperatures.

The cutting tool insert prepared through powder metallurgy is shown in Fig.2. The tool was fabricated with 0.75wt%GNP.

Fig.2. Prepared turning insert

Fig. 3 exhibits the fabricated cutting tool insert clamped in the tool holder at the ready-to-start position for machining and Fig. 4 shows the simulation of the tool path before the start of the machining.
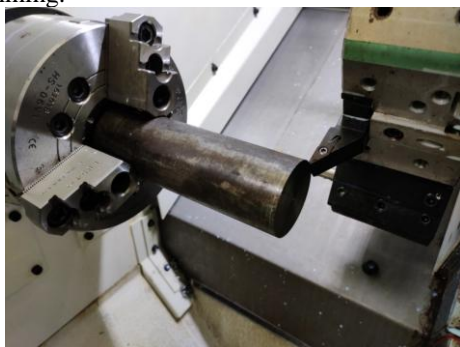

Fig.3 Cutting tool insert fixed in the tool holder

Fig. 4 Simulation of tool path before machining

To perform machining, the feasible cutting conditions were chosen based on the capabilities of the machine. The performances of the tools are found at different process conditions. The performance is stated in terms of temperature generated, flank wear and surface roughness. The above fourare the most performance measures of any cutting tool in a machining process. All the experiments were conducted in dry condition. All the experiments were carried out as per ISO 3685 standards.

IV. RESULTS AND DISCUSSION

A. Flank wear Vs Machining time

Flank wear is the most significant parameter that establishes the tool life. It is a predominant form of tool wear. During machining, tool wear occurs gradually leading to the degradation of the performance of the tool. Flank wear is caused due to the abrasive wear of the cutting edge with the workpiece being machined. It is gradual in nature and eventually leads to the total failure of the tool.

For sintered tools, as per the standards, flank wear of 0.35mm is considered to estimate the tool life. The flank wear was measured by using Nikon104 microscope with a magnification of X10. The experiments were conducted at the processing conditions of velocity 220m/min, feed rate 0.15mm/rev, and depth of cut 1mm.

Fig. 5 shows the values of the flank wear of the tools with respect to the machining time. Machining was done till the preset criterion of flank wear (0.35mm) was achieved. The turning process was paused after every 5min to observe the flank wear through the microscope.

From Fig.5 it is obvious that flank wear at any machining time is lesser for the Al2O3 tool with 0.75wt% GNP. There is a direct relation between the flank wear and the machining time. As the machining time increases, the flank wear of both the tools increases.

Flank wear becomes steeper and more rapid at higher machining times. The difference of performance of tools is more predominant with the machining time. At higher machining times, the difference between the performances is more discernable.
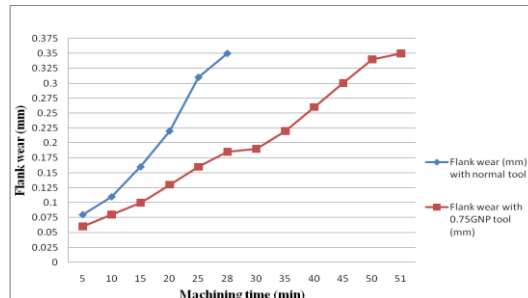

Fig. 5. Flank wear Vs Machining time

Better flank wear is observed for the GNP tool as it is harder and tougher than its counterpart. It is noted that Al₂O₃ tool without GNP crossed the preset flank wear of 0.35mm after 28min of machining time while GNP tool crossed it after 51min. This shows that the proposed tool is far superior as its tool life is almost double than that of the tool without GNP. Tool life of GNP tool is 51min where as that of without GNP tool is only 21min. Tool life of GNP tool is much longer.

B. Surface roughness Vs Machining time

Surface roughness (Ra) was measured by a surface profilometer at the cut off length of 0.8mm and sampling length of 4mm in each measurement. Fig. 4 shows the variation of Ra with respect to Machining time. Ra is observed to be increasing with the machining time. There is close relation between Ra and flank wear. An increase in roughness value was seen as the flank wear progressed.

From Fig.6 it is noted that Ra is increasing at higher rate for ATG-0 (normal Al_2O_3 tool with 0wt%GNP) than ATG-0.75 (Al_2O_3 tool with 0.75wt%GNP). As ATG-0.75 cutting tool has higher hardness than ATG-0, its flank wear was found to be better. Subsequently this results in better surface finish for ATG-0.75.

After machining with ATG-0 for 28 minutes, a poor roughness of the work piece was obtained as 2.98µm. However, with ATG-0.75 for the same machining time period of 28 minutes, the surface roughness (Ra) of the same work material was measured to be only 2.01µm. This indicates that ATG-0.75 is a much better cutting tool from the perspective of surface roughness.
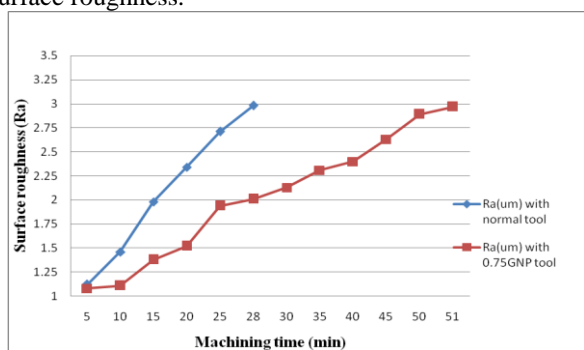

Fig. 6 Surface roughness Vs Machining time

C. Temperature Vs Feed rate

Estimation of temperature during a machining process is important as it influences the surface integrity of both work piece and the tool. Higher temperature drastically reduces the tool life and induces unwarranted residual stresses in work pieces. Moreover, it also reduces the hardness of the tool. Maximum temperature occurs at the tool-chip interface.

In the present work, temperature at the interface is measured by an infra-red thermometer. The temperature during the machining process was measured at different process conditions. Feed rate was varied from 0.025 to 0.35mm/rev with the step size of 0.025mm/rev. Velocity and the depth of cut were kept constant at 220m/min and 1mm respectively. Fig.7 shows the behavior of temperature against the feed rate. It is clear that increase in feed rate led to an increase in temperature in cutting zone. As feed rate increases from 0.025 mm/rev to 0.35 mm/rev, the temperature of ATG(0.75) increases from 360^0C to 558^0C while ATG(0) displays increase in temperature from 338^0C to 604^0C with increase in feed rate. ATG(0.75) is found to be a better tool as it incurred less temperatures during machining. This is because of the extraordinary thermal conductivity of graphene. Graphene has the extraordinary thermal conductivity of 5000W/mk. This high value of thermal conductivity makes the material dissipate the heat generated quickly.
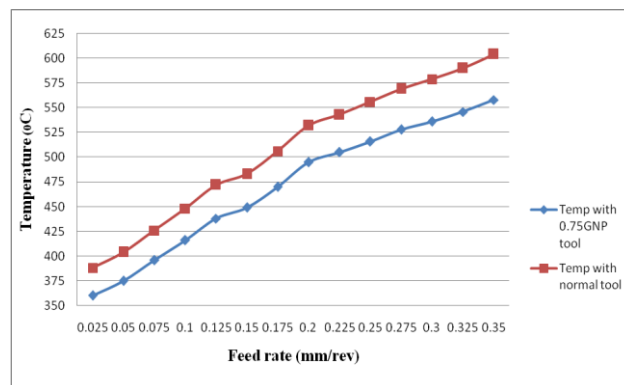

Fig.7 Temperature Vs Feed rate

Thermal conductivity of Al_2O_3 is 12W/mK while that of graphene is 5000W/mk. This huge value of graphene makes the cutting tool a special one. It is because of this fact, the proposed tool with 0.75%wt GNP exhibited much reduced temperature.

D. Cutting force Vs Feed rate

Fig.8 shows the comparative performance of the cutting tools, Al_2O_3/TiCN, Al_2O_3/TiCN/0.75GNP during machining. The values of cutting force are measured at various instants of feed rate. The cutting force was measured using a Kistler three component piezoelectric dynamometer (model 9265A).
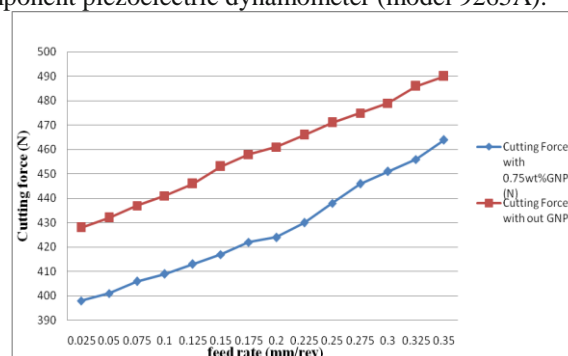

Fig.8 Cutting force vs feed rate

As it is observed from Fig.8, cutting force increases with increase in feed rate for both the cutting tools but ATG-0 shows more increase in cutting force than ATG-0.75. The cutting force of ATG-0 increased from 428N to 490N when the feed rate was increased from 0.025 to 0.35mm/rev. However, for the same range of feed rate, the cutting force of ATG-0.75 increased from 398N to 464N. This indicates that ATG-0.75 has generated much lesser cutting forces than ATG-0 during turning operation. Higher thermal conductivity generates lesser heat at the tool-chip interface. Heat generated has direct influence on the hardness of the tool. Higher is temperature generated, higher is the flank wear due to lesser hardness the tool achieves. Subsequently, higher is the flank wear higher is the cutting force. Because of the wear, the amount of tool that comes in contact with the workpiece becomes more. In the present case, as GNP has extraordinary thermal conducitvity and lubrication properties, the amount of cutting forces generated by Al_2O_3/TiCN/0.75GNP are much lesser. As GNP has very low coefficient of friction, it always reduces the force due to friction.

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Al$_2$O$_3$/TiCN/0.75GNP is certainly a superior tool when compared with Al$_2$O$_3$/TiCN as GNP makes the difference. GNP has excellent lubrication properties besides the extraordinary thermal conductivity. These properties make the cutting tool generate lesser cutting force.

V. CONCLUSIONS

- The proposed Al$_2$O$_3$- TiCN cutting tool insert at 0.75wt% turned out to be the better tool material as it led to improved results in terms of flank wear, surface roughness, cutting forces, and temperature generated.
- Tool life of Al$_2$O$_3$- TiCN with GNP was 51min while that of the tool without GNP was 28min. Almost the tool life got doubled. Similarly the tool with GNP obtained the roughness value of 2.10μm against 2.98μm in case of no graphene.
- The cutting force of Al$_2$O$_3$- TiCN   without GNP tool increased from 428N to 490N when the feed rate was increased from 0.025 to 0.35mm/rev. However, for the same range of feed rate, the cutting force of Al$_2$O$_3$- TiCN with GNP tool increased from 398N to 464N. This indicates that ATG-0.75 has generated much lesser cutting forces than ATG-0 during turning operation.
- As feed rate increased from 0.025 mm/rev to 0.35 mm/rev, the temperature of GNP tool increased from 360^0C to 558^0C while no graphene tool displayed increase in temperature from 3380C to 6040C for the same feed rate.
- The improvement in the different machining performances is obtained as Graphene has extraordinary fracture toughness combined with its unique thermal conductivity and lubrication properties.
- In essence, there is a conclusive evidence that the proposed composite Al$_2$O$_3$- TiCN with 0.75wt% GNP is a better alternative to conventional pure Al$_2$O$_3$- TiCN   cutting tool material.

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