

# Cutting temperature of graphene-reinforced ceramic cutting tool inserts during dry turning of hardened steels



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**Abstract** The amount of heat generated during machining operations under high speed and depth of cut inherently produces high temperatures at the cutting zone. Therefore, the temperature generated at the cutting junction of the tool and workpiece is a crucial parameter in determining the quality of the finished product. The effect of the generated cutting temperature, especially at elevated temperatures, primarily affects both the workpiece and the cutting tool. Knowledge of the cutting temperature generated at the tool tip can improve tool life and machining performance. In this work, turning operations were performed on a hardened steel workpiece of grade EN24 and EN36 using alumina-graphene composite ceramic tool inserts under different machining conditions on a precision lathe without coolant (dry machining). The maximum temperatures generated (offset temperature, i.e., 4 mm away from the tool insert tip) at the tool insert were measured during the turning of hardened steel workpieces with the aid of a calibrated thermocouple. A study was also conducted on the effect of different weight percentages of graphene in alumina ceramic tool inserts on the generated offset temperatures. During the machining of both the EN24 and EN36 samples, it was clearly observed that offset temperatures generated at composite tool inserts reinforced with 0.35 wt% and 0.45 wt% of graphene were lower at all machining conditions compared to offset temperature values generated at 0.15 wt%, 0.25 wt%, 0.55 wt%, 0.65 wt% graphene-reinforced alumina ceramic tool inserts, as well as pure alumina tool inserts.

**Keywords:** alumina, graphene, ceramic cutting tool inserts, cutting temperature, dry machining

## 1. Introduction

Ceramic materials exhibit high melting points, hardness, oxidation and corrosion resistance, as well as high chemical stability, when compared with other tool materials (Grigoriev et al 2019; Graham 2008). Due to these superior characteristics, ceramic materials have long been considered as cutting tool materials. Despite alumina possessing most of the desirable qualities required for a cutting tool material, such as high hardness, corrosion resistance, chemical stability, and economic viability, its use as a cutting tool material is limited by its low tensile strength, fracture toughness, and wear resistance. To overcome these limitations, several studies have suggested the use of carbon-based nanomaterials as reinforcing agents in alumina to curtail its brittleness and improve its properties (Llorca et al 1998; Yongqing et al 2001).

Out of all machining operations, turning is a fundamental type of machining required for certain manufacturing processes. Therefore, it is necessary to have certain knowledge about heat generation and temperature rise during this turning process (Mehul et al 2016). Specifically, when turning hard materials, the combination of dry cutting and high speed remains a challenge for researchers in terms of economic, environmental, and health aspects. In this regard, the use of ceramic materials as cutting tools in hard turning has been found to be beneficial at a variety of cutting speeds, which is possible at less cost. Generally, ceramic cutting tools are used in dry machining conditions to protect the tool edge from thermal shocks (Fox-Rabinovich et al 2014). At the same time, the development of smart ceramic cutting tools requires a better understanding of the thermal damage that occurs at the cutting zone due to temperature changes at the tool-chip interface during interrupted cuts. The heat generated from the primary and secondary shear zones often leads to rapid tool wear and occasionally unpredictable catastrophic tool failures (Trigger 1951).

Thus, real-time sensing of thermomechanical phenomena is essential for further advancements in machining processes. However, obtaining a clear line of sight between the camera and the cutting zone is difficult, and the high temperature gradient during machining makes local temperature measurement at the cutting interface difficult to extrapolate. Garcia-Gonzalez et al (2016) used an optically transparent yttrium aluminum garnet cutting tool that provides an optical path to the tool-chip interface. They imaged the interface with a low-noise camera mounted on a stereomicroscope to measure the rake face



temperature distribution. However, this method requires image processing, and interface temperatures might be different in machining with standard cutting tools due to their different thermal properties. Basti et al (2007) deposited a built-in thin-film thermocouple directly on the rake face of a ceramic cutting insert using sputtering and photolithography technique and measured the cutting temperature 0.3 and 0.5 mm away from the cutting edge, resulting in a measurement near but not beneath the tool-chip contact area. Therefore, direct temperature measurement of the cutting interface with thin-film thermocouples embedded in a standard tool is important for accurately characterizing the tool-chip interface temperature.

The cutting temperature during metal cutting has been measured using various techniques. Among them, the k-type thermocouple technique has been employed by several authors to measure the temperature between the tool tip and workpiece, and it has been concluded that the tool-chip thermocouple technique is the most effective method for measuring the average tool chip interface temperature (Abhang and Hameedullah 2010; Sushil 2014). Studies have also indicated that the temperature generated at the chip-tool interface is highly influenced by cutting speed, and an increase in cutting speed results in a surge in generated temperature at the cutting zone (Patel and Rajendrakumar 2020; Chinchankar and Choudhury 2013; Jiteen et al 2020).

The main objective of the present work is to prepare alumina-graphene composite tool inserts with varying weight percentages of graphene using powder metallurgy technique. The effect of graphene weight percentage on the generated offset temperature during the dry turning of hardened steel samples using alumina ceramic tool inserts will be studied. Additionally, the effect of different machining parameters, such as cutting conditions, on the generated offset temperature at tool inserts during turning will also be investigated.

## 2. Experimental Details

Tool inserts according to international standard SNGN 120404 are prepared initially from pure alumina and alumina-graphene composite powder with different wt% of graphene ranging from 0.15 wt% to 0.65 wt% with an interval of 0.1 using a hydraulic press under a compression load of 6 T using a tungsten die. These samples were then sintered using a microwave sintering technique at 1500 °C as they exhibited high relative density at that temperature (Vishnu Vandana and Suman 2021) and are shown in Figure 1.

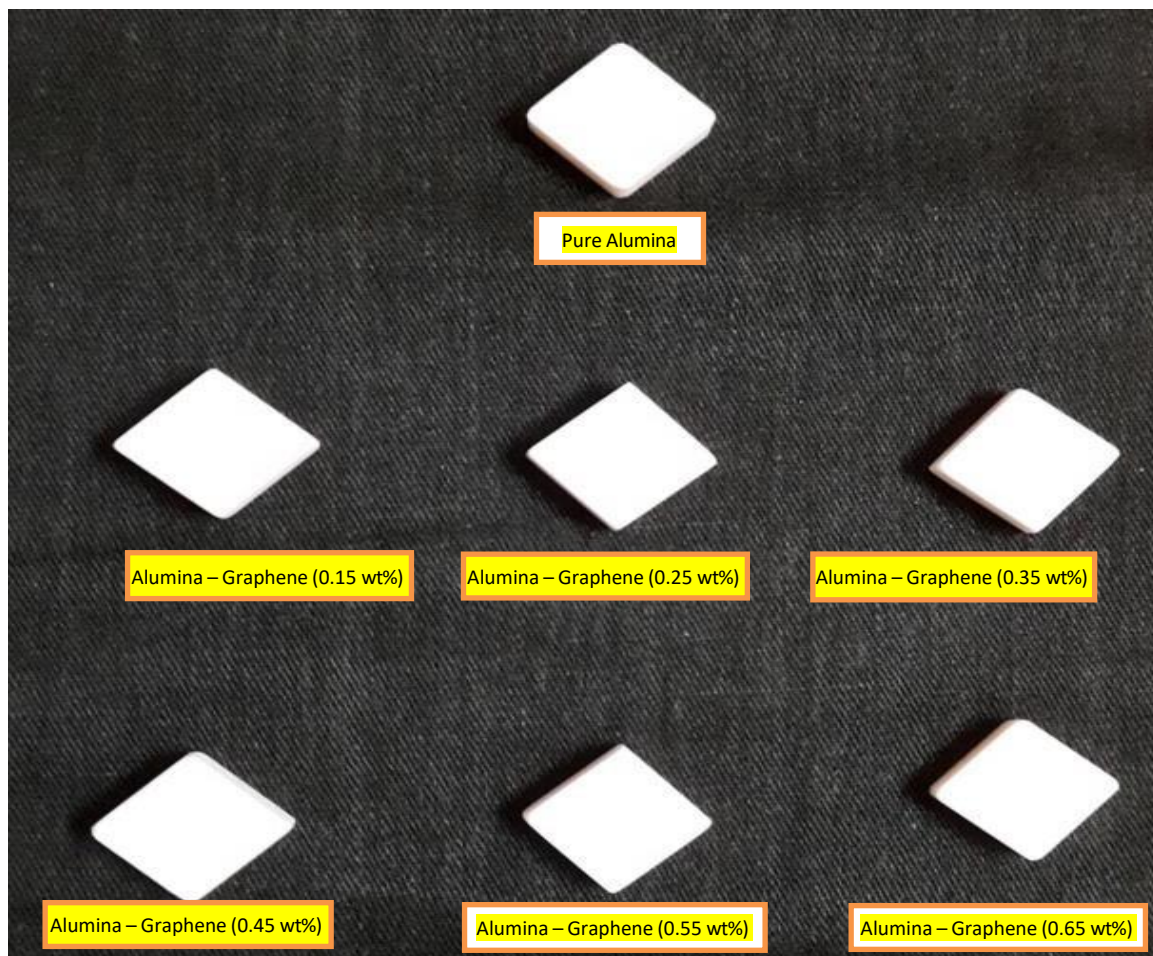


Figure 1 Pure Alumina and Graphene reinforced Alumina tool inserts.

Initially, for measuring the offset temperature at tool inserts, a hole of 1.6 mm diameter was made diagonally within the insert holder near the insert cutting face at a distance of 4 mm from the tooltip. After that, through this hole, one end of the K-type thermocouple (Figure 2) probe of 1.5 mm diameter is fitted, and the other is connected to a digital display unit indicating the temperature.



**Figure 2** K-Type Thermocouple for Temperature Measurement.

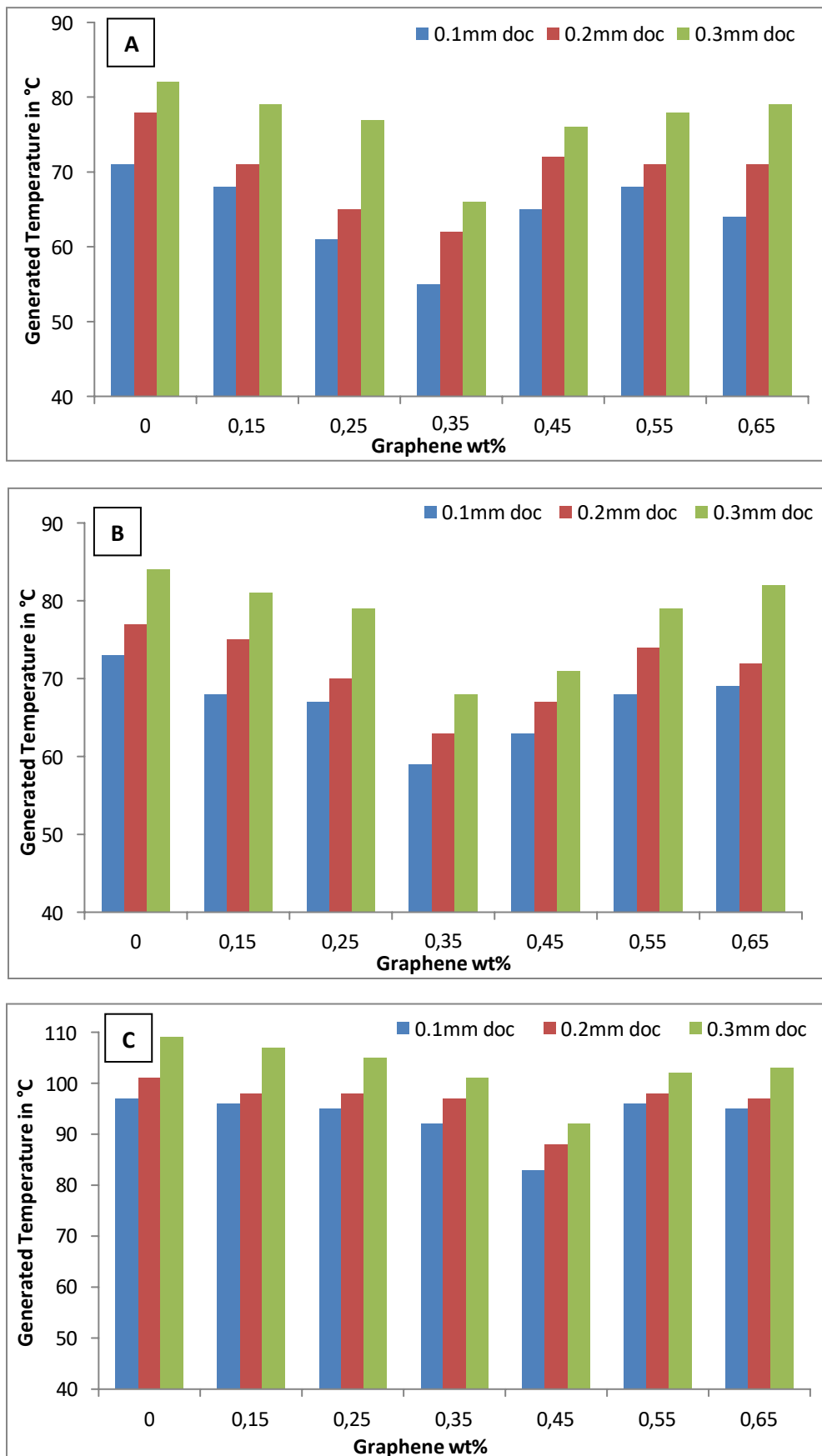
Turning operations are carried out on EN 24 and EN 36 hardened steel samples using a precession lathe (Indian make, SS&SG model) with prepared pure alumina and alumina-graphene composite tool inserts at cutting speed ranging from 100 rpm to 500 rpm with an interval of 200, feed from 0.3 to 0.8 mm/rev with an interval of 0.2 and depth of cut from 0.1 to 0.3 mm with an interval of 0.1. Turning operations are carried out for a duration of 5 minutes without using any coolant (dry machining), and the experimental setup is shown in Figure 3.



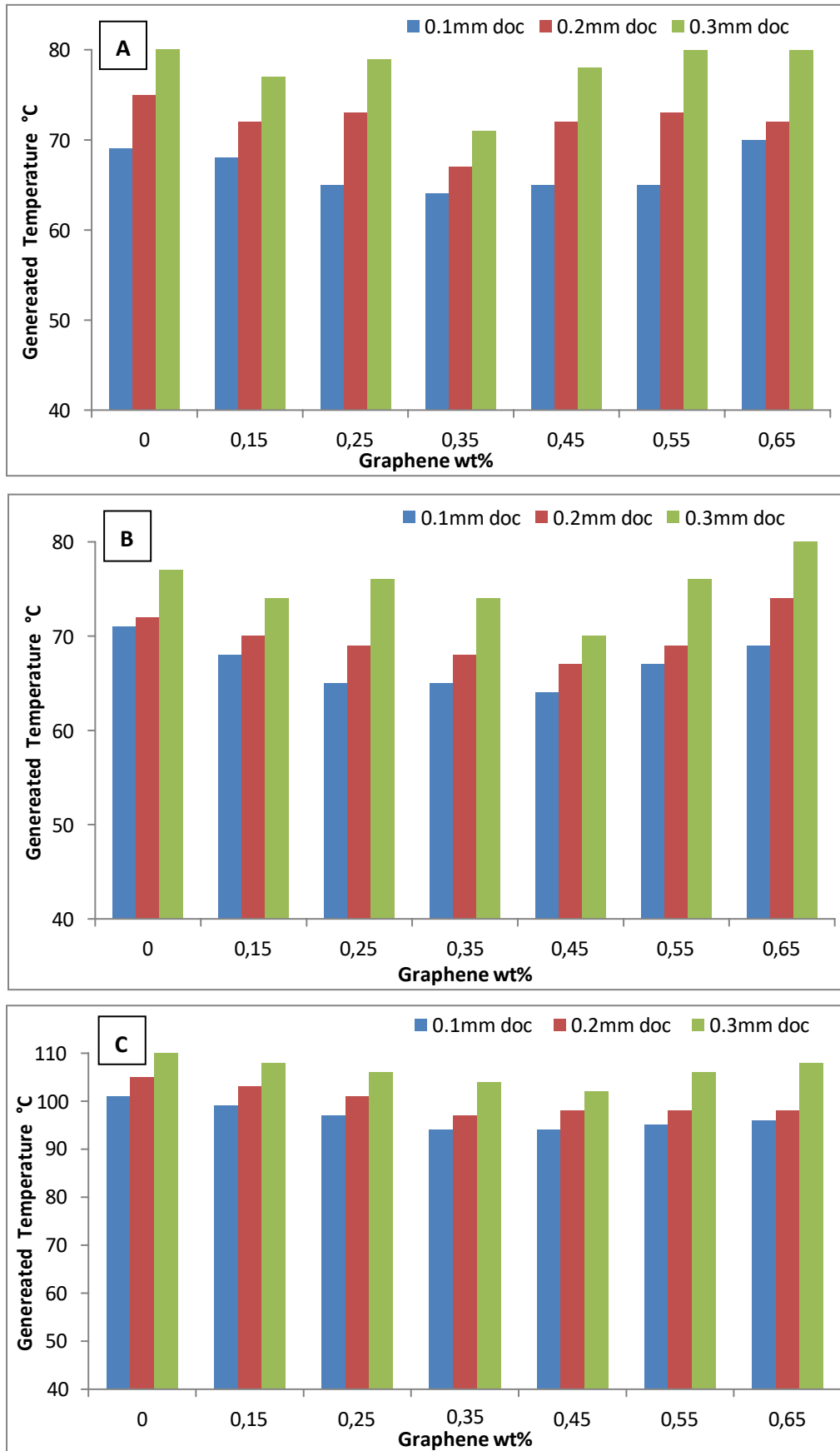
**Figure 3** Experimental Setup

Machining under high speed and depth of cut inherently generates more amount of heat as well as high temperatures at the cutting zone. Hence, to evaluate the performance of prepared alumina-graphene ceramic composite inserts in terms of generated temperature during turning operation, generated tool offset (4 mm away from the tooltip) temperature were recorded by using a K-type thermocouple sensor while machining on EN 24 and EN 36 hardened steels at above-mentioned machining conditions.

The obtained values of tool offset temperatures at different machining conditions were plotted for the alumina-graphene ceramic composite inserts are shown in Figure 4 and Figure 5.



**Figure 4** Temperatures generated while machining EN 24 samples with Alumina-Graphene tool inserts at a max Feed of 0.8 mm/rev and varying Depth of cut and speed. a) 100 rpm (b) 300 rpm (c) 500 rpm.



**Figure 5** Temperatures generated while machining EN 36 samples with Alumina-Graphene tool inserts at max Feed of 0.8 mm/rev and at varying Depth of cut and speed. a) 100 rpm (b) 300 rpm (c) 500 rpm.

From Figure 4 and Figure 5, it is evident that the offset temperature generated at the tool inserts (4 mm away from tip) of pure alumina and alumina-graphene ceramic composite inserts increased significantly during the machining of both EN24 and EN36 samples with increased speed. This rise in temperature is due to the production of more heat at the tool chip interface with an increase in cutting speed, which in turn increases the temperature of the tool chip contact area. The graphs illustrate that the offset temperature generated at the composite tool inserts reinforced with 0.15 wt% to 0.45 wt% of graphene is lower compared to that generated at pure alumina tool inserts while machining both the EN24 and EN36 samples at all machining conditions. The lower temperature generated at tool inserts can be attributed to the lubricating property of graphene, which might aid in reducing the friction generated between the contact surfaces during turning operation. However, the generated offset temperatures are observed to increase in the composite tool inserts reinforced with 0.55 wt% and 0.65 wt% of graphene when compared with the offset temperature generated in the remaining alumina-graphene composite (0.15 wt% to 0.45 wt%) inserts while machining both the EN24 and EN36 samples at all machining conditions. The increased reinforcement content of graphene may increase the agglomeration of graphene particles in the tool insert, which doesn't provide uniform lubrication during turning operation.

Among all cutting tool inserts tested in the experimentation, the alumina-graphene composite tool inserts containing 0.35 wt% and 0.45 wt% of graphene have shown remarkable reduction in the generated tool offset temperatures while machining both the EN24 and EN36 samples at all machining conditions. This can be attributed to the higher amount of graphene in tool inserts reinforced with 0.35 wt% and 0.45 wt% of graphene. However, with a further increase in the graphene reinforcement proportion in alumina, the lubricating protection of graphene appears to decrease due to the agglomeration tendency of graphene particles in the composite. The increased concentration of graphene particles in the alumina matrix might lead to this agglomeration. It can be concluded that the presence of an optimum amount of graphene, in 0.35 wt% and 0.45 wt% graphene-reinforced ceramic composite tool inserts, might serve as a lubricant while machining and aid in reducing the friction generated between the contact surfaces and thus reducing the spikes in the generated temperature during machining.

It is also observed that during machining, feed and depth of cut are not prominent factors in generating temperature. Since most of the heat generated while machining is at the chip-tool interface, the heat is carried away by the chip, instead of penetrating into the tool insert tip with increased feed and depth of cut values.

### 3. Conclusions

1. The generated offset temperatures at ceramic composite tool inserts reinforced with 0.35 wt% and 0.45 wt% of graphene were reduced by 7.33% and 15.59% respectively compared to the offset temperatures generated at tool inserts made with pure alumina during machining of EN24 samples at higher speeds (500 rpm), feeds (0.8 mm/rev) and depths of cut (0.3 mm).
2. During the machining of EN36 samples at the chosen higher speed (500 rpm), feed (0.8 mm/rev) and depth of cut (0.3 mm), generated offset temperatures at ceramic composite tool inserts reinforced with 0.35 wt% and 0.45 wt% of graphene were found to be reduced by 5.45% and 7.27% respectively, compared to the offset temperatures generated at pure alumina tool inserts.
3. The offset temperature values observed at the tool insert reinforced with 0.35 wt% and 0.45 wt% of graphene were lower than the offset temperature values generated at 0.15 wt%, 0.25 wt%, 0.55 wt%, 0.65 wt% graphene reinforced alumina ceramic tool inserts, and pure alumina tool inserts during machining of both EN24 and EN36 samples at most machining conditions.
4. At the selected higher speed (500 rpm), feed (0.8 mm/rev) and depths of cut (0.3 mm), the offset temperature values generated at the tool insert reinforced with 0.45 wt% of graphene were 8.91% and 1.92% lower than the temperature values at the tool insert reinforced with 0.35 wt% of graphene, respectively, during the turning of EN24 and EN36 samples.
5. Lower tool tip temperatures during machining help to maintain the high level of hardness of the chip face adjacent to the tool and prevent adhesion of the chips to the tool, thereby reducing the friction between the chips and the tool.
6. Among all composite tool inserts and pure alumina tool inserts, it can be concluded that alumina ceramic tool inserts reinforced with 0.45 wt% of graphene can be used for machining hardened steels at higher speeds without generating much higher temperatures.

### Ethical considerations

Not applicable.

### Conflict of Interest

The author declares that has no conflict of interest.

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