



Studying the Effect of un Coated and Multilayer Coated Tools on Cutting Temperature in Turning Operation

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HIGHLIGHTS

- The effect cutting velocity, feed rate, and cut depth on the hard turning cutting temperature of uncoated and carbide was investigated.
- Coated cutting tools have a lower tool temperature than uncoated ones compared to uncoated ones.
- The cutting velocity influences the tool temperature rise during the cutting process.

ABSTRACT

The present work studies three variables (cutting velocity, feed rate, and cut depth) on hard turning cutting temperature of uncoated and multilayer-coated carbide (TiN, TiN/TiCN, TiN /Al₂O₃/ TiCN) inserts are used in AISI 1045 alloy steel. The tool's temperature was measured simultaneously, measuring the temperature of the tool-chip interface using infrared radiation (IR) pyrometer in this investigation. This study investigated the performance of four distinct coated and uncoated PVD and CVD tools during turning operations. Four cutting speeds (56, 88, 112, 141) m/min, four feed rates (0.065, 0.08, 0.16, 0.228) mm/rev., in the experiments, a constant cutting depth of (1) mm was used. The results also show that Coarse cutting tools have a lower tool temperature than uncoated ones. In comparison to uncoated and other coated tools, the three-layer (TiN/ Al₂O₃/ TiCN) coating is especially effective in a range of (32% to 39%) than uncoated inserts at various cutting velocity and constant feed rates, with varying feed rates and consistent cutting velocity and lower by approximately (34% to 40%) than uncoated inserts.

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1. Introduction

Because of the severe impacts on the material qualities of the tool and the work item, knowing how to monitor the cutting point temperature of the turning tool caused by changes in the cutting state is well recognized [1]. In the cutting process, most of the energy is transferred to heat. At the tool-chip and tool-workpiece contacts, heat is created by plastic deformation and friction. The cutting zone's temperature rises due to the heat generated during machining. The cutting tool's strength, hardness, wear resistance, and life may be affected by temperature changes. This makes it difficult to monitor the accuracy of the machined component because of dimensional changes in the machined item and machined surface integrity, causing the workpiece to be damaged by heat, affecting its characteristics and service life [2]. Coated cutting tools are used to machine various materials, and cutting tools are getting more and more demanding in today's machining operations. According to market data, about 40% of all cutting tools used in modern industry are coated, and they perform more than 80% of all machining tasks. Some multilayer coatings are made using duplex processing techniques, such as a mix of CVD and PVD procedures [3]. A coating can be defined as a near-surface region with qualities distinct from the bulk material on which it is deposited. Coatings can be placed on the surface of materials to protect them from the elements, which can cause corrosion and other deteriorative reactions and improve their appearance [4]. Although recent improvements in numerous new coating materials have evolved from advancements in coating technology, TiC, TiN, TiCN, and Al₂O₃ are common coating materials [5]. The coating substance lowers tool-to-workpiece friction and interactions, reduces crescent pit wear, and extends the coated tool's service life and cutting efficiency [6]. Cutting performance can be improved by applying multilayer coatings to the cutting zone. The coating layer improves chemical inertness, oxidation resistance, hot hardness, and Wear resistance, which extends tool life [7]. In the case of the individual-layers technique, multilayer-coated tools are supposed to have different coating layers. In the deposition sequence, each coating layer with its coating thickness and thermal characteristics is deposited into the tool substrate without interfering with the others [8]. What is important about the tool or the material in the cutting

process is that the type of tooling material should always be tougher than the material to be processed. This basic fact is very important because it will determine the quality of the final product [9]. According to the existing records, the range of cutting speed and feeding that provides acceptable performance is extremely limited, so it is necessary to sort out the ranges that provide appropriate operating circumstances since the choice of operating standards is very significant [10]. Some common methods employed for measurement of Cutting Conditions, the following literature review:

Ucun and Aslantas [11] Cutting in an orthogonal manner experiments were performed at cutting speeds of 60, 120, 180, 240, 300 m/min, feed rates of 0.05, 0.075, 0.1, 0.2 mm/rev. as well as a constant cut depth (1 mm). Temperature values on the tool surface rise (38%) for the uncoated cutting tool, (24%) for the (Al_2O_3) coated tool, and (35%) for temperature values on the ($\text{TiCN}/\text{Al}_2\text{O}_3/\text{TiN}$) tool surfaces for those that have been coated. Those that have not been coated are very close to one another, with a (60%) increase in cutting velocity. El-Hakim et al. [12] showed how four cutting tools performed in machining medium hardened HSS : (c-BN-TiN), (Al_2O_3 -TiC), and (TiN) over a multilayer ($\text{TiC}/\text{TiCN}/\text{Al}_2\text{O}_3$) covering. They discovered that Al_2O_3 tribo-films' strong chemical and thermal stability protects the tool substrate by preventing heat generated at the tool/chip interface from entering the tool core. Ghodam [13] measured the temperature of coated and untreated tungsten carbide tools during machining. EN8 alloy steel was used as the workpiece (250 mm long and 45mm diameter). Compared to an uncoated tool, the coated tool can be utilized at a faster cutting velocity. Ghodam [1] Using a tool work thermocouple to measure the temperature of a cutting tool during the turning process, it is found that the coating of the tool increases the life for the same cutting velocity when compared to a tool that hasn't been coated. The maximum temperature of the coated tool was less than (520°C), and for the coated tool was (600°C). Kara [14]. Cutting temperatures in AISI 316L stainless steel orthogonal turning experiments were predicted. Cutting speeds of 75, 100, 150, 200, and 250 m/min, with feed rates of 0.05, 0.1, and 0.2 mm/rev and a consistent cut depth of 2 mm were used to turn bars with a diameter of (60.3 mm and a cutting length of 240 mm.). Because of its thermal conductivity qualities, (Al_2O_3 coating) increases heat flow to the chip and workpiece. Rezende [15] used The turning tests carried out with CGI steel. Tools were utilized with uncoated aluminum oxide (3 layers) and multilayer coated (1 titanium dioxide layer and 3 aluminum oxide layers). The lowest temperature was achieved with the multilayer-coated, too—the temperature rises as the cutting speed increases.

2. Experimental procedure

2.1 Cutting Tool Tips

The four varieties of commercially available tungsten-based cemented carbide inserts are uncoated, (TiN coated), (TiN/TiCN Coated) (TiCN on the inner layer, TiN on the outer layer), and (TiN/ Al_2O_3 /TiCN) coated (the inside layer is TiCN, the intermediate layer is Al_2O_3 , and the outer layer is TiN). All of the inserts may be used to machine a variety of high feed rates and speeds for steels. The International Organization for Standardization (ISO) assigned the same geometry to all of the inserts, classified as SNMM 120412. Table 1 [16] shows four different features of cutting tools and mechanical and thermal qualities. The cutting tools are shown in Figure 1.

2.2 Workpiece Material

The experiments were done using workpiece material of AISI 1045 carbon steel with a length (of 300 mm) and diameter of (50 mm) divided into four regions, as shown in Figure 2. Table 2 and Table 3 show the workpiece material's mechanical properties and chemical composition, respectively.

Table 1: Some mechanical and thermal properties of cutting tools

Insert Code	Coating compounds	Total coating thickness(μm)	Thermal conductivity (cal/cm.sec. $^\circ\text{C}$)
H13A	Uncoated	----	97
GC1015	TiN	2	79
GC1525	TiN / TiCN	5	68
GC4035	TiN / Al_2O_3 / TiCN	12	38

Table 2: AISI 1045 Nominal Composition [17]

Si%	C%	P%	Mn %	S%
0.2	0.45	0.02	0.58	0.025

Table 3: Coating layer mechanical properties [18]

Coating layer	TiN	Al_2O_3	TiC
Modulus of Young(E)[Gpa]	250	340-400	450-496
Ratio of Poissons (ν)	0.25	0.23	0.19-0.24
Density(ρ)[kg/m ³]	4650	3780	4650-49000

2.3 Conditions of cutting

Turning the workpiece on a manually operated center was used for the machining tests. The lathe's cutting temperature (temperature at the cutting zone) was calculated using a thermal camera, and these numbers were recorded to determine the multilayer effect. Table 4 show the Cutting Conditions.

Table 4: Conditions of cutting

Type of material	AISI 1045
Cutting velocity (V_c)	56,88,112,141(mm/rev.)
Depth of cut (t)	1 (mm)
Feed rate (s)	0.065,0.08, 0.16,0.228(mm/rev.)

As a guide, use the following linear equation:

$$V_c = (\pi \times D \times N) / 1000 \quad (1)$$

Where: V_c : cutting velocity,m/min, D: workpiece's diameter, mm

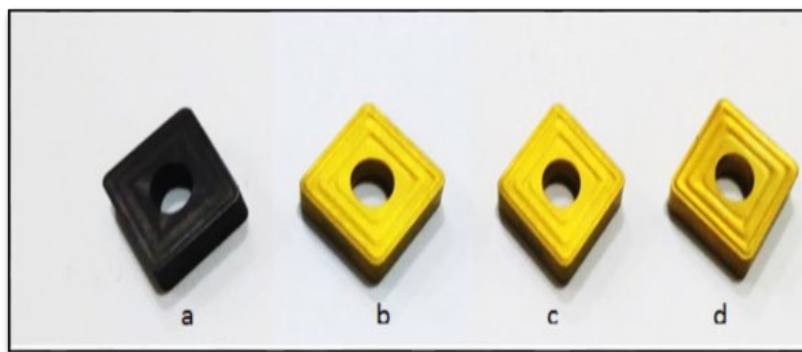


Figure 1: Cutting Tool Tips used in experimental work

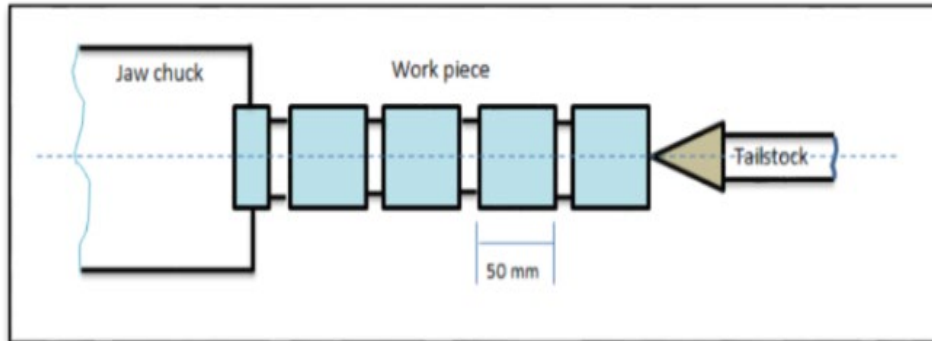


Figure 2: Workpiece dimensions

2.4 Experimental Setup

Temperature measurements were taken with an infrared thermal imaging camera to evaluate the tool temperature and prediction model. The temperature measurement instrument utilized was an infrared camera. [Models: Fluke Ti32], Figure (3). The Fluke Ti32 Thermal imagers are small, portable equipment. Some of the applications are preventive and predictive maintenance, repair verification, equipment troubleshooting, building inspections, remediation, restoration, and weatherization. The Ti32 imager is designed for the repair of industrial and commercial equipment. It contains high-performance (320 X 240) focal-plane array sensors and a 640 X 480 display that displays thermal and visual images. [19]. The lathe Center is equipped with an infrared camera system, as seen in Figure 4

The workpiece was carefully placed in the spindle's tool holder. Starting at the tooltip, the infrared camera is focused on this area. Figure 5 shows the focus of the thermal experiments. This area is a $(3 \pm 0.5 \text{ mm})$ tool tip.

Point the Imager at the object or region of interest for focusing and capturing an image. The Ti32 menu allows image storage and image setting adjustments. Each capture is saved as an image sequence. Because some of these frames are blocked by chips, only the images that clearly show the rake face are used. As shown in Figure 6. Each experiment was repeated more than (3) times, and the maximum reading was taken. The tool used an infrared camera to measure temperature distribution. The contour map was created to transmit the thermal image Quick Report from FLIR to a custom computer program (Smart View 3.1), as shown in figure 7.



Figure 3: Fluke Ti32 Thermal Imager



Figure 4: Set up of measuring temperature

3. Results and Discussion

The tests aim to compare the temperature variation of uncoated and multilayer-coated tools during machining. The machining tests were carried out by altering the cutting velocity and feed rates while maintaining a constant depth of cut. The difference in measured tool temperature for a certain feed rate of (0.065 mm/rev) at varying cutting velocities is clearly shown in Figure 8. The results show an increasing trend in tool temperature as cutting velocity increases, which is attributable to higher cutting power consumption as cutting velocity increases. As a result, the temperature rises for all four inserts. However, the (TiN/Al₂O₃/ TiCN) insert had the lowest tool temperature in each cutting velocity, by (40%) less than uncoated inserts, which had the highest temperature. Also, the blend shows a similar trend of (TiN/ TiCN), (TiN/Al₂O₃/ TiCN) inserts with a close tool temperature, especially at cutting velocity (88 m/min) and (112 m/min). This phenomenon explains the low effect of these types of coating and cutting velocity on the tool temperature.

Figure 9 shows the relationship between the cutting velocity and the tool temperature at a constant feed rate of (0.288 mm/rev). The results show that the temperature difference ranges of coated tools (TiN), (TiN/ TiCN), (TiN/ Al₂O₃/ TiCN) are lower than cutting tools without a coating of about (68 °C), (46 °C), (27 °C), respectively, at cutting velocity (56 m/min) and about (78 °C), (60 °C), (34 °C) when compared to uncoated tool at (141 m/min).

Figure 10 shows the relationship between the cutting velocity and the tool temperature at a constant feed rate of (56 m/min). Cutting tools of many kinds are used, and the tool's temperature rises as the feed rate rises. For all feed rates, the (TiN/ Al₂O₃/ TiCN) insert had the lowest tool temperature, with a temperature reduction of (41%) less than uncoated inserts, which had the highest temperature.

Because of the tool–chip contact length increase, tool temperature increases with increased feed rates while cutting velocity remains constant at ($v=141$ m/min) in all types of employed cutting tools, as illustrated in Figure 11. This is because heat energy increases when the tool–chip contact surface area increases. The results demonstrate that the temperature of coated cutting tools (TiN/ Al₂O₃/ TiCN), (TiN/ TiCN), and (TiN) is lower than the one of uncoated cutting tools in different ranges. The temperature difference for these cutting tools was about (70 °C), (43 °C), and (23 °C), respectively, at feed rates (0.065 mm/rev) and about (87 °C), (68 °C), and (42 °C), compared with the uncoated tool at a feed rate of (0.288 mm/rev) at constant cutting velocity. The curve shows a close point with a feed rate of (0.16 mm/rev.), which is slightly different from the general behavior of previous figures. The answer to that is the acceptable measuring factors and the increased thermal conductivity of the coatings, which affect the tool temperature.



Figure 5: Position of measuring temperature

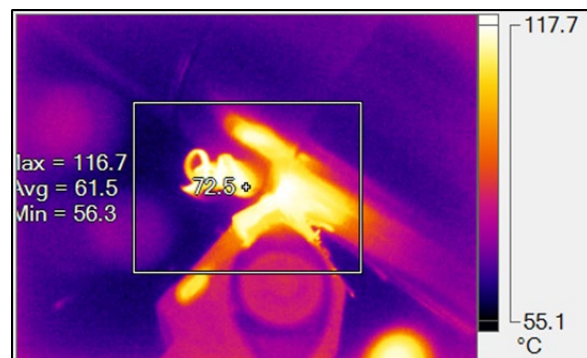


Figure 6: Temperature monitoring for a processing regime

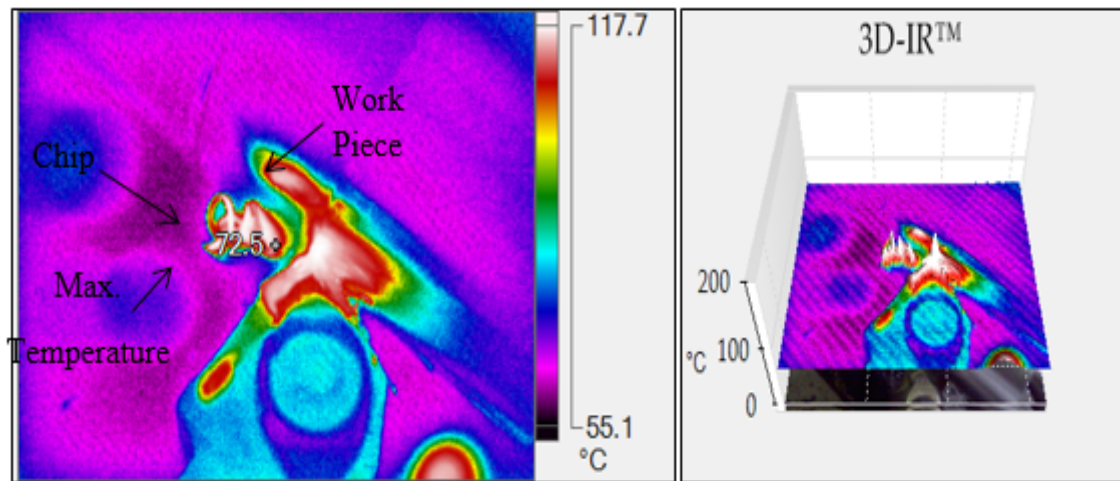


Figure 7: The IR image obtained in cutting process

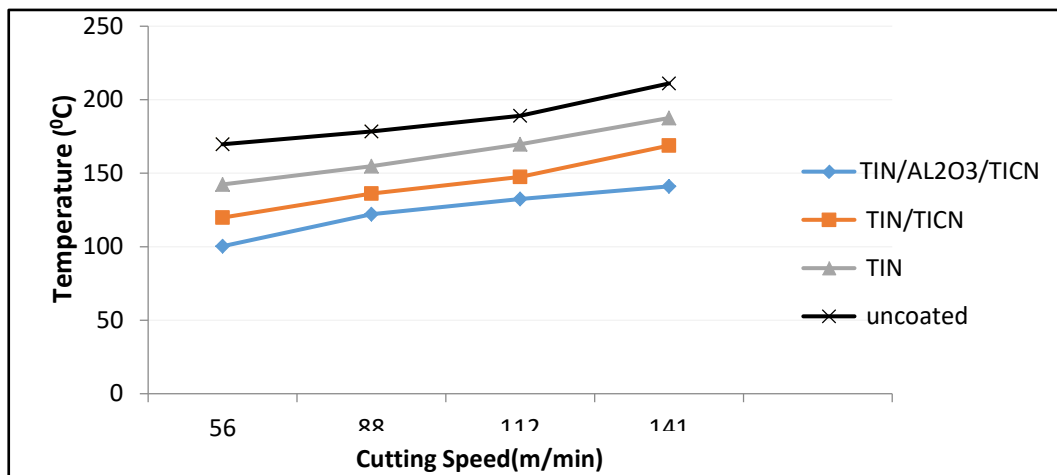


Figure 8: The relationship between cutting velocity and tool temperature for un coated and multilayer coated inserts at a constant feed rate of ($f=0.065$ mm/rev)

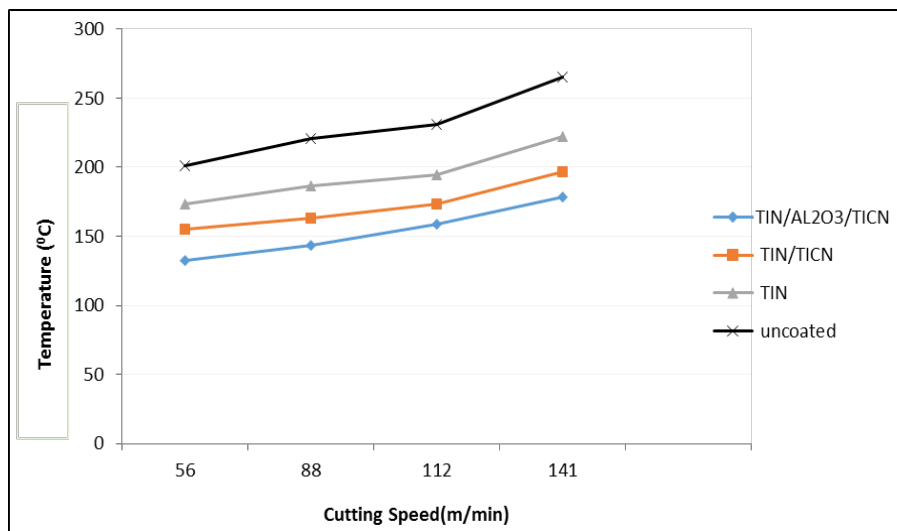


Figure 9: The relationship between cutting velocity and tool temperature for un coated and multilayer coated inserts at a constant feed rate of ($f=0.288$ mm/rev)

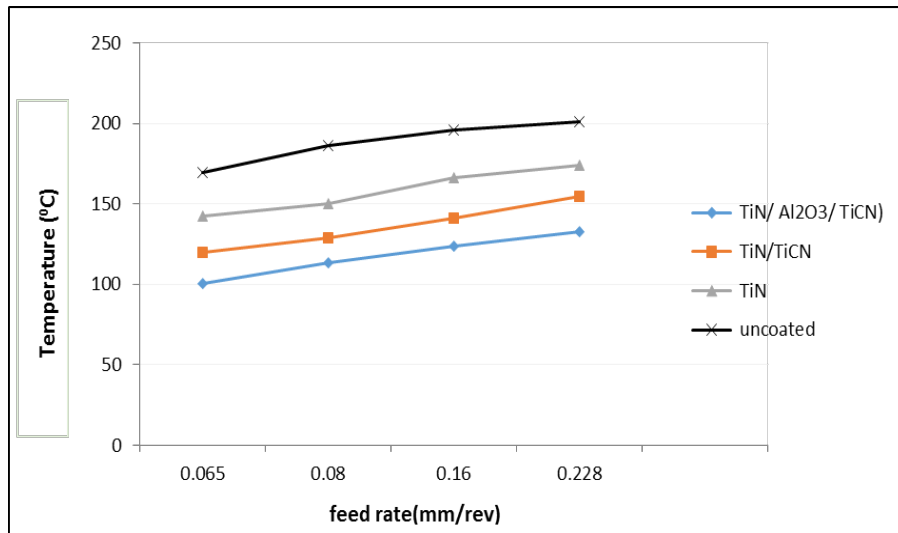


Figure 10: The relationship between cutting velocity and tool temperature for un coated and multilayer coated inserts at a constant cutting velocity of ($v=56$ m/min)

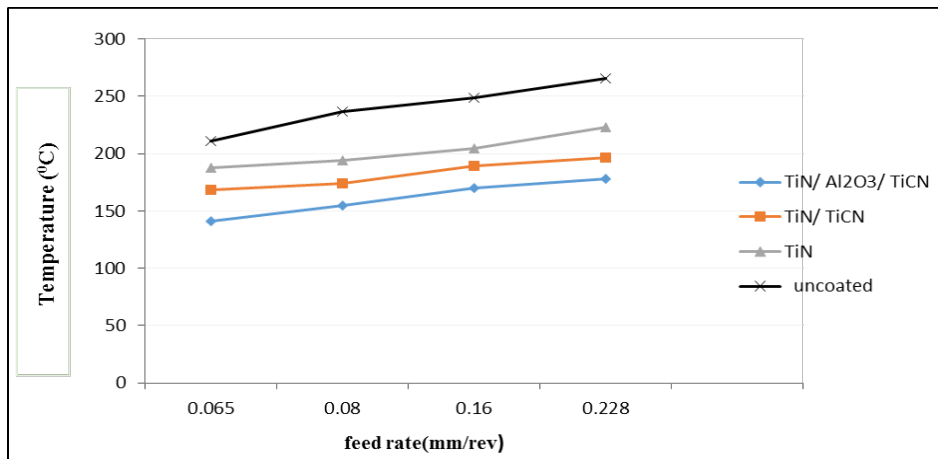


Figure 11: The relationship between cutting velocity and tool temperature for un coated and multilayer coated inserts at a constant cutting velocity of ($v=141$ m/min)

4. Conclusions

From the experiment done in this study, the following precise conclusions can be drawn:

- 1 An increase in the cutting velocity from (56 to 141) m/min was observed. As a result, the temperature of the tool increased by (43%) of (TiN/ Al₂O₃/ TiCN), (39%) of (TiN/ TiCN), (36%) of (TiN), and (32%) of uncoated tool temperature.
- 2 An increase in the cutting feed rates (0.065 to 0.288) mm/rev resulted in an increase in the tools temperature by (24%) of (TiN/ Al₂O₃/ TiCN), (22%) of (TiN/ TiCN), (18%) of (TiN) and (16%) of uncoated tool temperature.
- 3 Tool temperatures obtained for coated cutting tools are lower than uncoated ones, particularly for the three layers (TiN/ Al₂O₃/ TiCN) coating inserts. These were (32 %to 40%) lower than uncoated inserts at various cutting velocities and constant feed rates and lower by (34% to 40%) than uncoated inserts with various feed rates and constant cutting velocity.
- 4 Among all the cutting parameters mentioned, the cutting velocity influences the tool temperature rise during the cutting process.
- 5 Because of its quick response and ability to not affect temperature throughout the cutting process, infrared imaging is useful for detecting temperature in the cutting zone.

Author contribution

All authors contributed equally to this work

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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