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ANALYSIS OF CONTACT THERMAL RESISTANCE AND THE USE OF COATINGS ON HEAT TRANSFER IN CEMENTED CARBIDE METAL CUTTING TOOLS

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ABSTRACT

Objective: The objective of this study is to investigate the thermal behavior of coated cutting tools in industrial turning processes, aiming to enhance machining efficiency and prolong tool lifespan.

Theoretical Framework: The study is grounded in the concepts of heat transfer, thermally insulating coatings, and their impact on cutting tool performance. Key theories and models include thermal conductivity, thermal insulation, and heat dissipation mechanisms.

Methodology: The research employs numerical simulation using the COMSOL® Multiphysics package to model transient heat transfer within coated tools and their holders. Thermal contact resistance at the tool-holder interface is also considered. Two coating configurations (Model 1 and Model 2) with different materials are analyzed, resulting in six simulation scenarios.

Results and Discussion: The simulations demonstrate significant temperature reductions in the coated tools compared to uncoated ones, with Model 2 showing the most substantial decrease. These findings indicate the effectiveness of thermally insulating coatings in mitigating heat generation and improving tool performance.

Research Implications: The study's findings have practical implications for the manufacturing industry, suggesting that the use of specific coatings can lead to higher cutting velocities and prolonged tool lifespan. These insights can inform decision-making in tool selection and process optimization.

Originality/Value: This research contributes to the literature by providing a detailed analysis of the thermal behavior of coated cutting tools under extreme temperatures. The study's innovative approach and practical implications offer valuable insights for improving machining processes and tool performance.

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Keywords: Coating, COMSOL®, Contact Resistance, Cutting Tool, Heat Transfer.

ANÁLISE DA RESISTÊNCIA TÉRMICA DE CONTATO E DO USO DE REVESTIMENTOS NA TRANSFERÊNCIA DE CALOR EM FERRAMENTAS DE CORTE DE METAL DE CARBONETO CIMENTADO

RESUMO

Objetivo: O objetivo deste estudo é investigar o comportamento térmico de ferramentas de corte revestidas em processos industriais de torneamento, visando melhorar a eficiência da usinagem e prolongar a vida útil das ferramentas.

Referencial Teórico: O estudo está fundamentado nos conceitos de transferência de calor, revestimentos termicamente isolantes e seu impacto no desempenho das ferramentas de corte. Teorias e modelos-chave incluem condutividade térmica, isolamento térmico e mecanismos de dissipação de calor.

Metodologia: A pesquisa utiliza simulação numérica usando o pacote COMSOL® Multiphysics para modelar a transferência de calor transiente dentro das ferramentas revestidas e seus suportes. A resistência térmica de contato na interface ferramenta-suporte também é considerada. Duas configurações de revestimento (Modelo 1 e Modelo 2) com diferentes materiais são analisadas, resultando em seis cenários de simulação.

Resultados e Discussão: As simulações demonstram reduções significativas de temperatura nas ferramentas revestidas em comparação com as não revestidas, sendo o Modelo 2 o que apresenta a diminuição mais substancial. Esses resultados indicam a eficácia dos revestimentos termicamente isolantes na mitigação da geração de calor e melhoria do desempenho das ferramentas.

Implicações da Pesquisa: As descobertas do estudo têm implicações práticas para a indústria de fabricação, sugerindo que o uso de revestimentos específicos pode levar a maiores velocidades de corte e vida útil prolongada das ferramentas. Esses insights podem informar a tomada de decisões na seleção de ferramentas e otimização de processos.

Originalidade/Valor: Esta pesquisa contribui para a literatura ao fornecer uma análise detalhada do comportamento térmico de ferramentas de corte revestidas em temperaturas extremas. A abordagem inovadora do estudo e suas implicações práticas oferecem insights valiosos para a melhoria dos processos de usinagem e desempenho das ferramentas.

Palavras-chave: COMSOL®, Ferramenta de Corte, Resistência de Contato, Revestimento, Transferência de Calor.

ANÁLISIS DE LA RESISTENCIA TÉRMICA POR CONTACTO Y EL USO DE RECUBRIMIENTOS EN LA TRANSFERENCIA DE CALOR EN HERRAMIENTAS DE CORTE DE METAL CARBURO CEMENTADO

RESUMEN

Objetivo: El objetivo de este estudio es investigar el comportamiento térmico de herramientas de corte recubiertas en procesos industriales de torneado, con el fin de mejorar la eficiencia del mecanizado y prolongar la vida útil de las herramientas.

Marco teórico: El estudio se basa en los conceptos de transferencia de calor, recubrimientos térmicamente aislantes y su impacto en el rendimiento de las herramientas de corte. Las teorías y modelos clave incluyen la conductividad térmica, el aislamiento térmico y los mecanismos de disipación de calor.

Metodología: La investigación utiliza simulación numérica con el paquete COMSOL® Multiphysics para modelar la transferencia de calor transitoria dentro de las herramientas recubiertas y sus soportes. También se considera la resistencia térmica de contacto en la interfaz herramienta-soporte. Se analizan dos configuraciones de recubrimiento (Modelo 1 y Modelo 2) con diferentes materiales, lo que resulta en seis escenarios de simulación.

Resultados y discusión: Las simulaciones muestran reducciones significativas de temperatura en las herramientas recubiertas en comparación con las no recubiertas, siendo el Modelo 2 el que muestra la disminución más sustancial. Estos resultados indican la eficacia de los recubrimientos térmicamente aislantes en la mitigación de la generación de calor y la mejora del rendimiento de las herramientas.

Implicaciones de la investigación: Los hallazgos del estudio tienen implicaciones prácticas para la industria manufacturera, sugiriendo que el uso de recubrimientos específicos puede conducir a mayores velocidades de corte y una vida útil prolongada de las herramientas. Estos conocimientos pueden informar la toma de decisiones en la selección de herramientas y la optimización de procesos.

Originalidad/Valor: Esta investigación contribuye a la literatura al proporcionar un análisis detallado del comportamiento térmico de herramientas de corte recubiertas en temperaturas extremas. El enfoque innovador del estudio y sus implicaciones prácticas ofrecen ideas valiosas para mejorar los procesos de mecanizado y el rendimiento de las herramientas.

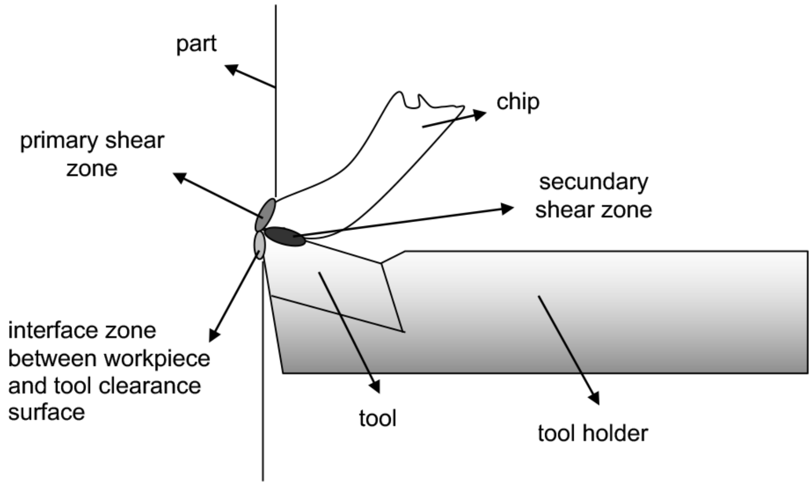
Palabras clave: COMSOL®, Herramienta de Corte, Recubrimiento, Resistencia de Contacto, Transferencia de Calor.

1 INTRODUÇÃO

The machining process, like other procedures involving significant material deformation, generates a considerable amount of heat. This heat is a crucial factor that significantly affects tool performance. The tool's geometry also plays a vital role, impacting the temperature distribution within the cutting zone (Carvalho, 2005), as show in Fig. 1. In the turning process, heat generation occurs in three key zones: the primary, secondary, and tertiary deformation zones. The main phenomena that generate heat in these zones are plastic deformation and friction (Dogu et al., 2006; Bhogal et al., 2022; Grigoriev et al., 2019). Such a study focuses on the secondary deformation zone, which is the contact point between the insert and the chip. This region exhibits high temperatures due to the small contact area and the high forces required to deform the workpiece (Pereira Guimarães et al., 2022; Kumar et al., 2022).

Figure 1

Zones of heat generation in a turning machining process



Source: Carvalho, S.R. (2005). Determinação do campo de temperatura em ferramentas de corte durante um processo de usinagem por torneamento (PhD thesis, Mechanical Engineering). Federal University of Uberlândia, UFU, Brazil, Uberlândia, MG.

The temperature generated at the contact between the insert and the chip is a common characteristic of the turning process. However, high temperatures can significantly reduce the insert's lifespan (Dimla, 2000; Lotfi et al., 2016; Ogedengbe et al., 2019). While buying a new insert does not significantly impact profitability, insert wear affects the entire process, including the workpiece's surface finish and stops for tool changes (Amigo et al., 2023; Antonialli et al., 2020; Das et al., 2022). Therefore, estimating cutting temperatures and understanding the parameters that affect them are crucial for better process control.

There are several methods to estimate cutting temperature in turning, including analytical, numerical, and experimental methods. García-Martínez et al. (2022) combined experiments and simulations to evaluate the temperature generated at the contact between the tool and the workpiece. However, their methodology was limited to uncoated inserts as they obtained temperature through natural thermocouples. Gupta et al. (2022) and Grzesik (2006) used finite element simulations to estimate cutting temperatures. Möhring et al. (2018) used analytical and numerical methods to estimate cutting temperatures and discovered that high cutting speeds can increase the temperature at the cutting tool's exit surface.

These studies highlight concerns about cutting temperature and use various methodologies to evaluate it. The different technologies being used to measure temperatures in machining include thermocouples, thermographic cameras, etc. Kovac et al. (2019) applied thermocouples to measure temperatures in machining. This means that there are several ways to measure and evaluate cutting temperature, and researchers are actively working to improve the understanding of this important aspect of the manufacturing process. It is important to continue to develop and refine these technologies to ensure accurate and reliable measurements of cutting temperature.

This emphasizes the need for more research on thermal aspects, not only to develop materials that can withstand high temperatures but also techniques for extending cutting tool lifespan (Carvalho, 2005). Such advances allow higher cutting speeds in machining operations while reducing tool replacement costs. The importance of temperature evaluation during cutting operations for understanding tool performance, wear, and lifespan is highlighted. Also, reducing lubricants and coolants is studied as they are a new trend in the field. While most past studies have focused on temperature distributions for uncoated cutting tools to improve lifespan (Zhao et al., 2018; Attanasio et al., 2010; Brito et al., 2009; Filice et al., 2007; Li et al., 2023), an alternative approach is to apply thermally insulating coatings to reduce wear (Liu et al., 2021). Research on such coatings includes analytical and numerical simulations. This may offer practical solutions to companies with limited experimental resources.

2 OBJECTIVES

This study has two objectives. Firstly, the main one is to establish the effectiveness of employing coatings within the turning process by addressing challenges related to direct and inverse heat transfer. This validation entails a meticulous comparison between computed results and empirical data derived from a controlled experiment conducted by Carvalho (2005) and Carvalho et al. (2006), as well as real-world turning machining scenarios. Secondly, the specific objective is to conduct an extensive literature review on direct and inverse heat transfer problems, with an emphasis on Contact Thermal Resistance (CTR). This may allow promoting disclosure of research findings to serve as pillars for subsequent investigations and developing expertise in COMSOL® Multiphysics software. Cumulatively, these objectives converge to facilitate a comprehensive exploration of the ramifications of coatings on the turning process and their consequential implications for heat transfer phenomena.

3 MATERIALS AND METHODS

This study aims to examine the thermal effects of these coatings on cemented carbide cutting tools. The methodology involves modeling the micron-thick coating on the tool using either a three-dimensional (3D) numerical model or a one-dimensional (1D) representation. Defined boundary conditions guide heat flux and temperature profiling. A significant contribution is the three-dimensional modeling of coated tools, which includes multilayer coatings and uses COMSOL® software to represent micron-scale coatings. Additional improvements include incorporating thermal contact resistance, temperature-dependent properties, and empirical correlations (Bergman et al., 2020) for convection heat coefficients, all included in the COMSOL® framework.

To facilitate a thorough analysis, a set of six simulations, designated as "Cases," are conducted in this study and shown below. Cases 1 and 2 encompass Model 1, that is, coating layers of Titanium Nitride (TiN), Aluminum Oxide (Al_2O_3), and Titanium Carbide (TiC), accompanied by contact thermal resistance. Meanwhile, Cases 3 to 6 correspond to Model 2. It features coating layers of TiN, Al_2O_3, and Titanium Carbonitride (TiCN), with variations in the presence of contact thermal resistance:

Model 1:

. Case 1: Uncoated condition with Contact Thermal Resistance.

. Case 2: Coated condition (TiN, Al_2O_3, and TiC) with Contact Thermal Resistance.

Model 2:

. Case 3: Uncoated condition with Contact Thermal Resistance.

. Case 4: Coated condition (TiN, Al_2O_3, and TiCN) with Contact Thermal Resistance.

. Case 5: Uncoated condition without Contact Thermal Resistance.

. Case 6: Coated condition (TiN, Al_2O_3, and TiCN) without Contact Thermal Resistance.

For the validation of the inverse problem, three distinct Test Cases are conducted. Each technique was applied to the same controlled experiment utilized for validating the direct problem. Experimental temperatures collected by thermocouples T1 and T2 serve as input data for the estimation of heat flux using each inverse method, followed by a comparison between the estimated and experimental fluxes. The results in Fig 2 highlight satisfactory estimations by all three techniques, closely aligning with experimental outcomes.

Figure 2

Comparison between experimental and estimated heat flux by the 3 techniques

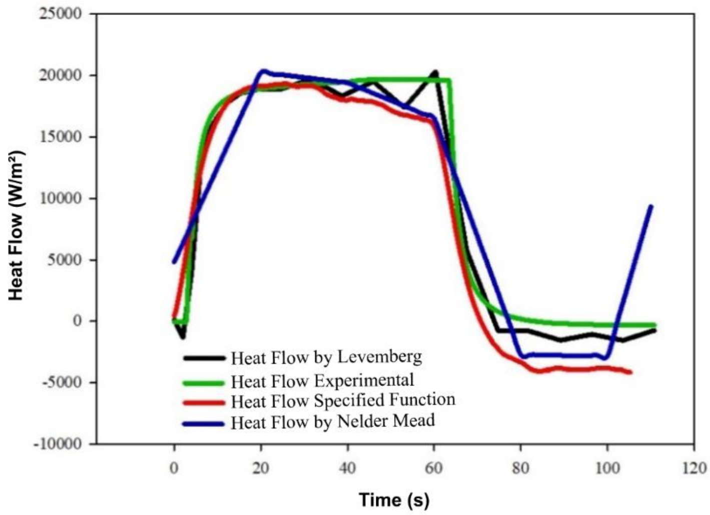
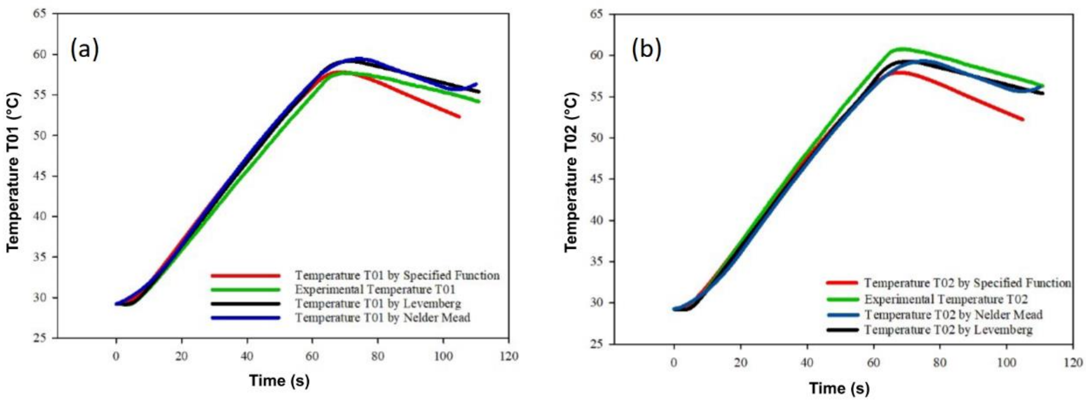


Fig. 3(a) and 3(b) further demonstrate a commendable correspondence between numerical temperatures, estimated by each technique, and Carvalho (2005) and Carvalho et al. (2006) experimental temperatures for T1 and T2 thermocouples. Notably, validation exclusively considers heat flux and estimated temperatures within the period during which the heater was active, up to 63.27 s.

Figure 3

Comparison of the numerical temperatures obtained through the fluxes estimated by each technique and the experimental one: (a) Thermocouple T1; (b) T2 thermocouple

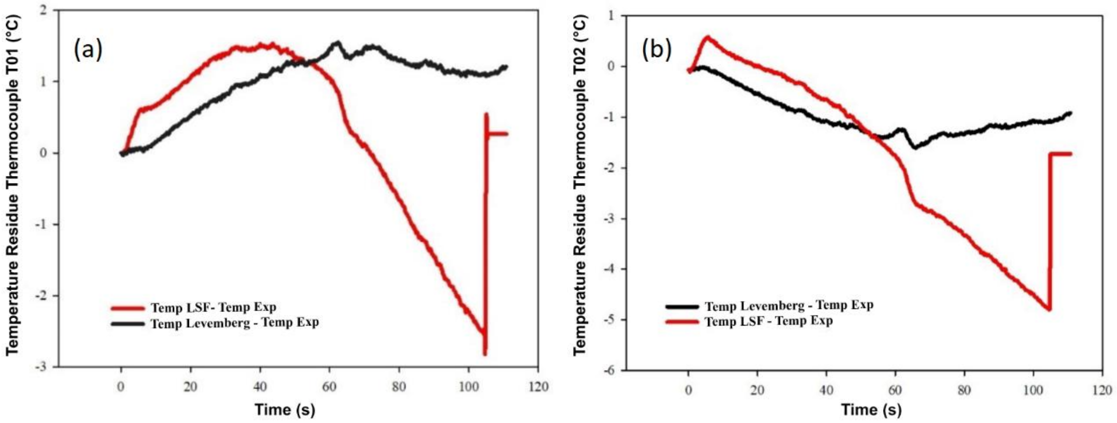


To emphasize the temperature comparison, the disparity between numerical and experimental data is depicted through Fig. 4(a) and Fig. 4(b). The deviations related to the

Nelder-Mead comparison were omitted due to the substantial computational demands of this method. Adjustments were made to the time step to mitigate extended simulation time and increased computational costs. It is noteworthy that within the relevant timeframe, temperature residuals remain below 3 °C, signifying a commendable alignment between numerical and experimental data concerning the LM and LSF approaches.

Figure 4

Temperature residual between LM and LSF in relation to experimental data for (a) Thermocouple T1 and (b) T2 thermocouple



A notable challenge in thermal analysis of machining processes lies in accurately determining the heat flux at the contact interface between the workpiece and cutting tool. To address this, the work by Carvalho (2005) and Carvalho et al. (2006) is introduced, wherein experimental tests were conducted to estimate the heat flux at the interface, crucial for the current study. Carvalho (2005) and Carvalho et al. (2006) utilized a conventional mechanical lathe IMOR MAXI - II - 520 - 6CV and an HP75000 Series B data acquisition system with an E1326B voltmeter controlled by a computer to observe heat transfer during turning, as shown in Fig. 5. Eight K-type thermocouples were strategically placed on accessible regions of the tool, toolholder, and wedge surfaces for experimental temperature measurement, as detailed in Table 1 based on defined coordinate axes from Fig. 6.

Figure 5

Illustration of the experimental scheme used to estimate the heat flux

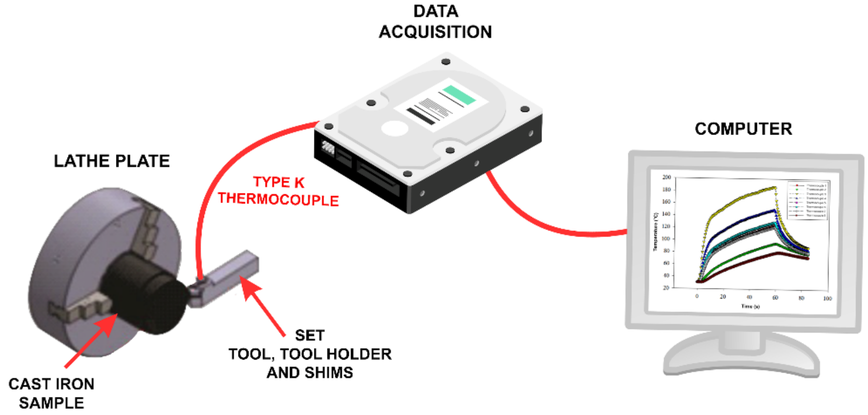


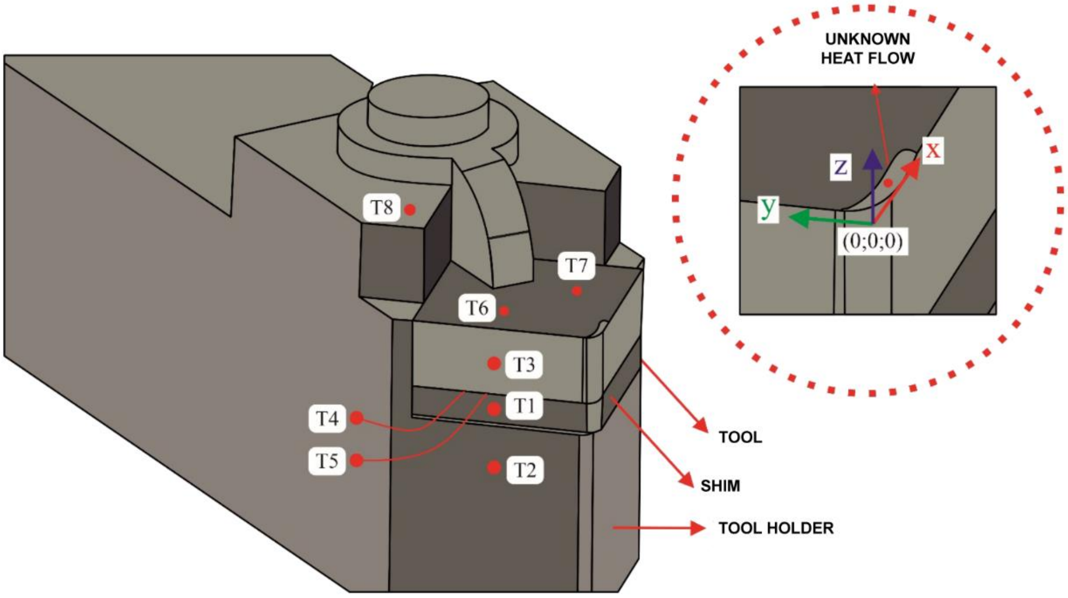
Table 1

Position of the thermocouples in the tool set, shim, and tool holder

Thermocouple position	1	2	3	4	5	6	7	8
X [mm]	0.000	0.000	0.000	4.490	6.528	7.222	9.512	5.300
Y [mm]	6.450	7.250	3.950	4.116	6.579	4.740	1.715	14.550
Z [mm]	-6.560	-11.660	-2.130	-4.840	-4.840	-0.010	-0.010	5.390

Figure 6

Positioning of thermocouples T1 to T8 on the tool set, shim, and tool holder



A SANDVIK® cemented carbide cutting tool (ISO SNUN 12 04 12 H1P - K10) was affixed to an ISO CSBNR 20K12 tool holder (SANDVIK® COROMAT) for experimentation. The choice of this tool was driven by its uncomplicated octahedral geometry without holes, aiding numerical modeling. The material for machining, ABNT FC 20 EB 126A gray cast iron, was selected due to its compatibility with the negative tool and its tendency to produce powdered chips, minimizing chip tangling and thermocouple damage. Tests were conducted on a 77 mm diameter and 77 mm long gray cast iron bar. Within the study by Carvalho (2005) and Carvalho et al. (2006), various tests explored the impact of machining conditions like feed and cutting speed on chip-tool interface temperature. In this context, the present work focuses on a single test, specifically Trial MDP2a, from Carvalho et al.(2006)'s research, with parameters outlined in Table 2. This test involved approximately 60 s of heating duration during the tool's contact with the workpiece, with data acquisition occurring at intervals of 0.5 s.

Table 2

Machining parameters used in the MDP2a test

Parameters	Values
Initial diameter (mm)	77.0
Machined length (mm)	77.0
Advance (mm/revolution)	0.138
Cutting speed (m/min)	135.47
Cutting depth (mm)	5.0
Rotation (rpm)	580

Source: Carvalho, S.R., Lima e Silva, S.M.M., Machado, A.R., & Guimarães, G. (2006). Temperature determination at the chip–tool interface using an inverse thermal model considering the tool and tool holder. Journal of Materials Processing Technology, 179(1), 97-104. https://doi.org/10.1016/j.jmatprotec.2006.03.086

It is noteworthy that a difference between the work of Carvalho (2005) and Carvalho et al. (2006) and the work of Ferreira et al. (2018), which is being the main work considered for the development of the current work, is the modeling of the contact area between the tool and the workpiece is done in a more realistic way.

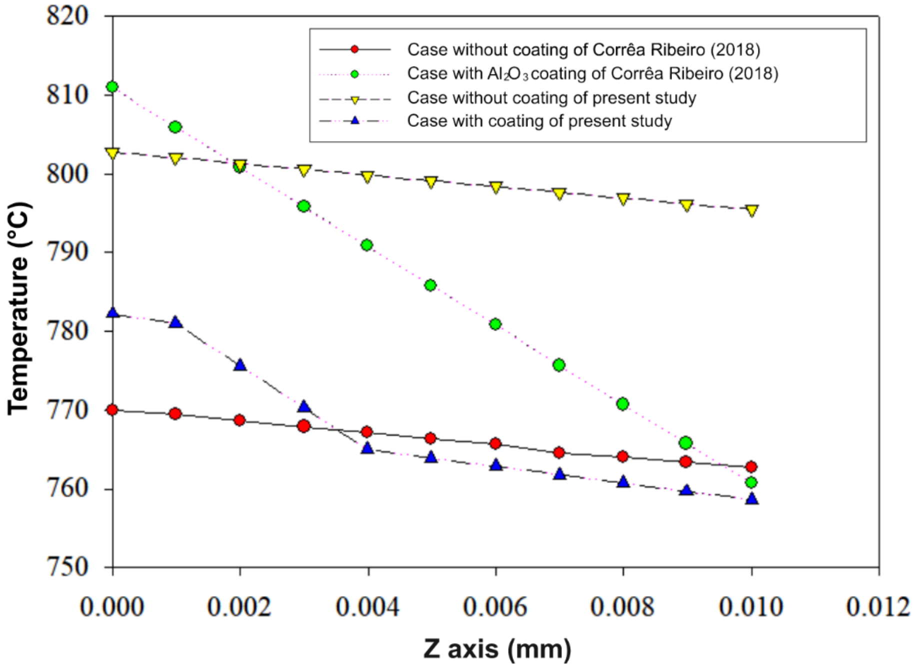
4 RESULTS AND DISCUSSION

Analysis of temperature variation between thermocouples and numerical probes comparing Cases 1 and 2 (Model 1) was conducted through the simulations proposed for Model 1, temperature curves were obtained in the analysis thermocouples. The results of Case 2, which considers the three layers of coating, where it is possible to observe that the temperature variation becomes greater due to the use of these coatings. This result is relevant, showing that the coatings retain more heat on the upper face of the tool and thus preventing it from passing to the substrate and reducing the tool's useful life.

Analyzing these comparisons between the temperatures of these three thermocouples, no relevant result was noticed as was observed in the analysis of the numerical probes. For this reason, the results of the probes began to be observed with more attention, and therefore a comparison was made of the values of the probes in both Cases 1 and 2 of this work with the values of the probes analyzed by Correa Ribeiro (2018). Fig.7 illustrates this comparison.

Figura 7

Comparison of temperatures in the coating, calculated in numerical probes, for t = 57 s, between this work and the work of Comparison of temperatures in the coating, calculated in numerical probes, for t = 57 s, between this work and the work of Correa Ribeiro (2018)



Source: Adapted from Correa Ribeiro, C.A. (2018). Análise da influência térmica de revestimentos e resistência de contato em ferramenta de corte de torneamento usando o COMSOL® [Analysis of the thermal influence of coatings and contact resistance in turning cutting tool using COMSOL®] (PhD thesis, Mechanical Engineering). Federal University of Itajubá, UNIFEI, Brazil, Itajubá, MG.

Figure 8

Position of analysis points A, B and C

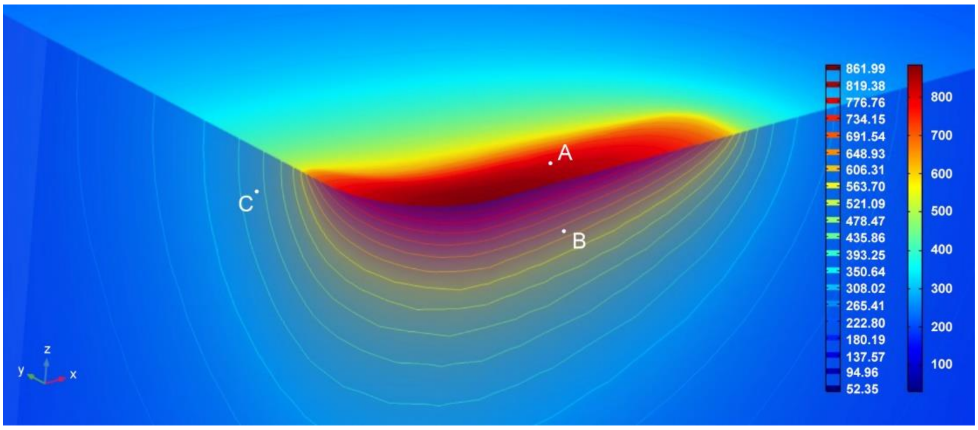
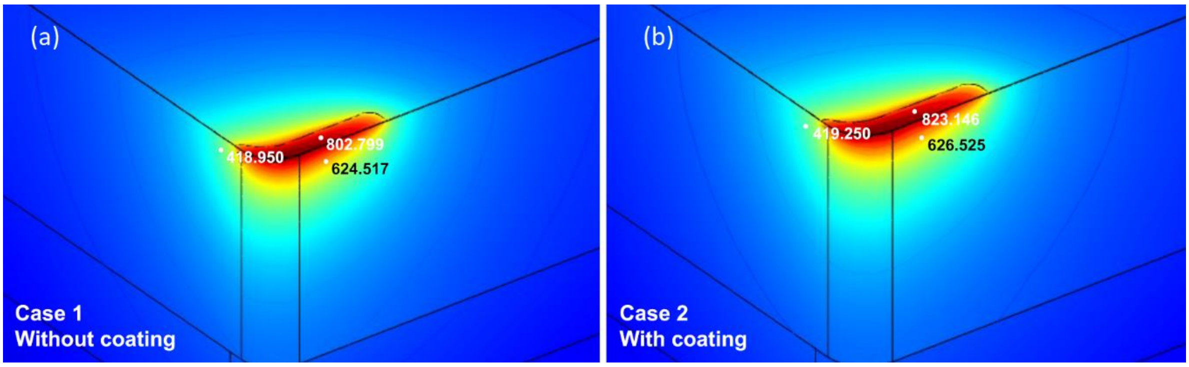


Figure 9

Temperature fields and temperatures of the three points between Cases 1 and 2 at time t = 57 s: Case 1 (No Coating); and Case 2 (With Coating)



Through this comparison, it was possible to validate the effectiveness of using the three layers of coating, with the aim of reducing heat transfer from the contact area to the rest of the cutting tool, Figure 8 shows the position of analysis points . It was observed in Fig. 9 that, as in the case considering an Alumina (Al_2O_3) coating by Correa Ribeiro (2018), Case 2 of this work presented a greater variation in temperature along the probes than the case without coating. These results agreed with the numerical results obtained by Correa Ribeiro (2018), and it was still possible to notice a variation of approximately 23.64°C between probe R00 and probe R10 (Table 3), in Case 2, which considers a multilayer coating of TiN, Al_2O_3 and TiC with a thickness of 10 μm. It was also possible to observe that the region of the blue curve in Fig. 9 (a), which comprises from z = -0.001 mm to z = -0.004 mm, representing the region of the Alumina Oxide (Al_2O_3) material coating, had a similar drop to the temperature drop of Correa

Ribeiro (2018) who used only an Al_2O_3 coating, represented by the green curve on the graph, as expected.

To validate once again the thermal influence of the coating on the heating of the substrate in Case 2, in addition to the use of Fig. 8, two distinct points were analyzed in the region near the contact area and one point above the tool-piece contact area. These three points, called A, B and C, along with the temperature field analyzed at time t = 57 s are illustrated in Fig. 8, while the coordinates of these three points are presented in Table 3.

Table 3

Coordinates of points A, B and C

Coordinates	Point A	Point B	Point C
X	1.500	1.434	0.000
Y	0.250	0.000	1.445
Z	0.000	-0.376	-0.311

An analysis of the temperature of these three points at time t = 57 s was conducted to verify the temperature variation between Cases 1 and 2. Fig. 9 shows the temperature field in the region of the tip of the tool and the temperatures of each point in each case at time t = 57 s. To facilitate the comparison between temperatures, Table 4 is presented.

Table 4

Temperature values, in Celsius, in the set for the instant of time t = 57 s

Analysis points	With coating	Without coating
Point A	823.15	802.80
Point B	626.52	624.52
Point C	419.25	418.95

In Case 2 the temperature at the three points was higher than in Case 1, and in addition, the temperature variation between the cases at point A, which is located precisely in the tool-piece contact area and at the top of the coating layers, was the greatest among the three points. Thus, it can be stated that the effect of using the three layers of coating was once again proven.

Temperature values captured by eleven vertically positioned thermocouples within the interface between the cutting tool and the workpiece, extending to a depth of 12.88 mm within the cutting tool. Notably, the observation of minimal temperature variation among the eleven thermocouples in Case 3 underscores efficient heat transfer through the tool.

The outcomes of Case 4, encompassing the three coating layers. Here, it becomes evident that the introduction of these coatings results in increased temperature variation. This significant finding suggests that the coatings effectively trap more heat on the tool's upper surface, thereby impeding its transmission to the substrate and consequently extending the tool's operational lifespan.

To facilitate a comparison among the examined thermocouples, graphs depicting the temperature contrasts for thermocouples T1 to T11 of Model 2 between Cases 3 and 4. Through this comparison among the thermocouples, the effectiveness of employing three coating layers to mitigate heat transmission from the contact region to the broader cutting tool structure has been validated. Nevertheless, a noteworthy observation pertains to the outcome of the thermocouple T1 comparison. Contrary to expected results, the presence of the coating did not yield the anticipated temperature elevation at the tool tip (the contact interface between the tool surface and workpiece), which theoretically should occur due to the insulating properties of the coating leading to reduced heat transfer. This discrepancy can be attributed to the utilization of the Thin Layer tool in modeling the coating within Model 2, as previously explained, which employs a 1D mesh to represent the coating. Influence of Contact Thermal Resistance on Temperature Variation between Coated and Uncoated Cases (Cases 3 to 6). To assess the significance of Contact Thermal Resistance in thermal simulations, temperature comparison graphs across each thermocouple, spanning T1 to T11 of Model 2. Through the comparisons, it becomes evident that the incorporation of Contact Thermal Resistance (CTR) within thermal simulations significantly influences the thermal curve values during the turning process. Notably, it is discernible that, apart from the overall higher temperatures observed throughout the process in Cases 3 and 4 - indicative of a more realistic simulation approximation - the divergence between the temperature curves in these cases has also magnified. This augmented temperature gradient among the curves underscores the thermal insulating effect introduced by CTR within the simulation.

One of the fundamental functions of the coating is to retain heat generated from chip shearing and friction between the cutting tool and the workpiece. By fulfilling this function, the heat transferred to the tool substrate is effectively reduced. The impact of the coating on substrate heating can be assessed through the temperatures derived from vertical analyses facilitated by thermocouples T1 to T11.

To assess the coating's effect on temperature attenuation during the penetration of both the coating and cutting tool, a comparison was conducted between temperatures calculated by the 11 thermocouples in Case 4 and their corresponding counterparts in Case 3. Similarly, a comparison was drawn between temperatures in Case 6 and Case 5.

The results indicate that, in instances involving coatings, there is a discernible reduction in temperature along the vertical analysis compared to cases without coatings. Notably, at time step t = 57 s, akin to the previous subsection of the Results, Case 6 exhibited significant temperature reductions within the assembly. Specifically, substantial reductions of 70.69 °C and 61.19 °C were observed for thermocouples T3 and T4, respectively, when juxtaposed with Case 5, the uncoated scenario.

When introducing the factor of Contact Thermal Resistance, the presence of the coating in Case 4 yielded even more pronounced temperature reductions within the assembly, amounting to 199.94 °C and 169.06 °C for thermocouples T3 and T4, respectively, compared to Case 3, which lacked a coating.

5 CONCLUSIONS

This study aimed to assess the temperature field in turning cutting tools with and without coatings, scrutinizing cutting and tool heating mechanisms. The subsequent conclusions arise from the numerical results obtained for the heat transfer thermal model in both coated and uncoated cutting tools. The simulations comprehensively evaluated the effects of coating and Contact Thermal Resistance (CTR) through the study of six Cases, two of which disregarded CTR. These simulations closely emulate actual turning operations, calculating temperatures at 0.5 s intervals. The derived temperature values were presented graphically to facilitate comparison and discourse on the efficacy of coatings. Numerical temperatures were validated against experimental values from the literature to affirm the accuracy of the direct method. Deviations were within 4.73%. The inverse method was also validated to identify the most effective approach for solving the thermal problem, with Levenberg-Marquardt's method offering the optimal cost-benefit ratio (Marquardt, 1963; Levenberg, 1944).

The research outcomes focused on two distinct modeling approaches for coating analysis: Model 1, with a three-dimensional (3D) domain, and Model 2, which employed a simplified one-dimensional (1D) mesh representation through the COMSOL® Thin Layer tool. The cases, denoted as Cases 1 to 6, encompass diverse coating arrangements and conditions, including considerations of Contact Thermal Resistance (CTR).

The results highlighted the efficacy of incorporating coating layers to control heat transfer. Model 1- Case 2, characterized by three coating layers, the temperature variation was minimally intensified, underscoring their capacity for heat retention. Model 2 - Case 3 exhibited efficient heat transfer through the tool, featuring minimal temperature fluctuations among distributed thermocouples. Furthermore, the integration of Contact Thermal Resistance in both models amplified the coating impact and exposed temperature discrepancies. Thus, reassuring its role in thermal insulation.

The research pointed out the intricate interdependence among coating configurations, contact thermal resistance and temperature distribution within the cutting tool assembly. The findings showed that the effectiveness of coatings in decreasing heat transfer, while the influence of Contact Thermal Resistance on temperature profiles was evident, providing insights for enhancing tool performance and extending longevity.

Comparative analysis of temperature curves across the six studied cases revealed that the applied coating layer on the hard metal tool, in both Model 1 and Model 2, yielded satisfactory results during continuous cutting. A temperature variation of approximately 24°C was noted in Case 2, implying a 3% temperature reduction due to TiN, Al2O3, and TiC coatings. A more substantial reduction of around 200 °C was observed in Case 4, indicating a remarkable 38.6% temperature decrease at an internal analysis point within the assembly.

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