Abstract

Machining tools' longevity and optimal performance are prevalent problems in manufacturing. Instrument failure can result in significant financial losses, especially for small-scale manufacturers. Thus, this paper investigates the effects of temperature on the cutting edge to guide the design of effective cutting tools and processes. An integrative literature review was used to compile relevant insights from different researchers. Four articles were sourced from Google Scholar using appropriate selection criteria. An assessment of the findings in the papers indicated two major effects of temperature on the cutting edge: wear and thermal cracking. The former is due to the reduced hardness and yield strength, while the latter originates from the thermal shocks and stress imbalance caused by cyclical heating and cooling.

Keywords: Cutting edge, temperature, heating, cooling, wear, thermal cracking.

Introduction

Machining is among the most important processes in manufacturing, especially in metal works. The main underlying objective is to cut out products and parts with high precision or remove unwanted material from workpieces. The machined components must also have good surface finishes and accurate dimensional tolerances (Ogedengbe et al. 1). These requirements necessitate specific cutting tool and machining process attributes. For example, Kiprawi et al. state that a precise surface finish normally demands high-speed machining to maximize the surface integrity's consistency (1). While such approaches achieve quality products, they pose an inherent risk to cutting tools.

The machining process naturally generates heat, which is amplified at high speeds. The heat is typically concentrated on the cutting edge/ zone (Ogedengbe et al. 1). As illustrated in Figure 1, the shear-plane, workpiece-tool, and chip-tool interfaces are the primary sources of heat at the cutting zone (Kumar, Amarnath, and Kumar 193). The high temperature is detrimental to the integrity of the cutting edge and the tool. For instance, Ueda reports that heat increases the wear rate, reducing the tool's usable life (334). Furthermore, the temperature can compromise a workpiece's integrity, such as the surface roughness, hardness, and residual stress (Ueda 334; Ogedengbe et al. 1). These effects can result in significant financial losses for manufacturing industries, necessitating elaborate responsive measures. Owing to the extensive effects of heat on the machining process, this research paper focuses on the impact on the cutting edge.

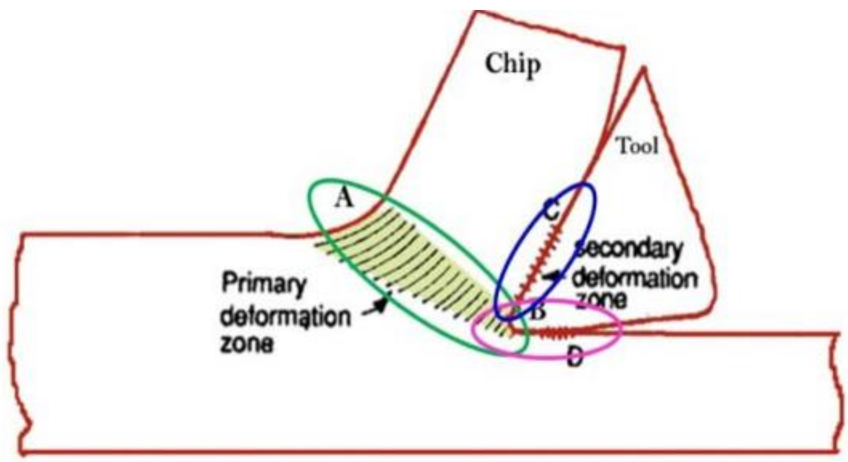

Figure 1: Sources of heat during the machining process (Source: Kumar et al. 193)

Literature Review

Researchers have extensively studied the cutting heat phenomenon over the years. The bulk of literature focuses on the sources and extent of heat and the effects on machined products. For example, Czan et al. report that the maximum temperature is experienced at the tool rake face at and around the cutting edge (66). They also observe that a high-temperature gradient in the machine substrata increases the risk of high tensile residual stresses. Sato et al. advance this claim by illustrating that cutting temperature is greater during down milling than up milling of the titanium alloy Ti-6Al-4V (1). Abukhshim, Mativenga, and Sheikh link the temperature at the cutting tool-workpiece interface to the cutting speed (787). Specifically, a high cutting speed reduces the workpiece temperature but elevates the contact temperature. Kiprawi et al. support this premise by arguing that high milling speeds increase cutting tool temperature with detrimental effects (1). Haddad et al. also report that machining parameters, particularly cutting distance, cutting speed, and feed speed, contribute to the machining temperature (1). These findings indicate that while the heat sources are similar in machining processes, the temperature effects on the tool and workpiece differ.

Therefore, the heating phenomenon in the machining process is well-researched. Individual studies, such as Ogedengbe et al., also elucidate the effects of temperature on cutting tools. These discussions relate heating to the cutting tool's hardness and heat resistance. However, specific insights into the direct impact on the cutting edge are relatively limited. Furthermore, studies compiling empirical findings on the cutting-edge dynamics during heating are inadequate, creating a research gap. Therefore, this article collects evidence from literature to elucidate the specific effects of temperature on the cutting edge and the impact on tool performance.

Methodology

The research was based on an integrative literature review to determine the reported effects of temperature on the cutting edge. Google Scholar was used as the main database for the article search. The search phrases "cutting edge temperature," "machining process," and "high temperature," and the Boolean operator "AND" were used. Twenty articles were initially identified and checked for relevance to the research topic. The inclusion criteria were articles published in the last 15 years by reputable journals and conferences and directly addressing the research topic. Each paper's abstract and conclusion were skimmed to determine compliance with the inclusion criteria. This process reduced the number of applicable articles to five. The selected papers were reviewed in detail, and their findings were tabulated and compared. The insights were then compiled to elucidate the specific effects of temperature on the cutting edge.

Results and Discussion

The literature review identified three main cutting edge phenomena associated with machining temperature: wear, thermal shock, and thermal cracking. These outcomes directly contribute to reduced machining tool performance and useful life.

Wear

Cutting tool life directly depends on the extent of wear resistance at the cutting edge. The temperature rise associated with machining/ cutting heat is primarily responsible for wear (Kareem and Daramola 36). This effect is mainly associated with the cutting edge length (Sonia, Mehta, and Upadhyay 38). Specifically, a smaller cutting edge concentrates the machining heat proximal to or at the cutting edge, reducing the yield strength and increasing the wear rate. The dislocation movement in metals at elevated temperatures causes the decline in yield strength by facilitating relatively easier plastic deformation. The low yield strength, coupled with the compromised hardness, is primarily associated with abrasive wear. Furthermore, increasing the cutting speed aggravates the temperature-induced wear by increasing the load on the cutting edge. Conversely, a longer cutting-edge results in a more uniform heat distribution over the cutting surface (Jain et al. 38). The regular heat distribution slows the reduction of yield strength and hardness, minimizing the abrasive wear rate. However, friction heating may still pose a significant problem for wear resistance. These findings illustrate that increased temperature contributes to the cutting edge's wear, compromising tool performance.

Thermal Shock and Cracking

High temperatures are a leading contributor to mechanical and structural failure on the cutting edge. Researchers mainly link heat with thermal shock and cracking at the cutting edge (Cep et al. 293; Le Coz and Dudzinski 12). The cutting-edge experiences rapidly varying temperatures during operation. Specifically, the surface is alternately heated during cutting and cooled when the tool exits the cut, loading the edge with cyclical temperature shocks. These effects are more severe at high cutting speeds, as illustrated in Figure 2 (Le Coz and Dudzinski 12). Figures 3 and 4 capture the cutting-edge temperature evolution during one cutting cycle and the temperature and thermal shock developments with cutting speed, respectively. The thermal shocks vary the tension and pressure stress on the surface layers (Cep et al. 293). These changes result in microscopic fractures on the cutting edge, which can induce brittle failure.

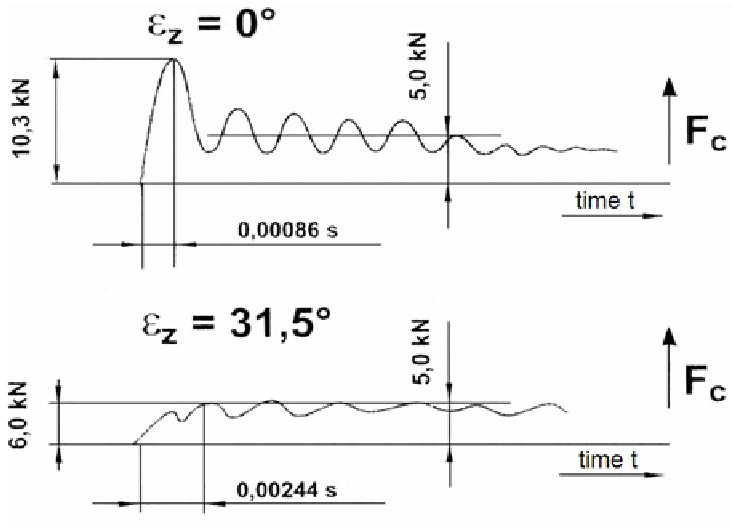

Figure 2: The measured cutting force increases with the time of cutting-edge entrance (cutting speed) and the bite angle ε_z. If the cutting speed is high, the time is assumed to be zero, and the mechanical shock peaks (Source: Cep et al. 293)

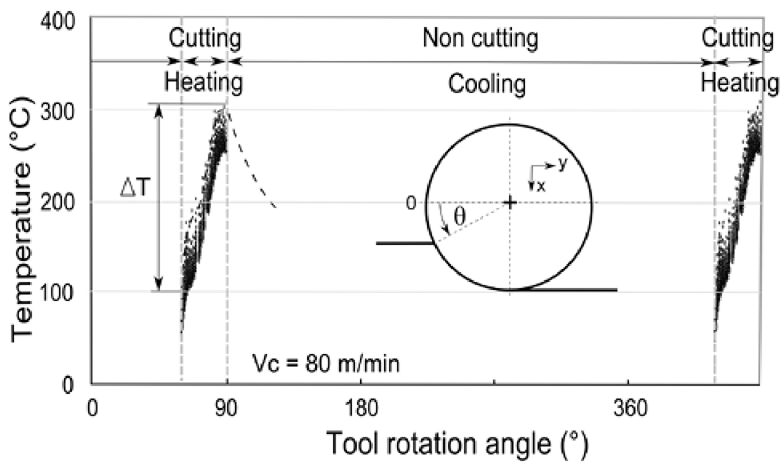

Figure 3: The cutting-edge temperature evolution during one cutting cycle (Source: Le Coz and Dudzinski 11)

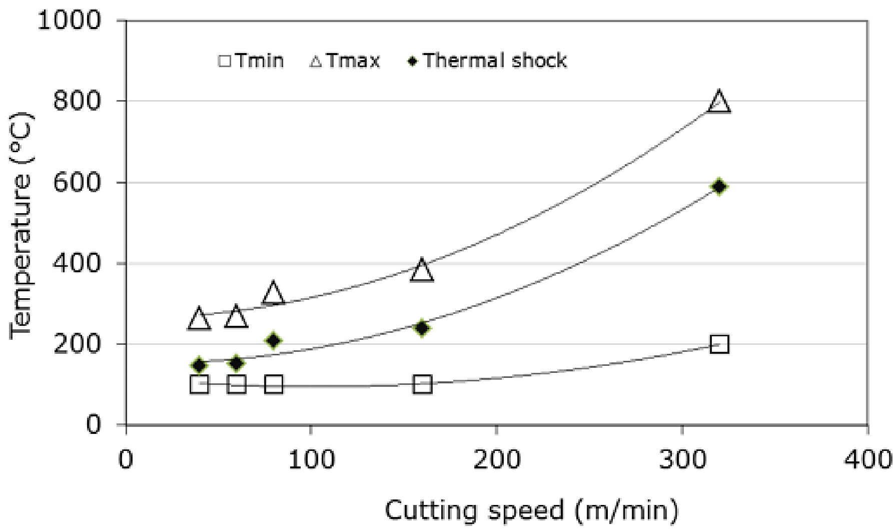

Figure 4: The temperature and thermal shock evolution with cutting speed using Inconel 718 as the tool material (Le Coz and Dudzinski 12)

As illustrated in Figure 5, small fractures appear when a cutting tool is heating. The cutting surface layer's temperature rises, while the interior layers' temperature remains low. This structure prevents effective cutting heat transfer from the surface (Le Coz and Dudzinski 12). Consequently, a stress imbalance develops as the surface pressure stress is converted into tension stress in the interior strata. Contrarily, the cutting surface experiences a sharp temperature drop at the end of cutting, and the internal layers cool down slower than the surface. This process retains the stress imbalance since the surface layer experiences tension while the lower strata experience pressure (Le Coz and Dudzinski 12). The tension changes interact with the mechanical shocks to fracture the cutting edge and cause brittle failure. Therefore, as illustrated in Figure 6, temperature is the driving factor compromising tool durability by instigating structural and mechanical failure.

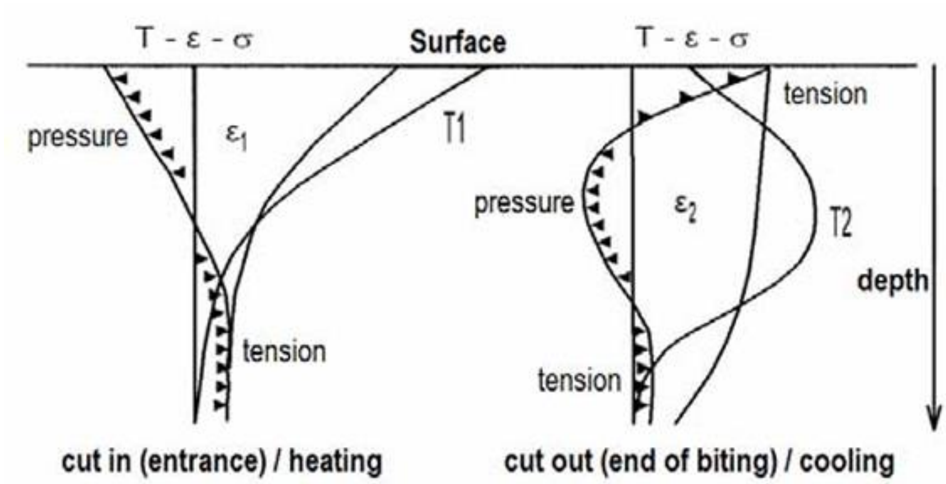

Figure 5: The impact of stresses on the cutting edge (Source: Le Coz and Dudzinski 12)

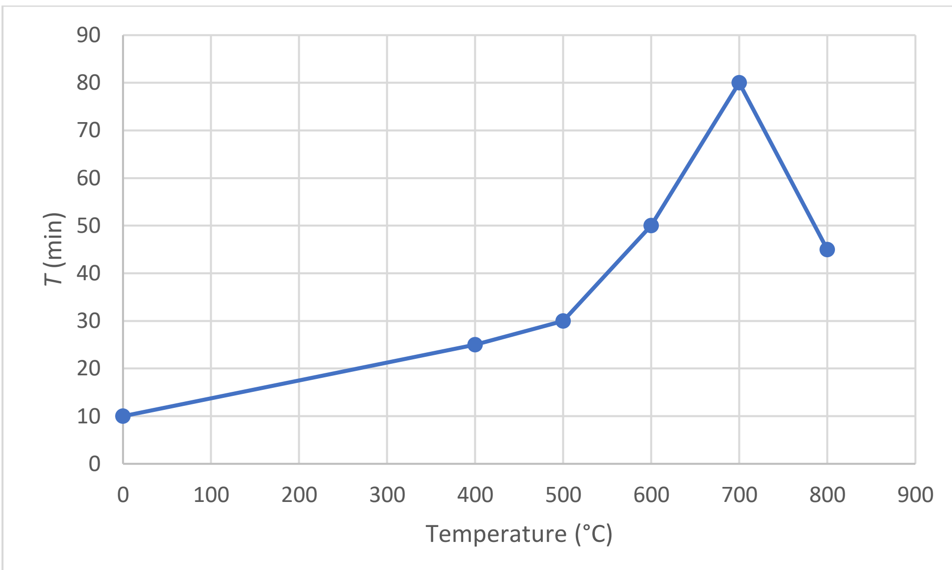

Figure 6: Cutting tool durability (measured as time) during interrupted cutting is contingent on heating. The least wear of the cutting-edge plate is at 700°C, beyond which the strength of the cutting material drops exponentially (Source: Cep et al. 295)

Conclusion

This research paper reviews the effect of temperature on the cutting edge of machining tools. The main impacts are generalized as wear and thermal cracking. The cutting process produces heat, primarily through friction heating. The high temperature reduces the hardness and yield strength at the cutting edge, increasing the abrasive wear rate. These effects are particularly substantive for small cutting edges. The increased wear compromises the tool's performance and useful life. Furthermore, the cutting process creates cyclical heating (when cutting in) and cooling (end of cutting) at the cutting edge and surface. This process loads the edge with alternating temperature shocks that create microscopic fractures. The heating and cooling also create stress imbalances between the outer and interior cutting surface layers, contributing to minute fractures. These events result in the cutting edge's brittle failure, which limits tool performance and longevity. These adversities worsen with cutting speed.

This research confirms the detrimental effects of temperature on the cutting edge. However, several concepts not covered in this study necessitate additional investigations. For example, the oxidative wear of the cutting edge at high temperatures should be investigated. Research alludes that while oxidation wear increases with temperature, the general wear rate may reduce since the resultant oxide layer has high hardness (Lontin, Khan, and Alharni 10). The impact of this phenomenon on cutting edges should be studied. Furthermore, future research should examine the ideal materials for creating machining tools with reduced wear and thermal cracking at the cutting edge. These studies should target alloys to combine the desirable effects of different metals. Considering these open research areas, effective metal machining should remain an active research area.

References

Abukhshim, N. A., P. T. Mativenga, and Mohammed Aslam Sheikh. "Heat Generation and Temperature Prediction in Metal Cutting: A Review and Implications for High-Speed Machining." *International Journal of Machine Tools and Manufacture*, vol. 46, no. 7-8, 2006, pp. 782-800.

Cep, Robert, et al. "Influence of Thermal and Mechanical Shocks to Cutting Edge Tool Life." *World Academy of Science, Engineering, and Technology*, vol. 56, 2009, pp. 292-295.

Czan, Andrej, et al. "Identification of Temperatures in Cutting Zone When Dry Machining of Nickel Alloy Inconel 718." *Procedia Manufacturing*, vol. 14, 2017, pp. 66-75.

Haddad, Madjid, et al. "Machinability and Surface Quality during High-Speed Trimming of Multi Directional CFRP." *International Journal of Machining and Machinability of Materials*, vol. 13, no. 2-3, 2013, pp. 289-310.

Kareem, B., and S. F. Daramola. "Effects of Temperature Variation on the Cutting-Edge Hardness of Selected HSS and HCS Single Point Cutting Tools." *International Journal of Engineering and Applied Sciences*, vol. 4, no. 8, 2017, pp. 36-41.

Kiprawi, Mohammad Ashaari, et al. "Study of Cutting-Edge Temperature and Cutting Force of End Mill Tool in High-Speed Machining." *MATEC Web of Conferences*, vol. 87, EDP Sciences, 2017.

Kumar, M. Pradeep, K. Amarnath, and M. Sunil Kumar. "A Review on Heat Generation in Metal Cutting." *International Journal of Engineering and Management Research (IJEMR)*, vol. 5, no. 4, 2015, pp. 193-197.

Le Coz, Gael, and D. Dudzinski. " Temperature Variation in the Workpiece and in the Cutting Tool When Dry Milling Inconel 718." *The International Journal of Advanced Manufacturing Technology,* vol. 74, 2014, pp. 1133-1139.

Lontin, Kevin, Muhammad Khan, and Bander Alharbi. "Investigation of the Effect of Temperature on the Wear Rate and Airborne Noise in Sliding Wear." *Materials,* vol. 15, no. 3, 2022, pp. 812.

Ogedengbe, T. S., et al. "The Effects of Heat Generation on Cutting Tool and Machined Workpiece." *Journal of Physics: Conference Series*, vol. 1378, no. 2, 2019.

Sato, Masahiko, Naoki Tamura, and Hisataka Tanaka. "Temperature Variation in the Cutting Tool in End Milling." *Journal of Manufacturing Science and Engineering,* vol. 133, no. 2, 2011.

Sonia, P. K., N. K. Mehta, and V. Upadhyay. "Effect of Cutting Tool Geometry on Tool Wear and Tool Temperature During Ti-6Al-4V Machining." *International Journal of Mechanical and Materials Engineering (IJMME),* vol. 8, no. 1, 2013, pp. 32-39.

Ueda, T. "Cutting Temperature." *CIRP Encyclopedia of Production Engineering*, edited by Luc Laperrière and Gunther Reinhart, Springer, 2014, pp. 334-345.