FMDB *Transactions on Sustainable Structures and Materials*

Design and Thermal Analysis of Cubic Boron Nitride Cutting Tools for High-Performance Machining Applications

R. Kumutha[1,*], V. Balaji[2], S. Raja[3], Saly Jaber[4], Fatma Bassyouni[5], Fatima Hamouche[6], Selçuk Bulat[7]

[1,2]Department of Mechanical Engineering, Loyola Institute of Technology, Chennai, Tamil Nadu, India.
[3]Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamil Nadu, India.
[4]Department of Analytical Chemistry, Saint Joseph University, Beirut, Beirut Governorate, Lebanon.
[5]Department of Chemistry of Natural and Microbial Products, National Research Centre, Cairo, Egypt.
[6]Department of Chemistry, Ibn Tofail University, Kenitra, Rabat-Salé-Kénitra, Morocco.
[7]Department of Nanoscience and Nanoengineering, Institute of Natural Sciences, Sakarya University, Serdivan, Sakarya, Turkey.
kamaleshmp@gmail.com[1], balajee2000@gmail.com[2], raja@skcet.ac.in[3], saly.jaber@usj.edu.lb[4], fatma.nrc@hotmail.com[5], fatima.hamouche@uit.ac.ma[6], sbulat@tse.org.tr[7]

Abstract: Cutting tools play a major role in manufacturing end products of the desired shape and size for high-end engineering applications. Cutting tool life is mainly influenced by the thermal stability and heat resistance of the cutting tool. The aim of this research is to design and thermally analyze a Cubic Boron Nitride (CBN) cutting tool for high-performance machining applications such as Laser Assisted Machining (LAM). The geometry of the cutting tool was constructed using a commonly used computer-aided design (CAD) software, namely, Creo Parametric. Then, the thermal behavior of the tool under the machining circumstances was evaluated by utilizing ANSYS to perform finite element thermal analysis. Key thermal performance metrics such as maximum temperature, minimum temperature, temperature distribution and total heat flow were studied to evaluate the effectiveness of the proposed tool material. The thermal performance of the CBN cutting tool was experimentally compared to a typical Inconel 718 cutting tool that is widely used for high-temperature machining applications. The simulation results show that the CBN cutting tool has better thermal stability, better heat dissipation characteristics and less thermal loading than the Inconel 718 tool. The results show that the developed CBN cutting tool may greatly improve the machining performance, tool life and reliability of the process in laser-assisted machining applications.

Keywords: Cubic Boron Nitride (CBN); Temperature Distribution; Machining Performance; Computer-Aided Design (CAD); Thermal Loading; Laser-Assisted Machining (LAM).

Received on: 20/08/2025, **Revised on:** 29/11/2025, **Accepted on:** 10/12/2025, **Published on:** 07/10/2026

Journal Homepage: https://www.fmdbpub.com/user/journals/details/FTSSM

DOI: https://doi.org/10.69888/FTSSM.2026.000818

Cite as: R. Kumutha, V. Balaji, S. Raja, S. Jaber, F. Bassyouni, F. Hamouche, and S. Bulat, "Design and Thermal Analysis of Cubic Boron Nitride Cutting Tools for High-Performance Machining Applications," *FMDB Transactions on Sustainable Structures and Materials,* vol. 2, no. 2, pp. 121–130, 2026.

Copyright © 2026 R. Kumutha *et al.,* licensed to Fernando Martins De Bulhão (FMDB) Publishing Company. This is an open access article distributed under CC BY-NC-SA 4.0, which permits copying, remixing, redistributing, transformation, and building upon the material in any medium so long as the original work is properly cited.

[*]Corresponding author.

1. Introduction

Laser-assisted machining (LAM) is a renowned technique for producing complicated parts that require mostly micro precision and machining of hard-to-cut materials such as nickel-based superalloys, titanium alloys, toughened steels and ceramic composites [1]. These hard materials are widely employed in aerospace, automotive, biomedical, military and energy industries owing to their superior mechanical strength, wear resistance, corrosion resistance and thermal stability [2]. Because of their better properties, these materials are more difficult to process and need special cutting tools [3]. Machining of these materials by cutting tools demands high cutting pressures, which lead to quick tool wear, poor surface smoothness and excessive heat generation, which would greatly limit the efficiency of machining and increase production cost. The heat generation at high temperatures induces residual stresses and microstructural changes in the workpiece, which reduce the quality and reliability of the created product. Hence, the knowledge of the thermal behaviour of cutting tools is important for the improvement of machining performance and increasing tool service life [4].

As a significant amount of heat is generated during machining, improving the performance of cutting tools under such high-temperature conditions has become an important area of research in modern manufacturing engineering [5]; [6]. Single point cutting tools have been widely used in turning, shaping, planing and boring operations. They have a single cutting edge and are meant to remove material effectively and to produce the desired geometry and surface finish. The edge is honed to suit the machining operation and can be resharpened many times to restore its performance. The tool holder tightly holds the cutting tool during machining, so as to offer stability against cutting forces and vibrations [2]. The tool geometry, such as rake angle, clearance angle, nose radius, and cutting-edge preparation, has a major effect on chip formation, heat generation, cutting forces, and tool wear characteristics [3]. Hardened high-carbon steels have been the material of choice for cutting tools in the past because of their comparatively high hardness and their simplicity of production. However, these materials lost their hardness very fast at elevated temperatures and limited their use for low-speed machining operations [9].

The discovery of high-speed steel (HSS) was a major step forward since it allowed machining at much faster cutting speeds and with sufficient hardness. Subsequent advances included cobalt-based alloys, cemented carbides, coated carbides, ceramics, cubic boron nitride (CBN) and polycrystalline diamond (PCD), all of which offered progressively better performance under more demanding machining circumstances [4]. Of these materials, cemented carbides are still the most often used cutting tools for conventional machining due to their balanced mix of hardness, toughness and cost-effectiveness. However, sophisticated applications using hardened steels and high-temperature alloys often demand improved tool materials that retain their mechanical qualities at high temperatures [7]. Cubic Boron Nitride (CBN) is one of the toughest engineering materials known and has received much interest. CBN is the second hardest material after diamond. It offers outstanding hardness, excellent thermal stability (retaining its properties over 1000–1200°C without substantial degradation), good thermal conductivity and minimal chemical affinity for ferrous compounds [10]. It has great hardness, outstanding wear resistance, excellent thermal stability, strong oxidation resistance and excellent chemical inertness in machining ferrous materials [9].

Unlike diamond tools, which react chemically with iron at high temperatures, CBN is chemically stable and maintains its cutting effectiveness at high temperatures. These properties make CBN especially ideal for machining hardened steels, superalloys and other difficult-to-cut materials. Moreover, its high thermal conductivity allows an effective dispersion of heat from the cutting zone, reducing the localized thermal concentrations, which often increase tool wear [7]. Inconel 718 is a nickel-based superalloy that has excellent mechanical strength, corrosion resistance, oxidation resistance and mechanical property retention at extreme temperatures. These properties have resulted in its extensive use in aerospace engines, gas turbines, nuclear reactors and other high-temperature technical applications. While Inconel 718 is mainly used as a structural material and not as a cutting tool material, its exceptional thermal resistance makes it an appealing reference material for comparative thermal research [13]. A comparison of the thermal properties of CBN and Inconel 718 provides useful information on the applicability of modern cutting tool materials for laser-assisted machining conditions [8]. Laser-assisted machining is a promising hybrid manufacturing technology to enhance the machinability of hard-to-cut materials. In this method, a high-energy laser beam preheats the workpiece locally just ahead of the cutting tool, which causes a decrease in the material yield strength and hardness before removal of the material [9].

This results in a significant reduction of the cutting forces, a more consistent chip production, reduced tool wear and an enhanced surface polish [20]. However, the laser also delivers a considerable amount of heat energy into the machining zone, and the thermal behaviour of the cutting tool is an essential process parameter affecting the process efficiency and the tool reliability. Thus, the understanding of temperature distribution and heat transfer properties of cutting tools is very important for the purpose of improving tool design and material selection in a laser-assisted machining environment. Due to the severe operating environment and the difficulties in monitoring transient thermal events, it is generally expensive, time-consuming, and difficult to experimentally evaluate the performance of a cutting tool under laser-assisted machining circumstances [18]. Finite Element Analysis (FEA) offers an efficient alternative by allowing full numerical simulation of heat transfer, temperature distribution, thermal stresses and deformation within the cutting tools [17]. Modern finite element software packages such as

ANSYS are now an essential tool in engineering design since they allow designers to estimate the temperature response of components without having to construct physical prototypes. The numerical simulation may substantially lower the development cost, shorten the design cycles and provide useful insight into the influence of material parameters and operating conditions on the performance of cutting tools [10].

2. Review of Literature

Several researchers have employed finite element methods to investigate machining processes. Tadavani et al. [11] experimented with laser-assisted machining on Inconel 718 using varying laser parameters, and the machining performance was evaluated through machining specific energy, surface roughness, tool wear, and chip morphology using optical microscopy, scanning electron microscopy (SEM), spark emission spectroscopy, and energy-dispersive spectroscopy (EDS). Regression analysis and analysis of variance (ANOVA) were employed to determine the influence of laser parameters and optimize the machining conditions. Preheating the workpiece to approximately 540 °C ahead of the primary shear zone reduced machining specific energy by 35%, surface roughness by 22%, and tool wear by 23% compared with conventional machining, while flank wear remained the dominant tool failure mechanism. ANOVA analysis showed that laser beam frequency is the most significant factor that influences the temperature, with the optimum machining conditions being 80 Hz frequency, 400 W laser power, 24 m/min cutting speed, 0.052 mm/rev feed rate, 540 °C preheating temperature, 2.51 J/mm² machining specific energy, and 130 N cutting force.

Tu et al. [12] fabricated a cutting tool using cubic boron nitride (cBN)-coated silicon nitride (Si_3N_4) with diamond interlayers created using electron cyclotron resonance (ECR) microwave plasma chemical vapor deposition (MPCVD). The performance of the cutting tool was evaluated by dry turning in hardened ductile iron. The performance of the cutting tool was compared with traditionally used TiAlN-coated tools by analyzing cutting force, cutting temperature, tool wear, and wear mechanisms. Results indicated that the cBN-coated tools exhibited lower cutting forces, reduced cutting temperatures, smaller tool wear, and longer tool life than TiAlN-coated tools. Crater wear on the rake face and flank wear were the predominant wear patterns, with abrasion and diffusion identified as the primary wear mechanisms. Lee et al. [13] fabricated laser powder bed fusion (LPBF) boron-enhanced Inconel 718 specimens with boron levels of up to 5000 ppm. The effect of boron addition on the microstructure, mechanical properties, and optical performance of the alloy was investigated after post-heat treatment and thermal cycling. The influence of the boron concentration and heat treatment was analyzed by microstructural characterization, tensile testing, microhardness measurements and optical reflectance analysis.

The addition of boron promoted the formation of Laves phases that increased the tensile strength, increased the microhardness up to 36.6% in as-printed and 9.2% after heat treatment, while decreasing the reflectance by ~10%, thus improving the optical absorptivity. Optimized heat treatment transformed elongated Laves phases into fine granular structures, improving mechanical stability and suggesting that boron-enhanced Inconel 718 could be a durable, coating-free material for high-temperature solar receiver tube applications. Carbonell et al. [14] developed a three-dimensional numerical machining model using the Particle Finite Element Method (PFEM) involving improved finite element formulation, adaptive mesh reconnection, and enhanced contact detection algorithms to simulate complex cutting processes. The developed model was verified by representative machining examples to confirm its capability to accurately reproduce the three-dimensional material removal under cutting conditions. The developed improved PFEM is capable of successfully simulating complicated 3D machining operations that cannot be simplified into 2D models and can accurately capture the material deformation and cutting behavior.

Validation studies have shown that the improved formulation provides reliable predictions and demonstrates the effectiveness of PFEM as a robust numerical tool for the analysis and optimization of practical machining processes. Mistry et al. [15] developed a finite element simulation model to investigate the influence of key process parameters in liquid-assisted laser beam micromachining (LBMM), with emphasis on the effects of liquid film thickness on thermal behavior. The simulation results were validated experimentally by performing micromachining under water and ethylene glycol films and comparing the predicted heat-affected zone and surface quality with experimental observations. Coelho et al. [16] proposed a framework based on neural networks to predict the high-fidelity temperature and heat flux fields in machine tools, based on the finite element simulation data generated under different initial conditions. A correlation-based sensor selection strategy was also studied to reduce the number of measurements while enabling thermal error compensation. Several time-series neural network architectures were considered, including RNN, GRU, LSTM, Bidirectional LSTM, Transformer, and Temporal Convolutional Network. The proposed framework was able to accurately predict the temperature and heat flux distribution at different operating conditions while reducing hardware requirements through optimized sensor placement.

The results showed that the method of modeling spatio-temporal thermal fields rather than directly predicting thermal errors is a flexible, cost-effective, and generalizable method for thermal error correction of machine tools. Xu et al. [17] comparatively studied the machining performance of 42CrMo4 high-strength steel with YT15 cemented carbide, KY1615 ceramic, and Ti (C, N)-based cermet cutting tools (T1500A, TMWNC, and TMWC) at different cutting speeds. The tool wear characteristics,

cutting performance, and wear mechanisms were analyzed by the cutting force, wear pattern, and tool failure mode. The Ti (C, N)-based cermet tools had better cutting performance, mainly due to abrasive wear, lower friction and better oxidation resistance. While the cemented carbide and ceramic tools suffered severe notch wear, chipping, adhesive wear and crater wear. The self-made cermet tools showed better performance than the commercial cermet tool in machining of 42CrMo4 high-strength steel at a cutting speed of 150 m/min, owing to their higher resistance to edge chipping and notch wear. Previous studies have shown that Finite Element Analysis is a powerful tool to predict the thermal behaviour of cutting tools in machining applications such as laser-assisted machining.

The current work is focused on the development of 3D models of Cubic Boron Nitride and Inconel 718 cutting tools in Creo Parametric and their thermal behavior investigation through finite element analysis in ANSYS. The main objective of the experiment is to determine critical thermal characteristics like temperature distribution, maximum temperature, minimum temperature, and total heat flux created during laser-assisted machining. The thermal reactions of two cutting tool materials are systematically evaluated to find a better thermal-performance material. The results of this study are expected to be of great benefit in the development of high-performance cutting tools which can operate in severe thermal environments, leading to enhanced machining efficiency, better tool life, reduced manufacturing costs and broader application of laser-assisted machining in the advanced manufacturing industries.

3. Materials and Methodology

3.1. Material Selection

The mechanical strength, thermal stability, wear resistance and heat dissipation capabilities of a cutting tool are the main factors that determine its performance in laser-assisted machining. Therefore, it is important to select a proper cutting tool material to ensure machining accuracy, extend tool life and preserve dimensional stability at high operating temperatures. In the present work, two advanced materials, i.e., Inconel 718 and Cubic Boron Nitride (CBN), were selected for thermal performance evaluation by finite element analysis. Inconel 718 is a nickel-based superalloy and is widely known for its superior resistance to oxidation, corrosion and high-temperature deformation.

The material has good mechanical strength in a wide temperature range, superior fatigue and creep resistance, and is therefore suited for use in severe thermal settings. Due to these properties, Inconel has been extensively used in aerospace, power generation and high-temperature engineering applications. Due to its structural stability at elevated temperatures and low thermal conductivity, it is a suitable reference material for testing the thermal behaviour of cutting tools. Cubic Boron Nitride (CBN) is a synthetic ultra-hard substance and is regarded as the second hardest engineering material after diamond. CBN is chemically stable and can machine ferrous materials and retain its hardness at very high temperatures, unlike diamond.

Table 1: Properties of Inconel and CBN

Property	Inconel	CBN
Density (g/cm^2)	8.2-8.5	3.48
Hardness (HRC)	30-45	45-70
Tensile Strength (GPa)	800-1400	500 -600
Elastic Modulus (GPa)	200	800
Thermal Conductivity (W/m.K)	10-15	100-200
Thermal Expansion (μm/m°C)	12-15	4-6

Furthermore, CBN has a far better thermal conductivity and lower thermal expansion than typical cutting tool materials, which helps in the effective transfer of heat away from the cutting zone. These features reduce thermal softening and tool wear and increase the machining accuracy in the high-speed and laser-aided machining processes. These benefits have made CBN one of the favoured materials for machining hardened steels, cast irons and superalloys. The material properties of the materials used were collected from the existing literature and are presented in Table 1.

Comparison of these parameters demonstrates that CBN has far higher hardness, Young's modulus and thermal conductivity and a lower coefficient of thermal expansion than Inconel. The improved qualities are predicted to improve the heat dissipation characteristics and thereby lower the thermal stresses during machining and to further enhance the performance of cutting tools under laser-aided machining settings. The general methodology employed is presented in Figure 1. The approach comprises: selection of material, 3D modelling, export of model, finite element meshing, application of thermal boundary conditions, thermal simulation and comparison of the obtained findings.

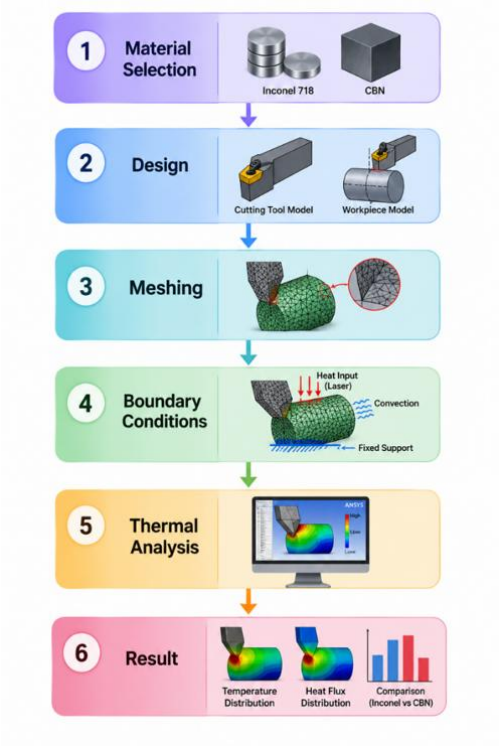
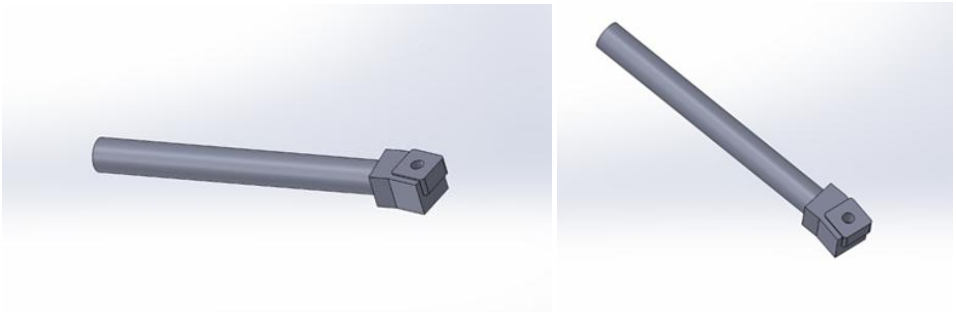


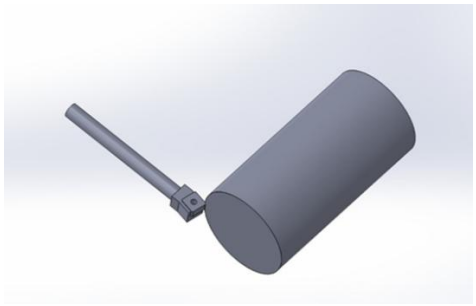
Figure 1: Research methodology

3.2. Design of the Cutting Tool

The three-dimensional model of the cutting tool was produced using SOLIDWORKS, a widely utilized computer-aided design (CAD) software package used in both industry product development and academic research.



(a) (b)



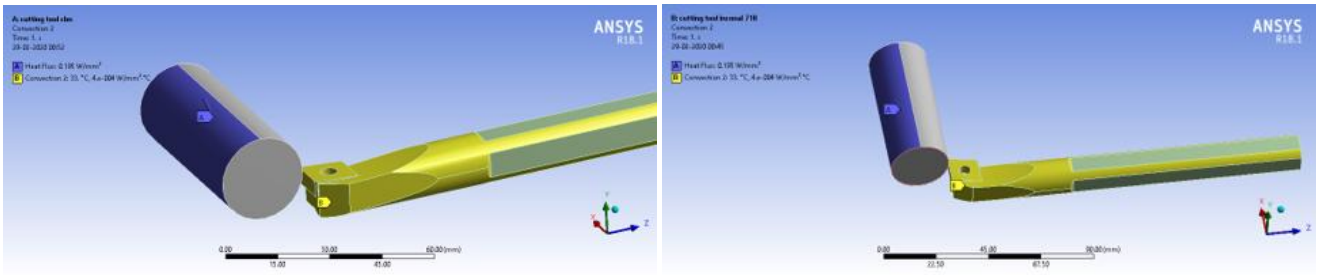
(c)

Figure 2: (a-c) Designed cutting tool and cutting tool with workpiece

The software provides realistic modelling capabilities to facilitate the design of geometrically complex components with great precision. Firstly, the 2D profile of the cutting insert and tool holder was developed using sketching tools that are accessible in SOLIDWORKS. Proper geometric dimensions were inserted according to conventional single-point cutting tool geometry. Then the two-dimensional designs were extruded into three-dimensional solid models utilizing the Extrude feature. Further geometric enhancements such as edge rounding and corner smoothing were carried out by Fillet and Chamfer operations to provide realistic cutting-edge geometry and reduce stress concentration during machining. Additional machining features, including insert pockets, seating surfaces and relief areas, were made utilizing the Extrude Cut process. The insert and tool holder were then assembled using normal assembly mates to achieve correct positioning and alignment. The cutting insert was provided with appropriate material qualities, while the tool holder was regarded as either hardened steel or carbide for good structural rigidity throughout the machining. A workpiece geometry was developed to simulate the contact between the machining tool and the material to be machined. The model of the cutting tool and workpiece is shown in Figure 2 (a-c). The design was then exported as an IGES (Initial Graphics Exchange Specification) file to allow the geometry to be transferred into the ANSYS Workbench environment for numerical analysis.

3.3. Thermal Analysis

The developed cutting tool was thermally analyzed using ANSYS Workbench, which is the predominantly used finite element analysis (FEA) software package for engineering simulation. The imported geometry was examined first for geometric consistency before the finite element mesh was generated.



(a) (b)

Figure 3: (a) and (b) Boundary conditions applied on the design

To discretize the model into a large number of finite elements, a suitable mesh was generated. Mesh refinement was performed especially along the cutting edge because this zone receives the highest thermal gradients during milling. The use of a finer mesh allows a better forecast of the temperature distribution and the heat flow, resulting in a more accurate solution, without loss of computational efficiency. The requisite thermal boundary conditions for laser-assisted machining were added after the mesh generation. Heat input related to the machining process was applied at the cutting interface, and relevant thermal constraints were applied to mimic heat transfer between the cutting tool, workpiece and environment. Both Inconel and CBN models were assigned material-specific thermal parameters such as thermal conductivity, density and coefficient of thermal expansion. Then the finite element solver estimated the steady-state thermal response of each cutting tool material. Simulation using the finite element method provided thermal analysis results such as maximum temperature, minimum temperature, temperature distribution and total heat flux for the tool simulated. Contour plots were generated to illustrate the thermal behaviour and identify regions of peak thermal loading. Finally, the thermal reactions of Inconel and CBN cutting tools were studied to determine the capability of these tools in laser-assisted machining applications. The comparative study between two materials helps in finding the effect of material attributes on the heat dissipation characteristics and overall thermal performance. The defined boundary conditions in the finite element simulation are summarized in Figure 3, and the temperature and heat flux distributions are presented in the next section.

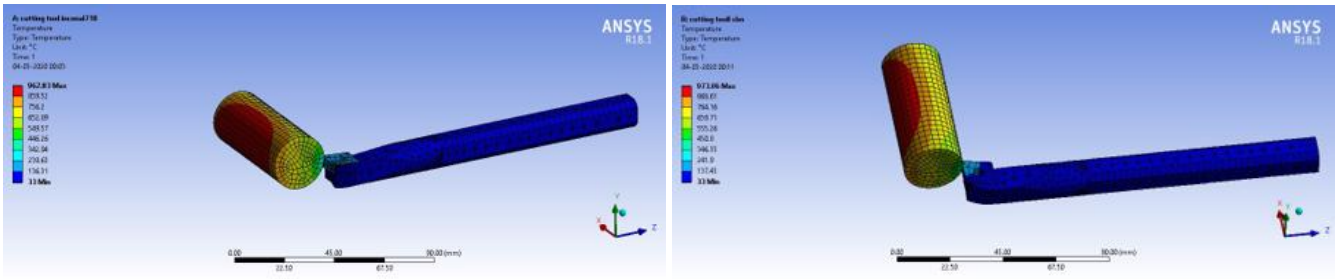
4. Results and Discussions

Two cutting tool materials, Inconel 718 and Cubic Boron Nitride (CBN), were evaluated for their thermal behaviour using finite element thermal analysis under laser-aided machining settings. The primary objective of this research was to investigate the temperature distribution and heat transfer characteristics of both materials to understand their performance under elevated-temperature machining conditions. The tool-workpiece assembly was thermally loaded with a cutting tool to simulate the environment of machining. The temperature field and total heat flux were acquired by ANSYS Workbench. Thermal behaviour of a machining tool represents one of the most critical elements controlling machining efficiency, tool wear, dimensional accuracy and tool life. The high temperature at the cutting edge induces diffusion wear, oxidation, plastic deformation and

thermal cracking, whereas effective heat dissipation reduces thermal damage and increases machining stability. Therefore, the numerical simulation results of temperature distribution and total heat flux are important indicators of the suitability of any material for laser-assisted machining.

4.1. Temperature Distribution

Temperature dispersion is the change in temperature inside the cutting tool and workpiece during machining. It demonstrates the way in which the heat energy created at the cutting interface is transferred from the tool body to the surrounding material [18]. Temperature contours generated from finite element analysis for Inconel 718 and Cubic Boron Nitride are presented in Figure 4. For both cutting tools, the highest thermal concentration occurs between the tool and the workpiece where the laser heating, friction and plastic deformation combine to produce a very strong localised heat [19]. Thermal conduction in the machining tool is controlled by a thermal gradient, which is established by the steady drop of the tool temperature from the cutting edge to the tool shank. The simulation findings reveal that only a moderate amount of the cutting tool experiences high temperatures and a significant portion of the heat energy is absorbed by the workpiece material. Such behaviour is expected in laser-aided machining, as the laser pre-heats the workpiece immediately ahead of the cutting zone, decreasing the cutting pressures and limiting the excessive heating of the whole cutting tool. The maximum temperature obtained for the Inconel 718 cutting tool was 962.83°C, and that of the CBN cutting tool was 973.06°C. The lowest temperatures recorded were 136.31°C and 137.45°C, respectively. The CBN tool has a slightly higher maximum temperature, but the difference between these two materials is around 10 °C, which is roughly 1% of the entire temperature range.



(a) Inconel 718 (b) CBN

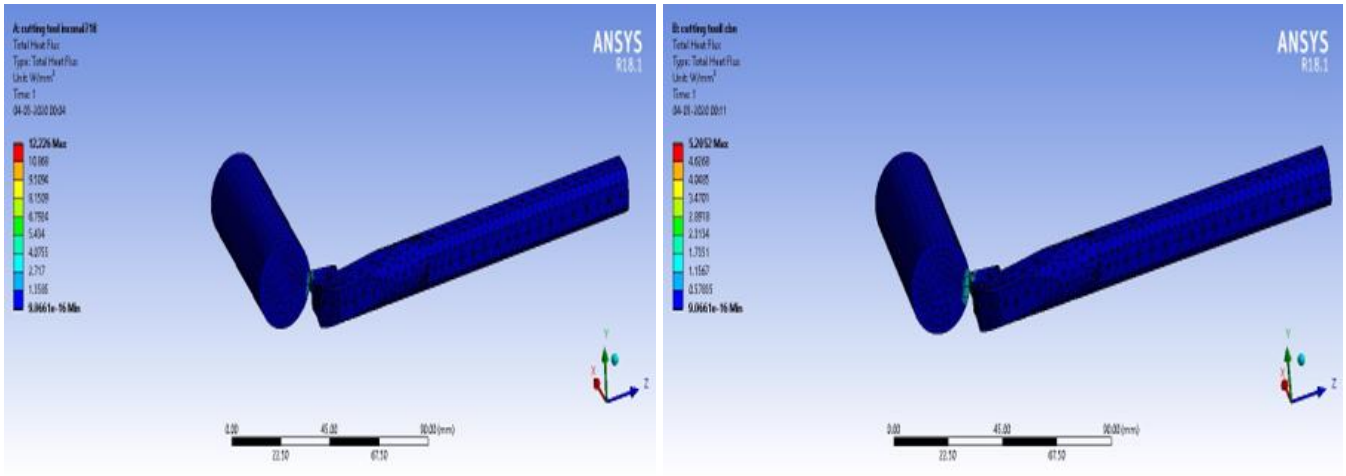
Figure 4: Temperature distribution

This little difference is regarded as negligible for real machining applications and does not reflect a poorer thermal behaviour. Instead, the thermal behaviour has to be evaluated in conjunction with the intrinsic material qualities. CBN has a thermal conductivity around 10 times higher than Inconel 718; thus, the heat is distributed throughout the entire tool instead of being focused at the cutting edge. The temperature field is thus more uniform, and the local thermal stresses are reduced. Such stresses are a common cause of the formation of fractures and of premature tool failure. Another important characteristic of CBN is its low coefficient of thermal expansion. Lower thermal expansion causes less dimensional variation during machining and helps maintain cutting edge geometry under high heat load. Dimensional stability is important in precision machining, as small thermal distortions can affect the surface finish and machining accuracy. The contour graphs in Figure 4 also show that the temperature gradients within the CBN tool are less steep than those within the Inconel tool. In general, smooth temperature gradients are likely to lower the internal thermal stresses and so improve the structural durability during extended machining operations. Both materials are able to endure high-temperature machining conditions, but the better thermal conductivity and lower thermal expansion of CBN show that it has better thermal stability even when the peak temperature is slightly higher.

4.2. Total Heat Flux

Heat flux represents the amount of thermal energy transported per unit area through a substance. During machining, the heat flux influences the heat removal capability of the machining tool to remove heat from the cutting edge [20]. Effective heat transport is important to reduce thermal softening, tool wear and improve cutting performance. Figure 5 shows the distributions of the total heat fluxes from the finite element study. The maximum heat flux for the Inconel 718 cutting tool was 12.226 W/m^2 and for the CBN tool it was 5.2052 W/m^2. The minimum heat flux values are 1.3585 W/m^2 for Inconel and 0.5783 W/m^2 for CBN, respectively. At first glance, the larger heat flow values obtained by Inconel may seem beneficial. However, heat flow has to be interpreted in connection with thermal conductivity and temperature gradients. Heat flux varies directly with thermal conductivity and the temperature gradient within the material. A larger heat flux means steeper local temperature gradients, i.e., the thermal energy is focused in a smaller region of the tool. Conversely, the heat transfer rate of CBN is more even due to its very high thermal conductivity. Lower heat flux values obtained in the CBN model suggest avoiding significant thermal

gradients, lowering thermal stresses and minimizing the probability of localized thermal damage. From the contour plots, it is observed that the heat transfer is well distributed throughout the whole CBN cutting tool, and there are no concentrated hot areas. Such behaviour is beneficial, as thermal stress concentrations are one of the main reasons for crack initiation and progressive tool wear during repeated machining cycles.



(a) Inconel 718 (b) CBN

Figure 5: Total heat flux

In addition, CBN maintains its hardness at temperatures reaching 1000°C, while other metallic materials gradually weaken with increasing temperature. Therefore, although CBN has a slightly higher peak temperature, it is projected to retain better cutting performance in longer machining processes. The heat flow distributions also indicate that there is no excessive localized thermal concentration in any material that would result in imminent thermal failure. Thus, both cutting tools are suitable for laser-assisted machining in the examined operating circumstances.

4.3. Comparative Analysis

The simulation results of the thermal analysis are summarized in Table 2. From Table 2, it can be seen that the temperature levels are similar for both cutting tool materials during machining. The greatest temperature difference between the two materials is roughly 10 °C, while the minimum temperature difference is just about 1 °C. Such tiny fluctuations show the good thermal resistance of both materials. The main difference between the materials is their thermal characteristics. Inconel 718 has poorer heat conductivity but great mechanical strength and oxidation resistance at elevated temperatures. Hence, it is still a good material for situations where excellent structural integrity under thermal loading is required [21]. Cubic Boron Nitride has, in contrast, far higher thermal conductivity, much higher hardness, higher elastic modulus and much lower thermal expansion. The above qualities improve the thermal stability, reduce deformation and maintain cutting edge sharpness during machining. The better hardness of CBN is more favorable, since cutting instruments mostly break down through abrasive and adhesive wear mechanisms. The improved hardness property of CBN provides good precision during the machining of the workpiece. This is possible due to the reduced wear and tear of the tool used for laser-assisted machining. During the machining, the tool undergoes repeated heating and cooling cycles, which is efficiently handled by the CBN tool [22].

Table 2: Overall result analysis

No.	Description	Inconel 718		CBN	
		Max.	Min.	Max.	Min.
1	Temperature (^{O}C)	962.83	136.31	973.06	137.45
2	Total Heat Flux (W/mK)	12.226	1.3585	5.2052	0.5783

4.4. Discussion with Published Literature

On comparison with the results published in the literature for similar work, it is identified that the results produced in the current investigation are in line with those found in the literature. It is also notable that CBN has been identified as a favorable material to be used as a tool due to its qualities like thermal stability and hardness, which it maintains at high temperatures. Since severe

heat generation occurs during the machining process, this material is capable of withstanding stress due to the heat evolved. Finite element investigations show that the generated heat during laser-assisted machining is dispersed uniformly in the surrounding areas, rather than concentrated at a point, which would lead to severe wear and tear and result in a poor surface finish. With the utilization of CBN, a smooth surface finish is possible [23]. The present results further support the use of finite element analysis as an efficient design tool for advanced machining applications.

5. Conclusion

The thermal investigation indicates that the high temperature produced during laser-assisted machining processes could be tolerated by both Inconel 718 and Cubic Boron Nitride (CBN). The temperature contour plots indicate that the thermal energy is largely focused at the cutting interface, whereas the other parts of the cutting tool have relatively lower temperatures. Thermal performance variations between the two materials are rather small, with Inconel 718 having a slightly lower peak temperature and higher heat flow. However, it is believed that CBN can achieve better long-term machining performance on account of its extraordinary hardness, higher elastic modulus, excellent thermal conductivity, lower coefficient of thermal expansion, and excellent thermal stability. These features are important because they help to achieve better dimensional stability, less wear of the tool, better reliability of the machining, and longer service life of the cutting tool in difficult working situations. Future work will be based on experimental validation of the finite element analysis results by sophisticated temperature measurement techniques such as infrared thermography and implanted thermocouples during the laser-assisted machining operations. Experimental studies could also increase the reliability and the practical applicability of the numerical results. So, this study concludes that Cubic Boron Nitride is the most suitable cutting tool material for efficient, dependable and high-performance laser-assisted machining applications.

Acknowledgment: N/A

Data Availability Statement: The research data supporting the reported findings are obtainable from the corresponding author upon reasonable request.

Funding Statement: The authors received no external funding for this research.

Conflicts of Interest Statement: The authors declare no conflicts of interest related to this study.

Ethics and Consent Statement: The study adhered to applicable ethical standards and guidelines. Informed consent was obtained from participants wherever required.

References

1. G. Chryssolouris, N. Anifantis, and S. Karagiannis, “Laser Assisted Machining: An Overview,” *J. Manuf. Sci. Eng.*, vol. 119, no. 4B, pp. 766–769, 1997.
2. K. You, G. Yan, X. Luo, M. D. Gilchrist, and F. Fang, “Advances in laser assisted machining of hard and brittle materials,” *J. Manuf. Process.*, vol. 58, no. 10, pp. 677–692, 2020.
3. K. Venkatesan, R. Ramanujam, and P. Kuppan, “Laser Assisted Machining of Difficult to Cut Materials: Research Opportunities and Future Directions - A Comprehensive Review,” *Procedia Eng.*, vol. 97, no.12, pp. 1626–1636, 2014.
4. B. M. P. Guimarães, C. M. da Silva Fernandes, D. A. de Figueiredo, F. S. C. P. da Silva, and M. G. M. Miranda, “Cutting temperature measurement and prediction in machining processes: comprehensive review and future perspectives,” *The International Journal of Advanced Manufacturing Technology*, vol. 120, no. 3, pp. 2849–2878, 2022.
5. Q. Liu, J. Liu, Z. Ming, B. Cui, and J. Wang, “Research Progress on Laser-Assisted Precision Machining Technology,” *Micromachines*, vol. 16, no. 2, pp. 1–18, 2025.
6. A. Seleznev, N. W. S. Pinargote, and A. Smirnov, “Ceramic Cutting Materials and Tools Suitable for Machining High-Temperature Nickel-Based Alloys: A Review,” *Metals*, vol. 11, no. 9, pp. 1–18, 2021.
7. M. A. Yallese, K. Chaoui, N. Zeghib, L. Boulanouar, and J. F. Rigal, “Hard machining of hardened bearing steel using cubic boron nitride tool,” *J. Mater. Process. Technol.*, vol. 209, no. 2, pp. 1092–1104, 2009.
8. D. Dubey, R. Mukherjee, and M. K. Singh, “A review on tribological behavior of nickel-based Inconel superalloy,” in *Proc. Institution of Mechanical Engineers, Part J: J. Eng. Tribology*, vol. 238, no. 6, pp. 706–732, 2024.
9. Y. Jeon and C. M. Lee, “Current research trend on laser assisted machining,” *International Journal of Precision Engineering and Manufacturing*, vol. 13, no. 2, pp. 311–317, 2012.

10. A. J. Shih, “Finite Element Simulation of Orthogonal Metal Cutting,” *Journal of Manufacturing Science and Engineering*, vol. 117, no. 1, pp. 84–93, 1995.
11. S. A. Tadavani, R. S. Razavi, and R. Vafaei, “Pulsed laser-assisted machining of Inconel 718 superalloy,” *Opt. Laser Technol.*, vol. 87, no. 1, pp. 72–78, 2017.
12. L. Tu, S. Tian, F. Xu, X. Wang, C. Xu, B. He, D. Zuo, and W. Zhang, “Cutting performance of cubic boron nitride-coated tools in dry turning of hardened ductile iron,” *J. Manuf. Process.*, vol. 56, no. 8, pp. 158–168, 2020.
13. J. Lee, M. Farias, H. Aparicio, H. Li, B. Nabavi, B. Zhao, F. Ahmed, P. Li, B. Xu, and J. Li, “Development of boron-enhanced inconel 718 with superior thermomechanical properties for high-temperature concentrated solar power applications,” *Solar Energy Materials and Solar Cells*, vol. 292, no. 10, p. 113787, 2025.
14. J. M. Carbonell, J. M. Rodríguez, and E. Oñate, “Modelling 3D metal cutting problems with the particle finite element method,” *Computational Mechanics,* vol. 66, no. 6, pp. 603–624, 2020.
15. V. Mistry and S. James, “Finite element analysis and simulation of liquid-assisted laser beam machining process,” *The International Journal of Advanced Manufacturing Technology*, vol. 94, no. 9, pp. 2325–2331, 2018.
16. C. Coelho, M. Hohmann, D. Fernandez, L. Penter, S. Ihlenfeldt, and O. Niggemann, “Data-Driven Temperature Modeling of Machine Tools by Neural Networks: A Benchmark,” *IEEE Access*, vol. 14, no. 3, pp. 44342–44362, 2026.
17. Q. Xu, J. Zhao, and X. Ai, “Cutting performance of tools made of different materials in the machining of 42CrMo4 high-strength steel: a comparative study,” *The International Journal of Advanced Manufacturing Technology*, vol. 93, no. 6, pp. 2061–2069, 2017.
18. W. Grzesik, “Determination of temperature distribution in the cutting zone using hybrid analytical-FEM technique,” *Int. J. Mach. Tools Manuf.*, vol. 46, no. 6, pp. 651–658, 2006.
19. G. Ren, H. Song, J. Dan, J. Li, P. Pan, Z. Yang, J. Xiao, and J. Xu, “Thermal analysis and machinability for laser-assisted machining of fused silica,” *Int. J. Heat Mass Transf.*, vol. 148, no. 2, p. 119078, 2020.
20. A. A. A. Figueiredo, G. Guimaraes, and I. C. Pereira, “Heat flux in machining processes: a review,” *The International Journal of Advanced Manufacturing Technology*, vol. 120, no. 3, pp. 2827–2848, 2022.
21. Z. Luo and Y. Zhao, “Efficient thermal finite element modeling of selective laser melting of Inconel 718,” *Computational Mechanics*, vol. 65, no. 11, pp. 763–787, 2020.
22. S. Khetre, A. Bongale, S. Kumar, and B. T. Ramesh, “Temperature Analysis in Cubic Boron Nitrate Cutting Tool during Minimum Quantity Lubrication Turning with a Coconut-Oil-Based Nano-Cutting Fluid Using Computational Fluid Dynamics,” *Coatings*, vol. 14, no. 3, pp. 1–18, 2024.
23. R. Andreotta, L. Ladani, and W. Brindley, “Finite element simulation of laser additive melting and solidification of Inconel 718 with experimentally tested thermal properties,” *Finite Elements in Analysis and Design*, vol. 135, no. 11, pp. 36–43, 2017.

Publisher’s Note: *The publisher remains impartial concerning jurisdictional claims in published maps and institutional affiliations. Responsibility for the content rests entirely with the authors and does not necessarily reflect the publisher’s perspectives.*