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REGULAR ARTICLE

Numerical Modeling of the Thermal Behavior of Thin Layers – Application to a Brazed Insert Assembled into a Cutting Tool

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Thin layers are widely used in engineering applications for their critical functional roles at material interfaces, particularly in joining and coating technologies. Among these, brazing is a key process that enables metallurgical bonding between dissimilar materials through a molten filler metal, ensuring structural integrity without melting the base components. In this study, the thermal behavior of brazed thin layers was investigated using a combined analytical and numerical approach. The analysis first focused on a one-dimensional structure, modeled using the finite element method (FEM) within Abaqus to simulate transient heat transfer. The numerical results showed excellent agreement with analytical solutions, confirming the accuracy and reliability of the FEM approach for predicting temperature evolution in layered systems. Building upon this validation, the method was extended to a three-dimensional model of a brazed cutting tool, consisting of a carbide insert joined to a steel body by a silver-based filler alloy. The simulation results revealed the temperature distribution within the brazing region, emphasizing the influence of material properties and geometry on the joint's thermal response. Overall, the study demonstrates that the finite element method is a powerful and reliable tool for analyzing and optimizing the thermal performance of brazed assemblies in cutting tool applications.

Keywords: Brazing, Steel body, Simulating, Heat flux, Thin layer, Abaqus

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1. INTRODUCTION

The Thin layers – often just a few micrometers thick – play a pivotal role across advanced engineering domains due to their efficient use of material, conformability, and enhancement of surface or interfacial properties (e.g., thermal, mechanical, tribological) [1-3]. In microelectronics, thin films manage heat dissipation and electrical conduction; in optics, they reduce reflectivity; and in tribological systems, they act as wear-resistant coatings [1, 2].

An essential application of thin layers is in brazing, a joining process in which a filler metal melts and wets the interface between components without melting the base substrates, thus achieving a metallurgical bond while minimizing distortion and preserving dimensional tolerances [4, 5]. Brazing is highly adaptable to automation and mass production, making it widely used in industrial manufacturing [5].

Specifically, induction brazing is frequently employed to attach cemented carbide inserts (e.g., WC–Co) to tool bodies made of steel or other substrates. Here, the braze forms a thin interfacial layer that not only ensures adhesion but also accommodates mismatches in coefficients of thermal expansion, and helps to distribute thermal and mechanical stresses during tool operation [6, 7]. Induction brazing, by providing rapid and localized heating, enhances joint reliability and production throughput [7].

Beyond mechanical considerations, the thermal behavior of the braze layer is crucial for tool performance and life. This thin layer forms a thermal pathway between the carbide insert and tool body; its thickness, microstructure, and thermal conductivity govern how heat flows through the assembly under machining conditions. However, literature explicitly addressing the temperature evolution within the braze layer under service conditions remains scarce.

Numerical and modeling studies-such as those exploring temperature fields during induction brazing and quenching of carbide tools-offer useful insights into thermal dynamics at macro scales [8]. Similarly, advances in multiphysics simulations of induction brazing provide detailed representations of electromagnetic and thermal coupling, capturing localized heating behaviors in complex assemblies [9]. These modeling strategies are highly relevant to understanding the thermal response of brazed thin layers.

Furthermore, studies of brazed cemented carbide-steel joints reveal that uneven heating or insufficient control of the brazing gap temperature can induce residual stresses, which may compromise joint integrity [10]. Such findings underscore the importance of knowing not just surface temperatures but also the internal thermal profile within the braze layer, which remains experimentally elusive.

Given this backdrop, the present work aims to investigate the evolution of temperature inside the braze

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layer in carbide-tool assemblies. The goal is to discern how heat penetrates this thin interface, how temperature distributes across it, and how its properties and dimensions influence thermal response. Gaining this insight is essential for refining brazing parameters, optimizing joint reliability, and improving tool longevity.

The numerical simulation was performed by using Abaqus as a Finite Element Method software. To validate the results, we have considered the one-dimensional case (Wire) composed of carbide insert, brazing and tool body. The analytical solution is compared to numerical results. In the other hand the 3D model was tested for many cases of meshing and the results don't change which means that the numerical simulation converged.

2. MATERIAL AND METHODS

2.1 Objects of Study

The cutting tool intended to be studied is shown by (Fig. 1 and Fig. 2) for the two cases respectively: one dimensional and 3D.

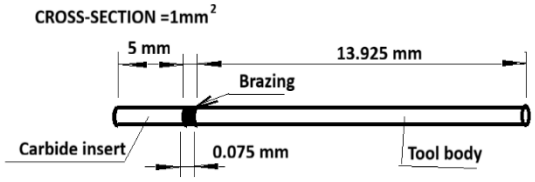


Fig. 1 – One dimensional problem

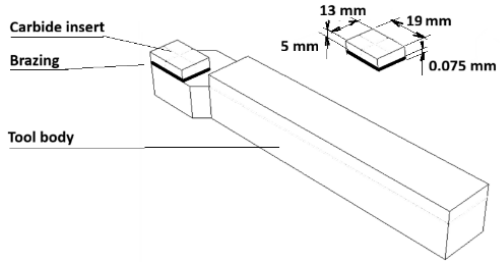


Fig. 2 – Geometry and dimensions of the brazed carbide insert

2.2 Theoretical Frame

The heat equation in the transient case is given as follows:

$$k_x \frac{\partial^2 T}{\partial x^2} + k_y \frac{\partial^2 T}{\partial y^2} + k_z \frac{\partial^2 T}{\partial z^2} = C \frac{\partial T}{\partial t} \quad (1)$$

where T – temperature, k_x, k_y and k_z – Coefficient of conductivity in respectively direction X, Y and Z, C – heat capacity.

When it comes into one-dimensional steady case, the Eq. (1) is reduced to the following expression:

$$k_x \frac{\partial^2 T}{\partial x^2} = C \frac{\partial T}{\partial t} \quad (2)$$

where T – temperature, k_x, k_y and k_z - coefficient of conductivity in respectively direction X, Y and Z, C - heat capacity.

The analytical solution of differential Eq. (2) is expressed by:

$$T(x) = Ax + B \quad (3)$$

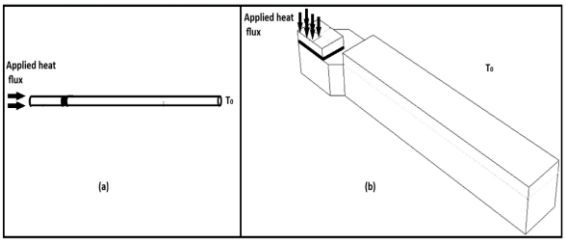


Fig. 3 – Loading and boundary conditions

The application is concretized by using a software of calculation which is Abaqus, to validate the simulation we considered the one-dimensional steady case of heat transfer. The obtained results are compared to analytical ones, then we move to the key topic of this work which is the study of heat diffusion inside a brazing used to assembly the insert and the tool body. At this stage it should be noticed that we have varied the mesh several times and in all cases the results are the same which means that the approach has converged and the results could be considered accepted.

The applied heat flux is given by Table 2.

The data related to the heat flux applied on the carbide insert, were supplied by the work performed by Haddag., et al [15]

Table 1 – Loading data

Case	Surface of application	Heat flux (W/m²)
One dimensional	Cross section (1 mm²)	10
Cutting tool	Limited surface (0.4 × 10) mm²	100

Typically, users ignore special styles, and prefer to use the default style «Normal».

3. RESULTS AND DISCUSSION

The results obtained after having performed the simulation are illustrated below.

3.1 One Dimensional Case

The analytical resolution of Eq. (3) and the numerical simulation of the given wire (Fig. 2) by using Finite Element Method Software, allowed us to obtain following results illustrated by (Figs. 4-6):

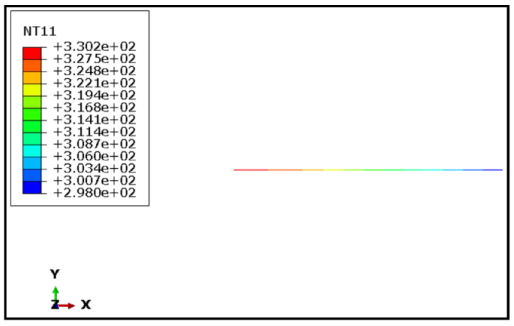


Fig. 4 – Distribution of temperature on the whole wire

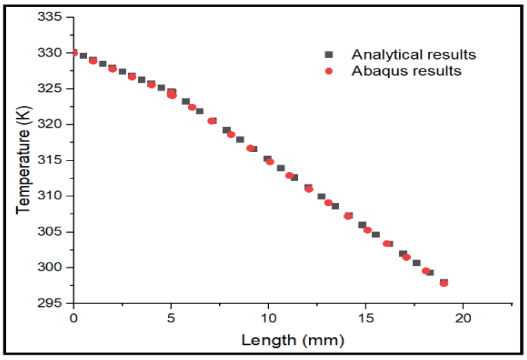


Fig. 5 – Evolution of temperature along the wire

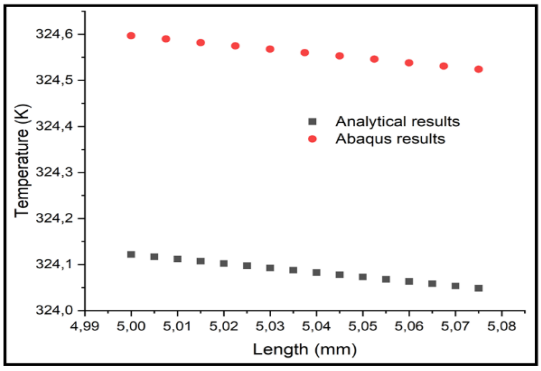


Fig. 6 – Evolution of temperature along the wire

The Fig. 5 shows a good agreement of numerical results with analytical ones. On the other hand, it is observed that the linear evolution of the temperature is more accelerated within the tool body (steel) than the carbide inserts, the slopes are respectively: – 1.11 and – 0.975. This could be explained by the existing differences between thermal properties. The Fig. 6 is complementary, it allows to see with details the distribution of temperature along the thin brazing. The slope is – 0.975 more accelerated than the carbide inserts this is due to the good properties of BAg-24 and the very short length of distribution of the temperature. The precision is about 0.146 % which is very acceptable.

3.2 Whole Cutting Tool

These results were obtained by simulating the cutting tool and the results are shown by figures (Figs. 6-9)

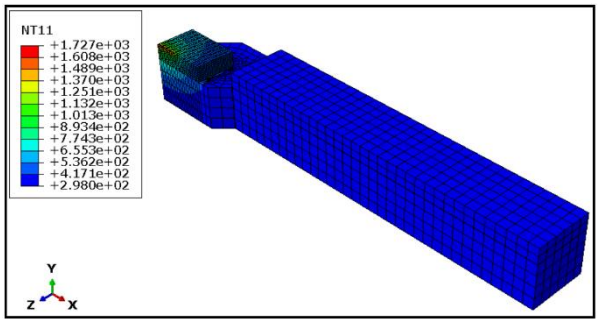


Fig. 7 – Distribution of temperature on the whole cutting tool

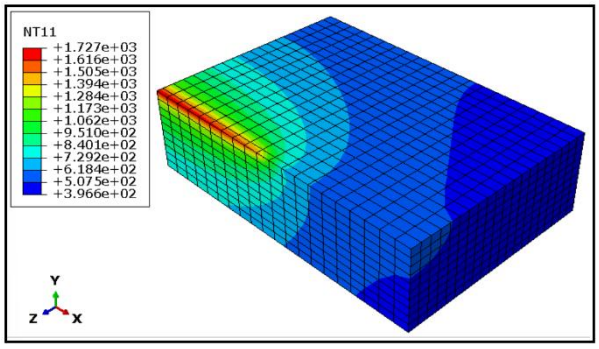


Fig. 8 – Distribution of temperature on the carbide insert

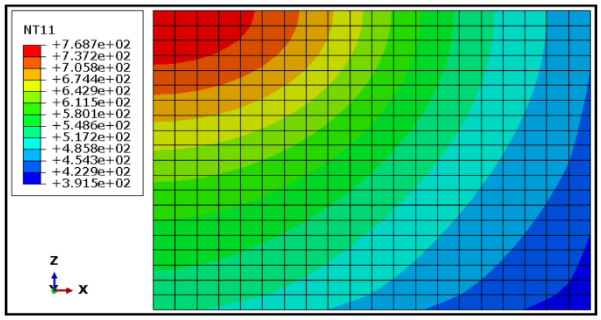


Fig. 9 – Distribution of temperature on the brazing

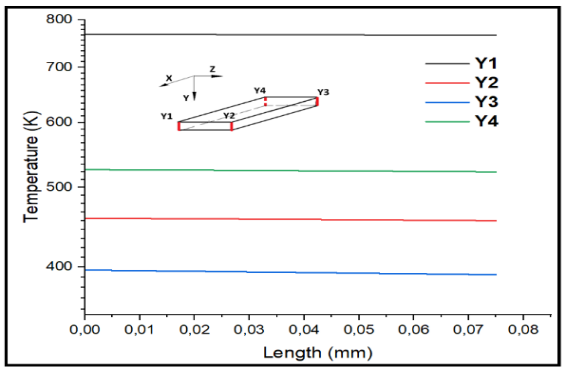


Fig. 10 – Evolution of temperature on vertical sides of the brazing

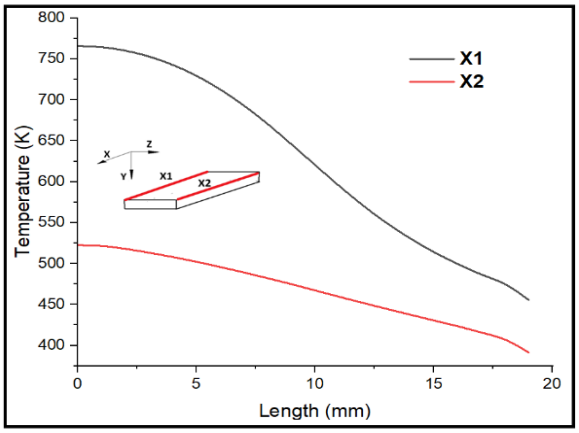


Fig. 11 – Evolution of temperature on longitudinal sides of the brazing

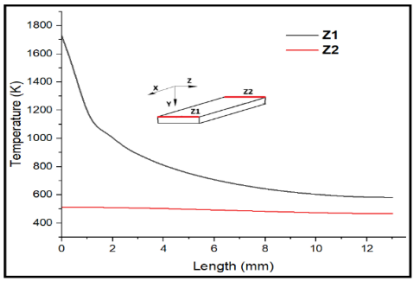


Fig. 12 – Evolution of temperature on transverse sides of the brazing

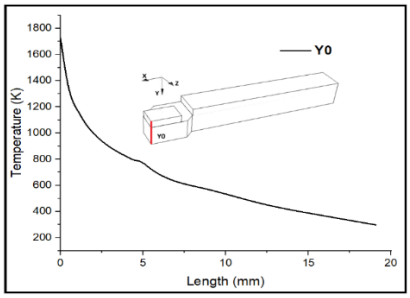


Fig. 13 – Evolution of temperature along the whole side

Figs. 7. and 8. show respectively the distribution of temperature on the whole cutting tool and the carbide insert, it reached 1727 K at the contact region. In the other hand the Fig. 9. shows isothermal circular regions, the maximum temperature is about 768 K.

The Fig. 10. illustrates that the distribution of temperature on the four vertical sides of the brazing is almost constant, but Fig. 11. shows a certain decreasing evolution of temperature along longitudinal sides. The transverse side shows a decreasing variation of temperature because it is closer to the applied flux but at the other transverse side there no evolution because it is a boundary.

When considering the whole side of the cutting tool, we observe an expected decreasing of temperature from 1725 up to 300 K

4. CONCLUSION

In this work we considered the cutting tool composed of carbide insert (Very heat resistant) assembled to the tool body by brazing. The brazing is about 0.075 mm of thickness, the study aimed to investigate the evolution of temperature through the brazing made of BAg-24 by using abaqus as a numerical simulation tool.

The simulation revealed that temperature reached a maximum equal to 768 K after having diffused through the interface between insert carbide and brazing which remains lower than the melting point of BAg-24 (879 K) and it should be noticed that cutting conditions generating a heat flux of 100 $W.m^{-1}.K^{-1}$ were hard.

The results look closer to practical and real values, the finite element method remains a powerful mean to perform an investigation.

Finally, the thermal behavior of thin layers could be modeled although their weak thickness.

DECLARATION OF COMPETING INTEREST

We have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Data will be made available on request.

AUTHORSHIP CONTRIBUTION STATEMENT

B. Meddour: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Supervision, Conceptualization, Project administration.

REFERENCES

1. J. Martan, P. Beneš, *Thermochimica Acta* **539**, 51 (2012) https://doi.org/10.1016/j.tca.2012.03.029.
2. L. Tang, C. Dames, *arXiv*. (Condensed Matter) (2023) https://arxiv.org/abs/2306.04960.
3. W. Grzesik, *Advanced Machining Processes of Metallic Materials: Theory, Modelling and Applications* (Elsevier: 2008).
4. M.M. Schwartz, *Brazing. 2nd Ed.* (*ASM International, Materials Park*: OH: 2003).
5. K. Bobzin, M. Öte, J. Hebing, *Welding in the World* **64** No 10, (2020) https://doi.org/10.1007/s40194-020-00928-w.
6. *Lucas-Milhaupt Brazing Experts. Considerations for Carbide Brazing. Lucas-Milhaupt Blog* (2016)
7. *Radyne Corporation, Induction Carbide Brazing. Radyne Blog* (2025)
8. V.A. Dutka, *J. Superhard Mater.* **30**, 128 (2008) https://doi.org/10.3103/S1063457608020081.
9. V. Bruyère, C. Durand, S. Roure, P. Namy, *Numerical modeling of induction brazing. COMSOL Conference Proceedings* (2023).
10. K. Bobzin, M. Öte, J. Hebing, *On residual stress issues due to temperature gradients inside braze gaps, underscoring need for internal thermal profiling* (2020).
11. W.D. Callister, *Materials Science and Engineering: An Introduction 9th Ed.* (John Wiley & Sons: 2014).
12. MatWeb Material Property Data https://www.matweb.com
13. Lucas-Milhaupt Technical Data – Silvaloy® 500 Series https://www.lucasmilhaupt.com/technical-resources/alloy-selector
14. G.S. Upadhyaya, *Cemented Tungsten Carbides: Production, Properties, and Testing* (Noyes Publications: 1998).
15. B. Haddag, S. Atlati, M. Nouari, M. Zenasni, *Heat Mass Transfer* **51**, 1355 (2015) https://doi.org/10.1007/s00231-015-1499-1.

Чисельне моделювання теплової поведінки тонких шарів – застосування до паяної вставки, встановленої в різальний інструмент

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Тонкі шари широко використовуються в техніці завдяки своїй важливій функціональній ролі на межах розділу матеріалів, зокрема в технологіях з'єднання та нанесення покриттів. Серед них ключовим процесом є паяння, що дозволяє створювати металургійний зв'язок між різнорідними матеріалами за допомогою розплавленого припою, забезпечуючи цілісність конструкції без розплавлення основних компонентів. У цьому дослідженні теплова поведінка тонких шарів, отриманих паянням, вивчалася з використанням комбінованого аналітично-чисельного підходу. Аналіз розпочався з розгляду одновимірної структури, змодельованої методом скінченних елементів (МСЕ) у програмному середовищі Abaqus для моделювання нестаціонарного теплопереносу. Чисельні результати продемонстрували відмінну узгодженість з аналітичними розв'язками, що підтверджує точність і надійність МСЕ для прогнозування зміни температури в шаруватих системах. На основі цієї верифікації метод було поширено на тривимірну модель паяного різального інструменту, що складається з твердосплавної пластини, припаяної до сталевого корпусу за допомогою припою на основі срібла. Результати моделювання показали розподіл температури в зоні паяння, підкреслюючи вплив властивостей матеріалів і геометрії на теплову реакцію з'єднання. Загалом, дослідження демонструє, що метод скінченних елементів є потужним і надійним інструментом для аналізу та оптимізації теплових характеристик паяних вузлів у різальних інструментах.

Ключові слова: Паяння, Сталевий корпус, Моделювання, Тепловий потік, Тонкий шар.