



**HAL**  
open science

## Thermal stresses in a ceramic-metal composites after brazing process

Vincent Cazajus, Sébastien Seguy, Bernard Lorrain, H. Weleman, Christian Prat, Moussa Karama

► **To cite this version:**

Vincent Cazajus, Sébastien Seguy, Bernard Lorrain, H. Weleman, Christian Prat, et al.. Thermal stresses in a ceramic-metal composites after brazing process. The International Conference on Structural Analysis of Advanced Materials, Sep 2005, Bucarest, Romania. hal-03273521

**HAL Id: hal-03273521**

**<https://hal.science/hal-03273521>**

Submitted on 1 Jul 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# THERMAL STRESSES IN A CERAMIC-METAL COMPOSITE AFTER BRAZING PROCESS

Cazajus V.<sup>1,2</sup>, Seguy S.<sup>1</sup>, Lorrain B.<sup>1</sup>, Weleman H.<sup>1</sup>, Prat C.<sup>2</sup>, Karama M.<sup>1</sup>

<sup>1</sup>Ecole Nationale d'Ingénieurs de Tarbes – Laboratoire Génie de Production,  
47, Avenue d'Azereix - BP 1629 – 65016 TARBES Cedex, FRANCE, [vczajus@enit.fr](mailto:vczajus@enit.fr)

<sup>2</sup>Société des Céramiques Techniques, BP 9 - 65460 BAZET - FRANCE

**Abstract.** The framework of this study is the thermo-mechanical analysis and the simulation of brazing process of ceramic and metal composites. Brazing is a welding process which produces the coalescence of materials by heating them to a suitable temperature and by using a filler metal, having a liquidus below the solidus of the base materials. The difference between ceramic and metallic materials coefficient of thermal expansion (CTE) leads to the development of residual stresses during cooling from brazing to room temperature which reduce the bond strength. The design of joints in engineering structures and the optimization of the industrial brazing process require to determine and to analyze such a phenomenon. In this way, the present work aims at first characterizing the progress these thermally induced stresses and then, at creating a numerical model able to predict their development in the ceramic-metal assembly during the brazing process.

**Keywords.** Ceramic-metal assembly, Residual stresses, Brazing process, FEM.

## 1. Introduction

During the production cycle of the ceramic-metal assembly, the difference between ceramic and metallic materials coefficient of thermal expansion (CTE) leads to the development of residual stresses during cooling from brazing to room temperature. It was found that the residual stresses induced by such a thermal expansion gradient could reduce the bond strength by initiating fractures on the interfaces [1;2]. Many studies have been carried out to estimate the residual stresses and improve the bond strength. Many analytical and

numerical analyses [2-7] have been used to calculate the residual stresses in the ceramic metal assemblies.

Residual stress distribution depends on the difference of coefficient of thermal expansion (CTE) and the elastoplastic properties of the components and on the joining, geometrical and cooling conditions. These main parameters of the brazing process, which influence the residual stresses, have been identified and analysed with the ABAQUS code. The results show that stress concentration occurs near the ceramic-filler metal

interface, which corroborates the experimental observations [6]. During cooling, the stresses increase gradually up to a value limited by the plastic yield stress of the filler metal.

## 2. Numerical model

The simulation conditions have to be defined according to the process to create a numerical model able to predict the residual stresses development in the ceramic-metal assembly. The figure 1 describes the cooling conditions of the brazing process.

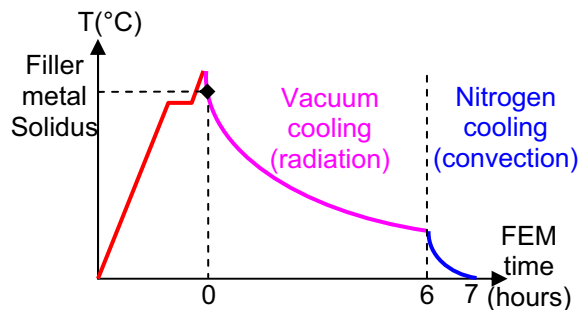


Fig. 1. Cooling conditions of brazing process

The node temperature according to time is given by a thermal analysis with the ABAQUS code. Initial simulation temperature is the filler metal solidus temperature after brazing stage. As the assembly is brazed in a controlled atmosphere furnace, the boundary conditions have to be defined according to the process. First, as the assembly is in vacuum atmosphere until a low cooling temperature, the boundary condition applied to its external surface is the furnace temperature. Then, cooling is accelerated by introducing nitrogen into the furnace; the boundary condition applied to the external surface of the assembly turns into the convection flow.

From this thermal analysis, the node temperatures obtained according to time are introduced in the mechanical analysis to obtain the stress-strain response. The thermal analysis effect on residual stresses is discussed with the uniform cooling hypothesis: all the node temperatures are assimilate to the furnace temperature according to time and introduced in the

mechanical analysis. Residual stresses responses with the thermal analysis and the uniform cooling hypothesis are compared.

The brazing process numerical simulation is now possible by modeling physical phenomena like thermal transfers, metallurgical changes and mechanical behaviours. Figure 2 gives the physical phenomena involved during brazing and their coupling relations.

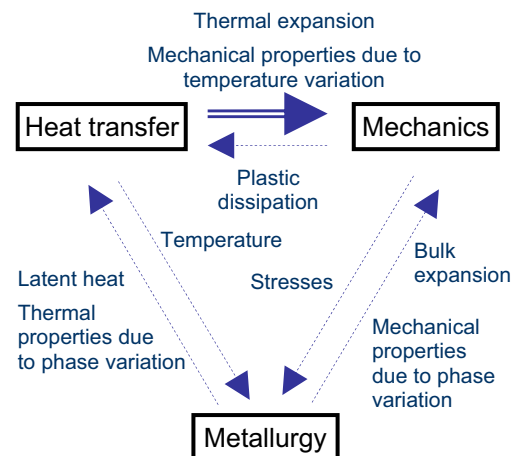
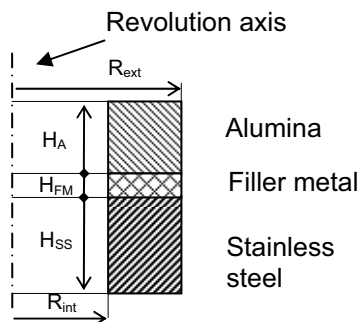


Fig. 2. Physical phenomena during brazing process and their couplings

The dashed lines represent physical mechanisms, which are neglected in our study. Ceramic, metal and filler metal haven't a metallurgical transformation after the filler metal solidification (Initial simulation temperature). The metal is an austenitic stainless steel what has no metallurgical transformation during the cooling from brazing to room temperature. There is no mechanical loading on the ceramic metal assembly, so the plastic dissipation is neglected and the thermal and mechanical analyses are uncoupled.

The assembly geometry (Figure 3) for this study is a cylinder. The model for the simulation is axisymmetric 2D. The bond between ceramic and metal component is a plane (disc area). Geometrical effects on residual stresses are carried out with factorial analysis. The geometrical parameters are the height of each component: alumina ( $H_A$ ), filler metal ( $H_{FM}$ ), stainless steel ( $H_{SS}$ ) and the internal ( $R_{int}$ ) and external radius ( $R_{ext}$ ) of the cylinder.

For a full cylinder the internal radius value is null ( $R_{int}=0$ ).



**Fig. 3. Geometrical parameters of the ceramic metal assembly**

Two two-level factorial analyses are performed to examine the impact of geometrical parameters on the Von Mises stress maximum value of the assembly, one for the full cylinder design ( $R_{int}=0$ ) and another one for the pipe design ( $R_{int}\neq 0$ ). In the factorial experiments, the maximum stress value is calculated for sixteen different assembly models where four factors are each assigned two levels. The factors and their levels are described in table 1-a. for the full cylinder ( $R_{int}=0$ ) and in table 1-b. for the pipe design ( $R_{int}\neq 0$  and  $H_{FM}=0.1\text{mm}$ ).

**Table. 1. Geometrical factors level (mm)**  
 a) full cylinder design – b) pipe design

a)	-1	+1	b)	-1	+1
$R_{ext}$	15	30	$R_{int}$	6	8
$H_{SS}$	10	20	$R_{ext}$	10	14
$H_{FM}$	0,05	0,15	$H_{SS}$	20	40
$H_A$	10	20	$H_A$	20	40

The ratio between the alumina and stainless steel height ( $H_A/H_{SS}$ ) represents an important factor. The filler metal height ( $H_{FM}$ ) maximum value is limited by the brazing process.

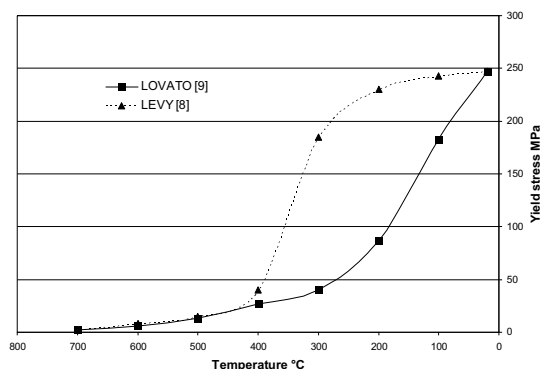
Materials behaviour depending on temperature has an important influence on the residual stresses distribution. Concerning the dependence of material behaviour on temperature, the ceramic is known to be linear elastic and its parameters have been identified through ultrasonic tests at room temperature. In opposition, the metal and the filler metal

exhibit elastoplastic behaviour depending on temperature [8;9]. Full bibliographic mechanical and thermal properties (table 2) are available for alumina (A), stainless steel (SS) and the filler metal (FM).

**Table. 2. Mechanical and thermal properties of each component depending on temperature**

Young's modulus E (GPa)							
T(°C)	20	100	200	300	400	500	600
A	330	330	330	330	330	330	330
FM	79	79	79	79	79	79	79
SS	193	191	183		168		148
Poisson coefficient $\nu$ (.10-2)							
T(°C)	20	100	200	300	400	500	600
A	26	26	26	26	26	26	26
FM	33	33	33	33	33	33	33
SS	22	27	27		31		37
Thermal expansion coefficient $\alpha$ (.10-6K)							
T(°C)	20	100	200	300	400	500	600
A	7,9	7,9	7,9	7,9	7,9	7,9	7,9
FM	20	20	20	20	20	20	20
SS	19	19	19	19	19	19	19
Yield stress $\sigma_Y$ (MPa)							
T(°C)	20	100	200	300	400	500	600
FM	247	183	87	40	27	13	6
SS	247	243	169	148	136	133	125

The residual stresses distribution of an elastic model and a plastic model are compared. Two yield stress evolution depending on temperature (Figure 4) are studied to understand their effect on residual stresses distribution, evolution and maximum value.



**Fig. 4. Filler metal plastic yield stress evolution depending on temperature**

### 3. Residual stresses

#### 3.1. Effect of the material constitutive laws

Figure 5 presents the evolution of the stress along the free side surface. It appears that the hypothesis of an elastic behaviour over-estimate the residual stresses. In this case the stresses are four times more important than those with the elastoplastic model. Simulation cannot be carried out in linear elasticity. Moreover, there are no difference for the residual stresses results between the perfect plasticity and the hardenable plasticity hypotheses. The work hardening model for the plastic strain stainless steel has a very low impact on the stresses values. In this simulation, the plastic strains are limited. The filler metal yield stress value is the most important material property to estimate the residual stresses values on the ceramic metal assembly. The perfect elastoplastic model appears to be the more suitable for the residual stresses estimation.

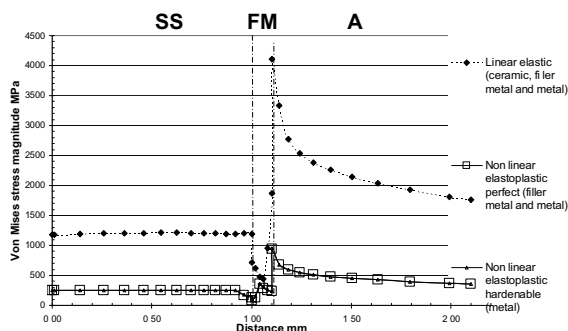


Fig. 5. Stress distribution along the assembly free side surface

In the high temperatures range (over 400°C) materials are less rigid, and upper their yield stress value there is flow of material. This result is true for the filler metal whose yield stress value at high temperature is very low, (13 MPa at 500°C). The filler metal flow at high temperature limits the stress growth on the other components of the ceramic metal assembly. The filler metal is an interface between two materials which accept the shearing strains created by the thermal expansion coefficient difference between the alumina and the stainless steel part.

In the low temperatures range (under 300°C), the materials are more rigid. Thus, the filler metal and stainless steel have the same plastic yield stress value (247 MPa at 20°C). The stresses increase at low temperature when the interlayer metal loses its ductility.

The residual stresses evolution follows the pattern of the filler metal plastic yield stress during cooling (figure 6). The residual stress value is limited by the plastic yield stress of the filler metal. The most important data is the plastic yield stress at 20°C, because the two different evolutions lead to a maximum stress difference of 20 MPa.

The yield stress evolution depending on temperature has a significant impact on residual stresses evolution during the brazing process but not on their final values.

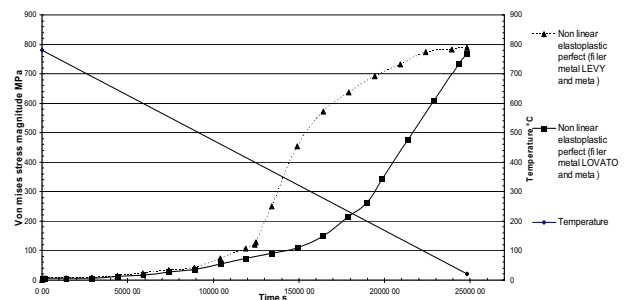


Fig. 6. Maximal stress evolution depending on filler metal plastic properties

#### 3.2. Effect of the cooling conditions

The thermal gradient in the ceramic metal assembly is low (3 at 5°C) during cooling simulation for the perfect conduction and for the radiation and convection hypotheses ( figure 7).

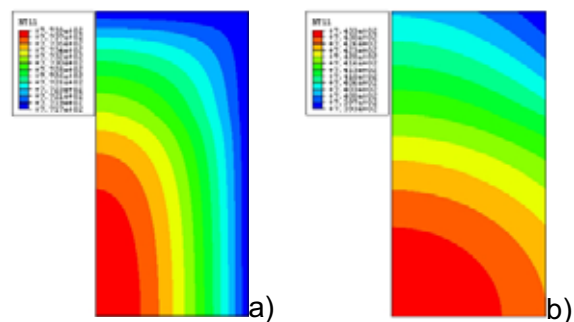
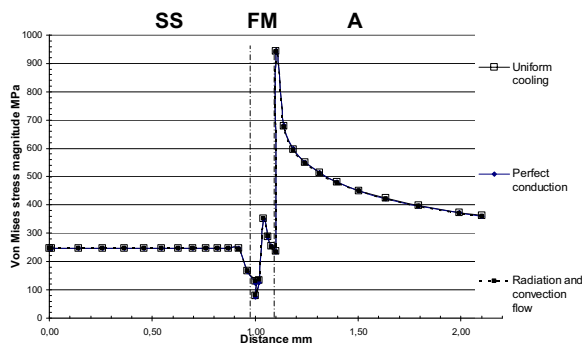


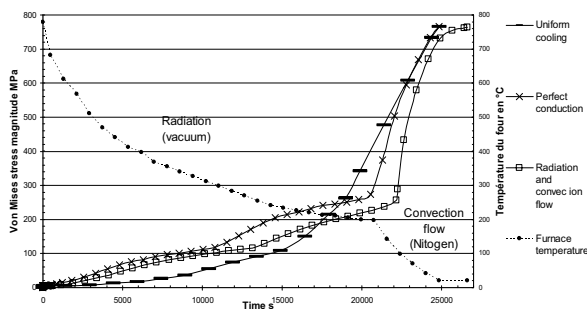
Fig. 7. Heat gradient a) perfect conduction - b) radiation and convection

Residual stresses responses with the thermal analysis and the uniform cooling hypotheses are the same (figure 8); the curves are perfectly identical for the two cooling conditions.



**Fig. 8. Final stress distribution along the free side surface depending on cooling conditions**

The thermal analysis shows that the heat gradient value in the ceramic metal assembly is very low, so this gradient has a significant impact on the residual stresses evolution and distribution during cooling but not on their final values (figure 9).



**Fig. 9. Maximal stress evolution depending on cooling conditions**

### 3.3. Effect of the geometry

The effects of the geometry are described in table 3-a. If the alumina height ( $H_A$ ) and the part radius ( $R_{ext}$ ) are increased, the stresses in the assembly will increase, because the effect is positive. Then, if the filler metal ( $H_{FM}$ ) and stainless steel height ( $H_{SS}$ ) increase, the stresses in the assembly will decrease with a smaller effect. These results are qualitatively interesting; nevertheless it's difficult to braze a high thickness of alumina. These results are correlated by existing data [7]. The maximum stresses are obtained for the biggest alumina and stainless steel height ratio ( $H_A/H_{SS}=2$  for  $H_A=+$  and  $H_{SS}=-$ ). The filler metal height ( $H_{FM}$ ) maximum value is

limited by the brazing process, so its impact on residual stresses is limited.

For the pipe design ( $R_{int} \neq 0$ ), alumina and stainless steel height don't have an important impact on the residual stress because the effects are very low. But if the internal radius ( $R_{int}$ ) increases, the stresses decrease, and if the external radius ( $R_{ext}$ ) increases, the residual stresses increase. For this geometry, it is necessary to limit the pipe thickness to limit the residual stresses.

**Table 3. Factors effects**  
a) full cylinder design – b) pipe design

a)	$R_{ext}$	$H_{SS}$	$H_{FM}$	$H_A$
<b>Effects</b>	13073,5	-1753,2	-408,6	16294,3

b)	$R_{int}$	$R_{ext}$	$H_{SS}$	$H_A$
<b>Effects</b>	-84,57	127,01	-1,82	-1,39

## 4. Conclusion

The following conclusions can be drawn for the different parameters effects on residual stresses during the brazing process simulation.

Mechanical behaviour and geometrical parameters have a significant influence on the residual stresses distribution and their maximum values. The difference between ceramic and metallic materials coefficient of thermal expansion (CTE) and the metallic materials elastoplastic properties are the most important parameters of the assembly mechanical behaviour. The ratio between the alumina height and stainless steel ( $H_A/H_{SS}$ ) represents the most important geometrical factor.

The cooling conditions and the filler metal yield stress evolution depending on temperature have only a significant impact on the residual stresses evolution during the brazing process and not on the final value.

## References

1. Zhang, J X., Chandel, R S., Chen, Y Z., Seow, H.P. - Effect of residual stress on the strength of an alumina-steel joint by partial transient liquid phase (PTLP) brazing, *Journal of Materials Processing Technology*, 122, pp.220-225, 2000.
2. Charles, Y. - Identification d'un mode de vieillissement dans un assemblage céramique-métal, Thesis, Ecole Normale Supérieure de Cachan, 2002.
3. Hsueh, C H., Evans, A G. - Residual stresses in metal-ceramic bonded strips, *Journal of the American Ceramic Society*, Vol. 68, No. 5, 241-248, 1985.
4. Yu, H Y, Sanday, S C, Rath, B B, - Residual stresses in ceramic-interlayer-metal joints, *Journal of the American Ceramic Society*, Vol.76, No.7, pp.1661-1664, 1993.
5. Iancu, O T., Munz, D., - Residual stress state of brazed ceramic/metal compounds, *Journal of the American Ceramic Society*, Vol.73, No.5, pp.1144-1149, 1990.
6. Santacreu P O. - Sur la mécanique des assemblages: calcul des contraintes résiduelles dans les assemblages céramique-métal obtenus par brasage réactif et caractérisation mécanique des interfaces, Thesis, Ecole Polytechnique, 1994.
7. Munz, D., Sckuhr, M A., Yang, Y. - Thermal stresses in ceramic-metal joints with an interlayer, *Journal of the American Ceramic Society*, Vol.78, No.2, pp.285-290, 1995.
8. Levy A. - Thermal residual stresses in ceramic to metal brazed joints, *Journal of the American Ceramic Society*, pp. 2141-2147, 1991
9. Lovato G. - Rhéologie des joints brasés : étude expérimentale et détermination par méthode inverse, Thesis, Ecole Nationale Supérieure des Mines de Paris, 1995.