Study Thermal Residual Stresses in a Bi-material Ceramic-Metal: Case of the Both Ag/Al_2O_3 and Pt/Al_2O_3.

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Abstract

In this paper, the evaluation of thermal residual stresses in Silver-Alumina and Platinum-Alumina assembly realized by solid state bonding, is carried out using the finite elementanalysis. The variation of the normal and shear thermal residual stress are evaluated near the interface of the bimaterials . The effect of the temperature gradient on the distribution of thermal stresses are highlighted. The mechanical resistance to fracture of the ceramic/metal assembly mainly depends on the intensity of residual stresses which are created after the elaboration process of the bimaterials. The obtained results show that the thermal residual stresses depend on the variation of the thermal expansion factor, the temperature of elaboration.

1 Introduction

When a ductile metal is combined with brittle ceramic matrix, the resulting structure can retain the high yield strength of a ceramic while exhibiting an enhanced resistance to fracture, this makes the bimaterials potential candidate for high performance structural applications Kolhe and al [1]. However the presence of residual stresses resulting from the elaboration process is primarily due to the difference between the coefficients of thermal expansion, decreases in a significant way the resistance of the bimaterials and can cause its fracture. The need of the evaluation of the thermal stresses, particularly at the interface of the bimaterials is important for a good knowledge of the mechanical behavior of these kinds of assemblies.

Several authors used the analytical and numerical models to evaluate the thermal stresses in the vicinity of the interface of bimaterials. The majority of the analytical models developed the concept of force equilibrium in computing thermal stresses Chen and Nilson [2]. Madenci and al [3] , Blanchard and Waston [4] , Kokini [5], Barsoum [6] have used the numerical methods, particularly the finite element method, for evaluating the thermal residual stresses in bimaterials.

The realization of the Silver-Alumina and Platinum-Alumina are made in a solid state. The mechanical resistance of this assembly depends primarily on the conditions of its elaboration, particularly on the atmosphere of elaboration. The fracture resistance is generally determined according to the nature of atmosphere of the elaboration of this kinds of junction Serier [7], Bailley and Black [8]. The Platinum and the Silver are noble metals and by reacting with the alumina do not gives an intermediate compound. Assembly of these metal with alumina non reactive junction.

For an accurate study of the thermal residual stresses we consider the case of non-reactive junction, for which only the effect of the difference of the coefficients of thermal expansion of the two bonded materials (Ag/Al_2O_3) and (Pt/Al_2O_3) is considered.

Young's Modulus of the Alumina , the Silver and the Platinum are very different and the Young's modulus of the Platinum is approximately twice highest that the Silver. The coefficient of the thermal expansion dilation of Alumina is comparable to that of Platinum and it is approximately twice weaker to that of Silver.

The present work deals with the distribution of the thermal residual stresses at the bimaterials interface and in the vicinity of the junction in both bimaterials assembly Pt/Al_2O_3 and Ag/Al_2O_3. The distribution of these thermal stresses is analyzed while varying the temperature gradient.

2 Determination of residual thermal stresses at the interface

Let us recall that the importance of the difference between the physical properties and conditions mechanical resistance properties of these bimaterials and particularly the resistance to the rupture of the interface and the Alumina in the vicinity of the interface Serier [9].

Stresses appear in any material subjected to a variation in temperature gradient. In the case of bimaterials, the stresses arise during the variation of temperature because of heterogeneity of the thermal expansion factor in particular during the cooling of the assembly from its temperature of elaboration.

The analysis of junction stresses ceramic-metal remains an important technological problem. The knowledge of the intensity and the distribution of the residual stresses in bimaterials metal-ceramics type is very determinant to evaluate the feasibility of the junction or its maintaining in service.

The distribution and the evaluation of the thermal residual stresses is realized by a numerical simulation with the finite element Franc2D. The structure was meshed with eight nodes quadrilateral elements.

2.1 Distribution of the residual thermal stresses at the interface

For reason of symmetry only the quarter of the structure is analyzed and the study of the distribution of the residual stresses was determined respectively as schematized on the figure 1, along the vertical 1 and 2.

The residual stress distribution shows that the Silver is in traction while the ceramics is in compression. Maximal Stresses are found to the level the interface but in the vicinity of the free edge ; far from the free edge the stresses σ_{xx} are negative. In alumina at the vicinity of the interface, the stresses σ_{xx} are negatives (compression stresses). The maximum stress are located at the free and they decrease from the edge to the center of the specimen. Inversely , the stresses σ_{xx} are positive in the silver near the interface and the maximum stresses are located at the center of the specimen. The couple σ_{xx} in the couple Pt/Al_2O_3 presents a similar behavior but the intensity of the σ_{xx} thermal stresses is negligible for this couple compared with the couple Ag/Al_2O_3 (Figure 2). This is due to the fact that the thermal coefficients of expansion of platinum and alumina are comparable.

Figure 2 shows the variation of the residual stresses in these two couples for position 1 and 2, that silver is in tension whereas ceramic is in compression.

The distribution of the residual stresses shows that at the edge silver and platinum are in compression whereas ceramics is in traction. The maximum stresses of compression are in silver in the vicinity of the edge and the maximum stresses of traction are in ceramics in the vicinity of the edge; far from of the edge the stresses become positive in metal. Figure 3 represent the variation of the normal residual stresses σyy for positions 1 and 2. We notice that in the case of the couple Pt/Al_2O_3 these stresses are almost null, whereas in the couple Ag/Al_2O_3 they are very significant. They show clearly that the stresses are very intense at the edges (in position 2) and decrease while moving away of this position (position 1).

On the figure 4 we represented the distribution and the level of the shear stresses in the xy plan. The most important stresses are localized on the level of the edge of junction to the interface. The stresses decrease when one moves away of the edge of assembly, for position 2 towards position 1. We notice that for the two couples the residual stresses are very important at the edge (position

2) and lower intensity as on when one moves away edge. They are minimal in the center of the specimen (position1). We will note however that the shear residual stresses σxy are extremely low in the case of the couple Pt/Al_2O_3.

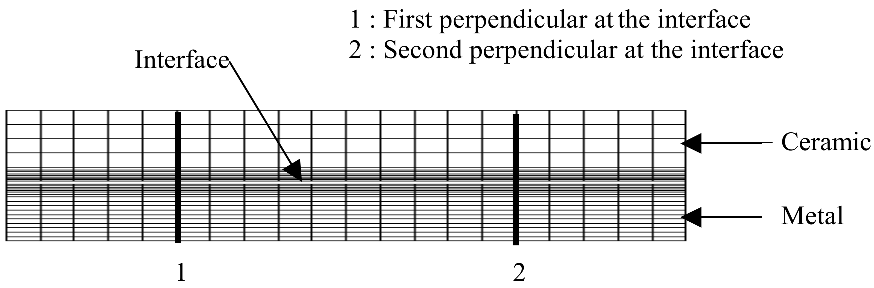

Figure 1 : Finite element mesh of structure near the interface

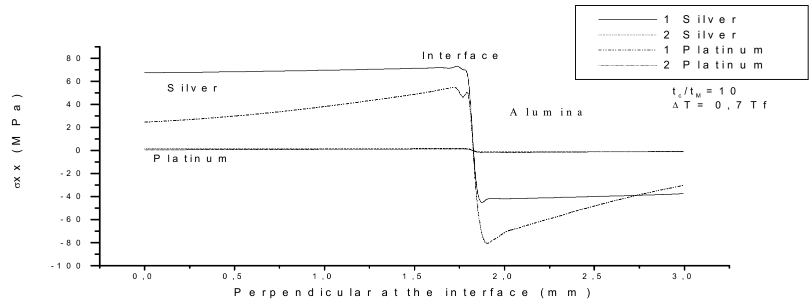

Figure 2 : Variation of the thermal residual stresses σxx for the both bimaterials.

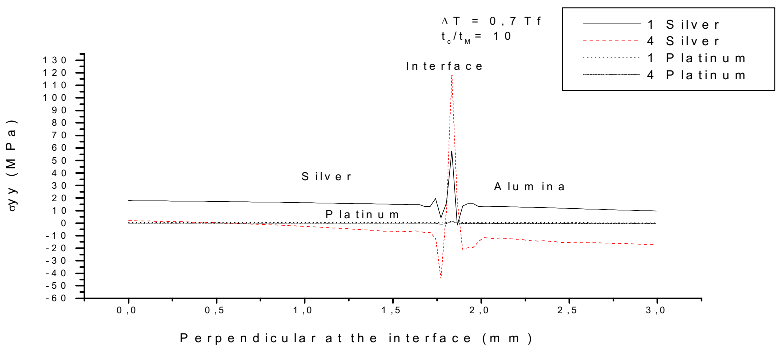

Figure 3 : Variation of the thermal residual stresses σxyy for the both bimaterials.

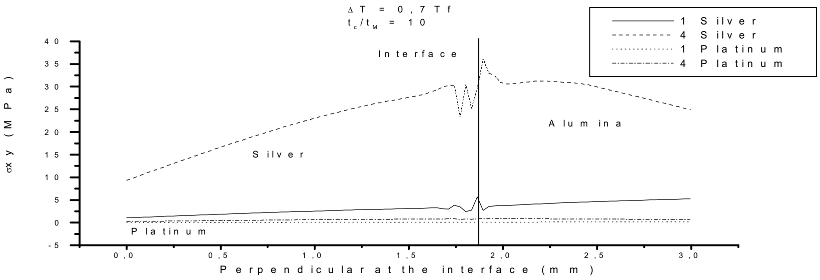

Figure 4 : Variation of the shear residual stresses σxy for the both bimaterials.

2.2 Effect of the temperature

The effect of the temperature on the resistance of metal-ceramic assembly is investigated. Indeed, the temperature operates many mechanisms and in particular it is the cause of the modification of the mechanical properties of metal by lowering its yield stress involving a modification of the conditions of deformation of metal. It activates the phenomena of surface diffusion (in volume and surface) evaporation-condensation. It is the most important parameter of creep of silver and Platinum. The mechanical properties of silver and Platinum are strongly decreased hot. The temperature allows the dilation of two materials constituting the assembly.

In the majority of the cases an increase in temperature led to an increase in the mechanical resistance of the junction but produces residual stresses due to the difference of the coefficients thermal expansion of alumina with the two respective metals Silver and Platinum. The junctions Pt/Al_2O_3 and Ag/Al_2O_3 are elaborate at high temperature. Their cooling of this temperature at the ambient temperature generates residual stresses because of the difference in thermal dilation coefficient of these metals and alumina. We represented on figures 5,6,7 the variation of the normal residual stresses σxx, σyy and the shear residual stresses σxy according to the temperature of elaboration of the couples Pt/Al_2O_3 and Ag/Al_2O_3. We notice that the intensity of the residual stresses σxx, σyy and σxy depends on the difference of temperature (temperature of elaboration and ambient temperature). The intensity of the stresses in alumina and in silver in the vicinity of the interface increases with increase temperature of solid state bonding. The highest residual stresses are generated by high temperatures and more particularly those close to the melting point of silver. In the case of the couple Pt/Al_2O_3 the residual stresses σxx, σyy and σxy almost do not depend on the temperature. Their variation according to this parameter is negligible.

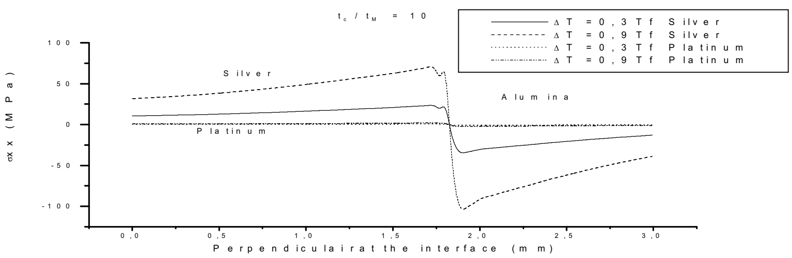

Figure 5 : Variation of the thermal residual stresses σxx vs temperature for the both bimaterials.

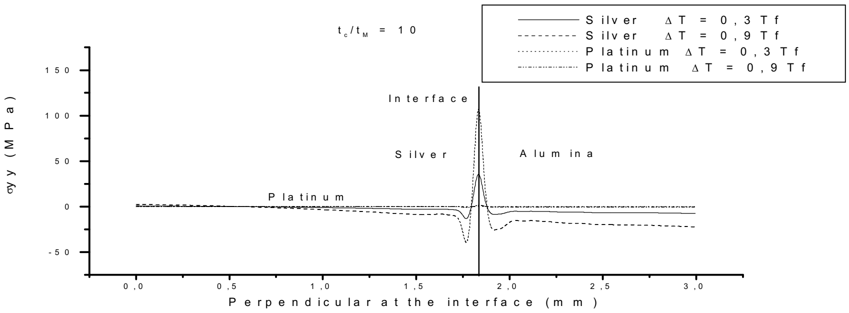

Figure 6 : Variation of the residual thermal stresses σyy vs temperature for the both bimaterials.

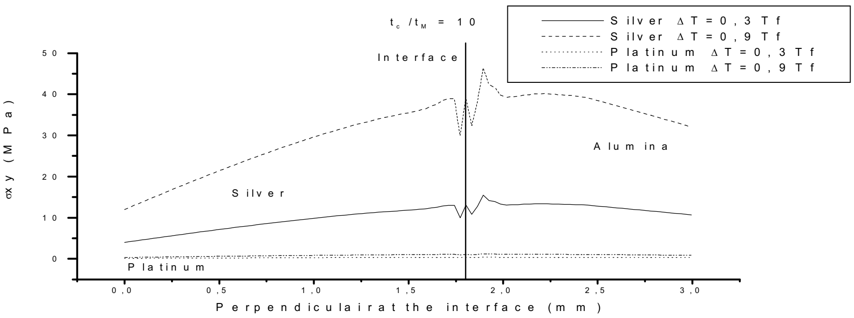

Figure 7 : Variation of the thermal residual stresses σxy vs temperature for both bimaterials.

3 Discussion

The amplitude of the normal and shear residual stresses and their distribution close to the interface of metal-ceramic junction are a function of the dimension of the assembly Serier [7], thickness of the metal and his work hardening, the Young modulus of two involved materials Kolhe and al [1] and more particularly of the difference in their physical properties in particular of the difference in their coefficients thermal of dilation . The junctions Pt/Al_2O_3 and Ag/Al_2O_3 were elaborated under an oxidizing atmosphere. The silver and platinum are noble materials and do not react chemically with alumina. The junction is known as not reactive and alone mechanical fixing and thermodynamic adhesion condition the mechanical resistance of interface Serier [7]. Our work carried on study by finite elements of the residual stresses created by the difference of the coefficients of thermal expansion of silver and alumina and those of platinum and alumina. Does this study show clearly that the cooling from the temperature of elaboration of these assemblies to the ambient temperature (ΔT) led the creation of the normal residual stresses σxx and σyy and of the shear stresses σxy. The amplitude of these stresses located in alumina and silver in the vicinity of interface grows with ΔT, whose sign is a function of the difference $\Delta\alpha=\alpha_{(Ag)} - \alpha_{(Al2O3)}$. These stresses cause a tension of silver and a compression in alumina. The most significant stresses are those created according to axis x (σxx), their amplitude is stronger in silver which has a coefficient of thermal expansion approximately twice larger than that of alumina. These stresses are more intense with the close vicinity of the interface far from the edge of the junction, where the breaking stresses of assembly are maximum and the rupture is cohesive. At the edge, zone where the breaking stresses of the connection are weaker and the rupture are adhesive, the stresses are the least intense. The level of compression is located on alumina close to the edge of assembly close to interface Barsoum [6], Yamada et al [10]. The couple Pt/Al_2O_3 whose thermal dilation coefficients are comparable almost does not lead to the creation of the residual stresses origin thermal and this whatever are its temperature of elaboration.

This allows ensure an intimate contact between these two materials and to accelerate adhesion thermodynamically. This adhesion leads to strong junctions and thus to more important residual stresses. The residual stresses σyy are affected too much by increase of thickness being given only the pressure applied for elaboration of assembly is done according to axis y. The residual stresses depend of the physical properties of assembly. The residual stresses whose intensity depends on the difference of temperature ΔT. They cause a cohesive rupture in alumina with stresses much lower than the breaking stress of alumina no related to a metal. They also lead to an important fall of the factor critical intensity of stress of alumina in the vicinity of interface Ferenc and Tomaszewski [11], thus being able to support starting and the propagation of crack under weak loading.

4 Conclusion

Our study shows that the residual stresses depend: - strongly of the difference of the physical properties of silver and alumina, i.e. difference in their dilation coefficients thermal. The intensity of these stresses and in particular the normal residual stresses σxx grows with increase of the variation in temperature. These stresses put silver in tension and alumina incompression. Let us note however that the Pt/Al_2O_3 couple whose two materials present comparable dilation coefficients thermal does not lead to the creation of residual stresses

5 Reference

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