

Effect of Thermal cycles and Dimensions of the Geometry on Residual stress of the Alumina-Kovar Joint

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Abstract: Finite element method is employed to determine the effect of variation of residual stress with dimension and the stress generated under its working condition along the Kovar. 3 different dimensions of Alumina-Kovar joint with height to diameter ratio of 3/10, using TiCuSil as a filler material. Transient Structural Analysis is carried out for three different dimensions (diameter× height) (i) 60mm× 20mm (Geometry 1) (ii) 90mm × 20mm (Geometry 2) (iii) 120mm × 20mm (Geometry 3). A comparative study has been carried out between the residual stresses developed in the brazed joint that have undergone 5 thermal cycles subsequent to brazing and that between the brazed joint. The heating and cooling rates from the brazed temperature is 10°C/ up to room temperature. The brazing temperature and holding time considered for the analysis are 900°C and 10 minutes. Representative Volume Element (RVE) model is used for simulation. Sparse Matrix Direct Solver method is used to evaluate the results, using Augmented Lagrange method formulation in the contact region. All the simulations are performed in ANSYS Workbench 15.0, using solver target Mechanical APDL. From, the above simulations it is observed high concentration of residual stress is observed along the filler region i.e. in between Alumina and Kovar, as a result of difference in coefficient of thermal expansion between Alumina and Kovar. The residual stress decreases with increasing dimensions of the geometry and upon application of thermal cycles, subsequent to brazing.

Keywords: Finite element method, residual stress, brazed joint, thermal cycles, RVE model

1. Introduction

Superior mechanical properties, corrosion resistance, thermal stability, electronic insulation, relatively low manufacturing cost and chemical inertness of Al_2O_3 ceramic has grabbed the attention in electronics, aerospace, nuclear, automotive, biomedical and tool industries for years [1-3] (Table 1). However the brittleness and processing inefficiency of Al_2O_3 has restrained its widespread application [4]. The primary prerequisite for broadening the dimensions of application, is to reliably join Al_2O_3 ceramic to metals [5,6]. Such kind of dissimilar material joining is highly challenging, as the difference in Coefficient of Thermal Expansion (CTE), chemical properties and Modulus of Elasticity (MoE) between the joining components, results in generation of residual stress [7,8]. This invokes technical and scientific community to perform extensive research for mitigating thermal stress in Al_2O_3 -metal joints. Different bonding/joining methods such as active brazing, ultrasonic brazing [9], friction welding [10], explosive welding [11], diffusion bonding [12],



transient liquid phase bonding [13], ultrasonic nano welding [7] are generally used for joining Al_2O_3 and metal. Among these methods active brazing is considered as the most applicable method to join Al_2O_3 to metal owing to its cost-effectiveness, requirement of relatively low joining temperature, superior bonding properties [14] and good flexibility with respect to shapes of joining components [15-17]. However, difference in thermal and mechanical properties leads to generation of thermal stress develops near a ceramic-metal interface both during fabrication and application. This phenomenon can deteriorate the strength of active brazed Al_2O_3 -metal joint [18].

Table1. Probable application of Metal-Alumina brazed joints

Ceramic/Metal/Filler			Applications	References
Ceramic	Filler	Metal		
Al_2O_3	Ag-Cu-Ti	TiAl	Fabrication in nuclear reactor	[19]
Al_2O_3	Ag-Pd-Ti	Kovar	Hydrogen separation from natural gas	[20]
Al_2O_3	Ag-ABA	Inconel	Electrical feed through in neutron sensors	[21]

A true understanding of deformation behavior of metal-ceramic brazed joint and its dependence on brazing parameters are highly necessary. In order to determine the strength of the metal-ceramic brazed joint it is important to determine variation in residual stress of the joint with variation in various brazing parameters such as heating and cooling rates, brazing temperature, brazing cycles (heating-cooling cycles). In this regard Finite Element Analysis (FEA) is an effective tool to determine an optimum range of brazing parameters for achieving highest mechanical strength. Various investigators have attempted the Finite Element Analysis of ceramic-metal joints to study the effect of various geometrical shapes of the joining components, thickness of interlayer, coefficient of thermal expansion of various interlayer and brazing parameters [18, 22-24]. In this paper, we have attempted to carry out the Finite Element Analysis of Alumina-Kovar brazed joint using Ticusil filler and study the effect of thermal cycles and diameter of the joining components.

2. Model description

Continuum models are considered for calculation of residual stress that is developed in a joined Al_2O_3 -Kovar specimen, when brazed and then cooled down to room temperature. Since non-uniform cooling is considered in this simulation study therefore equations of temperature and stress equilibrium both are solved. Dissimilar materials are assumed to be perfectly bonded at the interfaces. Numerical solutions are obtained employing Workbench 15.0. Workbench 15.0 employs finite element method to obtain the solutions to the partial differential equations in Lagrangian form. Quadrilateral elements are considered for all the simulations with

quadratic interpolation and reduced integration. All the materials are assumed to be elastic.

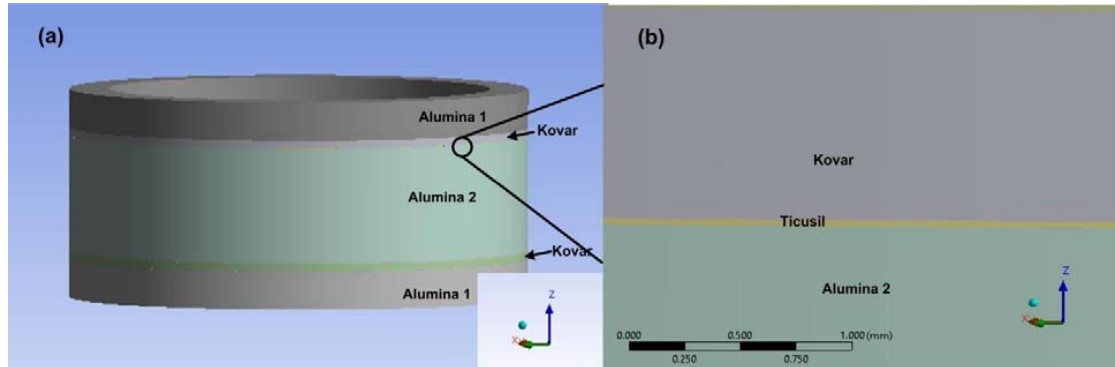


Figure 1. Geometry construction (a) Alumina-Kovar annulus ring (b) Magnified portion showing Ticusil filler

to be perfectly elastic in this current simulation study. Transient thermal analysis is opted for determining the temperature distribution across the body as a result of brazing, at the end of brazing process. Static structural analysis is carried out for determining the residual stress across the body. 3D geometries (refer to Figure 1) are created for the simulation, in ANSYS Workbench as per the dimensions given in Table 2.

Table 2. Dimensions of the various geometries

Dimensions of various geometry	Inner Diameter (mm)	Outer Diameter (mm)	Kovar Thickness (mm)	Filler Thickness (mm)	Alumina 1 Thickness (mm)	Alumina 2 Thickness (mm)
Geometry No.1	50	60	1	0.03	5	10
Geometry No.2	75	90	1	0.03	5	10
Geometry No.3	100	120	1	0.03	5	10

Material properties considered for the simulation are given in Table 3.

Table 3. Properties of Alumina Kovar and TiCuSil

Properties of materials	Alumina	Kovar	TiCuSil
Young's Modulus(in GPa)	350	138	85
Poisson's Ratio	0.22	0.317	0.36
Density(kg/m ³)	3900	8350	9400
Coefficient of Thermal Expansion(/°C)	8.4e-6	11.5e-6	18.5e-6
Thermal conductivity(W/m°C)	3	17.3	219
Specific Heat(J/Kg°C)	880	481.6	280

Following geometry creation comes the meshing, which involves dividing the whole geometry into small elements, as shown in Figure 2.

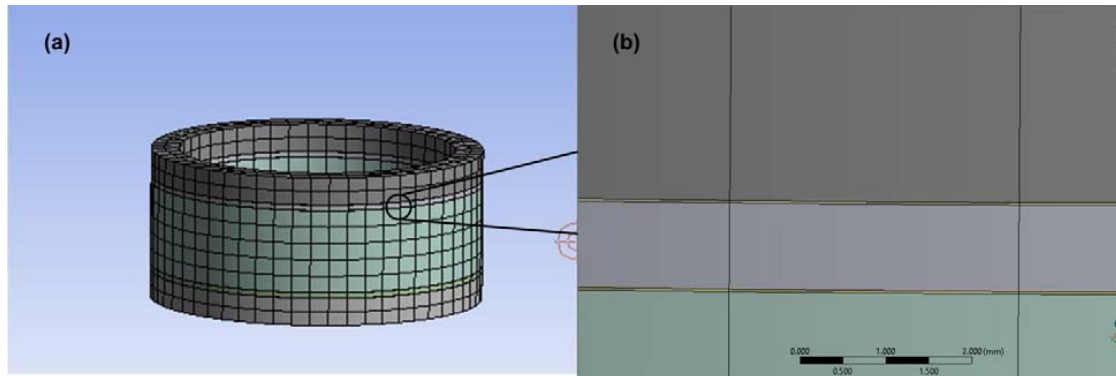


Figure 2. Typical finite element mesh for an interlayer calculation (a) entire mesh (b) near the interlayer Alumina-Kovar- interface showing interface

The size of the mesh determines the simulation time of the program. After meshing requisite boundary condition are applied for carrying out the analysis. Sparse Matrix Direct Solver method is used to evaluate the results and Augmented Lagrangian formulation is applied here for contact formulation. For carrying out thermal analysis a heating rate of 10°C/min is applied to the outer surface of all the components 30°C-900°C, with a holding time of 10minutes at 900°C subsequently cooling the whole assembly back to 30°C. The optimized operating parameters have been chosen on the basis of various literature reviews which will be applied to the experimental conditions carried out in the near future. For carrying out the structural analysis the displacement of top and bottom faces of the assembly is constrained along the Z-axis. Gravitational force is applied in the negative Z direction the whole body, as would be constrained by the sample holder in the brazing furnace. The application of load and boundary condition is presented in Figure 3.

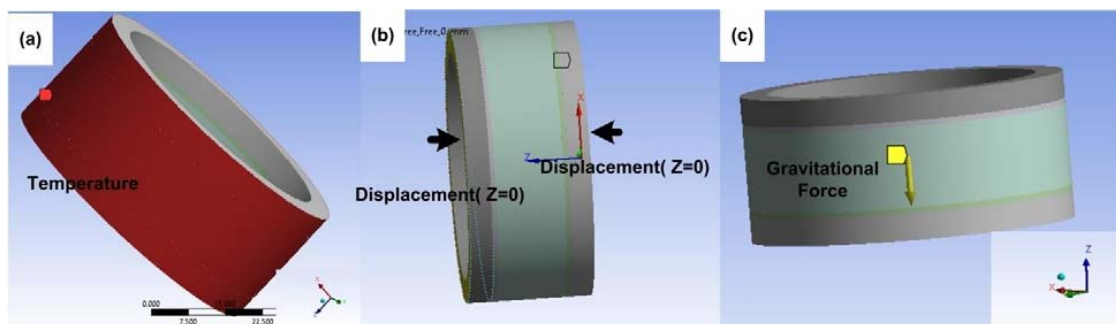


Figure 3. Application of load to the geometry (a) Thermal load during Transient Thermal Analysis (b) Application of zero displacement on both end faces during Static Structural Analysis (c) Application of Gravitational force during Static Structural analysis

To study the effect of thermal cycles on residual stresses three sets of simulations are carried out. One at the end of brazing process followed by cooling, one after conducting 5 thermal cycles between 600°C and

200°C subsequent to brazing followed by cooling to room temperature and the last one after conducting 10 thermal cycles between 600°C and 200°C subsequent to brazing followed by cooling to room temperature. The heating and cooling rates are given in Table 4.

Table 4. Brazing parameters for the analysis

Brazing Temperature(in °C)	Holding Time(in °C)	Heating/ Cooling Rate(°C/min)
900	10	10

The von-mises stress or the residual stress is determined according to the given below equation. The detail study of this criterion for von Mises yield criterion have been reported in literature [25-29].

$$F = \sqrt{J_{2D}} - \sigma_y = 0 \quad (1)$$

where, J_{2D} is expressed as the second invariant of deviatoric stress tensor, S_{ij} and σ_y are the yield stress in the simple tension

3. Results and Discussion

3.1. Variation of thermal stress with geometry

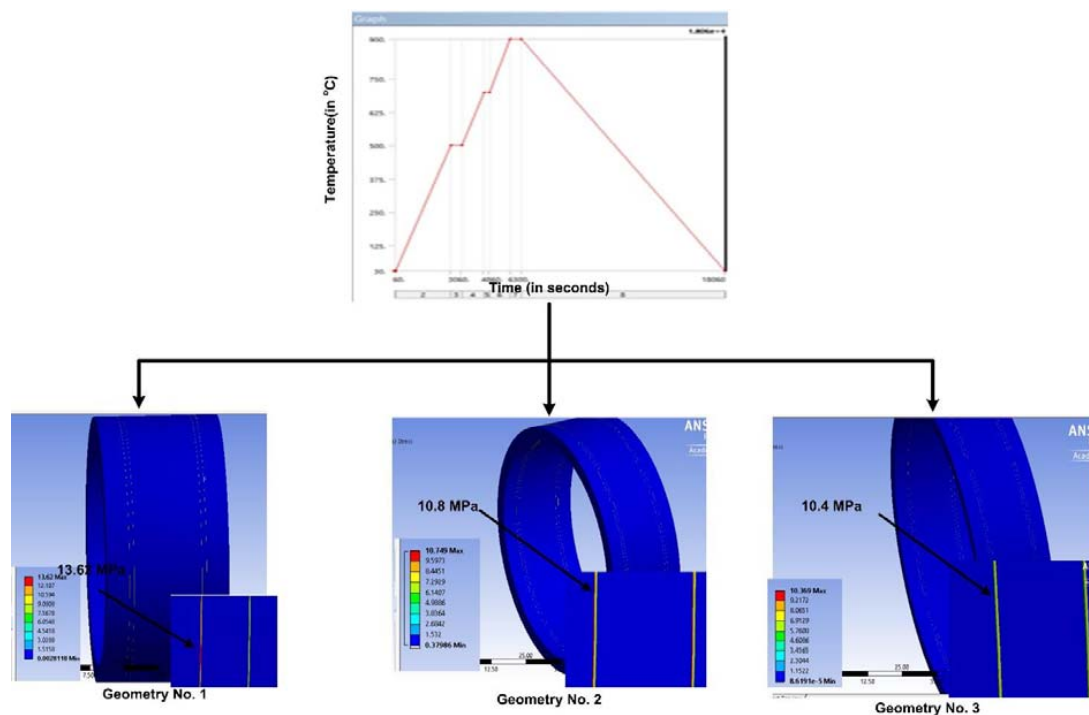


Figure 4. Variation of residual stress with varying geometry size

From the simulations (Figure 4) it is evident that the thermal stresses are high along the Alumina-Kovar joint owing to mismatch in CTE. It is also observed that the stresses are higher along the curvature. One keen observation however, the residual stress decreases with increasing diameter size. The decrement in residual stress might be due to decreasing curvature with increasing diameter.

3.2. Variation of thermal stress with thermal cycles

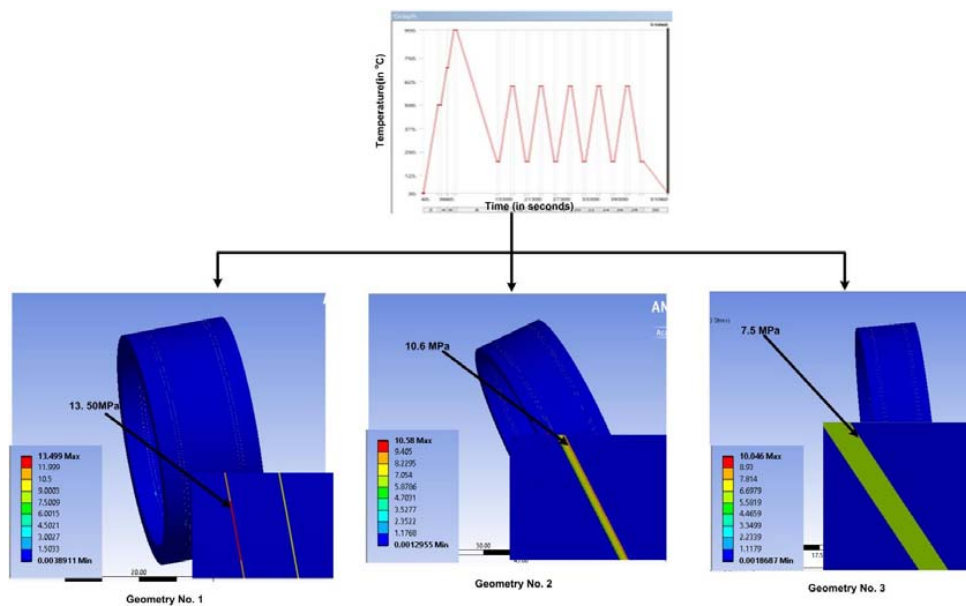


Figure 5. Distribution of residual stress after 5 thermal cycles

The residual stress decreases at the end of 5 thermal cycles (Figure 5) by an amount of 0.2 MPa for Geometry No. 1 and Geometry No. 2. However, for Geometry No. 3 decreases from 10.4 MPa to 7.5 MPa. Figure 6 shows the distribution of residual stress after 10 thermal cycles. It might be observed that the concentration of highest stress is not uniform across the filler. This might be due to the larger mesh size chosen for the study. A finer mesh may result in uniformity in stress concentration.

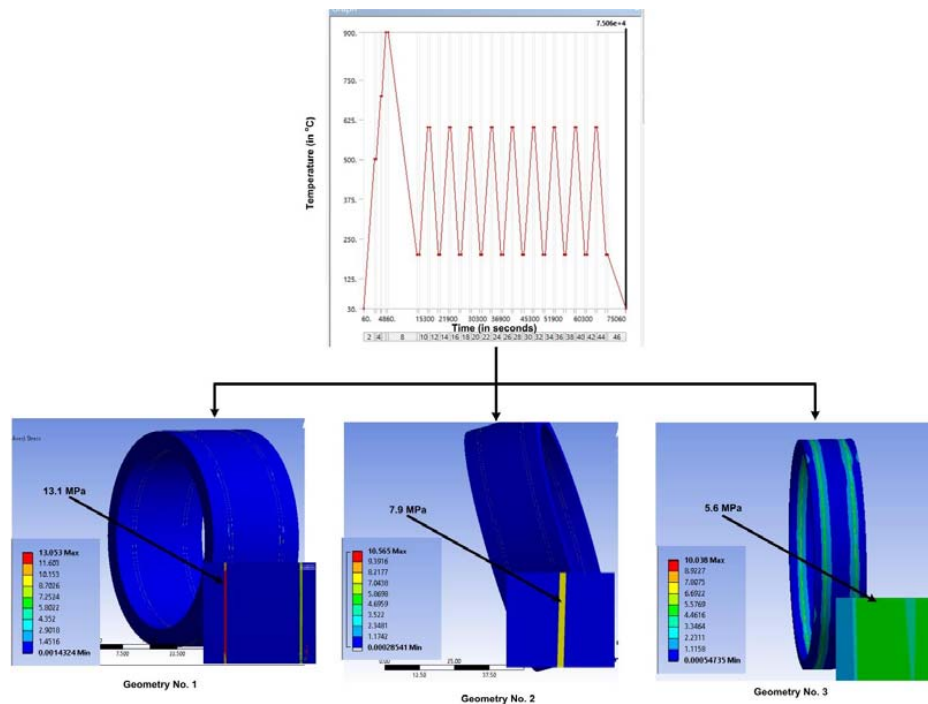


Figure 6. Distribution of residual stress after 10 thermal cycles

The application of cyclic heating cooling cycles leads to alleviation of residual stresses caused due to difference in coefficient of thermal expansion during cooling. A comparative study of effect of thermal cycles on the 3 geometry is given in Figure 7 for all the three geometries. It is evident from the graph that the effect of thermal cycles enhances with increasing diameter of the brazing components.

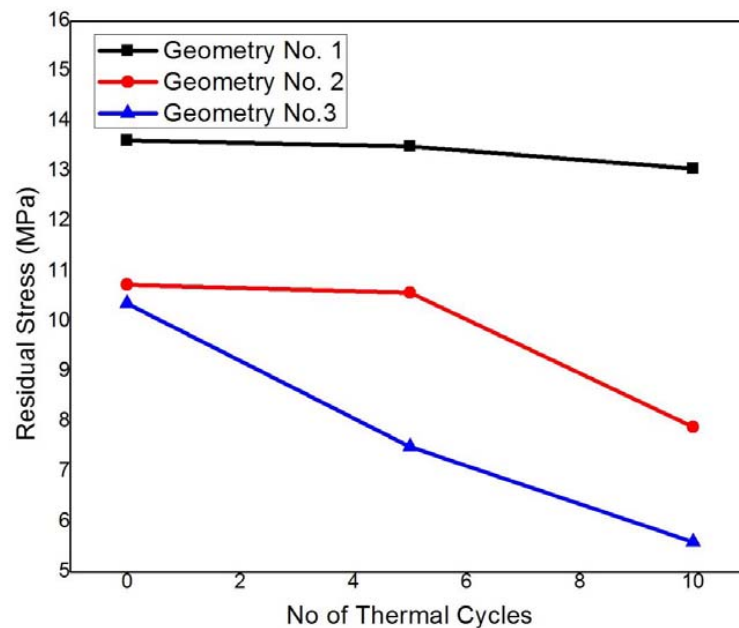


Figure 7. A comparative study of distribution of residual stress with varying geometry

4. Conclusions

Residual stress of the Alumina-Kovar brazed joint is carried out using Finite element analysis (Workbench 15.0) with varying geometry sizes and thermal cycles. The effect of geometry and thermal cycles on residual stress is determined. It is inferred that with increasing radius of the geometry and with increasing thermal cycles the residual stress decreases. With increasing radius the curvature of the geometry decreases as a result the residual stresses decreases. Similarly the stress generated due to CTE is released upon application of cyclic thermal cycles. The number of stress cycles may be increased to determine an optimum number of thermal cycles where the residual stress decreases to a minimum and thereby apply those number of thermal cycles in actual experimental conditions for the above mentioned geometry.

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