Analysis of Diffusion Bonding Using Finite Element Techniques
Sridhar P.V.S.S
PSG College of Technology
Ravishankar B and Thirumalai T
PSG College of Technology

Abstract
Diffusion bonding is a process by which two well-prepared surfaces are joined by the application of temperature, pressure and time. Temperatures applied varied from 0.5 to 0.8 of absolute melting of the lower melting point of the material in case of dissimilar materials. Pressures applied are a small fraction of room temperature yield strength to avoid macroscopic deformation. Times can be from few minutes to several hours. Surface preparation plays an important role. Analysis is done by modeling the faying surfaces. The area fraction bonded obtained in FEM is correlated with experimental results. By this method we can reduce the number of experiments to obtain the poreless joint.

Introduction
The widely used conventional joining processes cannot overcome the incompatibility barrier inherent in metals, alloys and non-metals. The barrier has been cleared with vacuum diffusion bonding (Fig. 1). Diffusion bonding is an expensive process as well as a time consuming process. The interest in this paper is the diffusion bonding of like materials.

Figure 1 - Vacuum Diffusion bonding set up at PSG
Ti-6Al-4V a two Phase alpha, beta alloy has been taken for experimentation. In this paper analysis of a theoretical model for diffusion bonding with a simple surface geometry has been used. In this paper experiments are carried out and their results are correlated with theoretical values.

**Theory of Bonding Mechanism**

Pilling's model, formulated for superplastic materials under isostatic conditions is used to develop an FEM analysis (Fig.2). On the application of the external pressure 'p' the bulk of the each sheet remote from the bond zone will experience a uniform hydrostatic compression and hence will remain undeformed. In the bond zone, the point of contact will deform plastically until the contact area can support the load generated by the applied pressure on the upper and lower surfaces of the sheets.

![Figure 2 - Diffusion Bonding Specimens in 2D](image)

The area fraction of the bond zone in contact will be applied pressure divided by stress corresponding to onset of general plastic yield. The material does not behave elastically but rather in a time dependent plastic manner. Here the reduction in the area of the non-bonded interface during bonding can be visualized in terms of two component events. Firstly, the axial collapse of the cylindrical columns of (Ref. Modeling procedure), constant external radius (radius of the cylinders) by power law creep and superplastic flow, and secondly by the transfer of matter from the interfaces which intersect the free surface of the nonbonded area by diffusion. The creep rate in the cylindrical cell is controlled by the effective stress subject to the condition that external diameter of the cylinder remains constant owing to the
constraint imposed by undeforming material above and below the bond zone. The axial collapse of the cylinder would normally result in an increase in both the inner and outer radii of the cylinder by small amounts. The material in the cylinder walls beyond the outer radius can be removed and redistributed with in the bore of the cylinder, reducing the internal radius and restoring the external radius. The rate of bonding due to diffusive mass transfer is dependent on the size of the interfacial void. The value of external radius is defined by the roughness of the original surface.

The total rate change in the fractional area of interfacial voids with time, is a result of diffusion from the bond interface intersecting the surface of the void.

**Modeling Procedure**

The above said was the mechanism by means of which diffusion bonding occurs in like materials. In this present work analysis is carried out for 2D. The surface profile of the bonded sheets is assumed as symmetrical voids spread through out the surface of the sandwiched sheets. These voids are half cylinders on both sheets in reverse direction so as to form cylinders, when both sheets are brought together in contact. Initially the two sheets are assumed to be in point contact. These symmetrical voids are assumed to be uniformly spread through out the interface. The model is built in the following manner so that no complication arises during meshing. PLANE82 was found to be suitable element for both sheets. Upper and bottom sandwiched sheets are in contact so as to form the bond, with CONTAC12 a point to point element is used across the interface. The various data necessary are given from standard values for CONTAC12 element. In this work creep data was used to include the mechanism of powerlaw creep (because of higher bonding temperature) and plastic deformation data to consider plasticity effects.

**A Single Solution**

With the completion of the model, a combination of static as well as contact analysis is done to satisfy our problem. In experimental work both work pieces are rigidly fixed in a die and punch press from the upper side. In ANSYS effects of the die are ignored and only punch effects are considered. All sidewalls are constrained in the X direction, and the base is constrained in X-Y direction. The upper surface is constrained in the X direction. Uniform temperature is applied throughout. The time interval was chosen as 1 hour. Calculations are performed earlier to determine the load to be applied on the specimen. Pressure is applied from the upper surface, which is much less than the yield strength of the material. This process is repeated for various specimens. Upon confirming the boundary conditions, post processing calculations are performed.

**Results & Discussion**

In ANSYS results are viewed in the Postprocessing. Various results that obtained like area fraction bonded (Fig.3 and Fig.4), Von mises stresses (Fig.5), vectorial plot showing how stress transform during bonding for a specific condition (Fig.6).

![Figure 3 - Bonded specimen at 1223 k, 25 Mpa](image)
Figure 4 - Bonded Specimen at 1223 k, 25 Mpa

Figure 5 - Von Misses Stress Plot 1223 k, 25Mpa
Calculation of Area fraction bonded

Using the various constants from the standard literature [2] and mathematical equations, the bonded area fraction calculated for experimental work. The fraction area of the bond zone in contact will be

\[ F_a = \frac{P}{\sigma_{ys}} \]

Where \( P \) is the external pressure on each sheet and \( \sigma_{ys} \) is the stress corresponding to the onset of the general plastic yield. In ANSYS real value of stress exponent of creep and activation energy taken into consideration for obtaining the bonded area fraction (for equations Ref.1).

Experiments are performed in a PSG diffusion bonding set up and those results are correlated with ANSYS results. The correlation coefficient found to be 0.93 was reasonable, although the difference was 32% and 23% in some cases. A series of analyses are carried out to shorten the variation between practical and simulated results.

Assumptions

This paper does not take into account the effect of grain size, unmatching of the ridges and initial contact area.

Conclusion

In this effort, a method was developed to analyze the percentage of bonding between two similar materials herein, Ti-6Al-4V with all specimens under identical surface finish and profile. The analysis results also indicate the importance of using accurate material properties and method adoption.
**Acknowledgements**

I am highly indebted to our professors, Dr.S.S.Ramakrishnan Head of the Metallurgical Department and Dr.P.C.Angelo Head of the Materials Testing and Research Center of PSG College of Technology, for providing excellent infrastructural facilities as well as computational facilities during this present work.

**References**
