



## **EXPERIMENTAL STUDY OF DIFFUSION BONDING/SUPERPLASTIC FORMING OF DISSIMILAR ALUMINIUM ALLOYS**

**Nepoleon V<sup>1</sup>, Prakash P<sup>2</sup>**

*<sup>1,2</sup> Assistant Professor, Department of Mechanical Engineering, Vels Institute of Science Technology & Advanced Studies-Chennai*

---

**Abstract:** The objective of this project work is to reduce the weight of components along with high strength. The SPF/DB technology is a widely used manufacturing method in the aerospace industry for complex components with Ti-based or Al-based alloys. The SPF/DB process will be used to reduce part count as well as the number of fasteners, assembly time, and weight, leading to cost savings for the product. The combination of solid-state bonding and superplastic forming has been readily applied to aluminium alloys to produce aerospace structures at low cost. Effects of bonding temperature, holding time, and pressure on the bonded specimens will be studied. In order to examine the inter-diffusion of metal atoms across the bonding interface will also be studied. In addition, comparisons will be made for contact ratios of specimens bonded under various conditions.

---

### **I. INTRODUCTION**

#### **DIFFUSION BONDING:**

Diffusion bonding is only one of many solid-state joining processes wherein joining is accomplished without the need for a liquid interface (brazing) or the creation of a cast product via melting and resolidification (welding). In its most narrow definition, which is used to differentiate it from other joining processes such as deformation bonding or transient liquid phase joining, diffusion bonding (DB) is a process that produces solid-state coalescence between two materials at a temperature below the melting point  $T_m$ , of the materials to be joined (usually  $>1/2 T_m$ ).

#### **Applications**

Diffusion bonding is applicable to an array of markets including aerospace, medical, energy, chemical plant fabrications and electronics and communication industries. Diffusion bonding is the preferred joining method for a number of microchannel devices and photo etched laminates, gigahertz waveguides and antennas, corrosion resistant manifolds and heat exchangers.

#### **Limitations**

Great care is required in the surface preparation stage. Excessive oxidation or contamination of the faying surfaces would decrease the joint strength drastically. Diffusion bonding of materials with stable oxide layers is very difficult. Production of thoroughly flat surfaces and also precise fitting-up of the mating parts takes a longer time than with conventional welding processes. The suitability of this process for mass production is questionable, particularly because of the long bonding times involved.

### **II. SUPERPLASTIC FORMING**

Superplastic forming is a metal working process for forming sheet metal. It works upon the theory of superplasticity, which means that a material can elongate beyond 100% of its original size. It's a neck free elongation process where near net shape can be obtained under low flow stress and low strain rate. To begin with, the material must have an ultra-fine grain size. It is then heated up to promote superplasticity.

**Applications**

Products can also be made larger to eliminate assemblies or reduce weight, which is critical in aerospace applications. Automotive structural components by eliminating assembly operations such as nuts, bolts and fasteners. Jet engine nozzle blades in space propulsion.

**Limitations**

The major limitation is its slow forming rate. Cycle times vary from two minutes to two hours, therefore it is usually used on lower volume products. Also materials must not be superplastic at service temperatures.

In this paper diffusion bonding and superplastic forming has done parallelly in which selective areas are bonded and formed in the same die to form the honeycomb structure and the fixture is designed and fabricated accordingly. Here experiments are carried out in dissimilar Al alloys namely AA 5052 and AA 6061 of 1 mm thickness and the process parameters are forming temperature, forming pressure, bonding pressure and bonding time. Hardness of the bonded specimens are tested and microstructural observation is done using Scanning Electron Microscopy. Finite Element Method is adopted for identifying stress/strain distribution, thickness distribution and profile of the superplastically formed diffusion bonded components using ABAQUS software and to compare with the experimental results.

**III. EXPERIMENTAL SETUP**

**MATERIAL SELECTION:**

1. Aluminium alloy 5052 of 1 mm thickness
2. Aluminium alloy 6061 of 1 mm thickness

AA5052 is a non-heat treatable alloy that is weldable. It is hardened by cold work. It has good forming characteristics and good corrosion resistance, including resistance to salt water. This alloy has relatively fair machineability. It is easier to machine in the hard temper than as annealed and the quality of finish is better if machined in the hard condition. Oil lubricants should be used for machining, except that very light cuts may be done dry. AA 5052 is readily formed at room temperature. Successive cold working decreases the formability. AL 5052 cannot be hardened by means of heat treatment. It does harden due to cold working.

*Table 2.1 Chemical Composition of AA5052 Alloy*

S.No	Material	Composition
1	Aluminum	Balance
2	Chromium	0.15 - 0.35
3	Copper	0.1 max
4	Magnesium	2.2 - 2.8
5	Manganese	0.1 max
6	Remainder Each	0.05 max
7	Remainder Total	0.15 mx
8	Silicon + Iron	0.45 max

*Table 2.2 Mechanical Properties of AA5052 Alloy*

S.No	Properties	Values
1	Ultimate Tensile Strength	230 Mpa
2	Tensile Yield Strength	195 Mpa
3	Modulus of Elasticity	70-80 Gpa
4	Poisson's Ratio	0.33
5	Melting Point	649 °C
6	Hardness, Vickers	60 HB
7	Density	2.68 x 1000 kg/m <sup>3</sup>
8	Thermal Conductivity	137 W/m-k

AA6061 is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminium for general purpose use.

*Table 2.3 Chemical composition of AA6061*

Component	Amount (weight%)
Aluminium	Balance
Magnesium	0.8 – 1.2
Silicon	0.4 – 0.8
Iron	Max 0.7
Copper	0.15 – 0.40
Zinc	0.25
Titanium	Max 0.15
Manganese	Max 0.15
Chromium	0.04 – 0.35
Others	0.05

*Table 2.4 Mechanical properties of Aluminium 6061 alloy*

Temperatue	UTS(Mpa)	0.2%prof stress(Mpa)	Brinell hardness	Elongatin 50mm dia(%)
0	110-152	65-110	30-33	14-16
T1	180	95-96		16
T4	179 min	110 min		
T6	260-310	240-276	95-97	9-13

**Density:** 2.7 g/cm<sup>3</sup>

**Melting point:** Approximately 580°C

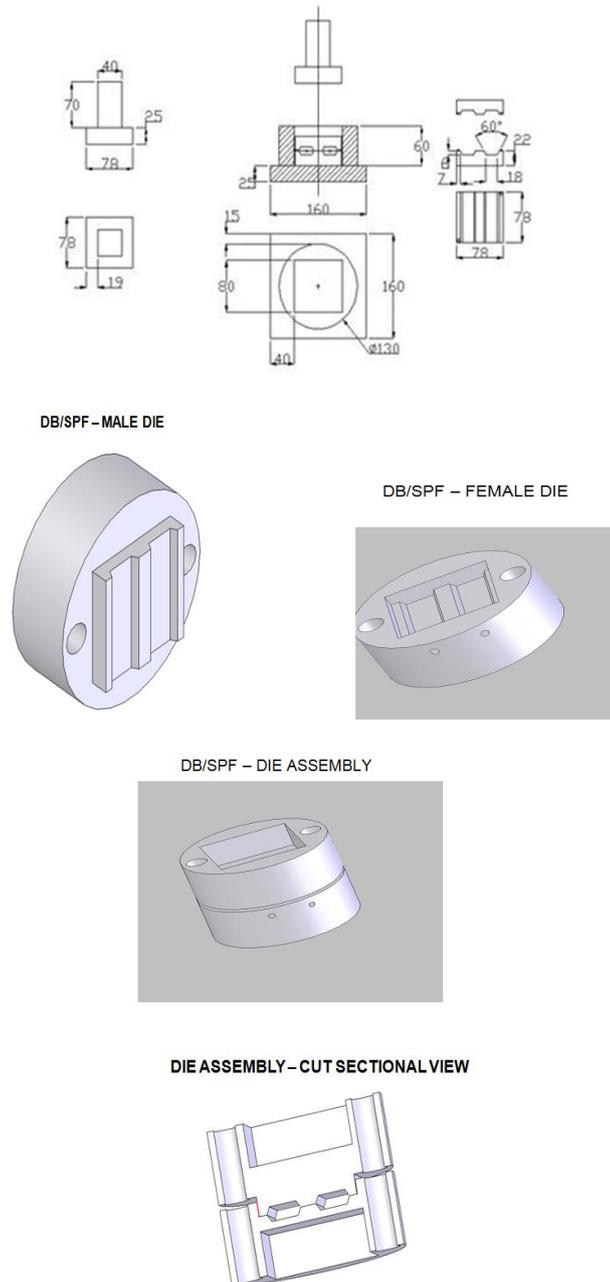
**Modulus of elasticity:** 70-80 Gpa

**Poissons ratio:** 0.33

**Material selection for Fixture Design:**

**HCHCR ( High Carbon High Chromium Steel )**

- High brittleness
- High corrosion resistance
- Withstand high load capacity
- Low economic cost



#### IV. EXPERIMENTAL PROCEDURE

Aluminium alloy 5052 of 1 mm thickness is cut into 78×78 cm square plates(2 specimens) for carrying out the experiment. Then the specimens are surface cleaned by fine silicon carbide emery sheet to achieve good bonding conditions. Then the specimens are set into the fixture and it is tightly closed by means of nuts and bolts. Then the fixture setup is kept into the superplastic forming furnace for subjecting it to a higher temperature. Mechanical load is applied on to the top of the fixture by means of screw press to achieve necessary bonding and it is calculated with the help of load cell. The temperature is set to 550 °C and it was maintained to 2 hours(120 minutes) with the help of temperature controller unit. Then superplastic forming at the selective areas are achieved by blowing compressed air via copper tubes which are brazed at the bottom die. Finally superplastically formed diffusion bonded specimens with honey comb structures are obtained. Then the specimens are tested by means of cutting the specimens using CNC Wirecut EDM Machine. Necessary bonding has been

achieved at the selective locations and a bonded sample is subjected to microstructural analysis. Formability studies were carried out at the selectively formed locations.

**Table 3.1 Bonding condition carried out in experiment**

Samples AA 5052 (1mm thick)	Bonding temperature (°C)	Bonding time (minutes)	Constant load for bonding (N)
1	550	120	4000
2	540	130	4000
3	530	140	4000

**Table 3.2 Forming condition carried out in experiment**

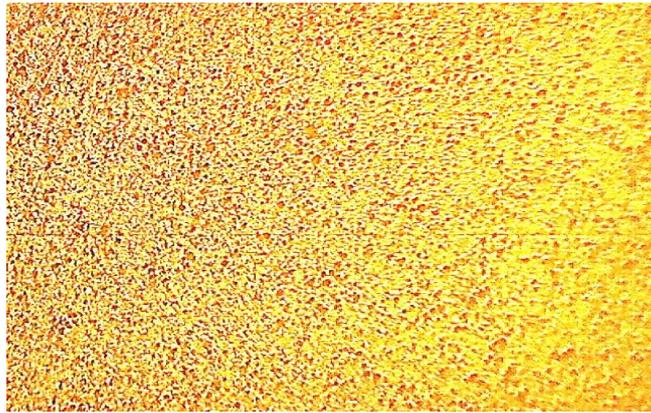
Samples AA 5052 (1mm thick)	Forming pressure (MPa)	Forming time (minutes)
1	0.2	45
2	0.3	60
3	0.3	75

## V. RESULT AND DISCUSSION

1. At the temperature of 550°C in 120 minutes with a constant load of 4000N, superior bonding is achieved and good formability conditions were attained at the pressure of 0.2 MPa in 45 minutes.
  2. At the temperature of 540°C in 130 minutes with a constant load of 4000N, superior bonding is achieved and poor formability conditions were attained at the pressure of 0.3 MPa in 60 minutes.
  3. At the temperature of 530°C in 140 minutes with a constant load of 4000N, poor bonding and formability conditions were attained at the pressure of 0.3 MPa in 75 minutes.
- Microstructural analysis are performed with ordinary metallurgical microscope and Scanning Electron Microscope and results were produced.



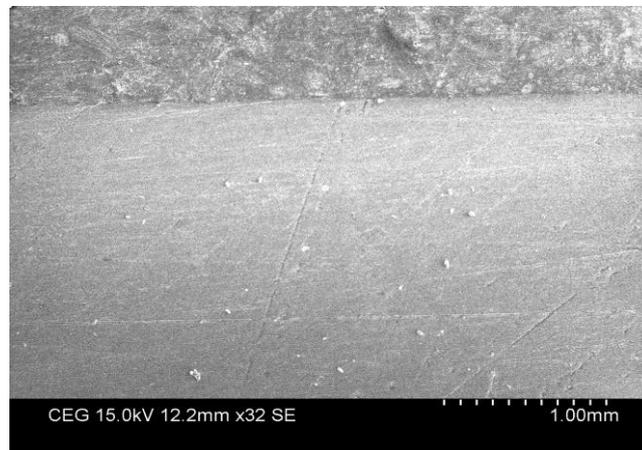
**Fig 4.1 shows the microstructural view of the bonded specimen. The oval mark indicates the interface bonding region which has to be disrupted to ensure enhanced bonding and eliminates metallurgical discontinuity.**



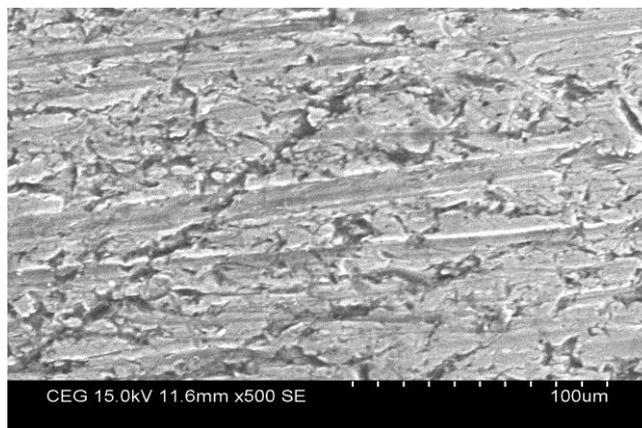
*Fig 4.2 shows the microstructure of the bonded specimen after etchant cleaning.*

Etchant used: Kellers Reagent (Mixture of Nitric acid, hydrochloric acid and hydrofluoric acid). Kellers reagent is mostly preferred for surface cleaning of aluminium alloys to prevent oxidation.

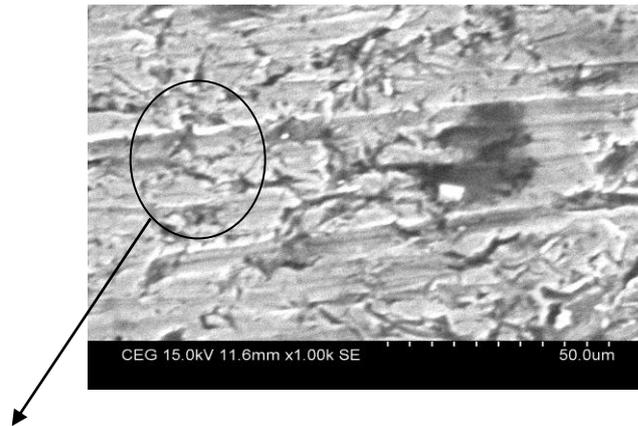
SEM images at the bonded locations are visualized at lower and higher magnification.



*Fig 4.3 SEM Image of the bonded specimen at lower magnification level*



*Fig 4.4 SEM image at higher magnification level*



*Fig 4.5 shows a slight metallurgical discontinuity at the interface grain boundary region.*

## VI. CONCLUSION

The Diffusion Bonding / superplastic forming experimental die setup has been designed and fabricated for the experimentation. The Aluminium alloy AA5052 and AA6061 has been identified for Diffusion Bonding experiment and procured. The chemical composition and microstructure has been performed for the AA5052 and AA6061 alloy and results had been shown. Experiment has been conducted for Diffusion Bonding of aluminium alloy AA5052, necessary bonding at selective regions are achieved and superplastic forming has been performed at the non bonded regions by supplying compressed air from the compressor via copper tubes which are brazed at the bottom die. Finally microstructural analysis and formability studies are carried out for the superplastically formed diffusion bonded specimens having honeycomb structures.

## REFERENCES

- I. AlHaza A., Khan, T.I. and Haq, I. "Transient Liquid Phase (TLP) bonding of Al7075 to Ti-6Al-4V alloy", materials characterization, pp.312 – 317, 2010.
- II. Anne Sunwoo and Reynold Lum, Lawrence Livermore National Laboratory, Livermore, California, USA. "Superplastic deformation enhanced diffusion bonding of Aluminium alloy '7475'" 1995.
- III. Bulent Kurt., Nuri Orhan., Ertan Evin. and Adnan Çalik. "Diffusion bonding between Ti-6Al-4V alloy and ferritic stainless steel", Materials Letters, pp.1747–1750, 2007.
- IV. Hidetoshi Somekawa, Hiroyuki Hosokawa, Hiroyuki Watanabe, Kenji Higashi "Diffusion bonding in superplastic magnesium alloys", Materials Science and Engineering, pp.328-333, 2003.
- V. Hidetoshi Somekawa A, Hiroyuki Watanabe B, Toshiji Mukai B, Kenji Higashi A, Material processing technology on "low temperature diffusion bonding in superplastic AZ31 magnesium alloy" 2003.
- VI. Horng-Yu Wu., Shyong Lee., and Yu-Hwang. "Genuine solid-state bonding characteristics of superplastic Al-alloys", Journal of Materials Processing Technology, pp.226–231, 2002.