DEVELOPMENT OF DIFFUSION BONDING JOINTS BETWEEN OXYGEN FREE COPPER AND AISI 316L STAINLESS STEEL FOR ACCELERATOR COMPONENTS

O. R. Bagnato[#], D. V. Freitas, F. R. Francisco and F. E. Manoel LNLS, Campinas, Brazil
T. Alonso, LNLS and USF, Campinas, Brazil

Abstract

Some of the characteristics of the diffusion bonding process between different materials are the non existence of plastic deformation and the absence of a region not thermically affected by the weld bead. That makes it a very interesting process for the production of components for particle accelerators. The process is being study at the LNLS aiming at the new developments related to the new SIRIUS light source. As part of the studies, samples of stainless steel were bounded to samples of stainless steel (SS), aluminium and copper under different conditions of time (30, 45 and 60 minutes), temperature (700 to 1100˚C) and applied load (ranging from 20 to 60kN). In this work we present the results of tests performed using the diffusion bonding welding performed at the LNLS. They point to a new method to produce components and accessories for particle accelerators and other equipments.

INTRODUCTION

The diffusion bonding process consists in applying a certain level of tension in the contact surface between the pieces that are intended to be joined when these elements are submitted to high temperature. The process fosters the interdiffusion of atoms through the contact surface, which is still in solid state [1].

The process shows some advantages when compared to other welding processes:

- It is capable of producing high quality junctions with virtually no, or none at all, discontinuity or porosity between the two surfaces.
- It allows the joining materials with different thermophysical characteristics, something not possible in some other conventional processes. Metals, alloys and ceramics have been welded by diffusion bonding.
- High precision components with complex cross sections can be produced without subsequent machining.
- The diffusion bonding process is free of ultraviolet radiation and emission of gases. So it is harmless either to the environment or to the health and safety of machine operators

It can be said that the diffusion bonding welding gives high quality to the joints, which may reach approximately the same mechanical strength of the base material. Welding parameters that must be considered are temperature, pressure, surface quality (surface roughness and sample preparation prior to welding), atmosphere (usually vacuum or inert gas) and diffusion time.

The purpose of this work was to show some of the various possibilities of diffusion welding involving stainless steel AISI 316L, determine the mechanical strength of unions of samples and make a correlation with the microstructure observed on the surface of the joints and their neighbourhoods.

MATERIALS AND METHODS

Materials

The materials used for the diffusion welding tests joining SS/SS, SS/Copper and SS/Aluminium the AISI 316L stainless steel alloy (alloy with 0.3% C, 2% Mn, 1% Si, 16-18% Cr, 10-14% Ni, 0.045% P, 0.03% S and 2-3% Mo) [2], Oxygen Free Copper and aluminium alloy 6061. That particular SS alloy was chosen due to its characteristic of not losing resistance to corrosion after undergoing heating processes at high temperatures, as it happens to other steels of the same series, and due to the fact that it is commonly used in components for synchrotron accelerators.

Figure 1: Diffusion bonding oven.

[#]osmar@lnls.br

Diffusion Bonding Oven

Diffusion welding is performed on specially designed equipment for this type of procedure (Figure 1). It consists of a vacuum chamber that has a pressing and heating system engaged [3,4].

This equipment is capable of operating with samples of up to 10cm diameter and 15cm in height and consists of a vacuum chamber with a pump capable of reducing the internal pressure up to $8x10^{-7}$mbar. The pressing system can be used to apply loads of up to 16 tons and the heating system can raise the inside temperature to about 1000°C. The pressing system need not necessarily be used, and that makes this furnace capable of performing other procedures, such as brazing.

The equipment allows the control of all process variables: quality of the internal atmosphere, heating rate, duration of the temperature plateau and surface tension of the sample.

The samples obtained from different setups of the experimental conditions underwent metallographic analysis, helium leak testing and were tested in an EMIC universal testing machine at the Materials Group lab.

Methodology

After the sample was placed inside the oven, the atmosphere of the chamber was pumped until it reached a pressure of about $5x10^{-5}$mbar. Once the atmosphere inside the chamber was stabilized, the oven power controller was turned on in automatic mode and the furnace was heated at the desired rate until the temperature of the process, which varied from sample to sample.

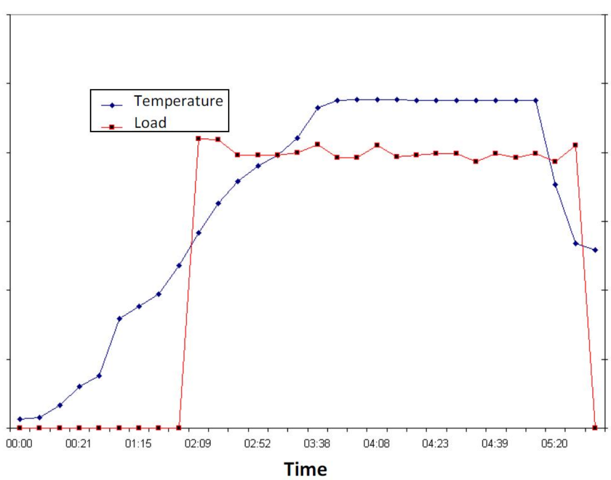

Figure 2: Example of a heating/cooling ramp and load application. The temperature plateau is in the range 50-90% of the melting point and the load varies from 2 to 10 tons.

When the temperature in the sample was close to 50% of the melting point, the load was applied and maintained throughout the heating process (Figure 2). The final temperature, the permanence time at these temperature and applied load were determined before each procedure and were often different in order to examine the effect of these variables on the quality of diffusion.

After removal from the oven the sample was prepared for the various subsequent tests. These tests could vary from sample to sample: folding, metallographic analysis, tensile test, permeability test, vacuum leak test, corrosion test [5,6] and electron microscopy.

Figure 3: Al/Al diffusion bonding welded sample.

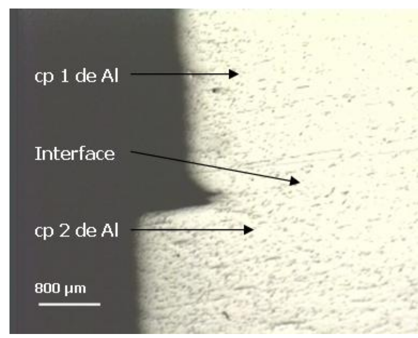

Figure 4: Micrograph of the interface of a duralumin sample. Magnification 50 times.

RESULTS AND DISCUSSIONS

The welding procedure was carried out several times involving various combinations of materials: aluminium with aluminium (Figures 3 and 4), 316L stainless steel with aluminium (figure 5) and 316L stainless steel with copper (Figures 6 and 7).

The SS/Copper samples were submitted to tensile tests (Figures 8 and 9). The tests show that the disruption always occurs in the copper part of the sample. It never

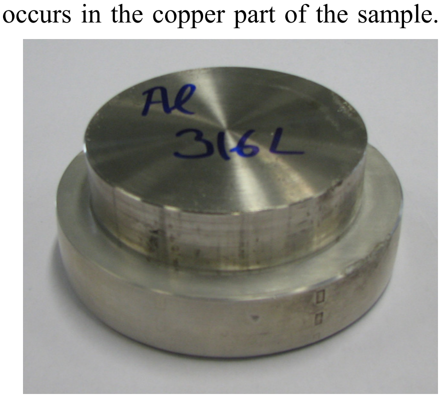

Figure 5: SS/Al diffusion bonding welded sample.

Figure 6: SS/Cu flange fabricated using diffusion bonding weld.

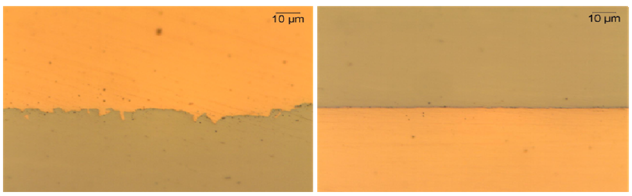

Figure 7: Micrograph of the weld interface of SS/Cu samples. The left picture shows a sample without polishing and the right sample with polishing. Both samples were approved in vacuum leak tests.

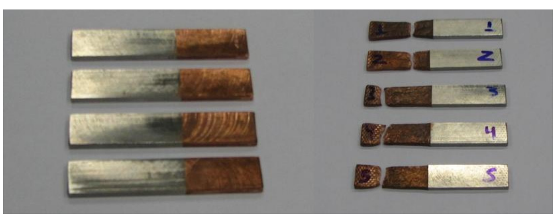

Figure 8: Example of a heating/cooling ramp and load application. The temperature plateau is in the range 50-90% of the melting point and the load varies from 2 to 10 tons.

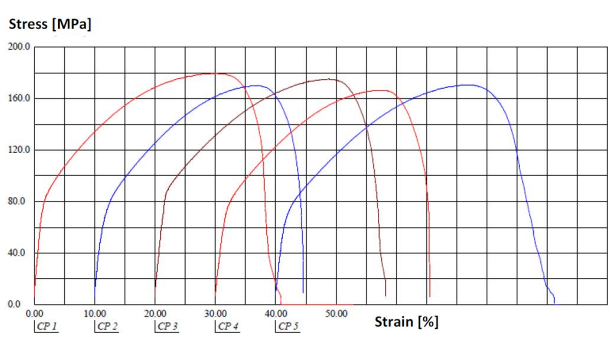

Figure 9: Results from tensile tests on SS/Copper samples

breaks in the union surface, which shows that the joint possesses a mechanical strength higher than the base metal. The result indicated that the pieces have lower mechanical strength than that of copper because the sample softened due to the time it spent under high temperature.

Vacuum leak tests were performed using a leak detector before and after the machining of samples in SS/Copper. The samples tightness was accepted for a leakage rate of the order of 10^{-10}mbar·L/s. This tightness lasted even after the samples pass through tensile test.

The results of mechanical tests were fairly consistent, so that for a given geometry and binding area, the maximum tensile strength was approximately 3.8 kN, consistent with literature values [7,8]. The union interfaces and its surroundings were quite homogeneous showing no porosity or cracks.

CONCLUSIONS

It is noteworthy that the same equipment can be used for diffusion welding of different types of materials without the need for physical alteration of the machine. For such purpose it is only necessary to change the process parameters. Furthermore the results indicate that the process can be used in the manufacture of components for the accelerators of electrons, especially in vacuum chambers and related accessories. Up to this time tensile tests and optical microscopy were performed only on SS/Copper samples. The next steps are to perform these tests with all types of samples produced, to experiment the welding process with other types of materials and alloys and to optimize the process parameters in order to minimize any distortion caused in the process while maintaining the physical, chemical and mechanical properties of the materials within the acceptable limit for each application.

ACKNOWLEDGEMENTS

We would like to acknowledge the Brazilian funding agency FINEP for the financial support.

REFERENCES

[1] D. M. Kazakov, "Diffusion Bonding Techniques", Ed. Mir, Moscow, 1998.
[2] ASM Metals Handbook, Stainless Steel and Materials for Special Applications, Metals Park, Ohio, USA, 1999.
[3] O. R. Bagnato "Propriedades Mecânicas de juntas $AlSi_{12}/Al_2O_3$ soldadas por difusão", UNICAMP, Campinas, 2002.
[4] M. M. Schwartz, "Ceramic Joining", ASM International, Materials Park, Ohio, USA.
[5] ASTM International, Designation A262-02a, "Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steel", Pratica E, 1988.
[6] M. F. Araújo and O. R. Bagnato, "Análise de ensaio corrosivo e metalográfico em aço inox AISI 316L unido por Diffusion Bonding", LNLS, Campinas, 2008.
[7] ASM Metals HandBook Volume 06 – "Welding, Brazing, and Soldering", USA, 1993.
[8] N. Pavlova and C. M. Neto "Aplicação do processo de soldagem por difusão na união de componentes inoxidáveis para uso espacial", ITA, São José dos Campos SP, 2005.