ANL/XFD/CP--82946

Conf-940714--45

Explosive Bonding and Its Application in the Advanced Photon

Source Front-End and Beamline Components Design

D. Shu, Y. Li, D. Ryding and T. M. Kuzay

Experimental Facilities Division

Advanced Photon Source

Argonne National Laboratory

Argonne, IL 60439, U.S.A.

and

Dave Brasher

Northwest Technical Industries, Inc.

547 Diamond Point Rd. Sequim, WA 98382, U.S.A.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Abstract

Explosive bonding is a bonding method in which the controlled energy of a detonating explosive is used to create a metallurgical bonding between two or more similar or dissimilar materials.

Since 1991, a number of explosive-bonding joints have been designed for high-thermal-load ultrahigh-vacuum (UHV) compatible components in the Advanced Photon Source. A series of standardized explosive bonded joint units has also been designed and tested, such as: oxygen-free copper (OFHC) to stainless-steel vacuum joints for slits and shutters, GlidCop [1] to stainless-steel vacuum joints for fixed masks, and GlidCop to OFHC thermal and mechanical joints for shutter face-plates, etc.

The design and test results for the explosive bonding units to be used in the Advanced Photon Source front ends and beamlines will be discussed in this paper.

1. Introduction

The process of explosive bonding (or called welding) has been well understood for over forty years, and there have been many excellent reviews on the intricacies involved [2-4]. Although academia has acknowledged explosive bonding as a novel and fascinating process, industry has been slow to realize its potential and the possible composites that are available. During the past 15 years, explosion bonding manufacturers have characterized and defined many aspects of the process. The challenge is to inform design engineers of the many composite possibilities that the process allows. A composite can be designed and fabricated that combines desirable properties of different metals. This allows the design engineer to optimize the performance of the composite for high temperatures, cryogenic temperatures, high

strength, high thermal or electrical conductivity, enhanced mechanical properties, corrosion resistance or any other application.

The third-generation synchrotron radiation facilities, such as the Advanced Photon Source (APS) currently under construction at Argonne National Laboratory, have presented a multitude of challenges in the design of beamline components [5]. The design solutions have led to many novel and advanced features; one example is the enhanced heat transfer concepts used in the design of ultrahigh-vacuum (UHV) components. To manufacture these components, bonding of dissimilar materials becomes a key process, and explosive bonding is one of the good choices.

In this paper, beginning with a brief description of the process of explosive bonding, the design of the bonding unit applied to the APS front-end and beamlines components is presented. This is followed by a discussion of the test results and conclusion.

2. Explosive Bonding Process

The explosive bonding process can metallurgically join similar or dissimilar metals. In many cases, it is considered a solid-state welding process and uses controlled explosive energy to force two or more metals together at high pressures as shown in Fig. 1. The resultant composite system is joined with a high quality metallurgical bond. The time duration involved in the explosive bonding event is so small, that the reaction zone or heat effect zone between the constituent metals is microscopic. During the process, several atomic layers on the surface of each metal become plasma to jet in front of the collision front effectively scrub-cleaning both surfaces which leaves virgin metal. The remaining thickness of each metal remains near ambient temperature and acts as a huge heat sink. Therefore, the bond line is an abrupt transition from the clad metal to the base metal with virtually no degradation of their initial physical or mechanical properties.

The obvious benefit of this process is the joining of metallurgically incompatible systems such as aluminum, copper, GlidCop, and stainless steels. Because any conventional joining method that uses heat during the bonding or

welding of incompatible metals may cause brittle intermetallic compounds to form.

In order for a quality bonding to be produced, the variables that affect the bonding formation must be controlled. The amplitude and periodicity of the wave pattern formed during explosive bonding can be controlled by adjusting three major parameters. The parameters are explosive detonation velocity (V_d in Fig. 2), explosive load, and interface spacing. The wave pattern formed at the bond line has most often been described as a fluid-flow collision [2]. The two constituent metals can be imagined to act as viscous fluids in the reaction zone and, just as in describing laminar or turbulent flow, a Reynolds number can be determined for the system. In a fluid flow collision, the interface turbulence can be controlled by the explosive detonation velocity and the collision angle (see Fig. 2). The collision angle for two impacting plates can be altered by changing the explosive load or interface spacing. A larger explosive load or interface spacing causes a larger collision angle and a more turbulent interface. It may be desirable attain a wavy interface to increase the shear strength of a transition joint. It also may be desirable to attain a flatter interface in a system where the reaction zone must be minimized for thermal kinetic reasons. It is important to optimize the interface wave pattern for specific applications.

3. Explosive Bonding Applications for APS

3.1. OFHC copper to stainless steel UHV joint

A number of OFHC copper to stainless-steel UHV explosive bonded joints has been developed and standardized for the APS front-end and beamline components. Fig. 3 shows the standardized unit design. It is a cylinder bonding unit that contains two concentric rings (a) and (b). The outer ring (a) is made from stainless steel, and the inner ring (b) is from OFHC copper. The two rings are bonded together using explosive bonding method. A typical application of this explosive bonding unit is the water-cooled fixed mask for an APS bending-magnet beamline frontend. As shown in Fig. 4, the outer ring is welded with a stainless steel UHV flange and the inner ring is

welded to the OFHC copper mask body.

Compared to the traditional brazing process, the major advantage to using this standardized explosive bonded unit in the fixed mask assembly is that the OFHC fixed-mask body can be kept in the cold-worked condition, which provides OFHC material yield strength almost up to four times higher than the annealed condition.

This standardized explosive bonding unit has widely been used in many other APS beamline components, such as X-ray beam position monitors and undulator white-beam slit assemblies, etc. [6-8].

3.2. GlidCop to stainless steel UHV joint

GlidCop is an aluminum oxide, dispersion-strengthened copper alloy (SCM Metals Products, Inc., 1994). It has been a material of choice for many high-heat-load components because of its good thermal conductivity and high yield strength. But, it is a material that is difficult to weld or braze using traditional methods. Explosive bonding provides a way to produce a quality, UHV-tight bonding between GlidCop and stainless steel. Fig. 5 shows the design of the high-heat-load fixed mask for an APS insertion-device beamline frontend. A rectangular explosive bonded unit (a) has also been developed for the APS insertion-device front-end photon shutter assembly [9] as shown in Fig. 6.

3.3 GlidCop to OFHC copper thermal-mechanical joint

Fig. 6 also shows the photon shutter blade (b), on which, a GlidCop faceplate has been explosive bonded to the OFHC copper water-cooling base. The use of the explosive bonding provides a reliable thermal-mechanical joint between the GlidCop and OFHC copper and keeps the OFHC copper in a cold-worked condition.

4. Test Results

In order to analyze quality and reliability of explosion bonding technology to join the dissimilar materials and predict the service life of the high-heat-load photon beamline components, several special designs and bond configurations of explosion-

bonded components were made for our tests on metallurgical properties, mechanical properties, and UHV compatibility [10]. Ultrasonic examination and UHV leak checks are the routine test methods for the explosive bonding components that will be used in the UHV beamline and front-end components.

Figure 7 shows explosion-bonded interfaces of one of GlidCop AL-15/304 stainless steel joints. It can be seen that the explosively bonded materials preferably exhibit a wavy bond zone interface. The ability to obtain good explosive bonds is directly related to the wavy pattern.

Tensile tests of explosion-bonded joints were carried out to study failure mode. Table 1 shows the test results for GlidCop AL-15 to 304 stainless steel explosive bonding samples. From this table, we can see that all tensile samples were failed within the base material GlidCop AL-15 (not at the bonding interface), even those endured the 800°C thermal cycle. It was suggested that good quality explosive bonds have been achieved between GlidCop AL-15 and 304 stainless steel.

Vacuum leak tests of GlidCop AL-15 to 304 stainless steel explosive bonding interfaces were done to examine the UHV seal ability of the explosion-bonded interface and to determine what a minimum bonding length is needed for the UHV seal. Two joint configurations and different lengths of the bonding interface were examined. UHV leak-tight was found in 5 mm joints in length of bonding interfaces.

5. Summary

1). Explosive bonding technology is one of the good choices to join dissimilar materials, such as 304 stainless steel, OFHC copper and GlidCop AL-15, used in APS high-heat-load beamline and front-end components. This is especially significant for GlidCop because of its welding difficulty. Explosive bonding can also keep the OFHC copper components in a cold-worked condition and prevent from recrystallization and softening of the OFHC copper.

2). Preliminary test results show that explosive bonded joints between GlidCop AL-15 and 304 stainless steel (as well as OFHC and 304 stainless steel) have good mechanical and thermal properties, and the use of the explosive bonding can

provides a reliable joint of the dissimilar materials.

3). Explosive bonded joints of dissimilar materials are suitable for UHV applications. A more than 5 mm joint in length is recommended for UHV sealing.

6. Acknowledgments

This work was supported by the U. S. Department of Energy, BES-Material Sciences, under contract No. W-31-109-ENG-38.

References

- [1] GlidCop is a trademark of SCM Metal Products, Inc.
- [2] G.R. Cowan et al., Met. Trans., 1971, vol.2, pp 3145-55.
- [3] V. Shribman et al., Prod. Engr., Feb. 1969, pp 69-83.
- [4] T.Z. Blazinski, Explosive Welding, Forming and Compaction, Applied Sciences Ltd., New York, London (1983), pp 189-343.
- [5] G.K. Shenoy et al., Status of Advanced Photon Source Project, Int. Symp. on X-Ray Synchrotron Radiation and Advanced Science and Technology, RIKEN, JAERI, Japan (1990).
- [6] D. Shu et al., Nucl. Instrum. Meth., A319, 1992, pp 56-62.
- [7] D. Shu et al., Precision White-Beam Slit Design for High Power Density X-ray Undulator Beamlines at the Advanced Photon Source, SRI 94, Stony Brook 1994.
- [8] D. Shu et al., Beamline Standard Component Designs for The Advanced Photon Source, SRI 94, Stony Brook 1994.
- [9] D. Shu et al., SPIE Vol.1739, 1992, 218.
- [10] Y. Li et al., Explosion Bonding of Dissimilar Materials for Fabricating APS Front-end Components -- Analysis of Metallurgical and Mechanical Properties and UHV Applications, to be published.

Figure Captions

Fig. 1, The explosive bonding event.

Fig. 2, The explosive bonding wave morphology variation.

Fig. 3, APS-standardized OFHC copper to stainless steel UHV explosive bonding joints for the APS front-end and beamline components. The outer ring (a) is made from stainless steel and the inner ring (b) is from OFHC copper.

Fig. 4, The water-cooled fixed mask for an APS bending-magnet beamline frontend.

Fig. 5, The high-heat-load fixed mask for the APS insertion-device beamline frontend.

Fig. 6, The APS insertion devices front-end photon shutter assembly; (a) rectangular explosive bonding unit, (b) OFHC copper photon shutter blade, (c) GlidCop faceplate.

Fig. 7, GlidCop to stainless steel explosive bonding interface wave pattern.

Table 1, Tensile Strength Testing of Explosion-Bonded Interfaces.

Table 1.

Sample Number	Heating Cycle	Tensile Rupture Position			Rupture Strength (Mpa)
		304 SS	GlidCop® AL-15	Joint Interface	
1	350°C 5 min.		x		399.2
2			x		397.8
3			x		397.4
4	500°C 5 min.		x		385.1
5			x		386.4
6			x		385.8
7	800°C 5 min.		x		376.1
8			x		374.4
9			x		378.8
10	500°C 10 min.		x		383.1
11			x		382.5
12			x		386.5
13	500°C 30 min.		x		385.1
14			x		380.7
15			x		381.9
16	Room Temp.		x		430.0
17			x		427.7
18			x		409.2

Figure 2. *Wave morphology variation.*

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

304 Stainless Steel

GLIDCOP® AL-15

0.2 mm

Fig. 7