Applications of Hot Isostatic Pressing (HIP) for a High-Gradient Accelerator Structure

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Abstract

In order to reduce the dark current from disk edges in a traveling wave accelerator structure at field gradients of up to 80 MV/m, a new type of disk has been proposed which comprises of a part made of Titanium around the beam hole area and a part of made OFHC at the outer ward. These two parts are joined by a hot isostatic pressing (HIP) technique. HIP causes diffusion bonding at temperatures ranging from 700 to 850 °C at an isostatic Ar gas pressure of 1,200 kgf/cm^2 in a pressure vessel. All samples have shown vacuum leak rate of less than 10^{-9} Torr•l/sec and a tear strength of about 6.4 kgf/mm^2 in the reaction zone between the two metals.

I. INTRODUCTION

The accelerating gradient of the Japan Linear Collider (JLC) is 100 MV/m for the X-band main linac and 50 MV/m for the S-band injector and the preaccelerator. We have already achieved the acceleration of an electron beam of 0.9 A and a pulse width of 0.2 μsec by utilizing a 0.6 m-long traveling-wave structure at a gradient of 85 MV/m with a 1μsec RF pulse duration at 50 Hz [1]. At this gradient, however, the dark current is very large from disk edges and breakdown occurs frequently, at 70 MV/m, however, fairly stable beam acceleration has been achieved. It seems to be feasible to operate the accelerating structure at this gradient for practical use after a reasonable processing period. In this sense, 50 MV/m operation at the S-band is quite promising.

Experimental studies on the upper limit of the electric field strength in conventional disk-loaded structures and single cavities have been reported from several laboratories [2][3]. From these studies, many factors have been found which must be discussed concerning the RF breakdown phenomenon with a dark current, such as the surface finish, micro dust, electron multiplication and vacuum conditions. However, the fundamental mechanism of RF breakdown is not yet clear. As described in references [4] and [5], electron multiplications at disk edges is one of the main reasons for limiting the accelerating gradient, other factors such as surface cleanness, surface finish and vacuum conditions were found not to be serious problems [6]. In order to reduce the dark current and to increase the upper limit of RF breakdown, we designed a new disk comprising two metals, OFHC and Titanium(Ti-6Al-4V). Since the secondary electron emission coefficients of Titanium is less than unity, the beam hole of a disk has been designed to be made of Titanium. We applied diffusion bonding by hot isostatic pressing to join Titanium to OFHC. We made the coaxial columnar blocks with OFHC (outer) and Titanium (inner) by this technique. This paper describes the preliminary results concerning the characteristics of HIP diffusion bonded OFHC-Titanium metals.

II. EXPERIMENTAL PROCEDURES

A. Hot Isostatic Pressing

Hot isostatic pressing (HIP) is a thermomechanical process for materials that makes use of an applied gas pressure in order to achieve both high density and diffusion bonding in the treated material. HIP generally subjects a material to pressures as high as 2,000 kgf/cm^2 and temperatures up to 2,000 °C in a pressure vessel. The source of heat is a furnace located within the pressure vessel, which hold temperatures well below the melting point of the material being processed. This method can be used for a wide range of materials such as metals, ceramics and composites.

B. Materials Characteristics

HIP was applied to the diffusion bonding of OFHC cylinders and Titanium bars. The chemical compositions of the samples are listed in Table 1. The composition of the OFHC is very high-quality type and that of Titanium corresponds to the Japanese Industrial Standards(JIS) type.

Table 1
Chemical composition of OFHC cylinders

MATERIAL	CHEMICAL COMPOSITION (%)									
	PB	ZN	BI	CD	HG	O	P	S	SE	TE
OFHC	5	<1	<1	<1	<1	3	2	8	<1	<1
	CHEMICAL COMPOSITION (%)									
	H	O	N	Fe	C	Al	V			
Ti-6Al-4V	*88	0.18	0.017	0.23	0.019	6.34	4.13			

* ppm (x10^{-6})

C. Fabrication Methods

Samples of OFHC cylinders and Titanium bars were machined from columnar blocks. The surface finish (RMS) of the inner wall of OFHC is less than 0.5 μm, and the one of Titanium bar is less than 0.2 μm. The dimensions of these samples are listed in Table 2.

Table 2
Dimensions of samples

	OFHC	Ti-6Al-4V
OUTER DIAMETER	ø 110 ± 0.1mm	ø 40 -0.05/-0.0mm
INNER DIAMETER	ø 40 +0.05/+0.0mm	
LENGTH	110 ± 0.1 mm	110 ± 0.1 mm
SURFACE FINISH (RMS)	< 0.5 μm INNER WALL	< 0.2 μm OUTER WALL

These metals were cleaned by acetone, the Titanium bars were then set inside of OFHC cylinders. Each sample was placed into a completely leak-tight soft-iron capsule. These capsules were then pumped down to less than 10^{-3} Torr and sealed-off.

The results at three different temperatures, (700, 750 and 800 °C) were obtained in an HIP cycle within a pressure vessel. The isostatic pressure was held at 1,200 kgf/cm^2 by pure Ar gas for 2 hours. The above parameters for HIP-cycle (temperature, pressure and holding time) are based on both metallurgical and economical considerations. A schematic view of the HIP-cycle is shown in Figure 1.

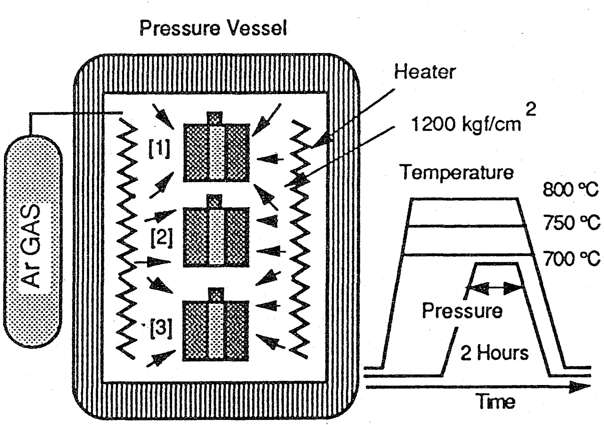

Figure 1. HIP diffusion bonding process.

III. EXPERIMENTAL RESULTS

A. Micro structures

The quality of HIP was studied with metallographical measurements (optical microscope and scanning electron microscope) and mechanical tests. At three different HIP temperatures (700, 750 and 800 °C) with an isostatic pressure of 1,200 kgf/cm^2 for 2 hours, all samples took on a fine, homogeneous micro stricture. In experiments at these three different temperatures no grain growth of the whole OFHC and Titanium was observed. The micro structures of an HIP sample and a forged OFHC are shown in Figure 2. A forged OFHC generally involves a large number of micro pores the size of a few μm at the grain boundary. Figure 2 shows that the micro pores disappeared in HIP-processed OFHC. Moreover, HIP-processed OFHC is much more homogeneous than forged OFHC. Titanium is free from porosity, even in a forged material.

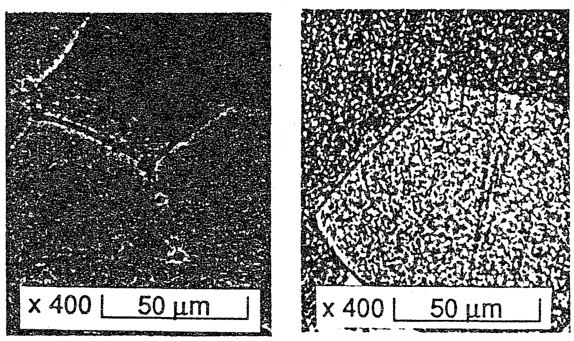

Figure 2. Optical micrograph showing forged OFHC (left) and HIP-OFHC (right) at a temperature of 800 °C and an isostatic pressure of 1,200 kgf/cm^2 for 2 hours.

B. Reaction Zone

The width of the HIP reaction zone in three samples ranged from 7.3 to 20 μm, corresponding to the applied HIP temperatures. These reaction zones were etched and measured by a scanning electron microscope (Figure 3).

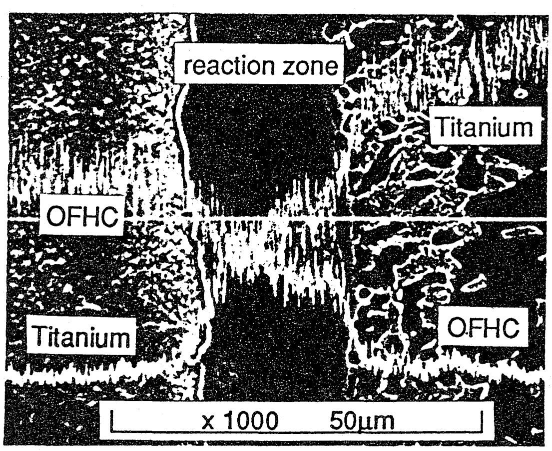

Figure 3. Scanning electron micrograph of HIP-processed OFHC-Titanium sample.

Figure 3 shows the reaction zone between two materials, indicating that the quality is high, no porosities and impurities can be seen. The x-ray analysis of the reaction zone in Figure 3 shows the contents of OFHC and Titanium within the reaction zone.

C. Mechanical Properties

The quality of HIP was studied using both mechanical tests and metallographical measurements. The tear strength was measured using plates with a thickness of 2 mm that satisfy JIS standard tear test specimens (Figure 4). Five specimens were machined from each sample. The reaction zone was located in the middle of the gauge length.

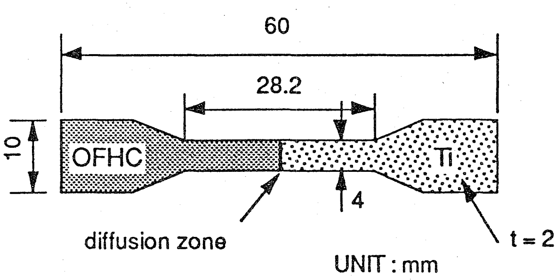

Figure 4. JIS standard tear test specimen. Top view.

We obtained an average tear strength of 6.4 kgf/mm^2 for the three different HIP temperatures. The minimum value of the strength was 4.9 kgf/mm^2. Figure 5 shows the tear strength of all the specimens, it does not depend on the HIP temperature. All of the test specimens were fractured inside of the reaction zone where the concentrations of OFHC and Titanium were equal.

The vacuum leak rate of the reaction zone was well blow 10^{-9} Torr•l/sec.

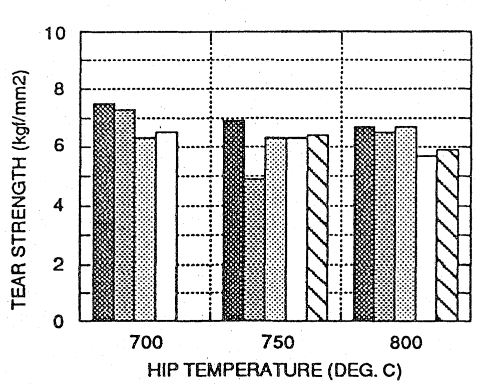

Figure 5. Tear strength according to the JIS standard test.

IV. DESIGN OF DISK STRUCTURE

A. Calculation of Q

A new disk structure was designed for a conventional disk-loaded structure comprising HIP-bonded OFHC and Titanium metals. The calculated results of the Q value using the MAFIA code was 12,000 for the $2\pi/3$ mode. This is about 14% lower than that for a normal cavity made of only OFHC. A drawing with the dimensions of the cavity is shown in Figure 6.

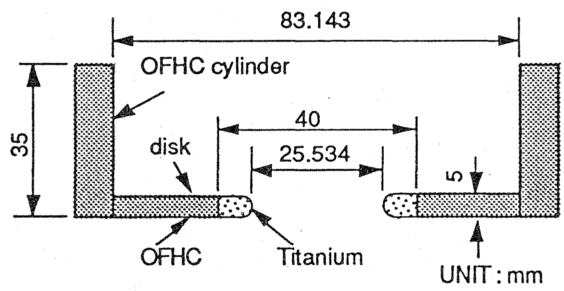

Figure 6. Titanium-bonded disk structure.

V. SUMMARY

An HIP diffusion bond of OFHC and Titanium was successfully achieved at temperatures ranging from 700 to 800 °C and a pressure of 1,200 kgf/cm^2 for 2 hours. The micro pores in both OFHC disappeared with HIP processing. The quality of the reaction zone is high and is free from both porosities and impurities. The minimum tear strength of the reaction zone is 4.9 kgf/mm^2. The vacuum leak late of reaction zone is less than 10^{-9} Torr•l/sec. The calculated Q-value of a Titanium bonded disk is 12,000. These results indicate that a Titanium bonded disk can be applied to high-gradient accelerator structures.

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