The Development of Volumetric Heating Technique

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1. Introduction

One of the most important tasks of the front ends in undulator beamlines is to handle the very intensive photon beam. In treating for such a high heat load, grazing geometry technique, inclining an irradiated surface to the photon beam to reduce the heat flux level, is very commonly used. In addition to this traditional method, advanced material such as Glidcop (copper alloy strengthened by adding alumina) for copper was applied to masks, absorbers and xy slits in SPring-8 because of its structurally toughness against the thermal stress. We, also, have been continuing Research and Development for the other two strategies, namely enhancing heat transfer coefficient technique [1], and the volumetric heating technique which is a way to dissipate surface heat flux in depth using a Low-Z material. The latter technique is applied to the pre slit, and graphite or beryllium are considered to be a candidate for the material of the irradiated body (Low-Z material). From the results of analyses and various evaluation tests, the followings were attained: 1) as for the static strength of the brazed joint between Low-Z material and cooling body made of copper, beryllium/copper (Be/Cu) joint is about eight times as large as graphite/copper (G/Cu) joint, 2) as for the vacuum properties, beryllium is much superior to graphite [2,3]. We are also investigating the fatigue strength and the microscopic analyses of the brazed joint.

2. Fatigue Strength

Although it is desirable to apply thermal load repeatedly for evaluating an influence of thermal stress, we put the mechanical load instead of thermal load because of the difficulty of the test. Two types of test pieces for the fatigue strength evaluation test, practical use geometry and general strength test geometry, were manufactured for Be/Cu joint.

2.1 Practical Use Geometry

Using an electro-hydraulic-servo fatigue testing machine, the load was applied by sine wave whose frequency is 4 HZ, and the stress ratio, namely the ratio of minimum stress to maximum stress, was set at 0.1. As shown in Fig. 1, even if the stress which was above three times as large as the calculated maximum thermal stress of the brazed joint represented by Mises's equivalent stress of 4.90 kgf/mm2 was loaded repeatedly, beryllium didn't exfoliate from copper but was pushed out within the range of about 2 mm at the bottom of the test piece. To confirm the influence of this slippage on heat transfer, microscopic observation and analysis were made as mentioned in chapter 3.

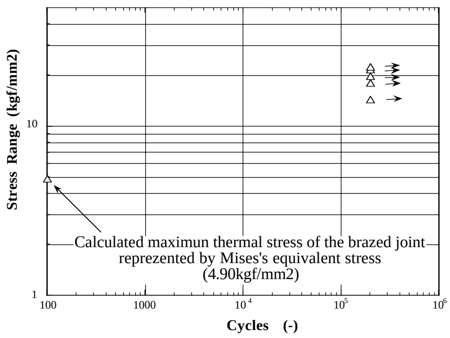

Fig. 1. Results of fatigue strength evaluation test for the practical use geometry type of Be/Cu joint, and compare with the analysis results.

2.2 General Strength Test Geometry

To compare the fatigue strength of Be/Cu joint with that of G/Cu joint, the test was carried out in both tensile and shearing directions in the same way as the G/Cu joint [4]. Although it occurred that many test pieces were broken at the joint while arrangement in the case of G/Cu joint, we scarcely experienced such a situation for Be/Cu joint. As shown in Fig. 2, the fatigue strength of Be/Cu joint is at least two times as large as that of G/Cu joint in both tensile and shearing directions.

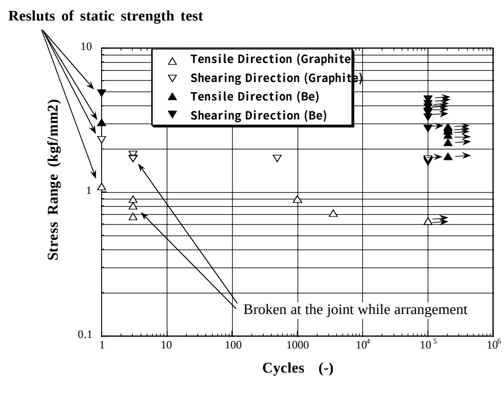

Fig. 2. Results of fatigue strength evaluation test for the general strength test geometry of Be/Cu joint as compared with the G/Cu joint results.

3. Microscopic Observation and Analysis

We executed some kinds of microscopic observation and analysis aiming at investigations on 1) the state of the brazed joint, 2) the starting point of the crack which equals to the weakest region of the test piece including the base materials and 3) the state of the joint after the fatigue evaluation test. For the G/Cu joint, microscopic observation by SEM (Scanning Electron Microscopy) directly after brazing and static strength test, and surface scanning analysis by EPMA (Electron Probe Micro Analysis) after static strength test were done. As for the Be/Cu joint, we added surface scanning analyses by AES (Auger Electron Spectroscopy) after static and fatigue strength tests to the items for G/Cu joint mentioned above. AES was selected for the surface scanning analysis of Be/Cu joint because the elementary analysis for beryllium is impossible for EPMA. The Ni base braze alloy and the silver base braze alloy (Ag: 59 %, Cu: 27.25 %, In: 12.5 %, Ti: 1.25 %) are applied to G/Cu joint and Be/Cu joint, respectively. By these observation and analyses, we have got some knowledge as follows.

(1) The intermetallic compound phases generated by brazing are (C+Cr) phase, (Cr+Ni) phase, (Ni+Cu) phase in order from the graphite side for G/Cu joint. As for the Be/Cu joint, (Be+O) phase, (Be2Cu) phase, (BeCu) phase, (Be+Cu+Ti) phase, (Ag+Be+Cu+Ti+In) phase are in order from the beryllium side.

(2) The starting point of the crack was assumed (C+Cr) intermetallic compound phase for G/Cu joint. As for the Be/Cu joint, (Be+Cu) intermetallic compound phase (at the midway of Be2Cu and BeCu or at the inside of Be2Cu) was assumed to be the weakest region.

(3) As shown in Fig. 3, although a part of beryllium was pushed out from the copper after fatigue strength test, the crack didn't spread and the other part seems to remain a good thermal contact as the same level as before fatigue test.

References

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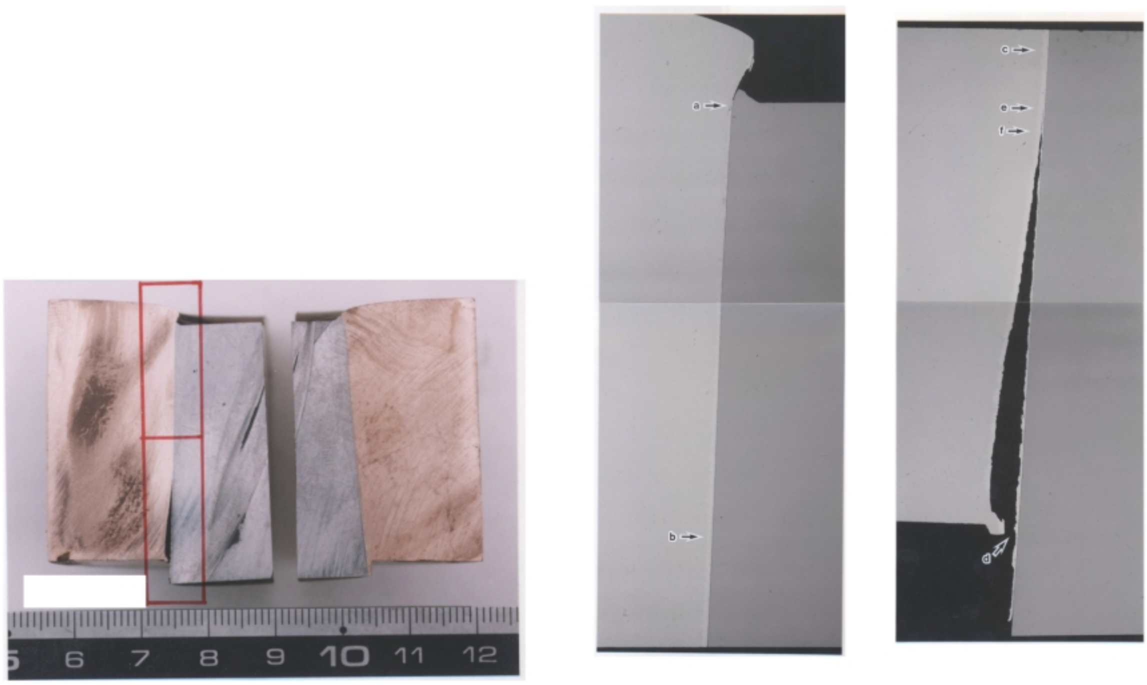

Fig. 3. Observation of the Be (inner) / Cu (outer) brazed joint after fatigue test. The above side is the top side on which the load was applied.