Joining of Silicon Carbide and Molybdenum with Vanadium Foil

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A joining pair of silicon carbide and molybdenum was fabricated using vanadium foil as an insert material. The optimum fabricating conditions are bonding temperature of 1198 K, bonding pressure of 30 MPa and bonding time of 10.8 ks. The joint had high shear strength levels of 150 MPa at room temperature and of 52 MPa at 973 K. At the interface of silicon carbide and vanadium, a layer of vanadium silicide V_3Si was formed.

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I. Introduction

Silicon carbide (SiC) is one of the fine ceramics which find application in a high temperature environment. Thus a joint of SiC with a metal should have high mechanical strength at elevated temperatures. Most of the joining methods developed so far have used soft metals and/or their alloys as insert materials or brazes. These soft metals have a low melting point in general and, therefore, joints thus formed have poor mechanical strength at high temperature⁽¹⁾⁽²⁾.

We have developed a bonding method of silicon nitride to molybdenum with a vanadium interlayer⁽³⁾. Vanadium has a high melting point and thus the joint has high shear strength at about 1000 K. At the interface of silicon nitride and vanadium, a layer of a vanadium silicide V_3Si was formed.

We have applied this method to make a SiC-metal joint and obtained a sound joint which has high mechanical strength at elevated temperatures.

II. Experimental

SiC was supplied from Asahi Glass Co. and contained both an aluminum (Al) compound and a magnesium (Mg) compound as sintering additives. It was supplied as rods of 12 mm diameter and was cut into disks of 5 mm thickness. Both surfaces of the disk were mechanically polished to a surface roughness of $3\ \mu\text{m}$.

Molybdenum (Mo) was a disk 5 mm thick and 8 mm in diameter and its surfaces were polished. Vanadium (V) foil of $25\ \mu\text{m}$ thick was used as an insert material. The purity of Mo and V was 99.95%.

The V foil was inserted between SiC and Mo disks and this assembly was bonded in a vacuum furnace equipped with a hand made mechanical press. When the furnace temperature reached to designed values, the mechanical

pressure was applied for a certain bonding time. The strength of the joint was measured by shear test with hand made jigs at room temperature and elevated temperatures. Details of the experimental procedures were the same to the previous paper⁽³⁾.

III. Results

Figure 1 shows the shear strength level of the joined interface at room temperature as a function of bonding pressure at the temperature of 1198 K and the bonding time of 10.8 ks. The strength level reached 130 MPa at bonding pressures higher than 30 MPa and times longer than 10.8 ks. With a further increase both in pressure and in time, the increase in the strength level of the joints ceased.

There were small peaks in the load-displacement curves and fracturing in the ceramics occurred at these peaks. The first small peak appeared at almost equal loads and some cracks were observed in the ceramics. The crack started at the upper edge of the metal disk,

Fig. 1 Effect of bonding pressure on the shear strength of the joint at room temperature at the bonding temperature 1198 K and the bonding time of 10.8 ks.

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which was smaller than the ceramics disk, and extended into the ceramics. This failure was evidently caused by residual thermal stresses concentrated on the boundary of the metal disk. The final fracture was, however, occurred at the ceramics-metal interface and the strength level of the interface was determined.

The influence of fabricating temperature is presented in Fig. 2. The pressure was 30 MPa and the bonding time was 10.8 ks. The strength increased with increasing temperature in the region between 1073 and 1198 K. At higher temperatures, it decreased with the increase in temperature and finally no bonding occurred at 1273 K. The strongest joints were obtained at 1198 K; their average interface strength was 125 MPa, the maximum and minimum values being 150 and 100 MPa, respectively.

The optimum fabricating conditions thus determined are:

Temperature, 1198 K;

Pressure, 30 MPa;

Bonding time, 10.8 ks.

The pressure and time listed above are the minimum necessary to attain high shear strength. Most of the results described below are for the samples fabricated in these optimum conditions.

Shear strength levels measured at elevated temperatures are shown in Fig. 3. In the high temperature measurement, test jigs used were different from those used at room temperature⁽³⁾. At high temperatures, the joint fractured at the interface and no small peaks appeared at a low load. The shear strength of the interface was 55 MPa at 673 K and 52 MPa at 973 K. The strength level seemed to be constant at the test temperatures between 673 and 973 K.

A SEM observation of the joined part revealed that the interface between the molybdenum and vanadium was a smooth and clear single boundary without any cracks or voids. Between V and SiC, a new layer about 1.2 μm thick was formed. Both boundaries of the layer were smooth and free of voids or cracks.

The distribution of several elements across the V-SiC interface was measured by EPMA. The distribution profiles of V and silicon (Si) showed narrow plateaus coinciding with each other in the intermediate layer. Thus the compound of Si and V should form the layer. The profiles of other elements such as Al did not show such plateaus.

X-ray diffraction patterns from the fractured surfaces showed the peaks originating from a vanadium silicide V_3Si in addition to those of V or SiC. The peaks of V were absent in the diffraction patterns from the ceramics side or vice versa, but the peaks from V_3Si were observed on both sides. No additional diffraction peak existed which might be assigned to other vanadium silicides. Thus, the joint fractured in the reaction layer which composed of V_3Si located between V and SiC. The X-ray patterns from the unjoined pairs treated at 1373 K showed strong V_3Si peaks with additional peaks of V_5Si_3 . None of the peaks could be assigned to vanadium carbide or graphite.

Fig. 2 Influence of bonding temperature on the shear strength of the joint measured at room temperature. The bonding pressure was 30 MPa and bonding time was 10.8 ks.

Fig. 3 Shear strength levels of the joints measured at elevated temperatures. Joints were fabricated under the optimum conditions. The results for $\text{Si}_3\text{N}_4\text{-V}^{(3)}$ are reproduced for comparison.

IV. Discussion

A study on high temperature reaction between SiC and platinum (Pt) was reported⁽⁴⁾. SiC was decomposed to form metal silicides at 1173 and 1273 K, where the Gibbs free energy of SiC decomposition was expected to be highly positive. In this system, however, alternating layers of Pt_3Si and Pt_2Si which contained carbon particles were formed in the reaction zone. Interfacial melting occurred in the system. These results were quite different from our results on the SiC-V system in which some reaction should occur through solid state reactions. It would be probable that free carbon was formed from the decomposition of SiC and dispersed in the reaction zones or metals. The free carbon should be very small particles for the SEM observation and X-ray diffraction measurement, which may be the reason why neither carbon (graphite) particle nor vanadium carbide was observed.

Our results are quite parallel to those at the interface of silicon nitride and vanadium⁽³⁾. The optimum bonding temperature was, however, lower than that for silicon nitride of 1328 K. The detectable reaction products were silicides of vanadium, V_3Si and V_5Si_3 , and not carbides or nitrides of V. The reaction phase formed at lower temperature is V_3Si and additional formation of V_5Si_3 at higher temperatures seems to weaken the strength of the joint. These results suggest that the reaction between Si and V is important in these systems so long as the decomposition of SiC or Si_3N_4 is allowed to occur. The temperature dependences of the shear strength levels for both SiC-V and Si_3N_4 -V are quite parallel as indicated in Fig. 3 in which the results for Si_3N_4 -V are reproduced. This suggests that the high temperature strength of these joints is determined by the strength of the reaction layer.

The first phase to be formed in Si and V reaction is V_2Si ⁽⁵⁾. The free energy change of formation of vanadium silicides at 1327 K was favorable to formation of V_5Si_3 ⁽⁶⁾. Our X-ray diffraction measurements, however, indicated that V_3Si was formed at first and then V_5Si_3 was formed at higher temperatures. The temperature range in which the V_3Si formed for SiC-V bonded pair was lower and narrower than that for Si_3N_4 -V bonded pair. These suggest that the thermochemical free energy change is not the principal parameter which controls the interfacial reactions in these systems. A similar

deviation from the thermochemical rule was reported in the Si-V thin layer reactions⁽⁵⁾⁽⁷⁾⁽⁸⁾. A probable reaction controlling factor is the transport properties of reaction species, V and Si, through the materials and the reaction products layers. To clarify these contributions, however, the concentrations, diffusion coefficients and activities of the reactive species should be known. Unfortunately, we have no such data at hand and studies to obtain the information are highly needed for each combination of ceramics-metal joints.

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