Short communication

INTERFACIAL REACTIONS BETWEEN SILICON BASE CERAMICS AND METALS

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1 INTRODUCTION

SiC is a candidate material for high temperature components. Joining SiC to metals expands the engineering application, and an understanding of the phase reactions at SiC/metal interfaces is required. The formation of compounds of Ti_3SiC_2 , $Ti_5Si_3C_x$ and TiC between SiC and Ti have been reported [1-2], though details of the process of interfacial reaction are still unclear. Even less reports exist on the other SiC/Cr [2] and SiC/Nb systems [3, 4]. Furthermore, information on reaction kinetics such as growth rates and activation energies of growth for reaction phases is necessary to control the SiC/metal interfacial structure. The present work aims to investigate the interfacial structure, reaction phases and diffusion path between SiC and metals Ti, Cr, Nb and Ta as well as growth kinetics of reaction phases.

2 REACTION PHASES AND DIFFUSIONS

2.1 SiC/Ti Couple

Upon bonding at 1673K, TiC granular phase adjacent to Ti and $Ti_5Si_3C_x$ containing fine TiC duplex phase zone next to SiC are formed during the bonding time of 0.3ks. A $Ti_5Si_3C_x$ single phase zone with a hexagonal Nowotny-type phase appears next to SiC for the bonding time of 0.9ks. The additional Ti_3SiC_2 (T) phase appears between $Ti_5Si_3C_x$ and SiC after the bonding time of 3.6ks. In SiC/Ti/SiC joint formed at 1673K for 7.2ks, unreacted titanium is still observed at the central part of the couple at this time. The sequence of phases observed at 1673K for the bonding condition shows the complete diffusion path between SiC and Ti as follows; SiC/ Ti_3SiC_2 / $Ti_5Si_3C_x$ / $Ti_5Si_3C_x$ +TiC/TiC+Ti/ β -Ti.

As discussed later this diffusion path between SiC and Ti at 1673K is explained on the tie line connecting SiC and Ti in Ti-Si-C ternary diagram, which is presumed from the diagram at 1373K. The sintering additive may affect the diffusion path. Since Ti_3SiC_2 and $Ti_5Si_3C_x$ phases have to appear on the diffusion path, the phase reactions and diffusion at the interface of SiC/ $Ti_5Si_3C_x$ containing TiC precipitate adjacent to SiC in SiC/Ti couple are still on the way to the diffusion path [1].

2.2 SiC/Cr Couple

The results on the SiC/Cr couple reported by Kurokawa [2] revealed the diffusion path only partially. In the present experiments, $Cr_{23}C_6$ and Cr_7C_3 next to Cr and $Cr_5Si_3C_x$ + Cr_3SiC_x next to SiC appear at 1673K for the bonding time of 0.3ks. The reaction zones grow with increasing the bonding time to 1.8ks. The complete path between SiC and Cr is established at this bonding time at 1673K as follows, SiC/ $Cr_5Si_3C_x$ / Cr_3SiC_x / Cr_7C_3 / $Cr_{23}C_6$ /Cr which is also predicted on Cr-Si-C phase diagram. The chromium at the central is consumed for the bonding time of 3.6ks, and the structure of the joining layer moves to the equilibrium with increasing a joining time. The joining structure becomes Cr_3C_2 and $Cr_5Si_2C_x$ zones between SiC, which are consistent with the Cr-Si-C phase diagram.

2.3 SiC/Nb Couple

In the SiC/Nb couple at 1790K and for the bonding time of 36ks, Nb_2C zone appears next to Nb, and $Nb_5Si_3C_x$ zone containing grains of NbC is formed next to SiC. X-ray diffraction experiments after mechanically polishing show a thin NbC layer at the interface between SiC and $Nb_5Si_3C_x$. The complete diffusion path between SiC and Nb is established at this bonding time as SiC/NbC/ $Nb_5Si_3C_x$ /NbC+ Nb_2C /Nb₂C/Nb. This diffusion path was also reported in Nb/SiC thin film produced by sputtering [3]. After consuming Nb, NbC becomes the layer zone with increasing the bonding time, and finally the layer structures of NbC and $NbSi_2$ are formed at the bonding temperature of 1790K.

2.4 SiC/Ta Couple

The reaction zone of SiC/Ta joint boned at 1773K for 7.2ks consists of Ta_2C next to Ta, and $Ta_5Si_2C_x$ next to SiC. At the joining time of 57.6ks at 1773K the reaction zone consists of layered $Ta_5Si_3C_x$ +TaC+ $TaSi_2$ +SiC. Using the Ta-Si-C ternary phase diagram a diffusion SiC/TaC/ $Ta_5Si_3C_x$ / Ta_2C /Ta is concluded.

3 REACTION MECHANISM

All diffusion paths between SiC and the metals Ti, Cr, Nb, Ta are described along tielines coupling SiC and these metals via intermediate compounds on the

Fig. 1. Diffusion paths between SiC and metals described on M-Si-C ternary phase diagrams.

corresponding M-Si-C ternary phase diagrams (Fig. 1).

The growth rate of reaction zones between SiC and metal have to be analyzed separately for each compound or zones formed. However, the growth rate of the reaction zone between SiC and metals was repeatedly treated as a single zone [1-4]. Thus, the present results for the growth rate of SiC/metal reaction zones are also analyzed as single phase zone as,

$$x^2 = kt, \quad (1)$$

$$k = k_0 \cdot \exp. (-Q/RT), \quad (2)$$

where k_0 and Q are a rate constant and activation energy for growth of reaction zone. The thickness for reaction zone is expressed in a term of $t^{1/2}$. From slopes of plotting k against $1/T$, activation energies for growth of the reaction zone are obtained. The growth rate for the reaction zone increases in the sequence of SiC/Ta, SiC/Nb, SiC/Cr and SiC/Ti system.

The Q and k_0 in the growth of reaction zone for SiC/Ti system are in agreement with results in references [1,2]. Although the Q for SiC/Cr system is the same order as that of the SiC/Ti system, the growth rate for SiC/Cr is lower than that of SiC/Ti system. The growth rates of SiC/Nb and SiC/Ta system are two or three order lower than that of SiC/Ti and SiC/Cr systems. It means that the reactivities of Nb and Ta against SiC are quite lower than that of Ti and Cr.

4 CONCLUSIONS

Microstructure and reaction phase formed during bonding in vacuum between SiC and the metals (Ti, Cr, Nb and Ta) were investigated. The complete diffusion path were established after certain bonding time at the bonding temperatures selected. All compounds produced along the tielines connecting SiC and each of these metals in the corresponding ternary M-Si-C phase diagrams were observed.

The growth rates of the interfacial reaction zones decreased in the sequence of SiC/Ti, SiC/Cr, SiC/Nb and SiC/Ta. Thus, the reactivity of metals versus SiC decreased in the order of Ti, Cr, Nb and Ta.

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