INVESTIGATION OF THE INTERACTION OF SILICON CARBIDE WITH REFRACTORY METALS AND OXIDES

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This paper describes the results of a study of the interaction of silicon carbides with refractory metals (Nb, Ta, Mo, W) and oxides (BeO, MgO, ZrO₂, ThO₂) held in contact for 2 hr in vacuum at 1200-2000°C.

Polycrystalline silicon carbide has many valuable technological properties. Its high hardness and compressive strength make it a useful abrasive material, and silicon carbide heating elements have several advantages over metallic ones because of their high electrical resistivity combined with a thermal stability and semiconducting properties. Silicon carbide is also an excellent heat-resistant material and is widely used in the metallurgical industry for fire-proofing and as an active deoxidizing agent. However, the suitability of silicon carbide for many applications often depends on its ability not to interact with other materials at service temperatures. Studies of the behavior of silicon carbide in contact with other refractory solids at elevated temperatures are therefore of considerable interest. It should be noted that some information on the interaction of various substances with silicon carbide can be found in the literature [1-3]. Researches in this direction were concerned mainly with finding materials suitable for use as binders in sintering SiC parts.

The aim of this investigation was to study the interaction of silicon carbide with refractory metals (Nb, Ta, Mo, W) and oxides (BeO, MgO, ZrO₂, ThO₂) at 1200-2000°C in a vacuum of about 5 × 10⁻³ mm Hg. Green silicon carbide powder (98.8% SiC; 0.60% free Si; 0.03% free C; 0.11% Fe; 0.05% Al), compact metals and hot pressed oxides of technical purity were used as the experimental materials.

Metal or oxide specimens were pressed with silicon carbide powder into graphite crucibles whose internal walls had been previously silicided. After holding at a test temperature and furnace cooling, the specimens were subjected to metallographic examination and microhardness measurements.

The results obtained are described below.

SiC Nb. A reaction between silicon carbide and compact niobium starts after 2 hr at 1300°C. Under these conditions a layer of a new phase (several microns thick) is formed on the metal surface; new phase inclusions are also formed in the subsurface layer 60 microns deep. Increasing the test temperature leads to an increase in the thickness of the surface layer and to the formation of a two-phase structure (Fig. 1a). The outer, more porous layer, has a microhardness of 1031 ± 100 kg/mm² which corresponds to the microhardness of niobium disilicide (≈ 1050 kg/mm² [4]); the layer adjacent to the metal and having a microhardness of 1705 ± 141 kg/mm² consists evidently of a niobium carbide of a nonstoichiometric composition. X-ray diffraction analysis revealed in this case the presence of two phases in the reaction products.
a niobium carbide NbC and niobium disilicide NbSi$_2$. The surface layer formed on niobium in contact with SiC at and above 1800°C has a single phase structure (Fig. 1b) and a microhardness of $1990 \pm 319$ kg/mm$^2$ which corresponds to the microhardness ($1961$ kg/mm$^2$ [4]) of niobium carbide of a stoichiometric composition. No formation of NbSi$_2$ was observed at these temperatures; this is probably due to the fact that the temperature range of stability of niobium silicide (up to 1950°C) is narrower than that of niobium carbide (up to 3760°C).

**SiC-Ta.** Compact tantalum starts reacting with SiC at 1200°C. A new phase in the form of a 5 microns thick layer adheres firmly to the metal surface (Fig. 2a). Surface layers formed at 1400–1500°C have a two-phase structure; the outer porous layer has a microhardness of $1685 \pm 95$ kg/mm$^2$ which, within the experimental error, is close to the microhardness of tantalum carbide TaC ($\sim 1599$ kg/mm$^2$ [4]). According to X-ray diffraction measurements, the products of reaction between Ta and SiC consist of a tantalum carbide TaC and tantalum silicides Ta$_5$Si$_3$ and TaSi$_2$.

The structure of surface layers formed at and above 1600°C becomes single-phase and consists of TaC which is formed not only at the contact interface but also along the tantalum grain boundaries, being precipitated in the form of narrow "tongues" and small inclusions (Fig. 2b).

**SiC-Mo.** The reaction in this case is quite different in character from those described above. It starts at 1200°C, and a new phase (in the form of fine brittle inclusions) is precipitated in the metal to a depth of 100 microns. The intensity of the reaction increases with rising temperature. Below 1600°C the metal specimen retains its shape, but above this temperature the exfoliation of a porous surface layer takes place (Fig. 3a, b). The microhardness of the new phase increases with the temperature of its formation from $1368 \pm 75$ to $1415 \pm 54$ kg/mm$^2$. According to X-ray diffraction data, the reaction products consist of Mo$_2$C and Mo$_5$Si$_3$; X-ray diffraction patterns of specimens heated to 1500°C show a few lines of molybdenum disilicide.

**SiC-W.** Compact tungsten starts reacting with SiC at 1500°C. The resulting new phase is formed only at the contact interface. When formed below 1800°C, it is quite a dense layer up to 10 microns thick (Fig. 4). At 1900°C the layer thickness increases to 500 microns, but the layer becomes brittle and porous; it was not possible to measure its hardness. X-ray diffraction measurements pointed to the existence of a mixture of two phases WC and W$_5$Si$_3$.

So the stability of the metals studied in contact with silicon carbide (as measured by the temperature of the onset of the interaction and the intensity of the reaction) increases in the order Mo-Ta-Nb-W, while their melting points increase in the order Nb-Mo-Ta-W. This points to a complex character of the processes taking place and indicates that they depend not only on the thermodynamic stability of the interacting materials and diffusional mobility of the components, but also on the composition of the reaction products, their volatilization rate, etc.

**SiC-BeO.** Beryllium contact with silicon carbide is stable up to 1400°C (Fig. 5a), some evidence of an interaction being observed at 1700°C. The resulting new phase is formed at this temperature at the contact interface; at 1800°C it is also precipitated in the specimen volume in the form of fused droplets with a metallic appearance. The results of X-ray diffraction analysis and microhardness measurements indicated that the reaction between BeO and SiC leads to the formation of a beryllium carbide Be$_2$C. In addition, the X-ray patterns showed a few weak, unidentified lines which could not be related to carbon, silicon, beryllium or beryllium silicide.