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Contact Interactions and Wettability of Cubic Boron Nitride Polycrystal with Gold Alloys Containing Transition Metal Additives

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Abstract: The wettability of cubic boron nitride with gold alloys containing vanadium, tantalum, niobium, and titanium additives as well as contact interactions between cBN and alloy were studied. Experiments were carried out in vacuum of 1E-03 Pa in the temperature range of 1100–1400°C. For the systems studied, the adhesion work of cBN towards the alloys was calculated. From the results it can be concluded that the wettability and adhesion in the system cBN-alloy increase as the temperature and concentration of the active component in the alloy grow. The order of the increase of the Θ angle value for the alloy additions studied is as follows: V–Ti–Nb–Ta. © 1997 Elsevier Science Limited and Techna S.r.l.

1 INTRODUCTION

Development of knowledge concerning high-temperature capillarity is impossible without the data on wettability and interactions at the interface and adhesion in new, not previously studied systems.

The aim of the present work was to determine quantitatively (under standard conditions) the changes of wettability of cubic boron nitride by two-component alloys prepared in such a way that into the same chemically inert metal, transition metals of high chemical affinity to a solid phase were introduced as well as to establish the interface formation regularities in these systems.

The wettability of cubic boron nitride by manganese, chromium, titanium dissolved in liquid copper, tin and indium was studied in Refs 1–3. However, tin and copper dissolve most of the high-melting transition metals to a limited extent and do not melt with them which causes difficulties in applications of these solvents.

Therefore in the present work gold was used as a solvent, which made it possible to use a wider range of alloy additions.

2 EXPERIMENTAL

Wettability studies were carried out using the method of sessile drop under the pressure of 1E-03 Pa at the temperature in the range of 1100-1400°C. The equipment used was described in Ref. 4.

Interactions occurring at the cBN–alloy interface were studied on the skew cross-sections of the as-crystallized composition using scanning electron microscope produced by Philips type XL-30 equipped with a detector of a characteristic X-ray radiation EDS-ISIS-Link.

In the studies gold 99.9 purity, electrolytic vanadium, titanium iodide (melted in vacuum for purification), as well as zone refined niobium and tantalum were used. The alloys were prepared directly during the experiment on the cBN substrates, on which wettability was studied.

In the investigations, this value of contact angle (Θ) was taken into consideration, which stayed constant during a long period of time (20–45 min).

Cylindrical polycrystals of cubic boron nitride were used as substrates for wettability studies. The samples were prepared by sintering kubonit micron powder of the 7/5 grit size in a 'toroid' type high pressure apparatus at 9GPa and 1800°C. Before sintering the powder was subjected to chemical-heat purification and surface activation. After sintering the plates were polished using diamond micron powders of various grit sizes in order to obtain the surface of the desired roughness. The porosity of the samples was assessed by hydrostatic weighing and did not exceed 1%.

3 RESULTS

The results of the experiments made it possible to examine the wettability changes of cBN by gold melts containing titanium, vanadium, niobium and tantalum additives depending on the concentration of the additive introduced (Fig. 1).

Pure gold is inactive to the cBN surface, the active metal affinity to boron and nitrogen decreases in the following order: V–Ti–Nb–Ta (Fig. 1).

The spreading of the melts over the cBN surface increases with the active component concentration and with the temperature of the experiment (Fig. 2). They are experimentally obtained curves.

On the other hand melt adhesion to cBN decreases. The adhesion work value was calculated using the Dupre equation according to the formula:

$$W_a = \varphi_{lg} * (1 + \cos \Theta)$$

where: φ_{lg} is the surface energy at the liquid–gas interface that was experimentally determined in this work by the method of sessile drop.

According to the X-ray spectrum microanalysis (Figs 3 and 4) the additive concentration in the samples increases towards the melt cBN interface due to the redistribution of the active component over the melt bulk. The uniformity of B and N distribution (right side in Fig. 3) indicates that there is no redistribution of these elements in the bulk of the samples, while the Ta and Au redistribution is observed and, really, the Au–Ta melt wet cBN best, the Au–Ta alloy was homogeneous: however the interaction between the Ta and cBN has resulted in the redistribution of Ta and Au seen on Figs 3 and 4. The spreading of a metal melt on

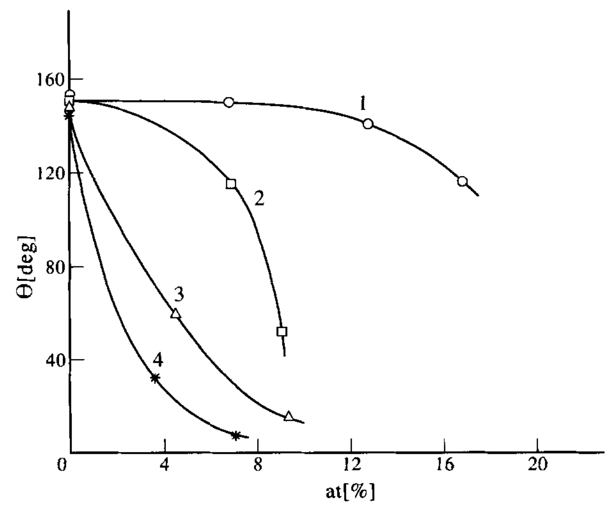

Fig. 1. Concentrational dependences of the wettability of polycrystalline boron nitride with gold melts containing additives: (1) vanadium, (2) titanium, (3) niobium, (4) tantalum (T = 1300°C, p = 1E-03 Pa).

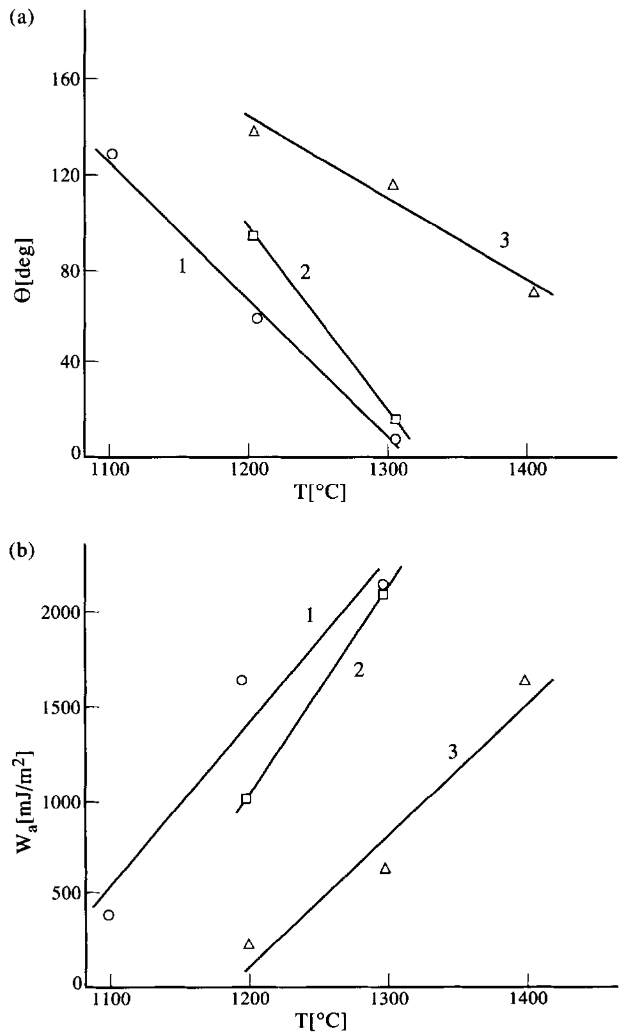

Fig. 2. Temperature dependence of wettability of (a) cBN and (b) adhesion work for the alloys: (1) Au-6.9at%Ta, (2) Au-9.3at%Nb, (3) Au-17at%V (p = 1E-03 Pa).

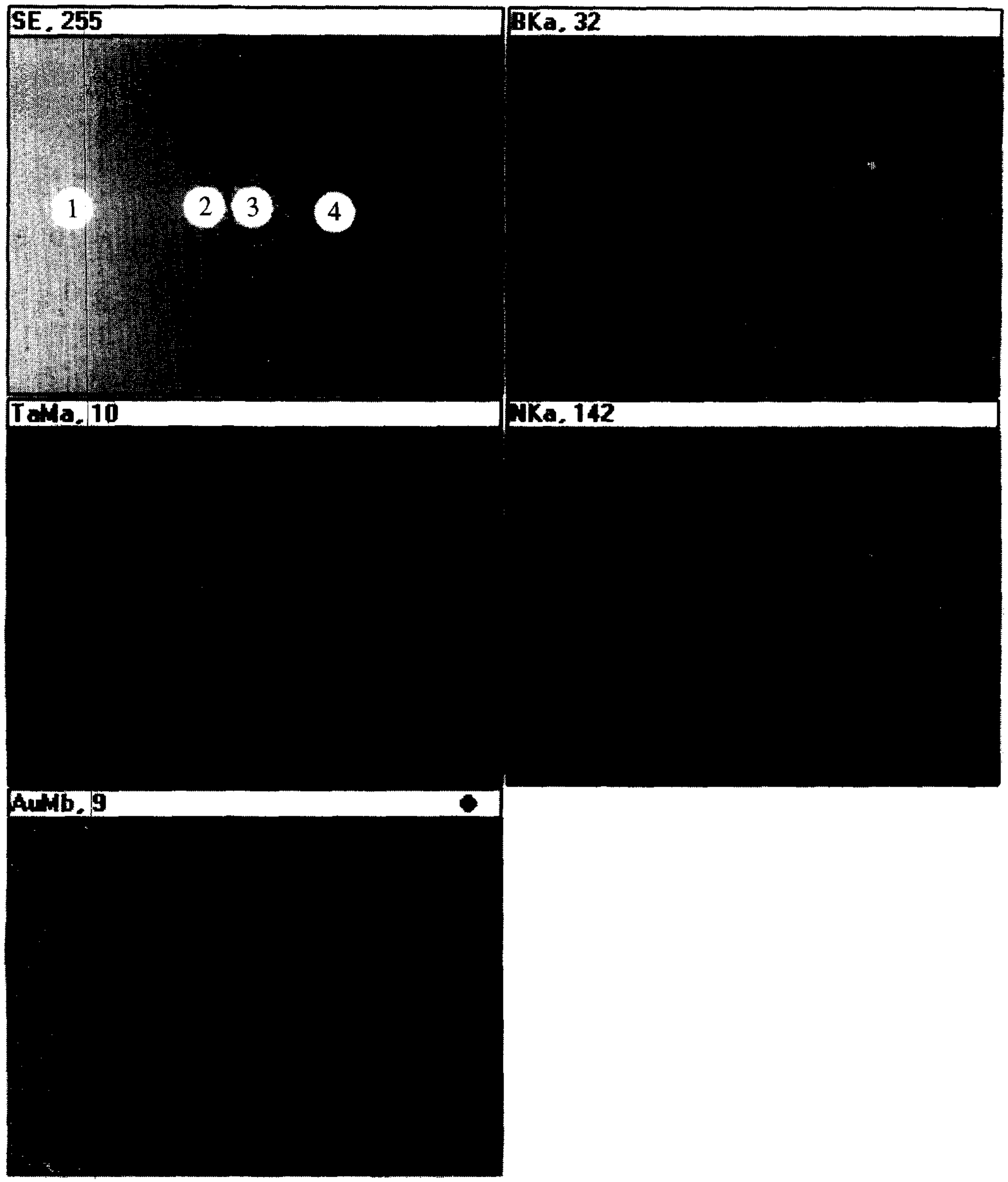

Fig. 3. Structure and point distribution of elements in the cBN–Au–Ta system (polished on the skew section).

the surface cBN is really due to the fact that the system attemps to reach thermodynamic equilibrium. Adsorption of the active components at the interface increases from V to Ta. Thus in points 3 and 4, the B/N ratio remains constant whereas at points 1 and 2 the ratio Au/Ta decreases towards the interface. No transition layer that might be associated with the formation of new phases at the cBN–melt interface was observed.

4 DISCUSSION

The experiments that have been carried out allow to conclude that the wettability and adhesion of alloys containing high-melting metals to cBN are determined by their chemical affinity to the solid phase components (boron and nitrogen) and increase in the vanadium group of the Periodic Table from vanadium to tantalum. This conclusion is supported by thermodynamic calculations.[5] In the same order, the tendency of the active additive to accumulate at the cBN–melt interface grows. This process is most significantly pronounced in the cBN–Au–Ta system.

The width of the interface layer enriched in the alloy additive grows from V to Ta and for Ta it is equal to 2 μm. At the same time lower concentration of the active component is observed in the melt bulk. According to the thermodynamic calculations, the formation of transition metals nitrides and borides in the systems studied is possible. Even though the penetration of the active metal into cBN was not observed, the diffusion into the melt of borides and nitrides being formed should not be excluded.

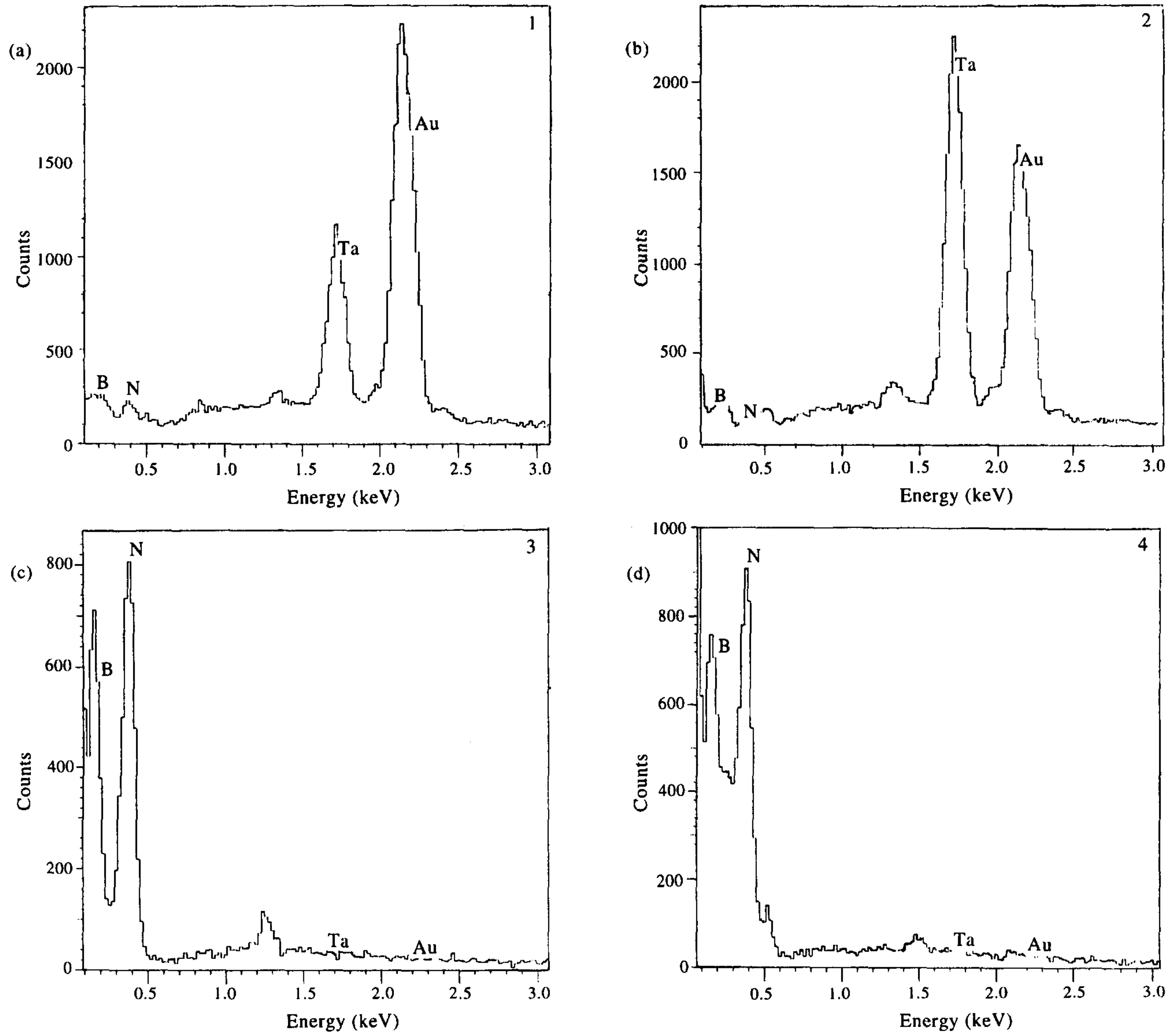

Fig. 4. Linear distribution of elements in the points shown in Fig. 3.

In the case of gold–titanium alloys, a certain lowering of wettability of cBN is observed as compared to the alloys gold–niobium and gold–tantalum even though their chemical affinity to boron and nitrogen is close in value. This is, evidently, associated with the lower thermodynamic activity of titanium in the alloy with gold which is supported by the shape of the diagram of Au–Ti.[6] We observed similar behaviour in the case of wettability of graphite by these alloys. Dependences of wettability of graphite by two-component alloys of gold is discussed in Refs 7 and 8.

5 CONCLUSIONS

Changes of the contact angles of boron nitride wettability with gold melts containing IV–V transition metals are similar as in the case of the wettability of graphite by these melts. However, owing to a much higher chemical inertness of boron nitride as compared with graphite, melts with VIII–VI transition metals do not show adhesion to BN while melts with metals of IV–V groups exhibit the adhesion towards cBN at much higher concentrations of the active component in the melt as compared with that shown in the case of graphite.

The fact that there is no transition layer at the cBN–gold melt interface (the melt containing below 15at% active component) also points to the high chemical inertness of boron nitride as compared to graphite and diamond.

Our findings allow Ti, Nb, Ta in the amount of 1–5at% to be used as the chemically active components of the melt when developing the compositions of binders, solderers and coatings.

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