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Wettability Studies of Cubic Boron Nitride by Silver–Titanium

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Abstract: In the present work the wettability of cubic boron nitride (BN) by titanium has been studied using BN–(Ag–Ti) as the model system. The method of sessile drop has been employed in the studies while heating the substrate and the metal to a temperature of 1000°C under a vacuum of $3 \cdot 10^{-3}$ Pa.

From the results of the studies it can be concluded that BN exhibits very good wettability by the Ag–Ti alloy. The contact angle, θ, is equal to 0° after 15 min of keeping the system at 1000°C. Calculated work of adhesion for the system studied is W_a = 3656 mJ/m^2. Such values of contact angle and work of adhesion must result from the chemical interactions that occur at the interface of the phases studied.

Microscopic studies of the structure of the cross section of the interface layer, as well as the point and linear distributions of Ti, Ag, B and N, confirm that in this system a chemical reaction between boron nitride and titanium takes place.

High chemical activity of titanium towards boron nitride makes it possible to use it as an additive for binding materials and solders.

INTRODUCTION

Boron nitride is a chemical compound that exists in two forms: cubic and hexagonal. The hexagonal form of boron nitride is commonly used for fabrication of refractory materials, whereas the cubic form is applied to produce composite materials. Owing to their unique physico-mechanical properties these materials are frequently applied in machine engineering as cutting blades that are especially useful for the processing of quenched steel and cast iron. As a binding phase of these composites, metals of groups IV–VI of the periodic table of elements or their compounds are most frequently used.[1–3] One of the most important criteria when deciding on the choice of the binding phase for sintering of the composites is the value of the contact angle, θ, of wetting of boron nitride by the components of the binder.

The aim of this work was to study the wettability of cubic boron nitride by metal, in this case by titanium, m.p. 1660°C.

Knowledge of wetting phenomena, as well as of interactions occurring at the ceramic–metal interface, allows control of the process of sintering of super hard materials. Wetting of the ceramic by metal is determined by two types of interactions occurring at the interface, i.e. physical interactions (van der Waals type, polarization, dispersion) and chemical (ionic, homopolar, etc.). The energy of physical interactions reaches values of 1 kJ, whereas the one corresponding to chemical interactions is usually equal to several tens or several hundreds kJ. Thus, it can be concluded that physical forces cannot provide enough energy to cause spreading of metal on the surface of ceramic material. Therefore the theory of adhesion and wetting connects directly the wettability of the solid substrate by a liquid metal or alloy with the chemical interactions of this substrate with the metal or alloy.[4–6]

One of the characteristic features of the wetting caused by chemical interactions is — apart from high values of interface forces — very strong dependence of the contact angle, θ, on temperature and occurrence of the so-called wetting threshold,

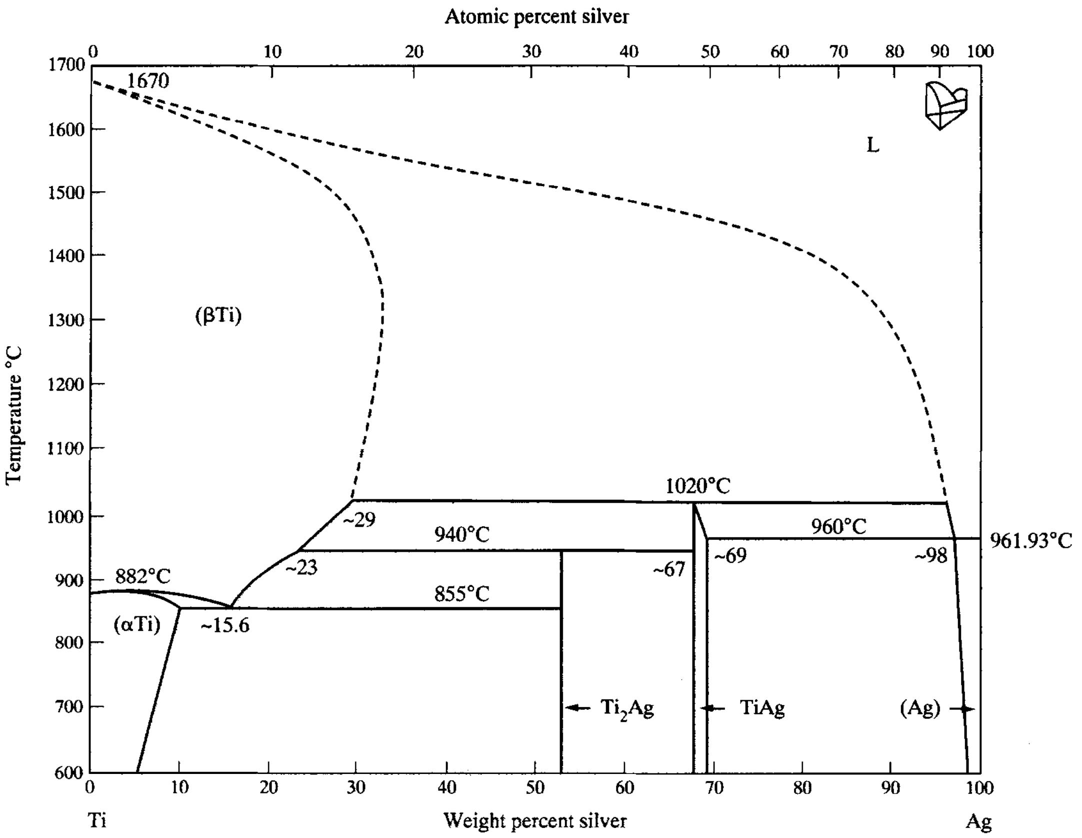

Fig. 1. Phase diagram of the Ag–Ti system.

i.e. the temperature at which the contact angle, θ, sharply decreases and the work of adhesion sharply increases. Thus, the type of changes and value of work of adhesion can serve as the basis for determination of the type of interactions (physical or chemical) taking place in a studied system.

When studying the wettability of the cubic form of boron nitride one should bear in mind that at the temperature of *ca* 1200°C it starts to transform into the hexagonal form. Therefore, in the experiments, model systems in which the metal studied is introduced into the so-called metal solvent are used. The metal solvent must be chemically inert with respect to BN substrate and to the metal studied, while forming with the latter solid solutions with low temperature eutectics.

EXPERIMENTAL

In the present work the wettability of cubic boron nitride by titanium has been studied. Because of the high melting point of titanium the contact angle has been determined using an indirect method, i.e. by applying titanium solvents. Silver has been chosen as a solvent since it forms low temperature eutectics with Ti (Fig. 1).

In the experiments Ag and Ti metals of 99·99% purity have been used (in the ratio of Ag–1·5% Ti). Boron nitride (Teplonit, purity 99%) in the form of pellets of diameter $d = 8$ mm (Institute of Super Hard Materials, Kiev) has been applied as the substrate.

Determinations of the contact angle have been performed using the method of sessile drop while heating both metal and substrate to a temperature of 1000°C in vacuum of $3 \cdot 10^{-3}$ Pa. Observations of the wetting phenomenon have been carried out in the horizontal plane with the possibility to determine the contact angle at any moment of time.

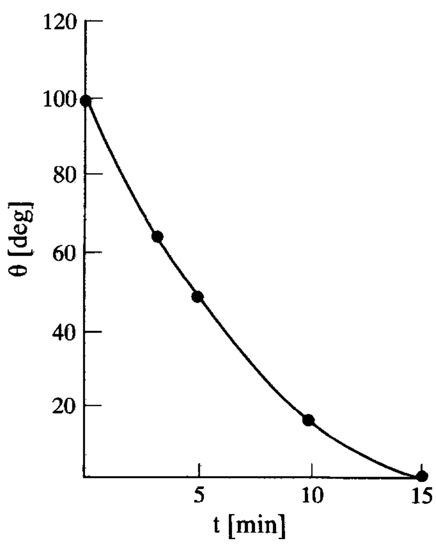

Fig. 2. Dependence of contact angle, θ, on time at a temperature of 1000°C.

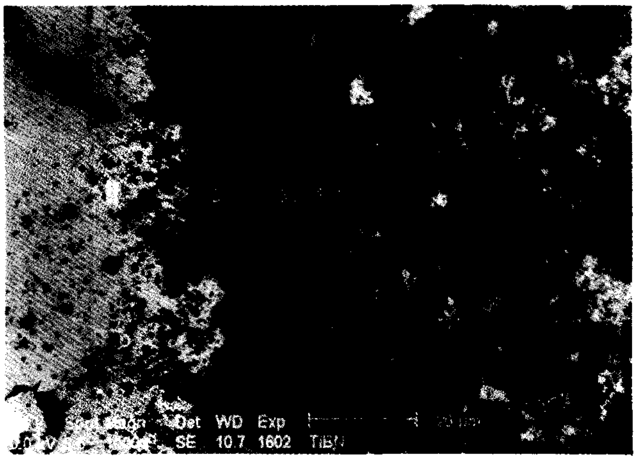

Fig. 3. Structure of the cross section of the sample after wettability studies in the BN–(Ag–Ti) system.

In order to determine the type of interactions taking place in the system (physical or chemical) the specimens have been polished on the transverse sections. The BN–(Ag–Ti) interface layer has been studied using a scanning electron microscope (Philips, type XL-30) equipped with the detector of characteristic X-ray radiation (EDS-ISIS-Link).

RESULTS

From the results of the experiments that have been carried out it can be concluded that titanium is a very good wetting agent for boron nitride. The dependence of the contact angle on time at a temperature of 1000°C is illustrated in Fig. 2. As can be seen, after only 15 min of keeping the system at 1000°C the angle θ equals 0°. The liquid metal spreads on the substrate very well.

It has been established by chemical analysis that the interface layer has the following composition: 98% Ti–2% Ag. The work of adhesion calculated for the Ti–2% Ag alloy is equal to

$$W_a = 3656 \text{ mJ/m}^2$$

The above value of the work of adhesion has been calculated using the following equation:

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

where σ_{lg} is the surface energy at the liquid–gas interface.

The value of the contact angle (0°) and high value of work of adhesion indicate that at the BN–(Ti–2% Ag) interface a chemical reaction occurs.

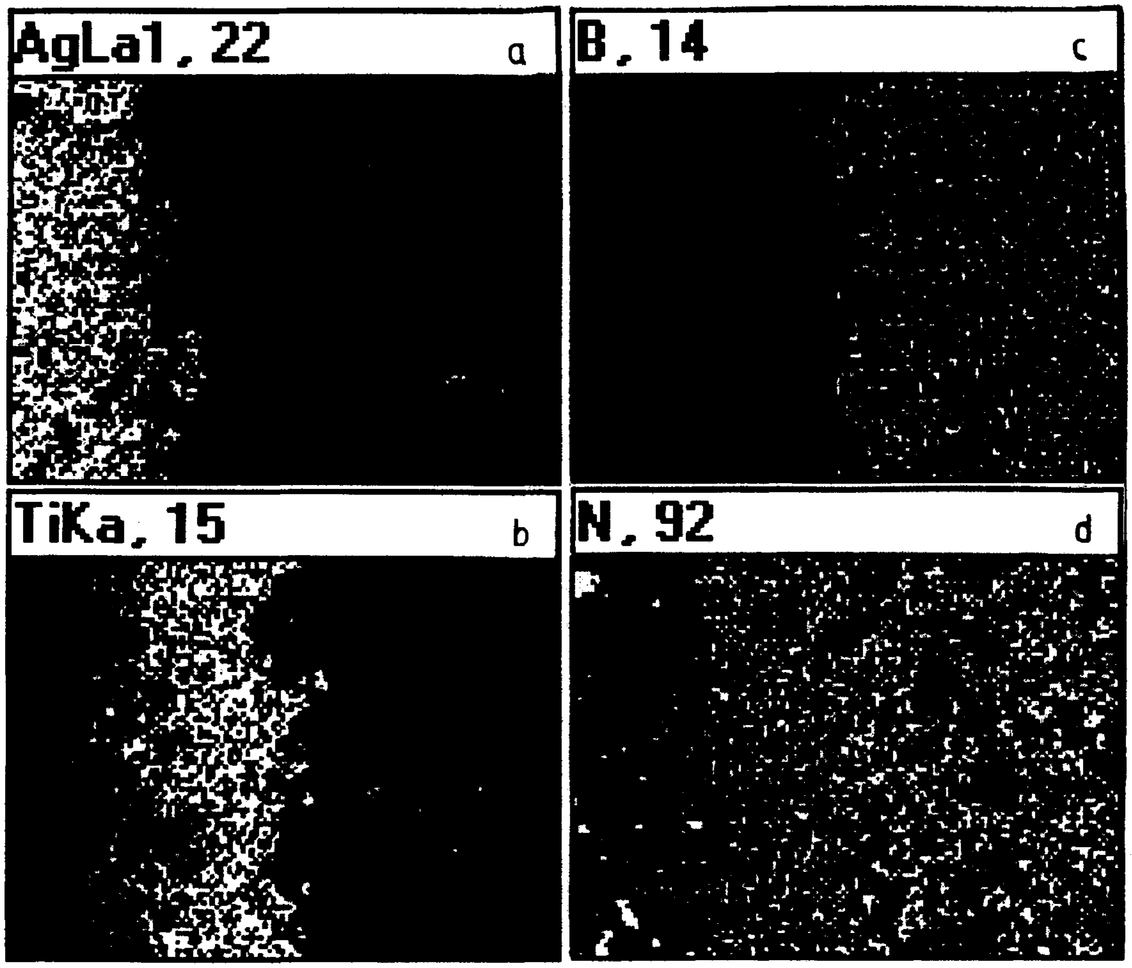

Fig. 4. Surface distributions of various elements in the interface layer shown in Fig. 3: (a) Ag; (b) Ti; (c) B; (d) N.

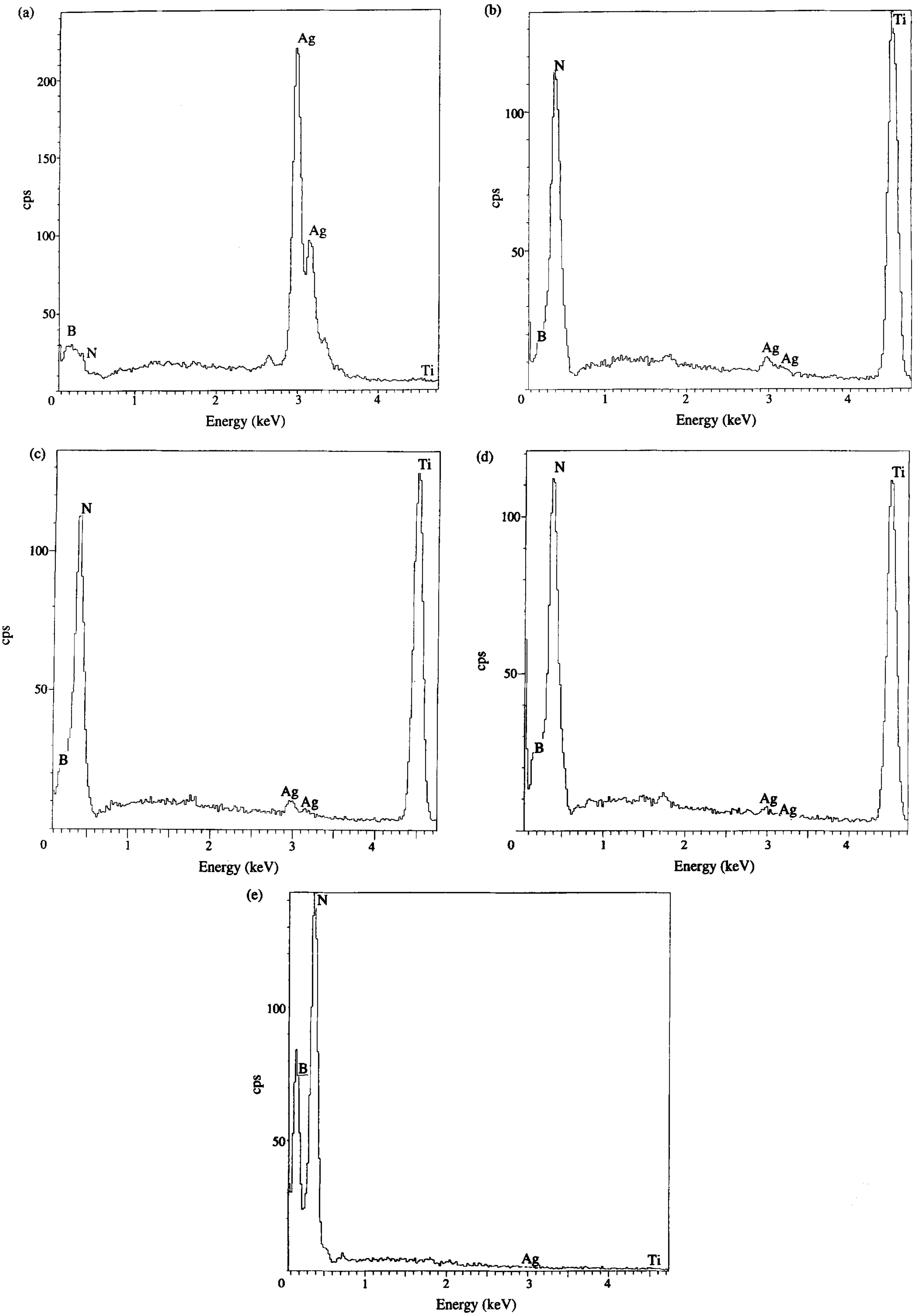

Fig. 5. Linear distributions of Ag, Ti, B and N in the points denoted in Fig. 3 as 1, 2, 3, 4 and 5.

This means that in the system studied the wettability results from the chemical interactions between contacting phases.

According to the calculations of chemical equilibrium in the BN–Ti system that have been carried out using the VCS algorithm[7] at a temperature of 1000°C and a pressure of $3 \cdot 10^{-3}$ Pa, two new phases are formed: TiB_2 and TiN.

In order to evaluate the structure of the interface and the possible diffusion of atoms from the interface, linear and point distributions of Ti, Al, B and N using the microprobe have been carried out. The structure of the cross section of the sample is shown in Fig. 3, and linear and point distributions of elements are shown in Figs 4 and 5, respectively. From the microscopic observations it can be concluded that titanium diffuses from the Ag–Ti solid solution towards BN and thus the amount of Ti in the solution decreases. At the BN–metal interface a distinct transition layer enriched with Ti with respect to Ag–Ti can be observed. This layer is also enriched with nitrogen, which has diffused from boron nitride to metal (Fig. 4b). However, diffusion of boron towards metal has not been observed.

From the linear distribution of elements (Fig. 5) one can conclude that there is significant diffusion of boron towards metal in the areas close to the interface.

From the measurements of the contact angle and the elements distributions (both linear and point) one can conclude that titanium exhibits high chemical activity towards boron nitride. Chemical interactions occurring at the interface result in the formation of titanium nitrides and borides in the regions close to the interface layers. Owing to its high chemical activity towards BN, titanium can be applied as the additive to binding materials during fabrication of composites or as an additive to solders when BN plates are fixed to the metal cutting tool. The chemical reactions occurring at the BN–Ti interface provide very good binding of the binder with boron nitride.

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