density of specimens. Alloy $B_3$ with a density of 80% of the theoretical value shows the highest oxidizability; alloy $B_3$ with a density of 93% of the theoretical value is practically immune to oxidation.

The coefficients of thermal expansion of alloys $B_1$, $B_3$, $B_5$, and $A_7.5$, as well as alloy C-8 investigated earlier, are listed in Table 3. As can be seen from the table, at 100° these coefficients differ but little from one another. With increasing temperature in the range 100-600°, the coefficient of thermal expansion of alloy $B_3$ increases from 2.21 at 100° to 4.86 at 600°.

| TABLE 3. Coefficients of Thermal Expansion of Test Alloys, $\alpha \cdot 10^{-6}$ (per 1°C) |
|-----------------|--------|--------|--------|--------|--------|--------|
| Alloy grade     | 100    | 200    | 300    | 400    | 500    | 600    |
| C-8             | 2.23   | 3.30   | 4.12   | 4.63   | 4.82   | 4.85   |
| $B_3$           | 2.21   | 3.06   | 3.76   | 4.36   | 4.66   | 4.86   |
| $B_5$           | 2.70   | 2.76   | -      | -      | -      | -      |
| $A_7.5$         | 2.47   | 2.76   | -      | -      | -      | -      |

It follows from what has been said above that alloys $B_3$, $B_5$, and $A_7.5$ may be recommended for tests in components. Alloys $B_1$ and $A_5$ require further development work.

**SUMMARY**

An investigation was conducted on the modes of sintering samples of silicon carbide with additions of boron and aluminum by hot pressing, and some physical properties of the resulting alloys were studied.

**LITERATURE CITED**

3. I. S. Kainarskii, É. V. Degtyareva, and V. A. Kukhtenko, Ogneupory, 12, 562 (1960).

**INVESTIGATION OF THE PHYSICAL PROPERTIES AND STRUCTURE OF TiC-WC-Co ALLOYS**

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Sintered WC-TiC-Co hard alloys are widely used in industry. The structure and properties of these alloys have been studied in many investigations, but nevertheless the character of the distribution of the binder (cobalt) between the carbide particles has not yet been fully elucidated [1, 2].

This paper presents the results of an investigation into the structure of TiC-WC-Co alloys as a function of composition, obtained by the method of electrical resistivity measurement. For the investigation, three series of alloys were prepared; the W:Ti ratio in each series was constant, while the Co content varied between 0 and 30%.
The alloys of the first series contained no titanium carbide, while the amounts of titanium carbide in the alloys of the second and third series represented about 16 and 64% of the carbide phase, respectively.

The alloys of the first series consisted of two phases - tungsten carbide (the WC phase) and a cobalt-base solid solution (Co). The alloys of the second series (16% TiC) had a three-phase structure, consisting of the WC phase, a solid solution of tungsten carbide in titanium carbide (the titanium phase), and a solid solution of Ti, W, and C in cobalt (Co). The alloys of the third series (64% TiC) had a two-phase structure, consisting of the titanium phase and cobalt.

The alloys were prepared by the normal procedure employed in the manufacture of sintered hard alloys. The cobalt-free specimens were produced by the method of hot pressing. The sintered specimens were nonporous and contained no structurally-free carbon. The alloys were subjected to homogenizing annealing and quenching.

The annealing conditions were: holding for 2 h at 1200° in a hydrogen atmosphere and furnace cooling at a rate of 40-50 deg/h to room temperature. The quenching conditions were: heating in a hydrogen atmosphere to 1200°, holding for 2 h, and cooling in oil at 20°.

The grain size of the WC phase and the solid solution of WC in TiC was scarcely affected by variation of the cobalt content and the heat treatment. Electrical resistivity was measured on as-sintered, annealed and quenched specimens. In addition, the alloys were subjected to metallographic and x-ray diffraction analyses, and their microhardness and bending strength were determined.

Electrical resistivity was measured by the usual compensation method with a double bridge circuit. Bending strength was determined in a type R-5 universal testing machine with a 30 mm distance between the supports, and microhardness with a PMT-3 tester at a load of 50 g. X-ray diffraction pictures were obtained in an RKD camera and in a URS-50-I apparatus.

The absolute values of electrical resistivity and the curves of the latter plotted against cobalt content differ substantially for the three series of test alloys (Fig. 1). The higher the titanium carbide content, the greater is the electrical resistivity.

Quenching results in an increase of electrical resistivity, while annealing results in its decrease. The greater the cobalt content, the greater is the influence of heat treatment. The value of electrical resistivity is of course determined principally by the composition of the binding phase. When the rate of cooling changes within the limits indicated, the electrical resistivity of the carbides remains unchanged.

In the two-phase WC-Co alloys, increasing the amount of cobalt to 6-10 vol. % leads to an increase of electrical resistivity (Fig. 1, WC-Co). A further increase of cobalt content results in an additional, although slower, increase of electrical resistivity in quenched alloys, but has practically no effect on the electrical resistivity of the series of alloys subjected to annealing.

In the alloys containing structurally-free tungsten carbide and a solid solution of WC in TiC (16% TiC), increasing the cobalt content to 6-10 vol. % gives rise to a sharp drop of electrical resistivity (Fig. 1, T15). A further increase of cobalt content is accompanied by an increase of electrical resistivity, which is particularly pronounced in quenched alloys. The electrical resistivity of the alloys consisting of the titanium phase and cobalt (64% TiC) gradually decreases with increasing cobalt content (Fig. 1, T60).

The x-ray diffraction analysis (table) demonstrated that, in the WC-Co alloys, the introduction of cobalt and variation of its amounts exerts no significant influence on the lattice parameter of the WC phase. Quenching these alloys produces very slight lattice parameter changes, which are due to thermal stresses.

In the two-phase alloys with 64% TiC in the carbide phase, increasing the amount of cobalt beyond 1.5% is accompanied by a decrease in the TiC-phase lattice parameter. The rate of cooling has no influence on the lattice parameter of the titanium phase, although some fluctuation of its values is observed.

In the three-phase alloys (16% TiC), containing structurally-free tungsten carbide and the titanium phase, the lattice parameter of the latter depends both on cobalt content and cooling conditions. Annealing results in a reduction of the lattice parameter of the TiC phase in comparison with quenched alloys; the difference increases with decreasing cobalt content.