JOURNAL OF MATERIALS SCIENCE 31 (1996) 5227–5230

Structural peculiarities of cermets design based on titanium carbide

Part I *Influence of chemical composition on the ductile–brittle transition temperature, microstructure and properties of cermets*

N.G. ZARIPOV, R.R. KABIROV
Institute for Metals Superplasticity Problems, Russian Academy of Sciences, Ufa 450001, Russia
V.N. BLOSHENKO
Institute for Structural Macrokinetics, Russian Academy of Sciences, Chernogolovka, Moscow Region 142432, Russia

The influence of chemical composition on the ductile–brittle transition (DBT) temperature, microstructure and mechanical properties of cermets based on titanium carbide (chemical composition of cermets TiC_x, (x=0.55; 0.65; 0.75 and 1.0) – nickel-based superalloy (Russian Trade Mark GS6U containing (wt%) Ni–10W–10Co–9Cr–5.5Al–2.5Ti–2Mo–0.15C) was studied. It was shown that high strength in cermets can be achieved if the structure of the frames is retained and the DBT temperature of the refractory phase is controlled. By changing the microstructure and its homogeneity, the chemical composition of the frames, the porosity value and the binding material, it is possible to synthesize new cermets for certain temperature regions. The optimum operating temperature of such materials depends on the DBT temperature and the temperature of the transition to a superplastic state of refractory phases.

1. Introduction

Cermets based on transition metal carbides are widely used for the production of cutting tools and forming equipment for cold- and hot-forming. They also have other fields of application, where high hardness, wear resistance, high-temperature strength and corrosion resistance are required (for example, oil-extracting and oil-processing industries). Therefore, the determination of the optimum combination between the strength characteristics of materials and their viscosity is the main problem in selecting cermets. This problem is often solved by the formation of such structure in which each refractory particle is surrounded by the metal-binding layers (for example, by means of liquid-phase sintering [1] or high-temperature self-propagation synthesis with subsequent force compaction during cooling (SHS) [2]). The properties of such materials usually depend on the properties of metal-binder phases.

The cermets consisting of two mutually penetrating frames of metal and refractory phases are more promising for high-temperature application compared to the cermets consisting of metal matrix with the uniform distribution of refractory particles. The major load in such cermets is borne by the refractory compound frames, whereas the metal phase inhibits the propagation of cracks occurring in the vicinity of stress concentrators. However, the brittleness of frames considerably limits the application of such materials and leads to the abrupt decrease of the general strength level of cermets. The creation of diffusion zones in carbide grains also results in the reduction of the high-temperature strength of cermets [3–5].

New possibilities in the design of plastic frames can be achieved by changing the chemical composition and the microstructure type of refractory compounds. This allows the control of the ductile–brittle transition temperature of frames [6]. The transition metal carbides with a wide homogeneity area are most suitable for such frames of this type. The ductile–brittle transition (DBT) temperature of these compounds depends on the deviation of the stoichiometric composition and can be changed within a wide temperature region [7].

This work studied the influence of the chemical composition and the microstructure type of refractory frames, produced by SHS and powder metallurgy, on the high-temperature mechanical properties of cermets, based on these frames, and ways to improve their structural strength.

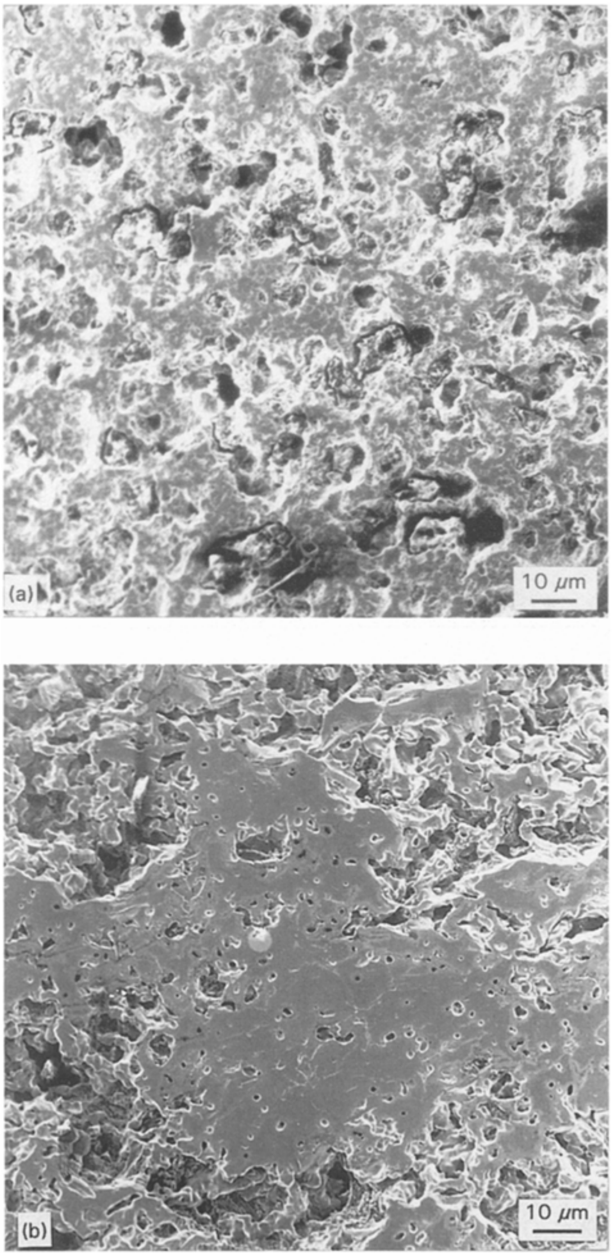

Figure 1 The microstructure of titanium carbide frames, (a) produced by means of SHS, (b) produced by means of powder metallurgy.

2. Experimental procedure

Titanium carbide is the most convenient object for such studies because this material possesses a wide area of homogeneity (C/Ti ratio can change from 0.5–1.0 [7]) and is extensively used for the production of cermets. The porous frames of different chemical compositions ($TiC_{0.55}$, $TiC_{0.65}$, $TiC_{0.75}$ and $TiC_{1.0}$) were produced by means of SHS. The powders of titanium and graphite with maximal size of particles < 63 μm were used during preparation of the frames. The reaction was initiated after preliminary heat treatment of the initial powder at 700 °C; the temperature of combustion was about 2700 °C. Pores of these frames are distributed homogeneously within the volume (Fig. 1a), while the porosity accounts for 40%–50%.

For a comparative analysis, similar frames were produced by means of powder metallurgy. In that case different mixtures of titanium powders with titanium carbide were prepared. The necessary chemical composition of titanium carbides was achieved by vacuum sintering of these mixtures at high temperatures. The porosity of these frames approximated 30%; however, the microstructure was greatly inhomogeneous both in grain size and in pore distribution (Fig. 1b).

The cermets were produced by the method of vacuum infiltration of porous frames by the nickel-based superalloy (Russian Trade Mark GS6U containing (wt %) Ni–10W–10Co–9Cr–5.5Al–2.5Ti–2Mo–0.15C) at 1500 °C for 0.5 h [5, 6].

Owing to the absence of a reliable technique for the determination of the DBT temperature by plasticity, that temperature was determined indirectly by strength changes.

Both the microstructure and the fracture surfaces of samples were studied using the Neophot-32 optical metallographic microscope and the JSM-840A scanning electron microscope with the energy-dispersive analysis device LINK; the chemical and phase compositions of the samples were investigated by means of X-ray analysis.

The porosity of the initial frames was measured both by the hydrostatic weighing method and by the quantitative metallography method. High-temperature compression tests were conducted at temperatures up to 1100 °C in air using the Instron-type mechanical testing machine.

3. Results and discussion

Let us consider the influence of the chemical composition of refractory frames on the DBT temperature. The results of the high-temperature compression tests of frames produced by both methods are shown in Fig. 2a and b. As seen from Fig. 2a, the chemical composition strongly affects the temperature dependence of the ultimate stress. The titanium carbide frames with larger deviation from the stoichiometric composition demonstrate the highest strength at low temperatures, and with increasing temperature the strength abruptly decreases. On the contrary, the titanium carbide frames with less deviation from the stoichiometric composition are characterized by higher ultimate stress at high temperatures, and with reducing temperature these frames fail at lower stresses. A similar dependence of the ultimate stress is observed in the frames produced by means of powder metallurgy as well (Fig. 2b). However, in this case the stress level is higher than that in SHS frames due to the lower porosity. A significant scattering of the stress magnitudes takes place for the frames produced by means of powder metallurgy, this scattering being connected with inhomogeneity of the microstructure.

The infiltration of the porous frames by the nickel-superalloy leads to essential changes of the microstructure and properties of the materials. The frame structure is completely retained after infiltration of the SHS frames; however, the structure of the frames produced by means of powder metallurgy is destroyed at

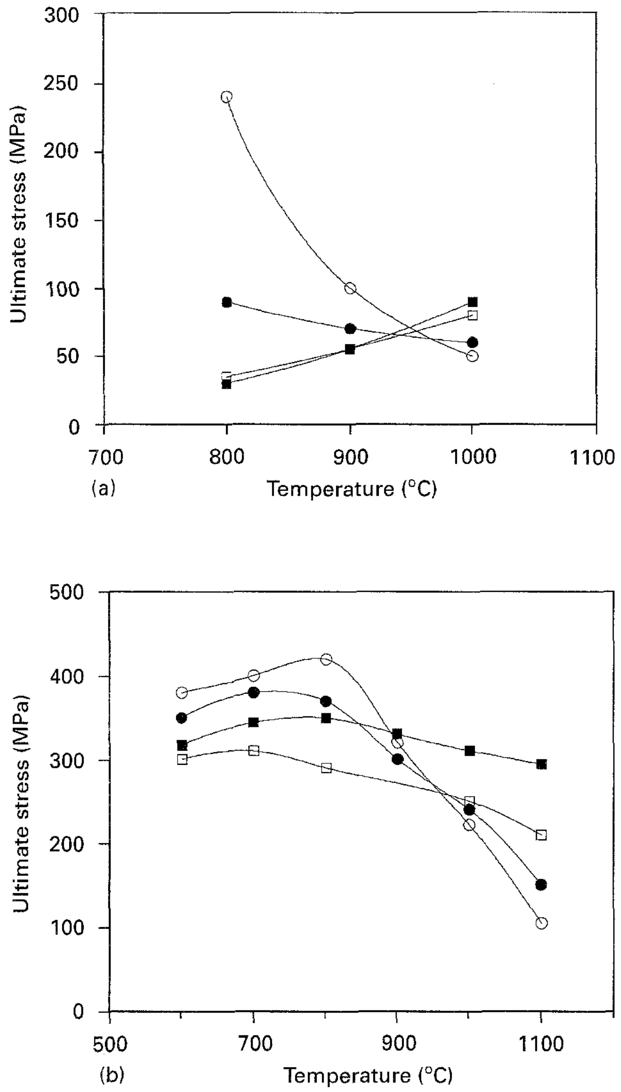

Figure 2 The temperature dependences of the ultimate stress for (a) the SHS frames and (b) the powder frames. (○) $TiC_{0.55}$, (●) $TiC_{0.65}$, (□) $TiC_{0.75}$, (■) $TiC_{1.0}$.

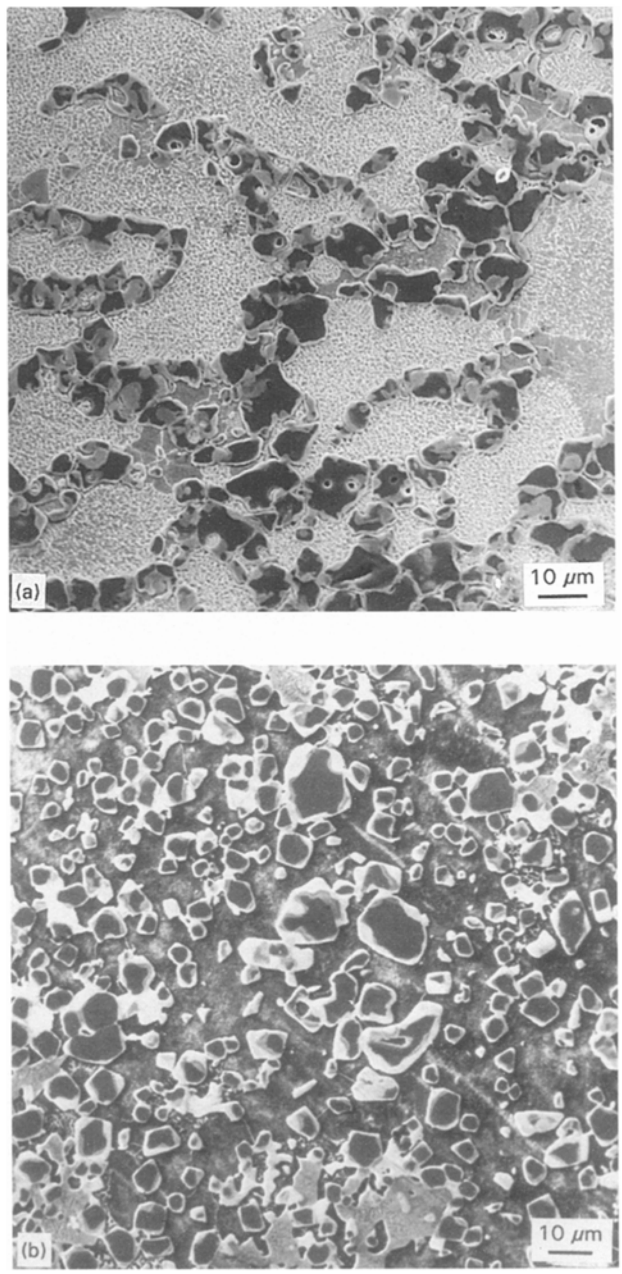

Figure 3 The microstructure of cermets produced by the infiltration of (a) the SHS-frames and (b) the powder-frames.

larger deviations from the stoichiometric composition (Fig. 3a, b). The temperature dependence of the ultimate stress during compression tests becomes monotonically decreasing for all cermets (Fig. 4). The clearly identified four temperature intervals are observed in cermets prepared from the SHS frames, where the maximum strength takes place (Fig. 4a). The cermets prepared from $TiC_{0.55}$ frames show the maximum ultimate stress at temperatures up to 650 °C. The strength of cermets in this temperature range decreases as the chemical composition of the frames approaches the stoichiometric composition. The rise in temperature decreases the difference in stresses. In the temperature region of 650–750 °C, the cermets based on $TiC_{0.65}$ frames have the maximum ultimate stress. The highest ultimate stress in the third temperature region (750–950 °C) corresponds to the cermets based on $TiC_{0.75}$ frames. The cermets based on the stoichiometric titanium carbides provide high strength at temperatures above 950 °C.

Such clearly identified stress dependence of the chemical composition is not observed in the cermets prepared by the powder metallurgy method. The materials having even the highest magnitudes of the chemical composition demonstrate almost similar strength (Fig. 4b).

Thus, the results of compression tests indicate that cermets produced by infiltration of the SHS frames with different chemical compositions show the maximum strength only in certain temperature regions. However, the changes of properties are not observed in the cermets produced by infiltration of powder frames. Such behaviour of cermets with different types of refractory frames can be explained by the changes of the microstructure and properties of carbide frames. For the SHS cermets, a brittle fracture of frames occurs at temperatures lower than the DBT temperature, when local stresses arise. In this case, the mechanical properties of cermets are mainly determined by the properties of the metal-binding phase. At temperatures above the DBT temperature, the refractory

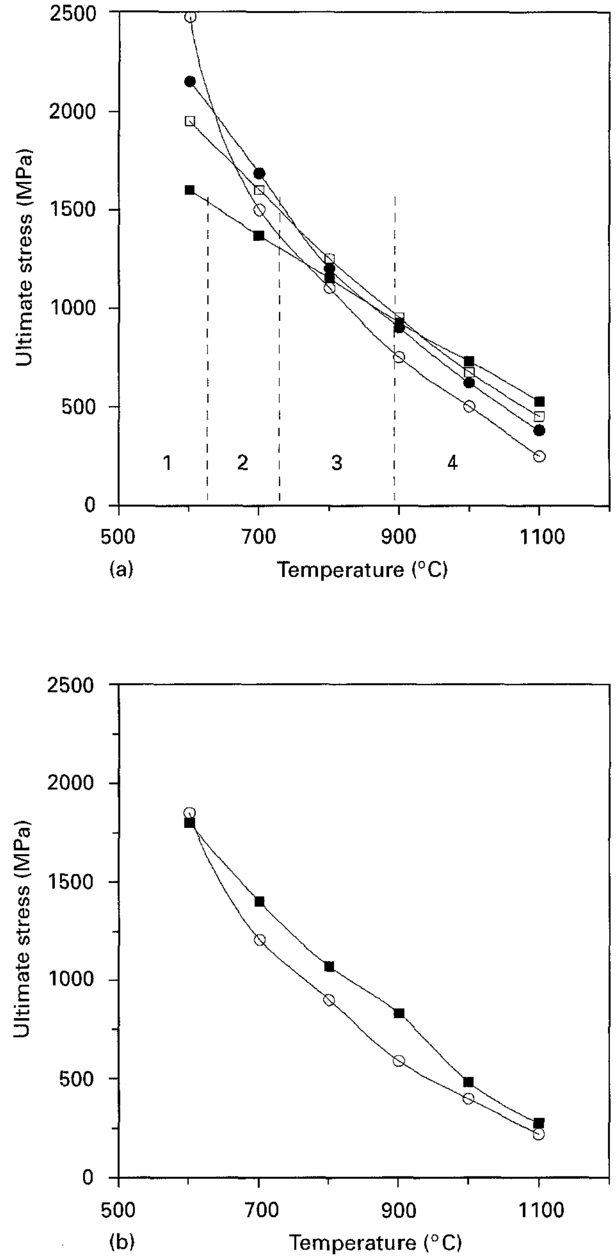

Figure 4 The temperature dependences of the ultimate stress for the cermets based on (a) SHS-frames and (b) powder frames. (a) (○) $TiC_{0.55}$ + superalloy, (●) $TiC_{0.65}$ + superalloy, (□) $TiC_{0.75}$ + superalloy, (■) $TiC_{1.0}$ + superalloy. (b) (○) $TiC_{0.58}$ + superalloy, (■) $TiC_{1.0}$ + superalloy.

frames become ductile and capable of stress relaxation due to plastic deformation, which considerably increases its strength properties. With increase of the deviation from the stoichiometric composition, the DBT temperature decreases and plastic deformation can be carried out at lower temperatures. Consequently, the strength of cermets increases in this region. At higher temperatures, large plastic deformation of refractory and metal-binder phases is possible, and the transition of cermets to a superplastic state at certain temperature–rate conditions can be observed [8, 9]. Owing to that, the strength of cermets sharply decreases. At these temperatures the materials with frames close to the stoichiometric composition exhibit high strength, because the DBT temperature is only being achieved in them.

The DBT temperature is a structurally sensitive parameter and its value is dependent on the homogeneity of the microstructure. The change of the DBT temperature depending on the chemical composition is more clearly observed in the SHS frames with more homogeneous microstructure, compared to the powder frames. The conservation of frames at subsequent infiltration provides regular changes of properties.

The above regularities of the changes in properties are also observed in the powder frames, although the inhomogeneity of their microstructure somewhat decreases the dependence of properties on the chemical composition. However, the fracture of the frame structure on infiltration leads to a disappearance of the difference in properties for different materials.

4. Conclusions

High strength in cermets can be achieved if the frame structure is retained and the DBT temperature of the refractory phase is controlled. By changing the microstructure and its homogeneity, the chemical composition of frames, the porosity value and the binding material, it is possible to synthesize new cermets for certain temperature regions. The optimum operating temperature of such materials depends on the DBT temperature and temperature of the transition to a superplastic state of refractory phases.

Acknowledgements

The authors thank Professor O. A. Kaibyshev and Professor A. G. Merzhanov for helpful discussions of the results, and Dr A. A. Kashtanova, Institute for Structural Macrokinetics of Russian Academy of Sciences, for the preparation of the samples. This research was made possible in part by Grant NYO000 from the International Science Foundation.

References

1. D. J. MILLER and J. A. PASK, *J. Am. Ceram. Soc.* **66** (1983) 841.
2. A. G. MERZHANOV, I. P. BOROVINSKAYA, V. I. YUCHVID and V. I. RATNIKOV, "Fundamentals of Materials Science" (Nauka, Moscow, 1981) (in Russian).
3. L. LINDAU, *Powder Metall.* **4** (1976) 210.
4. D. MOSKOWITZ and H. K. PLUMMER, "Proceedings of the International Conference on Science Hard Materials", Jackson, WY, August, 1981 (Plenum Press, New York, London, 1983) p. 299.
5. M. I. LANDA and R. F. MAMLEEV, *Poroshk. Metall.* **3** (1988) 99 (in Russian).
6. O. A. KAIBYSHEV, A. G. MERZHANOV, N. G. ZARIPOV, V. N. BLOSHENKO, V. A. BOKIY, R. R. KABIROV and O. YU. EFIMOV, *Dokl AN SSSR* **324** (1992) 325 (in Russian).
7. L. E. TOTH, "Transition Metal Carbides and Nitrides" (Academic Press, New York, 1971).
8. O. A. KAIBYSHEV, A. G. MERZHANOV, N. G. ZARIPOV, L. V. PETROVA, O. YU. EFIMOV and A. N. PITYULIN, *J. Mater. Shaping Technol.* **9** (1991) 77.
9. O. A. KAIBYSHEV, "Superplasticity of alloys, intermetallides and ceramics" (Springer, Berlin, 1992).

Received 23 January 1995
and accepted 24 April 1996