CERAMICS AND CERMET COMPOSITES: COMPARISON FROM THE POSITION OF FRACTURE MECHANICS

O. M. Romaniv* and B. D. Vasyliv*

On the basis of the crack propagation micromechanisms and energy dissipation analysis jointly with using special K_{Ic} - strength limit diagrams the mechanical efficiency of various types of ceramics and cermets was compared. It is shown that the structural-metallurgical principles characteristic for cermets create a basis for enlargement of use of ceramic materials in various power equipment under the influence of mechanical loading with higher resistance to quasibrittle fracture.

INTRODUCTION

In the last decades increases application of ceramic materials in components of energetic equipment. Such tendency is connected with metallurgical and technological possibilities of increase their crack resistance. From this point of view it is of great interest a comparative analysis of the efficiency of ceramics in the range of elevated temperatures and possible competitive ability of cermet composites. Such analysis is possible taking into account widespreding for ceramic materials fracture mechanics methods and evaluation of the critical and subcritical crack growth resistance and micromechanisms of energy dissipation as a measure of fracture toughness of such materials. The purpose of the work reported here is to perform comparative analysis of the possibilities and efficiency of various types of ceramics and cermet composites. From this point of view this work develops the insight on the ceramics efficiency propounded by Dauskardt and Ritchie (1), Fett and Munz (2), Mutoh and others (3).

* Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine, Lviv

EXPERIMENTAL PROCEDURE

For comparative evaluation of mechanical efficiency three types of classical conventional ceramics were used: at first Al_2O_3 as a simple model of one phase ceramics; considerable attention was paid to the alumina modified by zirconia (Al_2O_3-ZrO_2); also perspective silicon nitride ceramics modified by ittrium oxide (Si_3N_4-Y_2O_3) was thorough investigated. Both mentioned structurally complicated ceramics were studied from the point of optimization of proportionality both main intrinsic components and technological regimes of sintering which allowed to recieve optimal relations between volume strength and fracture toughness (4, 5). The mentioned above three types of classical ceramics were tested in comparison with two types of metal-ceramic composites. Main attention was paid to Ti-Si composite modified partially by Zr and Al. Ti-Si composites were prepared by Mazur and coworkers (6) in five various modifications using the various melting techniques. Structure of these cermets consist of eutectic mixture of α and β titanium plates fringed with boundary layers of Ti_5Si_3 and $(Ti, Zr)_5Si_3$. Biside of that taking into account wide extension in tool industry for comparison tungsten carbide - cobalt cermets (WC-Co) was investigated (7).

The mechanical tests were performed on square bulk specimens in bending. The crack resistance was examined on bulk specimens with central notch concentrator in conditions of three point bending. Succeptibility to subcritical crack growth on precracked specimens in conditions of soft and hard loading was examined. For comparison of the functional possibilities of various types of ceramics in the technical products special type of mechanical efficiency diagrams (MED) was used. These diagrams take into account comprehensivly the level of bulk or surface strength and crack propagation resistance of ceramics in the given temperature exploitation conditions.

For examination of fracture behavior of various ceramic materials the electron and optical microscopy approach in studying micromechanisms of crack propagation and elementary acts of fracture on various structural barriers and defects were used.

RESULTS AND DISCUSSION

The analysis of potential possibilities of mentioned types of ceramics after durable procedure of optimization of contents, regimes of sintering and thermal treatment showed the following results. The lowest level of interrelation between K_{Ic} and σ_b was observed in the simple modelling Al_2O_3 ceramics (Fig.1), where the main mechanism of fracture toughness is connected with fan cracking (Fig.2a). The level of K_{Ic} essentially grows in Al_2O_3-ZrO_2 ceramics (Fig.1). In the last case the improvement of crack resistance depends on the interrelation of tetragonal and monoclinic ZrO_2 (optimal properties at

15% of tetragonal phase are achieved (4)). In such conditions the effect of internal compressive stresses under the influence of polymorphic transformation (Fig.2b) achieves the maximum value. For the modified silicon nitride ceramics (Si_3N_4-Y_2O_3) also sufficient increase of fracture toughness is possible, but in the last case the dominant mechanism of energy dissipation is connected with barrier action of boundaries of stretched grains β-Si_3N_4. For pointed out materials the supplementary role in crack resistance increase can play observed grains twinning and crack bridging. Also can display the effects of interaction (closure) of crack surfaces (Fig.2e).

Both investigated types of cermets uncommensurably gain in comparison with mentioned ceramics in the level of fracture toughness (Fig.1). In that case the essential level of volume strength σ_b is provided although these materials waive to classical ceramics in the level of surface strength (Fig.1b). We observe distinctions in mechanical behavior of Ti-Si and WC-Co cermets which is connected with structural differences. In Ti-Si cermets the specific ceramic nature is connected with hard intergranular layers and vice versa in WC-Co system we observe hard grains in mild metallic cover. In the last case the higher level of surface strength is characteristic. Uncomparably higher level of fracture toughness of cermets is conditioned with principally different from ceramics dislocations mechanism of stress relaxation which is characteristic for metallic alloys.

So far as the ceramic materials are perspective for high temperature use so is of great importance comparable analysis of ceramics and cermets in the wide temperature range. Such analysis showed essential concurent possibilities and even some advantages of cermets which preserve till 800 °C (Fig.3).

The conventional ceramic materials distinquish drastically from the cermets in the subcritical crack growth behavior under static and especially cyclic loading. For investigated ceramics the unstable subcritical crack growth is characteristic which seize very limited interval of stress intensity factors (SIF) (Fig.4). For all that in conditions of soft loading the special effects of crack retardation and even crack stopping thanks to fan cracking in crack enclave can be observed (Fig.4, curve "Al_2O_3"). Sharp steep character of υ-SIF curves brings to the special approach in description this curves as one stage process. The special advantages of cermets consist in possibilities to offer essential resistance to crack growth under cyclic loading with possibilities to plot υ-SIF diagrams which are characteristic for metals. One of the principal indicator of increasing of resistance to brittle fracture of ceramics consist in their ability to form typical three stage υ-SIF curves (Fig.4, curve "Ti-Si").

From expounded above follows the significant possibilities to improve fracture resistance of ceramic materials by using mixed structures with metallic interlayers which are characteristic for cermets.

REFERENCES

(1) Dauskardt, R. H. and Ritchie, R. O., Closed Loop, Vol. 16, No. 2, 1989, pp. 7-17.

(2) Fett, T. and Munz, D., J. Mater. Sci., No. 10, 1991, pp.1103-1106.

(3) Mutoh, Y., Takahashi, M. and Takeuchi, M., Fatigue Fract. Engng. Mater. Struct., Vol. 16, No. 8, 1993, pp. 875-890.

(4) Vasyliv B. D. "Specific behaviour of high dispersed Al_2O_3-ZrO_2 ceramics under static and cyclic loading", Proc. 6th Int. Fatigue Congress, Berlin, FRG, Vol. 3, 1996, pp. 1693-1698.

(5) Romaniv, O. M. and Vasyliv, B. D. "Fracture of silicon nitride ceramics: structural aspects", Proc. 9th Int. Conf. on Fract., Sydney, Australia, Vol. 2, 1997, pp. 1351-1358.

(6) Mazur, V. I., Taran, Y. N. and Kapustnikova, S. V., "Titanium matrix composites", Pat. No. 5 366 570, 22/11, U. S. A., 1994.

(7) Siminkovych, V. M., Vasyliv, B. D. et al., Phys. Chem. Mech. Mater., No. 4, 1995, pp. 102-105.

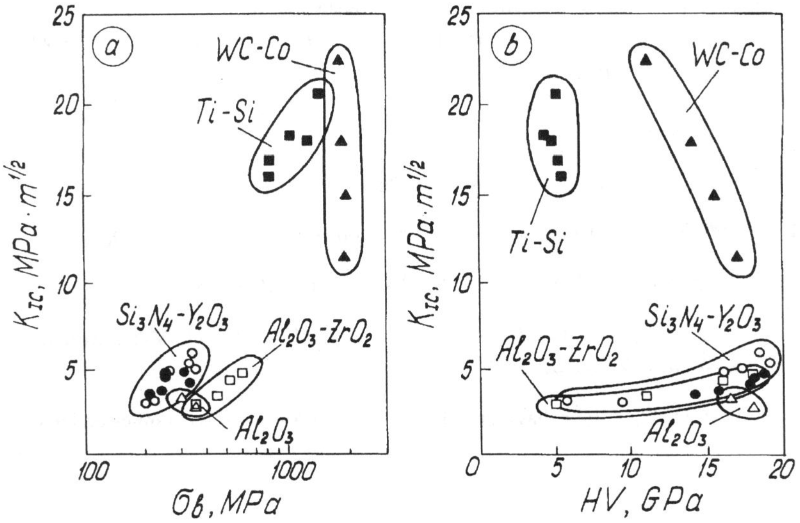

Figure 1. Mechanical efficiency diagrams in coordinates (a) "ultimate bend strength σ_b - fracture toughness K_{Ic}" and (b) "hardness HV - fracture toughness K_{Ic}".

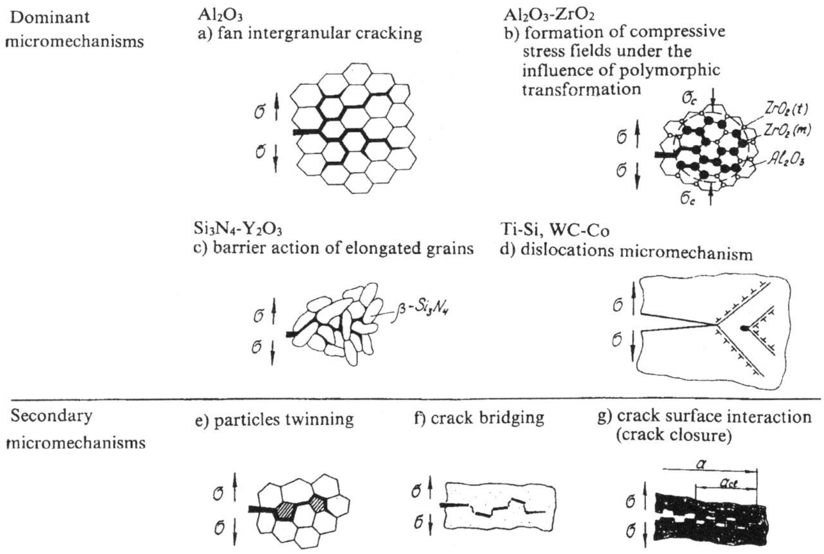

Figure 2. Dominant and secondary micromechanisms of stress relaxation in ceramics and cermets.

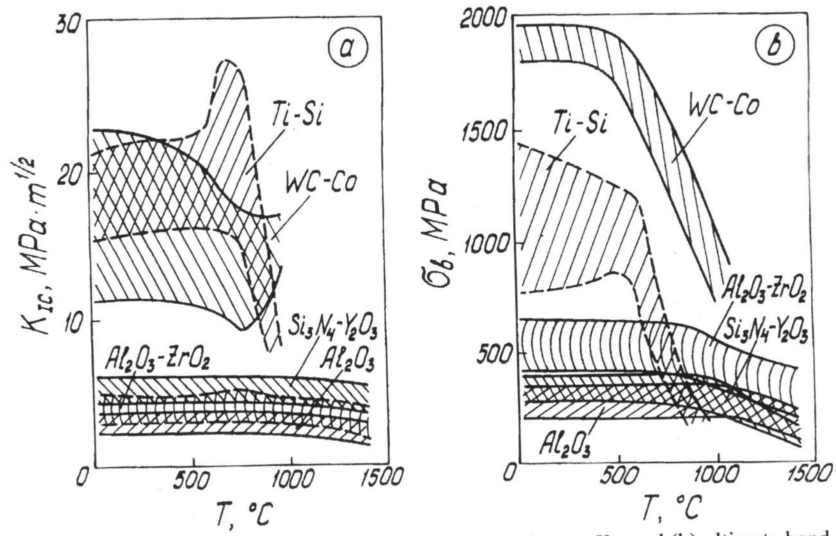

Figure 3. Temperature dependencies of (a) fracture toughness, K_{Ic}, and (b) ultimate bend strength, σ_b, of ceramics and cermets.

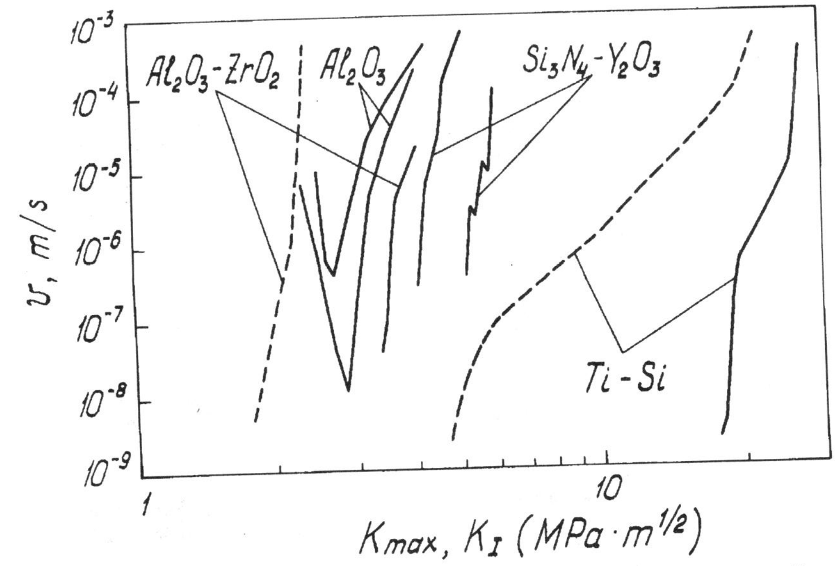

Figure 4. Kinetic curves of ceramics and cermets under static (solid curves) and cyclic (dashed curves) loading.