ESTIMATION OF THE CRACK GROWTH RESISTANCE AND ENDURANCE OF HARD TUNGSTEN CARBIDE-COBALT ALLOY PRODUCTS

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ABSTRACT

The legitimate application of the known fracture mechanics approaches to evaluation of K_{1c} level of metal ceramic hard alloy tool inserts has been verified. The influence of hard alloy plates soldering to the body-drilling tool on the alloy fracture toughness characteristic has been established. The regularities of the fracture toughness, K_{1c}, change during alloying of hard alloy with tantalum carbide has been found. Using the results of fatigue tests and comparative estimates of the resistance to cyclic deformation of hard alloys on a certain testing base, the limited endurance of hard alloy inserts was evaluated. The values of the cyclic deformation resistance indexes were employed for evaluation of the hard alloys ability to resist fracture and crumpling due to tantalum carbide alloying, operations of soldering and grinding.

INTRODUCTION

When manufacturing and using the hard cermet alloys it is very important to chose the appropriate methods for determining their serviceability and possibility to predict the stability of hard alloy products in service conditions. In this respect the primary importance is given to establishment of the characteristics of alloys fracture resistance that allow to evaluate the material sensitive to brittle fracture and to represent the product damage kinetics under operating loading conditions.

Material and Test Procedures

The hard tungsten carbide-cobalt alloy inserts used for reinforcement of drilling tools have been investigated. The regularities of the change of fracture resistance characteristics of WCo11–WCo alloy during sintering with addition of tantalum carbide under short-term static and cyclic loading have been studied. The effect of soldering (its simulation) and grinding on formation of fracture resistance characteristics of cermets was established during WCo15 alloy testing. Hard alloy elements produced by «Pobedit» plant (town of Vladikavkaz, Russia), Kirovograd plant of hard alloys (Ukraine) and «Dresser» company (USA) have been investigated (Table 1).

TABLE 1
PHYSICOMECHANICAL CHARACTERISTICS OF HARD ALLOYS

Alloy grade	A batch	Shape of hard alloy product; dimensions, мм	Physicomechanical properties			
			Rockwell hardness HRA	Ultimate strength under bending (σ_B), MPa	Material density (ρ), g/sм^3	Coercive force (H_c), e
WCo15 (85%WC–15%Co)	15002	plates Г1108	89	2510	14,1	81–89
	15003	Г1108 10×16×46	89	2254	14,1	–
WCo11-WCo (89%WC–11%Co), «Pobedit» plant (town of Vladikavkaz)	527	teeth Г25 ∅14×20	87	2240	14,4	85–88
WCo11-WCo (89%WC–11%Co), Kirovograd plant of hard alloys	11043	teeth Г25 ∅14×20	87	2520	14,3	83–88
WCo11-WCo type alloy (with addition of TaC),«Dresser» company (USA)	–	teeth ∅14,4×21	87	–	14,0	–

Technological process of drilling tools manufacturing presupposed the plates soldering to the steel body of the tool. To simulate the soldering process, the mounted body was placed under a rigid inductor and subjected to slow heating by high frequency current (HFC) up to 1050°C. After melting of the solder the hard alloy plates were extracted from the slots of a body and cooled. The as-supplied plates were ground. The process was performed on the toll-grinding machine according to a special regime (appropriate to the worn inserts grinding).

To establish the values of short-term strength under bending, σ_B, the prismatic specimens (6×10×46 mm), cut out of the hard alloy plates have been tested. The crack growth resistance, K_{1c}, of hard alloys was evaluated during testing the teeth and prismatic specimens (dimensions mentioned above) of the plates. For evaluation of the fracture toughness indexes, the special straight through notches were done on the specimens and chevron-notches were manufactured on the teeth.

In static three-point bending loading of the specimens on a universal testing machine УМЕ – 10ТМ, the «load P – specimen displacement δ» curve was recorded by a two-coordinate recording device ПДП – 004. The hard alloy teeth with a chevron–notch and a slot for applying tensile loading were tested on the same tearing machine with recording the deformation curve «load P – notch edges opening δ».

The values of ultimate strength under bending, σ_B, and fracture toughness, K_{1c}, were calculated by the known dependencies [1, 2]. For each testing series (state) of tungsten-cobalt alloys, not less than three specimens or teeth were subjected to fracture tests with the following averaging of the σ_B and K_{1c} parameters.

The limited endurance of tungsten-cobalt inserts was evaluated during compressive cyclic loading (testing base being 10^5 cycles) on УМП – 02 machine at 25 Hz frequency and stress ratio R = 10...20 [3]. A degree of the change of deformation amplitude depending on the initial loading level was recorded during cyclic compression of two opposite teeth (plate parts). On the basis of the obtained data on cyclic deformation resistance, the ability of the hard alloy material to resist significant compressive loading and its tendency to crumple and to change the working surface shape (no total fracture being present) were estimated.

Short-term strength under static bending of hard alloy

Three-point bending tests of tungsten-cobalt WCo15 alloy specimens did not show deviation from linearity on the deformation curve «load P – displacement δ» up to the specimen fracture. Heat treatment, that simulates soldering, of hard alloy plates does not lead to the qualitative change of the general character of linear dependence P–δ, thus demonstrating the perfect elastic behaviour of the material during deformation.

A wide data scatter, σ_B values, of particular specimens in one batch of the original material of the same alloy grade (from 1224 to 1860 MPa) was observed. The factors that cause this scatter in the ultimate strength values under bending are residual porosity and the state of the surface layer of the specimens.

The residual porosity is present in this or that way in the sintered hard alloys and has a significant influence on the ultimate strength of material. On the specimens fracture surface, tested for bending, one could often observe the fracture site of the pore shape. That means that during experiments the region of maximum tensile stresses in specimens contains the unsatisfactory situated pores that cause the fracture inself. So the σ_B value scatter in particular specimens greatly depends on the geometry, dimensions and location of defects, as the potential sites of fracture initiation. Since, the maximum tensile stresses under bending are formed on the surface, this type of tests are sensitive to the state of the surface layer and the presence of the surface defects that facilitate the crack initiation process in the specimens.

TABLE 2
ULTIMATE STRENGTH OF HARD ALLOY UNDER BENDING AFTER HEAT TREATMENT (SIMULATION OF SOLDERING)

WCo15	Ultimate strength under bending (σ_B), MPa	
	Original state	After heat treatment (simulation of soldering)
	1580	1910

The static bending tests showed that hard alloy of heat-treated plates possesses the higher strength than the original material (Table 2). In this case the scatter range of the ultimate strength values is much lower (from 1800 to 2074 MPa).

The increase of the ultimate strength, σ_B, under bending, due to material heat treatment is caused basically by the change of the stress state in the near-surface layers of the plates. In the external layers of the products after sintering, the tensile stresses are localised, that achieve significant values. The bulk heat treatment (especially HFC heating) causes the change of the hard alloy stress state. The tensile stresses transform into compressive stresses and their absolute value during HFC heating will be higher.

Phase composition and crack growth resistance of hard alloys

Numerous models of cracks propagation in tungsten-cobalt hard alloys, which use the parameters characterising alloy fracture resistance with the account of its frame structure, demonstrate that the composition and properties of binding cobalt phase are the prevailing factor in estimating crack growth resistance [4]. The state of the latter will also define the change of K_{1c}, depending on heat treatment conditions.

Comparative fracture toughness tests of the material plates in original state and those after heat-treatment showed that the crack growth resistance, K_{1c}, of hard alloy WCo15 increases after heat-treatment (Table 3).

The increase of the resistance to fracture (crack start) of hard alloy is a result of the growth of deformability of the cobalt component. Heat treatment causes the change of the binding phase content, due to additional solution of tungsten and carbon in cobalt, and also the decrease of specific contact surface of WC grains [4], thus positively influencing the fracture toughness of WC-Co cermet alloy.

TABLE 3
THE INFLUENCE OF HEAT TREATMENT (SIMULATION OF SOLDERING) ON FRACTURE TOUGHNESS OF HARD ALLOY.

WCo15	Fracture toughness, (K_{1c}), MPa$\sqrt{m}$	
	Original state	After heat treatment (simulation of soldering)
	16,4	17,4

Deformation properties of the hard alloy material depend greatly on composition and structure of binding Co-phase. The composition and, hence, the fracture resistance characteristics of alloys can be changed by introduction of tantalum carbide during sintering.

Crack growth resistance, K_{1c}, of hard alloy when alloyed with tantalum carbide TaC, becomes higher than in the alloys without tantalum (Table 4). The mechanism of tantalum carbide influence on fracture toughness is related mainly with the change of material composition and structure. When analysing the microstructure of phase components of the alloys, no influence of TaC on the volume distribution and mean dimensions of carbide phase grains was noticed. The cause of the increase of crack growth resistance of the material when alloying it with tantalum carbide is the change of the phases chemical composition. The addition of tantalum carbide into cermets, like WCo11-WCo, significantly changes the binding phase composition – the cobalt solid solution contains tantalum. Simultaneously, the tungsten carbide concentration decreases in the binding component. The change of the chemical composition of the cobalt solid solution gives the variation of the deformation resistance of the binding phase and the alloy as a whole.

TABLE 4
FRACTURE TOUGHNESS OF HARD ALLOY PRODUCTS, ALLOYED WITH TANTALUM CARBIDE

WCo11–WCo	Manufacturer	Fracture toughness, (K_{1c}), MPa$\sqrt{m}$	
		without TaC	TaC alloying
	«Pobedit» plant (town of Vladikavkaz)	17,3	–
	Kirovograd plant of hard alloys	21,5	–
	«Dresser» company (USA)	–	23,1

Among the factors that lead to the increase of crack growth resistance, K_{1c}, of tantalum-containing alloys, as compared to tantalum-free alloys, is also the elongation of the crack path due to the prevailing micromechanism of interphase cracking.

Endurance and damaging of hard alloys under cyclic loading

In service conditions the hard alloy elements of the rock-crushing tool operate under multiple impact loading. Therefore, the indexes of alloys stability under cyclic loading are the characteristics that represent to the highest degree the product service conditions. These characteristics include the sensitivity to structural components and defects typical for the static strength tests, on the one hand, and the ability of hard alloy materials to deform plastically without failure, on the other hand.

The limited endurance of the investigated WCo15 hard alloy plates was estimated during compressive cyclic loading. The hard alloy material in original state is more resistant to failure loading, than the alloy after heat treatment (an ultimate compressive load of fracture P_0^U is 66,2 kN for the material of as-supplied plates to compare with 47,7 kN for heat-treated inserts alloy) (Fig.1). According to the endurance curves of hard alloy, the range of values of initial compressive loads P_0 for the as-supplied material is much wider.

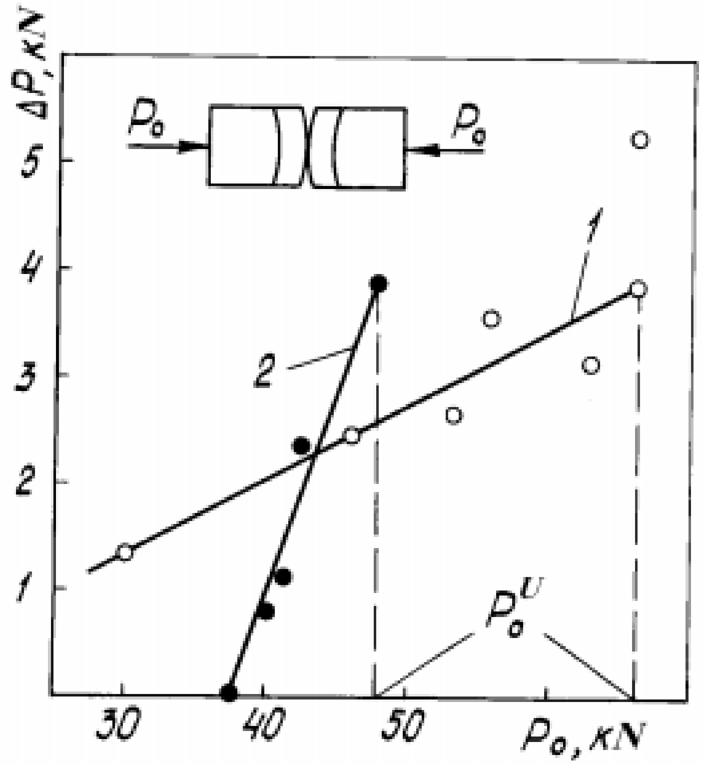

Figure 1: Fatigue endurance diagram of the WCo15 hard alloy:
1 – original plates;
2 – after heat treatment (simulation of soldering)

Heat-treatment increases the alloy tendency to crumple and to change the working surface shape in the range of the higher levels of applied compressive load P_0 (Fig. 1). The packing (crumbling) of the material in the contact region of plates is accompanied by the decrease of the initial compressive stress amplitude. The degree of ΔP decrease is higher for the material of heat-treated inserts.

The formation of intensively deformed material area in the contact zone corresponds to the beginning of the hard alloy plate damaging. At the following stages of fatigue damaging, the microcracking of the surface layers local volumes and crumbling of the alloy particles takes place. It was noticed that the area of the greatly deformed surface in heat-treated material is larger and a pronounced cracking of the microvolumes at the contact region is observed at lower loading amplitudes. The stage of subcritical growth of a set of microcracks and their coalescence precedes the main crack formation. Besides, a multiple cracking of material separate volumes near the contact region can be accompanied by the breaking off a great part of a product.

A typical feature of plates damaging subjected to grinding operation is significant crumbling of the material pieces in the contact region and formation of the localised site of macrocrack initiation in the near-surface layer structure. This is the cause of the lower ultimate compressive load of fracture (endurance) P_0^U for inserts material after grinding as compared with as-supplied plates (Fig.2).

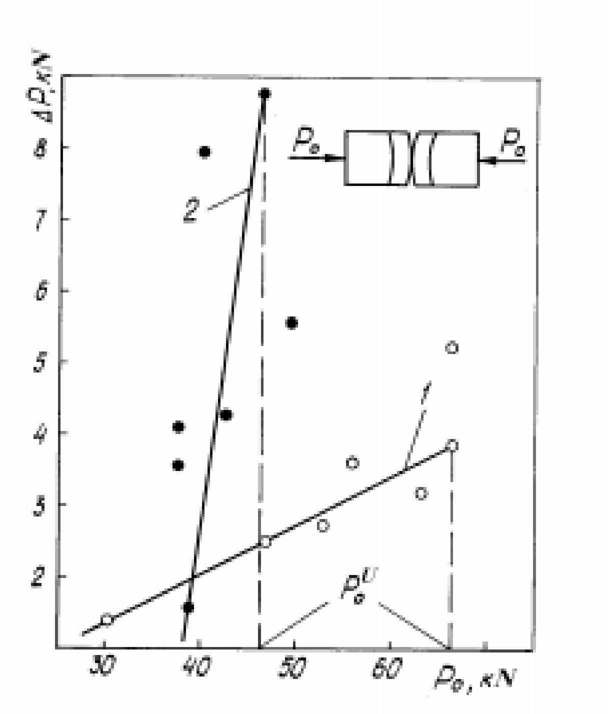

Figure 2: Fatigue endurance diagram of the WCo15 hard alloy:
1 – original plates; 2 – after grinding.

Addition of tantalum carbide in sintering process, improves significantly the limited endurance of hard alloy, like WCo11-WCo (Fig.3).

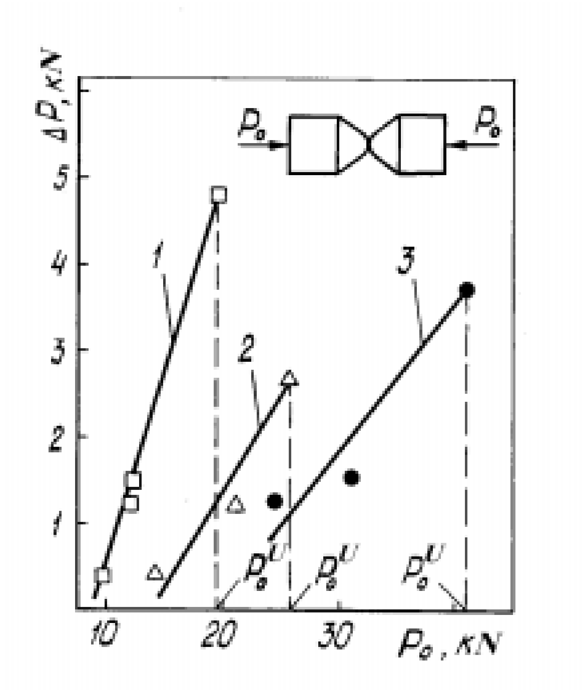

Figure 3: Fatigue endurance diagram of the hard alloy manufactured by Kirovograd plant of hard alloys (1), «Pobedit» plant (2) and «Dresser» company (3):
1 – WCo11–WCo alloy teeth without tantalum carbide;
2 – as in the first case;
3 – teeth from alloy like WCo11–WCo with addition of tantalum carbide

The value of P_0^U in the TaC alloyed material is much higher than for the alloy without tantalum carbide. Since fatigue tests under impact loading are sensitive to the presence of internal stress concentrators (defects), the increase of the ultimate endurance loads, when tantalum carbide is added into alloy, can be explained by a significant decrease of material sensitivity to structural stress concentrators.

References

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