FRACTURE OF VOLUME-REINFORCED MATERIALS FOR DRILL BITS

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Using the technology of centrifugal casting of composite materials with reinforced particles in the volume of the product, it is possible to produce cutting teeth for earth-drilling tools with high strength properties.

The composite material is of a complex structure, because during production of this material besides two phases: the matrix (first phase) and the particles (second phase), a third phase (transient zone) appears. Its main function - the load transfer between the matrix and the particle - is determined by mechanical requirements, because the earth-drilling instrument is very heavily loaded during its operation in the well.

The transition zone of centrifugally cast composite materials contains in its structure intermetallic and carbide inclusions formed due to the processes of diffusion during crystallisation and subsequent thermal treatment. This leads to the growth of structural stresses in the transition zone and to the formation of microcracks. The local stresses in the composite material are due to the difference in lattice parameters (i.e. solid solution of C in γ-Fe has a = 3.50 - 3.60 Å, and Fe_3WC has a = 11.102 - 11.146 Å) and to the difference in thermal expansion coefficients ($\alpha_{Fe} \approx 4.5 \cdot 10^{-6}$ deg^{-1}, $\alpha_{Fe-W} \approx 11.5 \cdot 10^{-6}$ deg^{-1}). Values of these stresses can be estimated in the following way

$$\sigma_{\Delta a} \approx G \frac{\Delta a}{\bar{a}} \quad ; \qquad \sigma_{\Delta T} \approx G \cdot \Delta\alpha \cdot \Delta T$$

where G - shear modulus

$\Delta\alpha$ - difference of thermal expansion coefficients

Δa - difference of lattice parameters

ΔT - difference of starting and final temperature of composite

$\bar{a}$ - average value of lattice parameters

Substituing $\Delta\alpha \approx 7 \cdot 10^{-6}$ deg^{-1} ; $\Delta T \sim 10^{3}$ °C ; $\frac{\Delta a}{\bar{a}} \sim 1$; $G \approx 5 \cdot 10^{10} \frac{din}{cm^2}$

one can obtain $\sigma_{\Delta a} \approx 5{,}2 \cdot 10^{10} \frac{din}{cm^2} = 5{,}2 \cdot 10^{3}$ MPa ; $\sigma_{\Delta T} \approx 3{,}5 \cdot 10^{9} \frac{din}{cm^2} = 3{,}5 \cdot 10^{2}$ MPa

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X-ray evaluation of these stresses gives the same order of these stresses. At high concentrations of the intermetallic phase these local stresses in the transition zone play a significant role in the occurence of macroscopic stresses in the composite tooth of the drill bit.

The microstructure of the transition zone adjacent to the matrix is characterized by a coarse double eutectic ($\alpha + \eta$) and by a triple eutectic ($\alpha + \eta + \theta$) based on α-solid solution. Fine η-phase can be observed at the boundaries of the reinforcing particles. The grain size in the transition zone is 5.

Under very high and concentrated load conditions the existence of these structures leads to early formation of microcracks and reduces the life time of the tool.

It was shown that metal plating of the particles is one of the most effective ways of stabilizing the structure and preventing the reinforcing particle dissolving. The metal chosen for plating has to form a continuous series of solid solutions with Fe, providing a reliable diffusion barrier at the particle - matrix interface and plastic transition zone without intermetallic and carbide inclusions.

For evaluation of the relative resistance to fracture of drilling tools made with plated and unplated particles in the composite materials two lots of 20-mm diameter teeth were cast for drill bits for medium hard rocks (M-type). Crushed tungsten carbide reinforcing particles, 0.63-0.9 mm in diameter, were used in four different steel matrices. The matrix materials used were: steel for hot dies (XI2M), drilling steels (D5 and 20XH3A), high-speed steel (P6M5).

Impact-fatigue testing of these teeth was performed according to the method described in (1). The number of impact cycles that caused a 50% reduction in the working height of the tooth was determined. The energy of the impact was 19.0 J. The results are shown in Fig.1.

It is seen from this figure that within $(2.0\text{-}4.0)10^3$ impact cycles the resistance to the impact loading is almost equal for all the materials. But at higher numbers of impact cycles fatigue effects affect the behaviour of the composite materials. Matrixes containing more carbide forming elements were found to have lower strength.

The fracture resistance of the composite reinforced by particles is related to the relative energy states of matrix and particle; the smaller the difference $(E_{matrix}+E_{particle}) - E_{trans.zone}$, the less energy is required for composite fracture.

$(E_{matrix}+E_{particle})$ is the sum of the surface energies of the matrix and the particle, $E_{trans.zone}$ is the sum of the surface energies of the compounds in the transition zone. This means that increasing the number of the intermetallic and carbide inclusions in the transition zone leads to increasing the probability of intergranular fracture between matrix and particle. This was confirmed experimentally. Metal planting greatly reduced the extent to which the reinforcing particles were dissolved and thus limited the formation of compounds at the particle boundaries. This was confirmed by optical and electron microscopy.

REFERENCES

(1) V.N. Vinogradov et al. Dolgovechnost burovyh dolot, M., "Nedra", 1977.

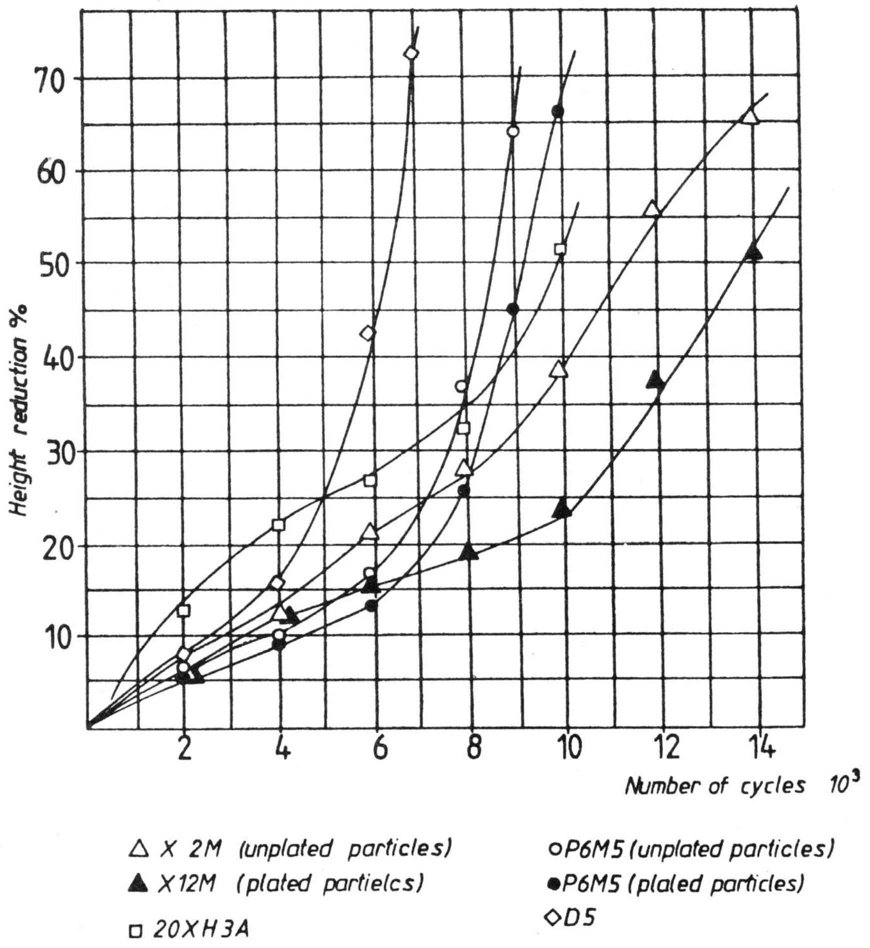

Fig.1 Resistance to impact loading of tested materials