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HIGH TEMPERATURE STRENGTH OF COPPER REINFORCED WITH TUNGSTEN FIBERS

by

D. M. Karpinos, E. S. Umanskiy, V. N. Rudenko,

L. I. Tuchinskiy

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13. ABSTRACT

A study of the strength and stability of tungsten-reinforced copper. Strength was higher than pure copper at all temperatures studied. Materials of this type made by hot dynamic extrusion are superior to any known heat-resistant copper alloys.

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GRAPHICS NOT REPRODUCIBLE

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As is known, there are several methods of creating reinforced metals (for example, lamination, impregnation, extrusion, etc.). One of the most promising methods developed at present is dynamic hot composition extrusion.

The momentary nature of the temperature and force influences does not permit the reinforced elements to lose their strength in the course of the manufacturing cycle. Compositions made of nickel and copper and reinforced with tungsten fibers and grids were obtained in this manner.

The results of an investigation into the momentary strength and ductility of nickel reinforced with tungsten grids are presented in [1].

The mechanical properties of copper reinforced with tungsten fibers oriented along the axis of elongation and copper reinforced with tungsten grids woven in the "Kulir smooth-weave" fashion are examined below. All materials were obtained by dynamic extrusion at a temperature of 950-1000°C. The sample manufacturing process is analogous to that described in [2]. The porosity of the obtained materials was 3-4%.

Indicators of the momentary strength and ductility during mono-axial elongation were determined on a multi-purpose type TsD-4 rupture machine equipped with a vacuum thermal chamber equipped with a nickel plate heater. The tests were made on flat samples having an effective cross-section of 3.0 x 3.5 mm^2 and an effective length of 38 mm with holes at the tips with pins in them for fastening in clamps. Elongation diagrams with $P - \Delta l$ coordinates on a 20:1 scale were recorded during the testing process. Clamp movement speed under tension was 3 mm/minute. The tests were conducted at temperatures of 20°C, 400°C, and 800°C. Heating was conducted according to the following scheme: the temperature was raised to the assigned value over the course of ten minutes, held there for five minutes, and [the specimen] was subsequently stressed to the point of destruction. Temperature was measured by a platinum-platinorhodium thermocouple.

Four or five samples of identical composition were tested at each temperature.

A Copper-Unidirectional Tungsten Fiber Composition

The dependency of the strength (σ_B) and ductility (δ) of reinforced copper on the content by volume of parallel tungsten wires (V_B) at room temperature is presented in Figure 1. The σ_B - V_B function differs from the linear function predicted by additive law. The strength of the composition essentially increases in comparison with the strength of pure copper at relatively small fiber contents by volume (from 18 Kg/mm^2 for pure copper to 28.2 Kg/mm^2 for a composition containing 8% tungsten by volume and up to 42.1 Kg/mm^2 when V_B = 22% tungsten by volume. However, further increasing the tungsten concentration to 33% by volume causes somewhat of a reduction in the strength of the composition.

The relative elongation of composite material is approximately two to three times less than the relative elongation of pure copper. In the range of 8% to 33% tungsten by volume, ductility decreases somewhat with an increase in the wire content by volume, while remaining, however, sufficiently high (δ attains 12-18%).

The temperature dependency of the tensile strength of combined copper-base materials reinforced with parallel fibers is presented in Figure 2 (curves 1, 2). Here the influence of temperature on the strength of copper and NMTs 65-20 German Silver (13.5-16.5% Ni and Co, 18-20% Zn, and the remainder Cu) is presented for comparison. When the temperature is increased to 400°C the tensile strength of the compositions decreases insignificantly. With a further increase in temperature a more intense loss of strength is observed.

At all of the test temperatures studied the strength of the compositions increased in comparison with the strength of pure copper. This increase is quantitatively characterized by the coefficient of hardening K, which is equal to the ratio of the tensile strength of the composite material to the tensile strength of the pure matrix at a given temperature.

The temperature dependency of the coefficient of hardening for systems containing 8% and 33% tungsten wire by volume is presented in Figure 3 (curves 1, 2). With an increase in temperature the value of K rises sharply, changing in the first instance from 1.7 at 20°C to 5.3 at 800°C and in the second instance from 2.3 at 20°C to 6.5 at 800°C. A diagram, the characteristic feature of which is the presence of two clearly defined sectors, is presented in Figure 4. A rapid increase in stress to the maximum value occurs in the first (ascending) sector. A slow decrease in the load accompanying the extraction of the fibers from the matrix is observed in the second (descending) sector. As is evident, the principal portion of the total ductile deformation occurs in the second sector.

The destruction of the samples having a low wire content has a clearly expressed ductile nature. A necking-down occurs in the destruct zone.

In the case of increased fiber concentrations (25% and 33% tungsten by volume) destruction begins in the matrix where a crack which traverses the entire matrix cross-section is formed. After this occurs, the gradual extraction and destruction of the exposed fibers (Figure 5) occurs. Metallographic analysis of the specimens showed that during elongation a concentration of the deformation which appears as a concentration of sliding bands near the interfaces occurs around the fibers.

A Copper-Tungsten Grid Composition

The reinforcing grid has a "Kulir smooth-weave" type structure. Loops placed in the direction of the sample axis form mesh rows -- placed perpendicularly they form mesh columns. In accordance with the data of [5] it is possible to hypothesize with a known approximation that the longitudinal strength of a grid (along the mesh columns) is determined by the tensile strength of each column with a force equal to the strength of two wires. In the case where the elongating forces are applied across the width of the grid (along the mesh rows), the wires which join the mesh colums resist rupture. The number of wires is equal to the number of rows in the strip being subjected to rupture. The ratio of longitudinal strength to latidunal strength is $C = \frac{2p_w}{p_l}$, where p_w is the latidunal density of the wire mesh and p_l is the longitudinal density of the mesh. For the type of mesh selected, $\frac{p_w}{p_l} \approx 0.8$; consequently, $C = 1.6$, i.e., the longitudinal strength of the grid is approximately 1.6 times greater than the latitudinal strength.

For the mechanical tests the samples were cut in such a manner that the grid mesh columns were aligned with the axis of the specimen.

It is interesting to note that the strength of the compositions was almost unchanged when the samples were heated to 400°C (see Figure 2, curves 3, 4, and 5). Increasing the temperature to 800°C lowers the strength by almost a factor of two; however, even in this case the strength of the composition exceeds the strength of pure copper by a factor of eight. As is the case with copper reinforced with parallel fibers, the coefficient of hardening increases with an increase in temperature for systems containing grids (see Figure 3).

The dependency of composition strength on grid content by volume (V_B) in the range being studied has a linear nature (Figure 6). It may be suggested that this dependency is analytically described by the expression [3]:

$$(\sigma_в)_к = (\sigma_в)_в V_в + \sigma'_н (1 - V_в), \quad (1)$$

where $(\sigma_B)_K$ is the tensile strength of the composition, $(\sigma_B)_B$ is the tensile strength of the fibers, and σ'_H is the tension in the matrix at the moment of fiber rupture.

When evaluating the strength of compositions reinforced with grids, one should take into account that it is principally the fibers which are placed parallel to the acting force which bear the load, i.e., for grids of the given weave this is only approximately 62% of the total content by volume (dotted straight lines in Figure 6).

The value of $(\sigma_B)_B$, calculated according to the method of least squares, which enters into formula (1) is approximately 170 Kg/mm^2 at 20°C and 400°C, and approximately 88 Kg/mm^2 at a temperature of 800°C. Comparing these data with the initial strength of the wire shows that [the initial fiber strength] is 40-45% realized in a composition at room temperature, and at temperatures of 400°C and 800°C it is approximately 60% realized. Evidently this is connected with the statistical nature of the distribution of the strength of the grid elements and their loading, and with the presence of additional defects which appear during the manufacturing cycle of producing the material.

The ductility of the grid materials is lower than the ductility of a composition with aprallel fibers. The relative elongation of grid materials does not exceet 4% at room temperature and 5-6% at a temperature of 800°C. The destruction of the samples has a brittle nature.

A Discussion of the Results

An analysis of the elongation diagrams and a study of reinforced sample fractures bears witness to the fact that the nature of the destruction of the compositions depends principally on their composition and the strength of the bond between the fibers and the matrix.

In copper samples with a low wire content (8% tungsten by volume) oriented in one direction, the destruction of the fibers and the matrix occurs practically simultaneously, whereas in compositions with a high concentration of parallel fibers (25-33% tungsten by volume) a separation of the layers of the material (separation of the fibers from the matrix and the extraction of the fibers) is observed.

Obviously, in samples obtained by the hot dynamic extrusion method the strength of the bond between the matrix and the fibers is considerably less than such forces in compositions obtained by impregnation [3].

If one assumes that the tangental stresses at the fiber-matrix interface are responsible for the layer separation of the systems, then it is possible to conclude, on the basis of the results presented, that these stresses increase with an increase in the fiber content by volume. At a specific fiber percentage by volume the magnitude of the tangental stresses becomes greater than the strength of the bond at the interface, and the compo- . 'ion is destroyed as a result of layer separation.

.n materials containing unidirectional fibers an unlimited distribution of cracks along the fibers occurs. In compositions reinforced by grids this is not observed. Evidently, fibers perpendicular to the tension hinder the distribution of cracks and the grid itself absorbs the principal portion of the applied stress.

Beginning with what has been presented, one may make the following conclusion: if the strength of the bond between the matrix and the fibers is not great and the matrix is incapable of transferring large loads to the fibers, then materials reinforced by grids must have a greater tencile strength than the tensile strength of a system reinforced by parallel fibers. In this case we shall not use additive law to describe the strength of compositions reinforced by parallel fibers.

If the strength of the bc.d between the matrix and and fibers is sufficient to transfer to the fibers those stresses which are close to the tensile strength of the fibers, then, in the first place, a linear growth in the strength of the composition, depending on the parallel fiber percentage by volume, must be observed (i.e., adhere to additive law), and, in the second place, reinforcing with unidirectional fibers must have a greater strengthening effect than reinforcing with grids. This assumption is confirmed by the results of the methanical tests of copper compositions reinforced with tungsten fibers (in these materials the bond between the fibers and the matrix is sufficiently strong) described in [4].

In copper specimens obtained by the method of dynamic hot extrusion the strength of materials reinforced by grids is greater at high fiber concentrations than the strength of compositions of similar composition having fibers laid in a parallel manner. For example, at a temperature of 400°C a composition with 38% tungsten grid by volume has a tensile strength of 42 Kg/mm^2 and a tensile strength of 21 Kg/mm^2 at a temperature of 800°C, whereas σ_B for a material with 33% tungsten fibers by volume is 35 and 16 Kg/mm^2, respectively, at the same temperatures. Here the tensile strength of compositions with apralle1 fibers beging to decrease when V_B > 22% tungsten by volume.

In nickel-based samples [1,4] a different picture is observed. The strength of a composite material containing 33% tungsten fibers by volume laid in parallel fashion is 22 Kg/mm^2 greater at room temperature than the strength of nickel reinforced with a 38% tungsten grid by volume. At 1100°C it is 13 Kg/mm^2 greater. In the range of compositions being studied the tensile strength of nickel with unidirectional fibers increases linearly with the increase in the fiber content by volume. This indicates sufficiently strong bonds between the matrix and the fibers.

The strength of tungsten fibers in compositions at room temperature is realized to a lesser extent at room temperatures than at high temperatures. This is probably caused by the fact that the ductility of tungsten increases with an increase in temperature, in connection with which the non-uniformity of fiber loading has a lesser effect.

The results show that copper-based materials reinforced with tungsten fibers manufactured by dynamic hot extrusion are superior to the best contemporary heat-resistance copper alloys, in terms of momentary strength indicators. This is especially apparent at high temperatures. For example, copper strengthened with a 38% tungsten grid by volume has approximately the same tensile strength at room temperature as NMTs 65-20 German Silver alloy, but at a temperature of 800°C its strength is six times greater than that of the alloy.

Moreover, it should be kept in mink that the dynamic hot extrusion regimes which were employed did not provide a sufficiently strong bond between the copper matrix and the unidirectional fibers if the fiber content by volume exceeded 20%. In these cases, as was indicated above, the hardening of the matrix by the fibers was not fully realized. However, such compositions have an increased ductility and in combination with a sufficiently high strength they may turn out to be useful for several design elements.

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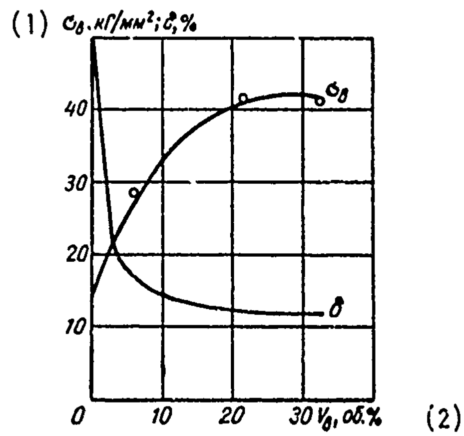


Figure 1: The influence of the content by volume of parallel fibers on the strength and ductility on a copper-tungsten wire composition (T = 20°C, wire diameter is 50 microns)

1 -- σ_B in Kg/mm^2, δ in %; 2 -- V_B in percent by volume

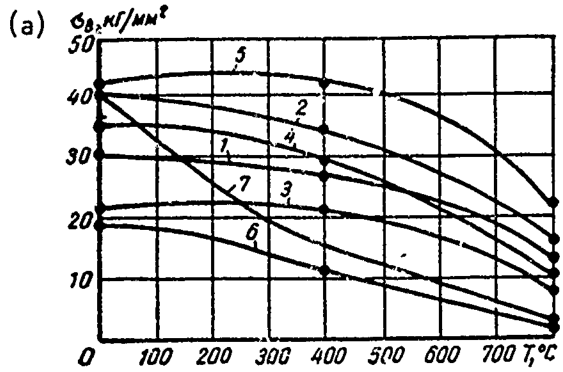


Figure 2: The temperature dependency of the tensile strength of copper-tungsten compositions: 1 -- Cu + 8% by volume W (oriented wire 30 microns in diameter); 2 -- Cu + 33% by volume W (oriented wire 50 microns in diameter); 3 -- Cu + 17% by volume W (30 micron diameter mesh); 4 -- Cu + 29% by volume W (30 micron diameter mesh); 5 -- Cu + 38% by volume W (30 micron diameter mesh); 6 -- pure copper; 7 -- MNTs 65-20 German Silver

(a) -- σ_B in Kg/mm^2

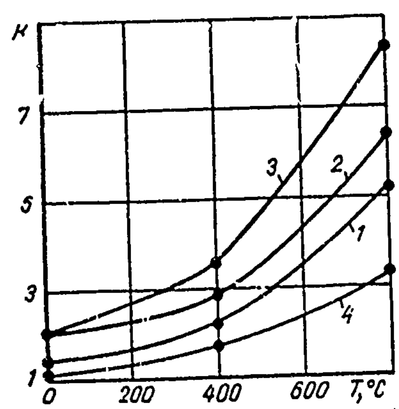


Figure 3: The coefficient of hardening of copper-tungsten wire compositions as a function of temperature: 1 -- Cu + 8% by volume W (oriented wire 30 microns in diamater); 2 -- Cu + 33% by volume W (oriented wire 65 microns in diameter); 3 -- Cu + 38% by volume W (30 micron diameter mesh); 4 -- Cu + 17% by volume W (30 micron diameter mesh)

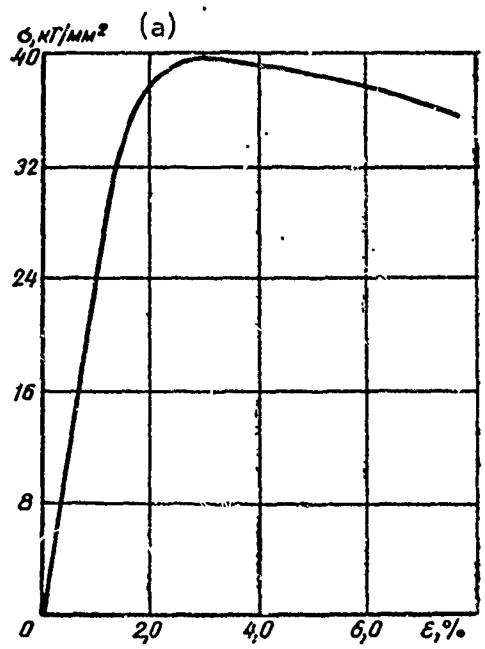
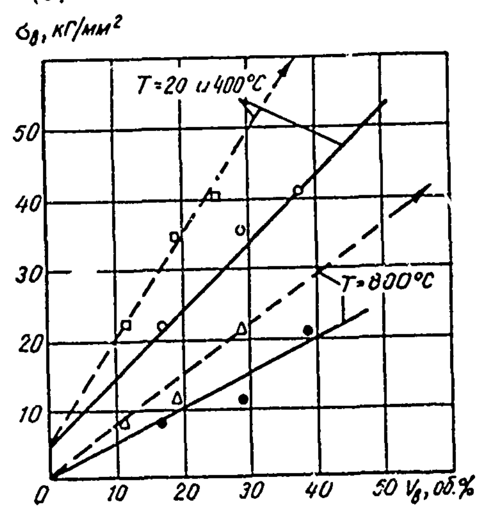


Figure 4: A typical elongation diagram of a copper-parallel tungsten fiber composition

(a) -- σ in Kg/mm^2

Figure 5: The destruction of a copper-33% by volume unidirectional tungsten fiber sample

(a)



(b)

Figure 6: The dependency of tensile strength on the content by volume of a 30 micron diameter mesh in a copper-tungsten composition (the dotted lines indicate those lines which were constructed after recalculating for the content by volume of fibers reinforced in the direction of the elongating tension)

(a) -- σ_B in Kg/mm^2; (b) -- V_B in % by volume

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