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REINFORCING ALUMINUM ALLOYS WITH HIGH STRENGTH FIBERS

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16. Abstract

A study is made of the possibility of reinforcing aluminum and aluminum-based alloys with fibers made of high strength steel wire. The method of introducing the fibers is described in detail. Additional strengthening by reinforcement of the high alloy system Al - An - Mg was investigated.

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REINFORCING ALUMINUM ALLOYS WITH HIGH STRENGTH FIBERS

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New materials with improved properties may be obtained /85* by various methods: by the creation of new alloy compositions and the treatment of metalooxide materials, as well as granules of high alloys, reinforcement of metals and alloys with high strength fibers, etc.

The possibilities of improving the properties of aluminum alloys by alloying have practically been exhausted. The materials obtained by methods of powder metallurgy, having satisfactory properties at increased temperatures, yield in their properties under normal conditions to many traditional alloys[1]. New possibilities of strengthening and stabilizing the properties of aluminum alloys are opened by the method of reinforcing aluminum and its alloys with high strength fibers.

The possible increase in the specific weight of the compositional materials obtained by reinforcing, as compared with traditional constructional alloys, is compensated by the significant growth in the mechanical properties.

Tensile strengthening of the material is determined by the stress arising in the reinforcement fibers, which take on the basic part of the applied load. In fiber reinforcement, the length of the fibers may be greater or less than the diameter of the grains in the metallic matrix. However, the condition of clear predominance of matrix plasticity over the plasticity of the fibers must be maintained[2]. It should be noted that the strengthening of compositional

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* Numbers in margins indicate foreign pagination.

[1] Glenny E. Cermets -- a hope that did not materialize, Eng. 194 (1962), 5045, p. 852.

[2] Ivanov I. I., Manuylov V. F., Tsipulin I. P. In-t "Tsvetmetinformatsiya", Byull. "Tsvetnaya metallurgiya", 1966, No. 24, p. 23.

materials is observed only in the direction coinciding with the direction of placement of the fibers withstanding a significant part of the load.

Compositional materials may be obtained in the form of sheets, strips and plates, wire, rods and rolled sections. However, the mechanism of reinforcement, as well as the technology of the production process for reinforced semi-finished products have not yet been fully studied. There are no recommendations for the regimes of plastic deformation which would ensure obtaining a semi-finished product with given properties.

The authors conducted a study of the possibility of reinforcing aluminum and aluminum-based alloys with fibers made of high-strength steel wire.

The components for the compositional materials studied were, for the matrix materials -- industrial aluminum AD1, alloy D20 and Al-Zn-Mg system alloy; reinforcement fibers of high-strength stainless steel wire with diameter of 0.2 0.8 mm (ultimate strength 1900 - 2800 Mn/m^2), obtained by the technology developed at the MATI [Moskovskiy aviatsionnyy tekhnologicheskiy institut imeni K. E. Tsiolkovskogo; Moscow Aviation Technological Institute imeni K. E. Tsiolkovskiy].

The selection was conditioned by the necessity of clarifying the possibility of obtaining a reliable combination of the components and by the study of the effect of various factors (volume portion of fibers, placement of fibers, regimes of rolling and thermal processing and others) on the mechanical properties of the compositional materials.

The compoxitional material was obtained in the form form of strips by rolling packets consisting of plates of the basic material and rows of reinforcement wire fibers located between them.

The contact surfaces of the components were prepared to ensure their reliable bonding in the process of joint plastic deformation.

Before rolling, the plates of matrix materials were cleaned with a metal brush and rinsed in acetone. The wire was subjected to etching in a 2% solution of HCl at 80°C, washed in hot water, and dried by a stream of hot air.

After preparation of the components, the packets were assembled for rolling. Measured or continuous fibers could be introduced into the packet.

The method of introducing measured fibers makes it /86 possible to obtain practically any placement of the fibers, but is associated with difficulties of introduction and complexity of the equipment used. The method of winding the wire onto the plates of matrix material is simpler. This makes it possible to place the fibers in parallel filaments with a given distance between them. The required distances may be ensured by winding the wire with a given span or by close winding with subsequent longitudinal-transverse rolling. In either case, winding must be done with regulated tension in order to ensure obtaining a dense packet and to prevent the possible disruption in the placement of the fibers during the rolling process.

From 0.5 to 30% of fibers by volume were introduced into the packets. Depending on the diameter of the wire and the volume portion of fibers, the number of layers of wire and the thickness of the matrix material plates varied and was determined by computation. For purposes of studying the effect of fiber placement on the properties of the compositional material, packets with longitudinal, longitudinal-transverse, and random placement of the fibers in regard to the roll axis were subjected to rolling.

The heating temperature before rolling was taken to be the same as in the production of bimetallic materials consisting of stainless steel - aluminum alloy, i.e., 400°C.

The scheme of compression provided for large degrees of deformation in the first pass (up to 40%) in order to ensure reliable bonding of the aluminum alloy with the steel fibers, as well as of the matrix layers with each other. In the subsequent passes, the degree of deformation was determined based on the final thickness of the strip and the plasticity reserve of the matrix.

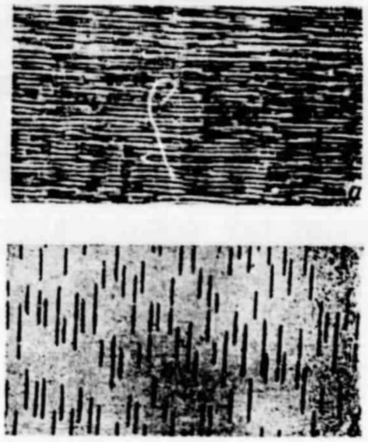
Preliminary studies have shown that noticeable strengthening is achieved only when the directions of extension and fiber placement coincide. Therefore, subsequently the results of studies of compositional materials with longitudinal placement of wire fibers are examined.

One of the main factors determining the properties of the compositional material is the volume portion of reinforcement fibers. Therefore, the effect of the volume portion of fibers on the properties of materials based on aluminum, alloy D20, and Al-Zn-Mg system alloy were studied first.

Strips of multi-layer packets with dense winding of the wire were obtained by hot longitudinal-transverse rolling. On the first pass, rolling was done in a transverse direction for the purpose of ensuring reliable bonding. Subsequent rolling was done along the length of the fibers.

It was established that the degree of deformation during rolling along the length of fiber placement has a significant effect on the properties of the compositional material.

In longitudinal rolling with a total extension coefficient (without considering widening) not exceeding 1.3, the wire fibers in compositional semi-finished products are practically not disintegrated (fig. 1,a) and the strength indicators have higher values as compared with the indicators of semi-finished products in which the fibers are disintegrated during rolling (fig. 1,b).



Distribution of fibers (placement along the roll axis) in compositional material:
a - μ = 1.3; v_f = 21%; b - μ > 1.3; v_f = 3%.

Part of the samples of compositional material based on alloy D20 were subjected to thermal processing consisting of quench-hardening from a temperature of 535°C with cooling in water and ageing at 170°C for 16 hrs. The mechanical tests of the heat treated samples showed an increase in strength of up to 593 Mn/m^2.

The samples, whose characteristics are indicated in the table, were subjected also to testing for impact viscosity. The impact viscosity ($a_н$) of aluminum-based compositional materials comprised 0.3 - 0.8 n/m, and for materials based on D20 -- 0.4 - 0.7 n/m.

Thus, the reinforcement of aluminum alloys with steel high-strength wire makes it possible to ensure a significant increase in the strength properties of series produced construction alloys.

Characteristics of compositional materials based on aluminum and alloys D20 and their strength in a hot-rolled state

Number of layers of wire	Volume portion of wire fibers	$\sigma_{в}$ · Mn/m^2
	Aluminum	
0	0	70
3	6.70	220
5	9.10	252
9	16.16	340
13	24.30	466
	D20	
0	0	200
5	6.80	266
7	16.50	460
13	21.00	536

Note. The ultimate strength of the wire is 1900 Mn/m^2.

Studies were conducted on the possibility of additional strengthening by reinforcement of the high alloy system /87 Al - Zn - Mg.

To ensure bonding of the layers of basic material to each other and to the fibers, plates of aluminum alloy during the rolling process were first clad with aluminum AB000. The cladding thickness comprised 4% of the thickness of the plate on each side. The preparation of the components and the assembly of the packets was done according to the methodology examined above. Longitudinal-transverse rolling of the packets was done at 400°C. The degree of deformation on the first pass (direction of rolling is perpendicular to the direction of the fibers) comprised 30 - 40%.

Beginning with the second pass, rolling was done along the direction of the fibers with compression ensuring total extension of 1.3 with longitudinal rolling. The samples cut from the reinforced strips were subjected to mechanical tests and the condition of the fibers was controlled by x-ray examination.

The heat treated samples were subjected to testing. The thermal processing consisted of quench-hardening from 450°C with water cooling and ageing at 100°C for 10 hrs. After the strengthening thermal processing, the ultimate strength increased from 490 to 815 Mn/m^2 for the Al-Zn-Mg system alloy.