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RECRYSTALLIZATION OF TUNGSTEN ALLOYS

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Tungsten alloys are used for reinforcing fibers in heat-resistant composites employed in the cold-worked condition at operating temperatures of 1100-1300°C. Intensive recrystallization is possible at these temperatures, leading to a sharp reduction of the ultimate strength and creep strength of the reinforcing fibers and thus lower strength of the composite material.

The recrystallization temperature of unalloyed tungsten depends greatly on the impurity concentration, which is determined by the method of production and may vary from 1400° for P/M tungsten to 850° for tungsten single crystals [1-4].

Impurities have a lesser effect on the recrystallization temperature of tungsten alloys than that of unalloyed tungsten. In this case the decisive factor is the nature and quantity of the alloying element. The literature data [1-8] on the effect of various alloying elements on the recrystallization temperature of tungsten are shown in generalized form in Fig. 1. Despite the various methods used and different degrees of deformation of the samples, the data give some idea of the comparative effects of alloying elements on the recrystallization of tungsten. The recrystallization temperature of tungsten is strongly affected by small additions of zirconium, hafnium, and boron, with an atomic radius differing greatly from that of tungsten, and with very slight solubility in tungsten.

When tungsten is alloyed with substantial quantities (1-30%) of refractory metals (molybdenum, rhenium, niobium) with unlimited or considerable solubility in tungsten the recrystallization temperature of tungsten first increases continuously with increasing amounts of the alloying element and then decreases or remains constant. This is probably due to the fact that the atomic radii of these elements are near that of tungsten. Substantial amounts of molybdenum, rhenium, and niobium also lower the melting point of tungsten and thus

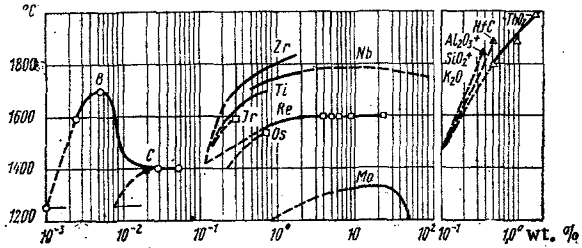

Fig. 1. Effect of alloying elements on recrystallization temperature of tungsten [1-8].

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TABLE 1

Material	Recrystall. temp., °C (holding 1 h)
Commercial	
VA (0,01 Al_2O_3; 0,005 SiO_2; 0,015 CaO; 0,01 K_2O)	1550–1600
VM (0,02–0,05 SiO_2; 0,17–0,25 ThO_2; 0,01 K_2O)	1750–1800
VT7 (0,7–1,0 ThO_2)	1900
VT10 (1,1–1,5 ThO_2)	1950–2000
VT15 (1,5–1,7 ThO_2)	2250–2050
Exptl. wire	
W–10Re–1,5 ThO_2	1950
W–20Re–1,5 ThO_2	1900
W–31,8 Mo–0,85 ThO_2–0,17 HfC	1600
W–30,8 Mo–4Re–0,14 HfC	1500
W–35,0 Mo–0,85 ThO_2–0,40 NbC	1500
W–2,0–2,2 ThO_2	2000–2050

may lead to a change in the energy of interatomic bonds and diffusion parameters (boundary and bulk self-diffusion), which control the recrystallization process.

The recrystallization temperature is highest for tungsten alloys containing dispersed particles of oxides (ThO_2, Y_2O_3, La_2O_3, Zr_2O_3) or carbides (TiC, NbC, ZrC, HfC). The effectiveness of dispersed particles is due to the fact that they sharply reduce the mobility of grain boundaries and subboundaries, inhibit redistribution of dislocations, and thus inhibit the formation of recrystallization nuclei. The effect of dispersed particles on the recrystallization temperature depends on their quantity, dispersity, and stability with respect to the matrix. However, the dependence of the recrystallization temperature on these factors has not been studied in sufficient detail.

The purpose of this work was to determine the effect of the quantity of ThO_2, and also the effect of combined alloying with molybdenum and rhenium along with dispersed particles and carbides HfC and NbC, on the recrystallization of tungsten wire. The chemical composition of the materials investigated is given in Table 1. Rods 2.8-3.0 mm in diameter were prepared by P/M techniques from all the materials. The rods were drawn under identical conditions with gradual lowering of the temperature from 1000 to 600°C to obtain wire 0.5 mm in diameter.

Recrystallization of the wire was investigated with relatively brief heating (up to 1 h) to 1600-2100° by passing a current through the samples and with prolonged heating in a vacuum furnace at 1300-1500°. The initial recrystallization temperature (T_{re}) of all materials was determined from the variation of the microhardness and microstructure at magnifications of 500 and 1000×. Recrystallization of some alloys was also investigated by x-ray analysis. The results of all investigations were almost always in agreement with the results of metallographic analysis. It was found that when the amount of ThO_2 increases to 1.5-1.7% the recrystallization temperature of tungsten wire rises, while increasing the amount of thorium oxide to 2.2% has no effect on T_{re} (Fig. 2). The recrystallization temperature of wire prepared from experimental alloys of W + 10% Re + 1.5% ThO_2 and W + 20% Re + 1.5% ThO_2 and experimental alloys containing molybdenum, rhenium, ThO_2, and HfC is no higher than that of alloys VT10 and VT15 (see Table 1). Thus, combined alloying of tungsten with refractory metals strengthening the solid solution along with dispersed hardening phases does

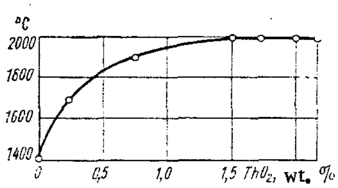

Fig. 2

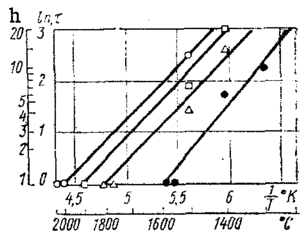

Fig. 3

Fig. 2. Effect of ThO_2 concentration on the initial recrystallization temperature of tungsten.

Fig. 3. Relationship between temperature and time of recrystallization for commercial tungsten alloys. ○) VT15; □) W + 20 Re + 1.5 ThO_2; △) VM; ●) VA.

not lead to any increase of the recrystallization temperature as compared with alloys containing only dispersed second phase. This conclusion agrees with data in [8], from which it follows that the addition of rhenium to alloys containing titanium, hafnium, and zirconium carbides does not lead to any additional increase of the recrystallization temperature.

Recrystallization of the wire with prolonged holding at 1300-1500° was investigated to determine the possibility of using tungsten filaments in heat-resistant composite materials. For this purpose the reinforcing material must retain high strength for prolonged periods at 1100-1300°. In this connection it is important to determine the temperature and time at which recrystallization begins. It can be seen from Fig. 3 that the higher the 1-h recrystallization temperature of commercial tungsten wire, the longer the strength is retained at lower temperatures. The variation established satisfies the well-known relationship

$$\tau_{re} = A e^{\frac{Q}{RT_{re}}}.$$

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STRUCTURAL HETEROGENEITY OF 70-TON INGOTS OF STEEL 34KhN1MAR

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Extensive segregation is observed in large ingots, which is responsible for uneven structural transformations during heat treatment of forgings from such ingots.

We investigated the $\gamma \rightarrow \alpha$ transformation in dendritic sections of various zones in a 70-ton ingot of steel 34KhN1MAR by use of high-temperature metallography. The melting procedure employed complete deoxidation with silicon and evacuation in the stream. The chemical composition of the steel was 0.36% C, 0.40% Mn, 0.30% Si, 0.012% S, 0.013% P, 1.42% Ni, 0.35% Mo, 0.11% Cu, and 1.35% Cr.

Samples were cut along the height of the ingot from the columnar, equiaxed, and globular dendrite zones, and from segregation zones not in the center. The dendritic structure was revealed by heat tinting. This method is sensitive to dendritic and zonal heterogeneities and permits selection of areas for examination of the microstructure in sections differing in degree of segregation.

After heat tinting, the microhardness was measured on sections selected for examination of the microstructure.

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