PROPERTIES OF SOME ELECTRON-BEAM MELTED NIOBIUM ALLOYS

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Niobium-base alloys, remarkable for their high strength at temperatures of up to 1350°C, high resistance to creep, and small thermal neutron capture cross-section, are potentially useful construction materials. Specifications relating to the use of niobium alloys (both cast and wrought) demand high strength over a wide temperature interval, combined with a certain minimum plasticity at room temperature; these properties are obligatory for all alloys with satisfactory welding characteristics.

Arc-melting, which is the most widely used method of fabricating complex alloys, does not always produce high-strength materials of technologically acceptable quality owing to high concentrations of impurities in the metal. It has been found possible, however, to produce alloys with low concentrations of harmful impurities and high strength and other useful properties (plasticity, weldability) by using electron-beam melting.

The present investigation is concerned with the strength and plasticity of niobium alloyed with elements of the IVa-VIIa groups.

Niobium made by the sodium-reduction process, 99.95% pure molybdenum and tungsten wire, electron-beam melted zirconium sheet, and arc-melted granular vanadium were used in the preparation of experimental alloys, each of which was remelted twice in an electron-beam furnace [1].

500-700 g ingots, preheated in air to 1200-1250°C, were forged (first on V-shaped and then on flat anvils) to 11-12 mm thick plates. After machining (planing) and pickling in a mixture containing equal parts of HF, HNO₃, and H₂SO₄, the alloys were recrystallized in a vacuum of 0.05 μ Hg.

The mechanical properties of the niobium alloys were measured on both cast and annealed specimens. Owing to lack of temperature control in the final forging stages, the strength and plasticity of hot-worked test pieces fluctuated within such wide limits that no systematic studies were carried out on forged alloys.

Tests at elevated temperatures were carried out in a vacuum better than 0.2 μ Hg, at a strain rate of 8.35 × 10⁻⁴ sec⁻¹. A ceramic-insulated molybdenum wire spiral was used as a heating element, and the test temperature was controlled to within ±5-10°C. Before testing, each alloy was annealed for 1 hr at 1400-1500°C. To obtain a preliminary indication of the quality of the alloys, systematic measurements were made on cast, forged and heat-treated specimens. Electron-beam melting enabled us to produce alloys with a Brinell hardness of 1700-1900 meganewton/m² [1 meganewton/m² ≈ 0.1 kg/mm²].

In addition to hardness measurements, compressive tests at room temperature were carried out on cylindrical specimens (16 mm in diameter, 15 mm high) to assess the quality (plasticity) of the alloys in the cast condition. The compressive load was applied in a direction parallel to the direction of crystal growth, and the tests consisted in recording the reduction in specimen thickness at which cracks could first be observed. The results showed that high-strength alloys became embrittled in the presence of molybdenum. Variation in the plasticity of alloys (in terms of the degree of deformation causing the appearance of first cracks) as a function of the total content of alloying additions is illustrated in Fig. 1, curve 1, branches 1a and 1b relating, respectively, to molybdenum-bearing and molybdenum-free alloys.

Tensile tests at room temperature were carried out on an IM-4R-type testing machine at a strain rate of 10⁻³ sec⁻¹. Test pieces with a gage length of 20 mm and 8 mm in diameter were machined from ingots in directions parallel and normal to the direction of crystal growth. It was found that with alloys whose elongation exceeded 15%, tensile tests could be carried out on the test pieces irrespective of their crystal orientation.

Different alloys with a total alloying additions content of 8-10 at.% may have similar strength and yet different ductility. Ternary and quaternary alloys in which at.% Mo/at.% W = 3 have a strength equal to that of alloys with at.% Mo/at.% W = 1, but are less ductile. This consideration is important when it comes to making satisfactory welds in sheet.

A 1.2% zirconium addition to ternary alloys increases their strength without lowering their ductility, which might even be improved; this fact is attributed to the de-oxidizing action of zirconium in the molten alloy. Zirconium forms an oxide which is readily removed during melting, since the ratio of partial pressures of the oxide and the metal is ≈100 [2].

The results of tests on fully recrystallized binary, ternary, quaternary, and five-component alloys at room temper-
It will be seen that, as far as the strength of the alloys is concerned, the saturation point is reached at a total alloying additions content of 12-15 at.

Many high-strength niobium alloys (C-120, AS-30, Kh-110, F-50) are based on the niobium-tungsten system. According to published data [3-5], niobium alloys containing up to 20% tungsten are much stronger than niobium and present no special processing difficulties.

From Fig. 1, curve 2, it will be seen that, as far as the strength of the alloys is concerned, the saturation point is reached at a total alloying additions content of 12-15 at.

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Since, in most cases, heat-resistant alloys operate at elevated temperatures for short periods of time only, their fitness for service at higher temperatures is assessed by the results of short-time tensile tests at the operating temperatures.

Comparison of our data on the high-temperature strength of electron-beam-melted niobium-tungsten alloys with the results obtained by other workers [4, 5] shows that the harmful effect of impurities on the strength of solid solutions becomes negligible even at 1100°C (Fig. 4).

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Figure 5 shows that the strength of a solid solution at 900-1400°C decreases gradually with the temperature. At the same time, the UTS_{alloy}/UTS_{Nb} ratio, or "strength factor" [8], which amounts to 2.5 at 20°C, increases to 3.0 at 900°C and reaches 3.6-4.3 at 1000-1200°C, respectively (Fig. 6).

Side by side with good all-round mechanical properties at room temperature, the 18.5% tungsten-niobium solid solution has satisfactory strength at elevated temperatures and can therefore be used for high-temperature service if the applied stresses are not too high.

As regards the high-temperature strength of niobium alloys, the (at.

If structural materials are required, it is more advantageous to alloy niobium with 7-10 at.

In view of these considerations, investigation of the mechanical properties of niobium-tungsten alloys over a wide composition range was of particular interest.

The results of such investigations carried out on a series of niobium-tungsten alloys, twice remelted in an electron-beam furnace, are given in Fig. 3. They show that when the tungsten content in cast alloys reaches 15 at.

Recrystallized alloys have high strength with plasticity remaining at a satisfactory level up to 18-20% (10-12 at.

Fig. 1. Variation in plasticity (1) and UTS (2) of niobium as a function of the content of alloying additions. Branch 1a relates to Mo-bearing and branch 1b to Mo-free alloys.

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Fig. 2. Effect of disproportion in atomic radii on the degree of hardening of niobium at 1200°C [9].

Disproportion in atomic radii (R_{Nb} - R_{element})/R_{Nb}, %

Test temperature, 1200°C