NATURE OF THE STRENGTH OF TUNGSTEN – NICKEL – IRON ALLOYS
PART I. PRECIPITATION-HARDENING CHARACTERISTICS OF W – Ni – Fe ALLOYS

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Strength and ductility are fundamental characteristics of heavy tungsten – nickel – iron alloys, which determine the usefulness of the latter as materials for sensitive and reliable gyroscopes.

The strength and ductility characteristics of a W – Ni – Fe alloy are governed by the conditions under which the material has been produced and, especially, by the rate at which it has been cooled from the sintering temperature. From the point of view of obtaining an optimum combination of strength and ductility, slow cooling (with the furnace) is recommended. The sensitivity of these alloys to cooling rate—a fact established experimentally by Green and co-workers [1]—has not yet been adequately explained. Heavy W – Ni – Fe alloys usually constitute two-phase systems consisting of a refractory phase (a tungsten-base solid solution) and a low-melting-point matrix phase (a nickel-base solid solution).

It must, however, be assumed that the sensitivity of these alloys to the rate of cooling from the temperature of liquid-phase sintering is determined by structural changes, in particular by changes in phase composition. The present investigation was undertaken with the aim of establishing the effects of composition and cooling conditions on the character and mechanism of structural changes in these heavy alloys. The compositions of the alloys investigated are presented in Table 1.

TABLE 1

<table>
<thead>
<tr>
<th>Composition</th>
<th>W, %</th>
<th>Ni, %</th>
<th>Fe, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>88</td>
<td>8.4</td>
<td>3.6</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>7.0</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>93</td>
<td>4.9</td>
<td>2.1</td>
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<tr>
<td>4</td>
<td>95</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>97</td>
<td>2.1</td>
<td>0.9</td>
</tr>
</tbody>
</table>

W – Ni – Fe alloy specimens sintered at a temperature of 1400°C (sintering time 2–4 h depending on the composition) were furnace-cooled to temperatures of 1300, 1200, 1100, 900, 800, 700, and 600°C, after which, to fix their structure, they were rapidly cooled in the furnace cooler at a rate of 600°C/min.

The resulting blanks were employed for the preparation of microsections and tensile-test specimens. Tensile testing was conducted with the simultaneous recording of the load-strain curve. The results of the tensile tests are presented in Fig. 1. The substantial strength and ductility variations observed are an indication that structural changes occur in the alloys during cooling from the sintering temperature.

An optical-microscope examination of the alloys after the heat treatments listed above failed to reveal any new structural characteristics in the phase constituents. This was largely linked with the difficulty of choosing a suitable reagent for the simultaneous etching of alloy phases exhibiting different chemical activities. In view of this, it was decided to employ an electron-microscope examination of the fracture surface of tensile specimens (microfractography). An important advantage of this technique is that the object being examined is a natural surface, formed during the rupture under the influence of certain physical and mechanical factors. The structure of the fracture facets of tensile
specimens was examined in the electron microscope with the aid of chromium-proshadowed two-stage collodion-carbon replicas [2]. The great depth of sharpness of the electron microscope, exceeding by two orders of magnitude that of the ordinary microscope, enabled all relief details of the fracture surface to be observed simultaneously.

Figure 2 presents electron-microscopical fractograms of heavy-alloy specimens. A detailed study of the fracture facets disclosed that slow cooling from the sintering temperature gives rise to aging processes, which radically affect the structure of the heavy alloys, particularly that of their interphase zones.

The aging process takes place in three very distinct stages:

1. Formation of parallel lamellas of a new phase, located along the grain surface and coherent with the tungsten lattice (Fig. 2a).

2. Comminution of the lamellas of the precipitated phase and formation of discrete precipitates (Fig. 2b).

3. Coagulation and growth of the new-phase particles (Fig. 2c).

The formation of the interphase zone is accompanied by the simultaneous aging of the binder phase. In electron photomicrographs of the fracture surface, this phenomenon manifests itself in the nucleation and growth of fine precipitates.

The validity of this interpretation of the aging processes occurring in heavy W-Ni-Fe alloys is confirmed by a number of indirect observations. In an x-ray microspectral study of the distribution of alloy elements during sintering, the authors found that the surface layer of the single-crystalline tungsten