SINGLE CRYSTAL PERMANENT MAGNETS

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Abstract

Single crystal permanent magnets produced from alloys like Ticonal possess the greatest level of magnetic properties and operating characteristics. These magnets are applied in the most reliable applications. The single crystals for permanent magnets are grown by Bridgman method. The specified crystallographic orientation of single crystal is set with a seed. Special heatproof containers are used to grow single crystals. These containers are made from corundum by plasma spraying.

It is shown that the multi-component alloy ability to form single crystal structure is strongly dependent on the value of distribution coefficient (K). K value can be affected through alloying. The principles of improved techniques of single crystal growing from multi-component alloys are given in the work.

Single crystal permanent magnets are prepared from Ticonal like alloys. Chemical compositions of these alloys are represented in Table 1.

<table>
<thead>
<tr>
<th>Ticonal Alloy Grade According Russian Standards</th>
<th>Cobalt</th>
<th>Nickel</th>
<th>Copper</th>
<th>Aluminium</th>
<th>Titan</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>ЮНДК35Т5АА</td>
<td>34.5-35.5</td>
<td>14.0-14.5</td>
<td>2.5-3.0</td>
<td>7.0-7.5</td>
<td>5.0-5.5</td>
<td>bal.</td>
</tr>
<tr>
<td>ЮНДК40Т8АА</td>
<td>39.0-40.0</td>
<td>14.0-14.5</td>
<td>3.0-4.0</td>
<td>7.2-7.7</td>
<td>7.0-8.0</td>
<td>bal.</td>
</tr>
</tbody>
</table>

The single crystal permanent magnets exhibit the record magnetic properties among this class of materials (Fig.1), and also possess unique physical properties and operating characteristics. Their properties are given in Table 2.

<table>
<thead>
<tr>
<th>Alloy Grade</th>
<th>Density, g/cm\textsuperscript{3}</th>
<th>Reversible Temperature Coefficient of Induction heat \textsuperscript{1}(BH)\textsuperscript{max}, %/°C</th>
<th>Tensile Strength, N/m\textsuperscript{2}</th>
<th>Hardness, HRC</th>
<th>Thermal Expansion Coefficient mm\textsuperscript{-1}10\textsuperscript{-6} °C</th>
<th>Resistivity, Ω cm (at.20°C)</th>
<th>Curie Temp., °C</th>
<th>Max. Operating Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>ЮНДК35Т5АА</td>
<td>7.3</td>
<td>-0.001</td>
<td>6.9\textsuperscript{-1}</td>
<td>55</td>
<td>0.28</td>
<td>54</td>
<td>860</td>
<td>550</td>
</tr>
<tr>
<td>ЮНДК40Т8АА</td>
<td>7.2</td>
<td>-0.001</td>
<td>5.8\textsuperscript{-1}</td>
<td>55</td>
<td>0.28</td>
<td>53</td>
<td>860</td>
<td>550</td>
</tr>
</tbody>
</table>
Fig. 1 Alloy UNDKT5 magnets demagnetization curves.
1 – Isotropic magnets;
2 – Magnets with columnar crystal structure;
3 – Single crystal permanent magnets.

Due to absence of grain boundaries in Ticonal alloys and their high Curie point these magnets show a very high temperature stability and durability. Their operating temperatures reach 550°C, and a guaranteed service life is 25 years.

Owing to the above single crystal magnets are used in the most reliable applications, i.e. in critical technologies. They are different kinds of apparatus and systems for guidance, navigation, traffic control and so on. Magnets with a perfect single crystal structure feature a highly uniform magnetic field. This property is applied to brushless motors with smoother motion and high rotor rotation rates. There are many other single crystal magnet applications in advanced technologies. The single crystals for permanent magnets are grown by Bridgman method in a special crucible under argon atmosphere. Fig. 2 shows an appearance of the crucible and growing unit. The growing unit includes a stationary cooler scanning inductor,
graphite heater and thermal insulation. The specified crystallographic orientation of single crystal is set with a seed. Special heatproof containers are used to grow single crystals. These containers are made from corundum by plasma spraying. They are in the form of a tube of round section or any other shape. An appearance of such heatproof containers is shown in Fig.3. The grown single crystals can be 8 to 50 mm in diameter and up to 220 mm long. Up to 8 single crystals are possible to be grown concurrently in one crucible. Fig.4 shows the microstructure of the grown single crystals.

**Fig.2.** Full-scale plant “Crystallizator-203”

1. Quartz;  
2. Chamotte;  
3. Graphite;  
4. Refractory container;  
5. Single crystal seed;  
6. Chamotte cover;  
7. Single crystal ingot;  
8. Inductor;  

A) Front view;  
B) The scheme of heating and cooling assembly

It is known that the alloy ability to form single crystal structure on directional solidification is strongly dependent on the value of distribution coefficient (K). The more this coefficient value is different from 1, the easier the alloy forms its single crystal structure. And on the contrary, the closer the alloy distribution coefficient comes to 1, the harder this alloy will form its single crystal structure. For binary alloys the K value can be determined by phase diagram. For multicomponent alloys K can be experimentally found and is referred to as a generalized distribution coefficient \(K_{\text{gen}}\). It has been established that K value can be affected through alloying or changing in alloy component ratio. Additives increasing both liquidus temperature and solidus temperature make \(K_{\text{gen}}\) hold away from 1 and, thus, facilitate
the single crystal growth. In this work the additives that favour Ticonal single crystal alloy growth have been found. These additives are hafnium, tantalum, niobium and sulphur, selenium, tellurium as well. The calculation methods for liquidus and solidus temperatures of the multicomponent alloys were drawn on search for additives. In addition, the main component ratio of the Ticonal alloys was varied in the permissible limits. As a result, the temperature range of alloy solidification has been extended and the ability of these alloys to form single crystal structure has been increased.

The development data made a foundation of improved single crystal techniques for permanent magnet production.

Fig. 3. Outside view of refractory containers
Fig. 4. Cross view of microstructure of grown single crystals