Highly stressed parts of the rotor in a centrifugal separator operating in aggressive media have been made from high-strength corrosion-resistant steel 09Kh15N8Yu for a long time.

The steel tested was melted in open electric arc furnaces and poured in ingots weighing 2.65 tons. The ingots were lengthened to a diameter of 300-400 mm and then cut into pieces and forged in a 2000-ton press.

After preliminary machining of pieces for rotor parts (head, base, disk holder, piston, ring) they were subjected to heat treatment: water quenching from 980°C (3 h), cold treatment at -70°C for 3 h, aging at 360°C for 8 h, air cooling. The mechanical properties were determined with tangential impact and tensile test samples prepared from control rings cut from the heat-treated parts.

When parts are manufactured by the technique used for the impact and tensile test samples, intergranular fracture is observed. Since intergranular fracture is inadmissible for separator parts, these parts are scrapped.

To establish the reasons for intergranular fracture we used statistical analysis of the chemical composition, mechanical properties, type of fracture, microstructure of impact test samples, and character of nonmetallic inclusions in materials from 190 parts manufactured from 103 heats of steel 09Kh15N8Yu.

It was found that the chemical composition of the heats matches GOST 5632-72; most heats contained 0.06-0.08% C, 14.5-15.5% Cr, 8-8.5% Ni, 0.8-1.2% Al, ≤0.6% Si, ≤0.57% Mn, ≤0.022% P, ≤0.010% S. No signs of variation in the type of fracture with the chemical composition of the steel were found.

Fractures of various types were observed on impact test samples — ductile, silky, and intergranular (Fig. 1a, b). The mechanical properties of pieces with different types of fracture after heat treatment are given in Table 1.

It can be seen that the strength properties of forgings with fractures of different types are practically the same, while the ductile characteristics and fracture toughness differ considerably. With intergranular fracture, $\sigma_1 < 2$ kgf-m/cm², $\delta = 2-10\%$ and $\psi = 2-37\%$, which are much lower than specified values ($\sigma_1 \geq 4$ kgf-m/cm², $\delta \geq 12\%$, $\psi \geq 45\%$).

Fig. 1. Fractures of impact test samples prepared from forgings of steel 09Kh15N8Yu after heat treatment (6×).

a) Silky; b) intergranular.
### Table 1

<table>
<thead>
<tr>
<th>Type of fracture of impact samples</th>
<th>$\sigma_{0.2}$, kgf/mm$^2$</th>
<th>$\sigma_b$, kgf/mm$^2$</th>
<th>$\delta$, %</th>
<th>$\psi$, %</th>
<th>$a_1$, kgf-m/cm$^2$</th>
<th>No. of heats</th>
<th>No. of parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>90–121</td>
<td>113–130</td>
<td>14–18</td>
<td>51–61</td>
<td>7.5–13.0</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>Silky</td>
<td>90–135</td>
<td>125–140</td>
<td>10–16</td>
<td>20–40</td>
<td>1.8–6.4</td>
<td>18</td>
<td>23</td>
</tr>
<tr>
<td>Intergranular</td>
<td>90–110</td>
<td>113–137</td>
<td>12–10</td>
<td>45–55</td>
<td>6.2–8.1</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Normal + silky</td>
<td>90–120</td>
<td>120–137</td>
<td>11–14</td>
<td>40–50</td>
<td>6.2–8.1</td>
<td>15</td>
<td>32</td>
</tr>
<tr>
<td>Normal + intergranular (50%)</td>
<td>104–115</td>
<td>122–132</td>
<td>19–13</td>
<td>39–42</td>
<td>4.8–7.0</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

![Fig. 2](image-url)

**Fig. 2.** Heating of ingots of steel 09Kh15N8Yu weighing 2.65 tons for forging (a) and heating of pieces 300–400 mm in diameter for extrusion (b).

With silky fracture the fracture toughness of the samples is also below normal in some cases.

Graphs of the furnace temperature during heating of ingots and pieces for extrusion are shown in Fig. 2. Analysis of these conditions indicates that holding of ingots and pieces at 1230 and 1250°C may last as long as 4 h. The difference between the temperatures of the furnace and the ingots was 40–50°C.

Metallographic analysis showed that 35% of the heats contain TiN (grade 3–4), 20% of the heats contain AlN (grade 3–5), and 45% of the heats contain large primary inclusions of AlN (grade 3–5) and small amounts of TiN (grade 1–2).

The difference in the character of the nonmetallic inclusions in forgings from different heats indicates that differences evidently occur in the melting and deoxidation procedures during melting in electric arc furnaces.

It was found that samples with intergranular fracture have a very large original austenite grain size (grades 2, 1, 0, and 1 according to GOST 5639–65), a coarse acicular martensitic structure (over grade 10), grains of retained austenite, and no δ ferrite. In the boundaries of the large primary grains one observes precipitates of dispersed AlN and TiN (Fig. 3a, b). Electron fractographic analysis of intergranular fractures revealed quasiseparation of the faceted structure. In the middle of most facets one observes precipitates of dispersed particles differing in shape (Fig. 3c). Inclusions within facets were extracted with carbon replicas and subjected to diffractometric analysis. The diffractographic patterns indicate that these particles are AlN.

The microstructure of parts with brittle fracture or mixed fracture (normal + brittle) is characterized by large original austenite grains (grade 1–3) and large acicular martensite (grade 9–10) of the Widmanstätten type. Grains of δ ferrite were observed in samples in which there were large nonmetallic inclusions of AlN but no TiN. Electron-fractographic analysis showed that parts with intercrystalline fracture are characterized by quasicleavage with predominance of sections of brittle fracture (riverine pattern).

With normal fracture of impact test samples the heats containing TiN of grade 2–3 have an original austenite grain size of grade 4–6. For heats containing nonmetallic inclusions — AlN — the austenite grain size is larger: grade 2–4. The grain boundaries are clean, with no dispersed precipitates of secondary phases. No grains of residual austenite or δ ferrite are observed, and the martensite is coarse and acicular (grade 8–9). Electron-fractographic analysis showed that a faceted structure is characteristic of normal fracture; the facets are clean, with no inclusions.