MANUFACTURING METHOD AND MECHANICAL PROPERTIES OF
LARGE ANNULAR FORGINGS OF TWO-PHASE TITANIUM ALLOY

N. A. Grekov, G. I. Arkovenko,
M. G. Zlatkin, and T. N. Sazonova

"Electrosila" Association
Leningrad, USSR

A method by which large annular forgings of a two-phase titanium alloy, weighting 1200-3500 kg, and with an ultimate strength of about 100 kg/mm$^2$ and satisfactory plasticity is described below. The distribution of mechanical properties along a section and also the macro- and microstructure of the forging material have been studied.

Continuous mechanical properties - stress relaxation and creep - have also been studied. It has been noted that the material possesses high resistance to creep and stress relaxation.

Stress corrosion tests of forging material spanning 16,000 hours and under conditions of increased moisture have not led to the appearance of corrosion cracking.

Testing of annular billets by internal static pressure up to yield strength has shown a high degree of homogeneity of forging material properties.

Introduction

Until recently the manufacturing of large forgings of titanium alloy with 100 kg/mm$^2$ ultimate strength has presented substantial difficulties. The known schemes and duties of hot deformation while manufacturing titanium alloy ingots weighing more than 1000 kg have not yielded uniform and equiaxial structure and, consequently, uniform mechanical properties along the whole cross section of the billets. Nevertheless, industry ever more frequently and more
urgently places these requirements before metallurgists and experts in physical metallurgy.

In 1964, the requirements of large electric machine buildings were finally met when after the necessary laboratory and semi-industrial investigation and development had been conducted, a set of large annular forgings of two-phase titanium alloy of BT3-1 type (Al6Cr2Mo2.5Fe0.5) was manufactured; the sizes of these forgings differed considerably from other items produced of similar alloys with similar mechanical properties. It is enough to say that the weight of one of these forgings exceeded 1200 kg.

The manufacturing of this set of forgings had as its objective the completion of research work on industrial specimens and the experimental testing of full-scale items under service conditions.
Later, after observations had confirmed the correctness of the technological parameters and evaluation criteria for the physical and mechanical properties of forging material that had been chosen, some additional series of large annular forgings of greater diameter were manufactured.

The present report contains the results of investigation of three forging variants manufactured of BT3-1 alloy.

1. Forging Production

All three variants of annular forgings were manufactured by multiple plastic deformation of the initial ingot in different directions. A definite degree of plastic deformation corresponds to each forging operation. The billet heating temperature has been successfully reduced from temperatures corresponding to the
### Sizes and Mechanical Properties of Investigated Forgings

<table>
<thead>
<tr>
<th>Variant</th>
<th>Forging sizes, mm</th>
<th>Mechanical properties</th>
<th>Impact strength, kgm/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>External diameter</td>
<td>Wall thickness</td>
<td>Height</td>
</tr>
<tr>
<td>I</td>
<td>1100</td>
<td>100</td>
<td>700</td>
</tr>
<tr>
<td>II</td>
<td>1205</td>
<td>150</td>
<td>940</td>
</tr>
<tr>
<td>III</td>
<td>1430</td>
<td>200</td>
<td>1160</td>
</tr>
</tbody>
</table>
β-zone to temperatures corresponding to the α + β-zone of BT3-1 alloy. The heat treatment of the forgings was carried out according to the condition providing maximum stability of mechanical properties to approximately 500°C.

2. Results of Tests and Investigations

2.1. Mechanical Properties and Structure

Observance of the above-mentioned conditions for billet forging and heat treatment of BT3-1 alloy yield the mechanical properties listed in the table.

The distribution of mechanical properties along the wall thickness of annular forgings for tangential specimens is shown in Fig. 1.

Fig. 1. Distribution of mechanical properties along the wall thickness of annular forgings for tangential specimens.
From Fig. 1, it can be seen that the differences in strength properties along the forging cross section are negligible. The difference in average value of ultimate strength from one variant to another does not exceed 4 kg/mm$^2$, less than the dispersion of strength properties within one forging, which varied from 2 to 7 kg/mm$^2$.

The macro- and microstructures of forging material were studied on transverse templates cut from the rings in the form
of sectors. The macrostructure of forging cross sections is shown in Fig. 2 and the microstructure is shown in Fig. 3.

As seen from the macrostructure photograph, the forging material has sufficiently high homogeneity. The size of the primary grains varies from 2 to 12 mm, and the size of \( \alpha \)-phase grains is 4-15\( \mu \). Studies of the microstructure of forgings along sections and along the periphery have shown it to be practically homogeneous.

The results of structure investigations under the electron microscope have shown that due to the chosen cooling speed round needles of secondary \( \alpha \)-phase which provides sufficient plasticity and strength are formed during the heat treatment process.

2.2. Stress Relaxation, Creep, and Tendence to Corrosion Cracking

Continuous mechanical properties, i.e., stress relaxation and creep, have been studied on specimens taken from the forgings of variants I and II. The data obtained are given in Figs. 4-6.

As can be seen from the diagram in Fig. 6, the general deformation obtained by tension of tenfold cylindrical specimens 6 mm in diameter during 1000 hours of testing does not exceed 0.02%.

Suitable tests were conducted to determine the tendency to stress corrosion in a humid medium. Rings of equal bending

![Graph](image-url)

Fig. 5. Relationship between stress decrease in relaxation test and temperature and initial stress level.
Fig. 6. Relationship between deformation obtained in 1000 hr creepage test and initial stress level.

Resistance (Fig. 4b) were taken as specimens. The operating stress was 65 kg/mm², the medium distilled water vapor, and the temperature 85-90°C. Soaking for 16,000 hours did not provoke corrosion cracking of specimens.

Under similar testing conditions with austenitic chrome-nickel-manganese steel now used for turbogenerator retaining rings,
cracking appears in about 50 hours, and in 750–800 hours the speci-
men is destroyed.

2.3. Billet Testing by Static Loading and Data of Experimental
Service

Forgings of variants I and II were subjected to general
static loading by internal hydraulic pressure. Billets were loaded
to yield strength, with 15 minutes holdup at these loadings. De-
formation during loading and after tests was measured at three
points along the height and on three diameters. The distribution
of residual deformation, as seen in Fig. 7, is sufficiently uniform
and is within the limits of 0.4–0.1%.

Retaining rings were manufactured from the forgings of the
first variant which have been in service more than 40,000 hours.
These retaining rings are loaded with static stress reaching 42
kg/mm².

The inspection of these retaining rings after continuous
service has shown that for this period of time there were no
changes in structure, surface, or geometry.

3. Conclusion

The work done showed that two-phase titanium alloy
Al6Cr2Mo2.5Fe0.5 (BT3-1) can with a high degree of reliability
be used for manufacturing of large annular forgings with ultimate
strength up to 100 kg/mm² at 20°C.

Optimum mechanical properties and homogeneity of their dis-
tribution along the whole billet section are being provided by a
special forging technology which had been developed and after
repeated testing is being successfully used for the manufacturing
of large annular forgings.