Life time of castings made of titanium alloy in Sea Water


Central Research Institute «Prometey», Russia 193015 St.-Petersburg, Shpalernaya str., 49.

ANNOTATION
Mechanical properties, corrosion endurance, weldability, casting properties of titanium-base alloys elaborated to produce castings for vessel pipeline systems are investigated. Workability of parts made of cast titanium and its weldments in air and seawater is determined.

Multicomponental pipeline systems of different purpose being operated under the internal pressure of transporting media include various shaped cast parts of bodies, valves, pumps, branch-pipes, T-joints and other elements, and the durability, reliability and safety of operation of the concrete object or production process as a whole depends on their quality.

For the systems production depending on their function they generally use the carbon steels, low-alloyed steels, copper and copper alloys, that frequently cannot meet the hard operating requirements.

The operational experience of vessel pipeline systems transporting outside seawater shows that instead of planned durability of 15-25 years the real service time of pipelines is 2.5-6 years. The main cause of such low life time of pipelines is a corrosion wear of materials (zones of couplings and flange joints and also packing fields of valve bodies. For instance, corrosion fracture of the packing field of a kingston valve (its body is made of bronze EpO101L2, disk and valve stem of broze A9Ж4H4ML1) results in the necessity of docking for repairing already after 2.5 years from the beginning of operation.

The problem of durability increasing at the expense of improved corrosion endurance of materials used for vessel systems is one of the main problems in shipbuilding.

In shipbuilding this problem is successfully solved by the use of titanium alloys [1]. They have an obvious advantage in corrosion endurance in comparison with other materials for vessel systems (Fig. 1).

The information about average corrosion rate of technically pure titanium and alloy on its base in calm and stiring (12 m / s) water compared with corrosion rates of other materials based on the data of is given in Table 1.

In shipbuilding the operational conditions at the influence of high pressure predetermine the high level of requirements for the equipment being produced.

The materials used in vessel systems besides providing high reliability and safety of sailing must ensure that compact hydro- and pneumohermetic structures can be made of them. The vessel systems of outside water made of titanium alloys are high-reliable, they guarantee the safe operation during 40 years and longer.

The level and status of titanium alloy production for shipbuilding allow to produce of them practically all needed intermediate products including castings for vessel systems of up to 1,500 kg weight.

For manufacturing of these castings in shipbuilding titanium casting alloys TJ13 and TJ15 are elaborated (of Ti-Al and Ti-Al-V systems), being the analogues of deformable titanium alloys. As the deformable alloys, as the casting ones have good weldability, they are thermally stable, have a good technique of production, satisfactory strength and plasticity in air and seawater.

Owing to the optimal combination of alloying elements and admixtures in these alloys the high level of mechanical properties is provided (Table 2). The narrow interval of crystallization promotes good fluidity, pneumo- and hydroleaktightness of castings.
Fig. 1. Vessel system inspection results:
I - outside water system; II - power plant cooling system; III - vessel equipment cooling system; IV - water system of fire extinguishing; V - drain-and-fan system; VI - ballast-drying system; VII - sweet water system.

Table 1
Corrosion rates of different materials in seawater

<table>
<thead>
<tr>
<th>Material</th>
<th>Technically pure titanium</th>
<th>Alloy Ti-5Al</th>
<th>Steel Cr3</th>
<th>Steel X18H9</th>
<th>Copper M3p</th>
<th>Brass ЛЦ30А3</th>
<th>Bronze БрО10Ц2</th>
<th>Alloy AMr6T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average corrosion rate in steady seawater, mm/year</td>
<td>0</td>
<td>-</td>
<td>0,087</td>
<td>0,0007</td>
<td>0,0190</td>
<td>0,0113</td>
<td>0,0114</td>
<td>0,0094</td>
</tr>
<tr>
<td>Average corrosion rate in a seawater flow (12m/s), mm/year</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0,0050</td>
<td>0,3410</td>
<td>0,1040</td>
<td>0,1260</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2
Guaranteed level of mechanical properties of casting alloys of ТЛЗ and ТЛ5 grades

<table>
<thead>
<tr>
<th>Alloy grade</th>
<th>σb (σu), MPa</th>
<th>σ0,2, MPa</th>
<th>δ, %</th>
<th>ψ, %</th>
<th>KCU, J/cm²</th>
<th>KCV, J/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>ТЛЗ</td>
<td>490</td>
<td>441</td>
<td>10</td>
<td>20</td>
<td>58,6</td>
<td>39,2</td>
</tr>
<tr>
<td>ТЛ5</td>
<td>637</td>
<td>588</td>
<td>8</td>
<td>15</td>
<td>49,0</td>
<td>29,4</td>
</tr>
</tbody>
</table>

Since the general nomenclature of parts made of titanium alloys consists of shaped body details of valves, pumps and pipelines themselves operating under the internal pressure, in order to provide their reliable operation the large complex of research has been carried out for the investigation and calculation of the effect of possible structural and technological stress concentrators to the durability of those parts in the conditions of static and repeated-static loading. The workability of parts made of cast titanium and its weldments in air and seawater was determined, the effect of cast surface to the strength of parts and mock-up samples was estimated. In Krylov Institute the full-size
body parts of valves and pumps and also the samples and mock-ups of whole-cast and cast-and-weld construction were tested to fracture [2].

To calculate the strength in the most stressed sections of real elements the special mock-up sample was designed. It included practically all the typical elements and their combinations, which are the integral parts of any body element. The casting imitated a body of T-joint element (Fig. 2). The holes in the cylindrical part of the body for nozzle joining corresponded to the stress concentration $\alpha_0 = 3-6$, which usually takes place in fittings, pumps.

The valve body was made of two size types: 1) body and nozzle wall thickness 12 mm, nozzle diameter 75 mm, $\alpha_0 = 3.5$; 2) nozzle wall thickness 8 mm, diameter 175 mm, $\alpha_0 = 6.0$.

The valve bodies of the whole-cast and cast-and-weld variants were tested with different surface condition (with up to 1 mm thick casting crust having elevated hardness, with crust removed by machining, with crust partially removed by grinding) at the lowcycle fatigue facility YMY450-650 at the loading frequency 1.25 cycle/min. The maximum pressure was up to 10000 MPa. The deformation was registered by a resistance gauge with a 5 mm base.

The static strength tests have shown that at the presence of stress concentrators the valve mock-ups of the whole-cast and cast-and-weld construction sustained the nominal stress of 0.7 ultimate strength.

Fig. 3 produces the durability in seawater of cast samples with casting crust of elevated hardness and without crust.

In the interval of low-cycle strength ($N=10^3 - 10^4$ cycles) at the presence of casting crust the durability of samples is approximately one hundredth as much, the level of repeated stress is also approximately half as much. The reduction of durability takes place mainly because in samples without crust much time is spent for the incubation period of a crack start.

The obtained results allowed to solve the problems of providing the required durability of vessel equipment made of casting titanium alloy (Fig. 4). The elaborated scientific-founded methods of calculation estimation of the product strength taking into consideration the presence of casting crust and stress concentration allow at the stage of TJ-type alloy structure design to choose its initial dimensions, to carry out the calculation check of strength and given durability of a product and to formulate the quality requirements depending on the operational medium and loading.

The standardization of acceptable defects in cast and cast-and-weld metal is carried out by increasing of the requirements from group 1 castings to group 5 ones. Massive castings having comparatively low operational stress in critical sections are ascribed to groups 1, 2, 3. The wall thickness of such castings is calculated in the first place in order to provide the corrosion endurance or structural rigidity, to limit the elastic deformations under loading and prevent leaks in zones of glands and rigid seals (diaphragms) of high pressure valves. The crust of such castings may have elevated hardness whereas in cast parts of groups 4, 5 (for energetic machine-building, vessel screws, etc) the properties of the alloys are realized with less strength reserve when the hard crust is not allowable.

The parts of groups 4, 5 are subjected to complete machining to remove casting crust with elevated hardness or are produced in metal moulds to prevent pollution of skin by interstitial impurities.
To eliminate internal defects of castings additional measures are stipulated. The technology of centrifugal casting into ceramic and metal moulds is mastered, the universal technology of volumetric repair of internal defects by high-temperature gas-static treatment HIP process) at the temperature 950°C and argon pressure 140 MPa is elaborated.

As a result, after HIP treatment the threshold strength of specimens made of T33 and T55 alloys is correspondingly 40 and 25% as large, the number of defects is one tenth as much, the expenditure of labour for radiography and repair of castings is lowered.

The operational experience of cast products testifies their high reliability. No significant damage of cast parts is found after 20 years of operation in seawater. No cases when the equipment including cast parts in pipeline systems became out of order are ascertained.

Owing to their high reliability the cast body parts of valves and pumps of pipelines are successfully used in responsible vessel systems of feeding, outside and sweet water, cooling systems of power installations, and also in fuel systems of control and automatics.

Up to present time in the shipbuilding branch more than 1000 different cast parts of pipeline systems are mastered.
The nomenclature of mastered flangeless fittings (shaped cast pipeline elements) and valve elements is very wide (more than 80 names), the pipelines of nominal diameter from 40 to 300 mm are fully complemented by that details.

REFERENCES
