Strength of welded connections of glass and metal

V A Ermishkin, S P Kulagin, N A Minina and A K Tomenko

A A Baikov Institute of Metallurgy and Materials Science, Leninskii pr. 49, 119334, Moscow, Russia

E-mail: minina1951@rambler.ru

Abstract. The purpose of this study was to study the strength of products, which was a structure made of a glass tube, to which molybdenum fringes were welded to the ends. Simultaneously with the deformation on the Instron-3382 testing machine, a video survey of the surface of the samples was carried out, which was analyzed by photometric analysis of structural images. It was shown that the product is elastically deformed and that the presence of edging reduces the structural strength of the product.

1. Introduction
In modern technology are increasingly used hybrid structural elements from dissimilar materials. Such elements allow better compliance of the properties of materials with the local operating conditions of the products than is possible for structures made of homogeneous materials. In the manufacture of hybrid products, inevitably, there is a need for technologies for the formation of permanent welded joints of parts with significantly different physical and mechanical properties that satisfy a number of requirements that provide the functional advantages of hybrid structures. Among them, the strength of the joints and their tightness are of paramount importance. Existing types of welding in those versions that are used to connect homogeneous materials are unsuitable for joining dissimilar materials. The difficulties in the formation of such compounds increase with an increase in the difference in the physical properties of the materials being joined. The aim of this study was to study the strength of products, which were a hybrid structure of a piece of molybdenum glass tube edged at the ends with molybdenum alloy adapters.

2. Materials and Methods
The hybrid structure under study is a glass cylinder with a diameter of 25.3 with a thickness of 2.15 and a length of 41 mm, which is connected on one side to the molybdenum bottom and, on the other, to the shaped adapter. The tube is made of ST grade glass and the molybdenum parts are made of foil 0.8 mm thick from alloy TSM-2A. Sealed welds between them were obtained by thermo-compressor welding. To determine the strength of the products, their samples were subjected to compression loading. The samples were loaded on an Instron-3382 testing machine at a strain rate of 0.1 mm / min with bringing them to destruction. Simultaneously with the deformation, the surface of the samples was recorded on a video camera. The video recording was subjected to frame-by-frame analysis with a fixed periodicity by the method of photometric analysis of structural images (PASI) previously developed at GVEM IMET RAS [1, 2]. PASI is a software-analytical complex in which a differential image comparison of the surface fragments of the studied objects and the brightness spectra of the reflection of visible light from them from an external source is carried out. In this study, the image of the fragment surface and
the luminance spectrum of the reflection from it in the state before loading are used as a reference, which are compared with their state at any selected instant of loading of the sample. From a comparison of the spectra, it is possible to establish critical states in which sharp structural changes occur, which are fixed on the spectrum as the appearance of characteristic peaks or troughs.

**Figure 1.** The results of the PASI analysis: a fragment of the surface of SM-1 and the spectrum of the brightness of light reflection from it at t = 0 s (left) and at t = 210 s (right); top images magnification × 10.

Intervals of the intensities of the spectra that correspond to them can be distinguished by color. PASI allows you to transfer the colors of the selected intervals to surface images, thereby visualizing the places where structural transformations occur. The system allows to obtain quantitative estimates of the areas occupied by certain structural components, the magnitude of the spectral densities and reflection intensities corresponding to critical states. Figure 1 shows a typical picture of the analysis of the state of the surface of the investigated object. It can be seen from the figure that the brightness spectra of light reflection from the surface of the fragments are represented in coordinates "spectral density $p(I)$ - reflection intensity - $I$". By spectral density is meant the ratio of the number of pixels with the same reflection intensity - $n(I)$ to the total number of pixels $N$, into which the analysed image is divided, i.e. determined by the formula:

$$p(I) = \frac{n(I)}{N}$$  \hspace{1cm} (1)

PASI provides for the selection of selected intervals using color painting and the transfer of color of the selected intervals to the image of the fragment surface, thereby visualizing those structural elements that contribute to the intensity of the reflected light of the corresponding interval. Along with the output
of data in a graphical representation, the full results of the analysis are displayed in tables. According to the results of PASI measurements, structural damage to materials is determined by the formula:

$$D_s = \frac{S_i(t) - S_{\text{min}}}{S_{\text{max}} - S_{\text{min}}}$$ (2)

where: $S_i(t)$ is the area under the spectral curve of the i-fragment of the sample, $S_{\text{min}}$ is the minimum area under the spectral curves of the fragments for the sequence of time points at which the selected fragments were studied. The values of structural damage for a sequence of time instants are combined into a damage function $D_s(t)$, which obeys the initial and final conditions: $D_s(0) = 0$, $D_s(t_f) = 1$. The concept of damage function was introduced in [3, 4].

3. Results and Discussions

As a result of testing the hybrid samples, their loading curves were obtained in the “$\sigma - \varepsilon$” coordinates and Figure 2 shows a typical strain diagram of a sample from a glass tube. It can be seen from the figure that the loading curve is almost linear, it is divided into four parts by three load failures corresponding to the moments of crack initiation. The slope of all four sections remains constant i.e. the appearance of cracks did not change the nature of the loading curve until the sample lost its bearing capacity as a result of cracking of the stealed part of the sample. Based on the assumption that the elemental volume of the glass part of the sample is constant under the elastic behavior of the sample during deformation, relation (3) was obtained:

$$\frac{\sigma_2^2}{2E} - \frac{\sigma_1^2}{2E} = 2Gl$$ (3)

where: $\sigma_2$ is the effective stress at $t = 209$ s, $\sigma_1$ is also at a time instant of 180 s, $E$ is the normal modulus of elasticity, $G$ is the specific propagation energy of the crack, and $l$ is the length of the crack increment in a given time interval. From equation (3) follows the formula for assessing the specific energy of crack development. The parameters of the stress-strain state corresponding to the points of load breakdown at the load curve (Figure 2) - these stress surges correspond to the moments of microcrack nucleation. Figure 3 shows a sample of SM-2 at the time it was unloaded. As can be seen from Figure 3, the glass body of the product is penetrated by a network of cracks. The beginning of crack formation refers to the moment of the appearance of the first crack, originating from the point of mating of the molybdenum adapter with the glass part of the sample. This crack is oriented parallel to the axis of the specimen.
Figure 3. Sample of SM-2 at the time it was unloaded (t = 210 s)

Figure 4 shows the results of comparing fragments of the same micro fragment before applying the load and after removing it at time t = 210 s.

Figure 4. The results of the PASI analysis of the micro fragment of sample SM-2 before (left) and after (right) its loading at time t = 210 s. × 70.

The figure shows structural damage to the glass, painted red with yellow edging. On the left half of the figure, a defect is visible that was present in the sample even before the load was applied.

4. Conclusions
1. The decisive role in the destruction of glass bodies of products belongs to the tangential tensile stresses, which are slightly higher in magnitude of the meridional stresses, taking into account the poor resistance of the glass to tensile stresses, cause cracking of the glass bodies.
2. The weakest point of SM-1 and SM-2 products is the places of welded joints of glass cases with molybdenum parts in the form of dyes. The reason for this is the increased stiffness of the molybdenum cap, which imparts a joint deformation of the welded joint of dissimilar materials.
3. The weakest point of SM-1 and SM-2 products is the places of welded joints of glass cases with molybdenum parts in the form of dyes. The reason for this is the increased stiffness of the molybdenum cap, which imparts a joint deformation of the welded joint of dissimilar materials.
Acknowledgements
The work was carried out according to the state task No. 075-00746-19-00 and with the financial support of the Russian Foundation for Basic Research (grant No. 17-08-00098a).

References
[1] Ermishkin V A, Lepeshkin Y D, Murat, D P and Ovchinnikov I N 2010 Method of photometric diagnostics of material structural condition by data of their surface digital coded image analysis Patent RU2387974.
[2] Ermishkin V A, Minina N A and Fedotova N L 2010 A method of photometric diagnosis of phase transformations in solids according to the analysis of the brightness spectra of the reflection of light from their surface Patent RU2387978.
[3] Kachanov L M Fundamentals of fracture mechanics. M.: Nauka, 1974.
[4] Miener M A Cumulative damage in fatigue. // Jour. Appl. Mech. 1945 V. 12. No. 9. P.159-164.