EXPERIMENTAL STUDIES OF LOCAL STABILITY OF SPHERICAL SHELLS WITH REINFORCED HOLES

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In various branches of modern engineering structures made up of an assembly of cylindrical or conical shells, many contain spherical apertures with the aim of giving them local transverse stiffness [1, 2]. The presence of a hole in spherical shells reduces their weight and insignificantly affects (in specific ranges of parameters) their supporting capacity with local loading [3].

Besides this, reinforcing holes with rings (in the case of circular holes) significantly increases supporting capacity of spherical shells, in particular, with local loss of stability due to critical stresses. A basic role is played by the strength of the reinforcement and also by eccentricity of the reinforcing ring joint with the spherical section. Joint eccentricity leads to strain in an internal collar, lowering the supporting capacity of the system.

Results are given in this work for an experimental study of the effect of reinforcing circular holes in spherical shells (sections) on their supporting capacity and the shape of wave formation during local loading by a die bed-plate [2].

Tests were made on spherical sections manufactured by explosive forming (hydroshock) of alloy AMg6 (12 models) and Kh18N9 (11 models). The technology of AMg6 alloy section preparation with holes using chemical machining was described in [3, 4]. Holes in Kh18N9 alloy sections were prepared by turning in a jig. A rectangular section ring (2 x 14 mm) and also a ring reinforcing the hole (3 x 4 mm) made of alloy AMg6 were joined to the segment by means of a glue based on epoxy resin ED-5. Basic parameters of the system were as follows: diameter of the main section surface, D = 180 mm; radius of curvature of the section surface, R = 130 mm; the spherical coordinate of the edge of the section, \( \vartheta = 45^\circ \); ratio of the radius to thickness, \( R/\delta = 440 \).

Before testing the section, deviations were fixed for thickness \( \delta_1 \), and ideal spherical shape \( \delta_2 \). Tolerances selected for tests were \( \delta_1 = \pm 0.035 \); \( \delta_2 = \pm 0.002R \).

A ring reinforcing the inside of the hole provided limiting conditions close to rigid fastening, and with local loss of stability it did not permit departure from flatness.

Stressing was carried out by two steel bed-plates with a contact angle \( \varphi = 3^\circ \). The load was applied to the supporting ring in its plane by means of a special unit [4].

1. Results of experiments for AMg6 alloy sections with \( \delta = 0.28 \) mm are presented in Table 1 and Fig. 1 (curve 1). Use was made of dimensionless parameters \( \omega = \delta/D \) and \( \chi = p_{s,o}/p_{S,c} \), where \( \delta \) is the diameter of the central hole; \( p_{S,o} \) and \( p_{S,c} \) are critical forces with local loss of stability, respectively, for a continuous section and a section with a hole.

Curve 2 was plotted from the results of 66 tests [3] for sections with unreinforced holes.

In the range \( 0 < \omega < 0.4 \) a spherical section with a reinforced central hole is equivalent to a uniform spherical section, and critical load and hollow shape are independent of the value of \( \omega \).

In the range \( 0.4 < \omega < 0.675 \) critical load is \( \approx 3-12\% \) greater than for a uniform section. (Here and subsequently the upper and lower value of deviations is given as a percentage.) This effect may be explained by the fact that operation of the structure approximates operation of a ring with a large moment of inertia. The shape and magnitude of the hollow does not make it completely possible for it to be located in a spherical section. The hollow, remaining elliptic, is strongly extended along the parallels, and the type of stability loss remains local and does not embrace the reinforcing ring.

TABLE 1. Values of $\lambda$ from Spherical Section Test Results

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Values of $w$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.430</td>
</tr>
<tr>
<td>AMg6</td>
<td></td>
</tr>
<tr>
<td>with reinforcement</td>
<td>0.83</td>
</tr>
<tr>
<td>Kh18N9</td>
<td></td>
</tr>
<tr>
<td>with reinforcement</td>
<td>0.66</td>
</tr>
<tr>
<td>without reinforcement</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Fig. 1. Experimental points in the $\lambda$-$w$ relationship for spheres of alloy AMg6 (2, 1) and Kh18N9 (4, 3) with reinforced (unbroken lines) and unreinforced (broken lines) holes.

Fig. 2. Scheme of test models with an eccentric reinforced central hole (a), and reinforcement without eccentricity (b).

TABLE 2. Test Results of Reinforced Sections for $w = 0.43$

<table>
<thead>
<tr>
<th>No. of ring $n$</th>
<th>$r_d / r_e$</th>
<th>$r_e / r$</th>
<th>$r_d / r^* %$</th>
<th>$r_e / r^* %$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12.5</td>
<td>0.64</td>
<td>12.5</td>
<td>0.64</td>
</tr>
<tr>
<td>1</td>
<td>12.7</td>
<td>0.63</td>
<td>12.5</td>
<td>0.64</td>
</tr>
<tr>
<td>2</td>
<td>15.5</td>
<td>0.64</td>
<td>22.8</td>
<td>0.66</td>
</tr>
<tr>
<td>3</td>
<td>18.7</td>
<td>0.64</td>
<td>35.0</td>
<td>0.68</td>
</tr>
<tr>
<td>4</td>
<td>23.4</td>
<td>0.64</td>
<td>51.5</td>
<td>0.70</td>
</tr>
<tr>
<td>5</td>
<td>24.0</td>
<td>0.66</td>
<td>55.0</td>
<td>0.80</td>
</tr>
<tr>
<td>6</td>
<td>23.0</td>
<td>0.70</td>
<td>66.7</td>
<td>0.84</td>
</tr>
<tr>
<td>7</td>
<td>34.8</td>
<td>0.68</td>
<td>76.1</td>
<td>0.84</td>
</tr>
<tr>
<td>8</td>
<td>45.0</td>
<td>0.70</td>
<td>78.0</td>
<td>0.90</td>
</tr>
<tr>
<td>9</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

At $w > 0.675$ there is a rapid reduction in critical load with an increase in diameter of the central hole, and failure proceeds by breakdown of all systems (as for a ring with the formation of plastic zones [3]).