Laboratory work № 2

THE INFLUENCE OF FRETTING CORROSION ON THE DURABILITY OF STRUCTURAL ELEMENTS MADE OF ALUMINUM ALLOYS

Purpose of work - and an understanding of the fatigue failure nature of the airframe structural elements in terms of fretting corrosion; study of the influence of contact pressures on the durability of flat elements under cyclic tension; the choice of the thickness of the flat structural elements to ensure a given durability in terms of fretting corrosion.

The content of the work

Fretting is a specific type of destruction of contacting metal surfaces of cyclically loaded structural elements, which occurs when they are relatively reciprocating micro-displacement in the presence of contact pressures [6].

Under variable loads and effect of contact pressure between mating parts, and in the presence of mutual micromovings occurs grasp portions local contact surfaces followed their rupture and tearing out of a part of the metal due to the periodic displacement of the surfaces. Formations formed on the contact surfaces of parts are stress concentrators that reduce the durability of connections. When air enters the contact zone, oxidative processes and formation of solid metal oxides occur on the surfaces of the parts. The accumulation of oxides in the contact zone and their removal during the loading process leads to deformation of the surface layers by abrasive particles, cutting of metal and oxide layers, their removal from the contact zone, changes in the package tie force and friction forces on the contact surfaces, as well as redistribution of forces between fasteners in shear multi-row connections.

Aviation metal alloys under variable loads and contact interaction are affected by fretting corrosion. It leads to a decrease in the durability of structural elements several times, which must be taken into account when designing, manufacturing and operating aircraft. Fretting- corrosion is intensively developed in the elements of bolted and riveted joints, in the contact zone of the hatches with reinforcement (thickening) of the cuts and hatches, in the contact surfaces of the walls of the holes and fasteners and fasteners with axial and radial tension. During the operation and life tests of aircraft structures, it has been established that 90 % of all damage occurs at points where characteristic contact friction of cyclically loaded parts is possible [4].

Ensuring the life of the airframe design up to 60 ... 80 thousand flight hours and its tightness, as well as reducing the mass of the structure required the use of bolt landings with elastic-plastic radial tension and axial tie of the package

Aluminum alloys of the type D16AT, V95AT, 1163 are most widely used for the manufacture of the main force elements of the airframe design.

For the experimental determination of the influence of contact pressures transmitted through the annular washer; a model of a longitudinally loaded joint has been developed for the durability of joints of flat elements (Fig. 2.1, a). The sample consists of two plates connected by pads for hinge mounting in the grippers of the testing machine. The working part of the sample has a rectangular cross section. The ratio of the width of the plate to the inner diameter of the support ring c/d assumed to be 1.5 as the most common in real compounds. The standard washers 5, used in real structures, are pressed against the outer side of the contacting plates-plates with the help of screws 2 fixed in the plates of the rectangular frame 3. Between the washer and the support of the fifth screw is the liner 4, which is the head of a bolt with a spherical depression on the end surface for centering the support heel of the screw, the head of the bolt and the washer.

Contact pressure between the washer and the lining are created by tightening the bolt with a calibration key to a predetermined torque value. To determine the contact pressure of the screw washer device previously tared through exemplary dynamometer DOSM-3-3, a power key and a special frame.

Fatigue tests were carried out on models, the joints of which are made of material Д16АТл5 with typical coatings on their surface. Contact pressure is transmitted through cadmium steel washer 2 mm thick, outer diameter $\boldsymbol{D}$ = 16 mm and internal diameter $\boldsymbol{d}$ = 8 mm .

The clamping force is equivalent to the tightening torque of the nuts M_t equal to 20 and m 10 H that generates contact pressure value of 91 and 45.5 MPa respectively. These values are in the pressure range under the bolt washer created in bolted joints, made according to aviation standards and tightened in accordance with the existing instructions for tightening the nuts. For chromansilic bolts with a diameter of 6 ... 16 mm, the contact pressure from normalized tightening on butt surfaces under the washer and the bolt head is in the range of 25 ... 120 MPa.

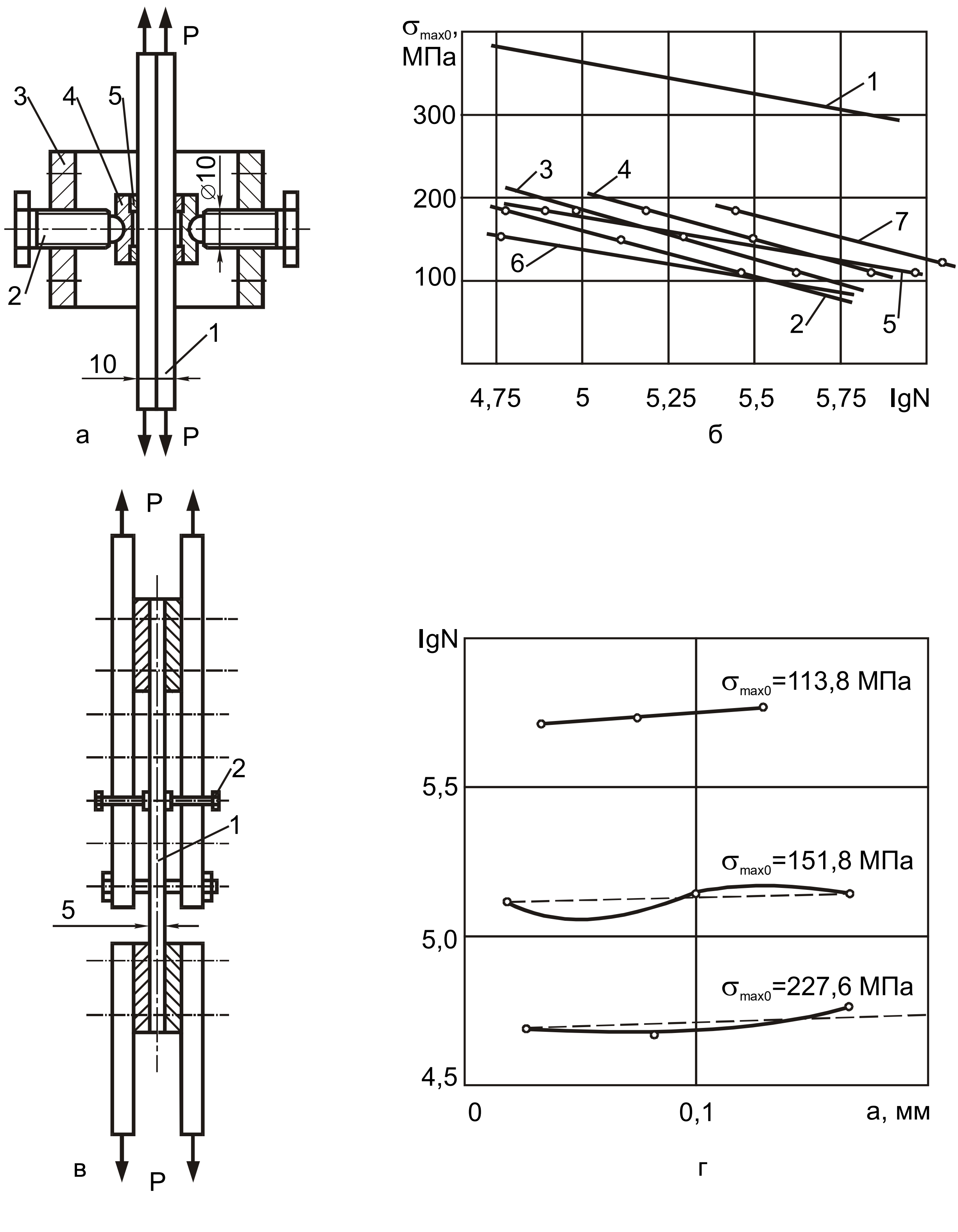


Fig. 2.1. The influence of contact pressure and micro displacement on the durability of flat plates: 1 - smooth; 2 - clad, σ_c = 91 MPa; 3 - clad, σ_c = 45.5 MPa; 4 - clad + anodized, σ_c = 91 MPa; 5 - clad + anodized + + FL-086, σ_c = 91 MPa; 6 - plate with a free hole; 7 - plate with a hole filled with a pin with tension 1 % $d_б$

Fatigue tests were conducted on the testing machine ЦДМ-10ПУ with a loading frequency f = 14 Hz with cyclic tension with asymmetry coefficient R= 0.1 on three load levels, repeated cycle stress amplitudes σ_a = 90.1; 72.1 and 52.2 MPa.

The test results are shown in Fig. 2.1, b. There, for comparison, the fatigue curve of a smooth sample of material Д16АТ is shown. with $\sigma_в$ = 402 MPa, calculated by formula M. N. Stepnova and E. V. Giatsintova [2].

$$\sigma_a = 2,344\,(\sigma_в - \sigma_m)^{0,63}\,[0,64 + 43,3(\lg N)^{-2,1}]. \qquad (2.1)$$

Comparison with the fatigue life curves shows that the contact pressure and propagation during the tests fretting corrosion under washer reduce the durability of samples of material D16AT more than hundred times.

Fatigue failure of all sample linings occurred in a cross section at the boundary of the outer diameter of the washers in the zone of intensive development of fretting corrosion. To reveal the effect of coatings on durability under fretting-corrosion conditions, fatigue tests of anodized specimens, as well as specimens, coated after anodization with FL-086, were conducted. The test results are shown in Fig. 2.1, b. It can be seen that anodizing contributes to an increase in the durability of samples under fretting corrosion conditions, however, even in this case, the limiting amplitudes of cyclic loads decreased by more than two times compared with the amplitude of a smooth sample, when $\sigma_c = 0$

For comparison in Fig. 2.1, b shows the fatigue curves of the plate with a hole d_0 = 8 mm b = 25 mm and plates with a hole filled with a titanium bolt with a radial tension equal to 1% of the bolt diameter (d_b) without tightening (σ_c = 0). It is seen that fatigue curves of plate under fretting-corrosion conditions lower than fatigue curve of plate with a hole filled with a bolt having a radial tightness.

It was experimentally confirmed that the calculation of the durability of structural elements should be carried out not only in the zone of geometric stress concentrators, but also in the zone of intensive development of fretting corrosion on the contact surfaces of loaded parts.

To determine the effect of the micro displacement on the durability of the plates under cyclic tension and the action of contact pressures, tests of the plates in the tool were carried out (Fig. 2.1, c). The amplitude of the micro displacements in the contact zone was changed due to the installation and pressing of the washers at different distances from the axis of the extreme row of the bolts of the grip to the center of the contact washer. Values at microdisplacements changed in the range of 0.01 to 0.25 mm, and the contact pressure values at the set and equal to 102 MPa.

From the test results shown in fig. 2.1, g, it can be seen that in the working range of change the size of the micro displacement does not significantly affect the durability of the plates under fretting-corrosion conditions.

Based on the results of an experimental study of the influence of contact pressures, the amplitude of micro-displacement, coatings and the shape of the contact on the durability of structural elements, an analytical expression is derived for calculating the durability of structural elements during fracture them in the fretting zone - corrosion from variable tensile loads:

$$\sigma_{a\ fr} = 2{,}344\,(\sigma_{в} - \sigma_{m\ fr})^{0{,}63}\,[0{,}64 + 43{,}3(lg\,N)^{-2{,}1}] -$$

$$- 4{,}068\,(lg\,N)^{0{,}918\,K_n}\,\sigma_c^{0{,}32}\,k_m\,, \qquad (2.2)$$

where σ_{fr} and $\sigma_{m\ fr}$ – the amplitude and average values of cyclic nominal tensile stresses in structural elements in the zone of fretting corrosion respectively,, MPa; $\sigma_{в}$ - tensile strength of aluminum alloy, MPa; σ_c - contact stresses in the fretting- corrosion zone , MPa; N - the number of cycles to failure; K_n - coefficient taking into account the effect of coatings on the reduction of amplitude values of stresses for a given durability; K_n = 1 - for clad sheet parts; K_n = 0.86 - for anodized parts; $K_п$ = 0.89 - for parts anodized and coated with FL-086; K_m - coefficient taking into account the change in the form of contact; K_m = 1 - with a rectangular shape of the contact; K_m = 1.36 - at the contact of the plate with the washer.

The obtained formula (2.2) can be applied to calculate the durability of the shear bolt joints in the fretting-corrosion zone (under the bolt head and nut), the bolts of which are installed along a sliding fit and tightened by the normalized torque.

When placing the bolts in the holes of structural elements with radial tension and tightening in the development zone of fretting-corrosion, strain from the action of the radial tightness of bolts is generated, which leads to increased durability of these components. To obtain fatigue characteristics of an unloaded bolt joint under fretting-corrosion conditions, we tested the strip with a hole filled with a bolt.

Sample for testing (Fig. 2.2, a) is a strip 60 mm wide with a hole with a diameter of 10 mm. A chromansil bolt 3 is installed in the hole along a sliding fit and with a pressure of 1% $d_б$. Under the head of the bolt and the nut 5, the sleeves 4 and washers 1 are placed with an external diameter of 20 mm and an internal one 10 mm. Nuts tightened with calibration wrench to $M_{кр}$ = 30 N*m, which causes contact pressure under the washer 61 MPa. Fatigue tests of the samples were carried out on the testing machine ЦДМ–10ПУ with a loading frequency of 14 Hz and a cycle asymmetry factor R = 0.1. The test results are shown in Fig. 2.2, b.

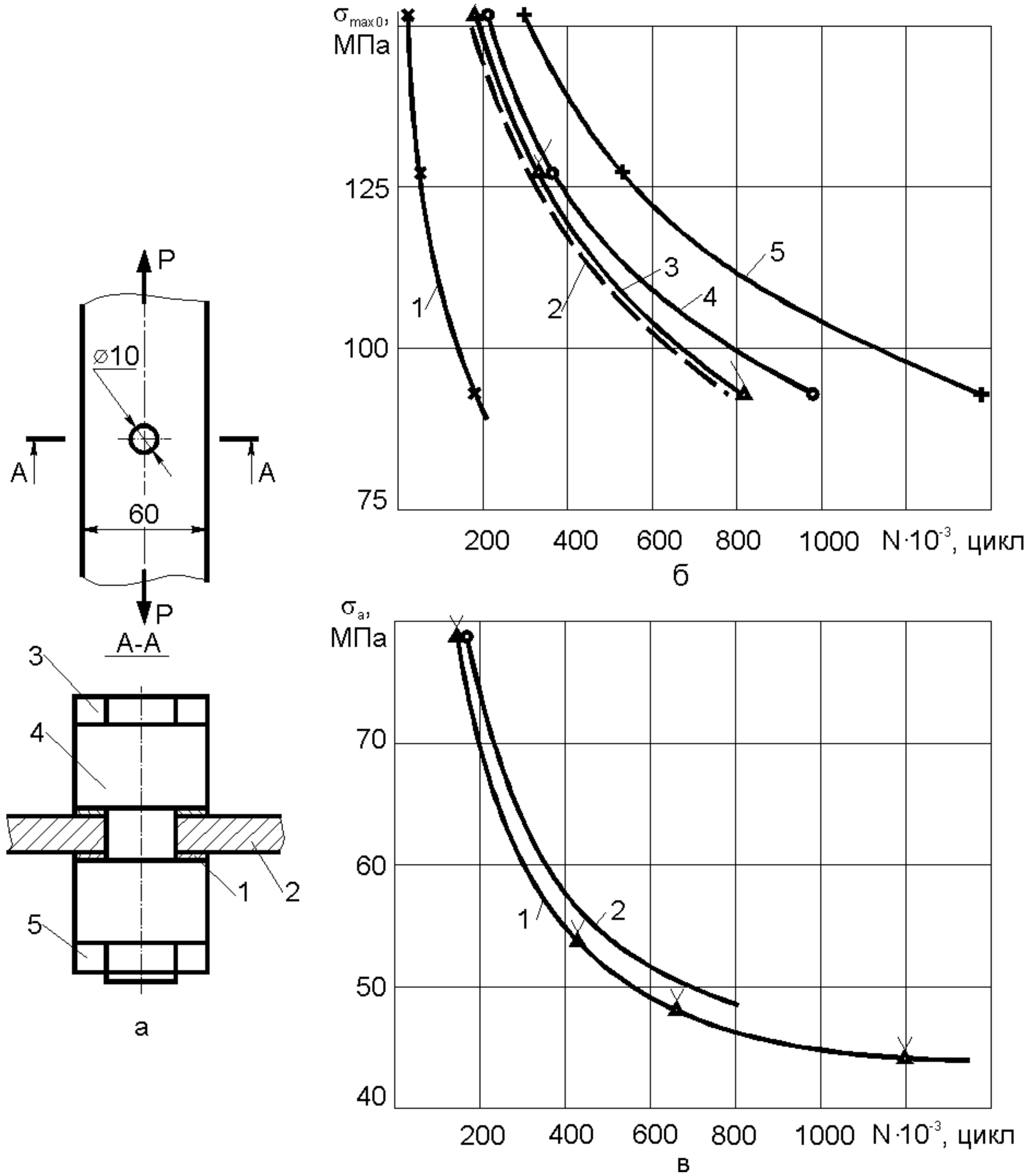


Fig. 2.2. Fatigue curves of a plate with a bolt-filled hole:
1 - without tightening and tightness; 2 - with a tightening without tension (calculation); 3 - with a tightening without tension; 4 - with tightening and tightness; 5 - without tightening with tightness

Fatigue failure of plates with a hole filled with a bolt without tightening and radial tension, occurred in cross section along the axis of the hole. Tighten the nuts to $M_{кр}$ = 30 N*m contributes to the durability of the joint in 4 - 8 times. With σ_{a0} = 63.2 and 79.1 MPa fatigue failure occurs in the zone of fretting corrosion on the outer boundary of the zone of contact between the washer and the surface of the plate.

For an analytical assessment of the durability of a strip with a hole filled with a bolt with a tightening and without a radial tension during the destruction of the plates in the zone of fretting corrosion, we use the formula (2.2). The calculation results are depicted by curve 2 in fig. 2.2, b. It can be seen satisfactory compliance of the calculated data and the results of the experiment.

To assess the durability of plates with a hole filled with a bolt with radial tension and tightening in case of destruction of samples in the fretting-corrosion zone, it is necessary to include an additional factor into expression (2.2), taking into account the effect of radial tension on the change in the limiting value of maximum non-zero stresses $K_{xп}$ i.e.

$$\sigma_{a\,fr} = 2{,}344(\sigma_в - \sigma_{m\,fr})^{0,63}[0{,}64 + 43{,}3(lg\,N)^{-2,1}] -$$

$$-4{,}068(lg\,N)^{0,918K_n}\sigma_к^{0,32}K_m K_{xn}.$$

Value of $K_{xп}$ when calculating the durability of compounds with tightness and tightening is 0.95 ... 0.9.

The fatigue failure of plates with a hole filled with a bolt with a tightening and a radial tension takes place in the zone of fretting-corrosion under the washer, i.e. durability is not determined by the geometric concentration of stresses, but by the intensity of fretting corrosion. In the case of the installation of tensioned bolts without tightening at the operating level of loads, the fatigue failure of the plates was caused by dents and nicks caused by mechanical damage caused by metal chips and tools. Therefore, the initial mechanical damage to the cladding layer of material D16AT, which may occur during processing and assembly, leads to a decrease in the durability of the joint made with the elastoplastic tension of the bolts.

The results of the fatigue test strip with a hole filled with a bolt with a radial tension, curve 5 shown in Fig. 2.1, b. It is seen that the durability of samples with tension and without tightening is the highest, since in this case the amplitude of stresses in the cross section weakened by the hole and the intensity of fretting corrosion between the bolt body and the wall of the hole decrease, and there is no reason for the development of fretting corrosion contact surfaces of the plate.

Conducted fatigue tests of plates with a hole filled with a bolt with a tightening at σ_m = 95.5 MPa and R = 0.1 (Fig. 2.2, c) showed that a change in average stresses under fretting corrosion conditions slightly affects the durability of a strip with a hole filled with a bolt.

Thus, it has been established that in an unloaded bolted joint, the use of tightening and tension promotes a significant increase in its durability. However, fatigue failure when using these tools occurs in the zone of intense fretting corrosion on the surface of the joint elements, i.e. fretting corrosion limits the further increase in the durability of structural elements, making it impossible to fully realize the positive effect of radial tension on the durability of joints.

The study of the influence of the nature of contact along the butt-planes on the static strength and durability of a single-bolt joint with a tightening was carried out on the samples of the eye shown in Fig. 2.3, a. The sample is an eye and lining having protrusions with a length l_{κ} = 14 ... 44 mm in mating planes, allowing to change their contact area.

The results of tests on static strength of the eye (Fig. 2.3, b) showed that the magnitude of the contact area on the joined surfaces insignificantly affects the strength of the eye, although with an increase in the contact area, the fastener is unloaded to a greater degree and there is some increase in the static strength of the lug.

The results of tests (Fig. 2.3, c) indicate that the eye durability depends on the magnitude of the contact pressure generated by the joint planes and contact area. With an increase in the contact area and tightening strength, the durability of the lugs increases to a certain value, limited by the development of fretting corrosion.

As a model for studying the effect of fretting corrosion on the durability of joints, a single-shear bolted joint is often used in aircraft structures and represents its work in the presence of an eccentricity of load transfer and stress concentration. The sample for fatigue testing (Fig. 2.4, a) consists of a profile and covers of aluminum alloy D16AT. The object of fatigue tests are covers made of D16ATT8 sheet material. Each cover is fastened with three countersunk bolts with a diameter of 8 mm. Bolt pitch - 30 mm, lintel in the cover - $2d$. Serial bolts mounted on a sliding fit.

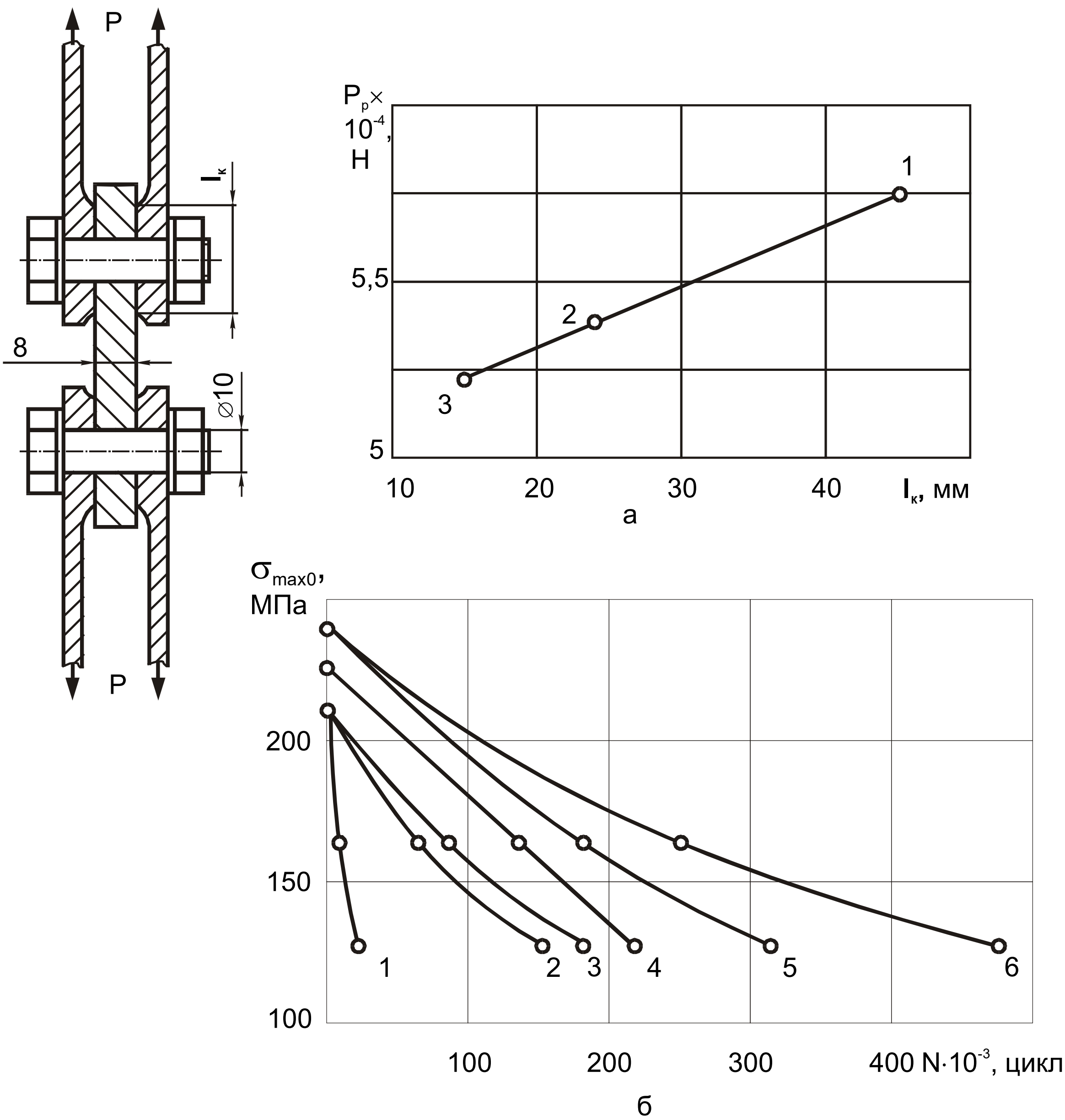
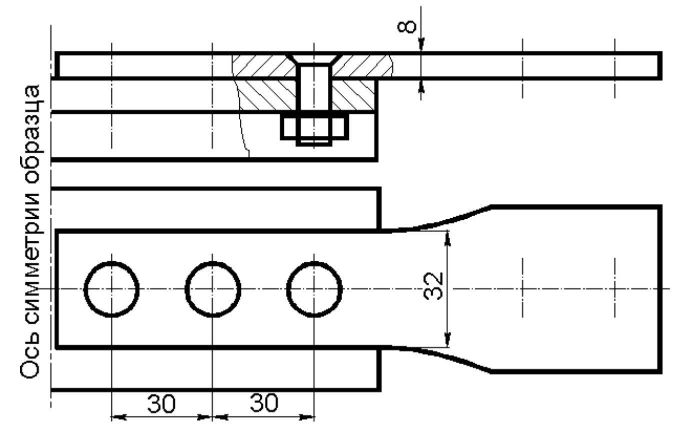
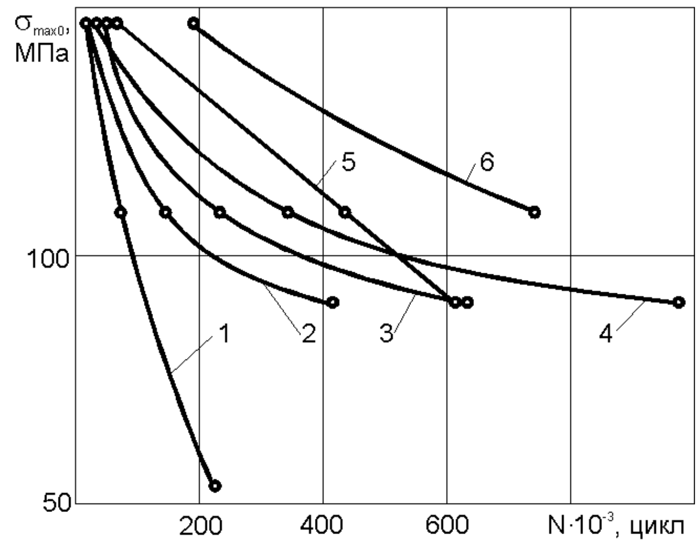


Fig. 2.3. The influence of the nature of the contact on the destructive load and durability of the eyes:
a - 1 - $l_к$ = 44 mm; 2 - $l_к$ = 24 mm ; 3 - $l_к$ = 14 mm ;
b – 1 - smooth pattern, M_t = 0 N·m; 2 - $l_к$ - = 14 mm M_t = 20 N·m;
3 - $l_к$ = 14 mm = 30 N·m; 4 - $l_к$ = 24 mm, M_t = 20 N·m;
5 - smooth sample M_t = 20 N·m; 6 - M_t = 30 N·m

Fatigue failure of the compound samples occurred not only along the hole axis, but also in the zone of intense fretting corrosion. A study was made of the anti-fretting characteristics of five types of plate coatings.



a



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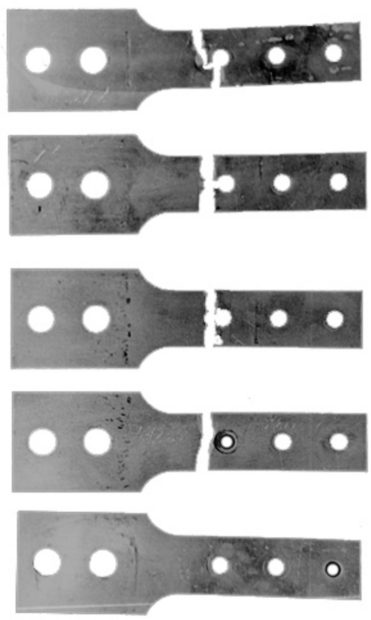

b

Fig. 2.4. Influence of the nature of the contact and coatings on the durability of a joint: a – sample for fatigue tests; b - fatigue curves for joint fretting corrosion conditions: 1 - without tightening; 2 - with tightening and cowering ФЛ-086; 3 - with tightening, anodized; 4 - with a tightening and cowering ФЛ-086+MoS_2; 5 - with a tightening and carbon fiber gasket; 6 - with a tightening and polymer filler; b - the nature of fatigue failure of samples

As a base case plates covering made of anodized "NH", in accordance with standard technology. The second variant of the coating is anodizing followed by the covering by FL-086 containing aluminum powder as a filler. The third variant of the coating is similar to the second, but instead of aluminum powder, powdered molybdenum disulfide in the amount of 5% is added into the covering composition. In the fourth version, a gasket of two-layer carbon fiber with a thickness of 0.3 mm was installed between the anodized surfaces. In the fifth variant, the anodized joined surfaces were covered with the ZP-3 polymer filler. The composition of ZP-3 as a filler was introduced 15 weight parts of molybdenum disulfide and 15 parts by weight of reduced content of asbestos.

An experimental assessment of the effect of the listed coatings on the durability of the joint was carried out on a single-cut model of the joint (see Fig. 2.4, a), in which countersunk bolts were installed by sliding fit with a tightening corresponding to M_t = 10 N*m. The results of fatigue tests are shown in Fig. 2.4, b.

Samples assembled without tightening were of minimal durability. The use of tightening the nuts increased the durability of the compounds by an average of 3 times, however, the samples with a tightening were mainly destroyed by fretting corrosion in the contact pressure zone.

The use of FL-086 primer with a filler in the form of aluminum powder led to a decrease in the durability of the sample compared to the durability of anodized samples. This is due to the wear of the primer and, as a result, a decrease in the tightening force. The destruction of the samples most often occurred along the axis of the hole of the first row of bolts.

The use of modified soil FL-086 with molybdenum disulfide increases the durability by 1.5 - 2 times compared with the durability of samples coated with serial soil. Using carbon fiber as an anti-fretting liner increases the durability of the joint in 1.5 - 2 times at high load levels, but at low levels carbon fiber gasket ineffective due to wear and decrease of tightening force.

Coating the anodized surface of the polymeric filler ZP-3 linings increased durability compound in 3 - 4 times by the exclusion of fretting-corrosion contacting surfaces. The destruction of the pads occurred in a section along the axis of the hole.

Individual task

Investigate the effect of contact pressures and coatings on the durability of flat plates (B = 30 mm) of aluminum alloy and choose the thickness of the plate to ensure a given durability in terms of fretting corrosion. Individual tasks to perform laboratory work are given in Table. 2.1.

Table 2.1 – Individual tasks for laboratory work

№	$\sigma_в$, MPa	σ_k, MPa	K_n	$lg\,N_{rq}$	Plate type
1	480	60	1	4,6	Flat smooth plate
2	470	62	1	4,7	
3	460	64	1	4,8	
4	450	66	1	4,9	
5	440	68	1	5,0	
6	430	70	1	5,1	
7	420	75	1	5,2	
8	410	80	1	5,3	
9	400	85	0,86	5,4	Plate with a bolt-filled hole with diameter 10 mm with axial tension
10	410	90	0,86	5,5	
11	420	95	0,86	5,6	
12	430	100	0,86	5,7	
13	440	105	0,86	5,8	
14	450	110	0,86	5,9	
15	460	120	0,86	6,0	
16	470	125	0,86	5,75	
17	480	130	0,89	5,85	Plate with a bolt-filled hole with diameter 10 mm with axial tightness and 1% $d_б$ tightening
18	475	120	0,89	5,95	
19	465	110	0,89	5,65	
20	455	100	0,89	5,55	
21	445	95	0,89	5,45	
22	435	90	0,89	5,35	
23	425	85	0,89	5,25	
24	420	80	0,89	5,15	
25	410	105	0,89	5,3	

Report content

1.A brief description of the method for calculating the durability of structural elements under fretting corrosion conditions.

2.A sketch of the character of the fatigue failure of sample plates and parts under fretting corrosion conditions.

3.Calculation of the influence of contact pressures and coatings on the cyclic durability of flat plates. Comparison of calculated and experimental values of the number of cycles to failure.

4.The choice of the thickness of the flat structural element to ensure a given durability in terms of fretting corrosion.

5.Development of constructive-technological methods to reduce the effect of fretting corrosion on the durability of plates with holes filled with fasteners with radial tension and tightening.

Test questions

1. In what conditions does fretting- corrosion develop?
2. What factors affect the process of fretting corrosion?
3. What is the impact of fretting corrosion on the durability of structural elements?
4. How can I calculate the durability of structural elements in the fretting corrosion zone?
5. What models of structural elements are used to study durability in terms of fretting corrosion?
6. What is the effect of tightness and tightness on the durability of joints under fretting corrosion conditions ?
7. How do coatings affect the durability of structural elements?
8. What are the ways to protect against fretting corrosion?