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FRETTING FATIGUE OF SHAFTS STRENGTHENED BY SURFACE PLASTIC DEFORMATION

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ABSTRACT

Influence of surface plastic deformation on fatigue resistance of shafts (carbon and low-alloyed steel) with the account of scale effect is considered. It is shown that such strengthening considerably increases fatigue resistance of shafts in the air including fretting conditions. Effectivity of such strengthening decreases sharply with the increase of the number of loading cycles under simultaneous influence of corrosive environment and fretting.

KEY WORDS:

Surface plastic deformation, fatigue, fretting corrosion medium.

INTRODUCTION

The strengthening of machine parts and elements with the help of surface plastic deformation (SPD) by burnishing, rolling, shot-peening and other similar methods is known for a long time [1-3] and is widely applied in different branches of engineering. However problem on such treatment efficiency for elements working in the fretting-fatigue failure conditions, and also under the effect of corrosion mediums still remains insufficiently studied.

The results of experimental research of rolling influence on the fatigue resistance and corrosion fatigue of shafts are presented in the present paper. These shafts-samples are of different diameters and they contact with metal packings imitating the fits of bearings, cog-wheels, screws etc. in different branches of mechanical engineering. The purpose of such difficalt and long-term investigations is to estimate durability of the strengthened details under corrosion fatigue and fretting-fatigue.

MATERIALS AND RESEARCH TECHNIQUE

The investigations have been conducted on samples made from 35 steel (σ_T =280) and 38X2H2MA steel heat treated to obtain different durability ($\sigma_{0,2}$=600 and 900 MPa). Cylindrical samples with the diameter of a working part of 5, 10, 20, 27, 50 and 200 mm have been used (Fig.1, a, b, c). The steel bushes (35 steel) have been capped in the center of the working part just after the hot molding. The external diameter and the length of bushes were equal to two diameters of a working part of a sample. The investigated shafts of working diameter 200 mm were fabricated from separate forging. After testing from the sample heads of diameter 400 mm the samples of the working diameter 50 mm have been fabricated. From the sample heads with the diameter 50 mm after testing the samples of the diameter 27 and 5 mm have been fabricated (Fig. 1, d). Such a scheme of sample manufacturing allowed eliminating the influence of the chemical composition factor and structure of steel during the investigation of a scale effect of case-strengthened details. All samples were geometrically similar.

Strengthening of the samples with the diameter up to 50 mm was carried out with the help of three-roller spring accommodation, and for the samples with diameter 200 mm - two-roller hydraulic device. Roller burnishing of the samples was conducted under different conditions (see Table).

TABLE. Conditions of a sample rolling

Diameter of a sample d, mm	Rolling dimensions		Rolling efforts P, N·10⁵	Number of passes	Strengthened depth t, mm
	Diameter D, mm	Radius of curving r, mm			
27	40	5	0,5	2	0,9
50	90	5	1,74	2	1,7
200	130	15	25,0	1	6,8

Rolling efforts were determined from the condition of the strengthened layer thickness identity for the samples of all diameters. This thickness was equal to t ~ 0,035d. Such thickness is recommended by many authors as optimum for a fatigue resistance increase. Samples have been tested on the specially built different power units equiped with cameras used to deliver the corrosion medium to a working part of samples. [4]. The number of simmilar-type machines allowed to test samples of different diameters - from 5 up to 200 mm. The type of loading – pure bending with the rotation of a sample. Frequency of a loading has been changed in the range 8-50 Hz. The 3% NaCl solution simulating the sea water have been used as the corrosion medium.

RESULTS AND DISCUSSION

Strengthening of working parts of the samples in the places of contact with packing details sharply increases their fatigue resistance. For 200 mm diameter shafts the fatigue limit increases more than in 3 times (Fig. 2). It was also shown that the efficiency of rolling increases with sample diameter growth. So, for the samples with 5 mm diameter the efficiency of is about 50 %, for the diameter of 27 mm - 85 %, 50 mm - about 100 % (Fig. 3). This fact can be explained first of all by magnification of an endurance strength absolute value of the not strengthened shafts with packed detail with the decrease of diameter. The scale factor under fatigue of strengthened samples with packings (number of loading cycles is restricted up to $2\cdot 10^7$) appears approximately at the same way, as in the case of non strengthened shafts testing. The fatigue resistance of shafts decreases with its diameter increase. It was established (Fig. 4) that the fatigue resistance of steel shaft in press joining is very low if the shafts were non treated by rolling. The failures of shafts under the packing edge can appear already at tensions less than 100 MPa after a loading of even several millions of cycles. Thus, the fatigue resistance of alloyed 38X2H2MA steel shafts appeared to be even lower than for the 35 steel shaft, in spite of the fact that the mechanical properties of alloyed steel are much higher. In contrast to testing without surface strengthening, the fatigue resistance of rolled shafts was the higher the better the strength properties of metal.

Thus, the application of rolling allows to implement potentially high strength resources of the thermally improved alloyed steels under cyclic loading in press joinings, that are widely used in mechanical engineering.

It was shown that the high strengthening effect is saved for a long time under condition of elimination of such joining contact with corrosion medium, for example, sodium salt solutions. In practice often occures that to the contact zone of the cyclically loaded strengthened detail with other parts of machines can penetrate the corrosion medium, for example, propeller shaft and steering shafts of ships, automobile springs, a drilling equipment etc. How long in these cases the surface strengthening protects details from failure?

To answer this question, it was necessary to increase number of loading cycles much above, that it is determinate by the existing standards or norms (up to 10^8 of loading cycles and higher).

The conducted by us testings for samples under the large number of loading cycles (Fig. 4) have displayed the limited nature of SPD application for corrosion fatigue durability increase of details with packings. With the test base increasing fatigue durability of strengthened samples decreases, especially in the case of steel contacting elements. Moreover, for more durable steels the corrosion fatigue endurance decrease intensity is higher.

For prolongation of the service life of such details it is necessary to eliminate conditions of corrosion medium penetration to the strengthened details, to ensure an additional electrochemical protection or to substitute a material of contacting details etc.

CONCLUSION

- Strengthening of steel shafts by surface plastic deformation considerably increases their fatigue resistance in the air including the presence of contacting elements causing fretting.
- During fatigue of shafts strengthened by rolling under fretting (limited number of cycles 10^7-$2\cdot 10^7$) the scale effect is revealed just as during the testing of unstrengthened shafts.
- Simultaneous influence of fretting and corrosive environment sharply decrease the effectiveness of shafts surface strengthening by plastic deformation with the increase of the loading cycles number.

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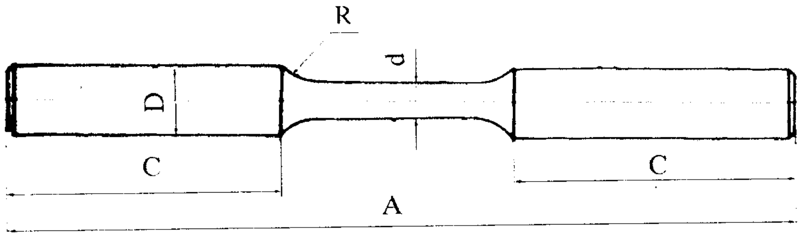
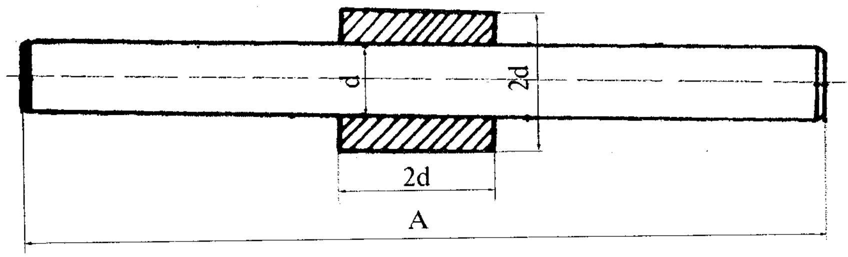


a



b

c

N	d	R	C	D	A
1	5	10	39	10	100
2	10	30	78	16,5	226
3	20	30	90	27	290
4	27	30	90	37	290
5	50	50	155	72	500
6	200	200	510	330	2130

d

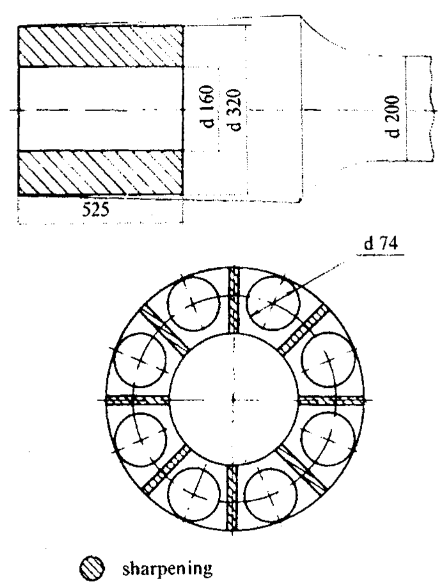


Fig.1 Scheme (a, b), size (c) and scheme of cutting (d) of investigated specimen.

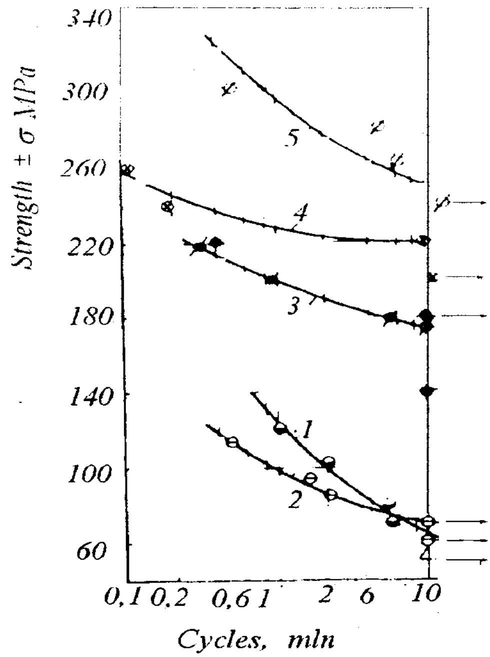


Fig.2 S – N curvers of non strengthened (1-2), strengthened (3-5) specimens (d = 200 mm) made from: steel 35 (1, 3); strengthened steel 38X2H2MA (2, 4); steel 38X2H2MA after heat treatment (5) with ring packing.

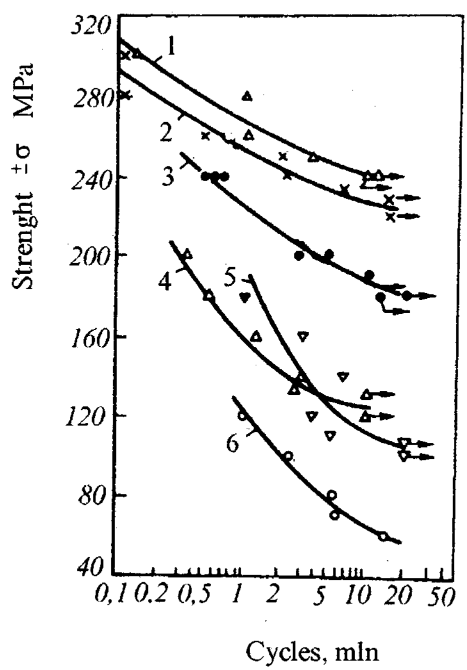


Fig.3 S – N curvers of strengthened (1-3) and non strengthened (4-6) specimens made from carbon steel 35 with ring packings. Specimens diameter: (1, 4) - 27 mm; (2, 5) - 50 mm; (3, 6) - 200 mm.

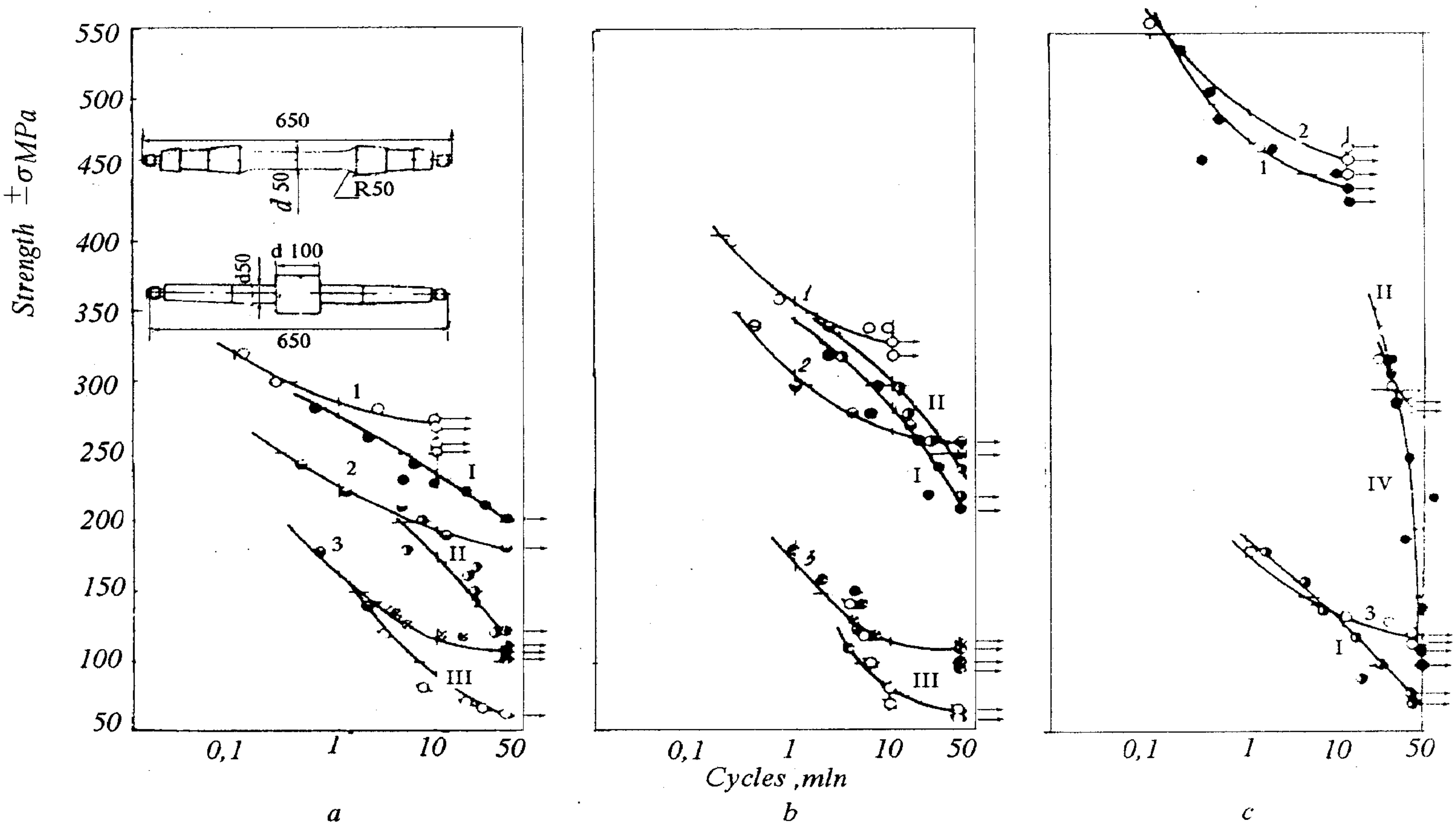


Fig.4 S – N curvers of specimens (d = 50 mm) made from: steel 35 (a), steel 38X2H2MA without heat strenghening (b) and steel 38X2H2MA after quenching (c): 1, I - rolled specimens without ring packings; 2, II, IV - rolled specimens witht ring packings; 3, III – specimens without rolling and with ring packing; 1-3 – testing in the air; I – IV – testing in 3% NaCl solution.

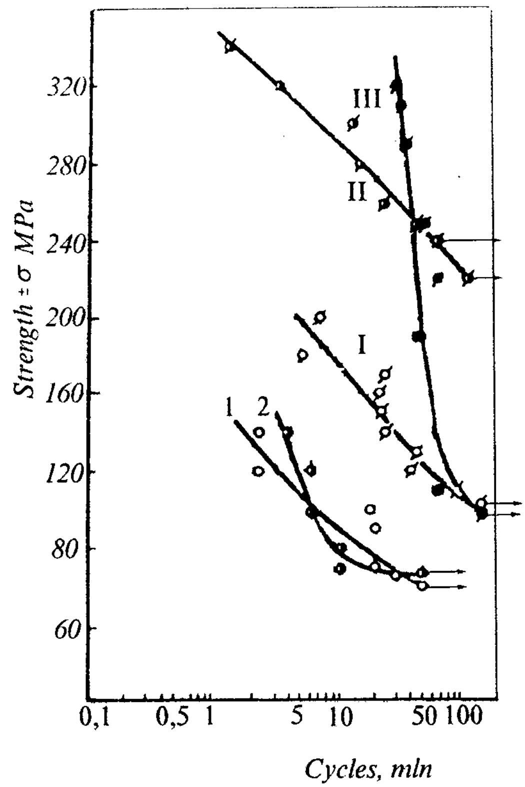


Fig.5 S – N curvers of specimens (d = 50 mm) with ring packings made from: steel 35 (1) and steel 38XHMA (2) without strengthening; after strengthening I - steel 35 (regime I), II - steel 38XHMA (regime II), III - steel 38XHMA (regime III). 1, 2 - testing in air; I,II,III - testing in 3% NaCl solution.