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Technological heredity effect on fatigue strength of hydropower plant parts after combined processing

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The paper investigates the effect of combined processing on fatigue strength. We developed a plant for combined processing, processed 40X steel samples with various modes. Furthermore, we experimentally studied the fatigue strength of the samples by the metal magnetic memory method, and found the relationship between stress concentration zones and combined processing modes under the heredity factor effect. Finally, we gave recommendations on the use of combined processing for hardening parts of hydropower plants.
Keywords: combined processing, fatigue strength, power plants, technological heredity, metal magnetic memory method

Introduction

The main reasons for the failure of hydropower plants are corrosion, wear and fatigue fracture, such as dimensional wear or fractures of pump and hydraulic motor drive parts, i.e. bearings, gear teeth, shafts, couplings [1–10].

The last two reasons are no less dangerous, since they require a long repair or lead to a complete stop of the plant. Therefore, the tasks of reducing wear and increasing the fatigue strength of such parts are relevant [5, 7].

The operational properties of parts of hydropower plants are affected by: manufacturing accuracy, surface roughness, material grade, material structure and hardness, as well as methods and modes for producing parts. This is due to the fact that accuracy and roughness cannot characterize the physical state of the surface layer of the metal. Surfaces with the same accuracy and final roughness can have varying degrees of cold work, uneven nature and residual stresses, their crystalline structure can be distorted to different degrees, as well as surface integrity due to microcracks, burrs, loosening, etc. The chemical composition and structure of the surface layer of the metal may be different. If the surface is obtained as a result of a number of physical and mechanical operations with the release of a significant amount of heat in the technological zone, individual chemical components can burn out, resulting in a decrease in the operational properties of the metal [8–10].

Many methods have been developed to increase wear resistance and fatigue strength, all of them having their own advantages, disadvantages and applications [10]. However, it is possible to make a parameters increase reserve by the methods of combined processing (CP) [8, 11, 12].With combined processing methods, when technological factors sequentially one after another or jointly in parallel affect the work piece, technological heredity is clearly manifested. Moreover, heredity affects not only immediately after the finishing operations of the technological process, but it can also occur during operation as a result of the influence of certain surface quality parameters created in the surface layer of a part during its previous processing. From the standpoint of technological and operational heredity, it is possible to establish a connection between technological operations and transitions, including the cases when combined methods of machine parts are applied [11–14].

Description of the Experiment

The study introduces a combined processing method, which consists in sequential electromechanical processing and diamond smoothing [15, 16]. We developed a trial plant composed of a universal lathe, a power source, a quench, a current supply system, and a quenching area cooling system, in which combined processing modes were worked out [17, 18].

On the surface there was obtained a regular microrelief with oil pockets to hold the grease during friction (Fig. 1). During electromechanical processing (EMP), there appear overlapping zones of the quenching bands, which depend on the feed rate S, with a decrease in hardness being observed in these zones. After EMP, a diamond smoother passing through the surface finally smooths out the microroughness of the profile, and when it gets into the overlapping zone, it forms grooves.

In [15, 16], the effect of CP modes on the samples wear resistance was studied. Comparative wear tests of the samples processed by various methods were carried out. Findings of research showed that CP increases wear resistance compared to high-frequency hardeningby 55%, cementation— by 50%, nitriding— by 45%. The obtained results allow us to recommend combined processing for hardening parts of power plants operating in conditions of intense friction with lubricant.

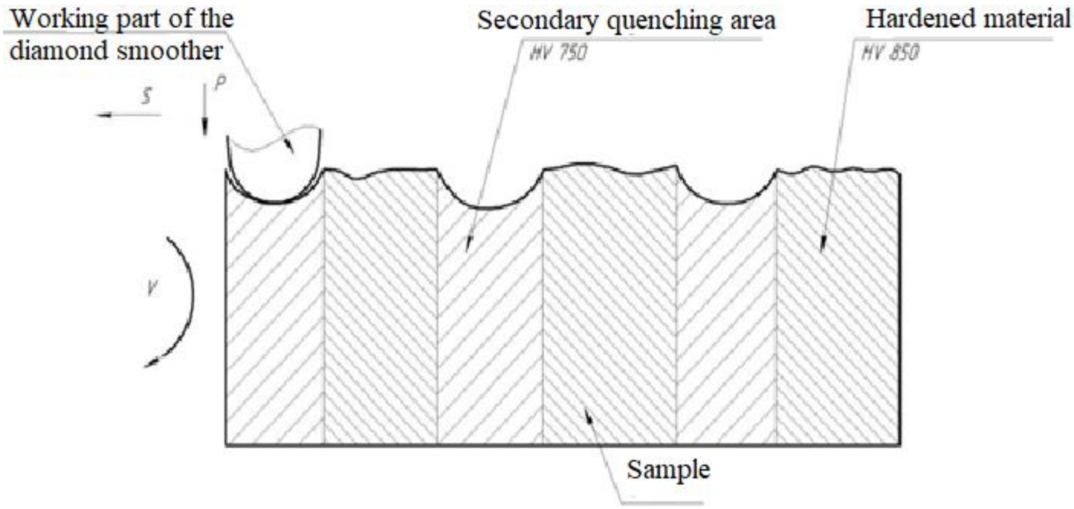

Fig. 1. Modeling the process of obtaining a regular microrelief: hardened material (HV 850), secondary quenching area (HV 750)

However, the overlap of quenching bands, which are the stress concentrators on the surface of parts, can significantly reduce fatigue strength and cause the destruction of the entire mechanism. Therefore, the task of diagnosing hidden stress concentrators and the center of crack propagation in power plants is relevant [10, 19–21].

The paper introduces the study of the combined processing effect on fatigue strength by the metal magnetic memory method (MMM) [22–24].

The MMM method is a non-destructive testing method based on the registration and analysis of the distribution of intrinsic scattering magnetic fields on the surface of the product in order to determine

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stress concentration zones (SCZ): defects, heterogeneity of the metal structure, and centers of crack nucleation.

For the study, we used samples made of steel grade 40X with a diameter of 12 ± 1 mm and a length of 120 ± 10 mm. To detect SCZ, we used an INK-3M-12 model device with a four-channel scanner which has two two-component sensors for measuring both normal and tangential components of the magnetic field, and a whole length counter with a wheel (Fig. 2).

Fig. 2. The INK-3M-12 model device for identifying stress concentration zones

The study was carried out according to GOST R ISO 24497-1-2009, GOST R ISO 24497-3-2009, GOST R ISO 24497-3-2009.The manifestation of technological heredity can lead to both improvement and deterioration of the operational properties of parts [12].

The problems of mechanics of technological heredity of the quality of the machine parts surface layer as a result of the plastic flow are studied in [11, 14]. The life cycle of a metal from a workpiece to failure during operation is considered as a single process of exhaustion of metal. However, the issue related to the properties heredity by the surface layer after machining, thermal and finishing treatment is not well understood. The formation of stress concentrators on the surface is affected by technological heredity. Due to stress concentrators, cracks can form on the surface of parts, and lead to fatigue fractures of parts.

a b c

Fig. 3. Samples for stage 1 of the study for the presence of SCZ after CP

At stage 1, we examined only those samples which did not have hereditary SCZ before combined processing.

To do this, the SCZ control was carried out at all stages of sample preparation:

• before machining (turning) (Fig. 3 a);
• after machining (Fig. 3 b);
• after combined processing (Fig. 3 c).

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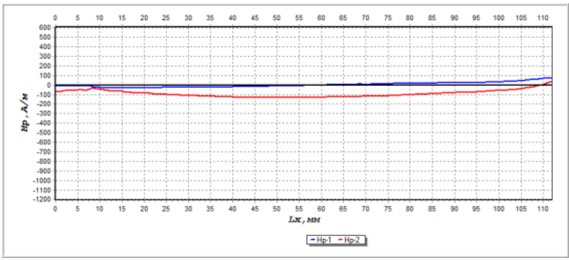
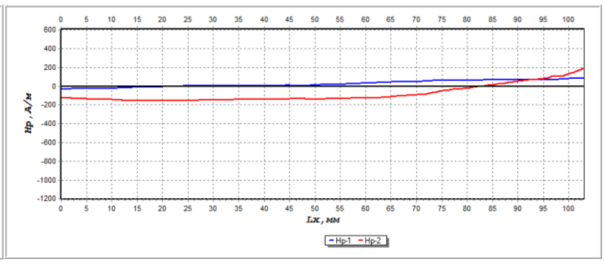
At stage 2, we studied the samples having SCZ before combined processing. The results of the study were obtained on magnetograms.

Experimental Result

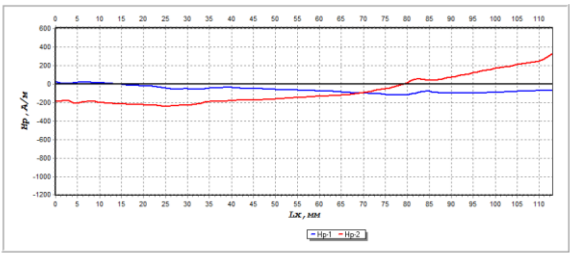
Findings of experiment 1 showed that after combined processing, SCZ on the surface of the parts were not found (Fig. 4, 5).

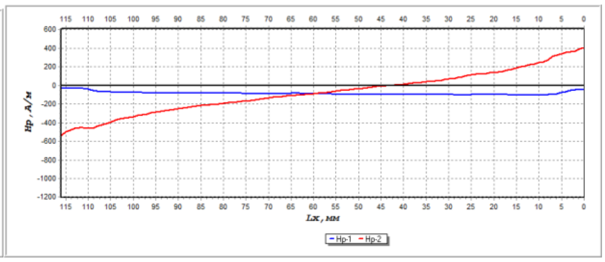
A comparison of the magnetograms before CP (Fig. 4 a, b) and after (Fig. 4 c, d) showed that the quenching bands overlap does not cause structural inhomogeneity and centers of crack nucleation on the surface.





a b

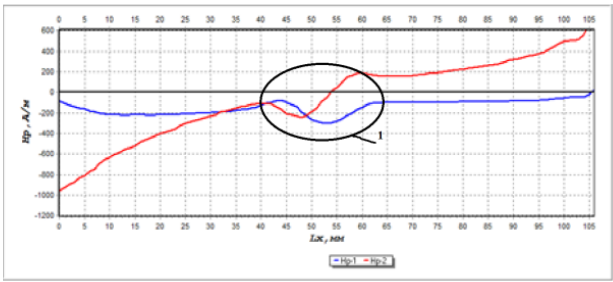


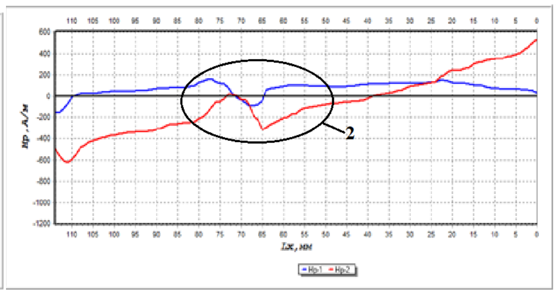


c d

Fig. 4. Magnetograms of samples: a, b — before combined processing, c, d — after combined processing

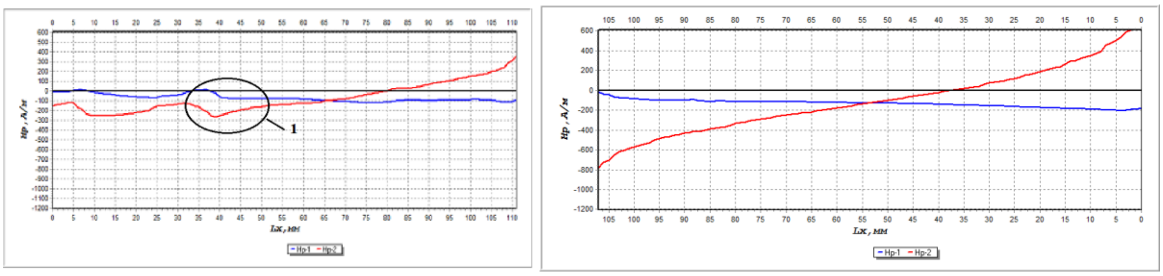
For stage 2 of the study we chose samples with SCZ before CP (Fig. 5). The results of this stage showed that in some samples SCZ did not have abrupt jumps (Fig. 6 a), and in some samples SCS were absent (Fig. 6 b).





a b

Fig. 5. Magnetograms of samples with SCZ before CP: a — region 1, b — region 2



a b

Fig. 6. Magnetograms of samples with SCZ after CP: a — reduction in the risk of crack propagation (region 1), b — absence of SCZ

It is possible to control the process of technological and operational heredity so that properties positively affecting the quality of the part are preserved throughout the entire process, and properties affecting negatively are eliminated at the beginning.

Conclusions

By successive hardening, i.e. EMP, and diamond smoothing, it is possible to control the characteristics of surface microgeometry in a wide range, improve lubricity and increase the operational indicator — wear resistance. The effect of technological heredity on the fatigue strength of parts of hydropower plants after combined processing is established.

The quenching bands overlap after CP reduces fatigue strength, and various defects in the surfaces of parts, in particular microcracks, can "heal". After CP, stress concentrators are not formed in the surface layer of the samples, and CP is a technological barrier to SCZ.

Thus, the combined processing method can be recommended to increase the wear resistance and fatigue strength of parts of hydropower plants.

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