Increasing durability by deformational hardening under the conditions of back-to-back endurance by creating heterogeneous patterns

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Abstract. A new method of increase the back-to-back endurance of machine parts – the static-pulse processing, which creates a work-hardened surface layer with high hardness on large depth is proposed. An important feature of the static-pulse processing is the possibility to obtain the difference in uniformity of hardened (heterogeneous) surface layer. The researches on influence of parameters of the hardened surface layer obtained by the static-pulse treatment on the durability under the conditions of back-to-back endurance were conducted. As a result, there were the first obtained recommendations on the uniformity of strain hardening of the surface layer, contributing to the increase of the back-to-back endurance of machine parts from steels Ck45, 41Cr4 and 35HGSA.

1. Introduction

The performance capabilities of machines and mechanisms were usually determined by the strength and durability of the most loaded critical parts, the external influences perceived by the surface layer on which are usually the cause of failure. Therefore, in the manufacture of such parts a hardening treatment that forms the surface layer as efficient as possible during operation is used.

For parts subject to high cyclic contact loads, a hardened layer should have a reasonably large depth (1.5...2 mm) to prevent deformation and destruction. Furthermore, as the results of recent researches show, the uniformity of hardening touch on a great impact on performance, including back-to-back endurance. The advantage of surface hardened layer with uneven (heterogeneous) structure, experiencing the effect of cyclic contact stresses, is slowdown by tough and ductile material the brittle crack that is originated in a solid structural component. Today, however, the creation by traditionally used methods of hardening machining the deep hardened surface layer with the requisite uniformity is quite a challenge. For its analysis it is proposed to use a relatively new method of surface plastic deformation (SPD) – static-impulse processing (SIP), which has wide technological capabilities in the formation of the hardened surface layer and allows you to create a greater depth (up to 6...10 mm) and a high degree of hardening (up to 6500 MPas) [1]. During SIP the plastic deformation of the hardened material is carried out by shock pulses, whose shape is fully adapted to the material properties and loading conditions, that increases the EFFICIENCY of the process. The static component of the load is designed for the best use of the pulse component. The SIP technology allows to adjust pretty exactly...
the uniformity of hardening, creating as homogeneous and heterogeneous hardened structure [2]. The adjustment of the uniformity is achieved by overlapping the plastic imprints, received as the result of influence on the material of the shock pulses. The uniformity of plastic overlapping of imprints is evaluated using the coverage factor $K$. If $K = 0$, the edge of one imprint borders the edge of the other; if $0 < K < 1$, then the imprints are overlapped; if $K = 1$ there is multiple indentation of the tool in the same place [8-10].

2. The study on the possibility of increasing durability by deformational hardening under the conditions of back-to-back endurance by creating heterogeneous patterns

To assess the ability of the SIP to create the heterogeneous structure improving the durability of machine parts under the conditions of back-to-back endurance the samples of steels Ck45, 41Cr4 and 35HGSA with initial microhardness of 2000 – 2200 MPas were taken. The choice of material is due to the fact that the steel Ck45 is the standard in the engineering and steels 41Cr4 and 35HGSA are used to create the heavy-duty machine parts, working in conditions of cyclic contact loads. [11-12] The samples are the plates of 20 mm thick which were reinforced with different intensity of shocks ($5 < a < 7$ J/mm) and with different overlap factor $K$. The rod rollers with a diameter of 10 mm were used as a tool. The choice of these technological parameters of the SIP is due to the fact that they are significantly affect the shapes, sizes, depths and degrees of hardening of the forming heterogeneous structures [1-3].

On the hardened tracks cut under the samples, the microhardness on the grid with a certain step on depth and in the direction of feed of the SIP tool was measured. According to the results of measurements of micro hardness, the graphs characterizing the distribution of the degree of hardening on the depth and along the surface of the samples were built (fig. 1-3). The analysis of graphs showed that the increase of the overlap factor (from $K=0.2$ to $K=0.5$) leads to the formation of an explicit heterogeneous structure of the hardened surface layer, which is characterized by alternating the hard and soft sections of different sizes. [7]

To study the durability the hardened SIP samples were subjected to cyclic contact loading by the components in the form of balls with the same contact load on a specially designed device [4-6]. This allowed to form on the surface of samples at the same time the traces of several raceways, which were studied after testing.

The resistance to contact spalling $\Delta I$ is a complex parameter taking into account the change during testing of sizes of the raceways of rolling balls and the area of spallings arised on them, which allows to evaluate the durability of machine parts, working in conditions of contact fatigue.

The results of experimental testing of resistance to contact spalling are presented in form of graphs in figure 4.

The results of the testing of samples with heterogeneous unevenly hardened structure produced by SIP proved the efficacy of use of this technology. So, when studying the effect of overlap factor on $\Delta I$ was found that for the steel Ck45 the maximum values of $\Delta I = 4$ to 6 was observed on the value of $K = 0.4$ (Fig. 2, a). The most effective value of $\Delta I$ for steels 41Cr4 and 35HGSA were achieved when $K = 0.3$ and were respectively 2 to 2.3 and 2.1 to 2.8 (Fig. 2, b, c). Influence of the value of intensity of shock on resistance to contact spalling on all of the tested steels showed that with increasing of $a$ the effective range of values $\Delta I$ moves in the direction of smaller values of the overlap factor, which is associated with the increase of the zone of deformable metal under a single imprint.

Conclusions

1. One of the most perspective directions of increase of the back-to-back endurance of machine parts is the creation of surface plastic deformation of heterogeneous hardened surface layer. One of the most effective ways of surface plastic deformation, allowing with high accuracy and in wide range to adjust the parameters of the hardened surface layer is static-pulse processing (SIP).

2. As a result of experimental studies is found that the most important technological factors of SIP that have the greatest impact on the value of resistance to contact spalling of the studied materials...
(steels Ck45, 41Cr4 and 35HGSA) with heterogeneous structure, are the energy of the shock pulses, the overlap of the plastic imprints and elastic-plastic properties of material.

**Figure 1.** Diagrams of distribution of microhardness in the surface layer of steel Ck45.

**Figure 2.** Diagrams of distribution of microhardness in the surface layer of steel 41Cr4.
Figure 3. Diagrams of distribution of microhardness in the surface layer of steel 35HGSA.

Figure 4. The dependence of resistance to contact spalling $\Delta I$ on intensity of shocks $a$ and overlap factor $K$: $a$ – steel Ck45; $b$ – steel 41Cr4; $c$ – steel 35HGSA.

3. For example for the steel 41Cr4 and 35HGSA, unlike steel Ck45, the maximum range of the resistance to contact spalling ($\Delta I$) was achieved by the creation of heterogeneous structures with less uniformity of hardening, forming when the overlap factor of imprints $K=0.3$ (for the steel Ck45 $K=0.4$). The numerical values of the resistance to contact spalling when creating a heterogeneous structure for steel Ck45 were in 2 to 2.5 times higher than the $\Delta I$, obtained for steels 41Cr4 and 35HGSA.

4. When increasing the intensity of shock when creating a heterogeneous structure of the SIP, the optimal values are shifted towards smaller values of the overlap factors due to the increase of the zone of deformed metal under the single imprint.
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References
[1] Kirichek A V, Soloviyev D L 2013 Nanostructure changes in iron-carbon alloys as a result of impulse deformation wave action, Journal of Nano- and Electronic Physics. 5 (4).
[2] Kirichek A V, Barinov S V 2015 "Study of Methods Relating to Increase of Contact Pitting Resistance in 45, 40H, 35HGSA Steel due to Development of Heterogeneous Structure Involving Mechanical Hardening Technique", Applied Mechanics and Materials, 756, 65-69.
[3] Kirichek A V, Barinov S V 2015 "Development of Parameters Describing Heterogeneous Hardened Structure", Applied Mechanics and Materials, 756, 75-78.
[4] Kirichek A V, Soloviyev D L 2013 Nanostructure changes in iron-carbon alloys as a result of impulse deformation wave action, Journal of Nano- and Electronic Physics. 5 (4).
[5] Kirichek A V, Soloviev D L, Altukhov A Y 2014 Production of quasicomposite surface layer of a metal material by shock wave strain hardening, Journal of Nano- and Electronic Physics. 6 (3).
[6] Kirichek A V, Soloviev D L, Altukhov A Y 2014 Deformation wave hardening of metallic materials, Journal of Nano- and Electronic Physics. 6 (3).
[7] Panin V E and Deryugin E E 2003 Mesomechanics of the formation of banded structures at mesoscopic and macroscopic levels. The Physics of Metals and Metallography 96 2-15.
[8] Schneider Yu G 1998 Techniques for Pressure Finishing: Reference Book (St. Petersburg: Polytechnic).
[9] Siegel R W and Fougere G E 1995 Mechanical properties of nanophase metals Nanostr. Mat. 6 1-4.
[10] Smelyansky V M 2002 Mechanics of Parts Strengthening by Surface Plastic Forming (Moscow: Mechanical Engineering)
[11] Valiev R Z, Korznikov A V and Mulyukov R R 1993 Structure and Properties of Ultrafine-Grained Materials Produced by Severe Plastic Deformation Materials Science and Engineering 168 141-148.
[12] Valiev R Z, Krasilnikov N A and Tsenev N K Plastic 1991 Deformation of Alloys with Submicro-Grained Structure Materials Science and Engineering 137 35-40.