*Виконано циклічні випробування сталі 40Х з проміжним поверхневим пластичним деформуванням зразків. Рівень деградації матеріалу визначали методом коерцитивної сили. Отримано підвищення довговічності сталі в 3–10 разів, межі витривалості на 10 %. Результати пояснюються заліковуванням дефектів матеріалу після поверхневої обробки, при якому відзначається зниження коерцитивної сили, а також диспергуванням структури поверхневого шару*

*Ключові слова: циклічне навантаження, поверхневе пластичне деформування, заліковування дефектів, змінення тонкої структури*

*Проведены циклические испытания стали 40Х с промежуточным поверхностным пластическим деформированием образцов. Уровень деградации материала определяли методом коэрцитивной силы. Получено повышение долговечности стали в 3–10 раз, предела выносливости на 10 %. Результаты объясняются произошедшим после поверхностной обработки залечиванием дефектов материала, при котором отмечается снижение коэрцитивной силы, а также диспергированием структуры поверхностного слоя*

*Ключевые слова: циклическое нагружение, поверхностное пластическое деформирование, залечивание дефектов, изменение тонкой структуры*

UDC 620.178.322, 620.179.141:620.191.33, 539.4, 539.61
DOI: 10.15587/1729-4061.2016.69644

# EFFECT OF THE STATE OF SURFACE LAYER ON 40X STEEL FATIGUE CHARACTERISTICS

**K. Vakulenko**
Candidate of technical science, Senior Researcher*
E-mail: karina_vak@inbox.ru
**I. Kazak**
Candidate of Technical Science, Senior Researcher*
E-mail: matsevlad@ipmach.kharkov.ua
**V. Matsevityi**
Doctor of Technical Science, Professor
Head of the material science department**
*Department of forming in machinery**
**Institute for problems in machinery NAS of Ukraine
Pozharsky str., 2/10, Kharkov, Ukraine, 61046

## 1. Introduction

Issues of increasing reliability and durability of engineering products become of key importance due to the increasing requirements for the mechanical properties of materials because of intensification of different technological processes and use under conditions of high temperature and power loads.

Technological support of operational properties of machine parts is inextricably connected with parameters of their surface layer state. For example, the endurance limit of parts mainly depends on the magnitude of the residual stress of the surface layer; the irregularities formed on the surface of the part during processing are one of the reasons for the decline of the endurance limit, as are stress concentrators.

As it is known, the mechanism of fatigue failure is related to the development and accumulation of microplastic deformations in the surface layer and is based on the motion of dislocations. Therefore, to improve the fatigue strength of machine parts, it is necessary to reduce the number of defects and hinder the distribution of the degradation processes in the metal surface layers.

At the present time, to increase resistance to fatigue failure of mechanical engineering products, different types of surface treatment (thermo-mechanical, chemical and thermal processing, surface plastic deformation, applying various kinds of coverings and so on) allowing to modify the surface layers while maintaining the necessary ductility and toughness throughout the material are widely used [1, 2].

The development of ideas about the possibility of healing discontinuities occurring in the metal (interstices, submicrocracks) being accumulated during cyclic loading can be considered as another important aspect in addressing the problem of increasing the durability of machine parts and equipment [3].

The ability to heal the accumulated fatigue damages resulting from the surface treatment when plastic deformation of surface layers is encountered can significantly improve the quality and mechanical properties of the material. This is especially important in terms of revitalization of metal properties of onworn bulky and expensive components of equipment during repairs.

## 2. Analysis of the published data and formulation of the problem

The resistance to fatigue crack initiation can be increased with the help of creation of the structural state which prevents (or hinders) the movement of dislocations and their way to the surface. Forming of such a structural state is achieved by surface hardening. One of the common methods of the hardening technology for the products' surface layers is plastic deformation. An important feature of the hardened layers received in this case is the barrier effect of the structural elements in the way of the propagating crack or in the process of its initiation.

Recently, the researchers to explain the reasons of increasing the fatigue failure during surface treatment increasingly involve presentation on the formation of nanostructured layers on the surface of the products, for example [4–6].

Let us dwell on some of the most interesting studies.

The work [5] presents the studies of structural changes after ultrasonic impact treatment (UIT) in the weld zone of St3 steel and their impact on the improvement of fatigue resistance. The structure of the surface layer obtained in the result of UIT is characterized by high density of defects of crystal structure (including dislocations) and misorientation between the elements of the structure typical for high angle boundaries. It is also noted that the nanocrystalline structure formed in this case is very heterogeneous – it is closer to submicrocrystalline structure with a large spread in the size of structural components. The thickness of the strained layer is about 25–30 microns. Dispersion of the structure and size of disorientation of its elements decrease with the distance from the treated surface, and the dislocation density decreases down to original. Furthermore, the residual compressive stress is formed in this layer, while the stresses in the weld material without UIT are tensile.

St3 samples fatigue tests carried out in the initial state after welding, as well as after UIT showed that a significant increase of fatigue strength and durability happened to the samples on which the UIT had been performed. The increase of the fatigue strength limit was about 50 % and durability increased by an order of magnitude.

The authors [5] explain the increase of the material fatigue characteristics by several factors: the formation of a subgrain structure (nanostructure) in the thin surface layer; the increase of density of various defects in the crystal structure; the creation of the compressive macrostresses in the surface layer.

All this together makes the nucleation of fatigue cracks in the hardened layer difficult and allows effectively thwarting the progress of already formed cracks and their output to the surface.

The work [7] presents a generalization of modern ideas about the origin and the relaxation of local internal stresses as a result of structural heterogeneity in metals. The author links the issue of increasing the fatigue strength with grinding a structure after the ultrasonic impact treatment. According to the author, the observed structural inhomogeneities break the macroscopic force field in the sample on local stresses. Increasing the number of such irregularities and reducing their size should lead to the decreased average stress. As a result of the ultrasonic impact treatment, the majority of stress concentrators when grinding the structure are healed with the simultaneous appearance of a great number of new less dangerous local stresses, the spread between which is being reduced.

In addition, the formation of nanograins leads to a change in the deformation mechanism in which the slip of dislocations and the accumulation of point defects do not play a decisive role in the accumulation of fatigue damage. The grain boundary sliding appropriate for nanostructures can lead to difficulty of microcracks initiation. However, it should be taken into account that crack propagation in nanostructured materials is faster [8–10]. Here a small thickness of the layer deformed as a result of ultrasonic impact treatment should play a positive role.

The studies presented in the works [6, 11] deserved attention. They are dedicated to establishing the ties between the character of the structure formed in the surface layer of the material at different methods of treatment and changes of its bulk properties.

The results of the tests indicate that the increase of the material's mechanical properties takes place in the samples of 18HGT steel heat-treated in different modes after additional ion bombardment of the surface: stress limit $\sigma_в$ increased by 17 %, yield limit $\sigma_{0.2}$ – by 34 % without the decrease in toughness. At this, the variation of property values significantly decreases.

The analysis of the influence of various parameters on the steel bulk strength after ion-surface treatment indicates that each of them (increase of the surface hardness, increase of the macro and microstrain and dislocation density, decrease of the size of the coherent scattering regions (CSR) contributes to the overall strengthening. However, none of them plays a critical role, since the level of their change in no way correlates with the strength values after ion bombardment.

The main factor responsible for this change in the properties, according to the authors, is healing the defects in the surface layer during the ion bombardment process and the formation of the nanocrystalline layer on the surface of the material.

This result is similar to the known Ioffe effect for rock salt [12], discovered when tensioning the samples of the rock salt in the air and in the water. When tensioning in the air, the samples were destroyed in a fragile manner while the strength limit was 5 MPa. If tensioning was carried out in the water medium, the samples were destroyed with shoulder effect (that is, plastically): contraction ratio was about 99 % and the strength limit increased up to 1500 MPa (the theoretical strength limit of the salt is about 2000 MPa). The author explained this effect by healing of minor surface defects of the sample due to dissolving salt in water. Thus, despite the fact that the surface layer dissolved during the tests was very thin, the strength of the entire sample approached the theoretical value with simultaneous increase in ductility (almost 100 %).

A similar effect was obtained when tensioning metal samples in the electrolyte and was called the Ioffe effect for metals [13]. The author managed to deform tungsten by 80–90 % in an alkaline medium, at this, the strength increased by 30 %.

In experiments [12, 13], tensioning of the samples occurred in the medium removing not only the effects existing on the surface of the sample before the start of the test, but the new ones being formed in the process of tensioning (accumulation of dislocations next to the boundaries of the grains, subgrains, the surfaces of the phase divisions, nonmetal impurities, and so on).

Since the experiments on tensioning the samples exposed to ion bombardments were carried out in the air (that is, with the absence of the medium which allows removing the surface layer damaged in the process of deformation), the authors [11] come to the conclusion that just healing the surface defects is not enough for visible increase of strength when keeping ductility. Besides, the formation of the nanocrystalline layer [6] on the surface as a result of the ion bombardment plays an important role.

It is known that the mechanism of plastic deformation changes in nanocrystalline materials. High concentration of vacancies on the boundaries of grains and subgrains ensures the grain boundaries slip of the structural elements relative to each other when tensioning the samples (as this happens at creeping or superplasticity), that is the mechanism of non-dislocation plasticity is being implemented [4, 14, 15]. That is the nanostructural layer which determines the behavior of the massive metal sample when tensioning. For the internal layers of metal, the normal dislocation mechanism is implemented, but dislocations going on the surface in the process of deformation due to high mobility of the point effects will not be accumulated in separate places and thus create stress concentrators. Eventually, significant increase in strength without loss of ductility occurs. The authors come to the conclusion that the role of the surface nanocrystalline layer is just functional, and the change of mechanical properties is related to the special behavior of this layer at deformation, and not to its slight strengthening.

In work [16], the studies have been conducted on the effect of various methods of surface hardening on the fatigue strength of samples of 18HGT and 20X steel with different heat treatment. Ion bombardment after hardening and tempering of the specified steels resulted in a slight increase in the fatigue limit $\sigma_{-1}$ (by 4–5 %) [17], at the same time greatly increasing static strength without reducing ductility. The positive effect of ion bombardment is manifested mainly in reducing the spread of failure stress values.

Improved durability of welds as a result of improving the properties of the transition layer between the weld metal and the heat-affected zone was obtained after ultrasonic impact treatment in the studies [18–20]. The positive effect is noted for steels of different strength classes with different levels of accumulated fatigue damage [18]. Treatment allows extending the durability of the connections with accumulated fatigue damages under variable loadings by a factor of 9–12 without formation of cracks [19], as well as during loading with constant amplitude [20].

Taking the above into consideration, one can say that there is a real opportunity to use various types of surface treatment to heal defects in products which were in operation and needed to reduce the level of metal degradation in order to prolong their service life.

## 3. The purpose and objectives of the study

The purpose of the research was to explore the possibility of increasing the durability of metal products by healing as a result of surface treatment of discontinuities of material accumulated during fatigue loading.

To achieve this goal, it was necessary to solve the following tasks:

– to conduct fatigue tests of two batches of samples of 40X normalized steel with an intermediate surface plastic deformation of the second batch of samples;

– to determine the coercive force of the second batch of samples after the first stage of fatigue tests and after conducting the surface treatment;

– to determine the level of macrostresses and the characteristics of the substructure of the samples material surface layer after fatigue testing and surface treatment;

– to conduct a comparative analysis of the test results of both batches of samples.

## 4. Materials and methods of research of influence of surface treatment on the change of the fatigue resistance characteristics

### 4. 1. Test material and method of fatigue testing

40X steel, which is used in machine construction for manufacturing the parts to which the high-strength requirements apply, featuring the following chemical composition C (0,36–0,44); Si (0,17–0,37); Mn (0,5–0,8); Cr (0,8–1,10) was chosen for the tests. The cylindrical samples with a working part's diameter of 8 mm and 100 mm of length were made of it (Fig. 1).

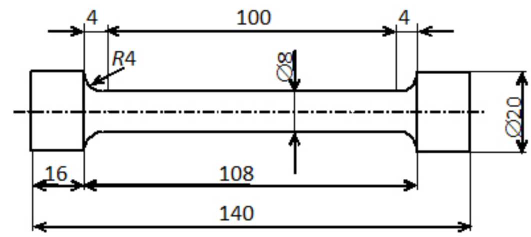


Fig. 1. The sketch of the sample for fatigue testing

The tests were conducted on a universal testing machine of MUP-30 type with an axial tensile load applied at the fatigue cycle of constant signs with an asymmetry factor of 0.3. The tests were carried out at a frequency of 11.4 Hz in the air medium at room temperature. The criterion of the end of tests was the achievement of the predetermined number of cycles ($5 \cdot 10^6$ cycles) or complete destruction of the sample with fixation of the number of cycles of destruction.

As the result of the tests conducted, the value of the test material's fatigue limit was determined and the fatigue curve was built which characterized the relationship between the maximum (peak) value of $\sigma_{max}$ cycle of stress and durability (number of cycles before failure N).

The tests were conducted on two batches of samples. The samples of the first and second batch were tested in one range of stress amplitudes. For the samples of the second batch, the tests were conducted in two stages. After the sample of the second batch at a certain voltage amplitude stayed for a number of cycles (~40 % of the total durability determined by the results of tests of the first batch of samples at a given amplitude), it was unloaded and removed from the testing machine. For each sample, to evaluate the degree of degradation of the material in the accumulation of fatigue damage in it, the measurement of the coercive force with the help of the magnetic Structuroscope (coercimeter) of the KRM-C-K2M model was carried out.

### 4. 2. Methods of samples' surface treatment

After Stage I of fatigue tests and measurements of the coercive force, the second batch of samples were subjected to surface plastic deformation (mechanical hardening). The deformation of the surface layer of the working part of the sample was carried out by means of the striker-ball of 5.5 mm diameter of ShH15 steel. The striker-ball was placed in a cylindrical mandrel, which was clamped in the tool holder with an electromechanical drive. The striker-ball's impact frequency was about 300 Hz, and the traverse was about 8 mm/min. Processing was carried out in 2 passes. To give the rotational motion to the treated sample and forward movement of the loading tool, the lathe-screw machine of S1E61VM model was used. The spindle speed – 56 rev/min, traverse slide – 0.144 mm/rev. The processing parameters were selected in such a way as to ensure the overlap of holes from the subsequent strokes of the striker-ball and uniform treatment of the entire working surface of the sample.

Following the conducted surface treatment on the second batch of samples, the coercive force was measured again, after which tests were continued at the stress level appropriate for each sample.

### 4. 3. Methods of X-ray diffraction studies

To study the changes in the fine structure of the surface layer (CSR size L and microstrain value ε) and the level of σ macrostresses, X-ray studies of the samples material after cyclic loading and subsequent surface treatment were carried out. Diffraction patterns were recorded on a DRON-3 diffractometer in chrome anode radiation. Diffraction extension analysis was performed on the lines (110) and (211) of $K_{\alpha}$-radiation. The Rechinger's method was used for extracting $K_{\alpha 1}$-component. The diffractometer's mode of operation and the slit width were chosen based on the condition of obtaining sufficient intensity of the lines with a small tool width.

Macrostresses were determined by the method of inclined shooting ($\sin^2\psi$-method), the essence of which is to determine the elastic deformation of the crystal lattice and subsequent conversion of it into stress. In conversion, the following values were used: Poisson's ratio ν=0.3, modulus of elasticity, E=210 GPa. To construct the sin2ψ-graph the diffraction line (211) was recorded at the angles ψ 0; +30; +50°, as well as φ=0° and 90°.

## 5. The results of fatigue tests and the effect of surface treatment on the change of the fatigue resistance characteristics of 40X normalized steel

The samples test results in the initial state (the first batch) are shown in Table 1, and of the second batch – in Table 2.

Table 1

The 40X steel samples' test parameters in initial state

| Load, kg/f | | $\sigma_{max}$, MPa | Number of cycles |
|---|---|---|---|
| $P_{max}$ | $P_{min}$ | | |
| 3000 | 1000 | 600 | 7500 |
| 2800 | 850 | 560 | 26000 |
| 2650 | 800 | 530 | 270000 |
| 2500 | 750 | 500 | 650000 |
| 2300 | 700 | 460 | 700000 |
| 2200 | 660 | 440 | 1500000 |
| 2100 | 640 | 420 | 5000000 |

Let us review the results of two-stage tests of the second batch samples. After the samples stayed for the number of cycles corresponding to the exhaustion of approximately 40 % of life duration, they were unloaded and taken away from the test machine. At this stage of the study, the measurement of coercive force was carried out.

After measuring the coercive force, the second batch samples which have passed the I stage of loading (and accumulated some part of fatigue damages) have been subjected to surface plastic deformation according to the method described. Then, the coercive force was measured again on the samples.

Table 2

Test parameters of the second batch of samples of 40X steel

| Load, kg/f | | $\sigma_{max}$, MPa | Number of cycles on the I stage | Total number of cycles |
|---|---|---|---|---|
| $P_{max}$ | $P_{min}$ | | | |
| 2900 | 920 | 580 | 8500 | 700000 |
| 2650 | 800 | 530 | 150000 | 1100000 |
| 2500 | 750 | 500 | 260000 | 2900000 |
| 2300 | 700 | 460 | 290000 | 5000000 |
| 2320 | 660 | 440 | 620000 | 5100000 |

It was found that as the result of the surface treatment of the second batch samples, the decrease of values of the coercive force took place in comparison with its values in the same samples after the I loading phase, from 1.2 to 2.6 A/cm, which ranged from 9 to 17 % respectively (Fig. 2).

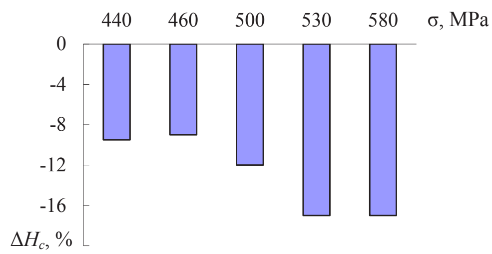


Fig. 2. Reducing the coercive force $H_c$ of the second batch of samples at different amplitudes of loading σ

Fig. 2 shows that there was a tendency to a much more significant reduction of the coercive force after the surface treatment on the samples tested at a higher amplitude ($\sigma_{max}$>500 MPa).

On the next stage of testing, the samples of the second batch were again subjected to cyclic loading with corresponding amplitudes up to the achievement of the accepted criterion of test ending.

When testing was completed, for both batches of samples the fatigue curves presented in Fig. 3 were built.

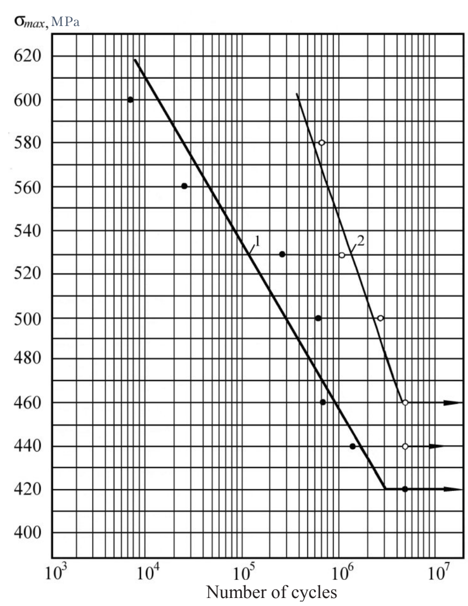


Fig. 3. The relationship between the stress amplitude of the cycle $\sigma_{max}$ and the number of cycles up to damage for 40X normalized steel: 1 – in initial state; 2 – with intermediate surface treatment

As can be seen in Fig. 3, for the second batch of samples, the inclined portion of fatigue curve shifts to the right that is to the area of higher durability. Thus, as a result of surface treatment, the durability of steel at an amplitude of 440 MPa increases from $1{,}5\cdot10^6$ to $5\cdot10^6$ cycles (in 3.3 times), at 460 MPa and $9{,}5\cdot10^5$ to $5\cdot10^6$ cycles (in 5.3 times). At amplitudes 530 MPa and above, the durability values differ by an order of magnitude. That is the surface treatment significantly increases the durability of the second batch of samples throughout the range of the investigated loading amplitudes.

At this, it is also observed that the endurance limit of the second batch of samples on the basis of $5\cdot10^6$ cycles increased from 420 to 460 MPa, which accounted for ~10 %. The increase of the limit of endurance on samples that have passed the preliminary operating time with subsequent surface treatment is also of practical importance. This fact indicates that, in the operation of various objects, it is possible to increase their service life by modifying the surface layer.

Study of the changes of the fine structure of the surface layer and macrostresses was conducted using X-ray studies of sample material after cyclic loading with different numbers of cycles, and after cyclic loading and subsequent surface treatment. Table 3 presents the results for the samples tested at $\sigma_a$=530 MPa.

The data of Table 3 show that, along with the increase of the number of cycles (from $1.5\cdot10^5$ to $3.5\cdot10^5$), the increase of the compressing macrostresses takes place in the surface layer from 8 to 13 MPa (by ~63 %). At the same time, such parameters of the fine structure as CSR and microdeformations do not change.

As for the samples subjected to surface treatment, the level of compressive macrostresses in them rises up to 50 MPa, i. e. more than 6 times higher than in the samples with the same number of cycles but without treatment. It also shows that the conducted surface treatment leads to a change in the fine structure parameters – CSR size is reduced by 3.4 times (with the approximation of the diffraction profiles by the Cauchy function, by 2.4 times with the approximation by Gaussian), indicating the formation of the fine-grained structure in the surface layer. In addition, there is an increase in the level of microstrain by 1.4–1.75 times, respectively, which also indicates the formation of ~~a~~ the developed substructure.

Table 3

The results of X-ray analysis of the structure of 40X normalized steel after cyclic tests and surface treatment

| Number of cycles | (hkl) | Experimental width of the diffraction line *B*, mrad | Physical width of the diffraction line β, mrad | $\beta_{211}/\beta_{110}$ | Size *L* CSR, Å | | $\varepsilon\cdot10^3$ | | σ, MPa |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cauchy | Gaussian | Cauchy | Gaussian | |
| $1{,}5\cdot10^5$ | (110) | 5,9 | 2,8 | 6,1 | 3300 | 1580 | 0,7 | 0,8 | –8 |
| | (211) | 23,0 | 17,0 | | | | | | |
| $3{,}5\cdot10^5$ | (110) | 5,9 | 2,8 | 6,1 | 3300 | 1580 | 0,8 | 0,8 | –13 |
| | (211) | 23,0 | 17,0 | | | | | | |
| $1{,}5\cdot10^5$ + +surface treatment | (110) | 7,0 | 5,6 | 5,5 | 980 | 670 | 1,0 | 1,4 | –50 |
| | (211) | 36,3 | 30,8 | | | | | | |

## 6. Discussing the results of the influence of surface treatment on the change of the fatigue resistance characteristics

Modern materials science ideas about the problem of increasing the strength allow identifying several factors affecting the change in the properties of the surface layer of the product:

– change of the fine structure of the material (CSR reduction, increase of the dislocation density, the microstrain growth);

– the occurrence of residual compression microstrain;

– healing of surface defects.

Let us analyze the results obtained in the experiment.

First of all, let us explain the choice of the number of cycles on the I stage of testing the samples of the second batch, namely, 40 % of the total durability. This choice was made based on the classification of stages (periods) of fatigue proposed in [3]. When working approximately for 40 % of the service life, the material is mostly in the second stage of fatigue, the duration of which is 20 to 50 % of the total number of cycles before the failure. At this stage, loosening of the material associated with the nucleation and development of submicrocracks takes place (that is, fractures, which can still be healed by various types of treatment).

As for the increase of durability when testing the samples of the second batch in the described experiment, it can be assumed as follows. In the process of the conducted surface treatment, the deformation of the surface layer of the material takes place. At the same time, the developing high strain at the center of the striker-ball strikes possess the hydrostatic component that can contribute to the healing of the submicro-irregularities by creating the conditions required for the implementation of chemical adhesion process [21, 22]. Reducing the coercivity $H_c$ values as a result of surface treatment of samples of the second batch after working a certain number of cycles (Fig. 2) serves as a confirmation of the validity of this claim, as this parameter allows judging the degree of degradation of the material structure as a result of the elastic-plastic deformation during the fatigue process [22, 23].

Some authors in explaining the mechanism of healing consider the diffusion and not the chemical adhesion as the decisive processes [24]. It is important to note that the chemical adhesion does not assume the participation in the process of setting of two bodies of diffusion, though under certain conditions after chemical adhesion there can be diffusion which increases the strength of the “adhesive bond”. In plastic deformation of the surface layer of the material as a result of annihilation of dislocations and healing of the submicro-discontinuities there is the increase of the number of vacancies in the adjacent metal volumes which can ensure the acceleration of self-diffusion, facilitation of dislocations climb and the formation of new boundaries and dispersion of structure.

The formation of the samples of the dispersion substructure in the surface layer as the result of surface treatment is demonstrated by the results of X-ray analysis (CSR size reduction and increase of the level of microdeformations). Substantial compressive stresses observed in the samples after the surface treatment, should promote healing of submicro-discontinuities, which in its turn leads to a decrease in coercive force after the surface plastic deformation. Also, at this, the likelihood of fatigue crack nucleation reduces dramatically, and the development of already existing cracks and their appearance on the surface slows down.

There is evidence that at this kind of treatment the formed structure in the surface layer of the material consists of dispersion subgrains with high angle boundaries [5] and high density of defects in the crystal structure.

The recent studies indicate that an increase in fatigue strength is generally determined not only by the level of residual stress of compression, but the material's structure as well: structure refinement to the nanosizes leads to a considerable increase in the fatigue limit [5, 17]. Getting this kind of structures is possible as a result of severe plastic deformation, including the material surface treatment by the striker-ball tools described in this paper.

Thus, increasing the durability of samples subjected to the surface strike treatment in the experiments described; can be explained by the combined effect of several factors:

– healing in the process of conducted treatment of the surface defects of the material's structure accumulated as the result of the fatigue damage;

– dispersing of the surface layer structure, leading to a change in the mechanism of fatigue damage accumulation. In this case, the motion of dislocations in conjunction with the appearance of high density of point defects is severely restricted because of the small size of the elements of structure. Therefore, the plastic deformation occurs by the non-dislocation mechanism with grain boundary sliding of the structural elements (grains, sub-grains), which reduces the likelihood of stress concentrators nucleation.

Such kind of treatment can also be used for new (yet unexploited) products for the healing of surface defects resulting from their manufacturing. In the future, it is planned to conduct the study of the influence of the surface treatment on the durability of the materials which were not subjected to prior fatigue loading.

## 7. Conclusions

1. Cyclic tests of two batches of samples of 40X normalized steel were conducted, which for the second batch were conducted in two stages. The duration of stage I of the tests for the second batch of samples was determined as the result of the test of the first batch of samples – it was about 40 % of their overall durability.

2. The influence of surface plastic deformation using the striker-ball tool with the electromechanical drive was studied for the durability of the samples of 40X normalized steel. It is found that the surface treatment of the samples which have passed the preliminary operating time; increases their longevity on average by 3–5 times, when increasing the load amplitude up to 530 MPa or more, the durability values differ by an order. At this, the strength limit increased by ~10 %.

3. Surface treatment of the samples leads to a decrease in coercive force values by 9–17 % (depending on the magnitude of the load amplitude), which indicates the decrease of the material degradation degree as the result of healing of the accumulated fatigue defects.

4. A study of the value of macrostresses and the fine structure parameters of the samples material after cyclic loading and surface treatment was conducted. It was found that the surface treatment leads to a significant increase in the level of compressive macrostresses (more than 6 times). The observed reduction in the size of coherent scattering and increase in the level of microstrain indicate the formation of the dispersed substructure in the surface layer.

5. The increase of durability of samples subjected to the surface shock treatment is explained by healing of the submicro-discontinuities accumulated at cyclic loading and the formation of the dispersion structure of the surface layer. In this layer, a transition to the nondislocation mechanism of plastic deformation with grain boundary sliding takes place, making it difficult to accumulate the fatigue defects.

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