The investigation of the deformation wave hardening effect on the strength of the medium and low alloy steels

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Abstract. The article presents the data on the effect of wave deformation hardening on the strength of the 45, 40X and 35 HGSA steel. To improve the strength of these steels, it is proposed to create structured areas consisting of alternating solid and viscous-plastic sections in their surface layer. The evenness of arrangement of the sections is characterized by the overlap factor. The studies found that wave deformation treatment of the samples, made of the 45, 40X 35HGSA steel, made it possible to increase the tensile strength by 8, 4.2 and 13%, the values of elastic deformations – by 37, 81 and 51% during their hardening with overlapping coefficients 0.7; 0.9 and 0.7, respectively.

1. Introduction

The surface destruction due to the strength loss is critical for a large number of products in different fields. The increase of the metal strength while maintaining sufficient ductility and viscosity increases the reliability and durability of machines (structures) and reduces the consumption of the metal used for their fabrication due to the reduced cross section of machine parts that has important economic value.

Strength can be enhanced both by applying different hardening technologies and by creation of composite materials [1-10]. The use of composite materials combining properties of the relatively soft matrix and durable high modulus (up to 4900 MPa and more) fibers, giving small deformation under loads, allows increasing the specific strength of the material by 20-40\% [2].

One of the most promising directions of modern hardening technologies development is the formation of the heterogeneous structure of the modified surface layer of solids, but not the gradient material that, on one hand, has no clearly defined areas boundaries with changed properties, and on the other hand, is similar in the properties to the composite material with the soft matrix and hard inclusions.

The heterogeneous structure generated in a homogeneous material is mainly applied to enhance wear resistance and durability under contact cyclic loading. The examples of heterogeneous structures are shown in Figure 1. To obtain the heterogeneous structure, the well-known methods of hardening were used such as heat treatment and chemical-heat treatment, and, more recently, with the advent of the wave strain hardening, the surface plastic deformation has been widely used [1, 2].
Increasing the surface strength by plastic deformation is more advantageous compared to other hardening methods, as it has a number of advantages. First, with its small energy-output ratio, it is possible to provide a greater hardening depth with smooth transition from a hardened surface to a non-hardened one, that is especially important for materials working in conditions of static load. Second, there is the possibility of parts machining of any sizes and configurations. Third, due to its manufacturability and ease of implementation, it is easy to achieve the mechanization and automation of the process. Fourth, there is the possibility of local hardening of details parts.

The creation of the heterogeneous structure by surface plastic deformation (SPD) in a homogenous material to improve the strength was not used. One of the reasons for this is the high energy consumption and low precision of creation of the hardened surface layer of large thickness with SPD methods, the lack of research of uniformity of the hardened cold-worked layer and its influence on the strength properties of parts of different steels.

The goal of the prospective research is to establish the deformation wave hardening effect on the strength of medium and low alloy steels.

2. Materials and methods
To solve this problem, it is proposed to use the wave deformational hardening that is a modern method of surface plastic deformation. It has wide technological possibilities for the formation of the hardened surface layer and allows one to create the layer with a greater depth (up to 6...10 mm) and a high hardening degree (up to 6500 MPa) [1]. The peculiarity of the method consists in deformational waves generation by the shock system with an intermediate member and their transfer to the deformation zone to strengthen responsible surfaces of machines details. The method effectiveness is achieved by the full use of the wave deformation energy during hardening. Depending on required hardening parameters of the surface layer, elements of the shock system are selected that generated the crash pulse of the required amplitude and duration. As a result of the deformation wave parameters control, there is an opportunity to form not only a uniformly hardened surface layer, but also areas that are heterogeneously reinforced. The uniformity of plastic overlapping of imprints is evaluated using coverage factor K. The range of the K change is from 0 to 1: when K = 0, prints do not overlap, print edges are contiguous with each other; when K = 1, there is a complete overlap of prints, strikes are in the same place. Figure 1 shows that as a result of microhardness measurements, it is found that in processing modes when 0 ≤ K ≤ 0.5, a pronounced heterogeneous structure of the hardened surface layer is formed, that is characterized by alternating of hard and soft areas. The examples of these areas are presented in Figure 1. In processing modes when 0.5 < K < 0.8, the upper surface layer is hardened enough evenly, and unevenly reinforced areas are displaced in the subsurface layer. In modes when
0.8 ≤ K < 1, the almost completely uniformly hardened surface layer is formed, and microcracks appear on the surface as a result of over cold hammering [1, 2].

To research the deformation wave hardening effect on the strength, flat samples Ck45, 41Cr4 and 35HGSA with a thickness of 7mm were used. The choice of samples material is based on the fact that steels 41Cr4 and 35HGSA are quite often used for the manufacture of machine parts working in severe conditions, and increased requirements for strength are imposed on them. Steel Ck45 is a reference in engineering. When hardening, the heterogeneous structure with uniformity of 0.2 < K < 0.9 was created. The rod roller with a width and diameter of 10 mm was used as a tool. The energy of strikes was 25 joules. The studied samples were hardened with the deformation wave only on one surface.

In addition, the investigation of the influence of the directions of tool strikes' prints on the processed material obtained for the same modes of wave deformation hardening was conducted. To do this, due to rotation of the hardening tool (rod roller) at a specified angle in the direction of its feeding, which coincides with the direction of the gap, the rod roller strikes' prints of different directions are applied to the processed surface. The examples of the rod roller strikes' prints of different directions are shown in Figure 2.

Strength characteristics of investigated samples were determined on a universal electromechanical machine with computer control WDW100E series.

![Stress-Strain Curve](image.png)

**Figure 2.** The diagram of stretching of Ck45 steel samples, hardened with overlap K=0.4, for different types of application of impact prints of the tool for hardening relative to the direction of its feed.

**3. The investigation of the deformation wave hardening effect on the strength of the medium and low alloy steels**

As a result of strength tests, it was found that due to the location of prints on type 1 and 2 shown in Figure 2 on the samples surface with the same strengthening modes, it was possible to increase the tensile strength by 4-5%. The prints of type 1, in comparison to 2, tend to be located in the surface layer, with relatively equal values of tensile strength, of more pronounced elastic properties. Therefore, only this type was used for hardening of all samples.
As we can see from Figure 3, as a result of Ck45 steel wave deformation hardening, the greatest increase in strength was 8% attained at $K=0.7$, while elastic deformations were increased by 43%, while the ductility was decreased by 37% compared to non-hardened samples. In addition, it was found that during hardening of steel Ck45 with the increase of the overlap ratio from 0.1 to 0.7, the tensile strength increases from 2.6% to 8%, the ductility decreases from 22 to 37%, and elastic deformations increase from 8.6% to 43%.

As it can be seen from Figure 4a, in case of 41Cr4 steel hardening, the greatest increase in strength was 13% attained at $K=0.9$, while elastic deformations were increased by 81%, while the ductility was decreased by 38% compared to non-hardened samples. When hardening steel 41Cr4 with the increase of the overlap ratio from 0.1 to 0.9, the tensile strength increases from 3.5% to 13%, the ductility decreases from 23 to 38%, and elastic deformations increase from 39% to 81%.
As it can be seen from Figure 4,b, the hardening by the deformation wave of 35HGSA steel allowed to achieve the greatest increase in strength only by 4.2% attained when $K=0.7$, while elastic deformations increased by 51%, while the ductility decreased by 28% compared to non-hardened samples. During hardening of steel 35HGSA with the increase of the overlap ratio from 0.1 to 0.7, the tensile strength increases from 0.4% to 4.2%, the ductility decreases from 1 to 28%, and elastic deformations increase from 39% to 51%. The sample with $K=0.9$ demonstrates a decrease in the tensile strength and ductility due to supercooled hammering in comparison with the sample with $K=0.7$.

4. Conclusion
1. It was found that the prints of the strikes of the tool which is perpendicular to the direction of feed, formed in the surface layer, can improve the tensile strength of the material by 5%, compared with the prints of directions obtained in the same modes of hardening by deformational waves.

2. It was found that through the application of wave deformation hardening of samples with a thickness of 7 mm and made of the 45, 40X, 35HGSA steel, it is possible to increase the tensile strength by 8, 13 and 4.2%, respectively, and the values of elastic deformations — by 37, 81 and 51%.

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