Structural heredity influence upon principles of strain wave hardening

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Abstract. It was established experimentally that by penetration of a strain wave through material hardened not only the technological modes of processing, but also a technological heredity - the direction of the fibers of the original macrostructure have an influence upon the diagram of microhardness. By penetration of the strain wave along fibers, the degree of hardening the material is less, however, a product is hardened throughout its entire section mainly along fibers. In the direction of the strain waves across fibers of the original structure of material, the degree of material hardening is much higher, the depth of the hardened layer with the degree of hardening not less than 50\% makes at least 3 mm. It was found that under certain conditions the strain wave can completely change the original structure of the material. Thus, a heterogeneously hardened structure characterized by the interchange of harder and more viscous areas is formed, which is beneficial for assurance of high operational properties of material.

1. Introduction
To improve performance properties, various methods of hardening are widely used in machinery [1-10]. The strain wave hardening is a relatively new method of surface plastic deformation. The peculiarity of the method is to generate the strain wave by a strike system, with an intermediate link and to post them into the deformation zone aiming at strengthening critical surfaces of machine parts. Efficiency of the process is provided by the full use of strain wave energy while hardening. This is achieved at the expense of a preliminary static approach of the system ‘tool-waveguide’ to the work surface and the subsequent dynamic loading of a hammer head. Static contraction provides regeneration of reflected strain waves. Deformation of the environment can occur at a depth of 6-8 mm, the degree of hardening can reach up to 150\%. Depending on the desired parameters of hardening of the surface layer, selected elements of the strike system are selected which generate an impact impulse of the required amplitude and duration. By means of control of the strain wave parameters, it is possible not only to form a hardened surface layer uniformly, but also to get heterogeneously hardened areas [1, 2].

As a result of hardening of steel samples by the strain wave, it was determined that various diagrams of microhardness can be formed (Figure 3g) under the same processing conditions. The aim of this work is to identify the causes and effects of this phenomenon in relation to the original structural technological heredity.
2. Effect of structural heredity on the conformity of strain wave hardening

For research carrying out some samples were cut out of round rolled metal (steel 45) of a rectangular cylindrical shape and with the thickness of 10 to 20 mm (Figure 1 a, b). The use of round bars is due to a known fiber direction of the original heritable structure (Figure 2, a). One part of samples cut out of round rolled metal was hardened so that the strain waves passed across the fibers of the initial heritable structure during processing and another part of the samples – by the passage of the strain waves along the fibers. All test samples were reinforced by the same strain wave with the same modes: strikes energy was 25 J; impact frequency was 23.3 Hz; prints overlap coefficient was $K = 0.4$; the tool was a cylinder of 7 mm width and 10 mm in diameter.

Hardening efficiency of material by the strain wave was evaluated by a change of microhardness diagrams of the surface layer. Research samples were cut on a reinforced track symmetry axis in the feeding direction (Figure 1).

On the obtained polished specimen, in the transverse and longitudinal directions with a pitch of 0.3 mm, micro-hardness with a diamond pyramid by the method of Vickers hardness test was measured (Figure 1 b). Based on measuring results of microhardness in the Statistica program, the diagrams were formed according to its distribution in the surface layer.

![Figure 1. Diagrams of studied samples.](image)

Microhardness diagrams of round bars of the original structure are presented in Figure 2. In the diagram (Figure 2a), we can see typical rolled fibers having a higher hardness as compared with basic metal. In figure 2b, we see the microhardness diagram of the sample with transverse arrangement of the original fiber structure, in Figure 2c, the structure is presented with longitudinal arrangement of fibers.

![Figure 2. a) the macrostructure of the metal after processing by pressure; b) distribution diagrams of microhardness in unhardened samples of cylindrical and rectangular forms.](image)
Microhardness diagrams in the samples hardened by a strain wave lengthwise and crosswise of the initial fibrous structure, are presented in Figure 3. The analysis of obtained diagrams has shown that in case of hardening of samples with a longitudinal arrangement of the hereditary fibrous structure (Figure 3, c-f), the strain wave owing to anisotropy of properties of the initial metal extends both on fibers and on the set of rods covering the whole sample. The material is more strongly hardened along fibers, however, the hardening degree is rather insignificant. Only in the surface layer for the depth of 2.5 mm, we can observe the fragmentary degree of hardening for more than 40%. Among fibers and where the fibrous structure is expressed more poorly, the degree of hardening is less - no more than 20%.

Figure 3. The microhardness diagram after hardening of the material by a strain wave.
Figure 4. Obtaining of the strain wave of local alternations of firmly viscous areas in the surface layer.

In case of strain wave propagation across fibers (Figure 3, a, b), the degree of material hardening of the surface layer is much higher, and the depth of an essentially hardened layer is greater. Practically the whole surface layer at the depth of 3 mm has a degree of hardening of 50 % and more. Most often a sample gets a multilayered gradiently hardened structure without strongly manifested fibers. The least hardened zone is formed, as a rule, in the centre of the sample. However, under certain conditions and processing modes, strain wave hardening is capable of changing the inherited structure - of breaking fibers and generating the spotty heterogeneously hardened structure with alternating harder and more viscous areas (Figure 4). In this case, a more intensive increase in operational properties of a material is observed too.

It is necessary to notice that in all cases, the surface layer of a material both with contact and from the opposite side of the sample is hardened at the expense of the reflected strain waves.

3. Conclusions
1. It is established that technological heredity has a strong impact on efficiency of strain wave hardening - the fibers are generated at the stage of metal rolling.
2. It is established that for obtaining of great values of depth and degree of hardening of the surface layer the strain wave should be directed across fibers of initial structure.
3. It is established that for hardening of the whole sample, the strain wave should be directed along fibers of the initial structure.
4. It is established that under certain conditions the strain wave can completely change the initial fibrous structure (Figure 4) and provide alternation of much harder and more viscous local areas at considerable depth of the surface layer or on all section of the sample. The given type of the hardened structure has shown itself in the increase of operational properties of machines parts [2-9].

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