Structural changes in steel during hardening by deformation wave

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Abstract. The article presents results of study possibility of hardening of high-manganese steel X120Mn12 by a deformation wave in the process of wave strain hardening (WSH). Features of the method is possibility of using shock waves for plastic deformation, which significantly expands the technological capabilities for formation of a hardened surface layer. The dominant design and technological parameters of the hardening treatment are established, which have the main influence on the microstructure and hardness of the hardened surface layer. Possibility of a significant increase in hardness and depth of hardened surface layer is established. The depth of hardened layer can reach 6-8 mm, and the hardness can be increased by more than three times. Microstructural analysis showed no cracks. The obtained results of conducted research can be used to develop a technology for strengthening the deformation wave of various heavy-loaded parts made of high-manganese steel.

1 Introduction

High-manganese steel has a single-phase structure consisting of austenite, and is not hardened by heat treatment. In the initial state, high-manganese steel has a low hardness of HV 1800 MPa and a high impact strength of 200-300 J/cm^2, but after hardening, the hardness increases to HV 6500 MPa, which is explained by the formation of a large number of crystal structure defects in the surface layer. The high viscosity of austenite, along with sufficient strength and wear resistance, makes X120Mn12 steel an indispensable material for parts that work on wear and impact at the same time. Steel is used to make the teeth of excavators' scoops, tractor tracks, diamond switch, parts of stone crushers, and others, where friction is accompanied by impacts and high pressures [1].

To strengthen high-manganese steel, it is necessary to use methods of surface plastic deformation (SPD), which provide high pressure in the deformation zone ($\geq 3\sigma_т$, where $\sigma_т$ – is the yield strength of the material) of the tool and the surface to be strengthened, which contributes to the formation of a large depth and degree of hardening of the surface layer [1-5].

Wave strain hardening (WSH) is one of the methods of SPD, which has the widest range of technological capabilities. In comparison with other known methods of SPD, it

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allows to provide a greater depth and a significant degree of hardening of the surface layer [1, 4].

2 Methods

To implement WSH, a pulse generator is used, the main elements of which are striker and waveguide of a certain shape. To strengthen flat surfaces, a tool is used - a cylindrical (rod) roller, which is installed with the possibility of rotation around its axis, at the end of the waveguide. The tool is affected by the deformation force (load), which has dynamic and static components (Figure 1).

In the impact system of the striker-waveguide, flat acoustic waves are generated, and in the contact spot of the tool and the treated surface, the dynamic component of the load is formed - the flow of shock pulses of a certain shape, duration and duty cycle. The shape of the pulse is described by the dependence of the change in the impact force on time. The shape, amplitude and duration of a single pulse have a decisive influence on the fraction of the impact energy of the striker on the waveguide transmitted to the hardened material and spent on its elastic-plastic deformation, and therefore on the efficiency of WSH [1, 5-8].

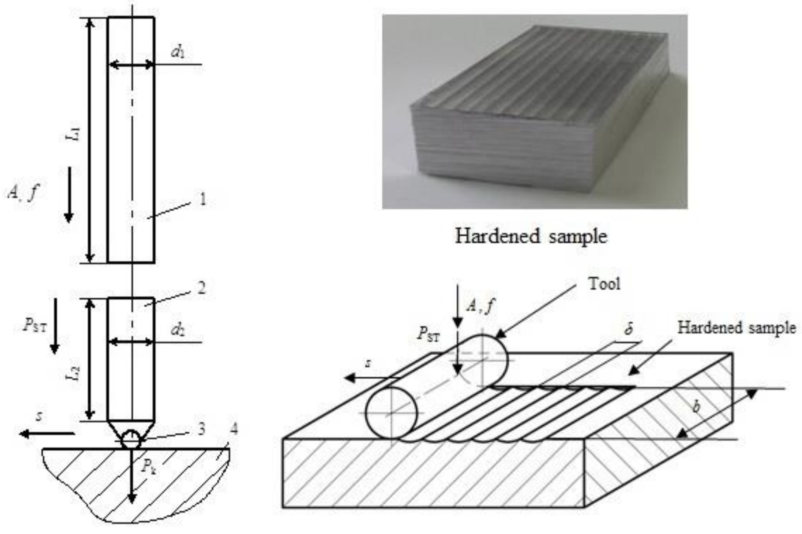

Fig. 1. Scheme of wave strain hardening (WSH): 1 - striker, 2 - waveguide, 3 - tool, 4 - sample, A - impact energy, f - frequency of impacts, P_{ST} - static load, P_c - contact force in the deformation zone, s - feed, b - tool width, L_1, L_2 - length of the striker and the waveguide, d_1, d_2 - diameter of the striker and waveguide cross sections, δ - plastic print size.

The shape of the pulse depends not only on the geometric parameters of the striker and waveguide, the acoustic properties of their materials and the collision rate, but also on the properties of the material being strengthened. To increase the efficiency of the process, to create a deeper hardened layer, the shape of the shock pulses must be adapted as much as possible to the properties of the material and the loading conditions [1].

The static component of the load does not allow the tool to come out of contact with the hardened surface immediately after the direct wave of deformation that occurs at the first stage of the strike of striker on waveguide is applied to it. It is designed for the most complete useful use of the energy of the dynamic component of the load due to the recovery of deformation waves reflected from the boundaries with different acoustic properties.

The hardened layer is the result of applying a set of plastic impressions of the working surface of the tool to the surface to be processed, which are formed under the influence of the dynamic component of the load, as well as the formation of wave states due to the interaction of direct and reflected acoustic deformation waves spreading in the material of the part. The main complex technological parameters of WSH, which determine the characteristics of the hardened surface layer, are [9-10]:

- specific impact energy

$$a = A/b, \tag{1}$$

where A – impact energy of pulse generator, J; b – tool width, mm;

- number of passes;
- tool diameter, mm;
- the overlap coefficient of individual plastic prints

$$K = 1 - \frac{s}{\delta f 60}, \tag{2}$$

where δ – characteristic size of the plastic print, mm, s – feed, mm/min; f – frequency of impacts, Hz.

3 Results and discussion

3.1 Results and discussion of experimental studies of the hardness, impact strength

Experimental studies of the effect of WSH modes on the hardness, impact strength and microstructure of the hardened surface layer of samples made of high-manganese steel (a=3.75-15 J/mm, number of passes – 1; 2; 3; 4, tool diameter D=10-25 mm, K=0.4-0.8). Special sample preparation equipment was used for the preparation of samples: an IPA 40 press, a Compument 250 PLC grinding and polishing machine. The microstructure of the samples was studied using a Leica DVM6A digital automated metallographic microscope, and the hardness and microhardness were evaluated using a Hardwin XL KB 30 S instrument.

As a result, it was found that when processing with a tool (rod roller) with a diameter of 10 mm, with a specific impact energy of 150/20 and 150/40 J/mm and an overlap coefficient of K = 0.4, the lowest depth and hardness are formed. When hardening with an overlap coefficient K = 0.8, a higher depth and hardness is formed, reaching HV 5140 MPa (Figure 2), however, partial re-hardening of the surface and the occurrence of microcracks are possible, which is unacceptable. The best results are obtained when hardening with an overlap coefficient K = 0.6. In this case, a high hardness and depth of hardening is achieved, while maintaining a sufficient resource of plasticity of the hardened surface layer. For a specific impact energy of 3.75 J/mm, the hardness at a depth of 2 mm at an overlap coefficient of K = 0.6 was HV 3500 MPa, and at an overlap coefficient of K = 0.4 was HV 2940 MPa.

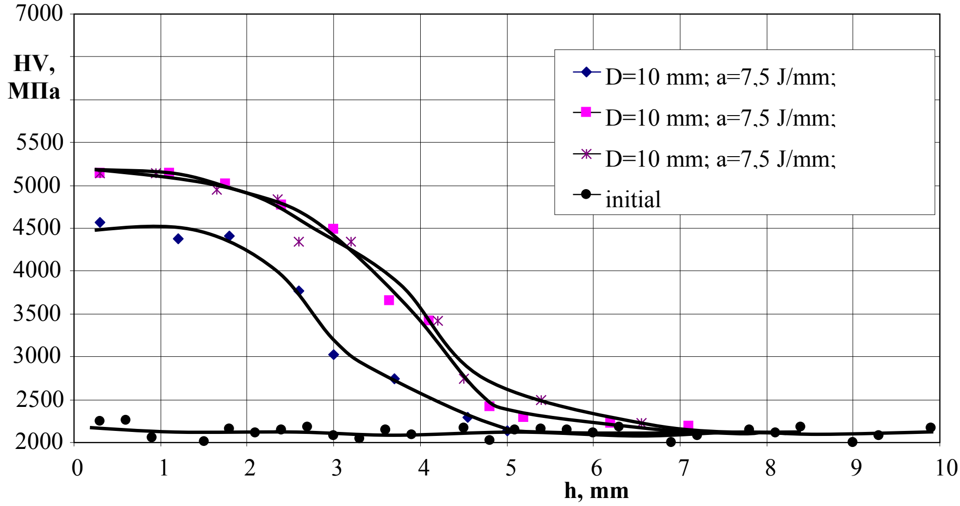

Fig. 2. Change in the hardness in depth (h) of the hardened layer depending on the WSH modes.

It is established that the number of passes increases the depth of the hardened surface layer. Hardening by the last pass with a roller with a diameter of 10 mm, with the available reserve of plasticity of the hardened material, contributes to increasing its hardness on the surface to a greater extent than when hardening with rollers of larger diameter of 20 and 25 mm. With an increase in the depth of hardening, the hardness on the surface of the samples increases significantly to HV 5700-6400 MPa (Figure 3).

The impact strength of the hardened samples decreased to 150-185 J/cm^2.

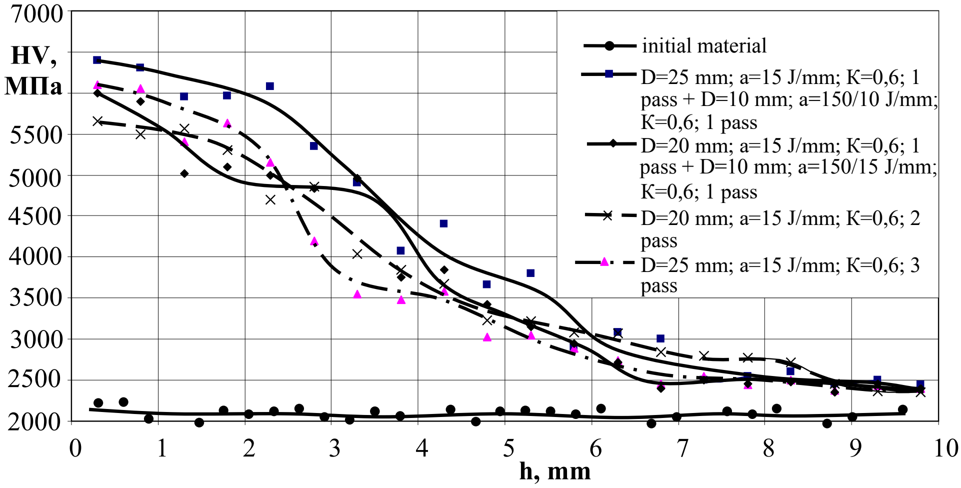

Fig. 1. Change in the hardness in depth (h) of the hardened layer depending on the WSH modes.

3.2 Results and discussion of experimental studies of microstructure

The structure of the initial sample made of X120Mn12 steel is a homogeneous austenite with uniformly distributed particles of the strengthening phase with doubles inside rounded austenite grains with an average grain size of 300-400 microns. The presence of intercrystalline porosity caused by the processes of primary crystallization of the metal is recorded (Figure 4).

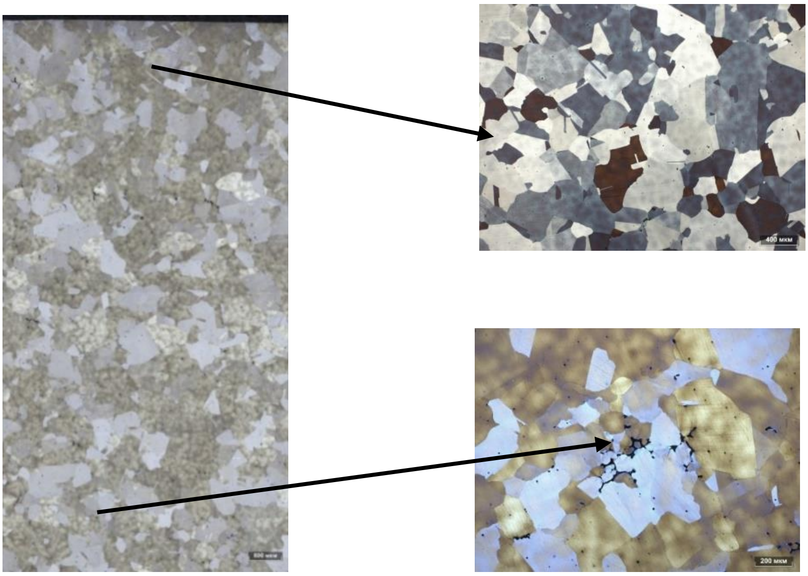

Fig. 2. Microstructure of a initial material made of X120Mn12 steel.

After WSH, deformation hardening occurs, the structure takes the form shown in Figure 5. No cracks were found on the surface and in the depth of the hardened surface layer. The depth of the hardening zone of all the studied samples is approximately at the same level of about 6-8 mm, the surface layers up to 2.5-3 mm are more hardened. Also in all samples, the elongation of the grains in the direction of deformation is observed, and a large number of slip lines appear.

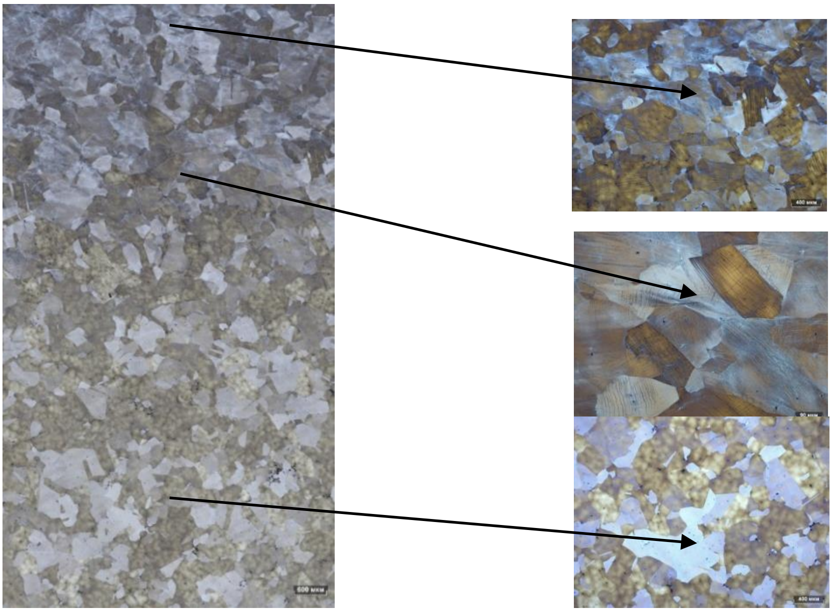

Fig. 3. Microstructure of the sample at different distances from the surface of high-manganese steel after WSH by a rod roller with a diameter of *D*=25 mm in 3 passes.

4 Conclusion

The use of WSH for hardening parts made of high-manganese steel allows to obtain a deep hardened surface layer (up to 6 ... 8 mm) with a maximum hardness reaching HV 6400 MPa, which is more than 3 times the hardness of the initial material.

When studying the hardness, impact strength and microstructure of the metal after WSH, it was found that the most effective modes are those that provide an overlap coefficient of plastic prints of 0.6. It should be taken into account that the distribution of the hardening along the surface will be uneven, the surface layer will alternate between hard and plastic areas, so the resulting structure will be heterogeneous and hardened. To increase the degree and depth of hardening, it is advisable to carry out processing in 2-3 passes. Alternating multi-pass hardening of tools with different diameters (first with a large roller, and then with a small diameter) allows to ensure the maximum degree of hardening and the greatest depth of the hardened layer.

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