Analysis of cavitation on the surface of steel under the ultrasonic cleaning

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Abstract. The article presents: the results of studies on the effects of cavitation on the surface of steel during processing in a liquid medium; the analysis of changes of the microstructure and the microhardness of steel under the effect of cavitation; the features of hardening and destruction of the surface layers of steel with a structure of granular pearlite and the martensitic steel structure. Comparative analysis of the structural transformations of the surface layers of steels 12H17 and U8 allows us to select the optimum time of ultrasonic treatment for a complete cleaning of the surface without destroying it.

1. Introduction
It is known that ultrasonic treatment in a fluid is widely used for cleaning metal surfaces from technological, biological and other types of contamination. Under the influence of ultrasonic cavitation in fluid, the plastic deformation processes are proceeding in the surface layers of the metal [1-4]. The intensity of these processes is determined by the structural features of the processed material [5-8]. Therefore, the efficiency of cleaning by using ultrasonic vibrations is determined by the choice of rational conditions under which the maximum degree of purification with a minimum negative impact of cavitation may be provided on the surface. This article presents a comparative analysis of the structural transformations of the surface layers of steels 12H17 and U8 under the process of ultrasonic treatment in the mode of developed cavitation.

2. Materials and methods
For research of cavitation resistance of steel under the process of ultrasonic treatment, the following steels were used: a 12H17 steel which structure is spheroidized carbides in the chromium alloyed ferritic matrix and a U8 steel with the martensite structure and a residual austenite content of 5-8 %.

After grinding, polishing, pickling by standard methods for carbon and alloy steel and application of the model pollution (preservative oil), the investigated samples were subjected to ultrasonic treatment in distilled water. To eliminate corrosion of the surface, sodium nitrite was added as a passivator. The intensity of the ultrasonic fluctuations of 57 kHz was chosen based on the possibility of obtaining a pre-cavitation mode (0.5 W/cm²), and the developed cavitation mode (1.5 W/cm²).

The microstructure of the surface layers was investigated under the microscope ‘Neophot-21’, the micro-hardness was measured with hardness tester PMT-3M.

The sequence of the operation in accordance with [9, 10] is the following: the intensity of the ultrasound of 0.5 W/cm² is set; a prepared sample is immersed in the ultrasonic bath and is held for 10 minutes; the microhardness of the treated surface is measured, and its microstructure is recorded.
Then, the process is repeated as long as no obvious signs of surface fracture are specified; similarly, the processing of the subsequent samples at 1.5 W/cm² ultrasound intensity is conducted.

3. Discussion of the experimental results
Changing of the microstructure of the surface of steels 12H17 and U8 under the influence of the developed cavitation is shown in figures 1 and 2, respectively. Microstructures in figures 1a and 2a are obtained after the ultrasonic cleaning during the time required to remove a layer of pollution. The microstructures in figures 1b and 2b correspond to the processing time, when signs of stable cavitation effects on the metal surface become visible. The microstructures in figures 1c and 2c illustrate the beginning of the surface fracture.

The results of measuring of microhardness of the treated surface of the sections in the mode of the developed cavitation are shown in table 1, and the change of the microhardness of the frontal section of the samples at maximum hardness on the surface – in table 2.

![Figure 1. 12H17 steel microstructure after: a – 10 min, b – 40 min, c – 120 min of sonication.](image)

The experimental results showed that during the ultrasonic treatment in the pre-cavitation mode, no changes in the microstructure of the surface of both investigated steels were revealed. The level of the micro-hardness of steel U8 also remained constant. The microhardness of steel 12H17 was slightly increased after 140 minutes of sonication. The main process determining destruction of the material in the process of cavitation is the mechanical action of pulsating vapor-gas bubbles in the liquid, during the closing, the surface in contact with the liquid receives the hydrodynamic shocks. The pressure at the impact point can reach 126-250 MPa and the temperature – 230-720 °C.
The developed cavitation mode for both steels is characterized by the following periods:
- an incubation period, including cleaning the surface from contamination and the time during which cavitation has no apparent effect on the surface state;
- a period of strain hardening is accompanied by an increased microhardness and transformation of the surface structure (twinning, grain crush to subgrains, the structural transformations, etc.);
- a period of the softening and destruction of the surface layers of the processed material.

The duration of each period, and the intensity of the processes of hardening and destruction is determined by the structure of the investigated steels.

Thus, in the process of cavitation impact on steel 12H17, the incubation period is 35-40 min. Then, a period of plastic deformation of ferrite starts, accompanied by the display of a relief on the surface, broadening the interface between the ferrite matrix and carbides, the display of the boundaries of ferritic grains, and the micro-hardness increased by 25% compared with the original one. Microhardness in the frontal section of the samples at a maximum degree of the surface hardening, decreases exponentially, reaching the original value at about 75 μm.

The hardening effect of the ferrite matrix is caused by formation of the subgrain structure, increasing of the dislocation solidity and complexity of the dislocation structure under the influence of the cavitating liquid bubbles.
Table 1. Changes in microhardness of surface of 12H17 and U8 steels in mode of developed cavitation.

| Processing time, min | Microhardness of surface of steel 12H17, MPa | Microhardness of surface of steel U8, MPa |
|---------------------|---------------------------------------------|--------------------------------------------|
| 0                   | 1810                                        | 8400                                       |
| 20                  | 1810                                        | 8400                                       |
| 40                  | 1930                                        | 8400                                       |
| 60                  | 2170                                        | 8410                                       |
| 80                  | 2430                                        | 8430                                       |
| 100                 | 2470                                        | 8450                                       |
| 120                 | 2330                                        | 8520                                       |
| 140                 | 2250                                        | 8500                                       |
| 160                 | -                                           | 8430                                       |
| 180                 | -                                           | 8390                                       |

Table 2. Measurement of microhardness in face section of samples.

| Microhardness, MPa | Distance from surface, μm |
|--------------------|--------------------------|
|                    | 10           | 25       | 50        | 75        |
| 12H17 [9]          | 2460         | 2070     | 1900      | 1800      |
| U8                 | 8500         | 8400     | 8400      | 8400      |

The subsequent period of weakening and fracture of the surface starts after two hours of the cavitation impact after a fall of micro-hardness, the formation of deep dents in the thin section as a consequence of the plastic flow of the ferrite base, and in this process, the carbide grains are involved. There are also signs of erosion of the surface areas.

U8 steel is characterized by a long incubation period, due to the high initial strength and hardness of martensite. Microhardness in the samples’ frontal section at the maximum degree of surface hardening remains practically unchanged. A slight increase in the surface microhardness of 3-4 % of the initial value starts 60 minutes after, and the visible traces of plastic deformation of the martensite start to appear in the microstructure after 80 minutes of cavitation. On microsections, the reorientation of martensitic needles and a blur relief, the emergence of micro-cracks at the boundaries of the prior austenite grains are observed. Hardening effect of the martensite can be due to an increase of the dislocation density or collapse of a residual austenite with formation of a martensite deformation.

The subsequent weakening and destruction along the boundaries of prior austenite grains appear under the mechanism of brittle fracture.

4. Conclusion

The experiments and analysis of their results suggest the following conclusions:

– cleaning efficiency with application of ultrasonic vibrations is dependent on the intensity and the time of action of the ultrasonic vibration;
– 12H17 and U8 steel processed with ultrasound in the pre-cavitation mode during experiment practically did not change the state of the samples’ surface;
– at the same, intensity of ultrasonic vibrations in the mode of developed cavitation, the cavitation resistance of the material is determined by its structure;
– the deformation hardening of the ferrite of steel 12H17 peaks in 100 minutes of the treatment and is accompanied by an increase of the microhardness of 25% compared with the initial following gliding fracture of the surface;
– ultrasonic treatment of steel U8 with the structure of the martensite showed that long time cavitation had no effect on the state of the surface layer, a slight increase of the microhardness in the
surface layers and subsequent brittle fracture of the surface are observed;
– comparative analysis of the structural transformations of the surface layers of steels 12H17 and U8 allows one to select the optimum time of ultrasonic treatment for a complete cleaning of the surface without destroying it, and if necessary, to set the optimal mode of steel 12H17 hardening.

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