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Research of AISI 321 steel microrelief after ultrasonic impact treatment with marker applying

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Abstract. The paper considers the influence of AISI 321 steel microstructure formed by ultrasonic impact treatment on the microrelief regularity of preliminary prepared by turning ($R_a=2.15\text{ }\mu\text{m}$) and grinding ($R_a=0.36\text{ }\mu\text{m}$) austenitic stainless steel samples. The developed technique application for exploration the microstructure influence on the microrelief local irregularity of AISI 321 steel made it possible to establish the absence of a significant effect of twins and grain boundaries on the regular microrelief formation. The most probable reasons for irregular microrelief domain's formation could be considered the design features of dynamic technological module and the quality of initial surface preparation before the ultrasonic impact treatment.

1. Introduction

Ultrasonic impact treatment (UIT) is one of the effective method for strength and wear resistance increasing of heavily loaded friction surfaces by the regular microrelief formation on the treated surface (surface's texturing by micro-dimples), nanocrystallization of the surface layer and generation of residual compressive stresses that favorably influence on the fatigue strength.

It is clear from references [1–7, 9, 10] that UIT improves the physical-mechanical and tribological characteristics as well as the fatigue strength of various parts and friction units due to the presence of a regular microrelief consisting of bulges and valleys (micro-dimples). Synonyms for «regular microrelief» definition used in the scientific literature are the «surfaces' textured by micro-dimples» or the «nano-corrugated surfaces».

An essential problem of UIT is obtaining completely regular microrelief such as the dimensions of all dimples are the same both in diameter and in depth and are located at equal distances. Probably such fully regular microrelief makes better tribotechnical characteristics compared to partially regular (not completely regular). The purpose of this exploration is to investigate the influence of AISI 321 stainless steel microstructure on the irregular microrelief formation during ultrasonic impact treatment.

2. Experimental details

Currently researchers [1–9] have complications in obtaining completely regular microrelief formed by ultrasonic impact treatment similar to our research team (see figure 1).



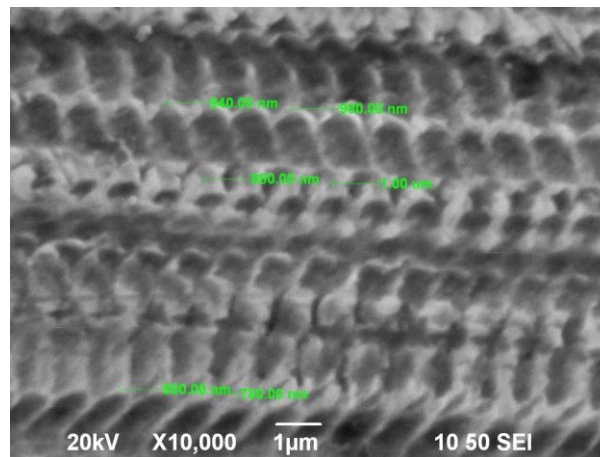


Figure 1. Partially regular microrelief formed by UIT, SEM, $\times 10000$.

It can be seen from figure 1 that the dimples (valleys) have various shapes, sizes and deepness. The bulges which separate the dimples also have different sizes and tilt angles relative to the horizontal line although the treatment of this surface was carried out under invariable modes. In our opinion a range of factors influence the variety of the surface microrelief patterns after UIT the main of which are:

- 1) The rigidity of the dynamic technological module construction which produces impacts on the surface with ultrasonic frequency.
- 2) Quality of the initial surface preparation before UIT (turned, ground, polished).
- 3) Physical–mechanical characteristics of the processed material (microstructure, hardness, stress state).

As it was noted above the influence of AISI 321 stainless steel microstructure on the irregular microrelief formation during ultrasonic impact treatment was investigated. Turned ($R_a=2.15\ \mu\text{m}$) and ground ($R_a=0.36\ \mu\text{m}$) samples in the form of rollers with 25.5 mm of diameter from corrosion-resistant high-alloyed austenitic AISI 321 steel were prepared for exploration. The content of the main AISI 321 steel elements is: C=0.12%; Cr=18.64%; Ni=10.1%; Ti=0.54%.

Ultrasonic impact treatment of the samples was produced by a spherical indenter made of a tungsten carbide (VK8) with a sphere radius of 3 mm. To generate impacts on the samples' surfaces was used the dynamic technological module DTM–07 constructed on the basis of the magnetostrictive transducer PMS15A–18. Processing modes: ultrasonic tool oscillation frequency $f=18\ \text{kHz}$, amplitude $\xi_m=50\ \mu\text{m}$, static load $P_{st}=20\ \text{N}$, relative travel velocity of the ultrasonic tool and sample $v=2\ \text{m/min}$, longitudinal feed of the tool $s=0.05\ \text{mm/rev}$.

To assess the microstructure influence on the local irregularity of microrelief it occurs a necessity of a special label (marker) applying to the sample surface nearby to explored area for convenience of searching it after removing microrelief by polishing. The most common method of marking is ion milling by a focused ion beam which is often embedded to a scanning electron microscope. Wire electrical discharge machining (WEDM) could be used for marker applying as an alternative of an expensive ion milling method (see figure 2).

The developed technique for exploration the microstructure influence on the local irregularity of microrelief consists of the following procedures:

1. Marker's applying of the by WEDM.
2. Sample's examination by scanning electron microscopy (the stage is set in such way that the edge of the sample is oriented horizontally (see figure 3a). The vertex of the marker semicircle is taken as the origin of the coordinate system).
3. Taking a micrograph of microrelief irregularity near the origin of the coordinate system by SEM.

4. Fixing on the XOY coordinate system with following calculation of the irregular microrelief area location using a scale ruler (see figure 3b).
5. Sample's mounting.
6. Grinding of a plane parallel to the cross section plane on a grinding machine.
7. Manual polishing of the sample plane until the removal of microrelief (herewith the thickness of the removable layer is controlled by a micrometer).
8. Sample's etching.
9. Contemplation of the previously selected domain's microstructure by light microscopy or SEM in order to establish the reasons of microrelief irregularity.

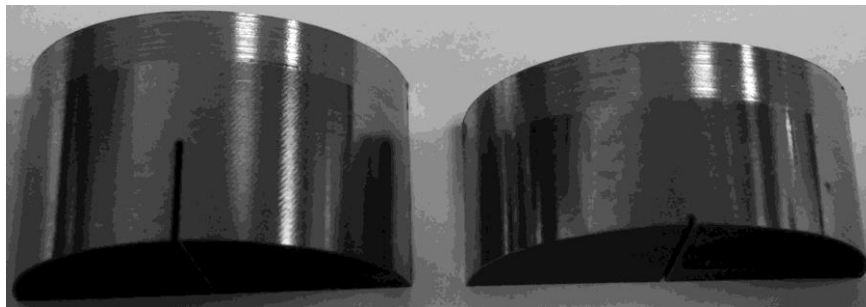


Figure 2. Markers applied by WEDM.

Morphology exploration of the turned and ground samples' subjected to UIT was carried out by JEOL JCM-5700 scanning electron microscope in high vacuum mode. Signal type was secondary electrons (SEI). *SpotSize* parameter was 50–60, accelerating voltage value was 20 kV, magnification ranged from 50 to 10 000 $\times$.

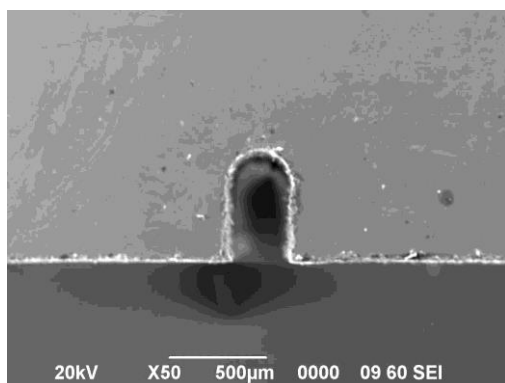


Figure 3a. Marker applied by WEDM, SEM: Alignment of the sample's edge.

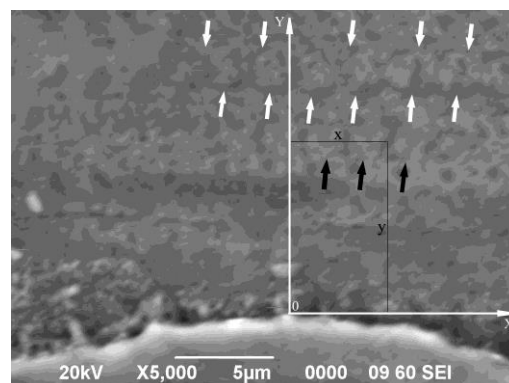


Figure 3b. Position of the coordinate system and areas with regular (indicated by white arrows) and irregular (indicated by black arrows) microrelief.

3. Results and discussion

Analysis of the AISI 321 steel samples' microstructure showed that the grain size varies in the range from 20 to 40 μm . Comparison of the distance between the dimples with the grain size (see figure 4) allows us to conclude that the ultrasonic tool during a single passage of any grain impacts it from 20 to 40 times forming a regular microrelief consisting of bulges and valleys (micro-dimples).

It can be seen from figure 4 that each dimple with serial number from 20 to 40 may occur exactly on the grain boundary or on the twin. The contact of the ball center attached to the ultrasonic tool and impacting the sample can probably lead to deviations from the regularity of the micro-dimples

location because of the material deformability in the grain boundary area may differ from the material deformability at the grain center. Usage the developed technique for exploration samples subjected UIT and containing areas with a violation of microrelief regularity (see figure 5) allows us to conclude that grain boundaries and twins do not significantly affect the microrelief regularity of previously turned and ground surfaces.

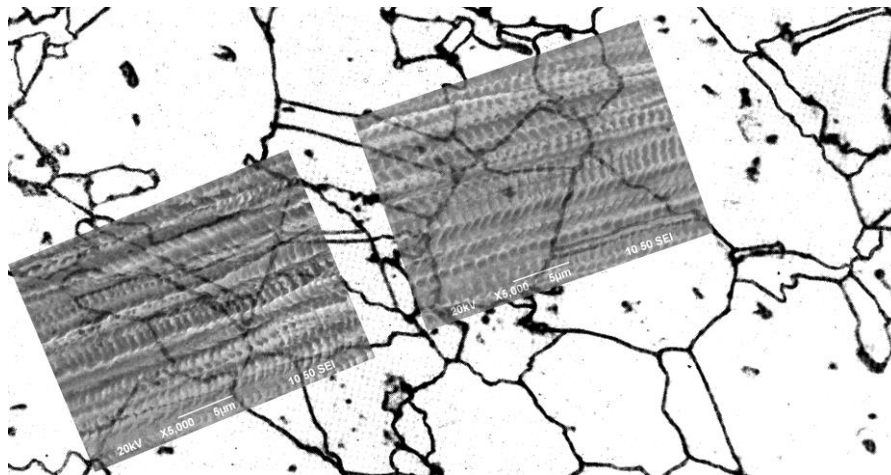


Figure 4. Comparison of the grain size with the distances between the dimples (the figure was obtained by superimposing the SEM micrographs with increased transparency on the microstructure photo in the image editor).

Areas with a significant accumulation of grain boundaries is characterized with a high degree of the microrelief regularity and conversely in some cases series of major grains with size ranges from 35 to 40 μm with a small number of boundaries and twins were located under the areas with an apparent violation of the microrelief regularity (see figures 5a, 5b).

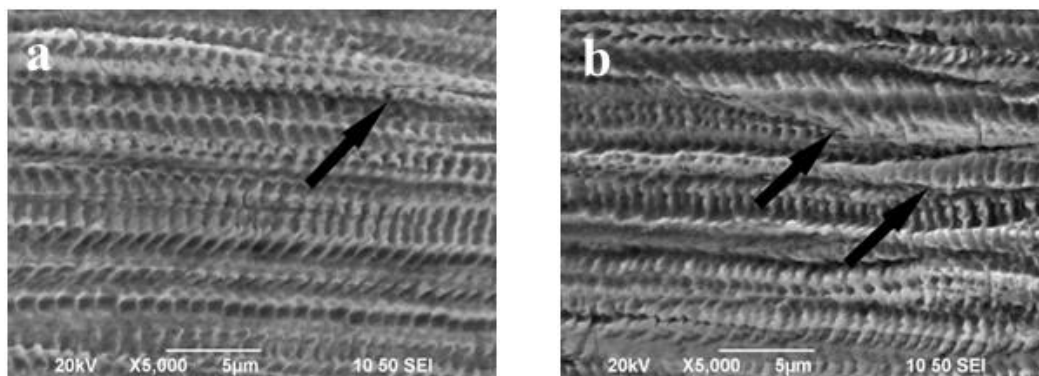


Figure 5. SEM micrograph of sample subjected to UIT. Black arrows indicate areas with an apparent violation of the microrelief regularity.

It should be noted that previously ground samples contain a fewer number of areas with a violation of the microrelief regularity in comparison with samples subjected to preliminary turning. Preliminary preparation of the surface before UIT was earlier considered by us [11].

4. Conclusion

This work has shown that the grain boundaries and twins in austenitic AISI 321 steel do not have a significant effect on the regular microrelief formation. The high surface concentration of grain boundaries and twins does not contribute to the areas formation with an irregular arrangement of

micro-dimples. Thus the most probable reasons of the areas formation with irregular microrelief include the design features of the dynamic technological module that impacts on the surface with ultrasonic frequency as well as the quality of the preliminary surface preparation before UIT. Surface grinding as a method of the surface preliminary preparation has a relatively higher influence on the degree of AISI 321 steel microrelief regularity after UIT compared to turning.

5. References

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