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SURFACE NANOCRYSTALLIZATION OF 36CrNiMo4 INDUCED BY ULTRASONIC PROCESSING

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Abstract. A nanocrystallized microstructure was generated on the surface of 36CrNiMo4 by sever plastic deformation induced by ultrasonic processing. The grain refinement mechanism of surface nanocrystallization was analyzed by optical microscope (OM), transmission electron microscopy (TEM), X-ray diffractometer (XRD), microhardness, and roughness test. The results show that the average grain size on the surface layer is about 25 nm after the surface ultrasonic processing, and the nanocrystallines present an equiaxed shape. The grain size increases gradually from the surface to the inside with the weakening of ultrasonic processing. The surface roughness decreases and the hardness increases significantly.

1. INTRODUCTION

Screwdrill is a mud-driven downhole drilling, which plays an important role on mud and power transmission. But the failure happens frequently for screwdrill especially for its main arbor, because it bears complex alternating load during the service. 36CrNiMo4 is widely used to manufacture the screwdrill. The structure and sealing integrity can be assured by improving the surface quality, and increasing the resistance to bending and impacting ,to ensure the normal operation of drilling.

The metal surface nanocrystallization is one of the material surface strengthening methods [1,2]. It forms a nanocrystal layer on the surface of the traditional engineering metallic materials, which can increase the while structure performance and service life. This technology uses the excellent performance of nanocrystalline materials combined with traditional metal materials, and has a very broad application prospect in modern industry. The surface nanocrystallization technology can increase the surface hardness, wear resistance [3,4], fatigue strength [5,6] and corrosion resistance [7,8]. Surface nanocrystallization methods contain high-energy shot peening [9], mechanical polishing [10], supersonic particle bombardment [11], etc. But up to now they still can not be put into practice use because of the complex manufacture technology, high production costs, and shape and size limitation.

The surface nanocrystallization by ultrasonic processing can generate compressive residual stresses and small roughness on the surface [12,13]. By using this method, the low cost and high efficiency features can be obtained, moreover the nanocrystal layer and the substrate can not be separated easily. Therefore, this paper presents an investigation on the nanocrystallization microstructure of 36CrNiMo4 induced by ultrasonic processing.

2. EXPERIMENTAL

2.1. Material

The test material is 36CrNiMo4 alloy steel, and its chemical compositions are listed in Table 1. This

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Table 1. Chemical compositions of 36CrNiMo4 (in wt.%).

C	Mn	Si	P	S	Mo	Ni	Cr
0.35	0.6	0.4	0.035	0.03	0.20	1.0	1.0

material has been modified treated, and its microstructure is tempered sorbite with a mechanical impurity with lath-shaped ferrite and granular cementite. The hardness is HV360.

2.2. Ultrasonic surface nanocrystallization processing

The ultrasonic surface nanocrystallization processing test is carried out on ultrasonic surface rolling processing (USRP) device TJU-UMSNT-1, which is provided by TianJin University. It consists of two parts: ultrasonic wave generator and USRP operator. The parameters such as rotation speed of main arbor, feeding amount, static working pressure, output amplitude, the working times, material and size, etc, are chosen according to the materials to be processed. Firstly, the blank was rough finished at numerical control machine, and then the operator of USRP was installed on the feeding of numerical control machine. At last, the specimen was ultrasonic rolling processed. After optimizing the processing parameters, the output frequency of the system is 20 kHz, and the output amplitude is around 10~50 μm and can be continuously adjustable. The shape at the end of impacting is spherical, and its material is hard alloy. The radius of the output side is 5mm, and the rotation speed of spindle and feeding amount are 337 r/min and 10 mm/min, respectively. The surface roughness is 0.01~0.088 μm. The applied static loading is around 100~300 N, and the emulsion is used as lubricating fluid.

2.3. Micro structural analysis

The micro structure was analyzed by XPT-7 metalloscope and high-resolution transmission electron microscopy (Phlilps TecnaiG F20). The structure was analyzed by D/Max 2400 X-ray diffraction. The grain size and micro strain were calculated according to the diffraction width and Scherrer-Wilson equation.

2.4. Hardness and surface roughness test

The hardness on the surface and along the thickness has been measured by micro-hardness meter MHV2000. The applied loading is 10 g, and the working time is 10 s. The roughness of the ultrasonic processed specimen is measured by 2201 type inductive surface roughness tester with high accuracy.

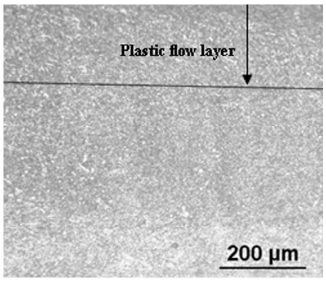

Fig. 1. Microstructure of 36CrNiMo4 by USRP.

3. RESULTS AND DISCUSSION

3.1. The microstructure of the ultrasonic processed surface

Fig. 1 shows the cross-section microstructure of 36CrNiMo4 alloy after processed by USRP. It can be found that a plastic flow layer with a thickness of 200 μm has been generated. The grain has a sever deformation in the flow zone, and the equiaxed grains before the rolling process has been changed to thin strip with the same direction. The grain boundary has become fuzzy and the trace of plastic

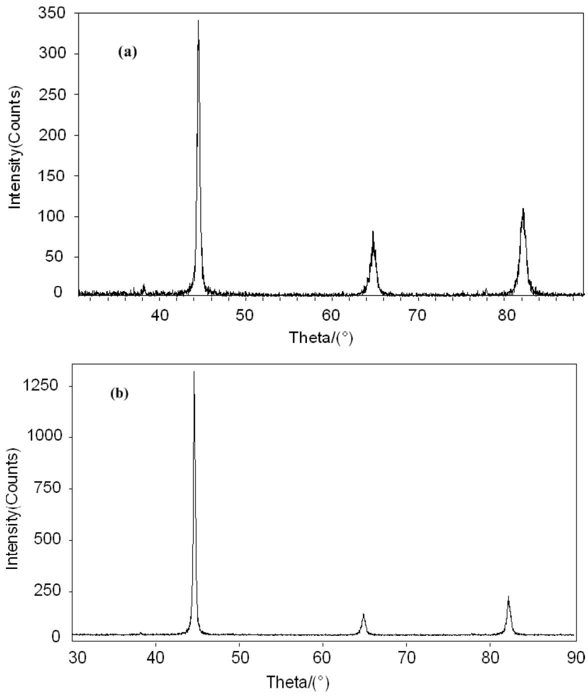

Fig. 2. The result of XRD after nanocrystallization at the surface (a) and 80 μm depth (b).

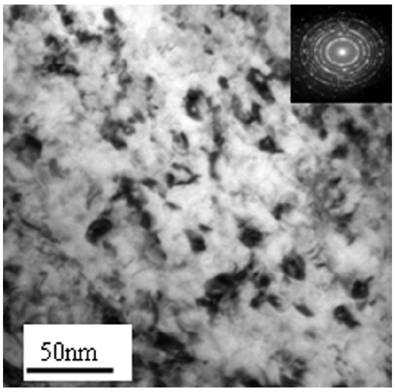

Fig. 3. TEM image after USRP and the selected area electron diffraction pattern.

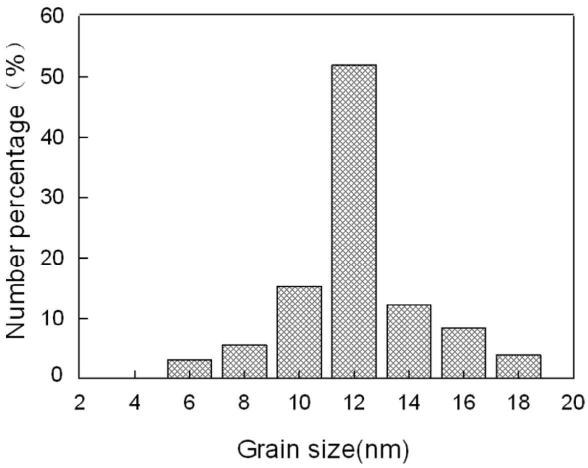

Fig. 4. A statistic analysis of grain size on the surface of 36CrNiMo4 by USRP.

deformation has become obvious. Another, the grain rheological change is continuous and has a gradual change from surface to the middle. There is no obvious deformation when the depth is larger than 200 μm. As the grain refinement in the material depends on the amount of plastic deformation, therefore the microstructure along the thickness shows a gradient distribution.

Fig. 2 shows the XRD result at the surface and a depth of 80 μm of ultrasonic processed specimen. It can be shown that the both diffraction peaks have been changed. The Bragg diffraction peak at 200 crystal face is wider than that of the original specimen, which is caused by the grain refine and the increase of micro strain. According to Scherrer-Wilson equation, the calculated grain size and micro strain on the surface is 14 nm and 0.433%, and their corresponding values are 65 nm and 0.168% at the 80 μm deep respectively. The increasing of micro strains shows that there is a lot of non-equilibrium grain boundary with high energy storage on or near the surface layer. As the grain size measurement by XRD method is influenced greatly by

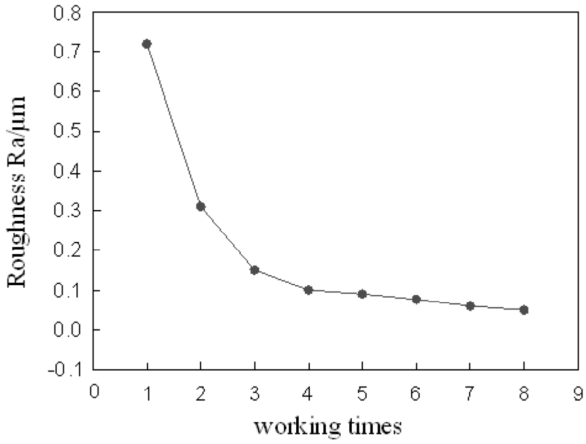

Fig. 5. Effect of the times of USRP on the surface roughness.

the diffraction width, which can lead to bad measurement accuracy. Therefore, the change of grain size with the depth should be measured by TEM method.

Fig. 3 shows the TEM image and the selected area electron diffraction pattern. According to the analysis method of polycrystalline diffraction pattern [17], the values of each *N* are 4 : 6 : 8 : 10 : 12 : 14 : 18. It is determined that it is body-centered cubic crystal, and the sample surface is the α-ferrite. Form Figs. 3 and 4, it can be seen that the grain on the surface has been nanocrystal with an equiaxed shape. The grain size is 6~18 nm, and the average size is 12 nm. The electron diffraction pattern shows that the nano-grain orientation is random in the selected area.

For the surface nanocrystallized specimen, the grain size along the thickness is gradually increasing. The strain and strain rate is very large on the surface, in which the dislocation density is very high, and it is easy to form the nanometer scale

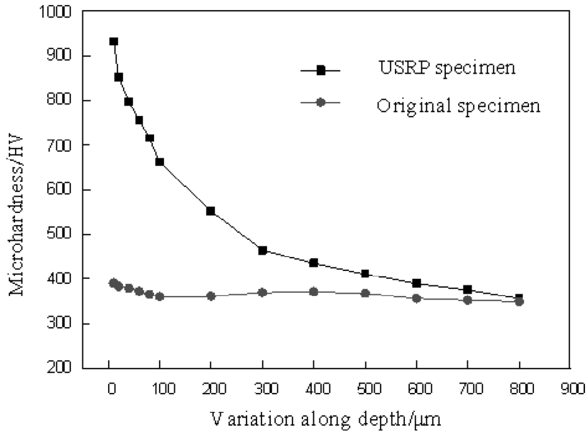

Fig. 6. Comparison of micro-hardness variation along depth.

dislocation walls. The equiaxed nanocrystals are finally formed by the development of dislocation wall and sub-boundary in the short axis. Compared with the coarse grains, the grain rotation and grain boundary sliding for the nanocrystals are very easy to implement. Therefore, the equiaxed nanocrystals with a random distribution are generated on the surface.

3.2. Measurement of surface roughness

After the ultrasonic rolling processing, obvious changes on the surface of 36CrNiMo4 have been happened and the brighter metal luster is shown. Fig. 5 shows the effect of USRP times on the surface roughness. After USRP, the surface roughness has decreased about 6 times. The roughness is almost the same after processed 3 and 4 times, which means that increasing the USRP times can not reduce roughness infinitely. The surface roughness will keep constant to the extent. Therefore, the USRP can decrease the surface roughness about 6 times, and good surface quality can be achieved on the mechanical parts.

3.3 Measurement of microhardness

Fig.6 shows the hardness along the thickness before and after USRP. Compared with the original material, a great increase in the harness can be shown after USRP. The hardness decreases with the increase of depth, and the hardness on the surface has increased about 2 times compared to the original material. The hardness within the 100 μm depth below the surface has increased obviously. As with the depth further increases, the hardness becomes stabilized gradually.

The harness increase after the USRP can be attributed to the interaction of grain refinement and work-hardening. Along the thickness, the grain size increases gradually while the hardness decreases. This phenomenon is agreed well with the traditional Hall-Petch relationship and the test results of the rest ultra-fine grained materials [13]. It can be drawn that the surface USRP has a surface hard effect for 36CrNiMo4 steel.

4. CONCLUSIONS

A thickness of 200 μm plastic flow layer is generated after USRP for 36CrNiMo4 steel, and the average grain of nanocrystal is about 25 nm. The grain size increases with the depth increasing.

After the USRP, the surface roughness has decreased about 6 times than that of before USRP.

After the USRP, the hardness has increased obviously compared to the original specimen, and it has increased about 2 times at the center. With the increase in depth, the hardness decreases.

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