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Research Article

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Study on wear resistance and corrosion resistance of sucker rod couplings after surface ultrasonic nano-crystallization treatment

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ABSTRACT

Aiming at the poor ability of wear-resistance and corrosion-resistance of sucker rod couplings, surface ultrasonic nano-crystallization treatment of sucker rod couplings was studied. The roughness, hardness, corrosion-resistance and wear-resistance of the coupling after surface ultrasonic nano-crystallization treatment were evaluated by experiments. The results indicated that corrosion-resistance and wear-resistance of the couplings after that kind of treatment is fine and it also can solve the problem of the wear-resistance of tube. The life of sucker rod and tube can be prolonged effectively.

Keywords: Surface Ultrasonic Nano-Crystallization Treatment, Coupling, Roughness, Hardness

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INTRODUCTION

At present, it mainly adopts chemical plating, hot dip plating, thermal spraying and other methods to improve the surface properties of the sucker rod couplings. However, those methods are limited in the oilfield application for the low adhesion strength and loose coating. Surface nano-crystallization includes structure nano-crystallization and geometry nano-crystallization[1]. After the structure nano-crystallization, the metal surface hardness can reach close carbide, which will greatly improve the wear resistance of mechanical parts. If the metal surface undergoes geometry nano-crystallization, the roughness will reduce to the nanometer scale. Its abrasion resistance, tightness, fatigue resistance, corrosion resistance performance can be significantly improved.

The ultrasonic surface nano-crystallization of sucker rod coupling is used ultrasonic metal surface nano-crystallization technology to reduce the surface roughness, improve the surface hardness and increase the fatigue resistance and prolong the life of the rod coupling.

The principle of surface ultrasonic nano-crystallization

Metal surface ultrasonic nano-crystallization is derived by high power ultrasonic. It acts on the metal surface and makes it occur extremely severe plastic deformation, which results in the grain has been broken, so as to obtain the nano-crystallization structure layer on the surface. At the same time as the squeezing effect of ultrasonic head on the metal surface, convex part move smoothly during mechanical parts surface control in the traveling mechanism is uniformly added to sag region, so it can achieve very high surface roughness, surface morphology of nano-crystallization[2].

Ultrasonic metal surface processing is a shock pressure finishing method (Figure 1), which works as follows: by ultrasonic surface working head nanometer processing is applied along the surface normal direction to the work of a certain level of ultrasonic frequency mechanical vibrations and under certain static pressure and feed rate conditions, working head pressure and ultrasonic shock and vibration transmitted to the surface is rotating mechanical parts to be processed. Extrusion head impact arising from plastic flow of the work piece surface of the original micro flattened crest, trough filled position to improve the overall performance of the metal surface.

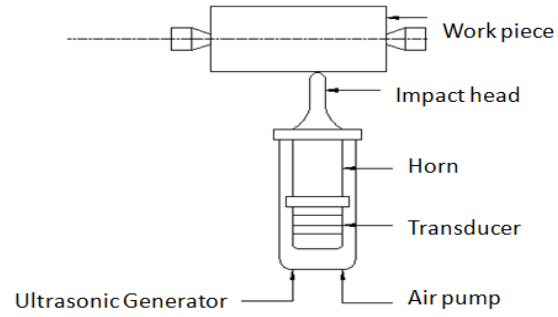


Figure 1. Ultrasonic surface processed schematic

Mechanical testing of rid couplings after surface ultrasonic nanocrystallization

Effects on the roughness with ultrasonic surface treatment

After surface ultrasonic nano-crystallization, common node hoop surface changed obviously, the average grain size of 50nm layer in the 20-80nm, as shown in Figure 2; the left part of the original surface is 40Cr, and the right part is surface ultrasonic surface processing, by comparison: surface after ultrasonic treatment with metallic luster bright[3].

Figure 2. 40Cr before and after ultrasonic treatment

With the high precision inductance type surface roughness measuring instrument, the specimen of 40Cr steel before and after ultrasonic surface processing of roughness are measured, as shown in table 1.

Table 1. 40Cr surface roughness

40Cr	Roughness Rα/μm			Average Rα/μm
	1	2	3	
Original sample	5.6	5.8	6.0	5.8
After ultrasonic treatment 4 times	0.085	0.12	0.09	0.098

According to the processing of Table 1 for surface roughness comparison test results ， we can see that after ultrasonic treatment of surface roughness reduced about 60 times than before treatment.

Effect of spindle speed and feed rate on surface roughness

By using hard alloy ball to impact the gun, ultrasonic surface processing of 40Cr. Force equals to 75N, the current is equal to 0.6A, equal to 2 times the processing times.

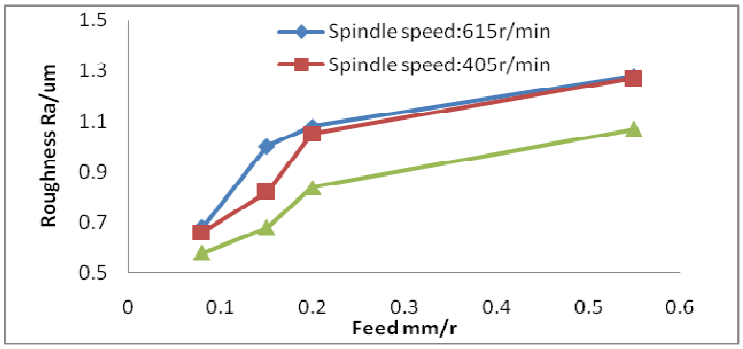


Figure 3. different spindle speed feed affect the amount on roughness

As can be seen from Figure 3, in the ultrasonic surface treatment process, when the spindle speed is the same, the lower feed rate, the roughness of the treatment of metal surface will be is lower; and when the feed rate is the same, the lower spindle speed, the roughness of the metal treatment surface will be lower. Based on the above

considerations, the metal rotary machinery parts ultrasonic surface treatment process, the spindle speed and the feed is low, the ultrasonic treatment of metal surface roughness is lower. But considering the processing efficiency, it selects the appropriate parameters of ultrasonic treatment process.

Influence processing times on roughness

With carbide ball for the head impact gun, 40Cr was treated on the surface by ultrasonic processing. Parameters set as follows: force is 190N, current is 0.2A, the feed amount is 0.07mm / r, as is shown in Figure 4.

As can be seen from Figure 4, when the ultrasonic surface treatment other process parameters fixed, the number of processing increases, as the metal surface roughness value is gradually decreased after the treatment, indicating the increased processing times can effectively reduce the surface roughness; processing and during the first three treatment, reducing the magnitude of the surface roughness is large, with the increase of the processing times, the decrease in the surface roughness decreases, and therefore, according to the surface quality of parts required to determine the processing times of the ultrasonic surface treatment, so that the processing efficiency of the highest part.

Analysis of surface micro hardness

The hardness changes of 40Cr after surface ultrasonic nano-crystallization treatment are measured by MHV2000 Vickers hardness measuring instrument in the thickness direction [4], the applied load is 10g, the reaction time is 10 seconds. Figure 5 shows the surface after ultrasound treatment nanofabrication sample surface hardness changes in the thickness direction.

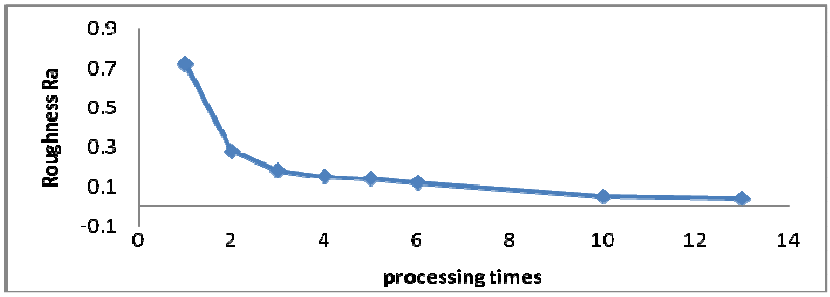


Figure 4. Processing times on the curve trend of roughness

As can be seen from Figure 5, the ultrasonic processing significantly increased the surface hardness of the sample, and with decreasing with depth, the surface hardness gradually increases. Compared with no change occurs in microstructure core part (about HV347), the sample surface hardness (around HVl460) increased by about three times, hardness within the depth range of 100 um below the surface were significantly improved. As the depth increases further, the value of hardness is gradually stabilizing.

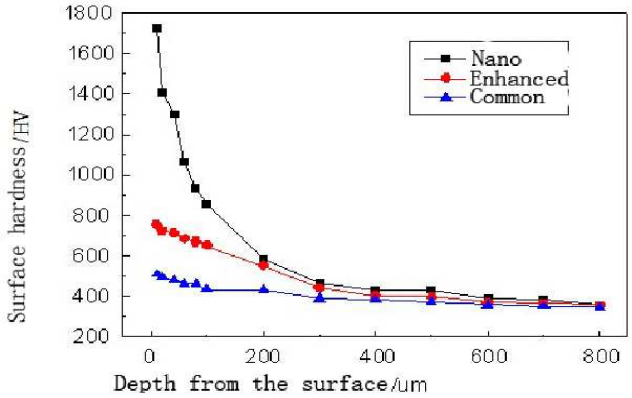


Figure 5. Three coupling hardness with depth curve

After nano- ultrasonic processing, the improvement of metal surface -hardness can be attributed to grain refinement and hardening of both effects. As can be seen from the correspondence between microstructure and properties of the sample, the sample thickness along the direction of the grain size increases, and the hardness decreases, this phenomenon is consistent with the traditional Hall-petch relationship, but also with other mechanical properties of ultrafine-grained materials research results are in agreement, so we can draw a conclusion that the nano- ultrasonic

processing of the metal surface structure can play an important role in enhancing surface-hardness, and thus can be used to improve the mechanical parts of the anti-fatigue and abrasion resistance [4].

Wear testing on couplings after surface ultrasonic nano-crystallization treatment

Measuring the amount of wear

Setting J55 tubing as a friction material，we selected nano couplings, common couplings, enhanced coupling at a relatively low speed conditions to compare the wear between 5kgf and 10kg f loads respectively. [5]

Tests were carried at room temperature, continuous grinding for 120 min without lubrication. The wear weightlessness of docking hoop sample are measured with an electronic balance with accuracy of one over ten thousand o, and the test results are shown in table 2.

Table 2 Results of different coupling wear

NO.	coupling	The friction pair	The friction pair(kg)	After the test load (g)
1	Nano coupling	J55	5	0.0850
2	Nano coupling	J55	10	0.1946
3	enhanced - coupling	J55	5	0.1908
4	enhanced- coupling	J55	10	0.2445
5	Common coupling	J55	5	0.2894
6	Common coupling	J55	10	0.4341

By the friction and wear data in table 2, the wear weight erosion rate of the match of nano coupling and J55 oil pipe material is lower than the other two kinds of matches. When the applied load is 5 KGF, nano coupling wear weight is about 55.5% of the regular coupling , and nano coupling wear weight is about 70.7% of the improved coupling ; while the load is 10 KGF, nano coupling wear weight is about 20.4% of the regular coupling ,and nano coupling wear weight is about 55.2% of the improved coupling .

All in all, nano coupling, compared with other two kind of coupling wear is significantly smaller. To analysis its reason, Partly because the surface quality was significantly improved, the friction coefficient becomes smaller; on the other hand, due to the increase of the sample conditioning state relative to the dislocation has certain screw rolling effect, it becomes difficult to relatively remote sliding, so vacancy produce in the surface or subsurface such as space is less. In the process of friction and wear, due to the small surface of nano-crystals，it can play a role in lubrication. When the friction and wear processes applied load is large, the amount of wear nano-coupling can be reduced by about 50% to common coupling. The nano treatment can significantly improve wear resistance.

Measuring of friction coefficient

Experimental material is 7/8 inch couplings and 1/3 of the circumference of the pipe diameter of 3 inches of J55. The pressure exerted on couplings is 1000N, and the varies with the time of mill are measured and recorded daily[5]. As can be seen from Figure 6, as time increases, the friction coefficient of the sample are first of all increases sharply and then gradually tends to a constant value. Throughout the course of the trial, the order of the coefficient of friction: common couplings enhance couplings, couplings nano described USRP process helps reduce the friction coefficient of the surface of the material, but the degree of improvement and no wear of the friction. When the load is applied increases exponentially, the friction coefficient increases in proportion accordingly.

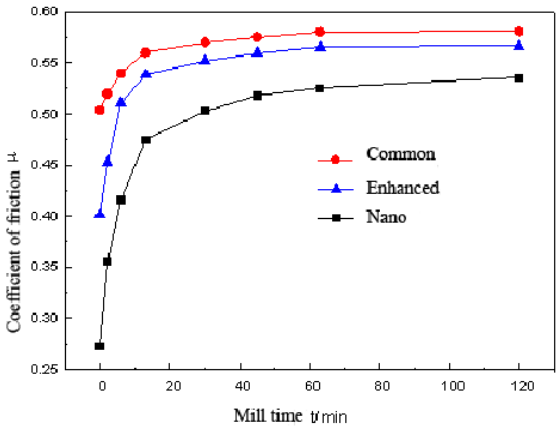
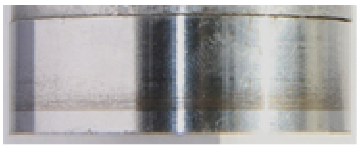


Figure 6. different coefficient of friction couplings

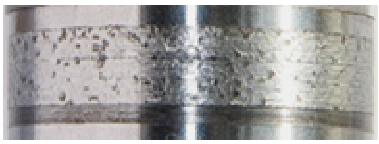
As can be seen from the Figure 6, with the increase of time, all of the friction coefficient of sample chart first, then gradually tends to a constant value. In the whole process of test, friction coefficient of the size of the order as follows: the common coupling, strengthen the coupling , nano coupling , explain USRP treatment is beneficial to reduce the friction coefficient on the surface of the material value, but the degree to the improvement of the friction and wear no apparent. When the applied load multiplied, and the coefficient of friction is proportional to the increase accordingly.

Comparison of three samples of the friction surface, we can see that, the main wear mechanism of nano and enhanced coupling friction surfaces is plow wear, while the common coupling is adhesive wear. Wherein, the nano-coupling has a small amount of wear of the surface layer is peeled off, while the enhanced coupling and common coupling have a different degrees of wear and oxidation stripping layer off. Because the friction process load is large, the friction coefficient increased to a larger value, the temperature rises rapidly during the reaction, tends to occur oxidation reaction, and the base body has a tendency to soften the creep beneficial micro-crack propagation. During the friction process, the plastic deformation of the substrate surface under load, so that dislocation slip and aggregation, resulting in a lot of vacancies and micro-cracks, and the surface becomes loose organizational structure softened. Forming a layer of softened wear will seriously weaken the alloy.



Nano coupling on J55 friction surface

Enhanced coupling on J55 friction surface

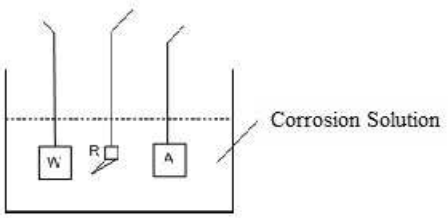


Common coupling on J55 friction surface

Electro chemical Corrosion Testing

Electrochemical test equipment and methods

By measuring the potential of the anodic polarization curve of the scanning motion samples, it can evaluate the corrosion resistance of the nano, enhanced and common coupling. The reference electrode is a saturated calomel electrode (SCE), Pt electrode is the auxiliary electrode, the sample is working electrode [6].



W-Sample to be tested, R-Saturated calomel electrode（SCE）, A-Platinum electrode

Figure 7. electrochemical test system diagram

The working area of the sample is 10mm×10mm, the other surface of the sealing portion is used with silicone rubber. Corrosive medium is used with 3.5% NaCl solution. The test temperature is 25 ℃. The samples are immersed in the solution after the potential is stable, the polarization is started. Potential scan rate is 18mV/s. When the current increase to 10mA, it must stop scanning.

Electrochemical analysis of test results

Figure 8 is a sample surface corrosion macro photos, relevant comparison parameters are listed in Table 3.

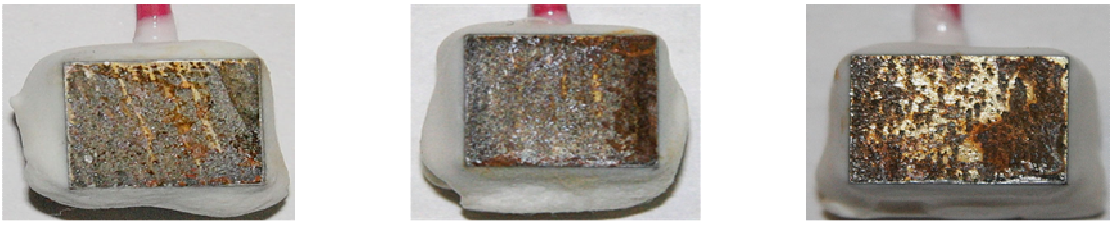


Figure 8. Comparison of three sample coupling surface corrosion

From left to right are: nano coupling, enhanced coupling, common coupling. As can be seen from the comparison of the sample surface corrosion photo, nano coupling sample, the proportion of the remaining fresh surface corrosion of metals is higher than enhanced coupling and common coupling.

Comparison with the data in Table 3, when the corrosion potential is the same, in the three couplings nano coupling corrosion current is small, indicating that its surface of the electrochemical reaction is weak, so that is corrosive resistant surface. Analysis of its causes , There is mainly the following two points, First, nano crystalline organization can be formed on the surface of the material from USRP treatment, it can prevent the corrosion process through rapid passivation, literature, corrosive, low carbon steel plate surface- treated nano, the surface exposed to air in two years , does not rust ; Second, in the alloy containing Cr, Cr is the main element forming a passivation film , in general , the more uniform distribution of Cr, the surface passivation film forms on the denser , the better the corrosion resistance , USRP agitation may be formed on a surface of the same grain refinement, so that the microstructure and a more uniform distribution of elements is conducive to the formation of the passivation film .

Table 3 Sample current values at different corrosion potentials

Volta / St	-0.3	-0.2	-0.1
Enhanced coupling	0.0036	0.0095	—
Common Coupling	0.0013	0.0065	0.0105
Nano coupling	0.0009	0.0058	0.0099

Enhanced coupling corrosion's current density is the largest of the three couplings, due to the surface hardening layer contains Ni, which is higher than the potential of the electrode substrate 40Cr, forming a metal corrosion, the coupling surface as a cathode and the anode substrate, thus it can accelerate anodic corrosion. In actual production, coupling surface, sucker rod coupling matrix and the body will form a galvanic cell corrosion, enhanced layer on the one hand due to the present of the high hardness of the drain pipe leading to a large number of production, on the other hand it also accelerate sucker and etching the substrate coupling, causing the rod breaking off phenomenon occurs.

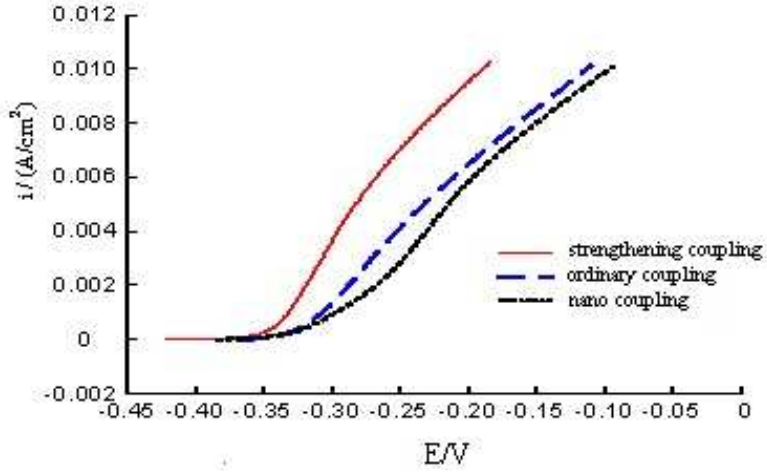


Figure 9. Three different coupling surface anodic polarization curves

Tests measured by the anodic polarization curves (Fig9) analysis after ultrasonic coupling nm process, which have a self-passivating metal surfaces, passivation film to enhance the corrosion resistance, excellent surface state, and due to the residual the compressive stress is generated, so that the surface micro-cracks in the closed state, and the breakdown potential and can have varying degrees of corrosion potential of a positive shift, indicating that the method can improve the corrosion resistance of the material.

Field Application

Dongxin Oil Production Plant carried out four test wells field applications of nano-knot cuff, in January 2010.Common couplings were used for comparative analysis with this. After 320 days, sucker rods were raised and found severe corrosion and wear in common couplings, while the nano-couplings were good. Common couplings matching with the tubing inside wear a groove, but nano-tubing couplings have no corresponding eccentric wear.

CONCLUSION

Nano coupling coefficient of friction is lower than common couplings and enhanced coupling;

(1) In the friction and wear test, the surface of nano-coupling theoretical life enhances by 6.3 times than common coupling, and by 1.8 times than enhanced coupling;

(2)Nano couplings corrosion resistance has improved: the corrosion current density reduced by 31% than common coupling, 75% lower than the enhanced coupling;
(3) Field application shows that ultrasonic surface of nano couplings corrosion wear resistance are better than common couplings. It also can protect co-ordinate with the tubing and prolong the life.

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