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Research on the effect of gas nitriding treatment on the wear resistance of ball seat used in multistage fracturing

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ABSTRACT

With the further development of unconventional oil and gas reservoirs, multistage fracturing technique has played an important role in completion process. Wear problem has severely restricted the development of this technique. However, surface modification of fracturing tools has not been studied widely. In this study, ball seats which act as key component in multistage fracturing were nitrided in ammonia (NH_3) and the nitride layer characterizations were investigated. Tribological tests were carried out to study the wear resistance of specimens. The test results show that microhardness and wear resistance are improved significantly by gas nitriding treatment. Based on the comprehensive analyses of the wear morphologies and debris, wear mechanisms are identified. The on-site fracturing experiment results indicate that the ball seat shows better wear resistance after gas nitriding treatment.

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1. Introduction

Over the past decades, hydraulic fracturing treatment has been widely used in many applications, which mainly includes unconventional oil and gas reservoirs such as tight gas, shale gas and shale oil [1,2]. Fracturing technology has a range of advantages such as improving reservoir permeability, increasing flow ability and production ability of reservoirs [3]. The ball seat technology used in multistage hydraulic fracturing has played an important role in the horizontal simulation completion process [4]. The oil and gas production environment represents severe conditions such as wear, erosion and corrosion [5]. Therefore, the selection of tool material should be considered carefully at every stage of design, manufacture and operation. The ball seat is used to activate the sliding sleeve for multistage fracturing of horizontal wells. The performance of ball seat severely restricts the fracturing effect and stages [6]. Generally, ball seat need to be removed by milling for installing oil pipe when fracturing process is completed [7]. In order to improve completion efficiency and reduce production cost, ball seat should have good milling performance. Thus, the substrate material with high strength cannot be chosen to manufacture ball seat, or it will be difficult to mill out after fracturing. In this study, gray cast iron was used to manufacture ball seat due to its excellent milling performance and adequate mechanical properties [8]. During fracturing process, when the downhole pressure is larger than the wellbore stress and rock tensile strength, fracture will take place at the weakest place of reservoir. To prevent the fracture closure, fracturing fluid containing sand as proppant is pumped downhole through pipeline. The sand contained in the fracturing fluid will slide rapidly on the inner surfaces of ball seat due to the inner surfaces are main working surfaces.

The cylindrical ball seat (diameter = 88 mm, length = 120 mm) studied in this paper is applied for horizontal well fracturing in Sheng li Oilfield. Under the actual working conditions (fracturing pressure = 40 MPa, flow rate = 3.7 m^3/min, sand ratio = 10%), wear phenomenon caused by friction between the sand and inner surface of ball seat is considered to be the most serious problem. The severe wear results in a series of problems such as weakening sealing performance, decreasing fracturing stages and causing fracturing pressure loss. All these above problems strongly inhibit the fracturing effect.

According to references, several studies have been performed on the ball seat. Wibowo et al. [9] explored the development and reliability of the ball and ball seat during hydraulic fracturing, which was made of high-strength corrodible material. It was found that high-strength corrodible material contribute to the good wear and erosion resistance. Halvorsen et al. [10] showed a milling operation study of ball seat which was placed deeply in one of the wells in North Continental Shelf and had to be removed as part of work. They found that milling operation time obviously increase production cost. So, the ball seat should be easy to mill out. Baihly et al. [11] presented an extensive study on the material mating performance of ball and ball seat under pressure. Their work showed that

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ball seat must have enough strength to avoid failure. Xu et al. [12] used finite element method to analyze the contact problem between ball and ball seat for horizontal wells staged fracturing. In their research, the maximum deformation of ball seat located at the place where ball mated with ball seat. It meant that surface of ball seat should have good wear resistance, or the ball seat would fail due to large deformation and severe wear. In a word, ball seat must possess properties such as high hardness, high wear resistance and corrosion resistance.

Taking requirements of surface and substrate strength into account, surface modification is a feasible method to solve these problems. According to related references [13–16], researchers have devoted their work to surface modification of cast iron. Jeong et al. [17] investigated the relationship between thermal fatigue resistance and microstructure of untreated and nitrided surface engineered nodular cast irons. The results showed that the treated surface improved the thermal fatigue resistance. Tošić and Gligorijević [18] used plasma nitriding to improve the fatigue properties of nodular cast iron crankshafts. It was found that the dynamic strength of nitrided crankshafts was 18% higher than the untreated ones. Their studies have indicated that nitriding process can significantly improve the mechanical and chemical properties of material such as wear resistance, fatigue resistance and corrosion resistance. Among the types of nitriding, gas nitriding treatment is considered to be a commercial and effective process to improve the surface properties of material because it is more feasible and has no limitations such as geometry of the specimens, production cost and complicated equipments.

The improvement of wear resistance will help to extend tool life for reducing tool failure risk and production cost. Previously, no work has been done to study the effect of gas nitriding treatment on the mechanical properties of ball seat. Aiming to improve wear resistance, ball seats were treated by the gas nitriding treatment in this study. The microstructure, microhardness and wear resistance of untreated and treated specimens were investigated. Finally, on-site fracturing experiment was performed to validate the wear resistance of ball seat. The results obtained can be instructive to modify the surface quality of fracturing tools, such as fracture sand jet, packer, and casing.

2. Experimental procedure

2.1. Gas nitriding process

The material used to manufacture the ball seat in this study was gray cast iron HT300, with the chemical composition given in Table 1. In the smelting process, the raw materials such as scrap, manganese, ferro-molybdenum and copper were firstly placed in the coreless induction furnace (GW-0.25) and then heated to molten iron. When the temperature of furnace was heated to 1693–1723 K, sample was sent to spectroscopic laboratory for ingredient analysis. When the temperature was heated to 1773–1783 K, the power of furnace was cut off. At the same time, inoculants were put into molten iron and stirred evenly. When the inoculation process was finished, the gray cast iron was casted with casting temperature controlled between 1743 K and 1753 K. In order to get high machining quality and precision, the gray cast iron was manufactured with the Computer Numerical Control (CNC) lathe (GSK980TDb). Moreover, to ensure the surface clean and avoid any oxide on the surface, the ball seat was cleaned with acetone in an ultrasonic cleaning machine and air dried. After the preparation, ball seats were treated in a nitriding furnace filled with ammonia (NH_3) (99.99% purity grade). Fig. 1 shows the schematic diagram of gas nitriding process used in this study. The ball seats were firstly placed in the furnace and then heated up to 833 K with a heating rate of 0.2 K/s, under an ammonia pressure of 20 Pa. When the temperature in furnace reached the required value, the pressure of ammonia was increased from 20 Pa to 0.01 MPa and the ammonia flow rate was maintaining at 200 ml/min. Then, the ball seats were placed in this atmospheric ammonia for 6 h at the specified temperature. Finally, the nitriding furnace was stopped to heat and the treated ball seats were cooled down to 473 K under an ammonia pressure of 20 Pa in the furnace. When the temperature was lower than 473 K, the ammonia was stopped to transmit into the furnace. Then ball seats were cooled down from 473 K to room temperature in the nitriding furnace. The untreated and treated ball seats were showed in Fig. 2. The dimensions of ball seat were also indicated. As it was seen, there were two cone surfaces at the inlet of ball seat. Moreover, the surface color of treated ball seat changed due to the nitriding reaction.

2.2. Characterization techniques

After the gas nitriding treatment, the phase constituents of the nitride layer were studied by X-ray diffraction (D/Max 2500v/pc, Rigaku, Japan) using Cu Kα radiation from an angle of 10° to 100° (2θ), with a rotation speed of 8°/min. To investigate the microhardness characteristic of nitride layer, the cross-section was measured using a digital microhardness tester (FM-700, F-T, Japan) with a diamond Vickers indenter under an indentation load of 50 g for 15 s, with the spacing of 25 μm between neighboring indents in the nitride layer and 80 μm in substrate. Microstructure characterizations were carried out by the metallographic microscope system (DM2500 M, Leica, Germany). The morphologies of the untreated and treated ball seats after tribological tests were examined by an Electron Probe Microanalyzer (JXA-8230, JEOL, Japan). The quantitative element analyses on the surface of untreated and treated ball seats were performed on the X-ray

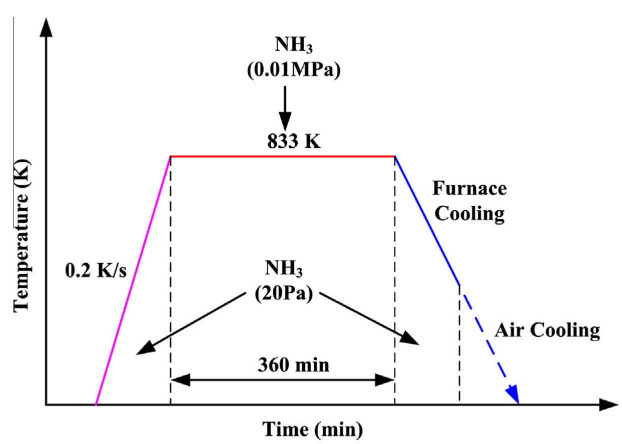

Fig. 1. Schematic diagram of gas nitriding process used in this study.

Table 1
The chemical composition of the gray cast iron used in this study (wt.%).

Cast iron	Fe (%)	C (%)	Si (%)	Mn (%)	Cr (%)	Mo (%)	S (%)	Others (%)
HT300	88.51	3.32	6.25	0.580	0.020	0.010	0.072	<1.0

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