Journal of Petroleum Science and Engineering 128 (2015) 140–144

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Effect of a nanoparticulate anti-friction coating on galling resistance of threaded oil-casing couplings

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ARTICLE INFO

Article history:
Received 5 June 2014
Accepted 4 February 2015
Available online 11 February 2015

Keywords:
tubing and casing
nano-copper
anti-friction coating
threaded oil-casing joint
galling resistance

ABSTRACT

Copperized oil-casing couplings exhibit excellent galling resistance, but owing to economic and environmental issues, there are limited techniques available for copperizing surface treatments. The use of a nanoparticulate anti-friction (NPAF) coating is presented here as a feasible alternative solution. A NPAF coating was fabricated by mixing nano-polytetrafluoroethylene (nano-PTFE) and polyacrylic resin with a high-concentration nano-copper ethanol colloid. The nano-copper ethanol colloid, which was prepared by a patented liquid-phase reduction method, has a nano-copper particle concentration of concentration from 14 to 20 wt%. The average particle size D_{50} of the nano-copper is about 95 nm. The NPAF coating was successfully used on the surface of threaded oil-casing couplings, which showed clear improvement in friction- and wear-reduction. The field experiments showed that the make-up torque was greatly reduced after using the NPAF coating on the knuckle-thread and buttress-thread casing couplings. The galling resistance of oil-casing couplings was also greatly improved.

1. Introduction

Oil-casing pipes are the most used pipes for drilling in oil wells and they occupy a market share of more than 80% in the total consumption of oil piping (Zhang et al., 2005). Different types of casing pipes are used for different stages of well build-up, which include spud-in, drilling, and final completion. As hundreds of casing pipes and threaded couplings are used for a well, huge economic losses may be caused by the failure of only one casing pipe or coupling.

Threaded connection is a widely used method in pipe connection, in which a pair of thin-walled steel pipes with spatial helical curved surface are placed in contact with each other and coupled by deformation under the action of an external force (Yuan et al., 2003). Galling of casing threads is one of the types of failure that can be caused by various factors. Three main factors of the galling of casing threads are adhesive wear, abrasive wear, and corrosion wear between the male and female threads (Xue, 1992). Some measures have been taken to reduce the casing thread failure issues. The main approaches to reduce galling are the phosphorization treatment and the smearing of compound greases specified in API 5A2 (American Petroleum Institute, 1972) on the surface of the threads. Because of the complexity of site operation, galling remains a frequent occurrence, so the make-up torque should be further reduced.

Du (2001) compared a number of surface treatments to improve the galling resistance of casing threads. Copperizing the coupling was proven to be the most effective way to improve the galling resistance between the casing threads. However, it could not be widely applied because of economic and environmental issues. Copper nanoparticles (nano-copper) have good thermal conductivity, good ductility, good performance in anti-wear, and anti-friction capability (Shi et al., 2005). Nano-copper particles have been widely used as an additive in gasoline engine lubricating oil and industrial lubricant. Properly dispersing the nano-copper particles in lubricating oil will promote its anti-wear and friction-reduction performance. Researchers have found that a nano-copper lubricating material has excellent surface repair ability and it can make the wear surface smoother under conditions with high temperature and high speed (Wang et al., 2009).

Polytetrafluoroethylene (PTFE) has a columnar streamlined structure and weak interaction between its molecules, which makes it slip very easily (Ballester et al., 2000). The PTFE particles can also form a metal-fluoride film under high temperature and high pressure to reduce abrasion. Among all polymers, PTFE has the smallest frictional coefficient, which is also stable in a wide temperature range even in a vacuum (Hu et al., 2006).

Abbreviations: API, American Petroleum Institute; CTAB, cetyltrimethyl ammonium bromide; D_{50}, mass median diameter; nano-copper, copper nanomaterial; nano-PTFE, polytetrafluoroethylene nanomaterial; NPAF, nanoparticulate anti-friction; PVP, polyvinylpyrrolidone; XRD, X-ray diffraction.

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http://dx.doi.org/10.1016/j.petrol.2015.02.008
0920-4105/

In the study reported here, a patented method (Meng and Wang, 2012; Meng et al., 2012) was used to prepare a high-concentration nano-copper ethanol colloid. A specific amount of PTFE nanoparticle (nano-PTFE) powder and epoxy were mixed with the colloid to obtain a nanoparticulate anti-friction (NPAF) coating material. The NPAF coating materials were applied on the surfaces of the casing couplings. A large number of field tests were conducted for the NPAF coating on the surface of phosphate layer of API casing couplings. The results proved that the NPAF coating can effectively reduce the make-up torque, greatly improving the galling resistance of threaded oil-casing couplings.

2. Experimental

In general, the roughness of the casing thread surface is between Ra 0.8 and 1.6 μm. Therefore, nanoparticles with an average size of <0.6 μm can be completely embedded in the convex groove of the threads. This is fundamental requirement for using particles to reduce surface friction and wear and to restore surface defects.

2.1. Preparation of copper particles

Polyvinylpyrrolidone (PVP) and the cationic surfactant of cetyltrimethyl ammonium bromide (CTAB), which acted as double-capping molecules, were dissolved in anhydrous ethanol. Next, 12.5 g of CuO was added to the 100-mL solution of anhydrous ethanol. The mixed solution was placed in an ultrasonic oscillation mixer to form a polymer suspension, and 15 mL of 80% hydrazine hydrate was added as the reducing agent. After 30 min of the reaction under ultrasonic oscillation mixing, the solution became red in color and was cooled down to room temperature. The preparation of the nano-copper ethanol colloid was then completed, and the colloid showed no obvious precipitation for one week.

Four samples identified as 1, 2, 3, and 4 were concentrated separately using a centrifugal concentrator (Zhengji Instrument Company, LTD, Jintan City, China). The concentration of nano-copper solid particles of the samples 1, 2, 3, and 4 were 14.64, 14.64, 19.21, and 19.21 wt%, respectively.

2.2. Characterization of copper particles

X-ray diffraction (XRD) analysis for the phase composition and crystallinity of the nano-copper particles was carried out using a Rigaku D/max 2200 PC (Japan) diffractometer with Cu K_α radiation (λ=0.151059 nm). The samples used in the XRD measurements were made by dripping the original nano-copper colloid onto glass slides and drying in an ambient atmosphere. Fig. 1 shows the X-ray diffraction patterns.

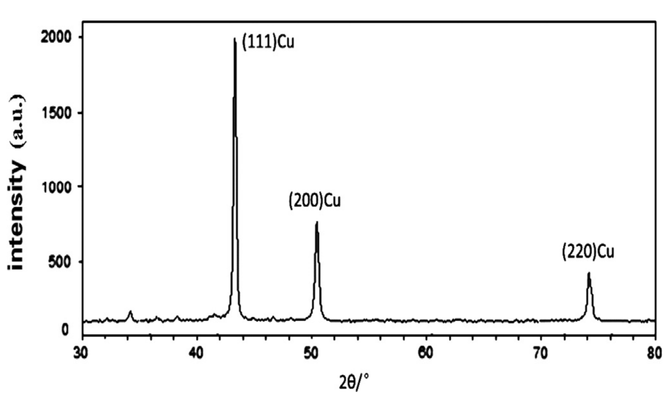

Fig. 1. XRD patterns of the copper particles.

It can be seen that Cu was the dominant phase in the sample material in Fig. 1. The XRD pattern corresponding to characteristic peaks of crystalline copper with a face-centered cubic (fcc) crystal structure. Based on the Debye–Scherrer formula, the size of a single crystal of the copper particle was about 32 nm. A small amount of impurity phase such as CuO and Cu_2O (2θ=34.36°) was also found.

Fig. 2 shows the nano-copper particle size distribution measured by using a LS230 particle size analyzer (American Beckman Coulter, USA). The particle sizes of nano-copper particles mostly ranged from 50 to 150 nm; the average size was D_{50}=95 nm, where D_{50} is defined as the mass median diameter, the size at which 50% of a sample's mass is comprised of smaller particles. Based on the upper XRD crystallinity analysis, the nano-copper particles are composed by two to three single crystals.

2.3. Characterization of nano-PTFE particles

The nano-PTFE particle powder used for the experiments was a commercial product. Its particle size distribution, shown in Fig. 3, was measured by the same LS230 particle size analyzer. The nano-PTFE particles mainly measured between 350 and 950 nm in diameter, with an average particle size of D_{50}=591 nm.

2.4. Preparation of NPAF

Polyacrylic acid resin is very easy to disperse in alcohol and has good adhesion on a metal surface. A certain amount polyacrylic acid resin was added to samples 1–4 to allow the nanoparticles to bond effectively to the surface of steel and to generate a layer of

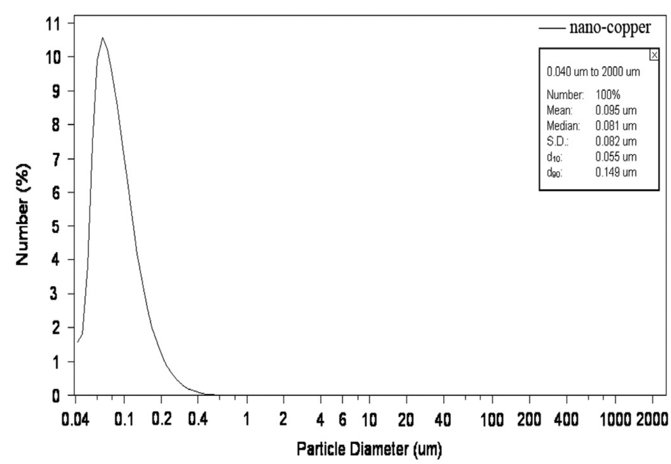

Fig. 2. Size distribution of nano-copper particles.

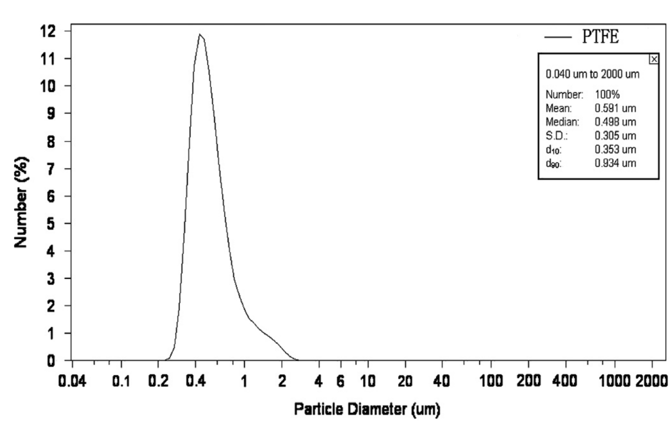

Fig. 3. Nano-PTFE particle size distribution.