Journal of Rare Earths 36 (2018) 209–214

Contents lists available at ScienceDirect

Journal of Rare Earths

journal homepage: http://www.journals.elsevier.com/journal-of-rare-earths

Tribological properties of nanometer cerium oxide as additives in lithium grease☆

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ARTICLE INFO

Article history:
Received 9 April 2017
Received in revised form
1 September 2017
Accepted 4 September 2017
Available online 9 October 2017

Keywords:
Nano-CeO_2
Tribological properties
Lithium grease
Worn surface
Rare earths
Additive

ABSTRACT

This paper presents a comparative study of the influence of nanometer-CeO_2 (nano-CeO_2) and temperature on tribological and lubricating properties of lithium grease. The morphology and structure of nanocrystals were characterized by means of transmission electron microscopy (TEM) and X-ray diffraction (XRD), respectively. Friction and wear tests were conducted on the friction and wear tester. Results show that the lithium grease with addition of nanometer-CeO_2 has much better friction-reducing and anti-wear performance than that of base grease. When the additive in grease is 0.6 wt%, the friction coefficient (COF) and wear scar diameter (WSD) decrease by 28% and 13% comparing with base grease, respectively. The base grease and grease with 0.6 wt% nanometer-CeO_2 both possess the lowest average COF and wear width at 50 °C. The worn surface morphology after friction test was analyzed by scanning electron microscopy (SEM) and NANOVEA three-dimensional profilometer. Under the lubrication of the lithium grease containing 0.6 wt% nano-CeO_2, few shallow furrows can be observed on the quite smoothed surface and the WSD decreased. Moreover, It was found that the nano-CeO_2 has been incorporated into the surface protective and lubricious layer by energy dispersive spectrometer (EDS) analysis.

1. Introduction

The energy consumption and loss of material in mechanical products are mostly caused by friction and wear.[1–5] Grease is an indispensable lubricant in mechanical devices to reduce friction and wear and extend life of equipment. The lithium-based grease is widely used in machinery, aerospace and other industrial fields,[6] due to its characteristics of high dropping point, pleiotropic performance and effective applicability.[7–11]

The investigation for nanoparticles as additives in grease has attracted widespread attention in recent years.[12–16] The rare earth nanoparticles have excellent properties.[17,18] Compared with the traditional additives, the rare earth nanoparticles possess excellent extreme pressure property, anti-wear performance and environment-friendly characteristics. And therefore the nanoparticles have been widely used in tribological field.[19–23] Ge et al.[24] studied the tribological properties of nanometer SiO_2 and nanometer TiO_2 as additives in grease, respectively. Results indicated that the mechanical effect of the nanoparticles takes on an important part in the good tribological behavior of nanometer TiO_2 grease and the good friction-reducing behavior of nanometer SiO_2 grease. Zhao et al.[25] researched the friction and wear behavior of the nano-calcium borate (NCB) as the additive in lithium grease. The result demonstrated that NCB can markedly improve the anti-wear and load-carrying capacities of the lithium grease. And with the addition of NCB additive, the COF of the lithium grease decreases. Chang et al.[26] found that the nano-TiO_2/CuO additives can improve the wear resistance of lithium grease and lower the COF. In recent years, although consideration research efforts have been aimed to investigate the tribological behaviors of nanoparticles as grease additives, there are few experimental investigations focusing on the role of nano-CeO_2 as lithium additives up to now. Nano-CeO_2 not only has the special properties of nanoparticles, but also has unique optical, electrical and magnetic properties due to unique f-layer electronic structure, making nano-CeO_2 be widely concerned.

☆ **Foundation item:** Project supported by the Natural Science Foundation of the Henan Province (152102210196), and the Foundation of the Henan Educational Committee (16A460001).
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https://doi.org/10.1016/j.jre.2017.09.004
1002-0721/

In this paper, the tribological behavior of lithium-based greases with different nano-CeO_2 contents was studied. And the frictional and lubricate properties of lithium grease containing nano-CeO_2 were investigated through friction and wear test. Additionally, the influence of temperature on tribological properties of base grease and additives contained grease was carried out. The COF, WSD and worn surface were analyzed in detail. We hope that our researches could make a reference in the utilization of the grease additive and in the application of this grease on large-scale production in the future.

2. Experimental

2.1. Characterization of materials

HP-R 380 °C universal grease (Synco Chemical Co. Ltd., USA) was used as base grease in the friction tests. Table 1 records the typical characteristics of base grease. These values were measured according to the GB 7324-1994 standard. The grain size of 90% nano-CeO_2 is no more than 500 nm, which was measured by laser particle size analyzer. TEM morphology and XRD pattern of nano-CeO_2 are shown in Fig. 1. It can be observed that nano-CeO_2 exhibits irregular particle morphology and obvious reunion (Fig. 1(a)). The non-uniform size distribution and irregular morphology of CeO_2 would be more likely to form smaller and irregular particles to fill in and repair the worn surface under the grinding action of frictional pairs. The characteristic peaks in XRD spectra (Fig. 1(b)) are consistent with the index of cubic fluorite structure.

2.2. Preparation of lubricating greases

According to the previous researches and viscosity of greases, different additive CeO_2 contents contained greases were prepared. In order to provide a brief analysis, the base grease and 0.2 wt%, 0.4 wt%, 0.6 wt%, 0.8 wt% and 1.0 wt% additives contained greases were marked as A0-A5 in order.

Table 1
Properties of the base grease.

Property	HP-R 380 °C universal grease
Density (20 °C) (kg/m^3)	950
Pour point (°C)	380
Flash point (°C)	400
Viscosity grade	3
Kinematic viscosity (40 °C) (mm^2/s)	380
Penetration (0.1 mm)	285
Dropping point (°C)	≥180

The additive CeO_2 contained greases were synthesized following the procedures below. Firstly, all the experiment appliances were cleansed in alcohol to ensure no impurities. Secondly, the base grease (50 g) and corresponding nano-CeO_2 additives were poured into the reaction vessel with evenly agitating. In order to ensure the base greases were blended homogenously with the nano-CeO_2 additives, the mixture was scattered in ultrasonic dispersion instrument for 20 min. Lastly, the greases were obtained after mechanical stirring and refined grinding by a three-roller mill three times.

2.3. Tribological tests as well as SEM and EDS analyses of worn steel surface

The anti-wear and friction-reduction performance of nano-CeO_2 as an additive in lithium grease at different contents were conducted on a MMW-1A universal friction and wear testing machine (Zhongke Kaihua Technology Development Co., Ltd., Lanzhou, China), as shown in Fig. 2(a). Throughout the test, the upper ball made of GCr15 steel (diameter 12.7 mm, hardness 59–61 HRC) was pressed down to contact the lower fixed three balls (GCr15 steel, diameter 12.7 mm, hardness 59–61 HRC). Fig. 2(b) affords the installation drawing of the friction pairs. The COF was evaluated automatically by a computer connected to the tester. According to Chinese National Standard GB/T 3142-82, all the experiments were operated with load of 392 N, rotational speed of 1200 r/min, and a period of 60 min at ambient temperature 75 °C. All the balls were cleansed by petroleum ether for 10 min in an ultrasonic cleaner before and after every tribological test. The WSD and worn surface morphology on the one of bottom balls were measured by optical microscopy and SEM (SHIMADZU, SSX-550, Japan), respectively. Moreover, the worn surface was analyzed through the NANOVEA three-dimensional profilometer (NANOVEA, ST400, USA). The influence of temperature (25, 50, 75 and 100 °C) on tribological performance of base grease and additives contained grease was carried out with a high temperature reciprocating friction and wear testing machine. These experiments were operated with load of 20 N, frequency of 30 Hz, and a period of 5 min.

3. Results and discussions

3.1. Influence of additive content to the greases

Fig. 3 shows the variation of the COF for the greases at different additive contents with test time. Original COF data were fitted by

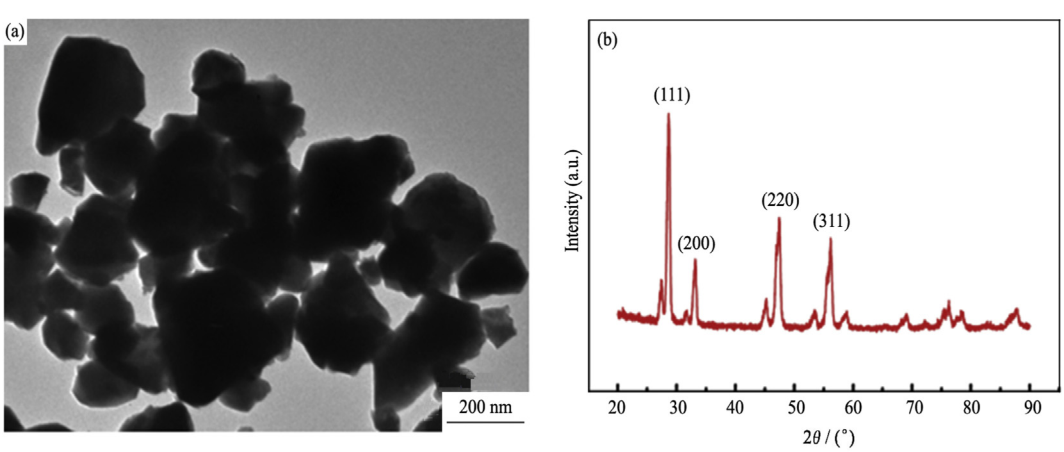

Fig. 1. TEM morphology (a) and XRD (b) pattern of nano-CeO_2.