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Short Communication

Investigation of Nickel Nanopowders and Their Application as Lubricant Additives

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Nanolubricants have attracted great interest due to the promise of friction and wear reduction by introducing nanoparticles (NPs). To date, the foremost challenge for developing a new nanolubricant is particle suspension. Numerous NPs have recently been investigated for use as oil additives. Nanopowders of some metals and their compounds exert an especially effective influence on the characteristics of lubricants. The use of NPs that include Ni, Cu, Fe, TiO_2 and other metallic NP additives in lubricating oils provides good friction reduction and anti-wear behavior. In this paper, we described the preparation of nickel nanopowders by the method of the electrical explosion of wire and their tribological performance as additives in oils. The obtained nickel nanopowders were investigated by the methods of scanning electron microscopy (SEM), transmission electron microscopy (TEM) and X-ray diffraction (XRD). The results of the investigation by SEM and TEM showed that the average diameter of these nanopowders is equal to 55.5 nm and their shape is spherical. Results of XRD investigation showed that nickel nanopowder has a pure fcc phase. The four-ball test results indicate that nickel nanopowders are potential additives for lubricating oils, and the tribological performance of lubricating oils can be improved significantly by dispersing nickel nanopowders in oils. Studies of tribotechnical properties have shown that the SAE-30 with nickel additives at concentrations of 0.4 wt. % has the best anti-wear properties in comparison with pure oil and other concentrations of nickel additive. The wear spot diameter has been reduced from 0.73 mm to 0.40 mm. The relative percentage of the friction coefficient has decreased by 47 percent.

Keywords: Nickel nanopowders, Anti-wear, Tribology, Lubricants.

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1. INTRODUCTION

In recent years, nanoparticles (NPs) have started to play more important roles as lubricant additives for their potential in emission reduction and improving fuel economy. Their characteristic size, normally less than 100 nm, will allow them to enter the contact region. In comparison with organic additives, NPs are considered thermally stable at elevated temperatures that makes them favorable as lubricant additives. Lubricant additives based on NPs can function as the friction reducer, anti-wear additive, extreme-pressure additive etc. Now many kinds of NPs have been investigated and proved to be excellent lubricant additives potentially, some of which have been industrialized [1-6]. A low concentration of NPs is sufficient to improve tribological properties, such as 0.05 % DDP-PbS [7], 0.1 % EHA-TiO_2 [8], 0.1 % DDP-ZnS [9], 0.15 % DDP-Cu [10], 0.2 % OA-PbS [11], below 1 % TiO_2 [12]. Qiu et al. [13] found that the concentration of Ni NPs between 0.2 and 0.5 % provides the best anti-wear behavior and friction reduction. Tao et al. [14] demonstrated that 1 % is considered the optimum concentration for the diamond NPs in paraffin oil. Choi et al. investigated the tribological efficiency of copper NPs at different lubrication regimes. It was evident that the Cu NPs were more effective in mixed lubrication than in full-film lubrication [15].

The results of studies on the morphology and structure of nickel nanopowders obtained by electric explosion of wire by scanning and transmission electron microscopy, X-ray analysis, and the possibility for their application as lubricant additives are presented in this work.

2. EXPERIMENTAL DETAILS

2.1 Preparations of Nickel Nanopowders

Nickel nanopowders were obtained in the Laboratory of vacuum nanotechnology, Combustion problem institute by electro-explosive evaporation of metal wire in argon atmosphere. The schematic diagram of the configuration of electro-explosive evaporation of metal wire method is shown in Fig. 1.

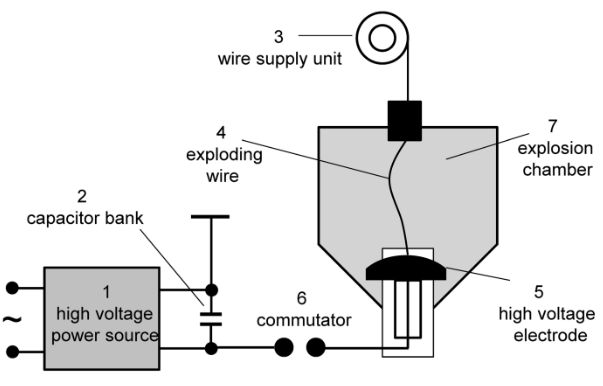

Fig. 1 – Configuration of electric explosion of wire equipment

Capacitors are charged from a high voltage power source. The metal wire supply mechanism provides an automatic wire supply unit. When the wire reaches the high-voltage interelectrode gap, the switch is turned on and the drive is discharged to this length of wire, and it explodes. Nickel wire with a diameter of 0.5 mm was used, the duration of a powerful current pulse was 10^{-6} s and a current density was 10^4 A/mm^2.

2.2 Methods and Apparatus for the Study of the Morphology and Structure of Nickel Nanopowders

The morphology of the samples was investigated by scanning electron microscope Gemini Ultra 55 of the company Zeiss, and a device for X-ray microanalysis of the company «Thermo Scientific» was used.

The studies by transmission electron microscopy (TEM) were performed with a transmission electron microscope JEM-2100 JEOL. Nanopowders were suspended in ethanol with a purity of 99.9 % for preparation of the samples. Further sonication was carried out in the solution for 5 min, after which the droplets of suspension were deposited on a copper grid.

The study on the structure of electro-explosive nickel nanopowders was carried out by the method of X-ray analysis using diffractometers Rigaku Mini Flex 600 XRD. X-ray spectra of the samples were obtained using copper radiation (λ = 1.5406 Å) in a digital form. The voltage on the X-ray tube was 40 kV, the tube current was 15 mA, the goniometer motion step was 0.02° and the shooting speed was 10° per second. PDXL2 software package with the base of diffractometric data PDF-2 was used for the phase analysis. Processing of the X-ray spectra to determine the angular position and intensity of the reflection was performed in program OriginPro 8.1.

2.3 Tribological Evaluation

The obtained nickel NPs were mechanically dispersed in SAE-30 (the viscosity of the oil at a temperature of 100 °C was 10.58 mm^2/s, and at a temperature of 40 °C it was 85.76 mm^2/s) lubricant at different amount: 0.05 wt. %, 0.1 wt. %, 0.2 wt. %, 0.4 wt. %. The nanopowders were mixed with lubricant and held for 4 h at a temperature of 25 °C to avoid possible NPs agglomeration. The subsequent operation consisted of processing the suspension by using sound waves with a frequency of 850 kHz, power 250 W at a temperature of 20 °C for 10 min. Tribological properties of lubricants without and with NPs were measured using a four-ball tribotester. The experiments were performed at room temperature. The rotation speed was 1200 rpm. The balls made of 100Cr6 with a diameter of 12.7 mm were used in the test. In this technique, one steel ball under load is rotated against three steel balls held stationary in the form of a cradle while immersed in the lubricant. The wear was evaluated according to the wear spot diameter (WSD) on the steel ball surfaces.

3. RESULTS AND DISCUSSION

Fig. 2 shows SEM, TEM images and histogram of the size distribution of Ni NPs. SEM images show that the size of the overwhelming number of particles does not exceed 100 nm. Thus, the formation of chain-like structures from small clusters (10 to 30 nm), as well as their partial sintering (so-called neck) is observed. The results of TEM studies are consistent with SEM. Fig. 1b shows that nickel NPs are spherical. The data of the histogram show that particles with a diameter of 40-70 nm predominate in the sample, the average diameter of which is equal to 55.5 nm. Analysis of the histogram shows that the size distribution of iron NPs is Gaussian with a standard deviation value σ = 30 nm.

Fig. 3 shows the X-ray spectrum of as-prepared nanopowders. It can be seen from XRD results that Ni nanopowder has pure fcc phase (PDF # 040850).

Fig. 4 shows the results of the comparison between the base oil and base oil with different amount of nickel nanopowders. As can be seen, with the increase in the concentration of nickel nanopowders, a decrease in the WSD is observed.

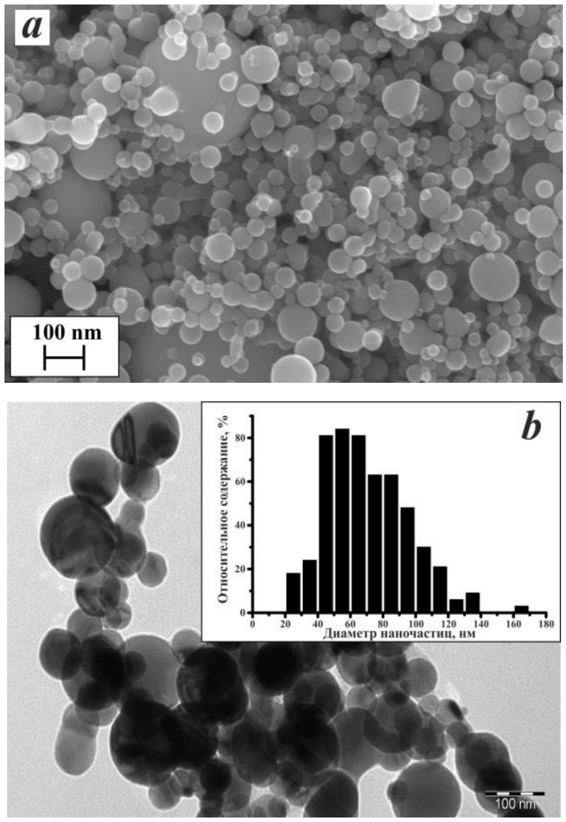

Fig. 2 – SEM of Ni NPs (a); TEM image and histogram of the size distribution (b)

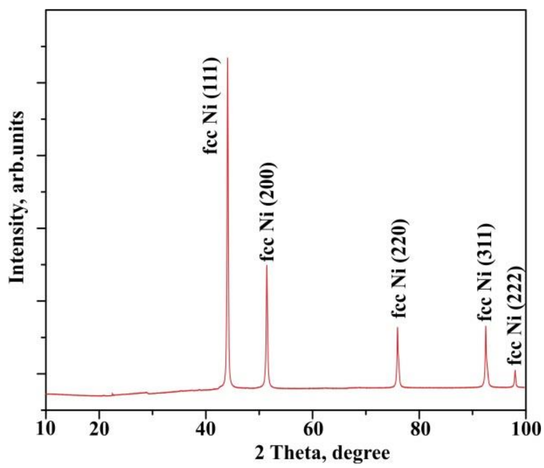

Fig. 3 – XRD spectrum of Ni nanopowder

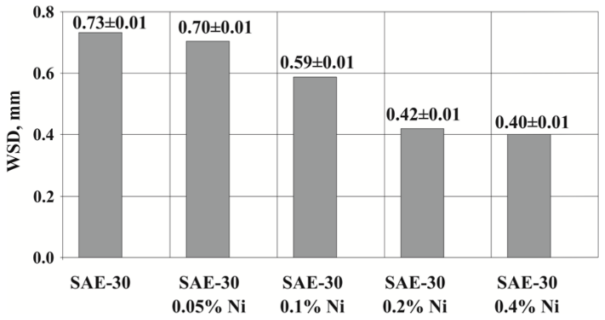

Fig. 4 – Dependence of the WSD on the content of nickel nanopowders in the grease

The lubricant containing 0.4 wt. % nickel nanopowders exhibits the most improved tribological results, reducing the wear by 45 %. This result confirms the tribological effectiveness of the investigated nickel nanopowders as lubricant additives.

4. CONCLUSIONS

Nickel nanopowders were obtained by the method of electro-explosive evaporation of metal wire. Size distribution histogram shows that particles with a diameter of 40-70 nm predominate in the sample. The shape of nickel NPs is spherical and nickel nanopowder has a pure fcc phase. The results of the tribological evaluation show the possibilities of using nickel nanopowders obtained by the method of electro-explosive evaporation of metal wire as lubricant additives. And the addition of nickel nanopowders to the grease SAE-30 improves its wear resistance.

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Дослідження нанопорошків нікелю та їх застосування як мастильних добавок

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Наномастильні матеріали викликали великий інтерес завдяки можливому зменшенню тертя та зносу шляхом введення наночастинок (НЧ). На сьогодні головним випробуванням в розробці нового наномастила є суспензія частинок. Нещодавно було досліджено численні НЧ для їх використання як масляних добавок. Нанопорошки деяких металів та їх сполук мають особливо ефективний вплив на характеристики мастильних матеріалів. Використання НЧ, що включають Ni, Cu, Fe, TiO_2 та інші металеві добавки в мастильних оліях, забезпечує помітне зменшення тертя та протизносну поведінку. У роботі ми описали отримання нанопорошків нікелю методом електричного вибуху дроту та їх трибологічні показники як добавок до мастильних матеріалів. Отримані нанопорошки нікелю досліджували методами скануючої електронної мікроскопії (SEM), просвічуючої електронної мікроскопії (TEM) та рентгенівської дифракції (XRD). Результати досліджень SEM і TEM показали, що середній діаметр цих нанопорошків дорівнює 55,5 нм, а їх форма є сферичною. Результати XRD дослідження виявили, що нанопорошок нікелю має чисту ГЦК фазу. Результати випробувань чотирикульковим методом вказують на те, що нанопорошки нікелю є потенційними добавками до мастильних олій, і трибологічні показники мастильних олій можна значно покращити, розподіляючи нанопорошки нікелю в мастилах. Дослідження триботехнічних властивостей показали, що мастило SAE-30 з нікелевими добавками при концентрації 0,4 мас. % має найкращі протизносні властивості порівняно з чистою олією та при інших концентраціях нікелевої добавки. Діаметр плями зносу зменшився з 0,73 мм до 0,40 мм. Відносний відсоток коефіцієнта тертя зменшився на 47 відсотків.

Ключові слова: Нанопорошки нікелю, Протизносний, Трибологічні, Мастильні матеріали.