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ANALYSIS OF THE IMPACT OF SiO_2 NANOPARTICLES IN CONVENTIONAL LUBE OIL ON AISI 52100 STEEL

ANALIZA UTICAJA NANOČESTICA SiO_2 U KONVENCIONALNOM ULJU ZA PODMAZIVANJE NA ČELIK AISI 52100

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Keywords
- AISI 52100
- tribology
- nanoparticles
- nano lubricant

Abstract

This study examines the application of nano lubricants on AISI 52100 steel surfaces. Spherical SiO_2 nanoparticles, ranging in size from 30 to 50 nm, are utilised to formulate the nano lubricants. Oleic acid (OA) serves as a surface-capping agent for SiO_2 nanoparticles. The morphology and crystallinity of these nanoparticles are analysed using high-resolution transmission electron microscopy (HRTEM) and X-ray diffraction (XRD). Fourier-transform infrared spectroscopy (FTIR) is employed to verify the presence of OA on nanoparticle surfaces. The tribological properties of nano lubricants are assessed using a Block on Ring Tribological Test Rig. The findings indicate that SiO_2 nanoparticles at a concentration of 0.5 wt.% achieve the greatest reduction in the coefficient of friction (COF) and scar width, with decreases of 48.27 % and 27.11 %, respectively.

Ključne reči
- AISI 52100
- tribologija
- nanočestice
- nano podmazivač

Izvod

U radu se istražuje primena nano podmazivača na površinama čelika AISI 52100. Sferne nanočestice SiO_2, sa dimenzijama od 30 d0 50 nm, su upotrebljene za pripremu nano podmazivača. Oleinska kiselina (OA) ima ulogu agensa za prevlaku sa nanočesticama SiO_2. Analiziraju se morfologija i osobine kristala ovih nanočestica korišćenjem transmisione elektronske mikroskopije visoke rezolucije (HRTEM) i metode difrakcije rendgenskih zraka (XRD). Tehnika infracrvene spektroskopije sa Furijeovom transformacijom (FTIR) je korišćena za ocenu prisustva OA u prevlakama sa nanočesticama. Tribološke osobine nano podmazivača se određuju korišćenjem tribometra sa blokom po disku. Rezultati pokazuju da nanočestice SiO_2 u koncentraciji od 0,5 % tež. postižu najveće smanjenje koeficijenta trenja (COF) i širine zareza, od 48,27 % i 27,11 %, respektivno.

INTRODUCTION

Nowadays, new tribological challenges are arising due to the modernisation in the technologies. The need for efficient and more economical lubricating oil is an essential need of the present times /1/. A variety of materials are used as tribological member materials, out of which AISI 52100 is a very common as a bearing material, /2, 3/. The reduction of the coefficient of friction and wear has been a major focus of researchers for the past several years. The required power loss between the pair of AISI 52100 needs to be reduced by the introduction of a nano lubricant, /4-7/.

The basic components of nano lubricants are nanoparticles (NPs), base oils, and suitable surfactants. The introduction of SiO_2 nanoparticles improves the tribological capabilities of the base oil /8-12/. In Reference /13/, it has been documented that there is a notable reduction in the COF as the concentration of SiO_2 nanoparticles increases from 0 to 0.6 wt.%. In a different scenario, when comparing the performance between SiO_2, graphite, Cu, CuO, and WS_2-SiO_2 in 15W40 lubricating oil shows the highest reduction in COF and wear by 25.55 % (at 588 N load) and 59.91 % (at 588 N load), /18/.

This research focuses on the effect of SiO_2 nanoparticles in conventional lubricating oil. The nanoparticles are first doped with oleic acid and then ultrasonicated in a base oil to prepare the nano lubricant. The prepared nano lubricant is being tested for wear resistance on the AISI 52100 steel surface. Block-on-ring configuration is used for the analysis of tribological performance of nano lubricants.

MATERIALS AND METHOD

Nanoparticles

SiO_2 nanoparticles are used to make nano lubricants. The average size of SiO_2 nanoparticles is 30-50 nm. These nanoparticles have been purchased from a supplier from Nano Research Lab, Jharkhand India. The shape of the SiO_2 nanoparticles is spherical and the specific surface area is 200-600 m^2/g according to the supplier's data sheet.

Nanoparticles are doped with oleic acid to improve dispersion stability. Four compositions of nanoparticles are used for the analysis which are 0.25, 0.5, 0.75, and 1 wt.%. The quantities of nanoparticles used to prepare nano lubricants are listed in Table 1.

Table 1. Quantities of NPs for nano lubricant preparation.

Expt. No.	NPs	% NPs	Oil (g)	NPs (g)
1	Base oil	0	100	0
2	SiO_2	0.25	100	0.25
3	SiO_2	0.5	100	0.5
4	SiO_2	0.75	100	0.75
5	SiO_2	1	100	1

Base oils

Conventional oil (Castrol GTX essential 15W-40) is used as a base oil for the preparation of nano lubricants. Conventional oil is used for this study because its lubrication performance can be potentially enhanced by using nanoparticles.

Methods

Formulation of nano lubricant

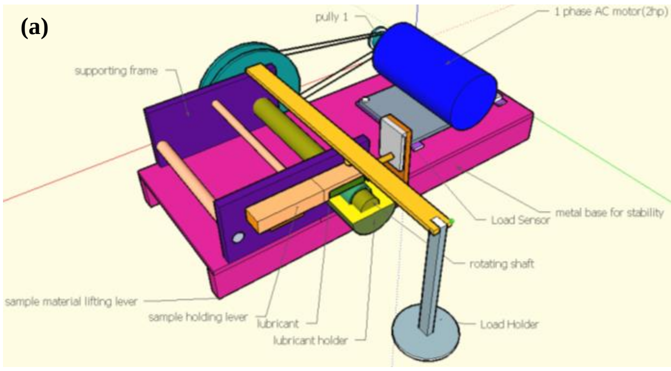
The surface of the nanoparticles is first modified with the help of oleic acid. The process of surface modification of nanoparticles is carried out with the help of a magnetic stirrer. Using a 250 ml beaker on top of a magnetic stirrer, first ethanol, and oleic acid within the beaker are stirred for 5 min at room temperature, and then nanoparticles are added to the solution and the solution is stirred until the dry nanoparticles are formed. These nanoparticles are then dried in a hot air oven at 100 °C for 4 hours. At the end of the process, the final dry surface-modified nanoparticles are used to prepare the nano lubricant. These surface-modified nanoparticles are used for the preparation of nano lubricants by extensive ultrasonication in the water bath for 4 hours.

Tribological testing

Tribological testing is conducted on a developed test rig in a block-on-ring configuration. This test rig is used to estimate the tribological capabilities of materials and lubricating oils. Figure 1 shows a pictorial representation of the test rig.

The load arm within the test rig is used for the application of the load. The speed is measured with the help of a rotation sensor. The friction force is measured with the help of a load sensor as shown in Fig. 1a. All the attributes of the experiments are saved with the help of a data logger.

The experiments are carried out for a rotational length of 5000 m at a speed of 1400 rpm. The load applied on the block is 50 N. Each experiment is repeated 3 times, and the average value is considered for further analysis.



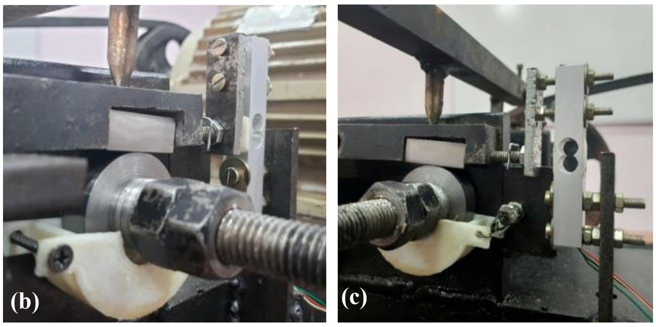


Figure 1. a) Tribological test rig; real images of test rig showing block on ring configuration, left view b); and right view c).

RESULTS

Characterisation

HRTEM

High-resolution transmission electron microscopy is employed to examine the morphology of the nanoparticles. The HRTEM images reveal that nanoparticles have an average size of 33.75 nm, falling within the 30-50 nm range. This also confirms the properties of nanoparticles given on the datasheet. Additionally, the images confirm that nanoparticles are spherical in shape. Figure 2 displays the HRTEM image of SiO_2 nanoparticles.

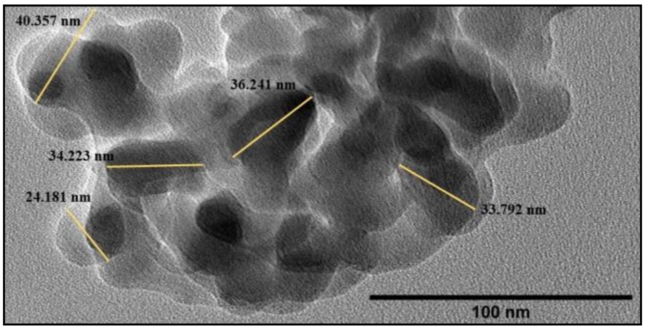


Figure 2. HRTEM image of SiO_2 nanoparticles.

XRD

Crystallinity of SiO_2 nanoparticles is validated through X-ray diffraction (XRD) analysis. The XRD pattern for SiO_2 reveals a prominent and well-defined peak at 35.28°, which is indicative of its crystalline structure. This peak confirms the presence of a crystalline phase in SiO_2 nanoparticles.

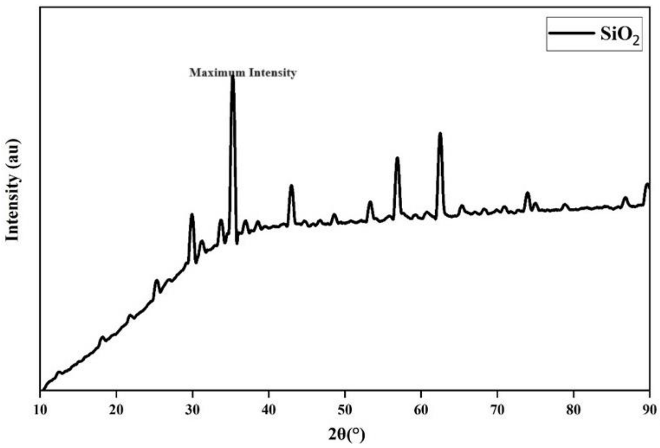


Figure 3. XRD pattern of SiO_2 nanoparticles.

Additionally, several other significant peaks are observed at 29.92°, 42.96°, 56.88°, and 62.48°, corresponding to planes 011, 102, 112, and 202, respectively /13-14/. These peaks further substantiate the crystalline nature of SiO_2 nanoparticles. Figure 3 provides a visual representation of the XRD pattern for SiO_2 nanoparticles, highlighting these distinct peaks and confirming their crystalline structure.

Fourier-transform infrared spectroscopy

FTIR spectroscopy is employed to verify the presence of oleic acid (OA) on the surface of SiO_2 nanoparticles. This analysis is conducted on both doped and non-doped nanoparticles. The FTIR spectra reveal distinct peaks at 1539 cm^{-1} and 2950 cm^{-1}, which confirm the presence of OA on SiO_2 nanoparticle surfaces /12, 14-17/. These peaks are indicative of the successful surface modification of nanoparticles with oleic acid. Figure 4 illustrates the FTIR spectra of SiO_2 nanoparticles, highlighting these characteristic peaks.

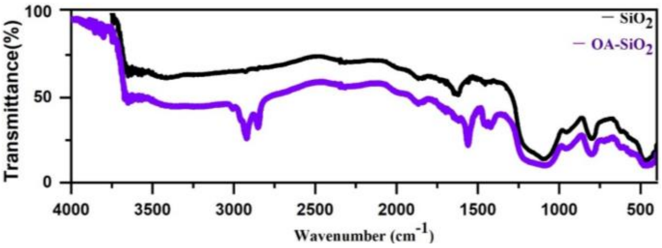


Figure 4. FTIR pattern of SiO_2 nanoparticles.

Tribological testing

Experimental investigation of tribological capabilities of nano lubricants is done by block on ring test rig. The test specimen blocks and rings are made of AISI 52100. This tribological test rig is extensively used for the assessment of dry and lubricated tribological behaviour of various materials. The results show that when base oil is used to estimate the COF and scar width, it is found to be 0.08 and 1.649, respectively. SiO_2 nanoparticles with 0.5 wt.% showed a maximum reduction of 48.27 % in COF. Here NPs reduce the COF from 0.08007 to 0.04142. It is also observed that when nanoparticles are used at 0.5 wt.% it reduces the scar by 27.11 %. The scar width reduces from 1.649 to 1.202 mm. Other results are listed in Table 2.

Table 2. Tribological testing results.

Ser. no.	Nano particles	% NPs	COF	% reduction in COF	Scar width (mm)	% reduction in scar width
1	base oil	-	0.08007	-	1.649	-
2	SiO_2	0.25	0.05540	30.81	1.412	14.37
3	SiO_2	0.5	0.04142	48.27	1.202	27.11
4	SiO_2	0.75	0.05087	36.47	1.31	20.56
5	SiO_2	1	0.05198	35.08	1.331	19.28

Figure 5 shows a graphical representation of the results for different compositions. The *x*-axis shows nanoparticles with their weight %, the *y*-axis shows the % reduction in COF and width of the scar. The graphical representation makes it easy to explain the findings in an effective manner. It is clearly seen in Fig. 5 that the reduction in COF and wear value increases with the use of nanoparticles from 0.25 to 0.5 and then decreases. So, it is clearly seen that the optimum quantity of nanoparticles is 0.5 wt.%.

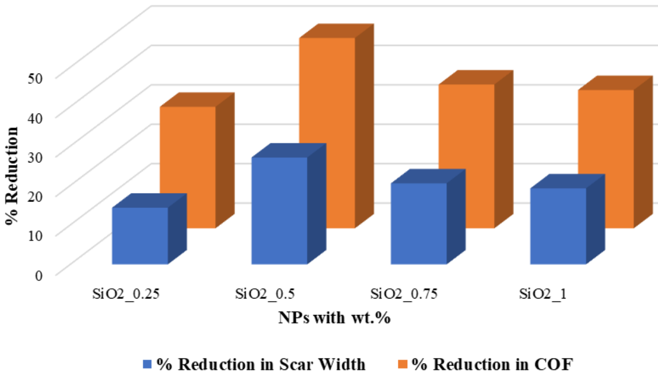


Figure 5. Graphical representation of results.

Wear scar analysis

Blocks and rings of AISI 52100 are used as test specimens. Wear scar images of blocks are used to analyse the performance of the nano lubricant. Figure 6 represents the scar images over the blocks.

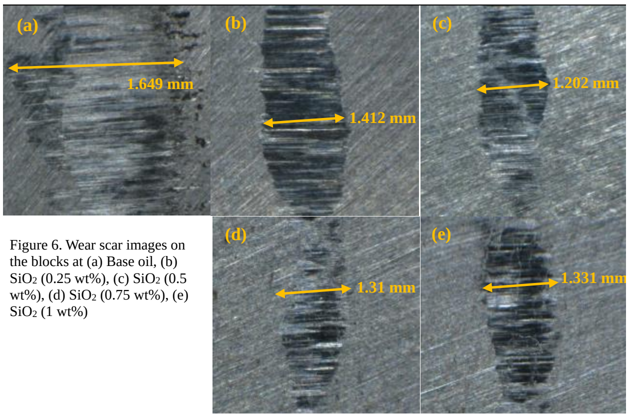


Figure 6. Wear scar images on blocks at: a) base oil, b) SiO_2 (0.25 wt.%), c) SiO_2 (0.5 wt.%), d) SiO_2 (0.75 wt.%), e) SiO_2 (1 wt.%).

CONCLUSIONS

This study aims to explore the tribological properties of nano lubricants enriched with SiO_2 nanoparticles on AISI 52100 steel surfaces. Inclusion of SiO_2 nanoparticles in the base oil significantly enhances its tribological performance. These nanoparticles, which are spherical and range in size from 30 to 50 nm, effectively reduce friction and wear. Oleic acid is used as a surfactant for SiO_2 nanoparticles, proving to be highly effective. Each composition tested shows a reduction in the coefficient of friction and wear values under a load of 50 N at a speed of 1400 rpm using a block-on-ring configuration. The optimal concentration of SiO_2 nanoparticles in conventional lubricant oil (15W-40) is found to be 0.5 wt.%. At this concentration, the nano lubricant achieves a maximum reduction in COF by 48.27 % and in wear scar width by 27.11 %. This significant improvement in the base oil's tribological properties is attributed to the ball-bearing and mending effects provided by SiO_2 nanoparticles.

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