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Mechanical and corrosion behavior of cuprous oxide nanoparticulates deposited AISI 5120 grade steel gear

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Abstract

In the present work the influence of cuprous oxide nanoparticulates on mechanical and corrosion behavior of AISI 5120 grade steel gear was investigated by using Vickers microhardness test, tensile test and salt spray test. Green synthesis precipitation method was used to produce the cuprous oxide nanoparticulates and then the synthesized nanoparticulates was deposited on steel gear face using sputtering technique. From the experimental results increase in microhardness of about 848 Hv, increase in tensile strength of about 555 MPa (↑8%) with reduction in area of about 55 % and outstanding corrosion rate of about 8 µm/y was observed for cuprous oxide nanoparticulates deposited steel gear than noncoated gear. Cuprous oxide nanoparticulates coating on steel gear face has strong influence on improvement in microhardness, tensile strength and corrosion rate than non-coated gear.

Keywords: Cuprous oxide, green synthesis, microhardness, tensile strength, corrosion rate.

I INTRODUCTION

Cuprous oxide is an inexpensive, non-toxic, abundance and simple processing red crystalline material suitable for mechanical, photovoltaic and optoelectric applications. The effect of special coatings on pitting damage of gears were reported by Moorthy et al [3]. They used C and Ni-B coatings on the gears. From their experimental results, the authors observed that the coated gears have exhibited slight improvement in contact fatigue performance. Wli et al. [4] carried out experiments on strength and deformations and investigated the characteristics of involute gear system for contact stresses, bending stresses and pitting failure. Mittal et al. [5] reported plant extracts for reducing metal ions to nanoparticles in a single-step green synthesis process and concluded biogenic reduction of metal ion to base metal is quite rapid. Stojanovic et al. [6] studied the tribomechanical behavior of gear boxes and pitting and they observed that results are correlated with the existing experimental results. Parikh et al. [7] used extracts of many plants for producing nanoparticles and they found that copper nanoparticles have excellent antimicrobial properties. Sadiasaif et al. [8] developed green production technique for making copper oxide (CuO) nanoparticles using aqueous extract of pterospermumacerifolium leaves. They used Visible spectroscopy, field emission scanning electron microscopy (FE-SEM), energy dispersive X-ray (EDX), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS) and dynamic light scattering (DLS) for various characterization studies and found plant-mediated CuO nanoparticles were oval shaped and well dispersed in suspension. Sweetysingh et al. [9] (2017) studied an environment friendly process for synthesis of nanoparticulates in the field of nanotechnology. Among all metal nanoparticulates, the copper nanoparticulates were plays a vital role due to its unique physical, chemical and biological properties. Copper nanoparticulate synthesis has been gaining attention due to its availability. The biogenic synthesis of copper nanoparticulate is considered to be a green and eco-friendly technology, since neither harmful chemicals nor high temperature are involved in the process. From the literature reports it was coating on gear to improve the microstructural, mechanical, tribological and corrosion properties but there was no attempt was made on cuprous oxide nanoparticulates by green synthesis technique. Hence the present work is focused on effect of green synthesized cuprous oxide nanoparticulate coatings on mechanical and corrosion behavior of AISI 5120 steel gear system. The samples were prepared with coating of green synthesized cuprous oxide nanoparticulates on a plain spur gear. Mechanical behavior of noncoated steel gear and cuprous oxide nanoparticulates coated steel gear were carried out by using Vickers microhardness tester and hydraulic operated tensile testing and corrosion behavior of samples by using salt spray corrosion technique.

II EXPERIMENTAL WORK

2.1 Green Synthesis

In this work green synthesis technique was used for producing cuprous oxide (Cu_2O) nanoparticulates. Copper as precursor and ammonium chloride with lactobacillus bulgaricus as reducing agent was used for processing Cu_2O in presence of datura leaf extract as bio-surfactant with an aqueous extract. Initially, 1000 ml lactobacillus bulgaricus was mixed with 100 g of ammonium chloride to make solution in stirring process. After that liquid molten copper of 250g is poured into the prepared solution. The color of solution is changed to yellow due to chemical reaction. Then copper mixture was taken out from the solution and allowed to settle down overnight and the supernatant solution was then discarded cautiously. In second step again melt the copper, which is separated from above first step, pour it in another vessel, which is containing datura metal leaf liquid washed with de-ionized water and ethanol for three times to take out the excessive starch bound with the nanoparticles. Ocher color precipitates obtained are dried at room temperature. After drying, Cu_2O nanoparticulates were stored in a airtight glass container for further analysis. The step by step synthesis process of Cu_2O nanoparticulates were shown in the figure 1.

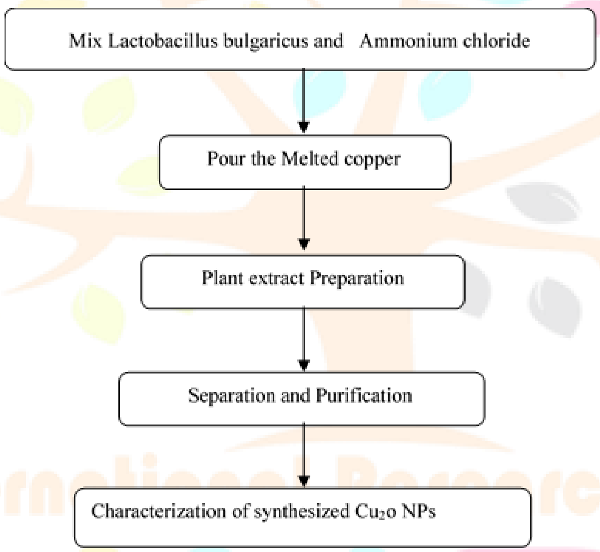

Figure 1: Cu_2O nanoparticulate preparation by green synthesis technique

2.2 Microhardness

Vickers Microhardness tester (at Omega inspection and analytical laboratory, Chennai) was used for testing the microhardness of cuprous oxide nanoparticulates coated/deposited steel gear and noncoated /deposited steel gear. Diamond shape right pyramid with square base, indenter face angle of 136° and maximum indenter load of 0.5 kg was used in this work. The indenter load applied on the gear sample for 10 to 15 seconds. An average of five indentations was made on each sample with a depth of 0.5m,1.0 mm and 1.5mm. Testing was carefully performed as per ASTM standards.

2.3 Tensile Test

Noncoated steel gear and cuprous oxide nanoparticulates coated steel gear have been used asper ASTM standards for measuring tensile properties. A hydraulic operated universal testing machine (Model: FIE UTN40, Load:Max.400 KN at Omega inspection and analytical laboratory, Chennai) was used to conduct the tensile test with a cross head speed of 0.15 mm/min at room temperature.

2.4 Corrosion Test

Corrosion properties of noncoated steel gear and cuprous oxide nanoparticulates coated steel gear have been tested by using salt spray corrosion method asper ASTM standards. The 5.4 % of sodium chloride (Nacl) solution with an exposure time period of 24 hours, chamber temperature between 34.3 ^{0}C -34.7 ^{0}C, salt solution of 7.1 pH, air pressure of 15 psi was used as salt spray testing parameters in this study Gear samples was cleaned properly before the test. The samples were cleaned gently in clean running water to remove salt deposits on the surface and then immediately dried for some time.

III RESULTS AND DISCUSSION

From the figure 2, it was observed that microhardness was significantly increased for coated steel gear due to deposition of Cu_2O nanoparticulates than non-coated steel gear. Maximum microhardness of about 848 Hv was observed for Cu_2O nanoparticulates coated steel gear, which was due to coating of fine grainsize of Cu_2O nanoparticulates. Cuprous oxide coating has strong effect on microhardness, tensile strength and corrosion rate of ALSI 5120 grade steel gear. From tensile test results presented in the Table 2 and Figure 4, it was noticed that there was a marginal increase in tensile strength (555 MPa), yield stress (389 MPa) and elongation (39%) with reduction % area of about 55, which was due to strong bonding effect of Cu_2O coated nanoparticulates on steel gear face and fine grain size of Cu_2O.

From corrosion test results presented in the Table.3 and Figure 4 it was noticed that, as the time increases from 0 to 5 years, the corrosion rate decreases from 40 to 8 **μm/y**. And also as the time increases the corrosion rate decreases either coated or non-coated gear tooth is used. In this experiment lubricant quantity is fixed. From the Figure 4, it is observed that corrosion rate can be estimated theoretically for any aspired time of the operation of the gear.

Table 1: Vickers Microhardness Test Results

S.No	Microhardness (Hv)	
	Non-coated	Coated
1	823	848
2	810	844
3	806	842

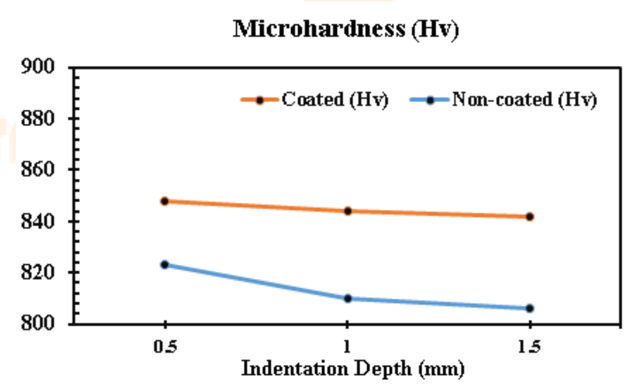

Figure 2: Microhardness of coated and non-coated sample

Table 2: Tensile Test Results

S. No	Property	Non-coated	Coated
1	Tensile Strength (MPa)	510.17	555.16
2	Yield stress (MPa)	371.77	389.55
3	Elongation (%)	35.86	39.54
4	Reduction (%) area	61.25	55.09

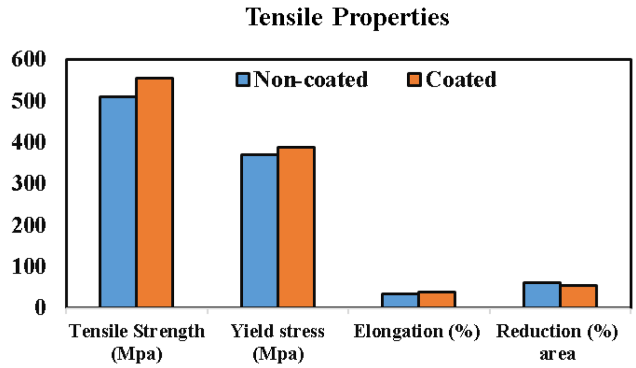

Figure 3: Tensile properties of coated and non-coated sample

Table 3: Corrosion Test Results

S. No	Time (hrs)	Corrosion Rate (μm/y)	
		Non-coated	Coated
1	1	62	40
2	1.2	56	28
3	1.5	50	20
4	2	44	13
5	3	32	11
6	3.6	25	10
7	4.2	18	10
8	5	12	8

Corrosion rate of coated gear was lower than that of non-coated gear. Red rust was formed on non-coated gear whereas no rust was observed on coated gear due to strong resistance of cuprous oxide nanoparticulate coating on the gear face. Cu_2O nanoparticulate coating on steel gear significantly improved the corrosion rate than non-coated gear. The corrosion rate of samples can be defined by penetration rate. It is the thickness loss of metal per unit of time. The rate of corrosion can be expressed in many ways such as μm/y (micrometer per year), mpy (mils per year) and mm/y (millimeter per year). The corrosion resistance can be classified based on the corrosion rate obtained from any one of the corrosion test. The corrosion rate less than 20 μm/y indicates outstanding corrosion resistance, corrosion rate between 20-100 μm/y indicates excellent corrosion resistance, corrosion rate between 100-500 μm/y indicates good corrosion resistance, corrosion rate between 500-1000 μm/y indicates fair corrosion resistance, corrosion rate between 1000-5000 μm/y indicates poor corrosion resistance and corrosion rate greater than 5000 μm/y indicates unacceptable range of corrosion. Both coated and non-coated steel gear shows excellent resistance towards corrosion in Nacl solutions. The corrosion properties of nanoparticulate deposited/coated steel gear is affected by various parameters such as atmospheric conditions, composition, grain size, deposition method etc., When compared to non-coated steel gear cuprous oxide (Cu_2O) coated steel gears have significant potential for improving outstanding corrosion behavior due to fine size of nanoparticulates, which allows for improved space filling and coating surface integrity. A Cuprous oxide nanoparticulates is deposited on the steel gear improves the physical properties of gear and allows it to be utilized as an efficient nanocoating. Cu_2O nanoparticulate coatings inhibit corrosion by forming a compact barrier and eliminating charge transfer such as oxygen permeability and ion movement. Furthermore, the Cu_2O nanoparticulate coating increases some other properties to improve corrosion performance such as cohesive and adhesive capabilities, hydrophobicity, agglomeration and distribution properties.

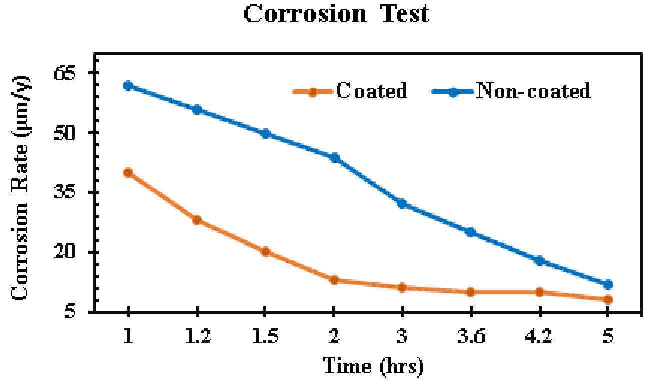

Figure 4: Corrosion rate of coated and non-coated sample

IV CONCLUSION

In this work green synthesized cuprous oxide nanoparticulate have been successfully processed, successfully coated on 5120 grade steel gear and then mechanical and corrosion behavior of cuprous oxide nanoparticulate coated and non-coated steel gear was investigated in detail. The conclusions derived from the testing are as follows:

- From the mechanical testing results, there is an increase in microhardness of about 848 Hv, and increase in tensile strength of about 555 MPa was observed, which as due to proper bonding of nanoparticulate coating on steel gear and also due to fine grains of cuprous oxide nanoparticulates.

- From the corrosion test results, it was observed that the Cu_2O nanoparticulate coating on steel gear significantly improved the corrosion rate than non-coated gear and forming a strong barrier on gear surface to prevent corrosion.

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