Investigation of Mechanical Properties on Nano Cuprous Oxide Coated/Uncoated Spur Gear

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October 1, 2020

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Abstract: Metals and their alloys have been widely used in all aspects of science and engineering. However the science of nanotechnology is driving newer demands and requirements for better performance of existing materials and also at a higher level of precision. This is naturally presenting complicated demands on the surface of these metals with a need for surface modification. In the present scenario it is noteworthy that nano scaled particle coatings enhances the mechanical properties in the metals rather than the macro or micro sized particles. Hence an attempt was made to characterize the mechanical properties of cuprous oxide nano particles coated spur gear (Mild Steel). The mechanical properties such as tensile, hardness and corrosion (salt spray) were experimentally investigated at ambient condition. A deep compression had been made between the coated and uncoated gear. The results reveal that the coated gear shows better performance compared with uncoated gears.

Key Words: Spur gear, cuprous oxide, Tensile strength, Elongation at break.

1. Introduction

The possibility of lightening mechanical components is becoming more and more important for the future, particularly in the automotive and aerospace fields, where the availability of more power with low gas polluting emission is fundamental. However, very often the fatigue behaviour, as well as the wear resistance and load bearing capacity of light alloys are poorer than the ones of steels. From this point of view, thin hard coatings deposited by means of PVD (physical vapor deposition) technique enables enhancement of hardness, wear, corrosion resistance and mechanical properties of mechanical components and are, for the time being, widely used in an increasing number of applications [1, 2]. A few decades ago, the cutting and machining tool field was the first to be interested in the improvements of the tribological properties achieved with these coatings, and from then on, their development has interested many other industries such as aerospace, automotive and biomedical ones.

Research studies have also demonstrated that the mechanical and corrosion properties of coated components can be increased by some coatings [3–10]. In fact, the residual compressive stresses induced at bulk material surface by some deposition processes prove beneficial to the fatigue resistance, provided that the coating is uncracked and free of defects.

Therefore, coated light alloys with similar or even better performances than the ones of traditional construction steels would be really important for structural and competition applications (11). In the present research work a spur gear mad of mild steel is considered. Further the Cuprous oxide nano particles were synthesized through bio synthesis precipitation method and it is coated on the gear with high temperature and normal temperature. The coated gears were subjected to mechanical and corrosion examination with certain parameters respectively.

2. Experimental details

2.1. Extraction of cuprous oxide nano particles

The Cuprous Oxide (Cu_2O) nanoparticles is synthesized with green synthesis method The synthesis process uses copper as precursor and ammonium chloride with lactobacillus bulgaricus as reducing agent in presence of datura metal leaf extract as bio-surfactant in an aqueous medium.

Initially, 1000ml of Lactobacillus bulgaricus is added with 100gm of Ammonium chloride followed by continuous rapid stirring to prepare a solution. Next 250 gm of melted copper is mixed with the prepared solution. Thus upon mixing the solution changes its colour to yellow which indicates the reaction between the copper and the prepared solution came to an end. Now the copper can be separated from the solution and allowed to settle overnight and the supernatant solution was then discarded cautiously. Secondly melt the copper which is obtained from the above step and mix it with a solution made of Datura Metal Leaf liquid. Wash it with de-ionized water and ethanol for three times to take out the excessive starch bound with the Nano-particles. Ocher color precipitates (Fig. 2) Obtained are dried at room temperature. After drying, Nano-particles were stored in glass vial

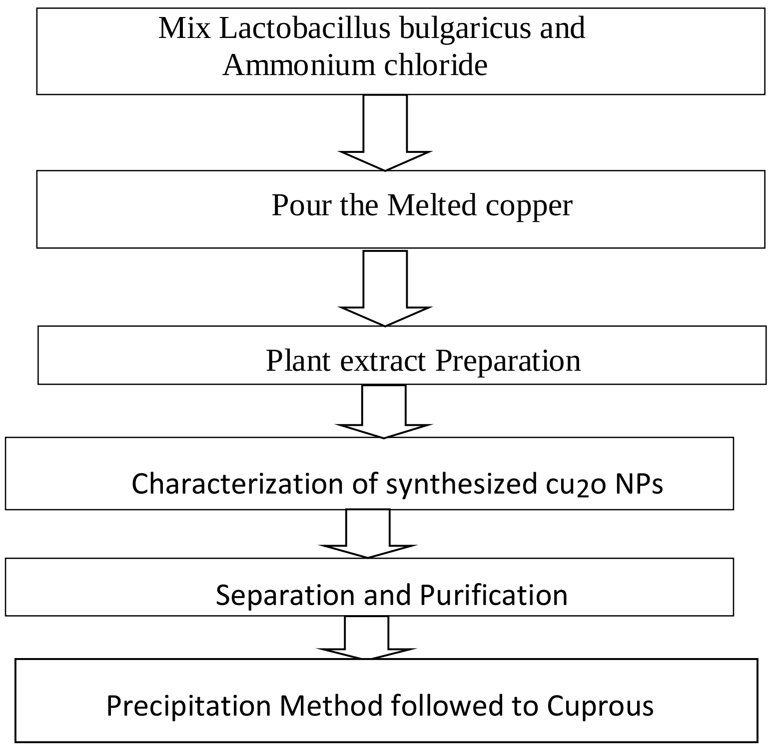

Fig.2.1. Methodology for Cu_2O nano particle extraction

2.1Coating of cuprous oxide nano particles on spur gear

In the present research work the green synthesized cuprous oxide nanoparticles had been coated on the spur gear substrate made of mild steel. The thin film coating is achieved by means of physical vapor deposition process namely sputtering. The sputtering method of thin film deposition involves introducing a controlled gas, usually chemically inert argon, into a vacuum chamber, and electrically energizing a cathode (Cu_2O nanoparticles) to establish a self-sustaining plasma. The exposed surface of the cathode, called the target, is a slab of the material to be coated onto the substrates. The gas atoms lose electrons inside the plasma to become positively charged ions, which are then accelerated into the target and strike with sufficient kinetic energy to dislodge atoms or molecules of the target material. It can be thought of as a sort of atomic scale bead blasting. This sputtered material now constitutes a vapor stream, which traverses the chamber and hits the substrate, sticking to it as a coating or "thin film".

2.2. Characterization of coated spur gear

2.2.1. Tensile behaviour

Tensile strength and percentage elongation at break measurements are among the most important indications of the strength of the material and are the most widely specified properties of the materials. The tensile property data are more useful in preferential selection of a particular type of plastics from a large group of plastic materials.Tensile properties such as tensile strength and percentage elongation at break were tested using microprocessor controlled universal testing machine (UTM), with an accuracy of ± 2 MPa. The specimens were prepared as per ASTM standard. A minimum of five samples were tested at room temperature for each composition and an average value was taken.

2.2.2 Tensile strength

The ultimate tensile strength (UTS) is the maximum stress a material can withstand while breaking. The tensile strength of a coated spur gear depends on the bonding between the coating and the substrate. The function of the substrate is to transfer the stresses to the load bearing coatings.

Tensile strength = Load at break / original cross-sectional area

$$= P / b \times d$$

Where, P is the load applied in N, b is the width in mm and d is the thickness in mm

2.2.3 Elongation at break

Ductility is a qualitative, subjective property of a material and the measurement of ductility is of interest to indicate to the designer, in a general way, the ability of the metal to flow plastically before fracture. The conservative measures of ductility that are obtained from the tensile test are the engineering strain at fracture (typically called elongation) and the reduction of region at break. In this examination, the elongation of the specimen at break has been computed by the accompanying expression (Budinski1998).

$$Elongation\ at\ break = Lf x\ 100/L0$$

Where Lf is the final gauge length after failure and L0 is the initial gauge length before loading (here the gauge length has been maintained as 50 mm).

2.2.2. Vickers Microhardness Test (VMH)

Three cylindrical specimens (5mm in diameter × 2 mm in length) were prepared from coated/uncoated gears. Each specimen was polymerized for 20 seconds. Vickers microhardness test (Shimadzu HMV; Shimadzu Corporation, Tokyo, Japan), was performed at the top (depth=0 mm) and bottom (depth=2 mm) surfaces of each specimen (three indentations for each specimen), using a 50-g load for 15 seconds.

3. Result and discussion

3.1 Tensile behaviour of coated and uncoated gear

3.1.1 Tensile properties of Non-coated and coated gear tooth

The variation in the tensile strength of the cuprous oxide coated and uncoated spur gear is displayed in table 3.1. The maximum tensile strength obtained was 555.16 MPa. Theoretically, the maximum coating strength of the substrate is gained by incorporating a high weight fraction of coating material. Thus there is an efficient stress-transfer mechanism at the coating-substrate interface occurs. Strong interactions allow more efficient load transfer and, hence, better mechanical performance. In comparison to the other metals, mild steel has the unusual ability to accept hard coatings. Besides that it might be due to the homogenous dispersion of nano cuprous oxide coating on metal substrate matrix the interfacial adhesion between Cu_2O and mild steel increased which results in the enhancement in the tensile properties of resultant material.

Table 3.1. Tensile Test Results

S.No	Property	Coated	Non-Coated
1	Tensile Strength (Mpa)	555.16	510.17
2	Yield stress (Mpa)	389.55	371.77
3	Elongation(%) in Gauge length of 50mm	39.54	35.86
4	Reduction (%) area	55.09	61.25

3.1.1 Elongation at break

Elongation at break (Eb) of the mild steel(Spur gear) substrate coated by nano cuprous oxide is shown in table. 3.1 The addition of Cu_2O coating increases the tensile elongation at break from 35.86% to 39.54%. This is due to the interference of coating in the mobility or deformability of the substrate. This interference is created through the physical interactions and immobilization of the mild steel substrate by the presence of mechanical restraints thereby reducing the elongation at break [12].

3.2. Chemical composition

In the present research after the coating process had been finished the specimens are subjected to chemical composition test to evaluate the materials present in the specimen. This test is assisted with Optical Emission Spectroscopy (OES). Optical Emission Spectroscopy (OES) is found to be the most accurate and reliable technique for producing qualitative and quantitative analysis of materials composition. It works by exciting atoms with energy that comes from a spark formed between the sample and electrode. The material composition of coated and uncoated specimens where depicted in table 3.2.

Table 3.2. Chemical composition

Equipment used: Optical Emission Spectroscopy (OES) - Foundry Master-Pro, Oxford, Germany		
Element	**% weight**	
	Without coating	**With coating**
Carbon	0.42	0.40
Manganese	0.63	0.63
Silicon	0.22	0.20
Sulphar	0.004	0.009
Phosphorous	0.008	0.010
Chromium	0.026	0.051
Nickel	0.021	0.014
Cobalt	0.004	0.004
Copper	0.034	0.002
Niobium	0.003	0.004
Titanium	0.004	0.003
Vanadium	0.009	0.008
Tungsten	0.01	0.02
Lead	0.007	0.007
Bismuth	0.016	0.019
Nitrogen	0.081	0.074
Molybdenum	-	0.005

3.3. Vickers micro hardness

The variation in the hardness of coated and uncoated spur gear is evaluated using Vickers micro hardness tester and it was displayed in table 3.3. From the table it is inferred that there is an increase in hardness when compared with uncoated spur gear. This improvement in hardness was attributed to the formation of adhesive properties on the substrate. The microhardness of the Cu_2O coated samples under were carefully observed and studied.. It is evident from the study that the microstructure evolved in coating depends on the processing parameters and hence such metallurgical parameter influence the grain size which is paramount to the buildup of surface hardness(13).

Table 3.3. Micro Vickers Hardness Test

Sample No	Property	Type of Coating	
		Non-coated	Cu_2o Nano Coated
1	Vickers Hardness	823	848
2		810	844
3		806	842

3.3 Corrosion Test

Corrosion test provides controlled corrosive environment and it has been used to produce relative corrosion information for specimens of metals. Salt spray Test is used to predict the corrosion. The Test Parameters are listed in the Table 3.4 and the results where depicted in table 3.5.

Table 3.4. Salt spray Test Parameters

S No.	Parameter	Value
1	Concentration of Sodium chloride	5.4% NaCl
2	Chamber Temperature	34.3^0 C -34.7 ^{0} C
3	pH of Salt solution	7.1
4	Air Pressure	15 psi
5	Collection of Solution per Hour	1.4 ml
6	Method of cleaning of specimen before loading and after completion of Testing	a) Specimen cleaned gently prior to loading b) Specimen washed gently in clean running water to remove salt deposits from their surfaces and then dried immediately.
7	Required exposure period	24 Hrs
8	Exposure period	24 Hrs

Table 3.5. Corrosion Test Results

S No	Time	Observation
1	At 24 Hrs (Non Coated)	Red rust Observed
2	At 24 Hrs (Coated)	No Corrosion

4. Conclusion

In the present work, green synthesized cuprous oxide nanoparticles where coated on spur gear and subjected to mechanical and corrosion test. It is noted that the tensile strength increases in coated gear when compared with the uncoated gear. The elongation at break increases with the coating on spur gear. The Vickers hardness test show there is a gradual decrease in hardness compared to coated and uncoated gears.

The corrosion resistance of the coated spur gear is high compared with uncoated gear. It is seen from the specimen that for uncoated upon 24hrs of salt spray a red rust is observed whereas in coated gear no corrosion is seen. It is concluded that cuprous oxide coated gears shows better properties compared with uncoated gears.

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