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Fatigue Performance Analysis of Ni-WC Composite Electro-Coated Gears

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***Abstract*—It has been observed that very few studies are concentrated on nickel composite coating on gears. Though found economical and effective, electro-deposition is rarely used to coat the gears. Only a few researchers have designed and implemented a proper test rig to study the contact fatigue of gears. Also there is found to be absence of mechanical properties of Ni/Ni-WC coating. There is lack of information regarding the FE analysis of coated gears. Therefore, the research work is carried to analyze the fatigue performance of gears using Finite Element Method.**

***Index Terms*— Fatigue, Electro- co deposition Ni-WC, coated, uncoated gears, FEA, Vibration.**

I. INTRODUCTION

Electroplating is consistently used to change surface properties of an article, for example, wear resistance, hardness, corrosion resistance etc. [1]. It is known not the most temperate and simple technique for coatings Numerous endeavors have been made to discover techniques for improving the surface properties of metal segments to secure against consumption, wear and pitting and diminishing their expenses since every one of them are the powerful factors the erosion of modern parts. Electrodeposition is considered as a standout amongst the most critical and financially savvy modern systems for delivering defensive coatings [2].

For Electrodeposition Nickel is frequently used. Ni coatings offer corrosion resistance, wear resistance alongside aesthetic quality to the part. Nevertheless, the extents of such coatings are constrained by the life range, mechanical quality, and wear and consumption imperviousness to the harsh environment. Numerous studies have demonstrated that Ni composite coatings upgrade the properties by expanding the nucleation destinations creating decrease in crystallite size prompting changed mechanical properties of the deposit. Along these lines these WC composite coatings draw attention in consideration and a wide range in applications [3].

Rolling Contact Fatigue is accountable for the failure of moving parts, gears, cam-shafts and incorporates breaking or setting/delamination limited to the nearby surface layer of bodies in rolling/sliding contact [4]. Contact fatigue results from a contact or Hertzian uneasiness state. This bound tension state results when rolling surfaces are in contact under

heavy loads. The contact geometry and the development of the moving parts convey a substituting subsurface shear stress. Subsurface plastic strain develops with expanding cycles until a crack is produced [5].There is

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formation of cavities in the component, and the operation becomes very noisy and rough. If the crack is allowed to extend it leads to disastrous failure of the component [6].The gear tooth fails mainly due to cavity formation or pitting [7].FEA can be used to predict the fatigue life of gears [8]. Computational models to fatigue initiation analyses are based upon the method which determines the ratio between the specific deformation and the number of loading cycles, often referred to as local stress-strain method. Vibration analysis can be carried out using a Vibration pick device which can be a accelerometer, velocity pick up or eddy probes [9]. It can be used to evaluate the smoothness of operation based on the output waveforms displayed by the device [10].

The FFT decomposed data to be transformed into a series of smaller data sets. Then, it composes those sets into even smaller data sets. At each stage, the results from previous steps are combined in unique way [11].

FEA of Gears

The FEA of non-coated and coated gears was conducted using static structural module in ANSYS workbench 14.0. The modeling was done using Solidworks-2014. The 3D model was later imported into ANSYS workbench into the Design Modeler. Following are the parameters of the gear.

- Type: Spur Gear
- Module: 2.5
- Number of teeth: 52
- Pitch Circle Diameter: 130 mm
- Outer Diameter: 135 mm
- Root Diameter: 123.75 mm
- Addendum: 2.5 mm
- Dedendum: 3.125 mm

The primary simulations were carried out with a gear with all its teeth modeled Figure 1 as the mesh refinement was conducted the time increased by large extent and to reduce the duration of the simulation the gear with few teeth was modeled Figure 2 to carry out the analysis.

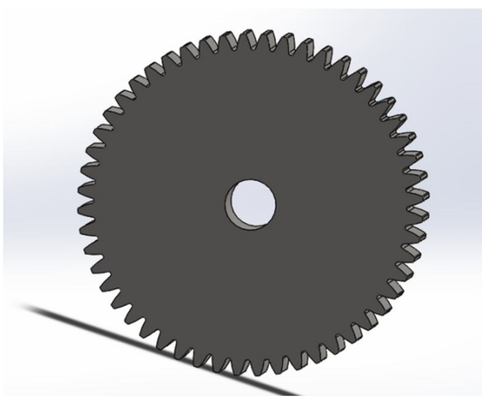


Figure 1. Gear with all teeth modeled

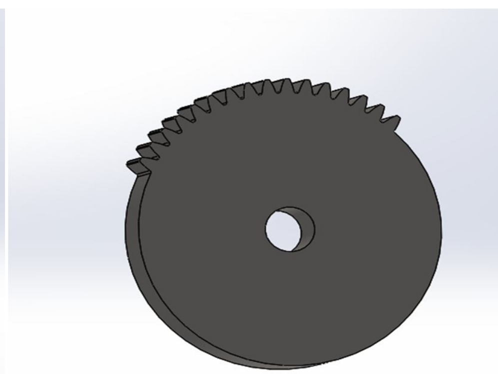


Figure 2. Gear with few teeth modelled

The two gears were meshed as shown in Figure 3

The meshing of the gears was initiated with the element size as minimum size/5. The mesh was further refined using the Advance Functioning tool with proximity “on”. The meshing was performed such that the element size was minimal around the gear teeth as they are critical features on the body which will be involved in the contact stress determination, while the remaining bulk of the gear was meshed with larger element size. Figure 4 gives the outlook of the mesh applied on the gears.

In the gear pair, the driver gear shaft area was made frictionless since a bearing was being use on the shaft followed by restriction of the gear translate about x, y, z axis and rotation about x, y and free about z. A moment was applied on the driver gear of 2.5 Nm since the gears were being loaded by pulley and rope system the moment was limited. It is shown in Figure 5.

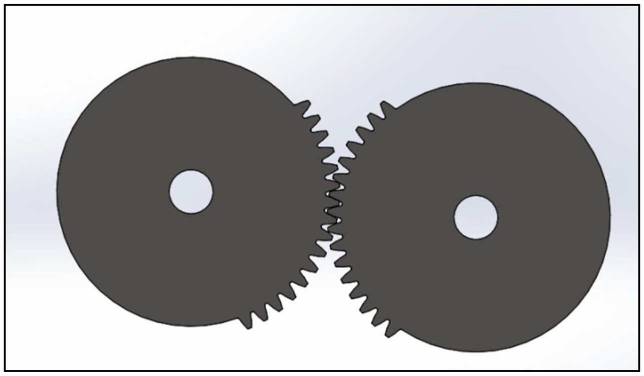


Figure 3. Gears in mesh

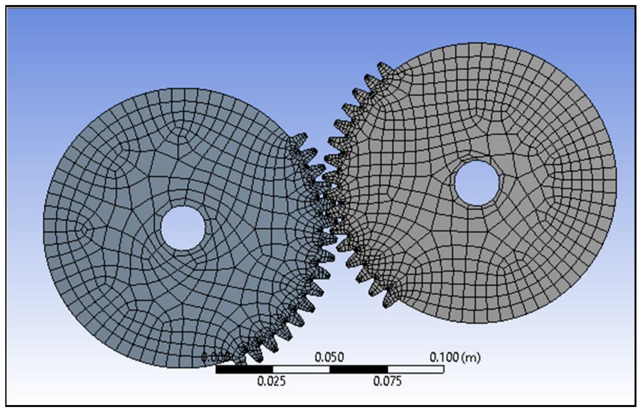


Figure 4: Meshing applied to pair of gears

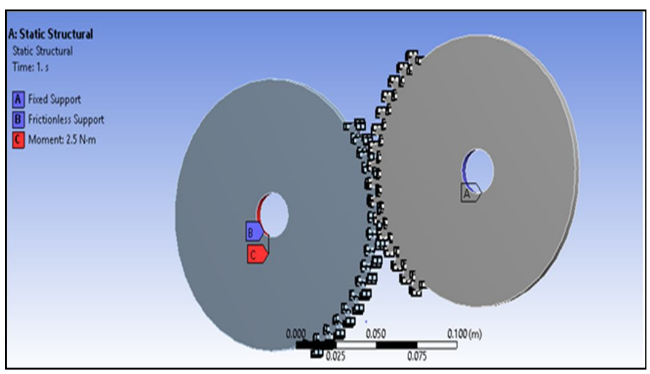
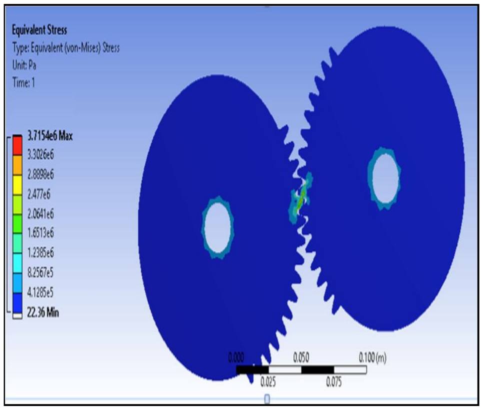


Figure 5. Boundary conditions applied on gear pair

To evaluate the contact fatigue performance of the Ni-WC coated gears the Equivalent Von Mises and Fatigue tool were used. It gives the single stress value after working down from several complex stresses. After applying all of the boundary condition and using proper tool to solve the problem, results were obtained in the form of plots. Figures 6 and 7 gives the stress plot and Figure 8 gives the life plot for the gears.

The modeling involved creating a shell like structure Figure 9 around the gear, which would behave as a coating of Ni-WC on the gears, and this was the additional step in modeling in comparison with the non-coated gears. Thickness of this layer was taken to be 100µm.

Figure10 and 11 give the stress solution for coated gears and stress distribution plot respectively.



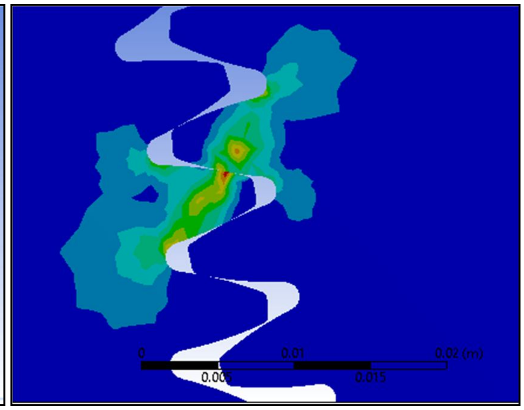


Figure 6. Stress plot for non-coated gears

Figure7. Stress plot at contact region

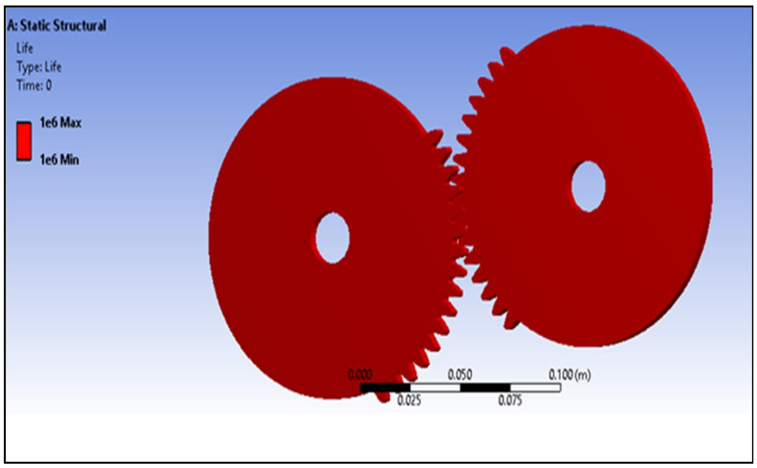


Figure 8 .Life Plot

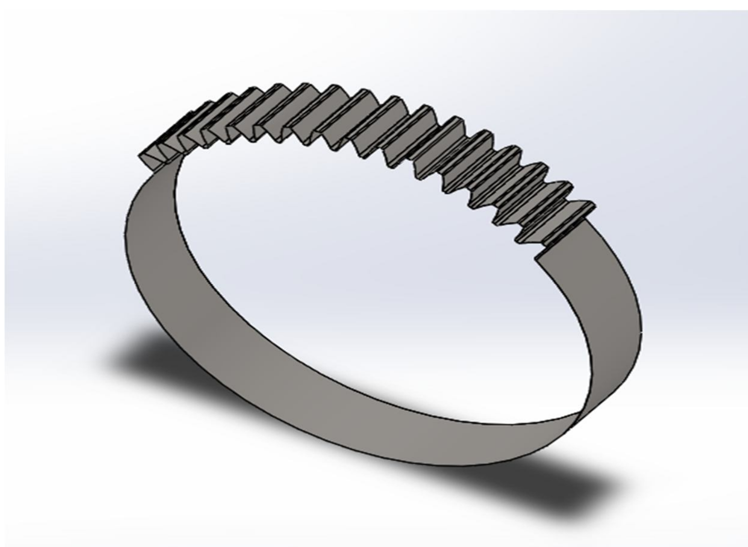
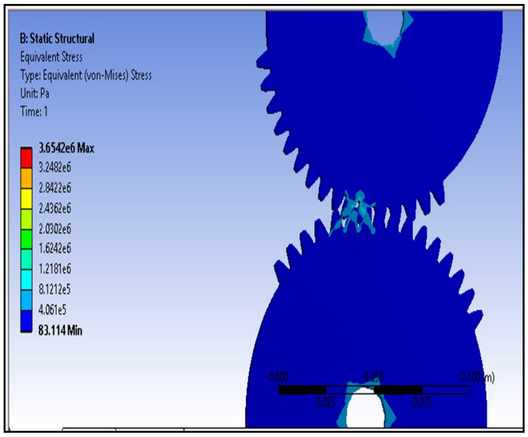


Figure 9.Coating layer modeled for gears



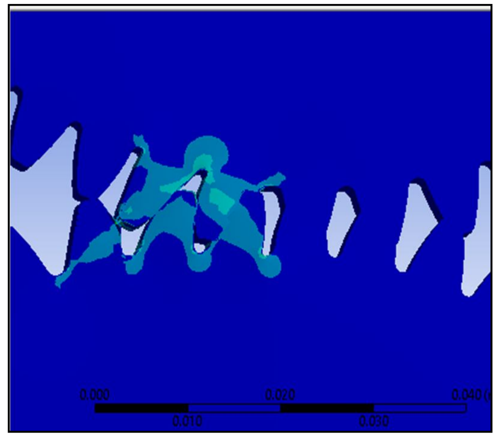


Figure 10. Stress plot of Coated Gears

Figure 11. Stress at the contact region for coated gears

II. Experimental Procedure

A. Fatigue Testing

Testing gears were mounted on the test rig Figure 12 and meshed properly. Torque is applied on gear by using a rope drive. It is varied as 0, 0.44, 0.74, 0.88, 1.32 Nm using standard weights to produce tension in rope. Each torque was applied for a period of 4 hours and gears were continuously running at constant rpm.

Figure 12. Fatigue Test Rig

Figure 13.Coated gears

For measurement of vibrations at the base plate, vibration pick up device is used. It is connected to Cathode Ray Oscilloscope (CRO) to display the vibration waveform. The vibration plots were obtained at three different positions and the coating was done by using Electro co deposition technique. The coated gear is shown in Figure 13.

III. Results

The stress analysis was done for gears with and without coating under various conditions.
The stress values for gears without coating were obtained at the following conditions

- Torque – 2.5 Nm
- Rotational Speed – 24 RPM
- Boundary Conditions:
- Driver Gear Support – Frictionless
- Driven Gear Support – Fixed
- Table1 illustrates the stress values

TABLE I. STRESS VALUES FOR NON-COATED GEARS

Element Size (mm)	Stress (MPa)
7	3.71
6	4.02
4.8	4.56

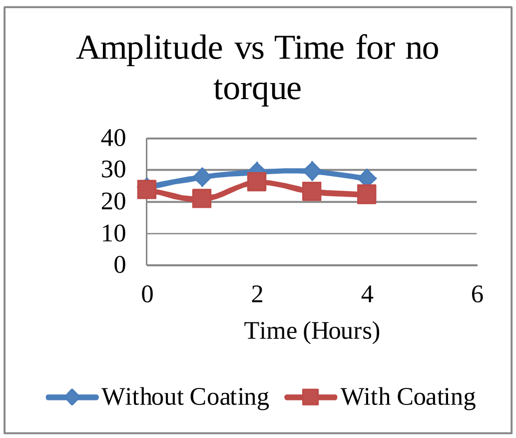
Solution convergence for coated gears was obtained at a mesh size of 4.8 mm for coated gears; hence the analysis for coated gears was done at that mesh size Results are presented in Table 2.

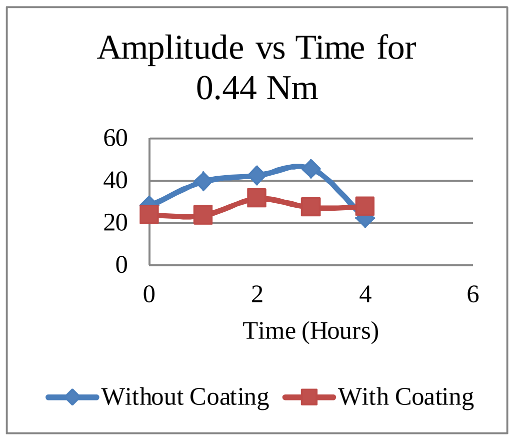
TABLE II: STRESS VALUES FOR COATED GEARS

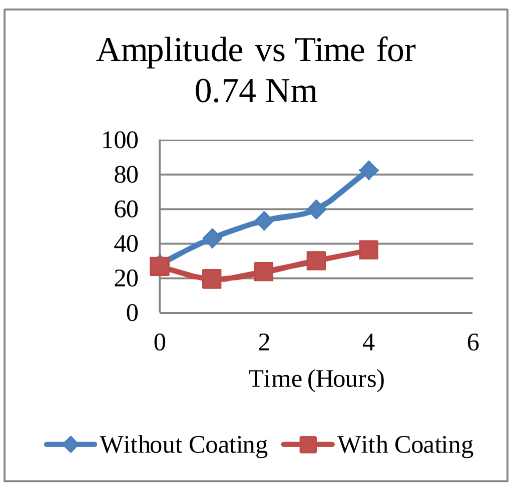
Element Size (mm)	Stress (MPa)
4.8	3.65

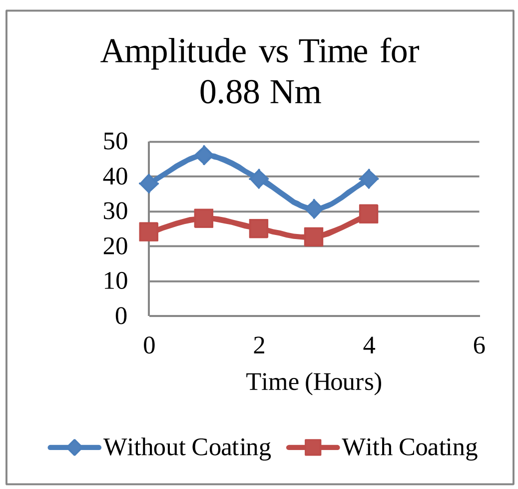
Comparison of the average of maximum amplitudes of the three positions

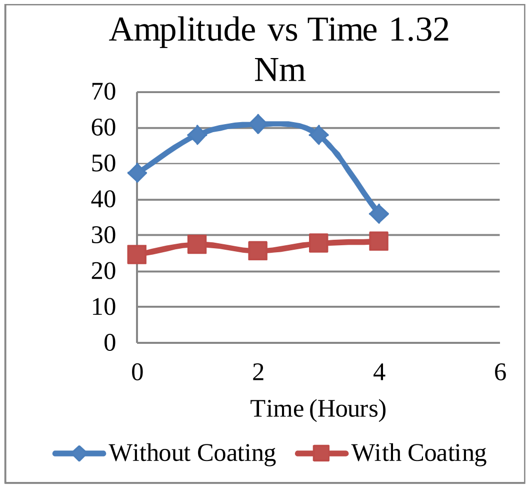
A plot of Amplitude v/s time comparing the average of maximum amplitudes for coated and non-coated gears for no torque and different torques are shown below











For no torque Amplitude of vibration starts increasing with time for non-coated gears, while it reduces initially for coated gears due to a more wear resistant surface.The increasing amplitude trend continues till the third hour of operation for non-coated gears, while for the coated gears amplitude starts to increase after one hour because of preliminary surface wear and starts to decrease from the second hour. Vibration amplitude again decreases due to the harder Ni-WC surface. A cyclic pattern is observed for coated gears.
For 0.44 Nm torque the amplitude of vibration for non-coated gears increases with time till the third hour. Non-coated gears show steady vibration amplitude till the first hour. This is because of the improvement in wear resistance induced by Ni-WC.After preliminary surface wear, coated gears show an increase in amplitude till the second hour. Then again the fresh Ni-WC surface provides wear resistance, thereby reducing vibration. At the end of the fourth hour the amplitude trend is tending to stabilize for coated gears.
For 0.74Nm torque the amplitude of vibration decreases till one hour for coated gears and then starts to increase at a steady rate. The increase continues till the fourth hour. The higher value of applied torque and longer operation time are accounted for higher wear. Non-coated gears show an increase trend in amplitude of vibration. The difference between the amplitudes of vibration of coated and non-coated gears increases with time.
For 0.88Nm torque For both coated and non-coated gears, the amplitude of vibration increases with time till the first hour due to the increase in torque and cumulative operation time. Loss of preliminary surface after fretting wear reduces vibrations till the third hour. The start of fretting wear on the fresh surface promotes increase in amplitude for both coated and non-coated gears. The amplitude of vibration remains to be lesser for coated gears.
For 1.32Nm torque, increase in applied torque increases the amplitude of vibration rapidly for non-coated gears. Coated gears show a very slight increase in amplitude. Though the non-coated gears have an increasing amplitude trend, the coated gears show a decrease in amplitude till the second hour due to the loss of preliminary contact surface. The wear of the fresh surface promotes an increase in amplitude till the third hour, after which the amplitude tends to remain steady. After 3 hours of operation the amplitude of vibration decreases for non-coated gears due to loss of the worn out surface and the onset of fresh contact surface.

IV. Conclusions

On comparison of the tabulated results of the coated and non-coated gears it was evident that the stress was reduced after implementation of Ni-WC coating on the gears by 1.2MPa and life was 10^6 cycles since the loading remained below the endurance limit. Simulation conducted with a suitable torque applied on the gears depicted that the life after coating was improved by 10 %.
FEA analysis was carried out in several iterations with varying gear module, mesh size, element type to obtain converging solution. Element size of 4.8 mm and hexahedral element type provided more accurate results.

It was clear from all the plots obtained in time domain and frequency domain that the amplitude of vibration decreases for coated gears. Reduction in amplitude indicates reduction in fretting wear due to rolling contact fatigue. Hence lesser wear can be accounted for better shear stress distribution on the gear tooth. Lesser stress increases the fatigue life of gears which is a direct result of electro coating of Ni-WC composite.
The amplitude of vibration had a steady increase pattern for the non-coated gears while the coated gears were found to have a slower increase in amplitude with time.

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