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Experimental Investigations to Enhance the Tribological Performance of Spur Gears Using Titanium Nitride Coating

Suhas S Aralikatti [1], Hemantha Kumar [1], B.S Ajay Vardhaman [2], M. Amarnath [3*]

[1] National Institute of Technology Karnataka, Surathkal, Mangalore 575 025, Karnataka, India
[2] Material Science Programme, Indian Institute of Technology, Kanpur, 208016, India
[3] Tribology and Machine Dynamics Laboratory, Department of Mechanical Engineering, PDPM - Indian Institute of Information Technology Design and Manufacturing, Jabalpur, 482005, India

Abstract

The surface is the primary element for two bodies coming in contact to transfer motion and load. Gear tooth surfaces must be tolerant to wear, scratch, scoring in order to have a better service life. Thus it is very important for contacting mechanical bodies to have better rigidity, hardness, and smoothness to combat all the damage and failure mechanism. The development of micro-pitting damage over surface modifies the geometry of the gear tooth profile which in turn alters the contact stress across the gear flank. This leads to high contact stress at local region and makes the rotation of gears very noisy, low performance and prone to premature failure. In the present study experimental investigations are carried out to assess surface fatigue failure in spur gears mounted in a single stage gear box operated under constant load and constant speed conditions. Friction co-efficient, gear tooth thickness and surface roughness have been considered to assess surface fatigue failure of uncoated and coated spur gears. Analysis of the results revealed that Titanium Nitride (TiN) coated spur gears showed reduced co-efficient of friction, surface roughness and gear tooth reduction rate than that of uncoated spur gears.

Key words: Titanium Nitride (TiN), fatigue, micro-pitting, gear tooth.

1. INTRODUCTION

Gears are rotating mechanical elements used for transmitting force and motion to accomplish a desired work or need. Gears transmitting large loads suffer from bending fatigue and surface fatigue. Surface fatigue result in surface wear such as micro-pitting, adhesion wear, scuffing, and scoring. Surface fatigue were known as an important factor in gear failure; pitting is one type of surface fatigue and often occurs in the early stages of gear failure. As pitting occurs, the load is applied only on a finite region of the gear, at the same time contact stress increases enormously in the contact area. This mode of failure leads to crack initiation at or near the contact surface, and may subsequently lead to damage varying in extent from microscopic pitting to severe spalling. The metal removed from the surface in such cases enters the machine system which in turn cause abrasive wear and failure of other components. Furthermore, the pits formed on the damaged surface lead to the formation of stress concentrations, which leads initiation sites for other modes of gear failure, e.g. tooth bending fatigue [1].

The total power loss of the gearbox is attributable to sliding and rolling frictional losses between the gear teeth, windage losses due to complex interactions with the air surrounding the gears and oil splashing and churning losses inside the gearbox as well as the losses associated with the bearings and seals. While churning and windage losses are mostly geometry and speed related whereas friction losses are mainly associated with sliding velocities and load.

*Corresponding author.
Email: amarnath.cmy@gmail.com (M. Amarnath).

Friction can be stated as the resistance to motion between two surfaces in relative sliding and rolling under dry or lubricated contact conditions. Lubricant applied to a rolling contact significantly alters the contact conditions and hence reduces the friction. Parameters related to contact geometry, surface roughness, speed, applied load and lubricant as a whole helps to define the lubrication conditions. As these factors are changing instantaneously during a mesh cycle, the friction will also change accordingly. In some of the earlier works, the sliding frictional loss was calculated by using average frictional coefficient value in a mesh cycle [2, 3]. On the other hand wear occurs whenever two or more surfaces interact and particles are generated mainly due to friction. Friction at a gear mesh has two components: sliding friction and rolling friction. Sliding friction is a direct result of the relative sliding between the two contacting surfaces. The magnitude of the sliding frictional force depends on the coefficient of friction between the contacting surfaces.

The surface treatments and coatings are considered as one of the most promising and reliable solutions to reduce friction, wear related problems in machine elements and structures. Coatings alter the surface properties by inducing residual compressive stresses which minimize the friction coefficient and enhance, composition etc. [4]. In the last five decades, numerous coatings and deposition methods have been successfully developed to reduce friction and to protect surfaces from damage in mechanical systems. Murthy and Shaw [5] carried out fatigue tests to evaluate the performance of coated helical gears mounted in back-to-back power recirculation gear box. The test gears were coated with Balinit C1000, niobium sulfide (Nb-S). Experiment were conducted under constant load and speed over 50 million cycles. Results obtained from the experimental investigations highlight the importance of Nb-S coated gears in improving contact fatigue performance

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compared to Balinit C1000 in terms of micro pitting damage propagation and tooth profile deviation. Baragetti et al. [6] performed rolling contact fatigue (RCF) tests on case hardened and physical vapor deposited tungsten carbide/Carbon (WC/C) steel spur gears. Results showed that RCF resistance of coated gears were higher than case hardened spur gears. Thus PVD-WC/C could be considered for improving RCF behavior of gears under lubricated condition. Authors have suggested the possibility of using coated Ti alloy as a substitution for standard construction steels. Broszeit et al. [7] discussed the functional properties of PVD chromium nitride compound (Cr_xN) coatings. From this experimental investigation authors have highlighted the enhanced properties such as adhesion, hardness, deposition rate and internal stress states. Zimmer and Kaulfub [8] presented their results of experimental investigation carried out to examine the possibility of thicker coatings up to 50µm for components and cutting tools to offer longer lifetime, hardness, toughness, and temperature stability. Martins et al. [9] studied the disulfide molybdenum/titanium (MoS_2/Ti) composite coating and described the deposition procedure. Several screening tests, such as Rockwell indentations, ball cratering, pin-on-disc and reciprocating wear were performed to evaluate the adhesion to the substrate, the tribological performance of this coating. FZG gear efficiency tests were performed on coated gears to evaluate the influence of the surface coating. Takadoum and Bennani [10] studied the effect of substrate surface roughness and coating thickness on the adhesion and tribological behavior of TiN deposited by reactive ion plating on steel substrates. Three coating thicknesses and three substrate finishes were considered in the experimental investigation. With scratch test author observed that poor finishing on substrate gives rise to worst adhesion of coating and better finishing gives rise to better adhesion. Wear of the steel increases with increasing TiN coating thickness and substrate surface roughness.

From the literature survey it is observed that only limited work has been done on analysis of coating performance on real time applications on machine elements such as gears and sliding contact bearings. All the test were conducted on specimen with standard dimensions and controlled operating conditions. The behavior of coating on real mechanical component is different than on specimen as mechanical components are manufactured by considering complex geometry than test specimen. These components are subjected to different machining stresses or forming stresses during their manufacturing. The test results obtained from the fundamental test on such as pin on disc, four ball test and scratch test etc. may not produce actual operating conditions of machine elements. Hence it is required to conduct an experimental investigations on actual operating condition of gears, cams, bearings, etc., to understand the behavior of coating.

2. EXPERIMENTAL SETUP AND TEST PROCEDURE

A gear test-rig shown in Fig. 1 has been fabricated for investigating surface fatigue wear on spur gear tooth. This set-up consists of a single-stage gearbox driven by a three phase induction motor 2.25 kW and an AC controller to regulate the motor speed. The test gearbox consists of a pair of standard involute profiled spur gears. V-belt and pulley pair connects the motor to the input- shaft of the gearbox. The output shaft of the gearbox connects the shaft of the torque load through a spider coupling which accommodates any misalignments. Dimensions and specifications of single stage gear box is given in Table 1 and Table 2. The brake drum is capable of providing 1-15Nm torque to the output shaft of the gear box. Care is taken to correct all kinds of misalignment using instruments and fixtures such as dial gage, vernier calliper, spirit level and C-clamps. C-section channels are used to fabricate base frame upon which gearbox is mounted and fastened by using base bolts. This assembly is mounted on a massive concrete block which can absorb vibrations and forces generated by gearbox if any. The gear pair are lubricated using Servo 4T (20w-40) engine oil.

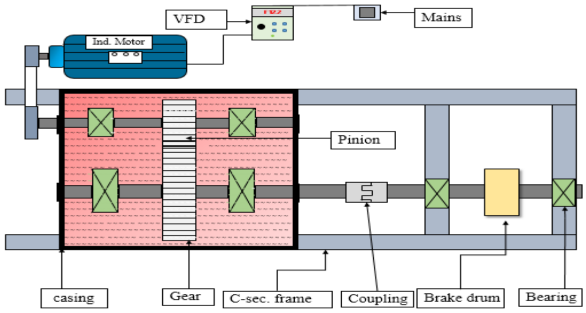

Fig. 1 Schematic view of experimental set up

Table 1 Dimensions and specifications of gears.

Parameter	Pinion	Wheel
Number of teeth	32	55
Module	2.5	2.5
Circular pitch, mm	7.854	7.854
Teeth height, mm	6	6
Addendum, mm	2.5	2.5
Pressure angle, deg.	20	20
Pitch circle dia, mm	80	137.5
Addendum circle dia, mm	84.55	142.5
Center distance, mm	108.75	

Table 2 Details of experimental setup.

Experimental setup details	
Motor power,(kW)	2.25
Rotation of pinion, rpm	400
Torque load at o/p shaft (N-m)	0-15
Test run hours	1200
Gear material	EN19T (structural Steel)

3. RESULTS AND DISCUSSIONS

During the experiments, the gearbox operation was paused to allow inspections of the gear flanks. After every 200 hours the surface roughness and tooth thickness measurements were carried out on the gear teeth flanks. The Fig. 2 (a) and (b) shows the photo images of the new uncoated and coated pinions. Further, Fig. 2 (c) and (d) shows the photo images of uncoated and coated pinion after 1200 hours of operation under constant load and speed conditions. The formation of micro pits on the uncoated pinion after 1200 hours of operation can be clearly seen in Fig. 2 (c). However, there is no indication of micro pits on polished surface of gear tooth surfaces as shown in Fig. 2 (d). This comparison between coated and uncoated pinion after 1200 hours under the same test conditions indicate that coating has great influence in reducing wear propagation on the pinion tooth surfaces.

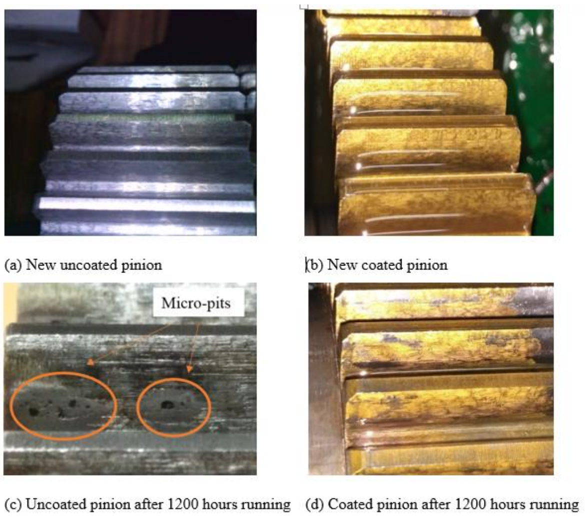

Fig. 2 Comparison of coated and uncoated pinions

Fig. 3 shows the variation in average roughness (Ra) values with respect to increase in load cycles. The roughness measurements were taken from the pitch circle region of the pinion tooth after a regular interval of 200 hours up to 1200 hours.

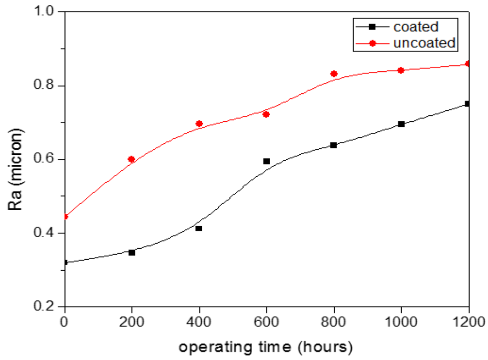

Fig. 3 Roughness variation in uncoated and coated pinions

The uncoated pinion gave an initial reading of 0.44 μm and it increased to 0.85 μm after 1200 hours of operation. Whereas for new coated pinion the initial roughness values found to be 0.32 μm and after 1200 hours of operation the roughness values increased up to 0.75μm. By comparing the initial reading of roughness between uncoated and coated pinion the roughness reduced from 0.44 μm to 0.32 μm even though both pinion made from same material and manufacturing methods. However coated pinion formed uniform layer deposition which filled up the valleys which led to a reduction in roughness values. However, roughness values showed increase in trend for both uncoated and coated pinions.

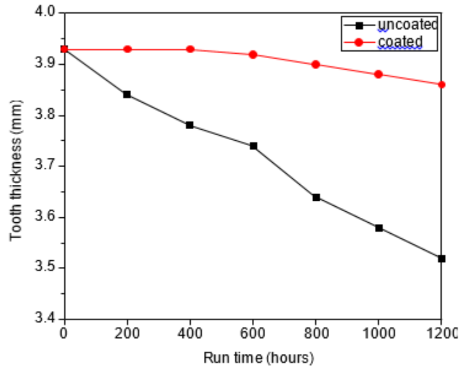

Fig. 4 Reduction in tooth thickness verses operating time

Fig. 4 shows tooth thickness variation for uncoated and coated pinion obtained during 0-1200 hours of operation. Tooth thickness reduction for coated pinion is lower than uncoated pinion, as coated pinion has hard ceramic coating of TiN on teeth surface which resist wear propagation.

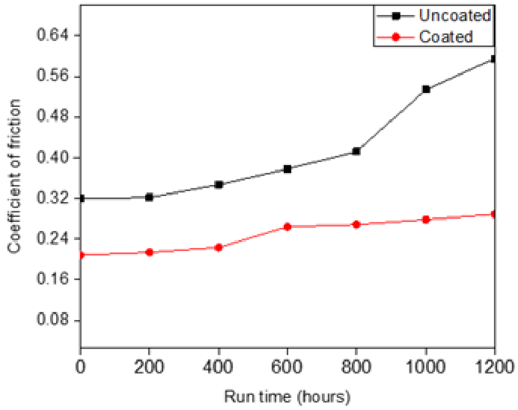

Fig. 5 Variation of friction co-efficient with respect to running time for both uncoated and coated pinions

The variation of coefficient of friction with respect to operating time is shown in Fig. 5. It is clearly seen that there is a slower rate of increase in friction coefficient values for coated pinion than uncoated pinion. The friction coefficient values for uncoated pinion is more because the surface roughness of the uncoated pinion is higher than that of coated pinion. The friction coefficient values obtained for uncoated pinion increased from 0.32 to 0.56 whereas, for coated pinion increase in friction coefficient values are comparatively less in the range of 0.20 to 0.28.

4. CONCLUSIONS

The comparison study between coated and uncoated pinions has been carried out to investigate the applications of TiN coating in enhancing the performance of spur gears. The following conclusions are summarized from the experimental investigations.

1. Surface roughness measured on TiN coated gears show lower values than uncoated gears however the

rate of roughness increase remains same for both uncoated and coated gears.

2. Tooth thickness values obtained for coated gears was relatively lower than uncoated ones.
3. Coefficient of friction values showed increase in trend for both the cases with respect to increase in fatigue load cycles. However the TiN coating reduced the coefficient of friction to great extent.

References

[1] Sergio Baragetti, “Fatigue resistance of steel and titanium PVD coated spur gears”, International Journal of Fatigue 29, 1893–1903, 2007.

[2] D. Klaffke, E. Santner, D. Spaltmann, M. Woydt, “Influences on the tribological behaviour of slip-rolling DLC-coatings”, Wear 259, 752–758, 2005.

[3] K.R. Kim, C.M. Suh, R.I. Murakami, C.W. Chung, “Effect of intrinsic properties of ceramic coatings on fatigue behavior of Cr–Mo–V steels”, Surface and Coatings Technology 171, 15–23, 2003.

[4] L. Cunhaa, M. Andritschkya, K. Pischowb, Z. Wangb, “Microstructure of CrN coatings produced by PVD techniques”, Thin Solid Films, 465–471, 1999.

[5] V. Moorthy, B.A. Shaw, “Contact fatigue performance of helical gears with surface coatings”, Wear 276–277, 2012.

[6] S. Baragettia,b, S. Cavallerib and F. Tordinia, “A Numerical Method to Predict the RCF Behaviour of PVD-coated Transmission Gears and Experimental Results”, Procedia Engineering 10, 1485–1490, 2011.

[7] E. Broszeit, C. Friedrich, G. Berg, “Deposition properties and applications of PVD CrxN coatings”, Surface and Coatings Technology, 115, 9–16, 1999.

[8] Zimmer and Kaulfub, “Hard Coatings with High Film ThicknessPrepared by PVD”, Plasma Process. Polym., 6, 152–156, 2009.

[9] R.C. Martins, Paulo S. Moura, J.O. Seabra, “MoS2/Ti low-friction coating for gears”, Tribology International, 39, 1686–1697, 2006.

[10] Takadoum and Bennani, “Influence of substrate roughness and coating thickness on adhesion, friction and wear of TiN films”, Surface and Coating Technology, 96, 272-282, 1997.