Faculty of Mechanical Engineering

EXPERIMENTAL INVESTIGATION ON THE INFLUENCE OF DLC COATING ON THE WEAR BEHAVIOUR OF HELICAL GEAR

Abdul Hakim bin Abdul Hamid

Master of Science in Mechanical Engineering

2019

EXPERIMENTAL INVESTIGATION ON THE INFLUENCE OF DLC COATING ON THE WEAR BEHAVIOUR OF HELICAL GEAR

ABDUL HAKIM BIN ABDUL HAMID

A thesis submitted
in fulfillment of the requirements for the degree of
Master of Science in Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled "Experimental Investigation on the Influence of DLC Coating on the Wear Behaviour of Helical Gear" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	……………………………
Name	:	Abdul Hakim bin Abdul Hamid
Date	:	……………………………

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature	:	………………………………………
Supervisor Name	:	Dr Reduan bin Mat Dan
Date	:	……………………………………….

DEDICATION

To my loving parents and siblings

ABSTRACT

The purpose of this research is to investigate the wear behaviour of amorphous hydrogenated carbon (a-C:H) coating deposited on the helical gears through wear debris analysis and oil analysis. The a-C:H coating were selected from various diamond-like carbon (DLC) coating variant using Pareto optimal analysis and weighted decision matrix, where it is deemed the most suitable for helical gear testing in this study. Helical gears were tested on a power recirculating test rig with constant loads of 100 Nm and speed of 1000 rpm. The tests were conducted for 9×10^6 cycles or an initial pitting of 1% covering the surface of the teeth. Samplings were obtained for approximately 60 ml of the lubricant for every 3.6×10^5 cycles which were then analysed through oil analysis which includes wear debris analysis as well as particle counting. The results revealed that the a-C:H coated gear reduces the particle generation by a factor of 3.11 as compared to the baseline testing. However, a-C:H does not improves the condition of the lubricant where in the uncoated gear, the lubricant oxidation increases per cycles while the coated gear is at a lower value while the viscosity of uncoated gear lubricant decreases per cycle as compared to the coated gear. Gear tooth image analysis reveals that the test reaches a micro-pitting stage with no visible pitting yet observed due to carburization of the base gear. However, a-C:H gears had a reduction in micro-pitting formation as compared to the uncoated gear yet peeling of the coating occurs. This suggest an extension of the life of the gear through the application of a-C:H coating is achievable.

ABSTRAK

Tujuan kajian ini adalah untuk menyiasat prestasi amorfus terhidrogen karbon (a-C:H) yang didepositkan di atas gear heliks dengan melalui analisis serpihan haus dan analisis minyak. Salutan a-C:H telah dipilih dari pelbagai variasi salutan karbon bersifat berlian (DLC) menggunakan analisis optimum Pareto dan matriks keputusan berat, di mana ia dianggap paling sesuai untuk ujian gear heliks dalam kajian ini. Gear heliks diuji pada rig ujian rim kuasa dengan beban berterusan sebanyak 100 Nm dan kelajuan 1000 rpm. Ujian ini dijalankan untuk 9×10^6 kitaran atau pengesanan lubang pada permukaan gear di skala mikro dengan 1% meliputi permukaan gigi. Pensampelan diperolehi untuk kira-kira 60 ml pelincir untuk setiap kitaran 3.6×10^5 yang kemudiannya dianalisis melalui analisis minyak yang termasuk analisis serpihan pakai serta pengiraan zarah. Hasilnya menunjukkan bahawa gear bersalut a-C:H mengurangkan penjanaan zarah dengan faktor 3.11 berbanding dengan gear tanpa salutan. Walau bagaimanapun, a-C:H tidak mempengaruhi keadaan pelincir di mana hasil kajian gear tanpa salutan menunjukkan pengoksidaan meningkat setiap kitaran manakala gear bersalut menunjukkan hasil yang sebaliknya, manakala kelikatan pelincir gear yang tidak bersalut berkurangan setiap kitaran berbanding dengan gear bersalut. Analisa imej gear gigi mendedahkan bahawa ujian itu mencapai peringkat pembentukan lubang pada skala mikro kerana karburisasi gear asas. Walau bagaimanapun, gear a-C: H mempunyai pengurangan pembentukan lubang pada skala mikro berbanding dengan gear yang tidak bersalut tetapi pengelupasan salutan berlaku. Ini menunjukkan bahawa pemanjangan jangka hayat gear melalui penggunaan salutan a-C:H dapat dicapai.

ACKNOWLEDGEMENTS

Advertently, I would like to express my sincerest gratitude to those whom are involved in the completion of this thesis, especially to my supervisor Dr. Reduan Mat Dan from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) who've given guidance as well as teaching me the value of being highly independent.

Additionally, I would also keen on extending my deepest gratitude to those involved in the technical aspects of the research, in particular towards Mrs. Hidayah, Mr. Azhar and Mr. Johardi, the Assistant Engineer from various laboratories of the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka. An apology from the bottom of my heart is given to them for all the childish whims that they have to put up with throughout this journey.

A million of gratitudes are dedicated to those important to me, especially to Miss Fadrah Hanim whom have contributed towards the completion of this thesis individually and directly. Thine tiring aid and support shalt be remembered for eternity.

True acknowledgements are dedicated to my loving parents and siblings for the continuous support morally. Thank you for raising me to be a determined and stoical individual which is the ultimate criteria for the realization of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF SYMBOLS

E	-	Elastic modulus
H	-	Hardness
H/E	-	Deformation relative to yielding
H^3/E^2	-	Resistance to plastic indentation
P_c	-	Critical pressure for plastic deformation
R_s	-	Recovery resistance
V	-	Wear volume
W_i	-	Weighing factor

LIST OF ABBREVIATIONS

a-C	-	Amorphous Carbon
a-C:H	-	Hydrogenated Amorphous Carbon
a-C:H:Si	-	Silicon Doped DLC
a-C:H:W	-	Tungsten Doped DLC
DLC	-	Diamond-like Carbon
FZG	-	Forschungsstelle fur Zahnrader und Getriebebau
Me-DLC	-	Metal Doped DLC
PACVD	-	Plasma Assisted Chemical Vapor Deposition
PVD	-	Physical Vapor Deposition
ta-C	-	Tetrahedral Amorphous Carbon
ta-C:H	-	Tetrahedral Hydrogenated Amorphous Carbon
X-DLC	-	Non-metal Doped DLC

LIST OF PUBLICATIONS

JOURNAL:

1. Abdul Hakim Abdul Hamid, Reduan Mat Dan, Azma Putra, Mohd Nizam Sudin and Rozdman Khaidir Mazlan, 2019. Wear Behaviour of a-C:H Helical Gear Through Particle Generation. *Defence S and T Technical Bulletin*, 12 (1), pp. 151-165.

PROCEEDING/CONFERENCE:

2. A.H.A., Hamid, R.M., Dan., N.I., Zulkafli, A., Putra, R.K., Mazlan, 2017. Investigation of the Wear Characteristics of Helical Gear Using Wear Debris Analysis. *Proceeding of Mechanical Engineering Research Day 2017*.

CHAPTER 1

INTRODUCTION

1.1 Research background

Gears are one of the main mechanisms for power transmissions in almost all machines. The primary purpose of gear system is to implement motion transmission as well as increasing or decreasing the speed of shafts carrying rollers or load. Recent development on design and manufacturing of gearboxes strives for a more compact yet yields a larger capacity. Due to the nature of the power transmissions which involves variable speed of rotary mechanism and heavy load, gear tends to experience failures at various cycle of the machine operation.

Thus, surface technology is a feasible solution towards improving the service life and is extensively developed which includes various methods such as surface hardening, shot penning and nitriding. Surface coating are a promising method to improve the surface performance where the current generations of hard coatings are the “diamond like carbon” (DLC). Various researches (Krantz et al., 2004; Fujii et al., 2010) are conducted on the influence of DLC coatings towards the improvement of the common failure mode resistance mainly the contact fatigue and scuffing resistance. Krantz et al. (2004) demonstrated an extension of the life of the tungsten DLC coated gear by a factor of 6 through accelerated fatigue testing. However, it is discovered that the performance of DLC coated gear changes with the load condition applied, under low load condition the gear exhibits a longer fatigue life while in a high load condition the fatigue life is comparatively shorter or equal to the non-coated gear (Fujii et al., 2010). Although DLC coating provides an advantage towards maximizing resistance towards gear failures, the complex interactions towards various parameters such as the elastohydrodynamic lubrication (EHL), temperature and contact pressures leads to a varied result of enhancements as well as deterioration.

1.2 Problem statement

Helical gears are employed for high speed and high load applications which subjects the gears to a high wear condition. This high wear conditions includes the two types of wear mainly but not specifically exclusive to gears which are scuffing and contact fatigue failure. Additionally, meshing gears results in various surface complications with every advancement in the material and design of the gear thus different demands deems a distinctive problems and solution. In order to alleviate the problems, a universal development is advocated through improvements on lubrications, gear material and surface to enhance the life of the gear or reducing the friction and wear. Application of coating proves to be sufficient in this matter compared to the method of altering the substrate or base material via case hardening or shot peening. This is due to a distinction between the mechanical properties of the coating and the substrate causing the tribological behaviour and subsurface stress field deviation as compared to the uncoated surface, which would either result in an enhancement or detrimental.

Diamond like carbon coatings are yet to be fully utilized in any industry that involves power transmission, thus an understanding to its wear behaviour in a specific condition are not yet well established. The primary purpose of this research intends to give an insight into the wear behaviour primarily involving scuffing and contact fatigue performance of the DLC coated helical gear under dynamic loading similar to those used in automotive applications with condition monitoring approach. This work focuses on the influence of the

DLC coating on the wear debris generation of the helical gear which is a part of the condition monitoring technique.

1.3 Research objectives

The primary objectives of the research are:

a. To select the most suitable DLC coating for helical gear mechanism usage.
b. To quantify and characterise the wear behaviour of DLC coated helical gear tested under dynamic loading with uncoated gear as a baseline.

1.4 Research scopes

The research investigates the correlation the wear behaviour of DLC coating under different dynamic loading characterisation. This research scopes are limited towards the following as well as covers:

a. Power recirculating gear test rig which is generally a four-square principle of load application for dynamic testing were set up to perform the experimentations.
b. The dynamic loadings are varied through varying the face width of the gear mesh which results in a varied Hertzian contact stress.
c. The wear behaviour of the DLC coating are limited towards a casehardened gear under spraying and reservoir lubrication condition. Other operating conditions may result in a profound variation with the data discussed in this research.
d. DLC coatings are limited to one variant which undergoes material selection to determine the most suitable variant for the experiment. This is due to time and resource constraint on the research.