International Journal of Latest Research in Science and Technology **ISSN (Online):2278-5299**
Volume 4, Issue 5: Page No.43-46, September-October 2015
https://www.mnkpublication.com/journal/ijlrst/index.php

INFLUENCE OF HARDNESS PROFILE ON FATIGUE FAILURES OF CASE HARDENED RACES

Matjaž Torkar, Bojan Podgornik, Franc Tehovnik
Institute of Metals and Technology, Ljubljana, Slovenia

Abstract- ***Different case hardened races, as a part of a constant velocity joint, were dynamic loaded and investigated. The visual inspection revealed the flaking of the surface on some races. The metallography of cross section of case hardened layer detected damaged surface and fatigue cracks below the surface. Both phenomena were results of differences in hardness profile and consequently concentration of stresses below the surface of case hardened layer. The fatigue failures were more pronounced at higher hardness of case hardened layer. For longer life time of the race is important to adjust the thickness and the hardness of case hardened layer to the position of predicted stress concentration below the surface.***

Keywords - Case hardened race; Fatigue cracks; Deformed martensite; Failure analysis

I. INTRODUCTION

Constant velocity joint consists of an inner race, cage for balls and outer housing (Figure 1)[1].

The most critical point in constant velocity joint is the contact between the ball and raceway of the inner race. For that reason an extensive testing is typically undertaken to minimize or avoid potential problems with vehicle, which often leads to longer and costly development periods [2, 3]. Most of the existing rolling contact fatigue models use a simplified stress calculation technique, such as Hertz's classical approach [4] analytical solution or simplified finite element analysis with applied Hertz's contact pressure [5]. It is well known that Hertz’s contact stress [6,7] refers to the localized stresses that develop as two curved surfaces come in contact and deform slightly under the imposed loads. The amount of deformation is dependent on the modulus of elasticity of the materials in contact. The contact stress is a function of the normal contact force, the radii of curvature and the modulus of elasticity of both materials in contact. If the maximum shear stress and principal stresses are plotted as a function of maximum pressure then a maximum shear stress exists somewhere below the surface of the raceway [8]. These contact stresses are cyclic in nature and over time lead to formation of sub-surface fatigue cracks. Hertz’s contact stress forms the foundation for the equations for calculations of load bearing capabilities in bearings, gears, and any other bodies where two surfaces are in contact.

Rolling-contact fatigue failures can be separated into two general categories: surface initiated and subsurface initiated. Subsurface initiated fatigue cracks usually start to propagate parallel to the surface and later abruptly to the surface [9,10].

The sub-surface stresses are typical at the contact of two rolling surfaces. The three axis stress field below the surface appears due the friction forces.

Characteristic of Hertz's stresses during the test is the highest stresses appears always below the surface. The depth of maximal stresses depends on pressure, geometrical conditions, topography of the surfaces, the roughness of the surfaces and effects of the lubricant.

Some authorities [11, 12] suppose that maximum Hertz's shear stress is responsible for the surface fatigue failure of such contacting elements. A crack, originating at the point of maximum shear usually progresses to the surface where lubricant pressure causes a flaking of the surface and accelerates the creation of surface pits. When such phenomena are formed on the surface of the race, the ball bearing should be replaced.

The endurance test of constant velocity joint were performed by standard procedure and with application of the same lubricant. After the tests the differences in the surface characteristics of racer 1 and racer 2 were observed.

The aim of the investigation was to identify the reasons for differences in fatigue failures of two different case hardened racers after the same endurance tests.

II. EXPERIMENTAL

The race was die-forged of 16 MnCr5 steel with chemical composition presented in Table 1. Race was machined and case hardened with two different hardness profile. Both races were exposed to endurance test with slow moving and high tension, according to recommendation of [13], with application of the same lubricant.

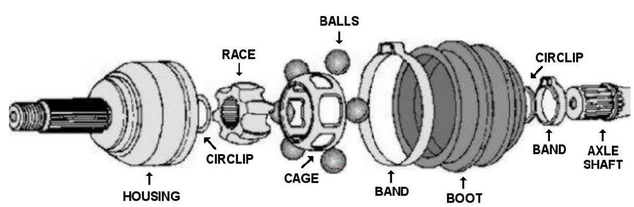

Fig. 1 Schematic presentation contant velocity joint components [1]

After the test the races were investigated by metallography and by electron microscopy. Samples for investigation were

Publication History
Manuscript Received : 23 September 2015
Manuscript Accepted : 2 October 2015
Revision Received : 25 October 2015
Manuscript Published : 31 October 2015

cut in the region of the damaged race. The investigations were performed by light microscope, scanning electron microscope (SEM) and by electron dispersive spectroscopy (EDS).

Table 1: Chemical composition of 16MnCr5 steel

	C	Mn	Si	Cr	S	P
Min.	0.14	1.00	-	0.80	0.020	-
Max.	0.19	1.30	0.40	1.10	0.035	0.025

All in wt. %

The samples for metallography were prepared by standard method with grinding on grinding papers, polishing with diamond paste and metallographic etching in 2 vol. % solution of Nital (2 vol. % of HNO_3 in ethanol).

(a) (b)

Fig. 2 Traces of wear after the test on the surface of: a) Race 1 and b) Race 2

The microstructure was observed by optical microscope Nikon Microphot FXA. The cracks were observed by scanning electron microscope (SEM) JSM-6500F with Field Emission source of electrons and analysed by INCA ENERGY Oxford Instruments Energy Dispersive Spectroscopy (EDS).
The Vickers hardness profile of the case hardened layer, base material and around fatigue cracks was measured by Wilson hardness tester. The microstructure of case hardened layer, base material, as well as around fatigue cracks was examined on both races.

III. RESULTS WITH DISCUSION

A Visual inspection of the races (Figure 2) revealed traces of wear and flakes observed on the surface of the race.

Metallography revealed the presence of fatigue cracks (Figure 3, 4) below the surface of the race at both components. It is evident that the sub-surface cracks and flaking of the surface was caused by Hertz's stresses.

Fig. 3 Cross section of Race 1 with higher hardness of surface, after durability test. The white fields represent plastical deformed martensite and/or rests of fretting corrosion on the loaded area.

Fig. 4 Cross section with cracks below the softer surface of Race 2, after durability test. Contact fatigue cracks propagating parallel to the loaded area.

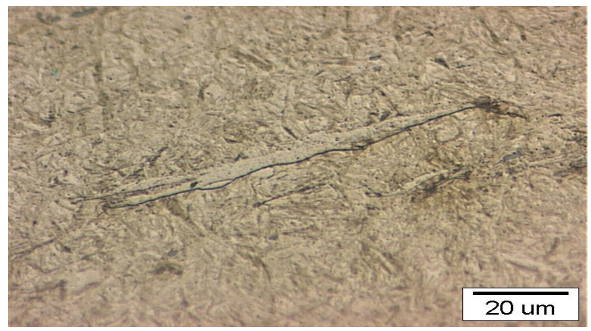

Fig. 5 Plastically deformed martensite with hardness 1076 HV 0.025, about 0.1 mm below the surface of Race 2

Metallography revealed in both racers the brighter kneaded layers near the cracks, as presented for race 2 in (Figure 5). The measurements of hardness in both components confirmed that brighter areas near the cracks represent deformed martensite, with the hardness of 1140 HV 0.2 at Race 1 and a little softer deformed martensite with 1074 HV 0.2 at Race 2. Fretting corrosion [14, 15] or degradation of grease [16] are two possible causes of white layers on the surface of the race 1. Fretting corrosion is typical at slow moving surfaces under high local pressure resulting in high local temperatures and degradation of grease. Beside that specific local pressure and slow moving increase the temperature at the contact point above the temperature of transformation of martensite to austenite. In such a case the white austenite layer is formed. White austenite layer has lower hardness than material around it. In specific cases the hardness can increase due deformation strengthening during the local kneading of material.

The aim of case hardening of the races is to diminish the formation of sub-surface fatigue cracks and to retard the flaking of the raceway. In general the sensitivity to fatigue is decreased by higher hardness of raceway with high residual compressive stresses and by optimal thickness of case hardened layer. It is important the thickness of case hardened layer is adjusted to the expected sub-surface distribution of stresses.

The race with higher hardness of case hardened layer (Figure 6) had flakes on the surface (Figure 3) which was not the case at the race with lower hardness of case hardened layer (Figure 4). We suppose the reason is in softer deformation induced martensite that could overtake more kneading of material during the endurance test.

The profile of hardness HV 0.2 through the case hardened layer was measured at both races on at not damaged surface. Based on criteria HV 550 the thickness of case hardened layer at both races was around 1.2 mm.

The races differ only in hardness near the surface of case hardened layer (Figure 6). This confirmed that both inner races have not been case hardened in the same conditions.

The cracks appear below the surface to the depth of 0.2 mm at Race 1 and some cracks were connected with the surface of the race, where the flaking of the surface was observed.

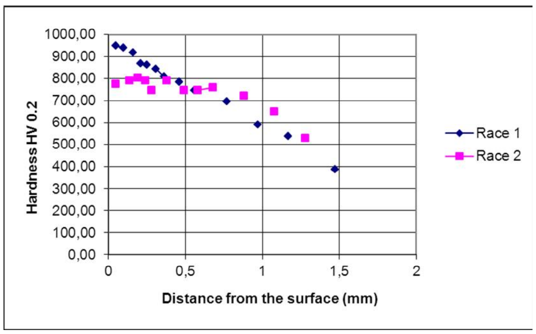

Fig. 6 Hardness profile in case hardened layer of Race 1 and Race 2

No flaking of the raceway of the Race 2 was observed, despite the presence of the internal cracks below the surface, to the depth of 0.5 mm. Lower hardness of case hardened layer means better ductility of material that hinders the crack grow and propagation. In both races the cracks are first parallel to the surface and surrounded by deformed martensite (Figure 4). Deformed martensite with the hardness of 1076 HV was present only below the contact point in the race. Out of the contact region, no cracks and no deformed martensite was observed.

Metallographic overview of case hardened layer did not detect the carbide net. Observed were only individual carbide grains.

SEM observations and the EDS line analysis were performed across the crack and deformed martensite layer to reveal the possible differences in chemical compositions as for instance the segregations. EDS line analysis did not reveal any change in concentration of analysed elements, C, Cr and Mn. The white layers therefore represent deformed martensite with the same chemical composition as base material (Figure 7 and 8).

Microstructure of the base material, below the case hardened layer is presented in Fig. 9 and 10. Both races have indentical base microstructure. The races were tested in similar conditions with the same lubricant. The only possible reason for observed failures is the difference of hardness profile in case hardened layer of the races.

The performed investigations of fatigue failures of races revealed the importance of planning of proper case hardening as one among the factors influencing the life time of the race.

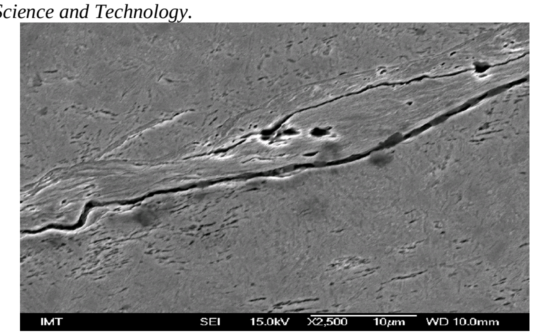

Fig. 7 Sub-surface crack surrounded by plastical deformed martensite in Race 1. (SEM)

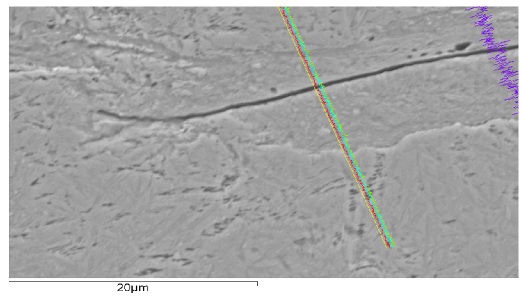

Fig. 8 Line analysis of C, Cr, Mn across the fatigue crack and deformed martensite layer in the Race 1. No segregations are present. (EDS)

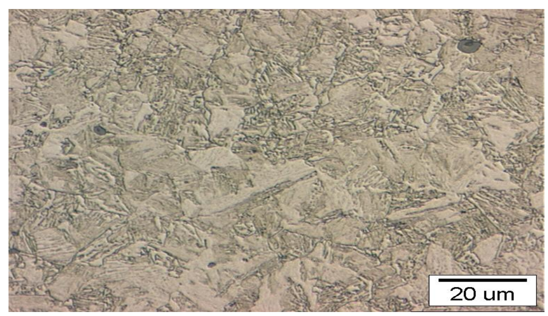

Fig. 9 Microstructure below the case hardened layer of Race 1

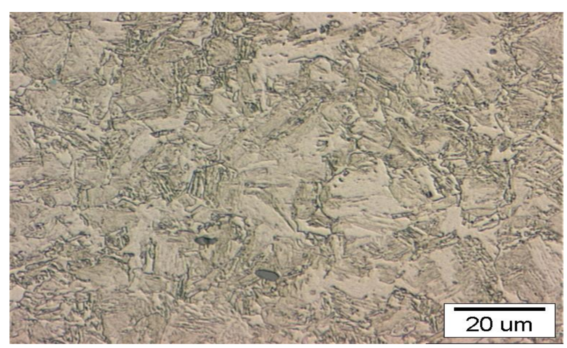

Fig. 10 Microstructure below the case hardened layer of Race 2

IV. CONCLUSIONS

After durability test of races, performed under identical conditions, the difference were observed on the contact surface of visual inspected races. Two selected races were investigated more in detail. The following conclusions can be drawn.

The metallography revealed fatigue cracks in the case hardened layer of race, close to the contact point. Cracks were surrounded by white layer of deformed martensite. In the case hardened layer The carbide net was not observed in the case hardened layer.

Comparison of both races showed the differences in HV hardness profile in the case hardened layer. The fatigue cracks were observed only on the surface of the contact area in the race with higher hardness of case hardened layer.

No flaking of the contact surface was observed on the races with softer case hardened layer.

For better endurance of investigated races the hardness and the thickness of case hardened layer should be adjusted, according to position of Hertz's stress concentration below the surface of the raceway, already at planning of manufacturing process of the race.

ACKNOWLEDGMENT

We like to express sincere appreciation to all participants in this work.

REFERENCES

[1] http:// www.google.com

[2] Chul-Hee Lee, Andreas A. Polycarpou, A phenomenological friction model of tripod constant velocity (CV) joints, Tribology International Volume 43, Issue 4, April 2010, Pages 844-858

[3] C. H. Lee, Development of a semi-empirical friction model in automotive driveshaft joints, International Journal of Automotive Technology, 2008, Volume 9, Number 3, Pages 317-322

[4] I. Kosenko, E. Aleksandrov, Volumetric modification of the Hertz contact problem and its application to the multibody dynamics simulation, Journal of Mechanical Science and Technology, Volume 23, Number 4, (2009), Pages 931-937

[5] Yonming Liu, Liming Liu, Sankaran Mahadevan, Analysis of subsurface crack propagation under rolling contact loading in railroad wheels using FEM, Engineering Fracture Mechanics 74 (2007), Pages 2659-2674

[6] N. Stalin-Muller, K.Dang Van, Numerical simulation of the sliding wear test in relation to material properties, Wear , Vol. 203-204, March 1997, Pages 180-186

[7] H.S. Ahn, B.J. Roylance, Stress behaviour of surface-coated materials in concentrated sliding contact, Surface and Coatings Technology, Volume 41, Issue 1, February 1990, Pages 1-15

[8] Mechanical Engineering Design, ed. Joseph E. Shigley, Charles R. Mischke, Richard G. Budynas, Mc Graw-Hill, 2004

[9] ASM Handbook Volume 11, Failure Analysis and Prevention, R. Ahmed, Rolling contact fatigue (ASM International), 2002, Pages: 941-956

[10] P.J.L. Fernandes, Contact fatigue in rolling-element bearings, Engineering Failure Analysis, Volume 4, Issue 2, June 1997, Pages 155-160

[11] T. Hong, J.Y. Ooi, B. Shaw, A numerical simulation to relate the shot peening parameters to the induced residual stresses, Engineering Failure Analysis, Volume 15, Issue 8, December 2008, Pages 1097-1110

[12] Hyung-Kyu Kim, Sung-Han Park, Hwan-Gyu Lee, Dong-Ryun Kim, Young-Ho Lee, Approximation of contact stress for a compressed and laterally one side restrained O-ring, Engineering Failure Analysis, Volume 14, Issue 8, December 2007, Pages 1680-1692

[13] H. Komiya, Rolling bearing lubrication technology trends and R&D efforts, JTEKT Engineering Journal English edition, No. 1003, 2007, 50-58

[14] R. Gutkina and B. Alfredsson, Growth of fretting fatigue cracks in a shrink-fitted joint subjected to rotating bending , Engineering Failure Analysis, Volume 15, Issue 5, July 2008, Pages 582-596

[15] R.B. Waterhouse, Fretting Corrosion, Pergamon Press, Oxford, 1972

[16] Chul-Hee Lee, Jae Young Choi, In Sik Jeon, Wonoh Cho, Hyukchae Yun, Grease degradation in constant velocity (CV) joints, Trybology Transactions, 54, 2011, Pages 825-831