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Analysis of Scoring Resistance on Coated Spur Gears by Considering Surface Roughness

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ABSTRACT

With the rise of velocity and momentum in machines as a result of technological developments, on gears, alongside refraction from the bottom of the gears and pitting formation, and scoring formation has showed up. In the scoring formation phase because of the fact that many parameters are influential, resistance calculations could not be stated precisely. In experiments made for this purpose, 20MnCr5 steel gears were coated using various coating materials (chrome, nickel and manganese), thus usage of coating material on gear mechanisms in terms of scoring was analyzed. In the experiments, gears were rotated with a speed of 3000 rpm and the oil temperature constant at 323±2 °K. Gears were exposed to loading at 15.2 Nm and continued by increasing 20 % until scoring formation was observed. It is seen in the experiments that coated gears have more scoring resistance than uncoated ones. It is also observed that coating materials increases the scoring strength of gears. According to the experiments, when gears run at the same conditions (speed, torque and lubrication), chrome coated gears are 10 times longer, nickel coated gears are 5 times and manganese coated gears are 1.5 times longer resisted when compared with uncoated gears. After the scoring formation, experiments continued for determining how the scoring formation developed. It is seen in the experiments that when scoring occurs the wear increases rapidly on the tooth of gears.

Keywords:
Scoring, Spur gear, Surface roughness, Coating material, Pitting.

INTRODUCTION

Gears are often used as power and motion transmission elements in the automotive industry. The ability of the gears to operate comfortably at high power and speed depends on determining the factors causing the wear and obtaining the appropriate conditions. Scoring is a case of rapid separation of little particles which are adhered to each other by metallic contact from gear surface in gear systems that work simultaneously [1]. There are many ways to prevent scoring (profile correction, use of coating materials, lubrication, etc.). Coating materials are made for increasing the wear resistance of the material, preventing the discontinuity on metals (scratches, pores) and gaining functional quality [2]. The facing of gears by coating materials is a usual improvement of strength method

Theoretical and experimental studies have been carried out to observe the formation of scoring on the gears. In theoretical studies some methods have been presented by Authors for the calculating of scoring. These methods are based on pressure or surface temperature on tooth profile when the gears are in action [3-14]. In experimental works, the closed circuit power circulating gear wear test mechanism (FZG) is used to investigate the strength of gears as a result of rapid wear [2,15-24]. Work to prevent scoring formation is generally in the form of profile modification [15-19] and coating the tooth surfaces with the coating materials [20-24]. The studies that profile modification on gears are indicates that; (+) profile modification is higher scoring resistance than (-) profile modification. Also the bigger profile modification ratio is the more wear it causes. The studies that using coating materials on gears are indicates that; coating materials increase the wear resistance and strength by decreasing surface toughness. All

Table 1. The Properties of Test Gears

Quantity	*Symbol*	*Unit*	*Value*
Number of teeth	z_1 z_2	- -	17 41
Module	*m*	mm	3
Tooth width	*b*	mm	20
Pressure angle	a_o	o	20
Pitch diameter	d_{o1} d_{o2}	mm mm	51 123
Addendum diameter	d_{b1} d_{b2}	mm mm	57 129
Dedendum diameter	d_{t1} d_{t2}	mm mm	43,8 115,8
Distance between the axis	*a*	mm	87
Contact ratio	*e*	-	1,86
Hardness	HB	-	170-220

Table 2. Abbreviated for test gears

Uncoated	K
Manganese	M
Nickel	N
Chrome	C

Table 3. The physical properties of the lubricant

SAE Number	80W/90
Density g/ml (15 °C)	0,906
Viscosity (40 °C)	200
Viscosity (100 °C)	17,5-18,5
Viscosity Index	95
Flaming Point °C	220
Flash Point °C	-27

works based on to find critical scoring load and to prevent scoring. The Authors didn't give any information what happens after scoring formation.

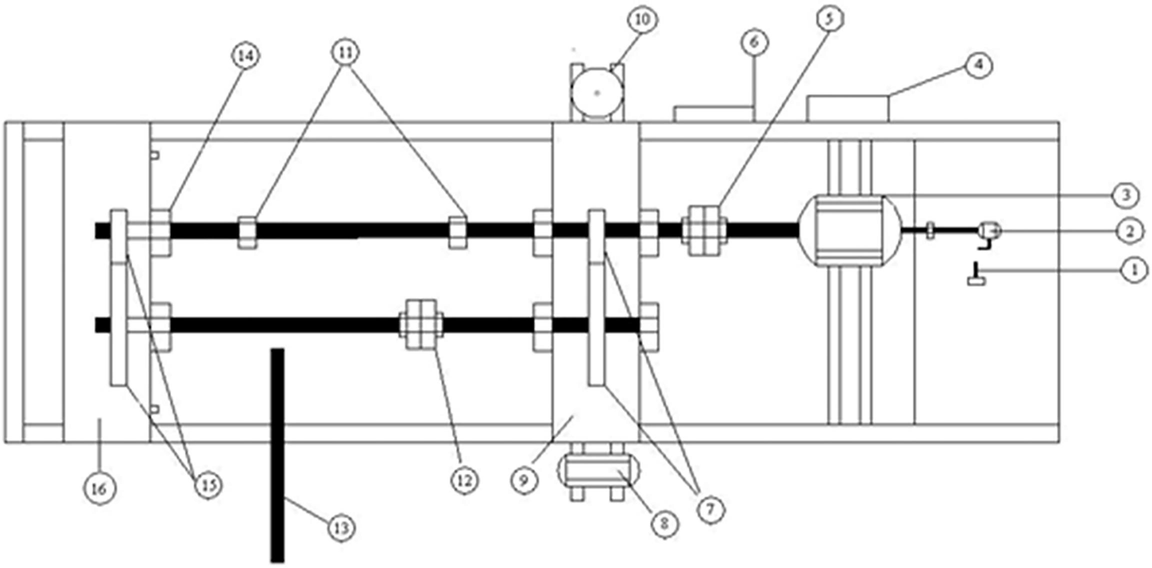
In order to determine scoring formation: (1) being appropriate to DIN 51354 [25], weight lost as a result of sudden wear in gears, (2) to observe pinion surface in coupling was 20% of the scoring amount in active profile were the methods used.

The aim of this study is to find the critical scoring load by using a new method, sudden change in surface roughness on gear surfaces. Another aim is examining what kind of development happens after scoring formation.

Experimental Study

Test Gears

Gears used in the experiments are 20MnCr5 steel and their hardnesses are between 170-220 HB. Data about gears are given in the table below. In Table 1 subscript 1



1. Counter 2. Reductor 3. D.C. motor 4. Power control unit 5. Coupling 6. Heating-cooling system control unit 7. Power transmission gears 8. Water transmission D.C. motor 9. Power transmission gearbox 10. Water can11. Plain bearings 12. Torque coupling 13. Loading bar 14. Plain bearing 15. Test gears 16. Test gearbox

Figure 1. The power circulating gear wear test rig

Table 4. Loading steps of experiments done for finding scoring load

Test Number	Force (N)	Torsion M_i (Nm)
1	15,2	15,2
2	18,8	18,8
3	21,9	21,9
4	26,3	26,3
5	31,6	31,6
6	37,7	37,7
7	45,5	45,5
8	54,6	54,6
9	65,5	65,5
10	78,6	78,6
11	94,3	94,3
12	113,1	113,1
13	135,8	135,8
14	162,9	162,9
15	195,5	195,5
16	234,6	234,6
17	281,6	281,6
18	337,9	337,9

shows the pinion and subscript 2 shows the gear.

In the experiments gears were coated by chrome, nickel and manganese. For practical use, coated gears are abbreviated in Table 2.

An immersion type lubrication system was used. The physical properties of the lubricant which is used in the experiments are given in Table 3.

Experimental Conditions

FZG (Forschungsstelle für Zahrender und Getriebebau) system, which was developed in Germany in which wear and fatigue experiments made has been used in the experiments. [1,2,17]. Closed circuit power circulating gear wear test mechanism is used to investigate the scoring strength of the gears as result of rapid wear (Figure 1).

In the experiments, gears were rotated with a speed of 3000 rpm and the oil temperature constant at 323±2 °K as appropriate to the literature [3,4,7]. Gears were exposed to loading at 15.2 Nm and continued by increasing 20 % until scoring formation was observed. Before the experiments hardness, surface roughness and weight of the gears were measured. Between every stage of the experiment, surface roughness and weight measurements were repeated. When values of weight showed a sudden increase, the scoring formation was examined by controlling the surface of the tooth [2,3]. In case there was not a sudden change in weighing, adding weight was continued. The experiment setup was a type that enables loading when motionless. Loading to the spindle that has torque coupling and connected to the testing gears was done by hanging weight with the help of moment handle. As a result of tightening cap screws on the torque coupling, closed circuit was completed. Loading steps of the experiments done for determining critical scoring load are given in Table 4.

In the experiment of weight loses method was used for determination of the scoring load, gears were burdened gradually and were run for 20 minutes. In between every stage, pinion and gear were weighted. The stage that wear increased suddenly gave critical scoring load [3,4,25]. For measuring weight loss, a sensitivity scale at sensitiveness of 0.1 mgr was used. For proof of the accuracy of experiments, it was examined if pinion surface in coupling was 20% of the scoring amount in active profile [3,4].

In the method of measurement of surface roughness, after completing coating of the gears, surface roughness was examined till scoring formation. Surface roughness was measured with the Taylor Hubson 3+ Surface Roughness Measurement Apparatus. In the measurements, mean surface roughness (Ra) and maximum point in the profile (Ry) were tried to be determined.

Experimental Results

Relation Between Weight Lost in Gears and Scoring

Being appropriate to DIN 51354, gears were burdened gradually, after every stage the pinion and gear were weighted. The stage that wear increased suddenly was defined as the critical scoring load. It is enough to take measurements from the pinion to observe the formation of the scoring. Since the system has a rate of 2.41, the pinion enters about 2.5 times more than the large gear

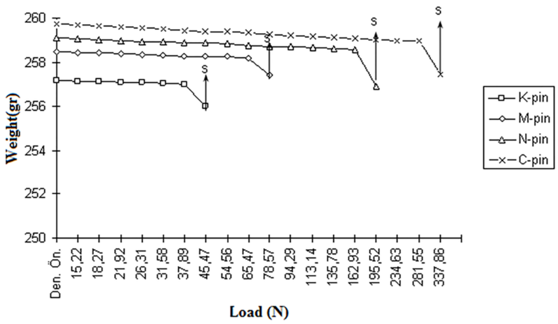


Figure 2. The changing of weight in the pinion to determine the critical scoring load

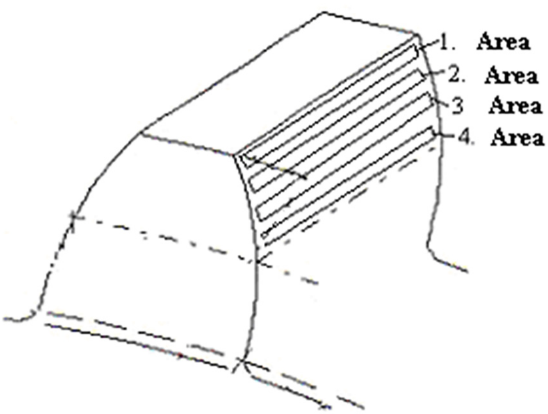


Figure 3. Areas that roughness measured

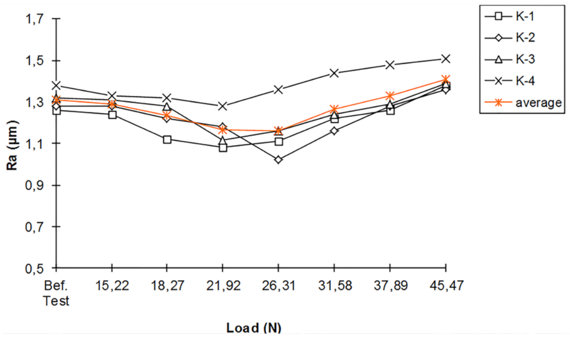


Figure 4. The average of mean surface roughness on uncoated pinion gear.

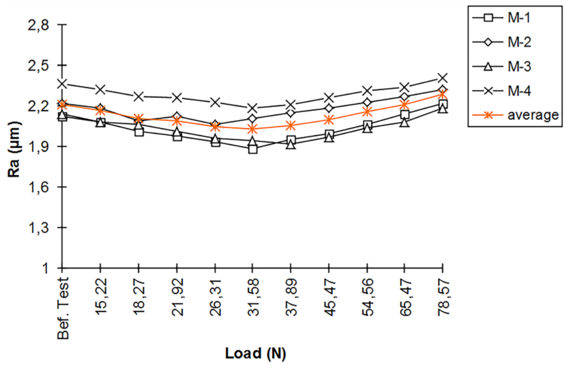


Figure 5. The average of mean surface roughness on manganese coated pinion gear.

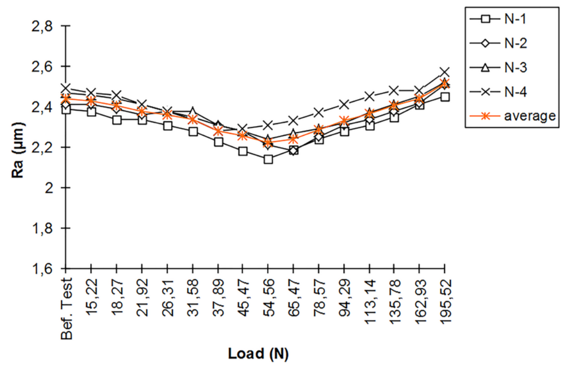


Figure 6. The average of mean surface roughness on nickel coated pinion gear.

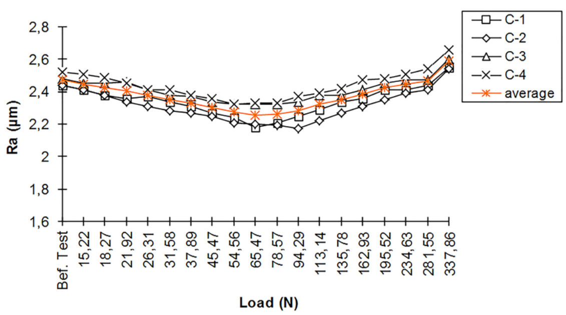


Figure 7. The average of mean surface roughness on chrome coated pinion gear.

ratio. Hence, wear is observed earlier in the pinion gear [1-3].

Results emerged after experiments were treated for every gear one by one. Weight graphic that occurred as a result of sudden increase of corrosion was given in Figure 2.

According to Figure 2, corrosion is seen in K, M, N and C, respectively. In the Figure, 's' shows the moment that scoring started. To Figure 2, while 7th stage of the experiment scoring on uncoated gear is observed, in manganese coated gear in 10th stage, in nickel coated gear in 15th stage and in chrome coated gear in 18th stage of the experiment sudden increase falling occurs. If a comparison is made after the experiments, usage of chrome-coated gear is more advantageous.

Effect of Surface Roughness to Scoring

For determining surface roughness, 4 different points were measured and then their averages were given in graphics. Because the fact that, during the same study, pinion coupling much more than gear, measuring only pinion is adequate. And the reason that surface was taken from rolling round to head of tooth is scoring was initially determined in these parts [1,2].

When surface roughness on uncoated gear was examined, it was observed that roughness decreased till 3rd load stage, then increased in certain proportion and in 7th stage got scoring by suddenly increasing.

According to Figure 4, the average of mean surface roughness of 4 areas is between other surface roughness values.

If the average surface roughness of the gears is examined (Figure 4-7); it is seen that in the course of production and because of the coatings resulted from coating materials at the load of starting to run roughness on surfaces of gears decreased to certain stage, until scoring formation it increased with a certain speed and at scoring formation roughness on their surfaces suddenly increased.

When the values of the maximum point in gears profile were examined, results parallel to the average surface roughness come into the picture. In Figure 8-11 if a comparison is made after the experiments, usage of chrome-coated gear is more advantageous.

Development of Scoring

After determination of scoring load experiments, experiments were continued on the gears that scoring occurred and following results were obtained. Gears were exposed to loading at 300Nm, were rotated with speed of 3000

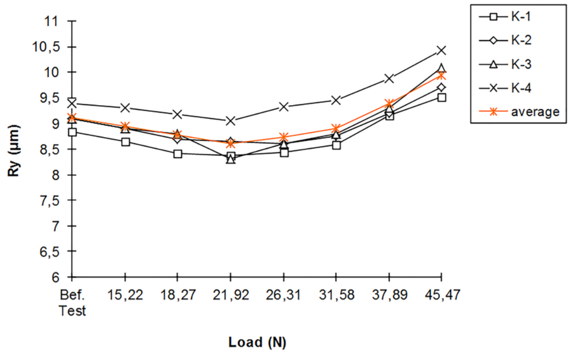


Figure 8. The average of maximum point in the profile on uncoated pinion gear.

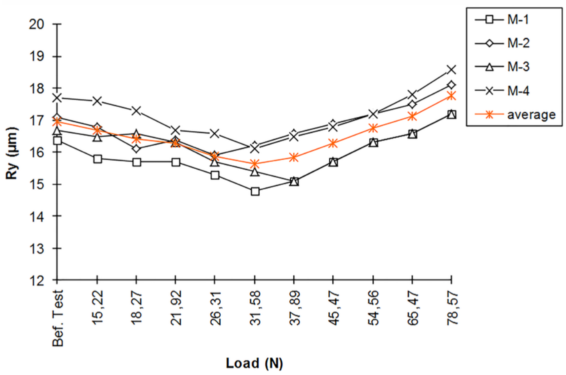


Figure 9. The average of maximum point in the profile on manganese coated pinion gear.

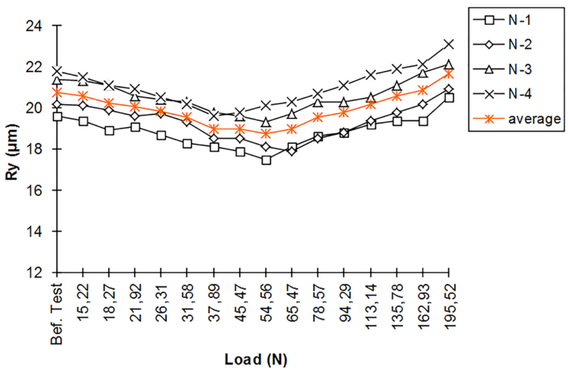


Figure 10. The average of maximum point in the profile on nickel coated pinion gear.

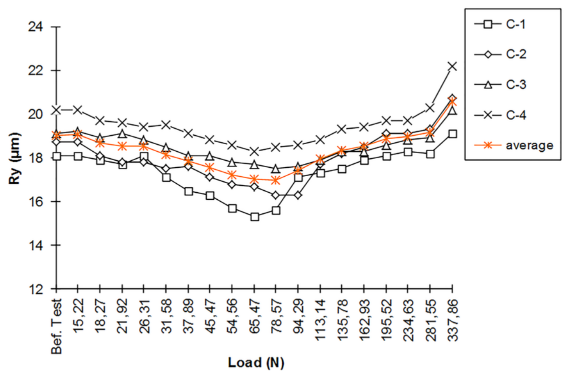


Figure 11. The average of maximum point in the profile on chrome coated pinion gear.

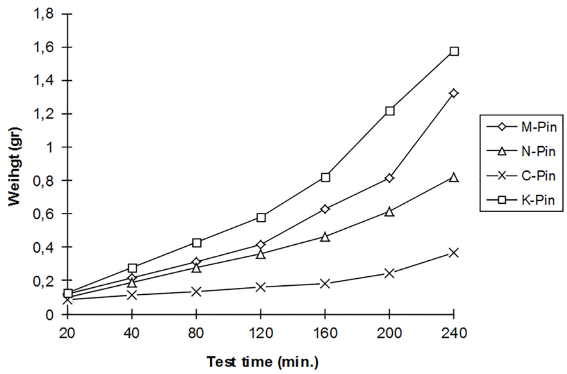


Figure 12. The changing of weight on pinion after scoring occurs

rpm. The temperature was constant at 323±2 °K.

As it is seen in the Figure 12, wear and thus scoring showed quick increase on pinion that load was excessive.

Results and Conclusion

In this study, scoring load that occurs as a result of rapid wear on gears coated with different coating materials was determined by considering surface roughness.

After the experiments for determination of critical scoring load on gears, at the same heat, speed and lubrication conditions, critical scoring load emerged in every gear was found as 45,47 N in uncoated gear, 78,57 N in manganese coated gear, 195,52 N in the nickel coated gear and 337,86 N in the chrome coated gear. According to these values, use of coating material on gears is advantageous in terms of scoring formation. The chrome coated gear run at 11 different loading stage 220 minutes more than uncoated gear. If the chrome coated gear run at 45,47 N, critical scoring load of uncoated gear, it could resist scoring much longer. Critical load that the chrome coated gear received scoring is 337.86 N, meanly, it received scoring as a result of running under 10 times the excessive load.

According to the experiments, compared to the uncoated gear chrome coated gear resisted approximately 10 times longer, nickel coated gear 5 times longer and manganese coated gear 1,5 times longer.

Besides after the experiments it was seen that after scoring started to occur, it continued rapidly. And this shows the effect of scoring formation on gears is a quite lot.

It was observed in the scoring load experiments that coating materials increased the scoring resistance of gears. Also coating materials prevent the discontinuities such as scratches and pores in the structure. The only disadvantage of coating material is accumulated corroded particles cause abrasive wear. In order to prevent abrasive wear, it is necessary to filter the lubricating oil well.

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