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Failure Analysis of Reverse-Gearbox Components for RL 15 Motorized Railway Trolley

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ABSTRACT

This research seeks to identify and analyses the frequent causes of a reverse-gearbox (RGB) components failure for an RL 15 motorized railway trolley (MRT). To achieve this goal,visual inspection was carried out on two failed samples- i.e. pinion (sample A) and ring gear (sample B). The failed samples of the RGB were subjected toRockwell hardness test, scanning electron microscope (SEM) and energy dispersive spectrometry (EDS) analysis in conformity with ASTM E18-15 and ASTM E1508test procedures. Finding from the Rockwell hardness test for sample A was found to be 42.83 HRC and sample B was 44.73 HRC. Both samples A and B were found to have lower surface hardness when compared with therecommended American Gear Manufacturing Association (AGMA) standard values (58 - 64 HRC) for gear teeth surface. The SEM micrographs of samples A and B revealed hardened heat treated surfaces, amidst the presence of ferritic and pearlitic phases with smattering of martensitic deposits. The SEM result of the chemical composition of sample A was found to correspond with that of AISI 4140 alloy steel and sample B was found to correspond with that of AISI 4130 alloy steel. While, AISI 4140 alloy steel contains 0.38% - 0.43% C and 0.80% - 1.1% Cr in the materials. On the other hand, AISI 4130 alloy steel has lower carbon content 0.28% - 0.33% and of the same chromium content (0.80% - 1.1%). Thus, for samples A and B, there were no deviations from AISI standards for chemical composition. It is worth noting that the EDS results of both samplesis evidenced by the absence of contaminants in the material. From the study, the cause of frequent failure of the reversed gear box components could be attributed to the comparatively lower surface hardness of the tested samples as revealedby the hardness test. The findings will in no little measure assist the railway authorities;bemore decisive on product choices, reduce operational and maintainability cost, and enhance the durability of the railway trolley (RT) systems.

Keywords: Failure, RL 15 motorize railway trolley, pinion, ring gear, SEM, EDS

I. INTRODUCTION

A gear is basically a toothed wheel that found application in the transmission of mechanical power. Gears offer advantages such as reliability and compactness. Their applications range from wristwatch to heavy industries [1]. High stress concentration on the contacting tooth surface is a common phenomenon when gears are in operation [2]. Gear tooth failures of different kinds occur in service, altering the operating characteristics of transmission and eventually leading to the failure of the whole mechanical assembly [3]. The specific application of a gear determines the necessary material properties. The area of application of metals and alloys are limited to their properties. These properties can be varied within limits by several methods, such as; mechanical working, grains size, grains structure, and heat treatment [4].

In most cases, except for an increase in noise level and vibration, total gear failure is often the first and only indication of a serious challenge in mechanical systems. Many modes of gear failure have been identified and documented, and such include; fatigue, impact, wear or plastic deformation. Of these, one of the most common causes of gear failure is tooth bending fatigue. Unarguably, fatigue is a common failure mode in gearing. Tooth bending fatigue and surface contact fatigue are two of the most rampant modes of fatigue failure in gears [5].

In Nigeria, railway transportation system has existed for over 116 years, with over 30 years of the use of manually-operated rail trolleys. Presently, modern rail trolleys manufactured by China Railway Shanhaiguan Bridge Group Company Limited are being used. The railway trolley (RT) has V-shape engine, two-cylinder, four-stroke diesel engine at engine power of 18KW, and a rated speed of 3600 revolutions per minute (rpm). The trolley has a width gauge of 1067 millimeters (mm) and a trailer load carriage capacity of 500 kilograms (kg)[6]. It requires less human drudgery to operate, and has proven to be much faster, convenient and effective. Refer to plate 1 below for a vivid illustration of the mechanical device.


Plate 1: RL15 Railway trolley and trailer.

The RT is meant for line-section inspection, light machines, tools and workers transportation on the tracks between stations, and it is often the responsibility of mechanical department of the Locomotive shops to repair and maintain the RT. The frequency with which the reverse-gearbox and other parts of these very supportive mechanical contrivances break- down after a short period (about 5 years) of purchase and delivery has been a cause of concern to the Nigerian Railway Authorities.

A careful examination of 6 Nos. of the failed motorize rail trolleys in Bauchi, Zaria and Kafanchan railway workshops revealed that the frequent reverse-gearbox failure poses a challenge to operational life of the trolleys, and hence raising very pertinent durability concerns, and bringing to question the material integrity of the selected gearbox components. From visual inspections, the damaged components comprise of the pinion and ring gear (refer to plates 2 and 3).


Figure 2: Reverse-gearbox


Figure 3: Failed components (from L-R): Ring gear and shaft, pinion, coupling, and rubber-damper

Many authors have made attempts to solve the problems associated with gear design, material selection, manufacture as well as failure of gears. The objective of this paper is to establish the causes of frequent failure the reverse gear box of RL-15 railway trolley, with a view of preferring solutions to the problem.

II. MATERIALS AND METHODS

2.1 Materials

The materials used for the research work were: Sample of failed pinion, and Sample of failed ring gear

2.2 Equipment:

The equipment used for the research work are: Rockwell Hardness Tester (Scale C), Scanning Electrons Microscope (SEM), and Energy Dispersive Spectrometer (EDS).

2.3Methods

2.3.1 Visual Examination

The purpose of which was to ascertain the possible causes and mode of failure of the Reverse-gearbox (RGB) components of the motorized rail trolley (MRT). The RGB assembly was dismantled, and its interior view is shown in plate 4. The RGB houses the pinion, the ring gear and the shaft. Power and motion from the main engine links the RGB and Axle -box through a Coupling Assembly. To identify the cause of failure of these cited components, samples of the RGB materials were taken for analysis. Sample A was shown in plate 5, and sample B is presented in plate 6. These samples were taken as representatives of the whole components. The basic data of the failed pinion and ring gear are presented in Table 1.

Plate 4: Interior view of Reverse-gearbox assembly consisting of pinion, ring gear and shaft

Plate 5: Sample A (i.e. failed Pinion) Plate 6: Sample B (i.e. failed Ring Gear)

Table 1: Basic Data of Failed Pinion and Ring Gear

Parameter	Failed Pinion	Failed Ring Gear
Number of teeth	8	37
Length of teeth (cm)	1.79	1.52
Tooth thickness (mm)	6.30	6.10
Inside diameter (cm)	2.30	10.00
Outside diameter (cm)	3.20	13.10
Number of failed teeth	8	37
Pitch diameter (cm)	3.30	13.40
Module	0.40	0.35
Helix angle	30˚	30˚
Surface hardness	42.83 HRC	44.73 HRC
Gear teeth ratio of Pinion to Ring gear	1: 5	

2.3.2 Scanning Electron Microscope (SEM)

The SEM analysis was carried out on sample A (failed pinion) and sample B (failed ring gear) in conformity with the ASTM E1508 test protocol [7]

2.3.3 Energy Dispersive Spectroscopy (EDS)

The EDS was conducted on sample A and sample B in line with ASTM E1508 [7].

2.3.4 Rockwell Hardness C-scale Test

The Rockwell hardness test was carried out on the samples to measure the permanent depth of indentation produced by a force/load on an indenter in accordance with ASTM E18 -15 test procedures [8].

III. RESULTS AND DISCUSSION

3.1 Hardness Test Results

The results of Rockwell hardness test conducted on the gear samples A and B are presented in Table 2.

Table 2: Hardness Test of the Failed Pinion and Ring Gear Samples

Samples	I	II	III	Average (HRC)
A (Pinion)	43.50	44.00	41.00	42.83
B (Ring Gear)	44.00	46.20	44.00	44.73

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From Table 1, the surface hardness of the sample A (pinion) is 42.83 HRC and sample B (ring gear) is 44.73 HRC. The results show that sample B possess a harder surface hardness than sample A. The differential surface hardness between sample A and sample B surfaces is likely to equalize the rate of wear. However, sample A is expected to harder than sample B because sample A, as the pinion, does more work per tooth than sample B, the ring gear, owing to the fact that the pinion has lesser number of teeth than the ring gear. Harder pinion teeth will help to correct the errors in the gear to an extent, and increase its ability to withstand wear due to its higher hardness number attributed to the cold-worked surface [9].

Figure 1 compares the hardness of the pinion and the ring gear to the recommended American Gear Manufacturing Association (AGMA) standard for gear teeth surface hardness. Thus, both the pinion and the ring gear surface hardness were found to be lower than the recommended AGMA standards; as the minimum surface hardness for gears [10]. Hence, it is recommended that the material be case-hardened to further increase its hardness property durability.

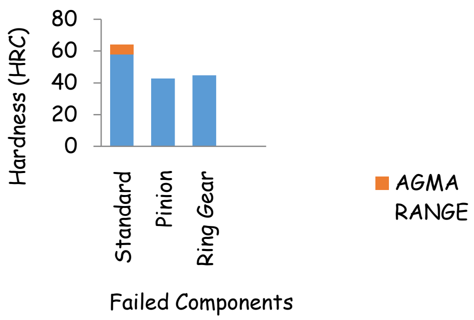

Figure 1: Bar chart comparing AGMA standard with failed pinion and ring gear surface hardness

3.2 Results of Elemental Composition of Samples.

The compositional analyses were carried out on sample A (failed pinion) and sample B (failed ring gear). The results are presented in Tables 3 and 4. From the result shown in Table 3, the sample A's composition was found to correspond with that of AISI 4140 alloy steel. AISI 4140 alloy steel contains 0.80% - 1.1% Cr which is the second highest to the composition of iron in the materials. In addition, its carbon content is low (0.38 % – 0.43%). This requirement is considered to have been met by sample A. While on the other hand, the results of sample B's composition shown in Table 4 corresponds with that of AISI 4130 alloy steel which has lower carbon content (0.28% - 0.33%) and having the same chromium content (0.80% - 1.1%). The compositional analysis revealed that both samples A and B are of the same gear train made of alloy steel of different grades. According to Karl and Erik [11], applications involving high core and case hardness such as automotive gears, universal joints, piston rings and others require high carburizing steel. This implies that AISI 4140 alloy steel is suitable for automotive gears due to its high carbon content, so also is AISI 4130 alloy steel. The result of the chemical compositions of sample A satisfies AISI 4140 alloy steel, while sample B satisfies AISI 4130 alloy steel requirements.

Table 3: Composition of Sample A (Failed Pinion)

Element	Composition (wt. %)	AISI 4140 (wt. %)
Fe	79.03	Remaining
C	0.39	0.38 – 0.43
Mn	0.84	0.75 – 1.00
P	0.031	0.035 maximum
S	0.021	0.040 maximum
Si	0.27	0.15 – 0.35
Cr	0.94	0.80 – 1.10
Mo	0.25	0.15 – 0.25

Table 4: Composition of Sample B (Failed Ring Gear)

Element	Composition (wt. %)	AISI 4130 (wt. %)
Fe	89.74	Remaining
C	0.31	0.28 - 0.33
Mn	0.56	0.40 – 0.60
P	0.02	0.035 maximum
S	0.03	0.040 maximum
Si	0.28	0.15 – 0.35
Cr	0.79	0.80 – 1.10
Mo	0.18	0.15 – 0.25

3.3 SEM Results

3.3.1 Microstructural Examination

The SEM views of sample A and Sample B are presented in plate 7 and plate 8. From plate

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VII, spots of from the smattering of martensitic deposits are visible by the dark spots and the grains sizes are coarse and could be attributed to presence of martensitic structures. It is suggested that cooling by quenching must have taken place in the cause of forming the material. However, the harder the material, the more the tendency of premature failure due to brittle effect [12]. On the other hand, Plate 8 revealed similar analysis as that of sample A with the same evidences. This is could be explained on the basis of the fact the both samples are of the same alloy steels as revealed from their chemical composition test (refer to tables 3 & 4), and must have under gone similar production, and heat treatment processes. The photomicrography of both samples revealed the presence of hardened, heat-treated surfaces with ferritic and pearlitic phases. This was made evident by the presence of the martensitic structure. Therefore, these characterizes the samples A and B as satisfactorily.

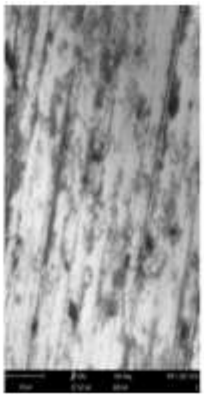

Plate 7: SEM view of Sample A
Plate 8: SEM view of Sample B

3.4Energy Dispersive Spectroscopy Result.

The EDS views of samples A and B in plate 9&10revealed the presence of major elements such as iron and manganese, and minor elements such as; silicon, calcium, cobalt, chromium, titanium, sodium, carbon, potassium and aluminum in both samples[13]. It is worth noting, however, that there was no indication of the presence of contaminants in both views, which would have been a major contributor to its failure.

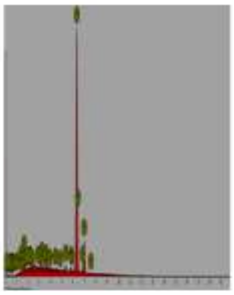

Plate 9: EDS view of sample A
Plate 10: EDS view of sample B

IV. CONCLUSION

From the foregoing, the causes of frequent failure of the reverse gear box components of RL-15 Railway Trolley (RT) was revealed, and the following could be concluded from the research:

i) The pinion has a surface hardness of 42.83 HRC, and ring gear has 44.73 HRC which were lower than the recommended AGMA standard of 58 - 64 HRC. This discrepancy in hardness could be responsible for the rapid wear of the gear teeth.

ii) The chemical composition of the pinion corresponds to AISI 4140 alloy steels, While, that of the Ring gear corresponds to AISI 4130 alloy steels, and hence it could be seen that the material integrity was not compromised for both samples.

iii) The EDS and SEM result of failed components, did not suggest that materialcontamination was the causative factor responsible for the failure. There was no evidence to show that the chemical composition of the components was compromised.

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