The Influence of Reprofiling on the Fatigue Life of Railway Wheel: case study at Addis Ababa Light Rail Transit Service

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Abstract— Railway is a superior means of transportation. Specifically, it has gained a crucial role in limiting traffic congestion in heavily crowded regions. In this perspective, rolling contact fatigue of railway components is a most crucial subject because it has an important role in determining the operational reliability of the wheel/rail system. Due to wheel wear, wheel re-profiling is usually required for proper wheel rail interaction operability. However, the re-profiling reduces the wheel radius and flange thickness. Therefore, the strain energy density in the wheel tread is expected to increase while the strain energy on the flange is expected to decrease in the re- profiled wheel .This effect would either increase or decrease the life of the wheel depending on how often the reprofiling is done. On the other hand, the maintenance costs are expected to increase as the re-profiling frequency increases. For quality service and improvement of the service life of the railway wheels, with reduction of maintenance cost, a problem solving research idea is formulated through comparing the fatigue cycles of crack initiation and propagation of the re-profiled and worn out non-profiled rolling wheels under cyclic loads. Therefore, this study is focused on the influence of reprofiling on the fatigue life of a railway wheel. The adopted method in this study is based on finite element models of worn out non re-profiled and re-profiled loaded rolling railway wheel on a rail. A case study is taken at Addis Ababa Light Rail Transit Service (AALRTS). The wheel profiles are generated through measurement before and after profiling at AALRTS. In a single pair of models of a worn-out wheel and a reprofiled one, the results show that the re-profiling decreases the fatigue life by 249610cycles.

Keywords— crack initiation, crack propagation, cyclic load, fatigue life prediction, rolling contact fatigue, wheel reprofiling, Wear

1 Introduction

CONSIDERING a number of criteria such as capacity, speed and environment, railway is a superior means of transportation. And railway wheels are used to support the wagon mass and guide the wagon along the tracks. The wheels and rails must be able to tolerate the applied tangential forces in order to affect wagon dynamic performance and reduce material deformation.

Rolling contact fatigue failure analysis is used to analyze the cause, type and position of failures. However, these depend on the standard materials, operating conditions and wheels and rails under consideration. Depending on the cause, type and position of the rolling contact fatigue, the way of distribution of cyclic axle load and its effects differ accordingly. The effects due to this cyclic load are damage (crack) initiation, propagation and failure. This work investigates the fatigue life of worn out wheel and the fatigue life of the reprofiled wheels at few reprofiling periods.

According to [9] the high wear rates observed on the excessively worn wheels were as a result of low yield strength relative to the load per axle. The typical wear mechanism found here is a combination of rolling contact fatigue and abrasive brake wear. It is recommended the specifications should consider minimum yield strength to determine axle load. Furthermore, the development of an optimized heat treatment process aimed at increasing the hardness and yield strength of wheel rims will result in a considerable increased wheel life. In general, High wear rates observed on the wheels were a result of low yield strength relative to the load per axle. The analysis on the wheel samples was done through tensile testing, Hardness testing, chemical composition examination, metallographic examination.
The condition maintenance and periodic replacement of railway wheel sets represent a significant cost faced by train operating companies. Rail wheels wear slowly, and could be expected to last for 10 years or more based on normal wear considerations. They are, however, also subject to tread damage caused by wheel slide events, rolling contact fatigue, flange wear and tread rollover. Therefore, wheels require

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regular re-profiling by machining.

Wheel re-profiling is essential element of vehicle maintenance. This maintenance procedure has a major role in the removal of surface defects or irregularities, and in controlling the shape and surface conditions of wheels. Although the benefits are well known, in many cases, they have not been translated into daily practice [5].

When a train travels on rails, all its load is applied to bogie wheel set; due to the complex contact force between wheel set and rails, the wheel tread and flange may develop different degrees of damage after certain mileage; since the worn train wheels immediately affect train operation quality (stability, safety, and passenger comfort) and service life of rails, the reprofiling of worn wheels is considered an important part of maintenance of trains in railway operation [7, 10].

However, the development of fatigue resistance material will help to minimize wheel maintenance, incidents, accidents, and fatality, excess maintenance cost and improve safety. In general, the significance of this study is to prevent sudden accidents, for railway safety and reliability, to improve life span and wear life of wheel.

2 Materials and Methods

Based on the information obtained from Addis Ababa Light Rail Transit Service (AALRTS), most of the north-south line wheels are affected by wear and wheel misalignment. In order to tackle those problems some of the rolling stock wheels were reprofiled one or two times based on AALRTS maintenance manual. Therefore it is important to check the effect of reprofiling on the fatigue life of the wheel through scientific research in order to develop a permanent solution.

The model is analyzed using Finite Element software ANSYS. In order to get the fatigue life of the worn wheel non reprofiled and to make a comparison with reprofiled wheels, given its material properties and its profile geometry and loading conditions. Main operation and technical conditions are stated in Table 1.

Table 1

Main Operation and Technical Conditions [6]

Main Parameters of Lines	
Track gauge	: 1435 mm
Minimum radius of horizontal curve	: Mainlines between sections 50 m ,Yard line 30 m
Minimum radius of vertical curve	: 1000 m
Maximum gradient	: 55 %
Type of rails for main lines and depot	: 50 kg/m
Empty vehicle load	: 44 tones
Switch Torque	: 40 KN
Empty vehicle load +Pay Load	: 63.02 Ton = 627.93231251968 KN
Axle load	: ≤11（1+3%）tones
Maximum Load Per Wheel	: 79 KN
Main Technical Indicators	
Maximum operation speed of the vehicle	: v = 70 km/h = 19.44 m/s
Average travelling speed	: ≥20 km/h
Main Dimensions of Wheel and Rail	
The principal rolling radii of the wheel	: R_{1w} = 330 mm= 0.33 m.
The principal transverse radii of the wheel	: $R_{2w} = \infty$
The principal rolling radii of the rail	: $R_{1r} = \infty$
The principal transverse radii of the rail	: R_{2r} = 300 mm
The angular velocity of the wheel withmaximum operating speed of the vehicle is	: $\omega = v/R_{1w}$ = 19.44/0.33 = 58.92 rad/s
pressure	: P = F/A =5.5 ton/π(80.5mm)^2= 2.403 MPa, 1 ton= 8896.4432 Newton, F=load per wheel,radius of the shaft at wheel contact is 80.5mm

MATERIAL PROPERTIES

For Addis Ababa Light Rail Transit (AALRT), the rail standard used is China National Railways standard of 50 kg/m. Wheel and rail materials are differing slightly in the amounts of chemical composition in the steels used. The material properties of railway wheel and rail are shown in Table 2 and Table 3, respectively.

TABLE 2

CHEMICAL COMPOSITION OF AALRTS WHEEL AND RAIL MATERIAL. [10]

Chemical composition (Wt%)	R7(wheel)	Rail
C	0.52	0.8
Si	0.4	0.28
Mn	0.8	1
P	0.4	0.04 max.
Ni	0.3	-
Cr	0.3	-
S	0.4	0.05max
Cu	0.3	-
Mo	0.08	-
V	0.05	-
Cr+Mo+Ni	0.6	-

TABLE 3

MECHANICAL PROPERTIES OF AALRTS WHEEL AND RAIL MATERIAL.[10]

Properties	Wheel	Rail
Density (kg/m3)	7800	7800
Poison's Ratio	0.3	0.3
Young's Modulus (GPa)	210	207
Yield Stress (MPa)	540	540
Ultimate Tensile Strength (MPa)	820	780
Hardness (HB)	241	
Elongation (%)	14	

The following table shows wheel measurement data which are used for this analysis during reprofiling process by under wheel lathe machine shown in Figure 1 recorded in 2017 at Ethiopian Railway Corporation Addis Ababa light rail service. In Table 4, Pre-measurement data indicate worn out non reprofiled wheel and post-measurement data indicate reprofiled wheel profile.

A. Addis Ababa Light Rail Transit Service East-West line train

B. Under Floor wheel lathe machine at Addis Ababa Light Rail Transit Service

Fig.1. East- West line train and Under Floor wheel lathe machine at Addis Ababa Light Rail Transit Service

TABLE 4
FIELD MEASUREMENT DATA OF AALRTS WHEEL PROFILE [2021]

Identification		**Pre-measurement data**			**Nominal data**			**Post-measurement data**		
Machining data	**12.10.2017** 11:01:52	Back to back	1379.53mm		Variant	50		Back to back	1379.31mm	
Operator ID	A00417	Gauge	1416.62mm		Diameter	611.10mm		Gauge	1415.52mm	
						Left	Right	Diameter difference	**0.04mm**	
									Left	Right
Reason for machining	0	Diameter difference	**0.12mm**		Flange thickness	17.98 mm	17.98 mm	Diameter	**611.20 mm**	**611.24 mm**
			Left	Right				Axial runout	0.17mm	0.46mm
Mileage		Diameter	**614.54 mm**	**614.42 mm**				Radial runout	0.03mm	0.04mm
Machining type	p-3911	Axial runout	0.09 mm	0.35mm				Flange height	**28.21mm**	**28.11mm**
Profile type	7418	Radial runout	0.04 mm	0.15mm				Flange thickness	**17.99mm**	**18.21mm**
Wheel set ID	**206 3Z**	Flange height	**28.66 mm**	**28.44mm**				qr cross measure	4.69mm	4.84mm
Identification		**Pre-measurement data**			**Nominal data**			**Post-measurement data**		
Wheel set position	0	Flange thickness	**17.98 mm**	**19.11 mm**						
Wheel set direction	2	qr cross measure	3.64mm	4.53mm						
Bogie ID										
Vehicle ID										
Vehicle direction 0=A-B,1=B-A	0									
Vehicle type										

A 3D model of wheel rail contact used for this analysis is shown in Figure 2.The boundary conditions are such that the rail are fixed on the bottom and are given a young's modulus of 210000 MPa. The contact algorithm chosen is small sliding with a friction coefficient of 0.33.The loads are given as pressure distributions of 2.403 MPa at the bottom part of the wheel hollow cylindrical hole where the axle is supposed to lie.

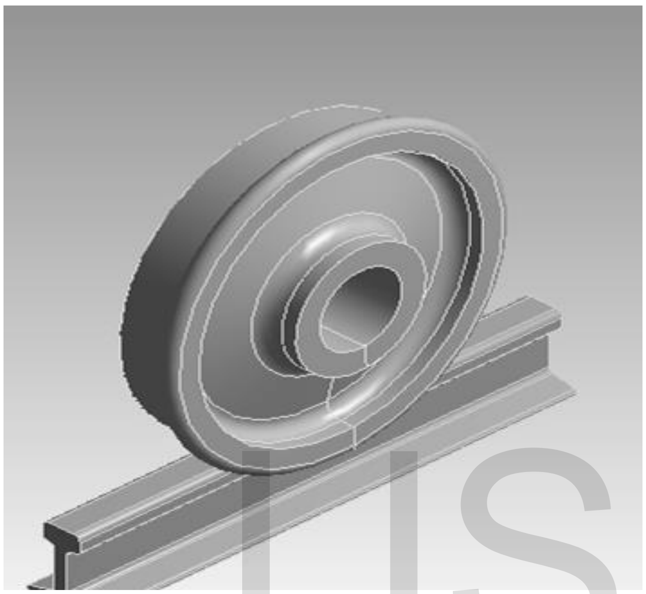

Fig.2. Wheel rail contact model

3 Computational results

In this section the result comparison for worn out non Re-profiled wheel versus the re profiled wheel are presented which are collected from Ansys.

TABLE 5

COMPARISON OF THE RESULTS OF WORN OUT NON RE-PROFILED WHEEL VERSUS THE RE PROFILED WHEEL

		Non reprofiling	Reprofiling	Remark
Fatigue life	Min	$5.4918e^5$	$2.9957e^5$	The fatigue life decreased on reprofiled wheel
	Max	$1e^6$	$1e^6$	
Fatigue damage	Min	1000	1000	The damaged increased on reprofiled wheel
	Max	1820.9	3338.1	
Safety factor	Min	0.90114	0.81111	SF≤1 the material is unsafe and the value decreasedon reprofiled wheel
	Max	15	15	
Biaxiality indication	Min	-1	-0.99998	-1indicates shear stress value and the value increased on reprofiled wheel
	Max	0.99135	0.99194	

From worn out non- reprofiled, the finite element analysis results fatigue life ranges 5.4918e5 to 1e6. And for reprofiled wheel, the result ranges 2.9957e5 to 1e6 when a 5.5 tones axle load is applied in the case of AALRTS trams.

CONTOUR PLOTS FOR NON RE-PROFILED WHEEL

From worn out non reprofiled wheel, the finite element analysis at the wheel rail contact location results that can be seen from Figure 3, fatigue life ranges 5.4918e5 to 1e6, fatigue damage ranges 1000 to 1820.9,safety factor ranges from 0.90114 to 15 and Biaxiality indication ranges -1 to 0.99135 when a 5.5 tones axle load is applied in the case of AALRTS trams

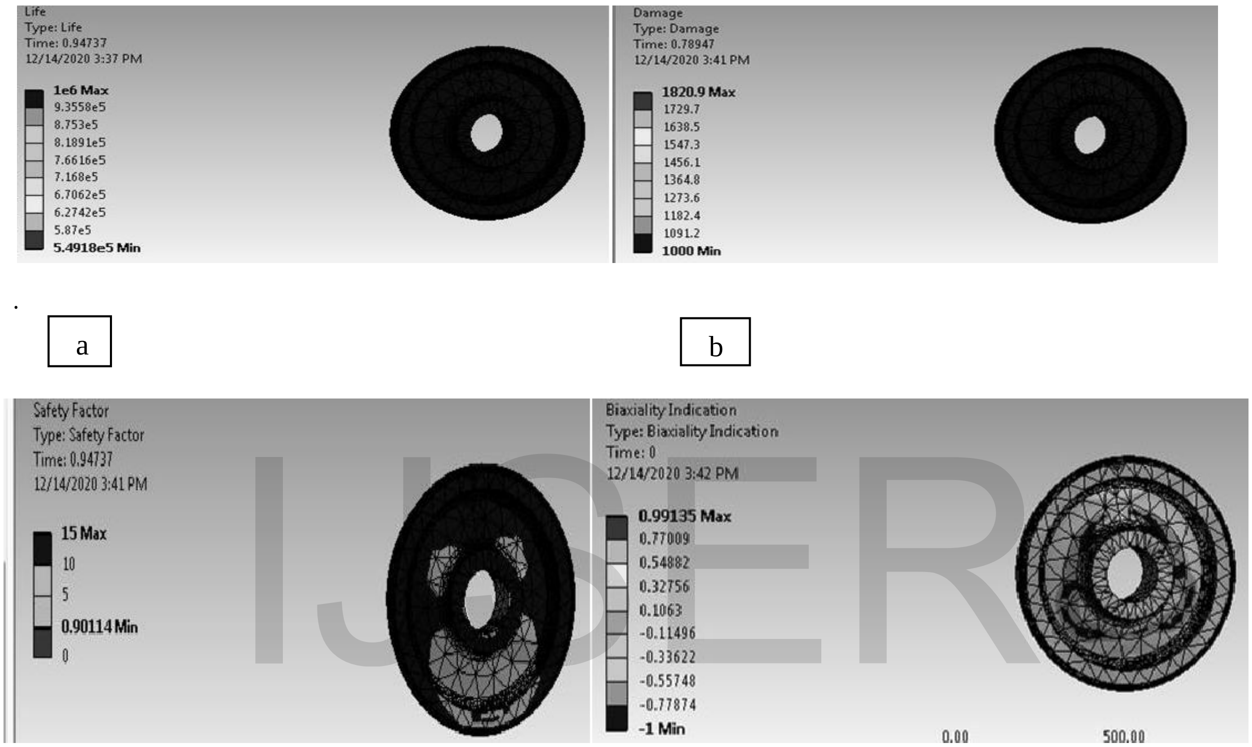

Fig.3. a. Fatigue life, b. fatigue damage, c. safety factor, d. Biaxiality indication of worn out non re-profiled wheel

c d

CONTOUR PLOTS FOR RE-PROFILED WHEEL

From reprofiled wheel, the finite element analysis at the wheel rail contact location results that can be seen from Figure 4 ,fatigue life ranges from 2.9957e5 to 1e6, fatigue damage ranges from 1000 to 3338.1, safety factor ranges from 0.81111 to 15 and Biaxiality indication ranges from 0.99998 to 0.99194 when a 5.5 tones axle load is applied in the case of AALRTS trams.

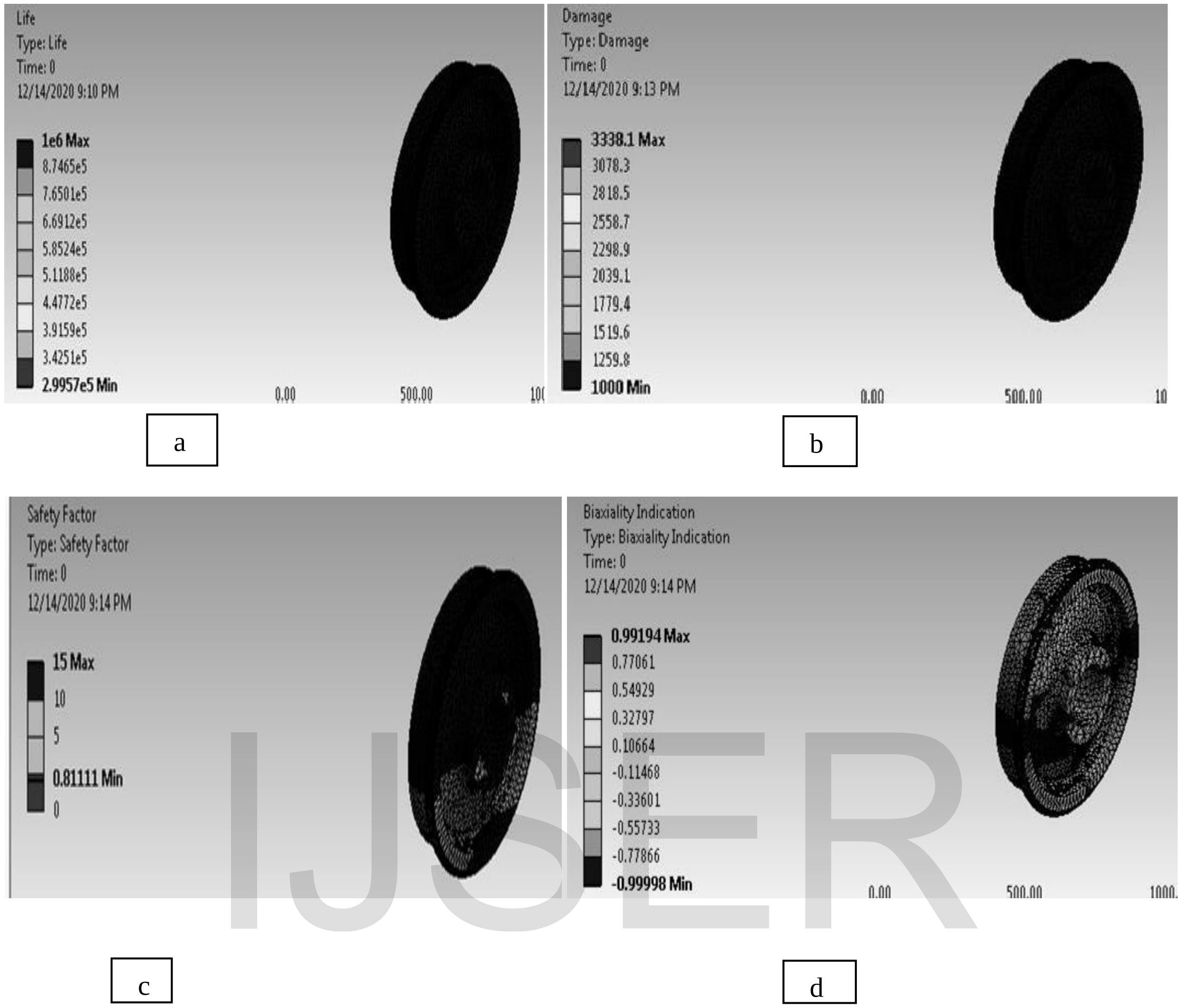

Fig.4. a. Fatigue life, b. fatigue damage, c. safety factor , d. Biaxiality indication of re- profiled wheel

4 Conclusion

FE results indicated that the fatigue life decreases by 249610 cycles for the re-profiled wheel. In this work based on the results tabulated in Table 5, it is demonstrated that the fatigue damage increased, the safety factor value decreased (the material is unsafe due to SF<=1), Biaxiality indication increased (shear stress increased) when the wheel is reprofiled. Therefore, from all results it can be concluded that the reprofiled wheel is not recommended for AALRTS (Addis Ababa Light Rail Transit Service) and it is important to find alternative solution like improvements on the design and manufacturing stage of the wheel to avoid the wear problem and to keep the life of the wheel.

5 Appendices

Operation and technical data of the wheel set [6].

项目 Item	动车转向架 Motor bogie	拖车转向架 Trailer bogie
型号 Type	CW12	CW13
最高运行速度 Max. operating speed	70km/h	
轨距 Rail gauge	1435mm	
轮对内侧距 Back to back distance	1380^{0}_{-2} mm	1377.7^{+2}_{-1} mm
轴距 Wheel base	1900mm	1800mm
轴重 Axle load	10.5t	11.5t
车轮直径 （新轮/磨耗到限） Wheel diameter (new / worn)	660mm/580mm	
转向架重量 Bogie weight	≤6t	≤4t

动车转向架轮对轴箱装置技术数据 Technical data of wheelset and axlebox of motor bogie	
弹性车轮滚动圆直径mm: Resilient wheel rolling circle diameter	
新轮 new	660
磨耗到限 wear to limit	580
最后一次镟轮 the last re-profile	595
轮对内侧距 mm Distance between back of wheel flanges	
单个轮对 Single wheelset	1380(0,+2)
落车状态 With the carbody	1380(-2,0)
同一轮对滚动圆直径差 mm Difference value of the rolling circle diameter of the wheel in one wheelset.	
新造 new	0.3
运用过程中 during operation period	2
同一转向架滚动圆直径差 mm Difference of diameter of rolling circle in one Bogie	
新造 new	3
运用过程中 during operation period	1%×d*
车轮踏面跳动 （图1-7中的尺寸D）mm Running deviation on the wheel tread （the value D on the figure 1-7）	
新造 new	0.6
运用过程中 during operation period	0.8

动车转向架轮对轴箱装置技术数据 Technical data of wheelset and axlebox of motor bogie	
车轮端面跳动 （图1-7中的尺寸C）mm Running deviation on the back face of wheel （the value C on the figure 1-7）	
新造 new	0.5
运用过程中 during operation period	1
轮缘高度(Sh) mm （具体位置见图1-8） Height of wheel flange (Sh) (the position is in figure 1-8)	
新造 new	28
运用过程中（参考数值，具体数值根据用户的运用经验确定） during operation period (only for consulting, this value will be define by the experience by the user)	25
轮缘厚度(Sd) mm （具体位置见图8） Thickness of wheel flange (Sd) (the position is in figure 8)	
新造 new	21.21
运用过程中 （参考数值，具体数值根据用户的运用经验确定） During operation period (only for consulting, this value will be define by the experience by the user)	15
一系上止挡间隙：E（弹性间隙，具体位置见图1-9） Clearance of primary top stopper：E (resilient clearance. The position is shown in the figure 1-9)	
使用新弹簧初次组装时: For the first assembly time and with new spring	23.5（0.5，-1.5）
运用期间：During operation period.	17.5（0.5，-1.5）

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