INVESTIGATION ON TRIBOLOGY OF WHEEL-RAIL: A CASE STUDY OF ADDIS ABEBA LIGHT RAIL TRANSIT (AALRT)

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By

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CANDIDATE DECLARATION

I hereby declare that the work which is being presented in this thesis entitled **“Investigation on Tribology of Wheel-Rail: A case study of Addis Abeba Light Rail Transit (AALRT)”.** In partial fulfillment of the requirements for the award of the degree of Masters of Science in Manufacturing Engineering is an authentic record of my own work, one of the problems AALRT is currently facing and has not been presented for a degree of any other universities, under the supervision of **Dr. Desalegn Wogaso (Asst. Professor)**, Mechanical Design and Manufacturing Engineering Program, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in this research has spent one year time duration to accomplish the whole work and all relevant resources of information used have been currently referred.

Lioul Fenta Demisie	______________	______________
Candidate	Signature	Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and supervision. This research can be submitted for examination with my approval.

Dr. Desalegn Wogaso (PhD)	______________	______________
Advisor	Signature	Date

ABSTRACT

This paper presents wheel wear at Addis Abeba Light Rail Transit and friction behavior of wheel material under both dry and lubricated conditions. The main purpose of this research is to investigate on tribology of wheel-rail for Addis Abeba Light Rail Transit and evaluate frictional behavior of wheel material for both dry and lubricated conditions. Composition, hardness and ring compression tests were the conducted experimental tests carried out during experimental analysis for both existing and alloyed wheel steel. The percentage compostion of carbon, manganese and silicon is gained 0.5%,0.7% and 0.25% respectively for exsting wheel and 0.8%,1.15% and 0.38% for alloyed wheel steel. Based on these findings, combination of issues related to inadequate friction management, poor track infrastructure, composition and hardness were key factors which had led to wheel wear. The parameters such as angular speed of the wheel, passengers loading, and total vehicles weight were calculated based on specification of the company. The hardness value of the wheel material increased from 98.88 HRC to 99.7 HRC. Suitable lubrication and better method of application, improved wheel material, revised track alignment for easing of sharper curves and improved workshop facilities were recommended in this work.

Key Words: Wheel-rail, Wear, Composition, Hardness, ERC, FEM

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ABBREVIATIONS AND NOMENCLATURE

AALRT	Addis Abeba Light Rail Transit
ERC	Ethiopian Railway Corporation
COF	Coefficient of friction
RCF	Rolling contact fatigue
FEM	Finite Element Method
Mn	Manganese
Mpa	Mega Pascal
Sd	Flange thickness
Qr	Flange slop quota
Sh	Flange height
Tp	Trailer w/t driver's cab and panto graph
Mc	Module car with driver's cab

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Wear is a lose or displacement of a material from contacting surfaces. And it is a natural phenomenon that exists when two bodies are in contact, perform a relative motion. This is also true for the case of wheel and rail in railway system. This wear is mainly dependent on the material they are made up of, composition, hardness and friction behavior of material. Friction occurs in all metal forming operations, and in general, it has significant negative impacts on deformation load and energy requirements, product surface quality, wear characteristics, and deformation of the materials. Due to this negative impact of friction, improper alloying and composition of wheel material wear rate is high in wheel-rail system.

Even though it has negative impacts it is well known that friction plays an important role in the overall integrity of metal forming processes and must be considered during the design process. Excessive friction leads to heat generation and wear of tool surface. Further; it can cause inhomogeneity in deformation, increase the deformation load requirement, and create defects in the work. In addition in case of Railway Corporation high friction results in high wheel-rail wear rate and increased rolling contact fatigue [1]. On the other hand transmitting tractive and braking effort between the wheel and rail is impossible without friction, and for this purpose friction should be maximized. In situations where wheel-rail friction is too low (e.g. during leaf fall season), the result is often slipped wheels, trains passing stations and signals, wheel burns, and poor steering through curves. However, low friction, particularly at the wheel flange contact, reduces wear and is generally safer.

Thus proper controlling of friction was necessary to achieve the best performance from the wheel-rail system. Determining the accurate friction factor and friction coefficient, therefore, is significant for understanding of the friction phenomenon of each material and at the die/work piece under different lubrication conditions and deformation process. On one hand, choosing an appropriate test method is quite significant. Currently, several methods have been developed to quantify the interface friction between work piece and dies such as, clamp-rolling, ring-compression… etc., in which the ring-compression test is widely accepted method. On the other hand, the generation of calibration curves is very crucial [2]. Friction calibration curves were obtained via elastic-plastic FE simulation and physical modeling as well as actual ring compression tests, and pointed out that the material properties and test conditions had important effects on the shape of friction calibration curves for both modeling and metallic materials. Recently more and more researchers applied the practical materials to conduct ring compression tests during measurements of friction factor due to the disadvantages of physical modeling experiments to not realize actual processing condition [3].

The wear on the wheel-rail is one of the most critical problems in railway systems due to high maintenance costs that generates, which can reach US $54 total annual per meter and US $1.5 million for a 30 km route. The removal of material from the surface by wear is a function of the sliding and contact stresses, where the amount of sliding depends on the contact patch geometry, normal force, lateral force, and friction coefficient [4]. In addition to friction, hardness and composition of wheel material highly affects the wear rate of wheel-rail significantly.

Therefore, in this research composition test, hardness and ring compression tests were conducted experimentally for both existing and alloyed materials. Hardness of steel was improved by alloying of metals using alloying elements, like, Manganese, carbon, Silicon, and Molybdenum, since an alloy is metal that is combined with other substances to create a new metal with superior properties. Hardenability is appreciably enhanced by Manganese, Molybdenum, Chromium and very small additions of boron (0.001-0.003%). On the contrary, nickel and silicon have mild influence on increase of hardenability of steels. It has been reported that when small amounts of alloying elements are added, the hardenability of steel is improved significantly. Though a very small amount of boron enhances hardenability of steels to great extent but its amount is so small that it is not regarded as alloying element in steel from point view of improving hardenability. Male carried out a study in order to obtained variations in the friction coefficient of metals during compressive deformation at room temperature and his results showed that the coefficient of friction tended to increase with an increasing deformation rate for different metals under dry condition and with a solid lubricant [5].

1.2. Problem Statement

Now a days, transit and transportation in terms of loads and passengers are essential issues of human life and large volume of air, territorial, marine and rail transportation is being performed every day. The interaction of wheel and rail and the resulting phenomena such as wear and sound are considered as very significant issues in railway transportation. Opening systems of rail and wheels, poor alloying and composition of wheel steel has always carried about costly items. The life of railway wheels is usually limited by wear. In Ethiopian Railway Corporation the wheel gives service a maximum of 9 months up to one year without wearing which needs more investigation on the wear behavior of wheel-rail system and causes of wear for wheel. The main problem in materials engineering is that assuming friction coefficient t (COF) and guessing of appropriate lubricant for respective materials rather evaluating and determining of exact values. But the basic criteria to reduce wear, increase durability and strength of wheel material is controlling the friction coefficient at the interface between wheel-rail tribo-system and frictional behavior of each materials.

Basically, certain level of friction is required for braking and sliding of wheel over rail. However, high frictional condition at wheel- rail tribology leads to increase wear rate of wheel. Therefore, it is essential to control the interface friction between wheel-rail systems and evaluate the frictional behavior of wheel materials under both dry and different lubricating conditions so as to find the value of friction coefficient and suitable lubricant. So the intention of this research is to solve this problem.

1.3. Objective of the Research

1.3.1. General Objective

The general objective of this research is to investigate wheel-rail tribo-system and evaluate the frictional behavior of wheel material for both dry and lubricated conditions.

1.3.2. Specific Objectives

- To determine/define important parameters to be considered in investigating causes of wheel wear
- To determine the frictional coefficients of wheel-rail tribo-system for existing and alloyed wheel material used in Ethiopian rail Way Corporation.
- To evaluate stress distribution using FE simulation for existing wheel materials
- To decrease wheel wear rate in terms of composition and hardness of wheel material

1.4. Scope of the Study

Through investigation in mechanical properties of existing wheel material in terms of composition, hardness, alloying and by controlling friction behavior of wheel material at both dry and different lubricant conditions the wear rate is expected to decrease. The investigation had been carried out on both roots of the Menilik II Square-Kality (North-South), Ayat-Torhayloch (East-West) and vehicles could be looked at and assessed from both stations. The research focused on wheel materials and operational conditions of AALRT vehicles and the general maintenance activities carried out at the depots. In this work, the data collection was limited from AALRT staff interviews, inspections and current wheel and vehicle data available in Site Company. The composition, hardness and ring compression tests of existing and alloyed wheel material has been done and compared.

1.5. Significance of the Study

This investigative research could be important to address the issues behind the wheel wear and suggesting recommendations to ease the problem facing in railway Corporation. This investigation could identify major causes of the wheel wear and problems in the maintenance shop and technical problems related to the vehicles and track conditions. Knowing the causes would point out the problem focus for solution to wheel wear reduction. Composition, hardness and frictional behavior of wheel steel had been identified. Which lubricant could be suitable for wheel steel to control friction has been stated. This work would put forward points of focus for future works related to wheel wear which can be instrumental for development of research work and their use in railway industries such as Ethiopian Railway Corporation (ERC). Generally this research work signifies the following points for Ethiopian Railway Corporation (ERC),

- Better operating performance of wheel-rail system and cost minimizing especially maintenance costs
- Improving life of wheel in wheel-rail system in railway transport and determined friction coefficient for wheel materials.
- To know the compostion, hardness value and proper lubricant for wheel materials
- Clarify friction behavior and impact of wear on life of wheel-rail system

1.6. Research Questions

- What was the problem caused by wear in wheel-rail system in Ethiopian Railway Corporation? Maximum life time of wheel was one or two years only which leads to increase maintenance cost and damage the operation performance.
- What were factors affecting wear in wheel-rail system? Environmental conditions due to open system, presence of third body materials during operations, chemical composition of wheel as well as rail materials and friction behavior.
- Why the author interested in this area? Unlike gears or rolling bearings which are sealed contacts with reduced exposure to the surrounding environment, a wheel-rail contact is an open system that is exposed to dirt and particles as well as natural and applied lubrication.
- For whom study is used? Ethiopian railway corporation

- How wear rate can be decreased?

By increasing the composition of highly wear resistance material from its constituent and decreasing composition of less wear resistance material and by controlling friction coeffient of the material and proper alloying.

1.7. Conceptual Frame work

Controlling both friction and wear can be considered as main concern for any machine components and materials. Reducing friction at acceptable levels can increase productivity of equipment's, machines or any devices involved. Taking friction coefficient from calibration curve in ring compression test by relating the change in internal diameter and height reduction and by comparing experimental results of alloyed material wear behavior could be enhanced.

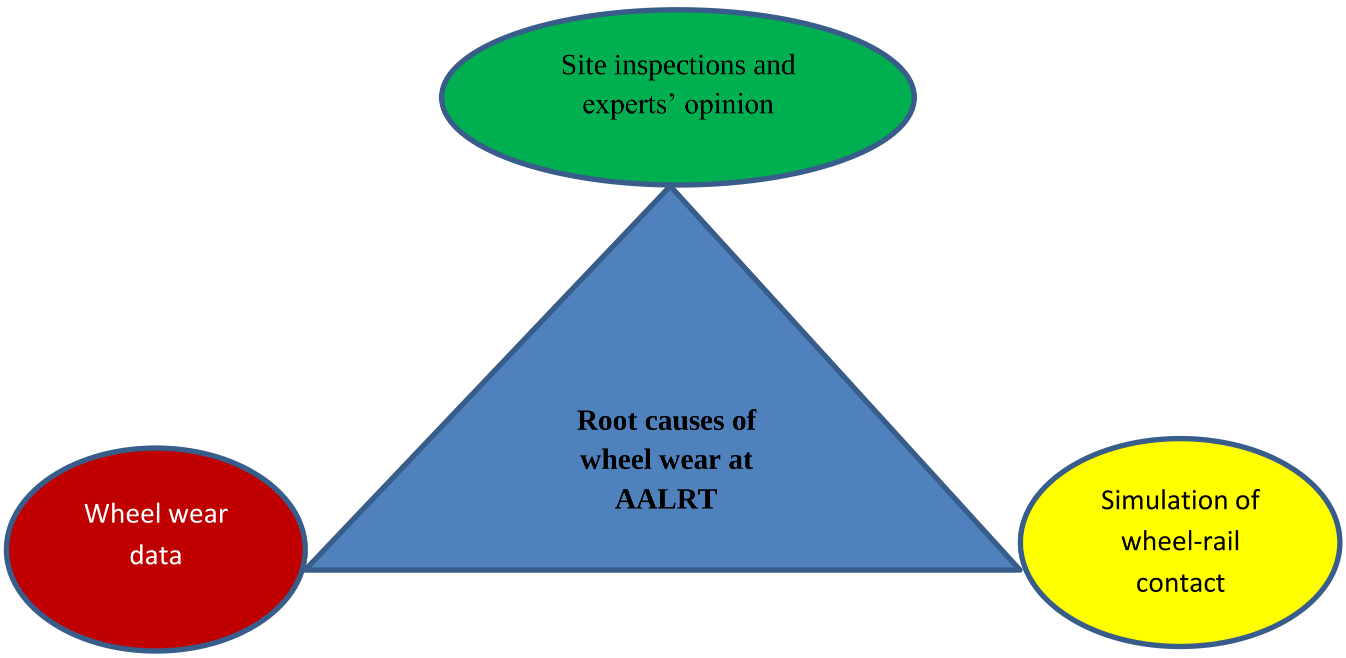

Figure 1. 1Triangulation of results

The wheel surface is subjected to high normal and tangential contact stress. The removal of material from the surface by wear is a function sliding and contact stresses. These quantities depend on the railway vehicle dynamics that is affected by the change of wheel profile shape: In railway maintenance practice three indexes, called wear control parameters denoted by the symbols Sd, *Sh* and Qr, are used to quantify the degree or severity of profile wear. The Sd index measures the flange thickness, the *Sh* index the flange height and the *Q*r index the flange steepness.

1.8. Limitation of the Study

The basic measurement of wear was in general analyzed by pin on disc machine for a century which measures the weight of materials before and after experiment to calculate the weight loss due to wear. But the absence of pin on disc machine in Ethiopia leads to the owner of this research to see different options. In this research the indirect measurement of wear has been done in terms of composition, hardness and friction coefficient value of the wheel materials. Each material has its own friction calibration curve but in this research friction coefficient had been taken from generalized friction calibration curve by male and by relating the change in dimensions from compression results. Due to the absence of direct measurement machine for wear and using generalized friction calibration curve leads the investigation gave approximate values of friction coefficient and friction factor of wheel material.

1.9. Thesis Organization

This research is organized in five chapters. The first chapter includes introduction which provides back ground of the study, problem statement, objective, significance of the study, research questions, conceptual frame work, scope and limitation of the whole research work. The second chapter covers the review of some journal articles, conference papers, which were referred during study. Also in relation and comparation with previes works, what is done in this study has been stated. The third chapter discussed about methods (techniques) and materials used. It covers geometry and other vehicle specification, loading conditions and seating capacity of the vehicles. All about data collection and actual wheel data measurements have been analyzed in this chapter. It includes different experimental tests like, composition, hardness and ring compression tests for both existing and alloyed wheel material. Chapter four deals about the results gained and discussion of results. Finally, the last chapter covers conclusion drown from the results explained in chapter four, recommendations and future works.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

So many researchers had researched out in relating the railway wheel wear with different parameters affecting the wheel. The use of ring compression test and FEM analysis is evident in many of journals, articles and researches done. These literature reviews are used in this research, in identifying potential factors that lead to wheel wear and to lay down the knowledge gab. Wheels are the most critical part of rolling stock and most care is given to them as they are the most stressed components of railway vehicles. The main importance of wheels in the rolling stock operation is that they guide the train on tracks through straight, curves and switches. The wheel surface is subjected to high normal and tangential contact stresses. The removal of a material from the surface by wear is a function sliding and contact stresses and removal of material is due to either adhesion or local plastic deformation.

2.2. General over view on wear of wheel and rail materials

During wheel-rail operation, the wheels of railway vehicles are subjected to wear. When the worn state of the profile reaches a limit value limited by international standards the wheels have to be re-profiled. In the Railway Corporation, it is well known that there were mission profiles (operating conditions, track geometry, wheel-rail profiles, etc.) where some train sets require the re-profiling of their wheel sets after only 80 km of service, whereas others are able to operate in similar conditions for more than 400.000km without need such a maintenance procedure. Furthermore, the Railway wheels can only be re-profiled 3 or 4 times and the wheel set substitution is very expensive [6].

The wheel wear characterization based on programmed measurements of the geometrical parameters *Sh*, Sd and Qr was widely used by the railway industry. Such assessment is a relevant criterion to evaluate the wear state of the wheels. This approach consists of monitoring periodically the geometrical parameters of the wheel profiles in order to check if they have reached the safety limit values defined by the technical specifications. When that happens, it means that the wheels have to be re profiled. The measurement of the wear parameters Sd and Qr allows predicting the influence of the wear state of the wheel profiles on the dynamic behavior Railway vehicles. For example, the flange thickness Sd is very important as it limits the lateral clearance of wheel set with respect to the track, which influences the vehicle stability. The flange slope quota Qr is an important parameter. If it is too small, the wheel flange will be almost vertical, which implies that the transitions (switches crossing) and the flange contacts will occur abruptly. Such a situation originates very high contact forces that damages both vehicle and infrastructure [7].

2.2.1. Method of Optimizing Stability and Wheel wear in Railway

A research procedure was conducted to optimize bogie suspension parameter in view of minimizing wheel wear produced by curve negotiation, though meeting stability requirements. The objective was to further minimize the wheel wear rate of a self-steering three-piece bogie without compromising vehicle stability. Simulation results indicate that wheel wear was theoretically the lowest for low lateral and longitudinal primary suspension stiffness and no friction at the Centre plate. As zero friction at the center plate was impractical, a low coefficient of friction and low primary suspension stiffness were chosen as the optimum.

One of the major causes of maintenance expenditure is associated with the wearing of the wheels and of the rails, requiring periodic wheel re-profiling and rail grinding operations that eventually led to the replacement of the wheels and of the rails. Unfortunately, the design of a railway represents compromising of curving performances (and hence reduce wear of the wheel/rail couple) and meeting stability requirements. As concluded in their work, the parameters affecting these two targets were bogie wheel base and the stiffness of the primary suspension in the horizontal plane (i.e. the longitudinal and lateral primary stiffness) [8].

2.2.2. Friction Coefficient

The coefficient of friction between railway wheels and rails is crucial to railway operation and maintenance. It was discussed that the friction coefficient decreases almost linearly with the increasing humidity and is independent of temperature. But temperature difference highly affects coefficient of friction. At both extremes of high and low values of coefficient of friction there were undesirable effects: at low values, trains lose traction, introducing skidding and damage to the track and safety issues. At high friction, catastrophic wear, accompanied by flaking and spelling of the rail could be expected. To avoid these extremes, ideally the friction coefficient should be maintained at an intermediate range between μ=0.2 and μ=0.3[9]. Due to the increasing interest in the low friction phenomenon between wheel and rail, more models were developed for the situation when the rail is contaminated, with theories [10]. In order to identify the effect of friction coefficient on the power dissipation in the wheel/rail contact several simulations were performed using a three-dimensional, multi body model of a railway vehicle implemented in the software package VI-Rail Adams. The power dissipation and wear rates of the inner and outer wheels of the first bogie of the vehicle running over a curve of a metro line were calculated for different friction coefficients varying from 0.2 to 0.7 [11].

2.2.3. Rolling contact Fatigue (RCF)

Rolling contact fatigue (RCF) plays a great role in determining the reliability of wheel-rail system. Therefore controlling RCF-related defects was ongoing for both safety and cost of railway transportation. RCF defects of wheel and rail materials are mainly caused by cyclic loadings of wheel-rail interface. Subsurface RCF is uncommon, but its consequences are usually serious, such as severe wheel and rail damage or even derailment. If the manufacturing process is well controlled, subsurface RCF failure could be largely reduced. Simulation model was conducted for assessing the wear and RCF in rails with particular emphasis on their competitive role, and the results indicated that the wear can remove the surface cracks due to RCF. It was noted that initiation and propagation of cracks were affected by lots of factors, such as microstructure of materials, contact pressure, shear stress, lubricant and operational environment. The investigation of rolling contact fatigue in track is hampered by multitude of train types and axle loads running on the network [12, 13]. It was discussed the relationship between the rail decarburization and RCF and the effect of decarburization was to increase the rail crack growth rate with increasing depth. The consequence of decarburization was to reduce the amount of carbon at the surface so that ferrite layer forms with a gradient microstructure with decreasing amounts of ferrite until the core material of pearlite and pro eutectoid ferrite is reached [14].

2.2.4. Relation between Friction and Wear

It was investigated that friction coefficient and wear are not material properties but they are the response of tribo system. They have a relation with each other. These two terms define the state of contact of not the martial properties of the bodies. The purpose of the investigated research was to understand the wear mechanisms by studying the characteristics of wear and friction by using different materials. Due to partly transferring of the thin soft layer to counter surface by adhesion in tribo elements, relative displacement takes place at the interface which is between surface of coating and transfer layer. This layer is of smaller shear strength of the softer material than that of the underlying elemental material. As a result low friction can be obtained and moreover the wear of tribo-system can also be reduced [15].

It was clearly discussed friction and wear of wheel/rail system influences the running performance of rail vehicles and the life of system components. With a better understanding of the causes (friction) it would be possible to put the right construction on the effects (wear) and effectively counter damage to system components. To this end, the behavior of the wheel and rail material would be experimentally analyzed under various operating variables without lubricants [16]. On the other hand effect of lubricant and temperature on friction coefficient during hot forging of Nimonic 115 super alloy was investigated using FEM to derive friction factors during hot ring compression test. An upper bound method was employed to calculate friction factor during hot compression. Various contact conditions were applied including dry contact and lubricated conditions using graphite, glass and mica sheets in hot ring compression and hot compression processes. As a result the major advantage of using hot compression for driving of friction factor is dependent only on the geometrical measurement of the shape change [17].

2.2.5. Classification of Materials

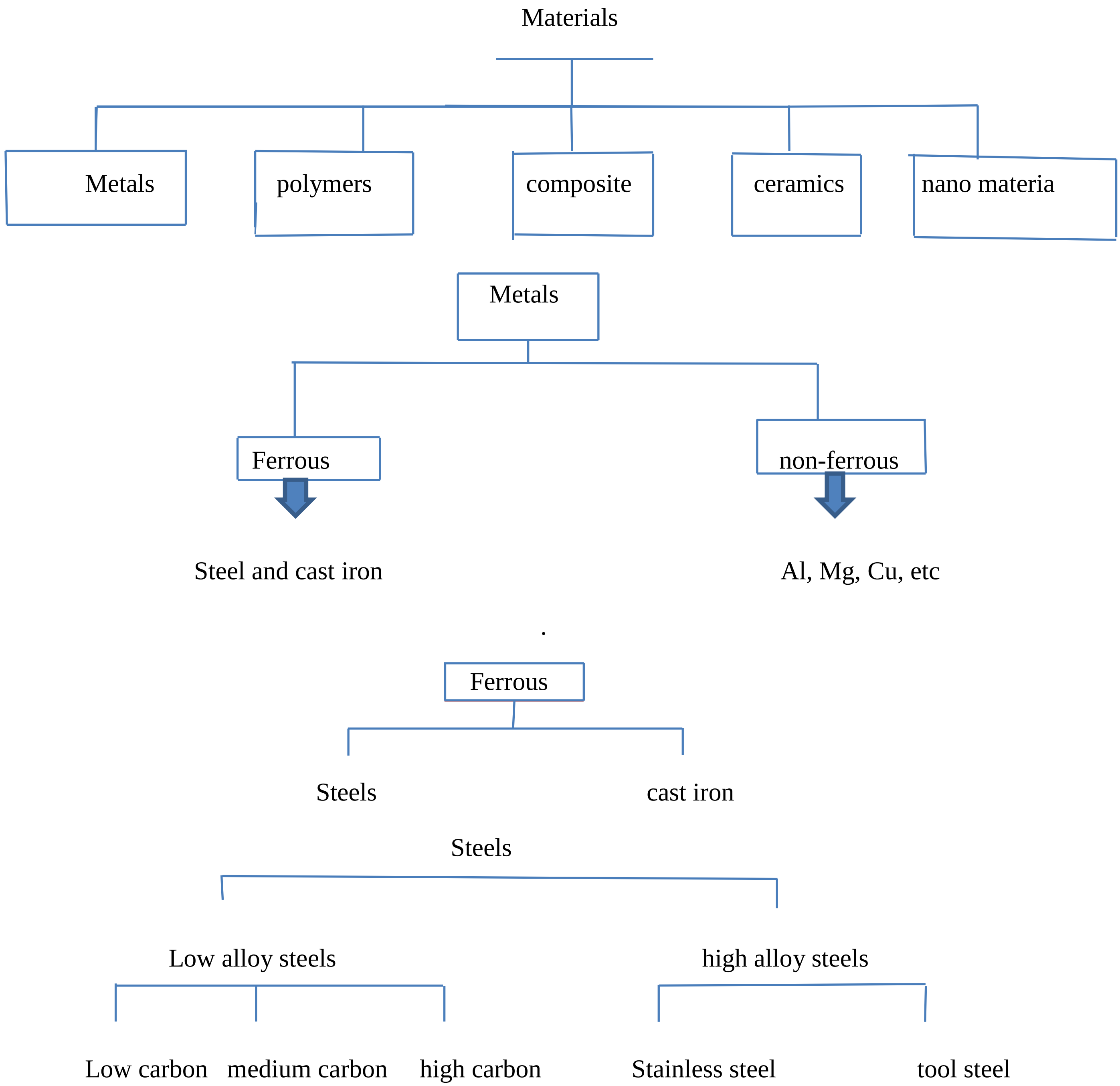

Figure 2. 1 Flow chart for classification materials [18]

Steels are basically alloys of carbon and iron which contains other alloying elements and several grades are available based on carbon contents.

Table 2. 1 alloys with carbon content percentage [18]

Alloy	Carbon content
Low alloy	<10%wt
Low carbon Medium carbon High carbon	<0.25%wt 0.25 to 0.60%wt 0.6 to 1.4%wt
High alloy	>11%wt

2.2.6. Mechanical properties of Common Steel

The physical properties of steel include: high strength, medium weight, durability, ductility, corrosion and wear resistance. Steel offers great strength, even though it is medium in weight. The term ductility means steel can easily molded in to desired shape. Other physical properties of steel what are totally different are its component elements viz.iron and carbon. Steel has the ability to cool down rapidly from extremely hot temperature after being subjected to oil or water. Physical properties depend on the percentage composition of the constituent elements and the manufacturing processes. Steel grades are classified by many standard organizations, based on the composition and physical properties of metal. The deciding factor for the grade of steel is basically its chemical composition, and applied conditions. The higher carbon contents the harder and stronger the steel metal is [19].

2.2.7. Chemical Composition of Steel

Steel is an alloy of iron and other elements. Some elements are intentionally added to iron for the purpose of attaining certain specific properties and characteristics. Other elements are present incidentally and cannot be easily removed. Such elements are referred to as “trace” or “residual” elements. Many product specifications have mandatory requirements for reporting certain elements. Most mills routinely provide heat analysis which includes the elements below. Although it is possible to analyze for other elements this is most often not practical or necessary unless they are additions (e.g. Pb – Lead, Sb –Antimony or Co - Cobalt). There are thousands of steel alloys and their categorization is complex and varies by governing body. However, it could be broadly grouped into Plain Carbon Steel, Ultra Low Carbon (ULC) Steel, High Strength Low Alloy (HSLA) Steel, Alloy Steel, High Alloy Steel (including Stainless Steel and Tool Steel) and Electrical Steel. Advanced High Strength Steel (AHSS) is the newest classification of steels [20].

2.7.8. Characteristics Required by the Wheels

- Wight: Wheels are unsprang parts; therefore light weight is preferable from the view points of their influence over riding comfort and bogie parts. This characteristic is especially important when designing high-speed vehicles.
- Web fatigue strength: A web must have sufficient fatigue strength to withstand cyclic mechanical stress caused by the Wight of the body.
- Rolling contact fatigue strength of tread: Sufficient fatigue strength to withstand the rolling contact stress (Hertz stress) between the tread and rail is necessary.
- Characteristics of stress alternation caused by thermal attach: when the rim expands because of thermal input caused by tread braking, thermal stress is developed at the web and rim areas. Sometimes the excessive thermal input changes the normal stress distribution given by the production stage into an abnormal situation.
- Thermal crack and fracture resistance: This is the characteristic relating to thermal cracks initiated on a rim by the frictional heat generated by tread brake and their propagation, in worst case, wheel fracture takes place.
- Wear resistance: Abrasion/wear is developed on a tread when it is in contact with a rail. In case of a tread brake wheel; it is also developed by the friction between brake shoes and the tread. This is the characteristic directly related to the wheel life.
- In some cases, non uniform wear becomes problematic rather than the wear amount itself [21]. In this research Manganese, silicon, carbon, molybdenum and nickel were used as an alloying element to achieve the above wheel steel requirements.

2.7.9. Effects of alloying elements on Steel

Manganese (Mn): Manganese increases hardenability and tensile strength of steel, It is also able to decrease the critical cooling rate during hardening, thus increasing steels hardenability much more efficient than any other alloying element. A deoxidizer and degasifier reacts with sulfur to improve forge ability. It increases tensile strength, compressive strength and highly resistance to wear. Manganese also tends to increase the rate of carbon penetration during carburizing and acts as a mild deoxidizing agent. However when too high carbon and too high manganese accompany each other, embrittlement sets in. Manganese is capable to form manganese sulfide (Mn) with sulpher, which is beneficial to machining. At the same time, it counters the brittleness from sulpher and is beneficial to the surface finish of carbon steel [22].

Vanadium (V): Vanadium is used to refine grain size. Steels contain vanadium have much finer grain structure than steels of similar compositions without vanadium. It decreases the rate of grain growth during heat treating processes and raises the temperature at which grain coarsening sets in thus improving the strength and toughness of hardened and tempered steels. Contents up to 0.05% increases hardenability while larger amounts tend to reduce hardenability due to the formation of carbide. Vanadium lessens softening on tempering and induces secondary hardness on high speed steels. Increases strength, hardness, wears resistance and resistance to shock impact. It retards grain growth; permitting higher quenching temperatures. It also enhances the red-hardness properties of high-speed metal cutting tools [23].

Phosphorus (P): Phosphorus increases strength and hardness, but at the expense of ductility and impact to toughness, especially in higher carbon steels that are quenched and tempered. As such its content in most steel is limited to a maximum of 0.05%. Phosphorus prevents the sticking of light-gage sheets when it is used as an alloy in steel. It strengthens low carbon steel to a degree, increases resistance to corrosion and improves machinability in free-cutting steels.

Molybdenum (Mo): Molybdenum adds corrosion resistance and high temperature strength. It primarily increases the corrosion resistance of steels and strong carbide former and usually present as an alloy in steels in amounts less than 1%. It increases hardenability and elevated temperature strength.

Silicon (Si): helps increase the steel's strength and hardness, but is less effective than manganese in these functions in some high temperature service steels. And also contributes their oxidation resistance. In steel castings 0.35 to 1% is commonly present [24].

2.3. Parametric analysis of Wheel wear in Fast vehicles

Dynamic model for a high-speed vehicle was set up, where the wheel set was regarded as flexible body, and the actual measured track irregularities and line conditions were considered, the final goal being to reduce the wheel profile wear of high-speed trains and extend the service life of wheels. In this model, the influence of different parameters was considered which influences wheel profile; such as, primary suspension, stiffness, track gage, and rail cant on the wear of wheel profile were studied through iterative calculations. Numerical simulation results show that the type XP55 wheel profile had the smallest cumulative wear depth, and the type LM wheel profile has the largest wear depth. As recommendation, to reduce the wheel profile wear, the equivalent conicity of the wheel should not be too large or too small. In addition, a small primary vertical stiffness, track gage around 1,435-1,438mm, and a rail cant around 1:35-1:40 were favorable for dynamic performance alleviation and reduction of wheel wear [25].

2.3.1. Influence of Wheel profile on Wear

The wear depth and distribution of four types of wheel profiles (LM, LMA, XP55, and S1002) were compared taking the line conditions for the same operating mileage. With increasing running mileage the wear depth initially increased rapidly and slowdown. Because the type LM profile had the largest equivalent conicity, the wheel wear was close to the flange. The S1002 profile had the smallest equivalent conicity and the wheel wear was near the outside of the wheel [22, 23,24,25]. This shows that the equivalent conicity shouldn't be too large or too small because this will only intensify the wear.

Table 2. 2 Wear distribution zone for different wheel profiles (mm) [25]

No.	XP55	LMA	LM	S1002
1	-47-+18	-44-+24	-52-+16	-46-+29
2	-44-+24	-43-+24	-45-+26	-51-+24
3	-44-+26	-45-+26	-44-+25	-47-+27
4	-51-+26	-45-+32	-43-+31	-51-+31

2.3.2. Influence of Primary vertical stiffness on Wear

To compare the influence of primary vertical stiffness on the wear depth and range, the primary vertical stiffness on the wear depth and range, the primary vertical stiffness with values 0.8, 1.0, 1.2 and 1.4 MN/m was adopted for the calculation. In figure explained below, it is shown that the primary vertical stiffness has little influence on the wear range. In the wear stage 3, the primary stiffness has little effect on the wear depth but further in the wear stages, 1.0 MN/m will cause greater wear than the others, and the least wear brought by the stiffness 0.8 MN/m. With the increasing of running mileage, the wear depth increases rapidly in the early stages and slowly in the later stages [25].

2.3.3. Influence of Track gauge on Wear

The computed track gages were 1,432, 1435, 1438 and 1,441 mm, and their influences on the wear depth and distribution of the wheel profiles were compared. Wear depth reduced and wear range gradually moves away from the flange with the increase in track gage in the first stage. In the lateral stages, track gages 1,435 and 1,438 mm have the least wear depth. It can be concluded that slightly widening the wheel gages, can result induced wear.

2.3.4. Influence of rail cant on wear

Rail cants of 1:25, 1:30, and 1:40 were selected for the wheel wear investigation. The wear depth was small when the rail cant angles were 1:35 and 1:40, and the wear distribution was near the flange. Therefore, as recommended in this work, the rail cant should be 1:35 and 1:40 to reduce wheel wear [25].

A vehicle dynamic model and wheel profile wear model were established and the following conclusions were obtained based on analysis parameters that possibly influence the wear of the wheels. Among the four type's wheel profiles, the type XP55 wheel had the smallest cumulative wear depth, and LM the largest wear. To reduce the wear of wheel profile, an appropriate wheel equivalent conicity needs to be designed, and must not be too large or too small. Mainly focuses on the train-track interaction and mechanisms of irregular wear. These authors discussed the causes, consequences and suggest solutions to minimize the problems for several types of wheel and rail wear [25]. The track gage should be between 1,435 and 1,438 mm, a too large or too small gage would aggravate the wheel wear, and rail cant should be between 1:35 to 1:40. Roller rig bogie prototype was used to analyze the influence of the wheel profile wear on the running stability (critical speed) of railway vehicles. He presented a methodology to minimize the wheel wear by optimizing the primary suspension stiffness and the center plate friction of a self-steering three-piece bogie without compromising the vehicle stability [26].

2.4. Research gap

Plenty of researches have been done to study the wear performance and mechanisms of wheel-rail system. Nonthless , such tests have been systematic and comprehensive; they have not been all-embracing enough to summarize all the wear mechanisms in the wheel-rail contact in railway industries, so a final conclusion has yet to be reached. Abrasive wear tests were carried out on the samples using pin on disc wear test. And the tests were carried out under restricted values of speed, load and time setting. Therefore, this research applied ring compression tests at a given loads, speeds and time setting to control friction coefficient providing improved frictional behavior of wheel materials through investigation in composition of steel, hardness, alloying which was indirect controlling of wear. In this investigation of rapid wheel wear of AALRT vehicles, the general causes of wheel wear are going to be presented through interviews with experts and technicians at AALRT depot in which they address the general problems leading to the current wheel wear. Actual wheel data measured at AALRT depots was analyzed to identify which line of operation was more affected between Kality and Ayat line vehicles and to study the severity of the wheel wear problem.

CHAPTER THREE

3. METHODS AND MATERIALS

3.1. Introduction

In this research the third chapter basically covers the material and the techniques used. AALRT operational characteristics, data collection as well as analysis and actual wheel data measurements also included. The applied methods, which are well organized, provide a step by step approach to achieve the specific objectives. Based on the forgoing technique three experimental works namely, composition tests, hardness and ring compression tests have been carried out. FEM simulation was used for verifying experimental works for ring compression tests and evaluation for friction factor.

3.2. Materials

As it is investigated in different international journals, there are several wheel and rail material standards but closely similar in their properties. In the entire standards wheel steel material is somewhat softer than that of the rail differing slightly in the amounts of carbon, silicon, and manganese in the steels used. For the present experimental work, wheel steel (AISI/SAE1050) were used as a wheel material for investigation and experimental analysis. For Addis Ababa light rail transit (AALRT), the rail standard used is China National Railways standard of 50 kg/m while the international is 60kg/m. The following tables table 3.1 and 3.2 shown below represents chemical composition and mechanical properties of a given material.

Table 3. 1 Material composition of steel wheel and steel rail

Chemical composition (wt. %)	C	Si	Mn	P	Ni	Cr	Mo	V	Fe
CSN12071(rail) (AISI/SAE 1070)	0.7	0.39	1.2	0.05	0.03	0.25	0.002	0.022	97.34
CSN12071(Wheel) (AISI/SAE 1050)	0.65	0.35	0.8	0.035	0.003	0.01	0.001	0.003	98.15

Table 3. 2 Mechanical properties of corresponding wheel and rail materials

Material type	Hardness value (HRC)	Yield strength (M pa)	Tensile strength (M pa)
CSN 12071(Wheel) (AISI/SAE 1050)	125-130	560	900-1050
CSN 12071(rail) (AISI/SAE 1070)	129.131	570	1021-1032

AISI standard (AISI /SAE 1070 rail and 1050 wheel) and Chinese standards (Appendix A)

Manganese, silicon, carbon, vanadium, molybdenum, sulfur and Phosphorus were used as alloying elements.

3.3. Methods

3.3.1. Data Collection and Analysis

For the most part, Ethiopian railway corporation is serving the transportation sector and the economy in general, and thus doing a great deal of work for the country. But the risk in terms of wheel wear of train vehicles is a major concern. Wheel/rail contact is very important factor for the movement of the train and at the same time, wear is taking place in the process. It is impossible to stop wear completely but it can be minimized to some extent.

Nevertheless, the life of railway wheels is usually limited by wear. In identifying factors that lead to wheel wear at AALRT, wide range of combined causes are possible and to identify these causes, data collection was carried out through oral interviews with maintenance personnel, visual inspections of track and vehicle components. In addition, actual wheel data of vehicles measured after some mileage travel, before and after wheel profiling which includes vehicles from both routes. The research findings could be very instrumental to determine the factors that brought about the problem and based on them, it is possible to find solution to minimize the problem of wheel wear. For the case of AALRT, the wheels are worn on the flange side with reduced flange thickness including worn tread section. The wheels are of 660mm diameter with minimum 580mm allowed explained in Appendix F. As the problem of rapid wheel wear at AALRT, there is no definite reason why the problem occurred but technicians and experts gave different technical points. Some said that rapid wear occurred due to poor construction of track with irregularities. Others said that small curves constructed inside and outside the depots led to high frictional contact, thus contributed to rapid wheel wear. Others agreed that the wheel material is of a low standard and thus sensitive to wear.

3.3.2. Site inspections and Interview Discussions

In this research interview and inspections were carried out to identify the potential causes that lead to wheel wear from the point view of operational and technical problems observed at AALRT. The factors that are considered to be potential causes are identified based on interviews and inspections carried out with technicians/experts in the field. Interviews were undertaken with four personnel at Kality depot namely the head maintenance department who holds Masters in railway engineering, two rolling stock maintenance experts of whom are Bachelor degree graduates in Mechanical Engineering and a technician who manually operates/works on AALRT vehicles. They have taken necessary trainings in China in their respective positions, on rolling stock maintenance including wheel and rail interaction. Interview questions are shown in Appendix A. The following challenges were pointed out during interviews with the head maintenance personnel, and technicians at AALRT depots. The general technical problems observed were related to friction management, lack of maintenance facilities and track system. These are some of the challenges that potentially aggravate the wear problem.

a) Lack of testing of vehicles

Basic tests on AALRT vehicles are carried out at both depots of which are daily inspection of vehicles before the trains start operations like lighting checking, checking appearance of entire bogie (painting damage, mechanical damage, etc.), and whether the components are loose or missing. Additionally, annual, quarter and monthly maintenance are carried out. Overhaul maintenance of vehicles and load testing take place at overhaul maintenance workshop which contains load tester and fixed/movable lifting jack. Wheel re-profiling activities were carried using floor wheel lathe machine at the wheel re-profiling workshops

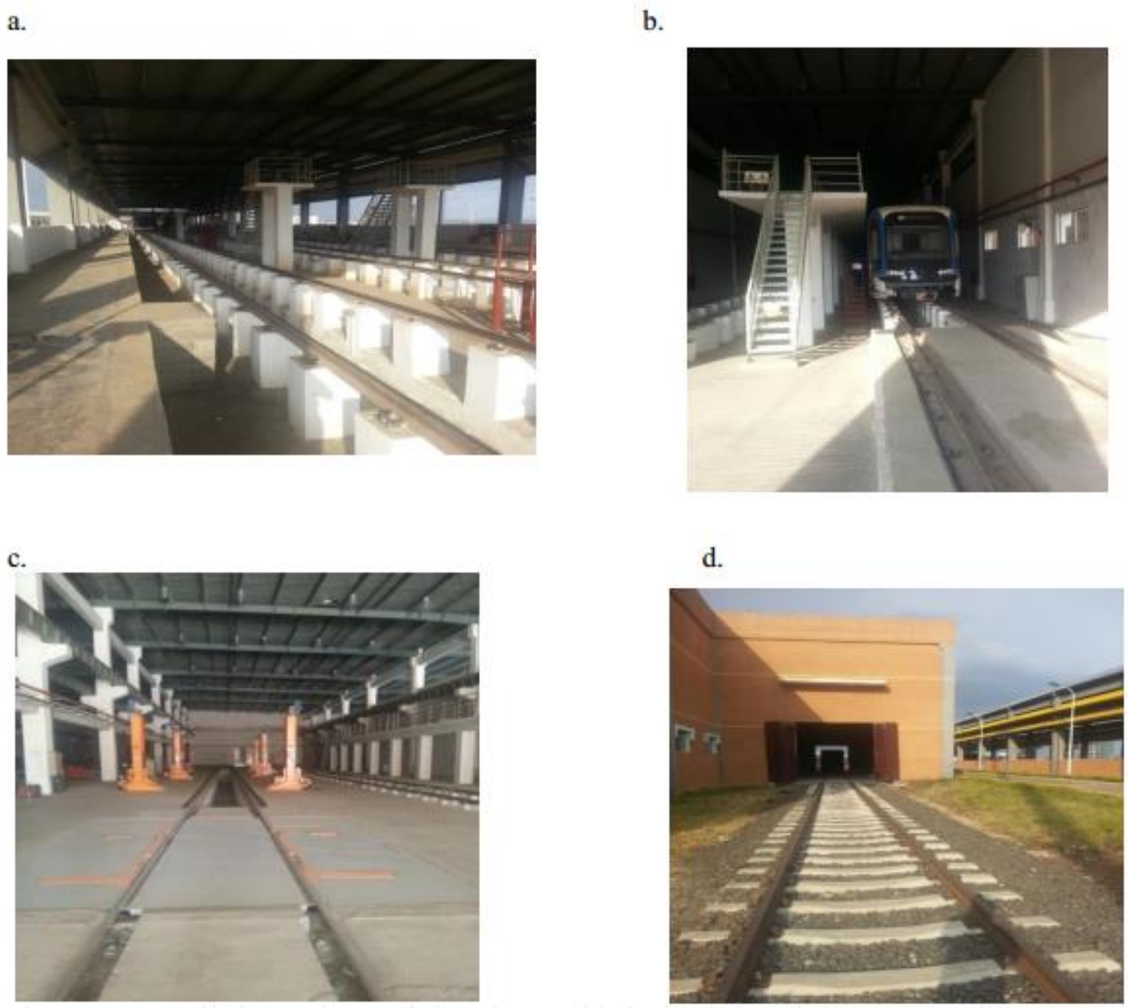

Figure 3. 1 a) daily inspection workshop b), monthly inspection workshop

c) Overall maintenance workshop, d) wheel re-profiling workshop

b) Limited application of required lubrication on wheel and rail

It is said that lubrication system is applied for vehicle components periodically. When the vehicles are running, there is a lubricating system attached in front of the wheels that releases lubricating oil during curvature of the vehicle called flange lubricator; however, the device had run out of oil for most vehicles and as of what it was gathered from the interview, this device has been abandoned and it is not refilled with oil due inaccessibility of the right type of oil in the country. Routine maintenances that are taken on the track are lubricating the rail fasteners with grease and making sure that they are fastened well. Some portion of the rails at curves are manually lubricated but due to severe conditions like direct sun ray, the lubricating oil is not doing its intended job.

3.3.3. Actual wheel data Measurements

Actual wheel data measurements were undertaken at both depots of Kality and Ayat by AALRT technicians. The inspection of vehicles and track was carried out for the purpose of examining and measuring vehicle wheel and rail conditions. Most of the vehicles measurement were taken before they were about to be machined using lath. From the data records, some vehicles were about to be machined for the first time while some were being machined for the second and third time. Therefore, full measurements of wheel flange thickness and tread diameter were taken before and after machining of the wheels. A total of 24 vehicles operating from both depots, were inspected. 9 vehicles inspected at Ayat depot while 15 vehicles inspected at Kality. The following table shows the summary of vehicles that were inspected at the depots. Full measurements of wheel parameters for the vehicles inspected were provided in Appendix B

Table 3. 3 AALRT Vehicles inspected from both routes

Vehicle Number	Depot Location
104,107,108,109,110,111,114,115,119	Ayat wheel re-profiling workshop
205,206,207,208,209,210,211,212,213,215 216,217,218,219,220	Kality wheel re-profiling workshop

3.3.4. Comparation between AALRT vehicles of East-West and North-South routes

In this investigation, wheel data measurements of AALRT vehicles from both routes, which were recorded by AALRT workshop personnel, had been shown in Appendix B. Vehicles of similar mileage were compared with measurements taken before wheel-lathe machining at their respective depots. The purpose of the analysis was to find out which route was affected more and also to determine which type of wheel wear is critical for case of AALRT. The following table shows vehicles from both routes, used for comparation of flange thickness and tread diameter which are selected based on total average mileage run similarity.

Table 3. 4 Vehicles selected for comparison from the two routes

East-West vehicle No.	Mileage run, Km	North-south vehicle No.	Mileage run, Km
115	45540	212	44026
114	45551	205	49030
108	40415	215	47312
111	45551	208	43452
110	54807	218	54471
109	76430	206	75028
115	69044	216	66522
108	52732	210	51662
Average run, Km	**53758.75**	Average run, Km	**53937.88**

The following two tables 3.5 & 3.6 shows flange thicknesses of vehicles from both routes summarized from Appendix B. The average flange thickness per wheel and per bogie was computed for vehicles of each route.

New wheel diameter 660mm, worn limit 580mm

New flange thickness 21.21mm, worn limit of 15mm (Appendix C)

Table 3. 5 East-West (Ayat) vehicles Flange thickness (Sd)

Ve.No	Flange thickness(Sd) in mm for respective wheels											
	1	2	3	4	5	6	7	8	9	10	11	12
115	20.62	19.75	20.39	20.28	19.2	15.13	19.77	14.08	20.71	20.59	20.45	19.91
114	19.6	20.48	20.29	20.47	18.52	19.71	18.4	19.63	19.68	20.34	21.11	19.99
108	20.44	20.4	19.94	19.66	18.59	17.81	17.9	16.94	19.64	19.67	20.05	20.08
111	18.52	18.79	18.05	18.59	17.14	13.11	17.26	13.04	19.68	20.34	21.11	19.99
110	18.71	19.11	18.86	18.64	17.13	14.58	17.02	13.09	19.71	18.67	18.97	18.06
109	18.71	18.59	19.16	18.28	12.45	17.42	13.68	16.42	18.65	18.27	19.18	18.24
115	21.41	19.37	21.15	19.99	19.34	15.24	18.52	14.09	21.45	20.51	20.98	19.82
108	21.29	20.63	20.87	19.87	18.78	18.65	18.6	18.04	20.71	19.97	20.98	20.43
A.sd/w	19.91	19.64	19.84	19.47	17.64	16.46	17.64	15.67	20.03	19.80	20.35	19.57
	19.72				16.85				19.94			

Table 3. 6 North-south (kality) vehicles flange thickness (Sd)

V.No	Flange thickness(sd) in mm for respective wheels											
	1	2	3	4	5	6	7	8	9	10	11	12
212	16.06	17.5	17.02	13.66	16.49	17.69	17.48	17.62	16.63	19.38	16.41	16.93
205	16.71	16.54	17.48	13.48	17.38	18.24	16.38	17.37	16.48	16.59	17.59	18.51
2015	17.07	17.93	15.46	13.46	18.05	16.75	17.09	15.45	16.54	16.65	16.17	16.03
208	16.34	17.53	13.45	18.34	17.05	15.44	17.28	14.47	18.68	16.96	17.09	15.99
218	13.7	16.65	14.16	13.86	17.08	16.14	14.11	12.83	18.38	18.06	16.02	15.26
206	17.08	16.77	16.57	15.74	15.41	15.38	14.6	14.34	16.52	16.09	16.07	15.47
216	16.52	16.1	15.96	15.02	17.86	16.84	18.15	17.53	18.47	16.75	16.6	14.75
210	16.12	16.36	16.3	14.39	15.52	14.21	17.51	17.45	16.4	16.93	16.38	14.98
A.sd/w	16.20	16.92	15.80	14.74	16.86	16.34	16.58	15.88	17.26	17.18	16.54	15.99
	15.92				16.41				16.74			

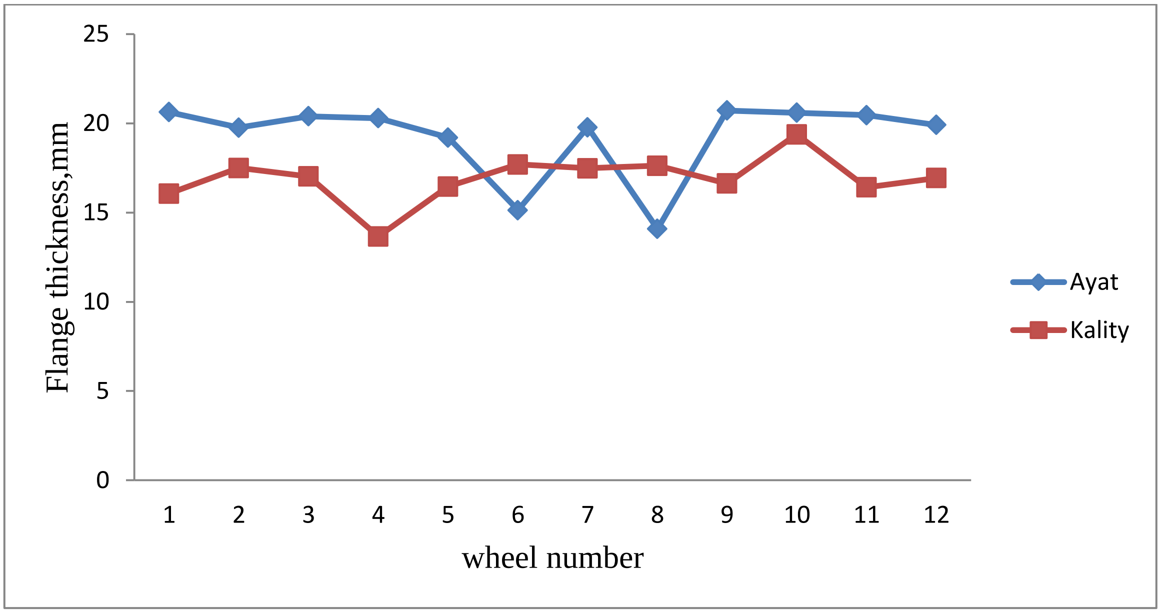

Figure 3. 2 Comparison of Hayat and Kality vehicles in average Flange thickness (Sd) per wheel

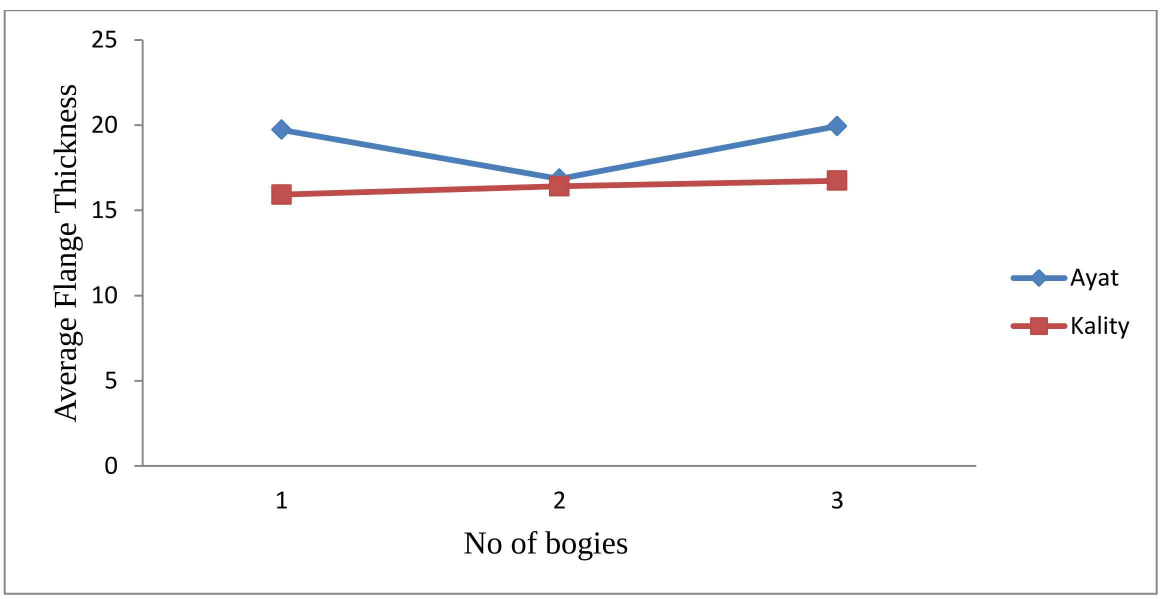

Figure 3. 3 Comparison of Ayat and Kality vehicles in average flange thickness /bogie

Total average flange thickness of Ayat vehicles=18.83mm. Total loss=New wheel-worn wheel=21.21-18.83=2.38mm, percentage loss=11.2%. Total average flange thickness of kality vehicles=16.36mm. Total loss = New wheel – Worn wheel = 21.21- 16.36 = 4.85mm, Percentage loss = 22.9 %. The above figures 3.2 and 3.3 show comparison of average flange thickness between selected Ayat and Kality vehicles. As shown in figure 3.2 the average flange thickness per wheel of Kality vehicles is greatly worn than that of Ayat's vehicle. Kality vehicles, with average flange thickness of 16.36 mm, show a total percentage loss of 22.9 % in flange thickness as compared to Ayat vehicles'18.83 mm average flange thickness with percentage loss of 11.2%. It can be observed that tailor (bogie 2) bogies' flange thicknesses are worn greatly compared to other two motor bogies. One of the characteristics of trailer bogies is that these types of bogies do not promote self-steering through curves, increasing flange forces and angle of attack which leads to flange wear and noise and thus the wheel life of trailer bogies is less than that of motored bogies [27]. This is especially the reason for wheel flange wear for Kality vehicles due to adverse conditions of sharper curves in the route. The following two tables show tread diameters of vehicles from both routes summarized from appendix B. The average tread diameter per wheel and per bogie were computed for vehicles of each route

Table 3. 7 East-West (Ayat) vehicles Tread diameter (Td)

V.No	Tread diameter(Td) in respective wheels											
	1	2	3	4	5	6	7	8	9	10	11	12
115	659.7	659.5	659.8	659.7	659.9	660.3	659.9	660.3	659.9	659.7	659.6	659.4
114	659.9	659.7	659.9	660.0	660.3	660.1	660.3	660.0	659.0	659.8	659.8	659.7
108	659.9	659.5	659.7	659.6	660.5	660.3	660.2	660.3	659.9	659.6	659.9	659.5
111	659.2	658.7	658.9	658.7	659.8	660.4	659.7	660.3	659.9	659.8	659.8	659.7
110	659.3	659.1	659.4	659.2	660.0	660.3	659.8	660.4	659.8	659.3	659.2	659.0
109	658.8	658.7	658.9	658.8	660.4	659.9	660.2	659.9	659.2	659.0	658.9	658.8
115	659.1	658.8	659.1	659.1	635.1	635.9	634.9	635.4	659.3	659.0	858.8	658.7
108	659.7	659.2	659.3	659.3	654.4	655.1	653.7	654.0	659.5	659.2	659.5	659.2
A.Td/w	659.4	659.2	659.4	659.3	656.3	656.5	656.1	656.3	659.7	659.4	659.4	659.2
A.Td/b	659.3				656.3				659.4			

Table 3. 8 North-South (Kality) vehicles Tread diameter (Td)

V.No	Tread diameter(Td) in mm for respective wheels											
	1	2	3	4	5	6	7	8	9	10	11	12
212	659.7	659.6	659.7	659.4	660.1	660.1	660.1	660.2	659.3	659.9	659.6	659.5
205	659.4	659.5	659.6	659.6	660.2	660.2	660.0	660.0	659.6	659.6	659.6	659.7
2015	659.6	660.0	659.8	659.7	660.3	660.4	660.1	660.3	659.8	659.8	659.8	659.6
208	659.4	659.5	659.6	659.8	660.1	660.3	660.2	660.1	659.7	659.6	659.4	659.6
218	659.3	659.6	659.3	659.4	660.2	660.2	660.1	659.9	659.1	659.7	658.9	659.3
206	648.5	648.5	647.4	647.5	638.8	638.9	637.3	637.6	652.6	652.7	652.4	652.6
216	648.9	649.1	645.6	645.5	660.0	660.0	660.0	659.8	647.3	647.2	647.2	647.3
210	659.0	659.3	659.4	659.2	660.1	660.3	650.7	650.9	659.3	659.5	659.2	659.2
A.Td/w	656.7	656.9	656.3	656,3	657.5	657.6	656.1	656.1	657.1	657.2	657.0	657.1
A.Td/b	656.5				656.8				657.1			

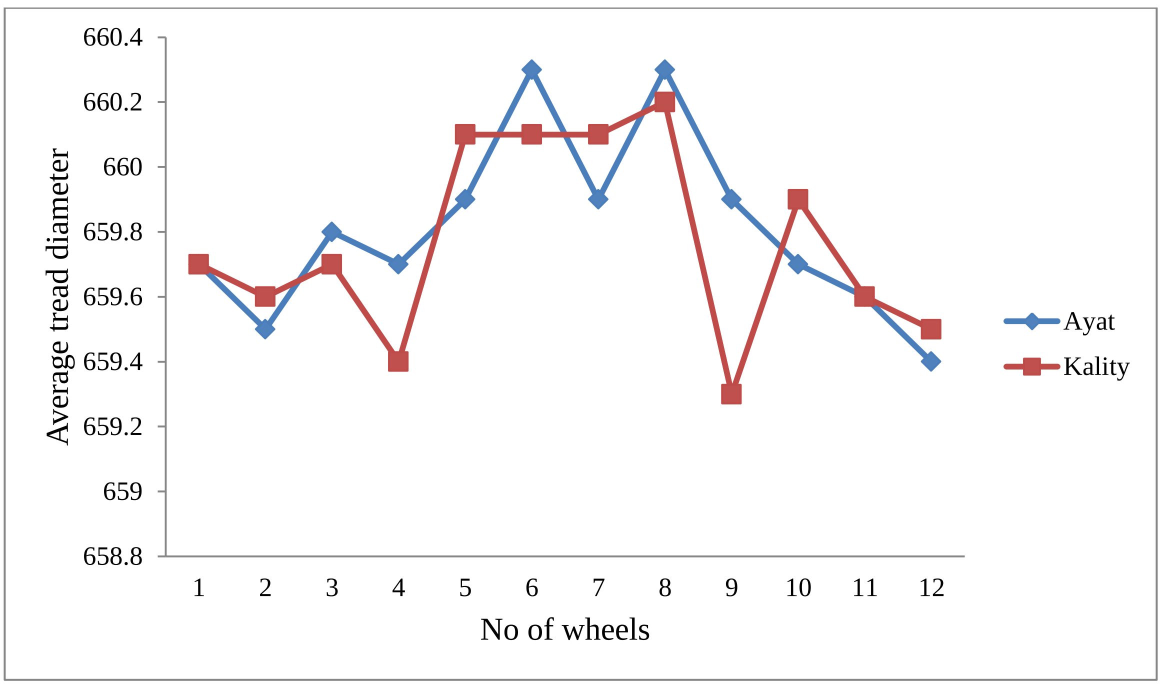

Figure 3. 4 Ayat and Kality vehicles in average tread diameter (Td) per wheel

The horizontal value shows the number of wheels and vertical data represents the average tread diameter of vehicles.

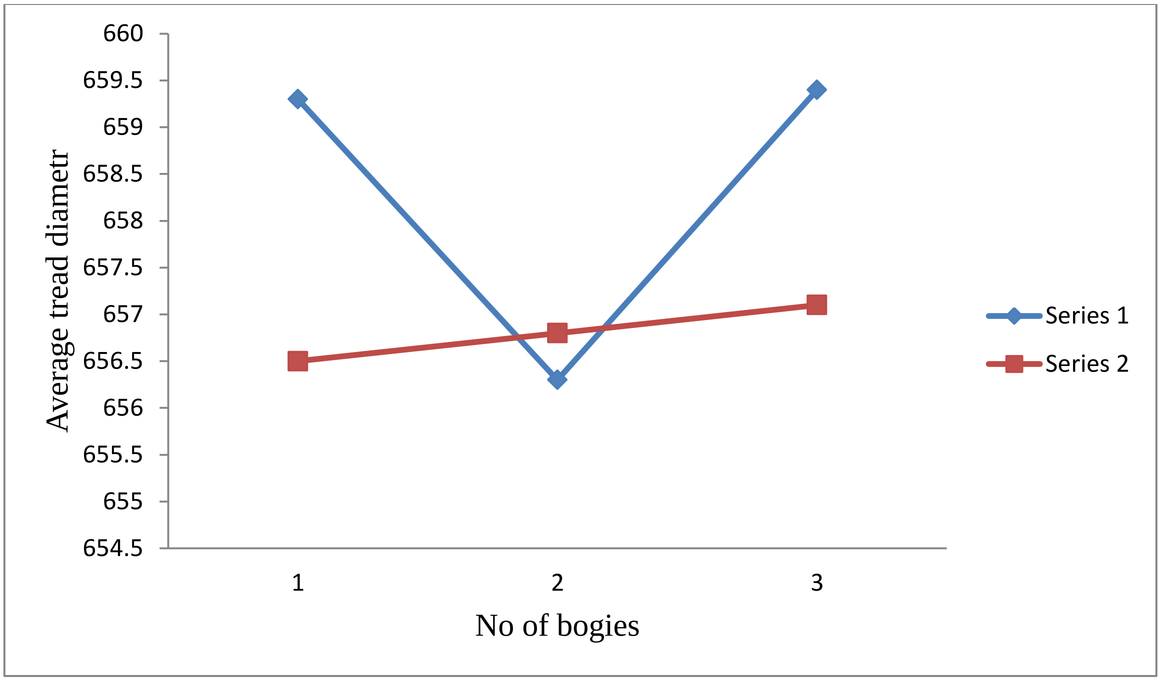

Figure 3. 5 Ayat and Kality vehicles in Tread diameter (Td) per bogie

Total average tread diameter of Ayat vehicles = 658.3 mm, then total loss = New wheel– Worn wheel = 660 – 658.3 = 1.7 mm, Percentage loss = 0.25 %. Total average tread diameter of Kality vehicles=656.82 mm. Total loss = New wheel – Worn wheel = 660 – 656.82 = 3.19 mm, Percentage loss = 0.48 %.

The above two figures show comparison of average tread diameters between selected Ayat and Kality vehicles. As shown in figure 3.4 the average tread diameter per wheel of Kality vehicles is greatly worn than that of Ayat’s vehicle. Kality vehicles, with average tread diameter of 656.2 mm, show a total percentage loss of 0.48 % in tread diameter as compared to Ayat vehicles’ 658.3 mm average tread diametr with percentage loss of 0.25 %. Average tread diameter of the trailer bogies for Ayat vehicles is much more worn than the other two bogies which is because trailer bogies tend to wear at a greater rate than the rest due to increased forces at contact since these bogies don’t allow self-steering. Under normal conditions, trailer bogies do wear faster than motorized bogies.

3.4. Experimental procedure

3.4.1. Mold design and Sample Preparation

Thanks for AALRT, it gave 3kg wheel scraps and samples were initially prepared as followed based on ring geometry dimension specification. The dimensions taken were,

Outer diameter of rings (Do) =42mm, internal diameters (Di) =21mm, and height of rings (t) =14mm.Thus specification obtained based on [28].

Area of the ring (A) $=\pi/4[(Do)^{2}-(di)^{2}]mm^{2}$……………………………………………(1)

Volume (V) of the ring

$= \pi/4[(Do)^{2}-(di)^{2}]\, t= \pi/4[(42)^{2}-(21)^{2}]*14=14539.77mm^{3}=14.53977cm^{3}$

Density of steel is $7.85g/cm^{3}$, therefore the total mass of the ring required is m=114.12g. For total 5 no of samples 5*114.12=570.7g. But for lose and other cases consideration during casting 1kg chips has been used.

Figure 3. 6 Wheel scrap taken from AALRT for casting

Figure 3. 7 Patterns in mold

3.4.2. Sand Casting

Sand casting is one of the few available processes for metals with high melting temperatures such as steels, nickel, and titanium. Because of its flexibility, heat resistance, and relatively low cost, sand casting is the most widely used casting process. Castings are produced by pouring liquid metal into a mold cavity. A mold is formed into the geometric shape of a desired part (ring). Molten metal is then poured into the mold; the mold holds this material in shape as it solidifies. Although this seems rather simple, the manufacturing process of metal casting is both a science and an art. In this research using sand casting technique and electric furnace the steel scrap were melted/casted to its melting temperature (1538%) at Akaki iron and steel industry for composition, hardness and ring compression tests.

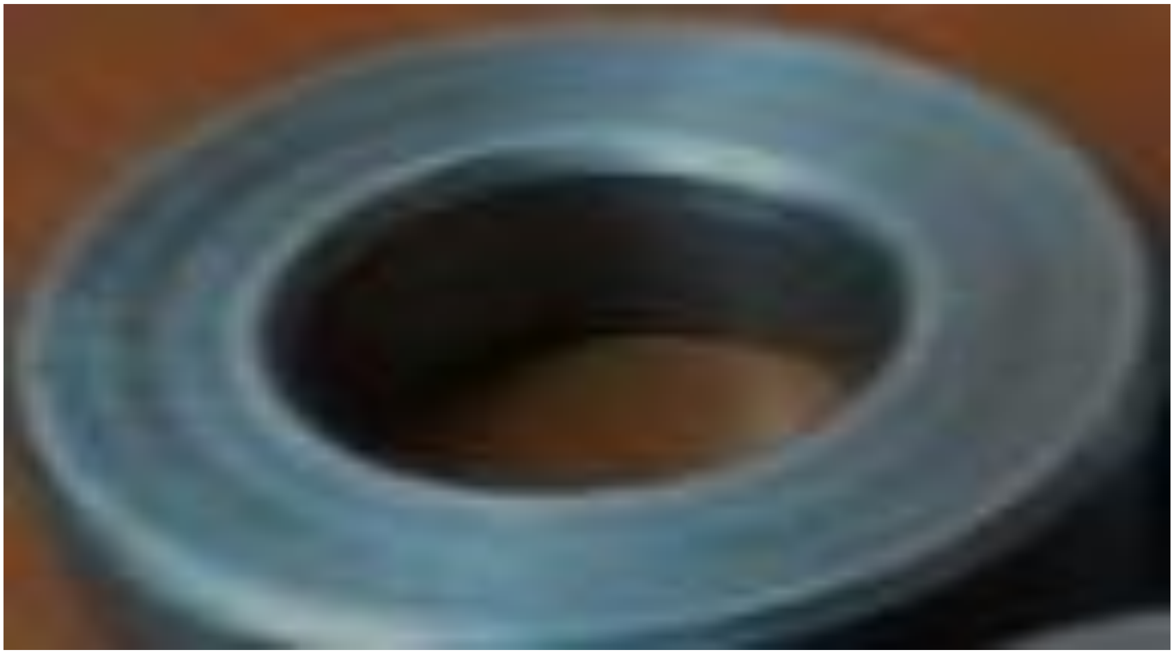

Figure 3. 8 Prepared ring sample

3.4.3. Composition test for Existing Wheel Steel

As it has been explained in materials section in table 3.1 the site company gave chemical composition of existing wheel material. So to check the validity of the given data it was required to conduct composition test for existing wheel material. Chemical composition analysis could be required for the application of achieving a full picture of a chemical structures and concentrations of the components in a sample. To aid product development, the concentration of specific components, such as an active ingredient which impart a unique function to the product, should be determined in order to understand the products performances or quality. Spectrometry is advice used to measure the composition of constituents of given materials. In this research the prepared sample composition has been tested to compare with composition specified by Site Company (AALRT) and sample developed by alloying.

Figure 3. 9 Composition test for existing wheel from scrap

Table 3.9 shown below explained the test results of composition test using spectroscopy

Table 3. 9 existing wheel steel composition

element	C	Si	Mn	P	S	Cr	Mo	Ni	V	Fe
% con.	0.5	0.25	0.7	0.05	0.05	0.02	0.001	0.005	0.002	98.4

3.4.4. Hardness test for existing wheel Materials

Hardness is defined as the resistance of a material to permanent deformation such as, indentation, wear, abrasion, and scratch. Hardness is a mechanical property that is related to

- Wear resistance of a material
- Its ability to abrade or indent to another material
- Its resistance to permanent or plastic deformation

Hardness measurements widely used in laboratory and as industrial tests (widely used on castings and forgings) as a tool characterizing the mechanical properties of materials. There are many hardness tests currently in use. The necessity for all these different hardness tests is due to the need for categorizing the great range of hardness from soft rubber to hard ceramics. Selecting of the appropriate hardness test is dependent upon; the

- Relative hardness of the material being tested and
- Amount of damage that can be tolerated on the surface of specimen or material

The types of hardness testers in use of product are based on a no of arbitrary definitions of hardness. Some of these definitions are:

- Resistance to permanent indentation (indentation test),
- Resistance to scratching (scratch test),
- Energy absorption under impact loads (dynamic hardness test) and
- Rebound of a falling weight (rebound test) [29].

Based on the above definitions for this research hardness test was carried out by using indentation (Rockwell) hardness tester at Federal TVET institute (Ethio-China), Addis Abeba, Ethiopia.

Figure 3. 10 Sample and Rockwell hardness tester setup

General principles of Rockwell (indentation test) shown in figure 3.10.

- A hard indenter (small sphere, pyramid or cone) is pressed into the surface of material to be tested under a specific load for a definite interval of time.
- The size or depth of indentation is measured.

The table below shows the result of hardness test for existing wheel materials with composition of explained in table 3.9

Table 3. 10 hardness results of existing wheel materials (Appendix D)

No of trials	Description of tests	results	Remarks
1	Rockwell test HRC	99.4 HRC	Force 150kgf
2	Rockwell test HRC	98.2 HRC	>>
3	Rockwell test HRC	99.0 HRC	>>
4	Rockwell test HRC	98.7 HRC	>>
5	Rockwell test HRC	99.1 HRC	>>
average		98.88 HRC	

3.4.5. Ring Compression test for existing wheel Steel

Friction in metal forming is an important variable and has significant effects on both the work piece (ring) and process variables such as deformation load, metal flow, surface quality, and internal structure of the product in any metal forming process. This technique utilizes the dimensional changes of a test specimen to arrive at the magnitude of frictional coefficient. The ring compression test is universally accepted as perfectly valid method by which determine simply and reliably the adhesion friction factor in plastic deformation process. Its methodology is based on the application of geometric changes as both the reduction in thickness and the decrease in bore inner diameter in the strained ring itself. In this paper the performance of that test is the basis for establishing the coefficient of friction on pressing process both in existing and alloyed wheel steel.

3.4.6. Procedures for Dry Condition

- All examined specimens have the same dimension ratio of (6:3:2 or 42:21:14) that is OD, ID, H respectively.
- Initial thickness, internal and outer diameters could be measured and recorded.
- Specimen freely placed on the lower die in the way that centerlines of both coincided.
- Then started pressing the specimen at a constant speed of (0.5 mm/s).
- When the specimen compressed, it becomes released.

- The new thickness, inner and outer diameter has to be measured. However, due to barreling and irregularity on both inner and outer circular surfaces of the specimen, several diametric readings have taken and an average value should be recorded.

3.4.7. Procedures for Lubricated Conditions

In addition to the above steps the specimen and the die contacting surfaces have been lubricated before the ring becomes compressed using different lubricants like, grease, and oil. The friction factor is sensitive to contact between specimens and die. When the lubricants applied, the steel rings dimensions changed. The change in dimension, outer diameter, internal diameter, and reduction in height, using standard calibration curve available for friction conditions by male and cockroft was used to evaluate the friction factor and friction coefficient. With good lubrication both inner and outer diameter increases as the specimen is compressed; and with poor or no lubrication, friction is high, and the inner diameter decreases. The direction of barlling depends on the relative motion of circular surfaces with respect to flat dies.

If the specimen's internal diameter increases during deformation, the friction is low; if the specimen's internal diameter decreases during deformation the friction is high. Using this relationship friction calibration curves, were generated by Male and Cockcroft relating the percentage reduction in the internal diameter of the test specimen to its reduction in height for varying degrees of the coefficient of friction. The following figure illustrates the friction calibration curves constructed by Male and cockroft as friction coefficient and friction factor indicator for various change in internal diameter versus change in height reduction. Therefore, in this research the friction coefficient and friction factor have been taken by relating the percentage reduction in internal diameter and reduction in height. The curve line which passes through the intersection point is friction factor and friction coefficient.

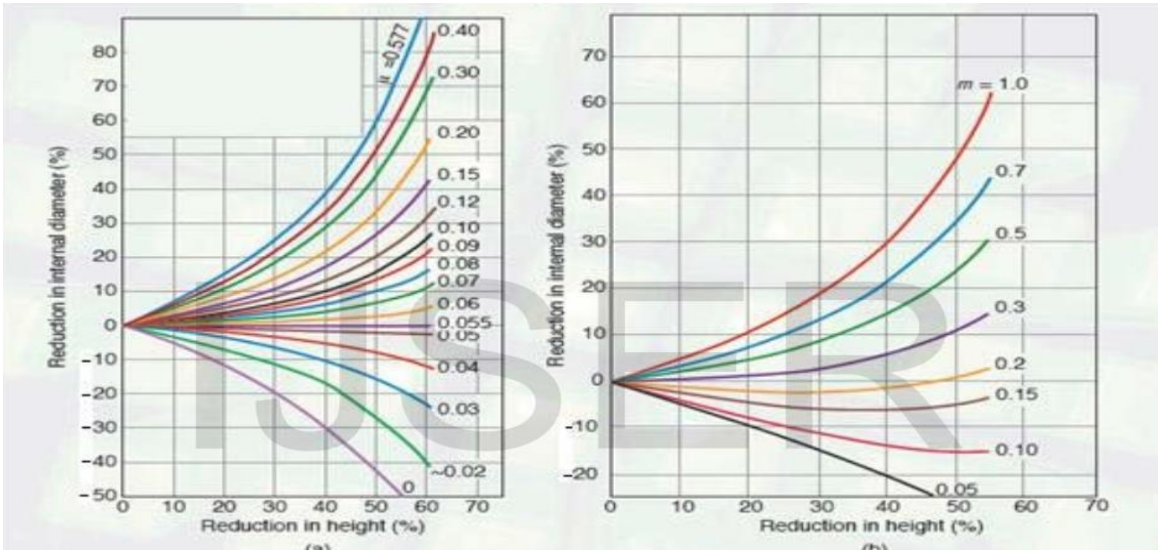

Figure 3. 11 Standard friction calibration curves [30]

Table 3. 11 Geometric changes under deformation for existing wheel

Condition	Load(KN)	Do	Di	H	ΔDo	ΔDi	ΔH	Area	σ(Mpa)
Dry	1500	48.1	19.85	11.4	6.1	1.15	2.6	1507	995
	2700	59.9	17.2	7.86	11.8	2.65	3.54	2584.4	1044.8
	3040	60.2	15.3	5.71	0.3	1.9	2.15	2661.1	1142.4
Oil	1500	48.5	19.61	9.66	6.5	1.39	4.34	1544.6	971.13
	2700	59.2	17.53	7.1	10.7	2.08	2.56	2509.9	1075.7
	2900	59.24	16.63	5.64	0.04	0.9	1.46	2537.77	1212.48
Grease	1500	48.26	19.51	11.1	6.26	1.49	2.9	1529.49	980.72
	2700	59.9	17.2	7.86	11.64	2.31	3.24	2584.35	1044.75
	3010	60.2	15.7	5.76	0.3	1.5	2.1	2651.37	1214.2

Due to irregularity of the prepared sample different diametric readings were obtained and average diameter was taken for both dry and lubricated conditions during deformation process.

Table 3. 12 Friction coefficient value of existing wheel material

Lubricant condition	Load, KN	Final read ings,mm			Reduction in inner diameter	Reduction in height	Friction coefficient	Friction factor
		Do	Di	H	(ΔDi/Di)*100	(ΔHi/Hi)*100	μ	m
Dray condition	1500	47.98 48.21 48.1 48.1	19.86 19.84 19.85 19.85	11.36 11.45 11.40 11.4	5.48	18.57	0.2	0.6
	2700	59.91 59.93 59.86 59.9	17.09 17.2 17.31 17.2	7.81 7.87 7.90 7.86	18.1	43.86	0.14	0.5
	3040	60.21 60.24 60.15 60.2	15.31 15.29 15.30 15.3	5.71 5.71 5.71 5.71	27.61	59.21	0.12	0.45
Grease Condition	1500	48.26 48.26 48.25 48.26	19.50 19.49 19.53 19.51	11.2 11.1 10.90 11.1	7.1	20.7	0.15	0.6
	2700	59.7 60.1 59.9 59.9	17.5 16.9 17.2 17.2	7.8 8.0 7.79 7.86	18.1	43.86	0.12	0.5
	3010	60.2 59.9 60.4 60.2	15.70 15.69 15.71 15.7	5.75 5.77 5.76 5.76	25.23	58.9	0.12	0.71
Oil condition	1500	48.51 48.49 48.50 48.5	19.62 19.60 19.61 19.61	9.64 9.67 9.66 9.66	6.62	31	0.09	0.32
	2700	59.21 59.10 59.30 59.20	17.7 17.4 17.5 17.53	7.1 7.0 7.2 7.1	16.5	49.3	0.11	0.37
	2900	59.24 59.23 59.25 59.24	16.65 16.63 16.61 16.63	5.64 5.64 5.64 5.64	20.8	59.71	0.095	0.35

As explained in the above table for existing wheel material the expected friction coefficient was evaluated on friction calibration curve developed by male and cockroft in figure 3.11 and the lowest value has been obtained in case of oil as a lubricant condition.

3.5. Alloying of Metals

An Alloy is a combination of metals or of a metal with another element. It is defined by a metallic bonding character and most alloys are made by melting the metals, mixing them while they are liquid to form a solution, and then leaving them to solidify it. Alloy steel is steel that is alloyed with a variety of elements in total amounts between 1.0% and 50% by weight to improve its mechanical properties. Alloy steels are broken down in to two groups. Low alloy steels and high alloy steels. Alloy steel is the standard term referring to steels with other alloying elements in addition to carbon.

Common alloyants include;

- manganese (the most common)
- nickel
- carbon,
- molybdenum,
- vanadium,
- Silicon and boron.

Less common elements include; Aluminum, cobalt, copper, ceium, Niobium, titanium, tungsten, tin, zinc, lead, and zirconium. Alloying elements are added to achieve certain properties in a material and they are added in lower percentage(less than 5%) to increase strength or hardenability, or in larger percentage (over 5%) to achieve special properties, such as corrosion resistance or extreme temperature stability [31]. Manganese, silicon or aluminum are added during steel making process to remove dissolved oxygen, sulphur and phosphorus from the melt. Chromium, vanadium, molybdenum and tungsten increase strength of steel by forming second phase carbides. Nickel and copper improve corrosion resistance in small quantities. Alloying elements also have an effect on eutectoid temperature of steel. Manganese and nickel lower the eutectoid temperature and are known as stabilizing elements.

With enough of these elements the austenitetic structure may be obtained at room temperature. Carbide-forming elements raise the eutectoid temperature; these elements are known as ferrite stabilizing elements.

3.5.1. Alloying Process

Steel making is the second step in producing steel from iron ore. In this stage, impurities such as sulfur, phosphorus, and excess carbon are removed from the row iron, and alloying elements such as manganese, vanadium, silicon, nickel and chromium are added to produce the exact steel required. Alloying a metal is done by combining it with one or more other elements. The most common and oldest alloying process is performed by heating the base metal beyond its melting point and then dissolving the solutes into the molten liquid, which may be possible even if the melting point of the solute is far greater than that of the base. Modern day steel production makes use of both traditional row materials (iron) and alloying materials to turn them in to steel. With this in mind, here are six steps to modern steel production explained.

Step 1 Iron making process: As iron is the main component of steel it firstly needs to be made. Iron ore, lime, and coke are placed in to a blast furnace and melted. The resulting liquid known as molten iron is then formed. As molten iron still contains around 4%-4.5% impurities such as carbon which intern make the metal brittle, they need to be eradicated.

Step 2 Primary steel making: There are two main methods for making steel and these are basic oxygen steel making (Bos) and Electric Arc Furnaces (EAF). Bos methods for example involve adding scrap (recycled) steel to the molten iron when in the furnace. Oxygen is then forced through the liquid (the Bessemer process) to cut the impurities in the molten metal down to 0.5%-1.5%.

Step 3 Secondary steel making: next the newly formed molten steel needs to be adjusted to make the perfect steel composition. These are done by either manipulating the temperature and/or certain elements. This may include processes such as degassing, stirring, ladle, injection, argon bubbling.

Step 4 Casting: Now there are the bones of steel. The next step is to pour it in to cooled molds. This causes metal too cool quickly. Once cooled the metal is then cut in to desired lengths depending upon the application.

Step 5 First forming: also known as primary forming, the initial shapes of slabs, blooms, and billets are formed in to their various shapes usually by hot rolling. Products that are hot rolled are then divided in to flat products, long products, and seamless tubes

Step 6 The manufacturing, fabrication and finishing process: Finally a variety of secondary forming techniques including shaping, machining, jointing and coating give the products required shapes and properties. The present investigative research more particularly concerned wheel steel that was alloyed to resist both wear and thermo-mechanical deterioration, especially in the thread and flange regions of such wheels. Alloying elements were added to steel in order to improve specific properties such as strength, wear and corrosion resistance. Although theories of alloying have been developed, most commercial alloy steels have been developed by an experimental approach with occasional inspired guesses. In this research wheel scrap, Nickel, Silicon, Manganese and carbon were melted with their melting points of 1540 ^{0}c,1453^{0}c,1414^{0}c,1246^{0}c and 1150^{0}c and wih respective weight of 1.5kg, 150g, 500g, 1.3 kg and 1.2kg respectively. Based on the above procedures and theory the compositions of alloyed material were experimentally determined using spectrometry.

Table 3. 13 composition result of alloyed wheels

C	Si	Mn	Cr	Mo	V	Nb	Ni	W	Cu	P	S	Co	Fe
0.8	0.38	1.15	0.06	0.003	0.003	0.03	0.03	0.01	0.04	0.02	0.02	0.2	97.4

Table 3. 14 hardness test result of alloyed wheels

No.of trials	Description of test	Result	Remark
1	Rockwell test HRC	99.9 HRC	Force=150kg
2	Rockwell test HRC	99.7 HRC	>>
3	Rockwell test HRC	100.0 HRC	>>
4	Rockwell test HRC	99.1 HRC	>>
5	Rockwell test HRC	99.8 HRC	>>
6 average		99.7 HRC	

In most cases any given desired resistance to thermo-mechanical deterioration through the use of alloys must be considered in the context of the degree of sacrifice of steel's pearlite structure that will be caused by the specific alloying elements employed. This remains a very important consideration because a pearlite structure serves to impart the quality of wear resistance to steel wheels. The technical and latent literatures reveals that many alloying materials have been added to a host of wheel steel formulations for the purposes of striking a balance between imparting hardness (and hence wear resistance) to a steel and imparting resistance to thermo-mechanical deterioration. By way of general example only, it is well known that in situations where wear resistance is the more desired property, high carbon steels having carbon contents ranging from about 0.65 to about 1.0 weight percent are preferred. Steels often include 0.30% manganese, but certain carbon steels can include up to 1.5% manganese for high wear resistance applications. Such steels are especially hard and, hence, high wear resistant [36]. As it is explained in table 3.13 carbon percentage is 0.8 which is in between 0.65 and 1 and manganese content is 1.15% which is not more than 1.5.

3.5.2. Effect of Hardness on Wear Resistance

The wear test was carried out using a twin disc type rolling contact test machine. The wear test was performed with a contact stress of 1.2 Gpa (Hertz stress) and a slip ratio of 10% in a (non- lubricated) dry environment. Wear resistance was evaluated by weight loss at a total of 1.6×10^5 revolutions. Accompanying the increased hardness, weight loss due to wear decreased and wear resistance improved [37]

3.5.3. Relation between Hardness and Yield strength of Wheel material

Yield strength: The resisting stress experienced by a body when it reaches the end of the elastic limit. To be more precise, its stress experienced by a body that results in a strain equal to 0.2% of fracture strain. Yield strength or yield stress is materials property defined as the stress at which a material begins to deform plastically. Yield point is the point where nonlinear (elastic plastic) deformation begins. The stress required to cause permanent deformation is known as metal's yield strength, and up to this point the metal is undergoing elastic deformation. Application of further plastic or permanent deformation, until the point where the metal can no longer withstand the stress being applied to it and it ruptures. The stress value at which rupture occurs is the metal's ultimate strength.

.**Hardness**: The ability of the material (particularly, the surface) to resist wear. It is the ability of a material to resist scratching, abrasion, penetration or wear on it is known as hardness or the ability of material resists plastic deformation. Though the definitions look different, one can find out that both the properties are infarct quite similar, when we look at the way they are measured. In brinell and Vickers hardness test, a particular portion (well something like a point) of the material surface is dented by indentor on application of small load. The surface area of the indentation is measured and the hardness is given by the ratio of the applied load to the dented surface area. That is exactly how yield strength is measured (load for plastic deformation/area subjected to load). Therefore hardness could hint on materials yield strength. After all, hardness is a manifestation of yield strength on the surface.

Low carbon steel ($\sigma y/\sigma u$)=65%=0.65

Medium carbon steel ($\sigma y/\sigma u$=0.85)

High carbon steel ($\sigma y/\sigma u$)=90%=0.9

Yield strength=3.33 (VH)…………………………………………………... (3) [38]

Therefore, yield strength for existing wheel material =3.33*98.88 =329.27 M pa. And yield strength of alloyed material =3.33*99.7=332 Mpa.

Since, the existing material is medium carbon steel and alloyed steel is in the range of high carbon steel the ultimate tensile strengths were calculated and there values became 387.4 and

390.6 Mpa respectively. The young's modulus of steel is always constant that has numerical value of 200 Gpa.

By using Archard's sliding wear model, in which the wear is equivalent to (sliding distance × load)/hardness, is often used to simulate the wear prediction of wheel and rail.Therfore the wear value for both existing and improved wheel material per meter was calculated as follows.

Wear = (sliding distance ×load)/hardness…………………………………….. (4) [39]

W1 = 1×52517/98.88 =531.1Nm/HRC

W2 =1×52517/99.7 =526.7 Nm/HRC, where W1 and W2 are wear values of existing and modified wheel material respectively which shows the modified wheel material can resist wear beter than the existing material due to its hardness value.

The table 3.15 below shown explained the friction coefficient and friction factor of alloyed wheels using ring compression test under lubricated condition by using oil as a lubricant to compare the value with existing one.

Table 3. 15 friction coefficient of alloyed wheel steel

Lubricant	Load,KN	Final readings, mm			Reduction in internal dia	Reduction in height	Friction coefficient	Friction factor
		Do	Di	H	(ΔDi/Di)*100	(ΔHi/Hi)*100	μ	M
Oil	1500	47.90 47.93 47.89 47.91	19.94 19.90 19.98 19.94	9.0 9.20 8.82 9.0	5.1	35.71	0.09	0.3
	2700	59.20 59.21 59.19 59.20	16.3 16.29 16.30 16.30	5.26 5.28 5.27 5.27	22.38	62.34	0.09	0.34
	2815	59.23 59.22 59.24 59.23	16.67 16.68 16.67 16.67	5.67 5.68 5.68 5.68	20.62	59.43	0.09	0.31

3.5.4. Deform 2d Analysis of Ring Compression

DEFORM-2D is a powerful process simulation system designed to analyze the two-dimensional (**2D**) flow of complex metal forming processes using an axisymmetric or plane strain assumption.

3.5.5. Input parameters

Table 3. 16 input parameters

Parameters	values	
	exsting	Alloyed
Young's modules	200 Gpa	200 Gpa
Poison' s ratio	0.3	0.3
Density	7.85kg/m^3	7.85kg/m^3
Strain hardening exponent(n)	0.15	0.26
Strength coefficient	540Mpa.	640Mpa

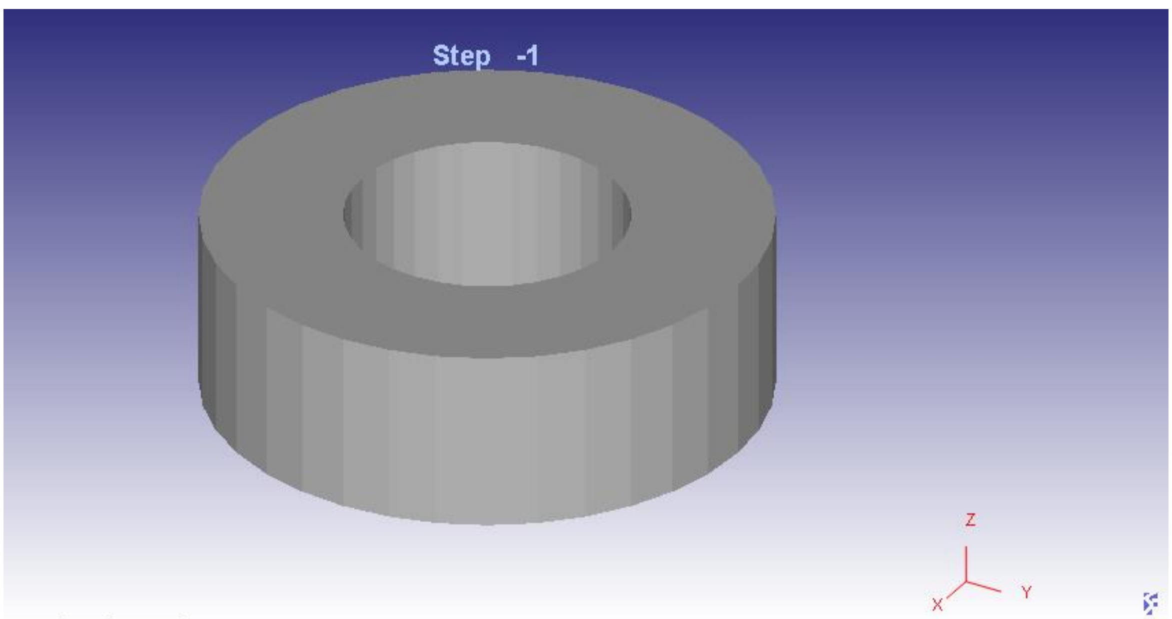

Figure 3. 12 Work piece

The three dimensional modeling was done by using deform software for the given dimensions of ring (42, 21, 14=OD, ID, H) respectively. These dimensions were given as per standard ratio of 6:2:1, outer, inner and diameters and height of steel rings.

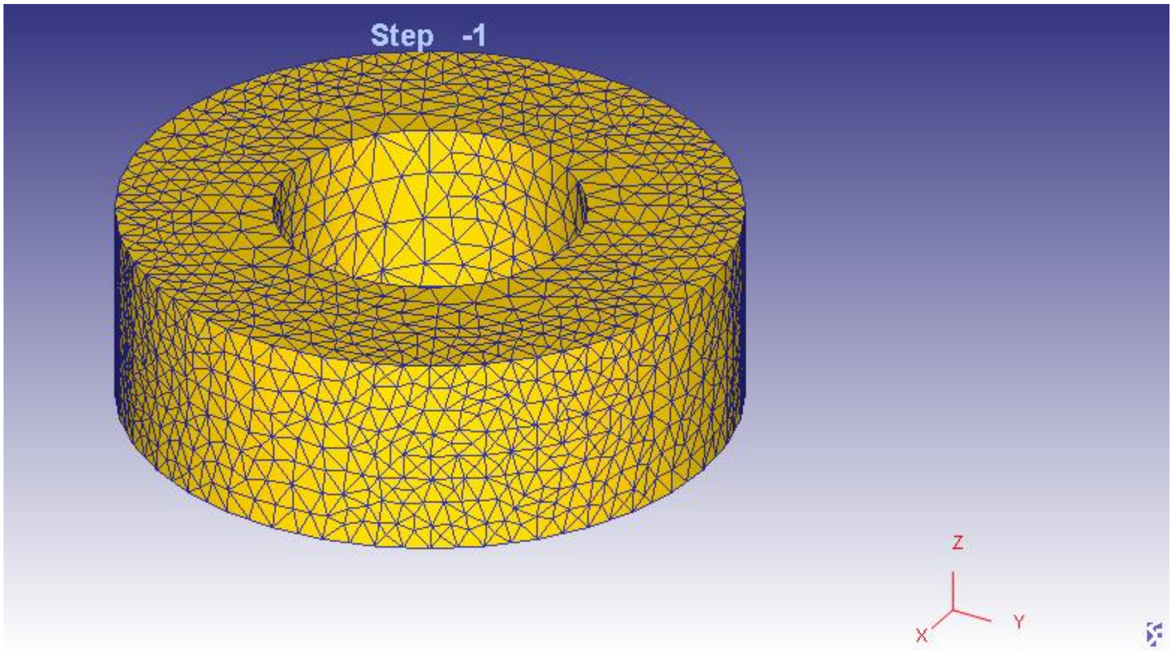

Figure 3. 13 Work piece meshed

The prepared steel ring was meshed in to 20000 equal no of elements.

The mesh is medium type mesh.

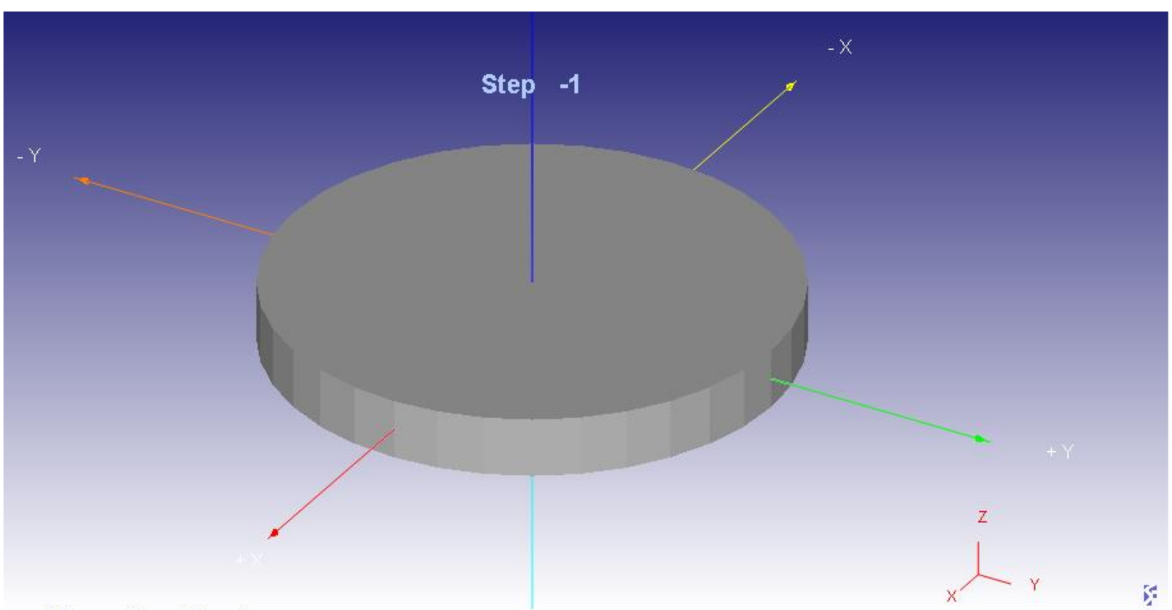

Figure 3. 14 Top die

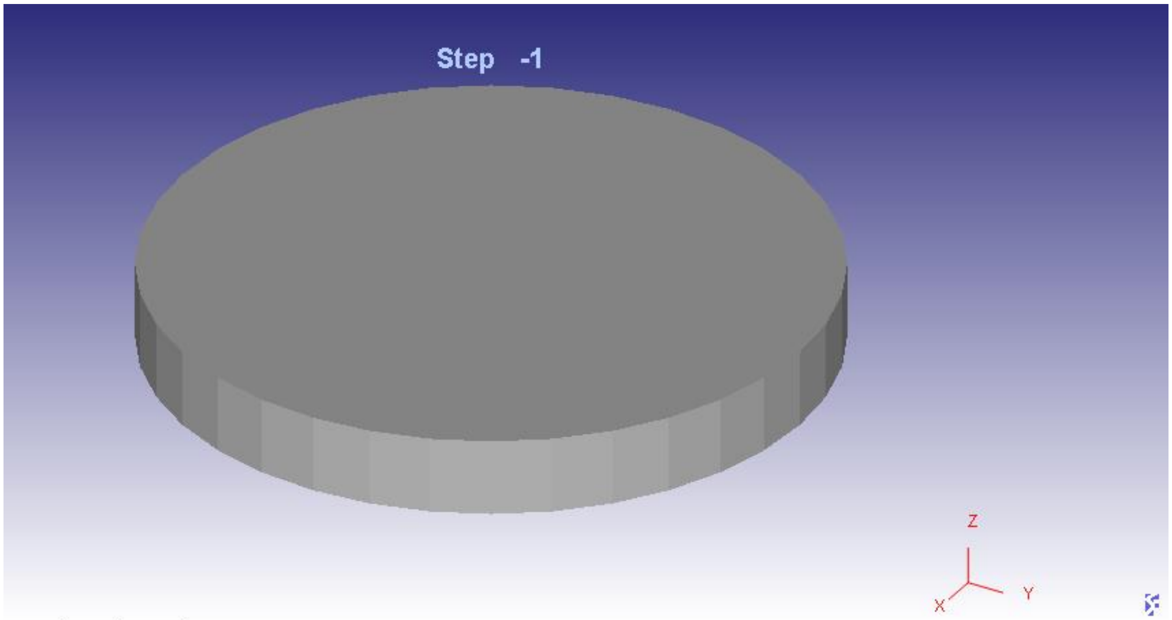

Figure 3. 15 bottom die

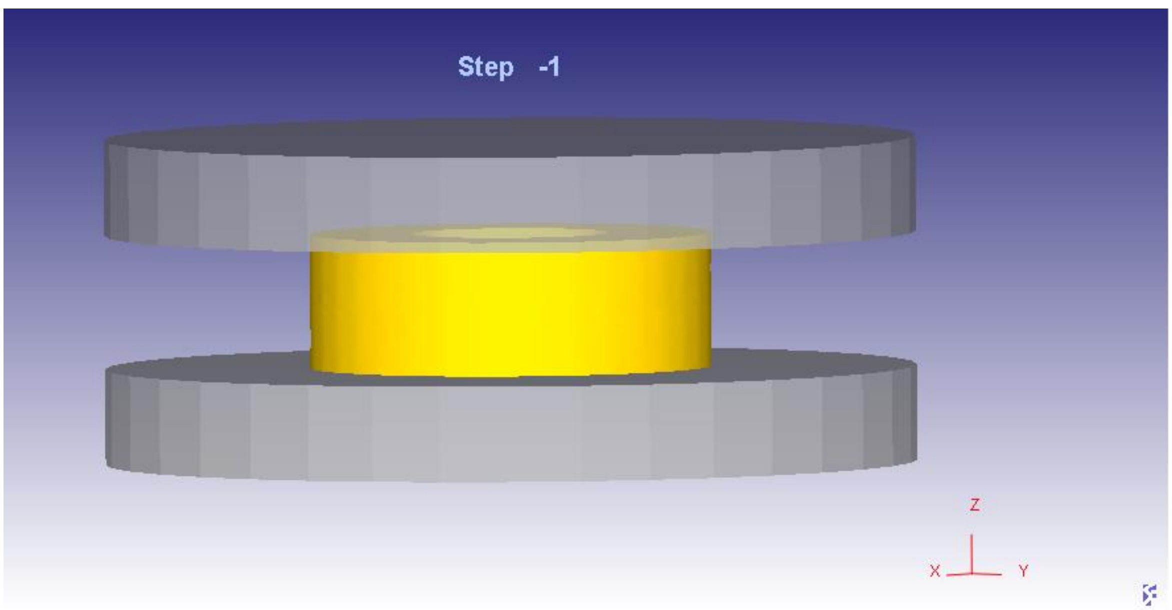

Figure 3. 16 Assembly for compression before deformation

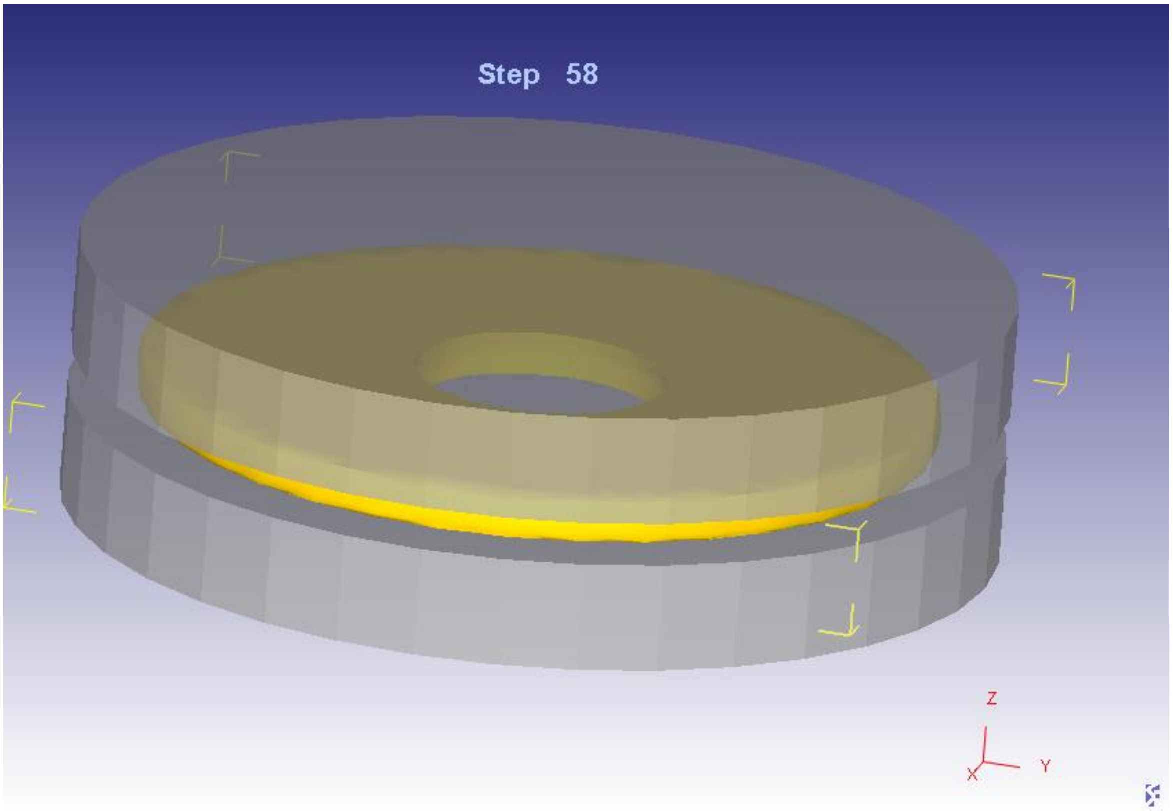

Figure 3. 17 Assembly after deformation

3.6. Load and Support

Material properties and datas were used based on Ethiopian Railway Corporation, Addis Abeba Light Rail Transit (AALRT) specification. Vertically downward load is sum of 3% allowance, maximum axle load. The overall load is the sum of the total tram weight and carrying capacity of vehicle. The overall load is classified to each axle of the vehicle then the axle load is classified to each wheel vehicle.

3.6.1. Seating Capacity of Vehicles

The vehicle is designed to hold many passengers at a time thus it is spacious and designed for more people to stand to use space for servicing more people at once. The following table 3.17 below shown expresses seating capacity of vehicles which was obtained in Site Company.

Table 3. 17 seating capacity of AALRT wheels (AALRT data explained in Appendix E)

Number of passengers (persons)	seated	standing	Total
Seats (AW1)	65	0	65
Seating capacity (AW2) (standing: 6 persons/m^2)	65	189	254
Overload capacity (AW3) (standing: 8 persons/m^2)	65	252	317

3.6.2. Vehicle Weight

Weights of vehicles are given in following table with vehicle axle load of ≤11（1+3%)t and taking 60 kg as average weight of each passenger.

Table 3. 18 Vehicle weight of AALRT vehicle (AALRT spec. in Appendix E)

Item No	Loads	Car body weight	Passenger weight	Total weight
1	Empty vehicle load (t)	44	0	44
2	Seating capacity (t)	44	15.24	59.24
3	Over load capacity (t)	44	19.02	63.02
4	Axle load	≤ 11(1+3%) t		
5	Axle number	6		

3.6.3. Wheel Load

In this model the load is static load on the wheel, which is applied on the center of the wheel down ward. In case of the tram car we do have three bogies each having two axles and the wheel load will be one half of the weight of the axle load. The total numbers of the axles are six. Therfore the total vertical load is calculated as follows

Tram car weight=44 ton

The load applied on each axle=7.333 ton=73333N

The load applied on each wheel=3.667 ton=36667N

Carrying capacity=60kg/person*317person=19020kg

Over all load applied on wheel=tram car weight on each wheel + carrying capacity

=36667+190200/12=52,517N

Maximum axle load =2*52,517+73333=178367N for each axle.

Therefore, for 6 axles 6*178367=1070202N

The total vertical load=maximum axle load+3% of maximum axle load=1102308.06N.

3.6.4. Velocity of Wheel

Since the wheel is rolling on the top of rail, its velocity can be decomposed in to its components naming the moving velocity and angular velocity. The product of angular velocity magnitude and radius of the wheel gives the magnitude of the moving velocity of the wheel.

Table 3. 19 velocity and other parameters (recorded data on AALRT, Appendix E)

Maximum operation speed	70km/h
Maximum test speed	80km/h
Axle load	≤11(1+3%)t
Track gauge	1425mm
Fixed wheelbase	1900mm
Wheel diameter	Dia 66omm(new wheel),580mm(worn wheel)
Axle box bearing	Tapper roller bearing nut

The maximum operation speed of the tramcar is 70km/h and Wheel diameter is 660mm then the rotational velocity can be calculated as:

From V=Wr, W=V/r=70km/h/ 330mm=58.9225rad/s. The maximum test speed of the vehicle is 80 km/hr.

3.7. Wheel and Rail contact Modeling

- ✓ To simulate the 3D contact interaction analysis of Rail-Wheel, the following stages were considered.
    - Accurate modeling of the railway system
    - Material modeling that is, elastic or elastic-plastic
    - Boundary conditions
    - Loading conditions
    - Combination of rotational and linear motion of the wheel
    - Defining contacts to impacted elements
    - Friction coefficient

To create solid model, the precise profiles in accordance with the actual sizes have been taken in to consideration. Therefore, component of this system have been modeled through the accurate engineering drawing via solid work.

3.7.1. Rail Modeling

3.7.2. Guide lines for Rail grade Selection

Since the rail is the most important component of track supper structure, means the running surface, carrier, and guiding element for the rolling vehicles [39]. To be able to safe and with stand their functions, the rails and the rail steels must meet the following requirements.

- High wear resistance
- High resistance to deformation caused by compression
- High fatigue strength
- High yield strength, toughness, toughness/tensile strength and hardness
- High resistance to brittle fracture
- Good weldablity
- High degree of steel purity and good texture

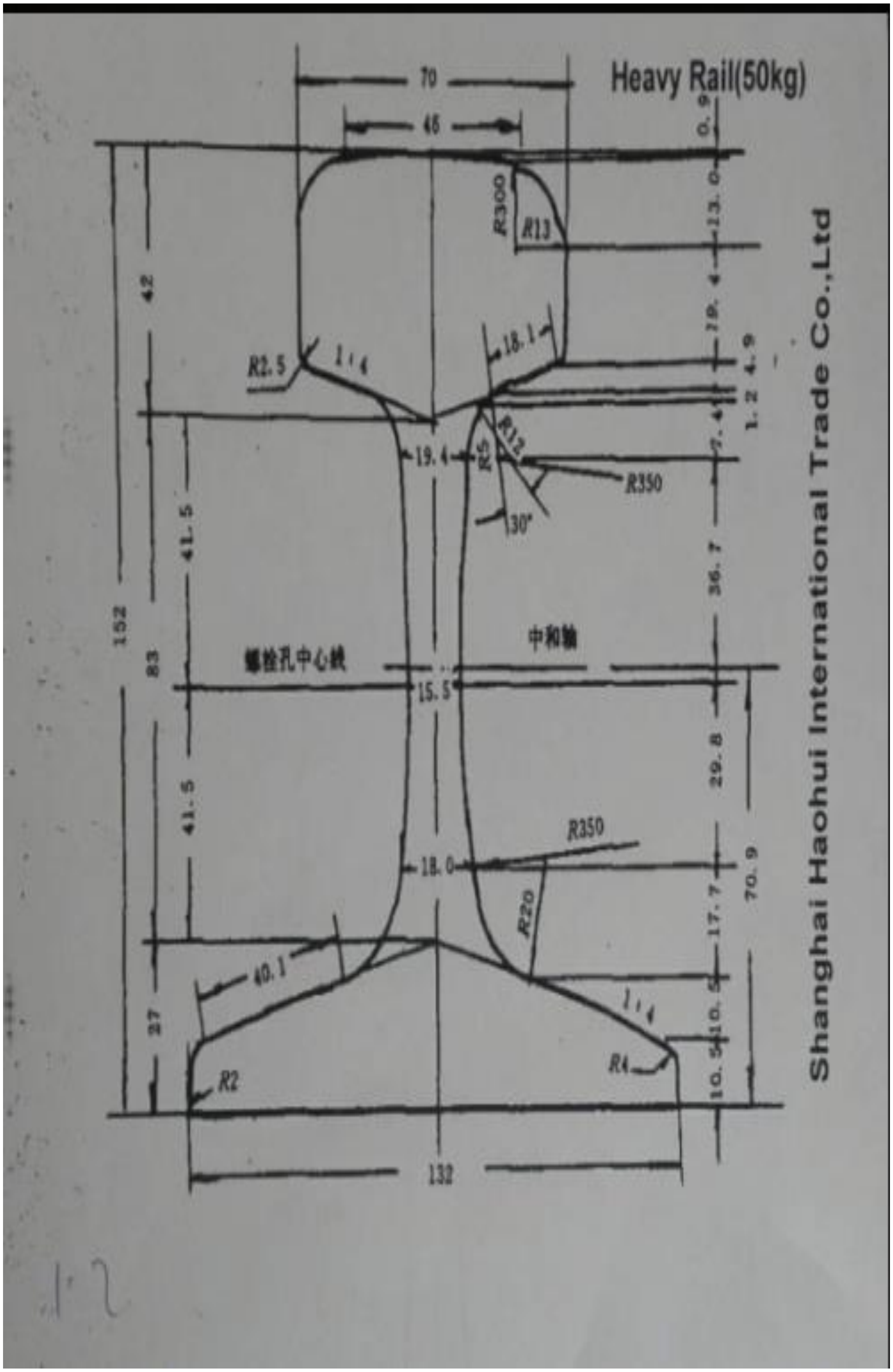

Figure 3. 18 Rail cross sectional parameter and profile (constaction dept, Appendix F)

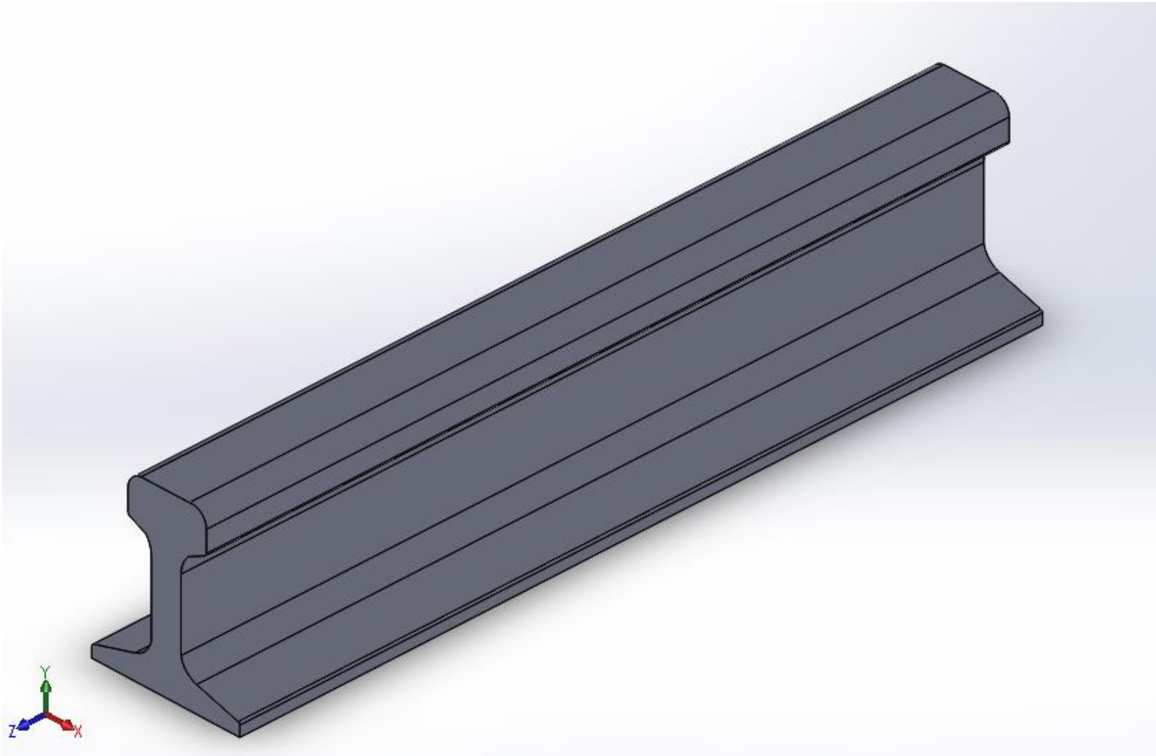

Figure 3. 19 3D Model of railway rail

3.7.3. Wheel Profile and its Nomenclature

The resistance (yield strength and tensile strength) and the hardness are considered as indicators of the railway wheels performance during its operation, since yield stress has higher influence on the damage response caused by contact fatigue of the bearing and wear resistance is associated with increasing hardness of the material. The following figure shows the railway wheel profile and nomenclature.

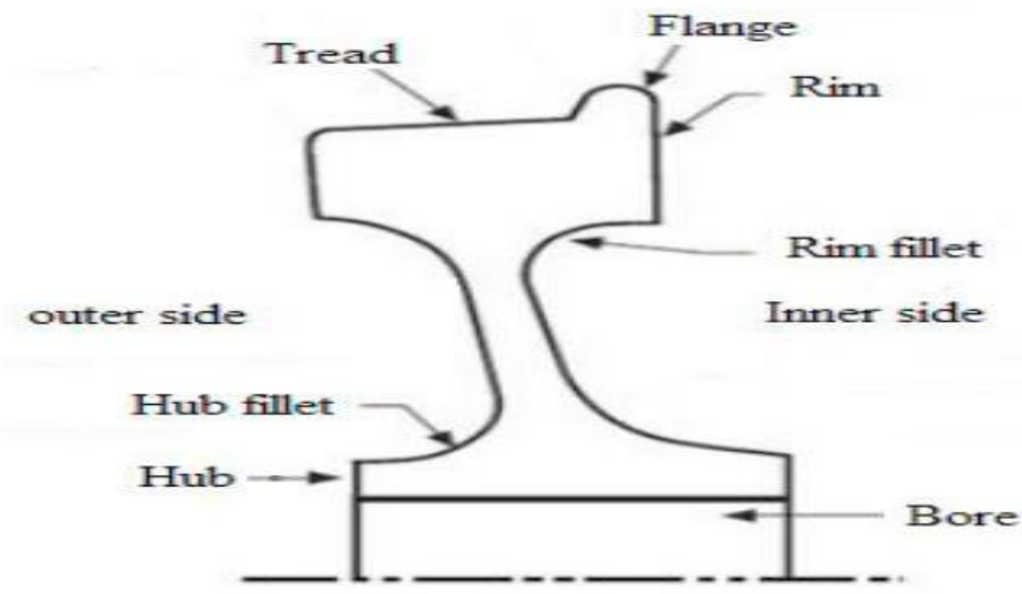

Figure 3. 20 Wheel profile and nomenclature [40]

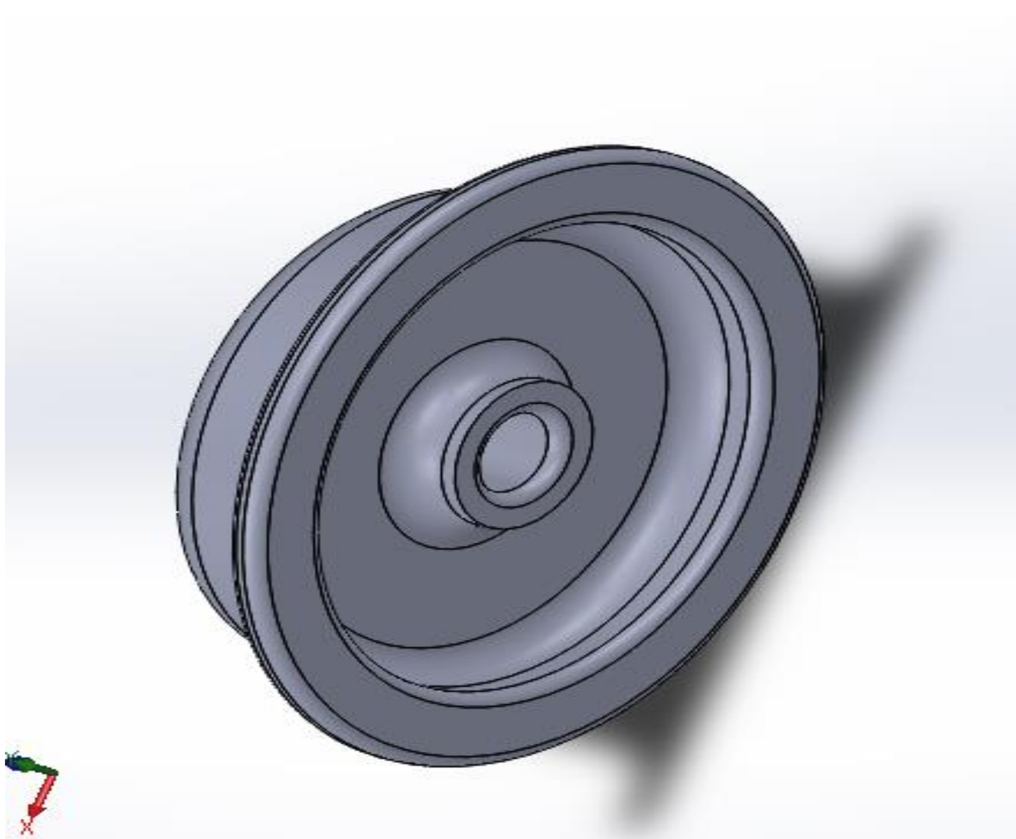

Figure 3. 21 3D model of wheel

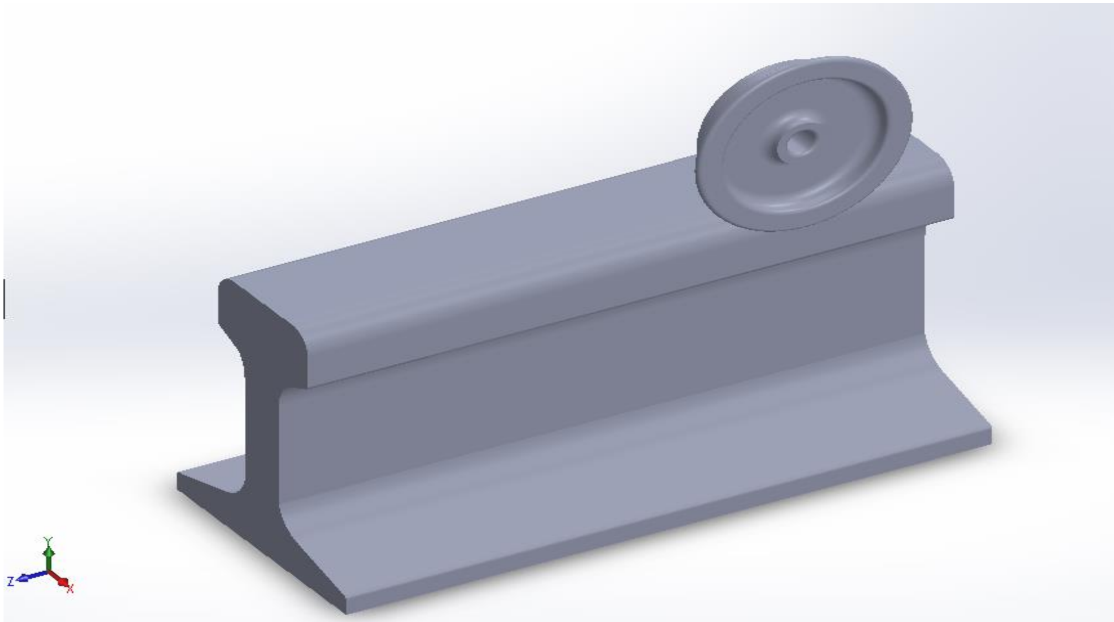

Figure 3. 22 Railway wheel-rail contact modeled using solid work

The required data to model the rail and wheel is obtained from AALRT specifications

3.8. Contact analysis using Ansys work bench 15.10

3.8.1 Input parameters

Table 3. 20 Input parameters for simulation using ansys

Parameters	Value	
	existing	alloyed
Force	36667N	36667N
Angular velocity	58.9225rad/s	58.9225rad/s
Standard earth gravity	9806.6mm/s^2	9806.6mm/s^2
Poison’s ratio	0.3	0.3
Young’s modulus	200 Gpa	200 Gpa
Yield stress	329.27 Mpa	332 Mpa
Ultimate stress	387.4Mpa	390.6 Mpa
Density	7.85Kg/m^3	7.85Kg/m^3
Strain hardening exponent	0.15	0.26
Strength coefficient	540 Mpa	640 Mpa
Friction coefficient	0.095	0.09

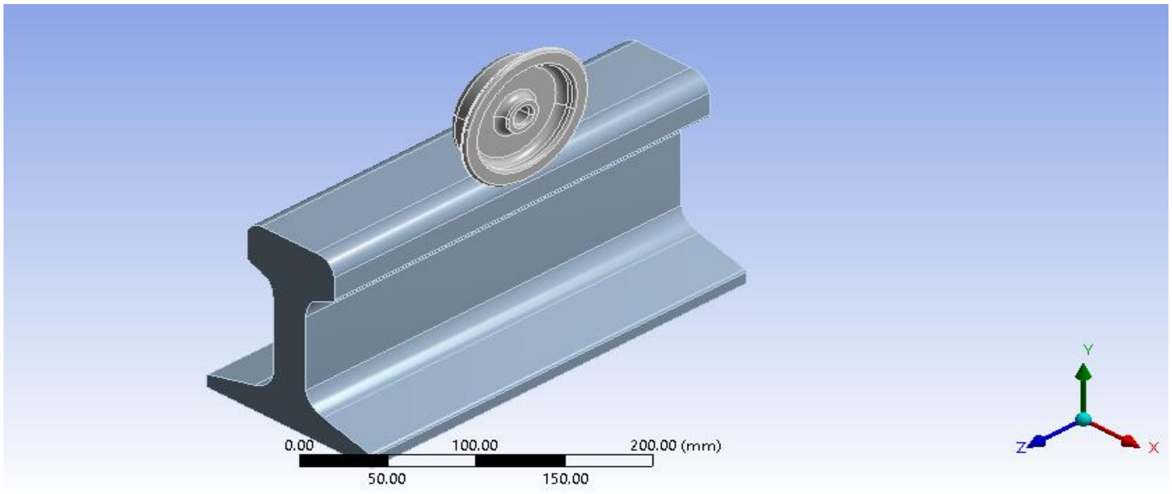

Figure 3. 23 Imported model to ansys

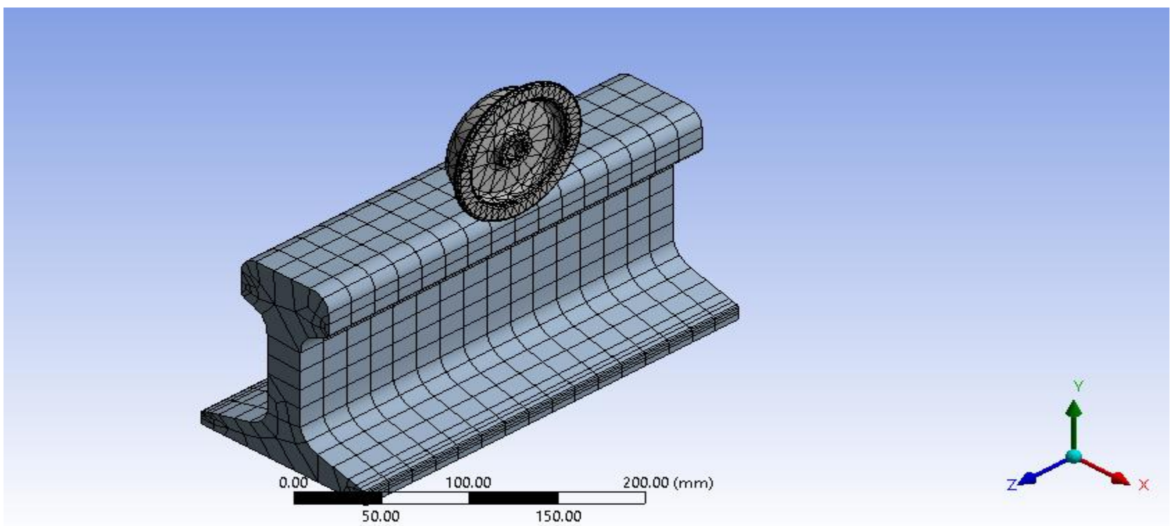

Figure 3. 24 Model mesh

In Finite Element analysis the basic concept is to analyze the structure, which is an assemblage of discrete pieces called elements, which are connected together at finite no points called nodes. A network of these elements is known as mesh. For this analysis, the wheel-rail contact model was meshed with rectangular Finite elements. The size of meshing type is medium size mesh.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Comparation of Composition test Results

Table 4. 1 Comparation of composition results for both existing and alloyed steel

Element	C	Si	Mn	P	S	Cr	Mo	Ni	V	Fe
%con.exsting	0.5	0.25	0.7	0.05	0.05	0.02	0.01	0.005	0.002	98.4
%con.alloyed	0.8	0.38	1.15	0.02	0.02	0.06	0.03	0.007	0.003	97.47

As it has been illustrated in the above table composition tests were carried out two times in this research and the composition of alloying elements were obtained.

4.2. Comparation of Hardness Values

Table 4. 2 hardness test results for both existing and alloyed wheel steel

No.of trials	Description of test	Results		remarks
		existing	alloyed	
1	Rockwell test HRC	99.4 HRC	99.9 HRC	Force 150kg
2	Rockwell test HRC	98.2 HRC	99.7 HRC	>>
3	Rockwell test HRC	99.0 HRC	100 HRC	>>
4	Rockwell test HRC	98.7 HRC	99.1 HRC	>>
5	Rockwell test HRC	99.1 HRC	99.8 HRC	>>
Average	Rockwell test HRC	98.88HRC	99.7HRC	>>

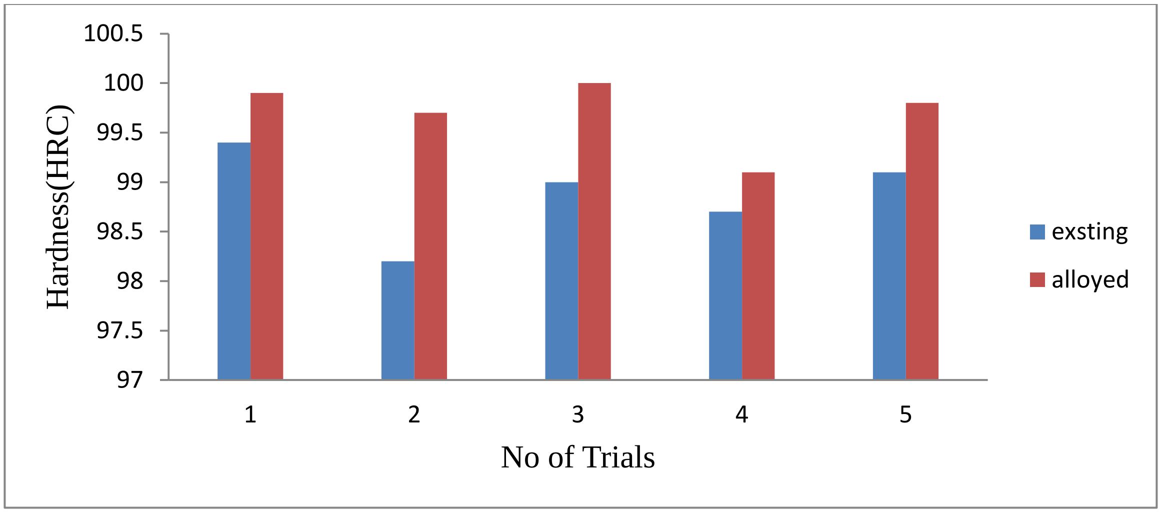

Figure 4. 1 hardness test result for both alloyed and existing wheel

Manganese increases hardenability and tensile strength of steel, It is also able to decrease the critical cooling rate during hardening, thus increasing steels hardenability much more efficient than any other alloying element. Due to alloying the hardness of the material was increase which leads intern the wear resistance of the material. As shown in the above figure initially the wear was high and it gradually decreases when the hardness value is going to high. So through composition, alloying and by controlling friction wear of wheel steel had been decreased. The lubricity of lubricants is one of the most significant factors since it directly determines the interface friction, which intern influences the stresses, pressing load, and forging energy. In this research the interface friction coefficient and friction factor between the work piece and dies was determined under both dry and lubricated conditions.

The result obtained is shown in table 4.2 and 4.3 below. From the table it is clear that the interface friction can vary under dry and lubricated conditions. The specimen having dimension as outer diameter 42mm, inner diameter 21mm and height 14mm,is used for the analysis but the dimension change occurred under the ring compression is different for each lubrication condition.

Table 4. 3 Geometric changes and resulting stresses

Condition	Load(KN)	Do	Di	H	ΔDo	ΔDi	ΔH	Area	σ(Mpa)
Dry	1500	48.1	19.85	11.4	6.1	1.15	2.6	1507	995
	2700	59.9	17.2	7.86	17.9	3.8	6.14	2584.4	1044.7
	3040	60.2	15.3	5.71	18.2	4.3	8.29	2651.4	1146.56
Oil	1500	47.91	19.94	9.0	5.91	1.06	8.09	1489.8	1006.8
	2700	59.2	16.3	5.27	17.2	4.7	8.73	2542.6	1061.9
	2900	59.1	16.63	5.26	17.1	4.6	8.74	2530.7	1215.9
Grease	1500	48.26	19.51	9.66	6.26	1.49	4.34	1529.46	980.74
	2700	59.2	15.89	5.70	17.2	5.11	8.3	2552.9	1057.6
	3010	59.24	15.7	5.64	17.24	5.01	8.36	2554.1	1217.65

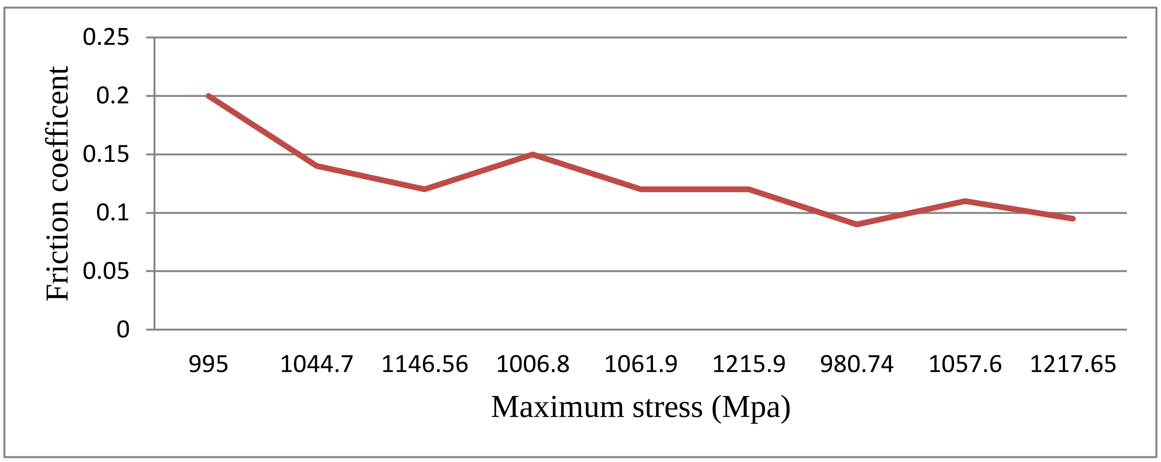

Figure 4. 2 Friction cofficent vs Maximum stress

The above figure showed the friction coefficient values and maximum stress developed for both dry and lubricated conditions. Based on this plot and experimental analysis 0.15, 0.13 and 0.09 were the evaluated friction coefficients for dry, grease and oil conditions respectively. Then it was revealed that 0.09 as a friction coefficient and oil as a suitable lubricant.

Table 4. 4 Friction coefficient result of existing wheel

Lubricant condition	Load, KN	Final readings ,mm			Reduction in inner diameter	Reduction in height	Friction coefficient	Frict. factor
		Do	Di	H	(ΔDi/Di)*100	(ΔHi/Hi)*100	μ	m
Dray condition	1500	47.98 48.21 48.1 48.1	19.86 19.84 19.85 19.85	11.36 11.45 11.40 11.4	5.48	18.57	0.2	0.6
	2700	59.91 59.93 59.86 59.9	17.09 17.2 17.31 17.2	7.81 7.87 7.90 7.86	18.1	43.86	0.15	0.5
	3040	60.21 60.24 60.15 60.2	15.3 15.29 15.31 15.3	5.71 5.71 5.71 5.71	27.14	59.21	0.12	0.45
Grease Condition	1500	48.1 48.3 47.9 48.1	19.8 20.0 19.75 19.85	11.2 11.7 11.4 11.4	5.5	18.6	0.14	0.7
	2700	59.7 60.1 59.9 59.9	17.5 16.9 17.2 17.2	7.8 8.0 7.79 7.86	18.1	43.86	0.11	0.5
	3010	60.2 59.9 60.4 60.2	15.7 15.69 15.71 15.7	5.67 5.68 5.80 5.71	25.23	39.5	0.2	0.71
Oil condition	1500	48.21 48.28 48.29 48.26	19.51 19.51 19.52 19.51	9.64 9.67 9.66 9.66	4.76	31	0.09	0.32
	2700	59.21 59.10 59.30 59.20	15.89 15.88 15.90 15.89	5.50 5.81 5.80 5.70	24.33	9.3	0.1	0.53
	2900	59.24 59.23 59.25 59.24	16.61 16.63 15.64 16.63	5.64 5.64 5.64 5.64	20.81	59.7	0.1	0.35

Table 4. 5 Friction coefficient results of alloyed wheel

Lubricant	Load,KN	Final readings, mm			Reduction in internal dia	Reduction in height, mm	Friction coefficient	Friction factor
		Do	Di	H	(ΔDi/Di)*100	(ΔHi/Hi)*100	μ	M
Oil condition	1500	47.90 47.93 47.89 47.91	19.94 19.90 19.98 19.94	9.0 9.20 8.82 9.0	5.1	35.71	0.09	0.3
	2700	59.20 59.21 59.19 59.20	16.3 16.29 16.30 16.30	5.26 5.28 5.27 5.27	22.38	62.34	0.09	0.34
	2815	59.21 59.22 59.20 59.21	16.68 16.69 16.65 16.67	5.25 5.27 5.26 5.26	21	62.34	0.09	0.3

4.3. Actual Wheel Data Measurements

4.3.1. Comparation of Flange Thickness per Wheel

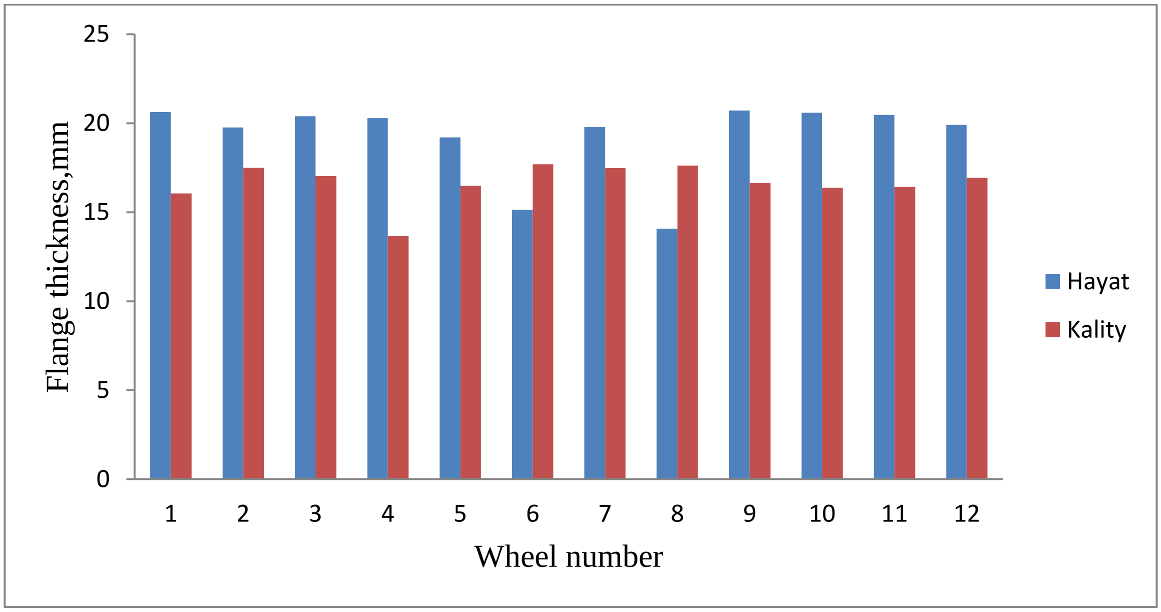

Figure 4. 3 Flange thickness comparation per wheel

4.3.2. Comparation of Flange Thickness per Bogie

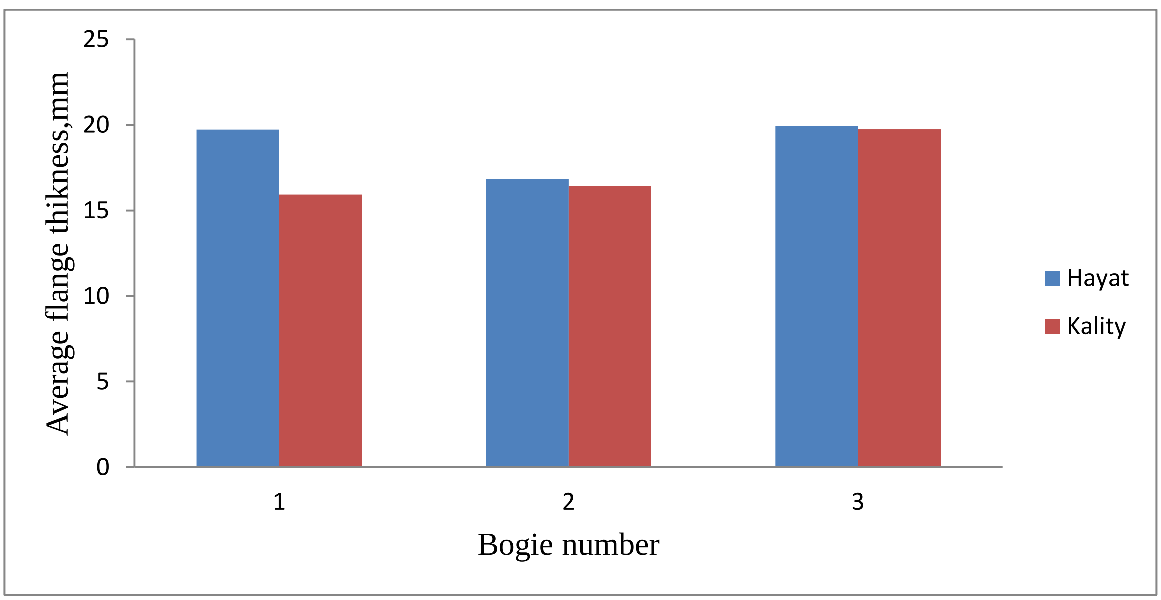

Figure 4. 4 Average flange thickness per bogie

As shown in figure 4.4 the average flange thickness per wheel of Kality vehicles is greatly worn than that of Ayat's vehicle. Kality vehicles, with average flange thickness of 16.36 mm, show a total percentage loss of 22.9 % in flange thickness as compared to Ayat vehicles'18.83

mm average flange thickness with percentage loss of 11.2%. It can be observed that tailor (bogie 2) bogies' flange thicknesses are worn greatly compared to other two motor bogies. One of the characteristics of trailer bogies is that these types of bogies do not promote self-steering through curves, increasing flange forces and angle of attack which leads to flange wear and noise and thus the wheel life of trailer bogies is less than that of motored bogies. This is especially the reason for wheel flange wear for Kality vehicles due to adverse conditions of sharper curves in the route.

4.3.3. Comparation of Tread Diameter per Wheel

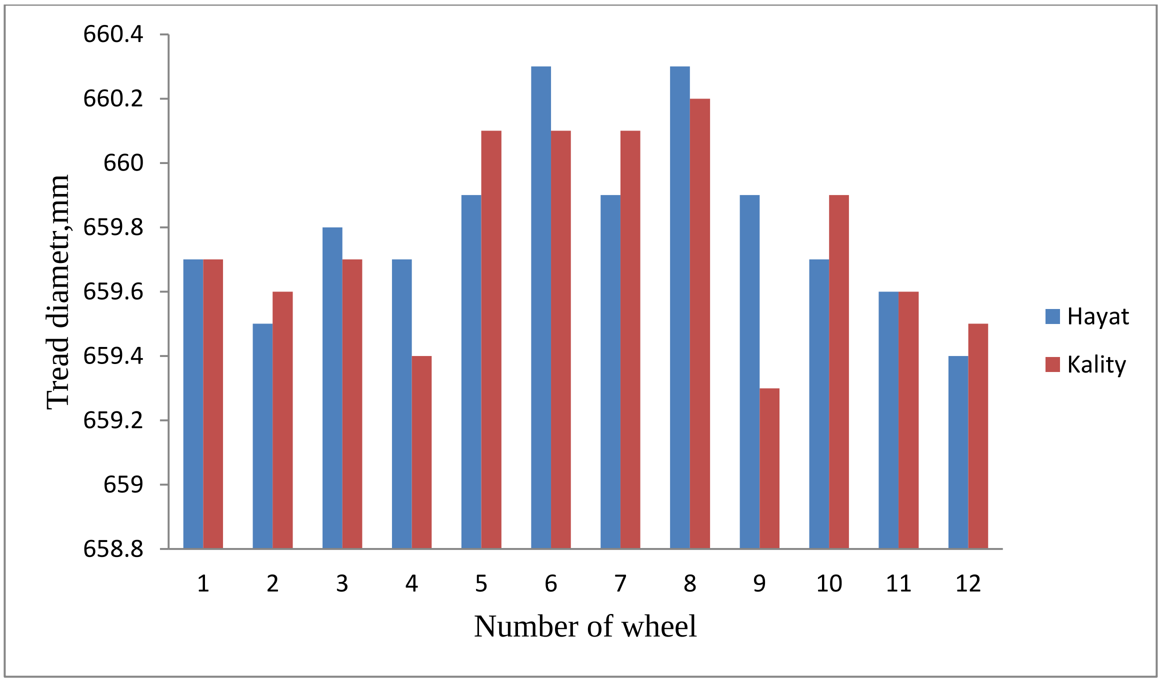

Figure 4. 5 Tread diameter per wheel for the two routes

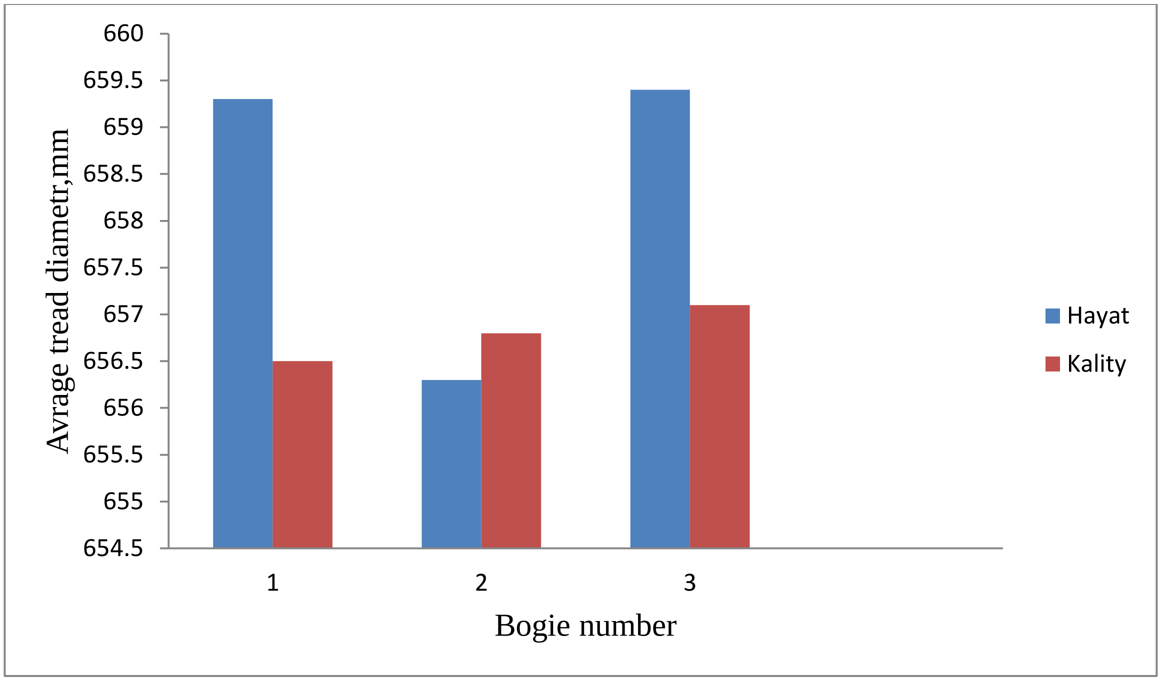

Figure 4. 6 Average trade diameters per bogie

As shown in figure 4.6 above the average tread diameter per wheel of Kality vehicles is greatly worn than that of Ayat's vehicle. Kality vehicles with average tread diameter of 656.2 mm, show a total percentage loss of 0.48 % in tread diameter as compared to Ayat vehicles' 658.3 mm average flange thickness with percentage loss of 0.25 %. Average tread diameter of the trailer bogies for Hayat vehicles is much more worn than the other two bogies which is because trailer bogies tend to wear at a greater rate than the rest due to increased forces at contact since these bogies don't allow self-steering. Under normal conditions, trailer bogies do wear faster than motorized bogies.

4.3.4. Deform Results

Deform soft were done to verify experimental analysis of ring compression test. 3D modeling was done and illustrated in chapter three.

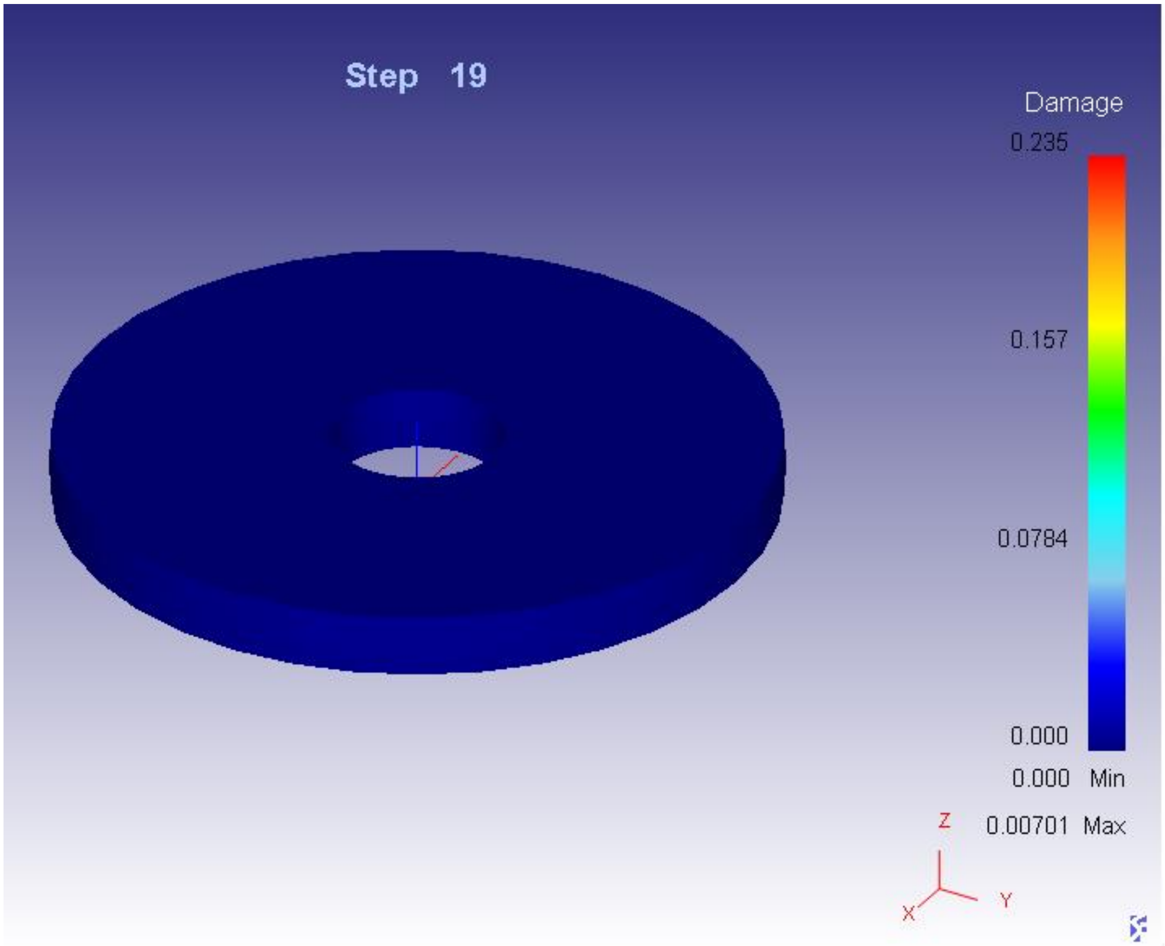

Figure 4. 7 Damage for exsting wheel

The maximum damage created during deformation of exsting wheel is 0.235 by using deformation load required of 2900 KN. Since exsting wheel is not hardened and strengthen damage becomes increased. And damage is maximized around the inner part of the ring which is displayed in red color as shown figure 4.7 above because of inner diameter is sensitive to friction.

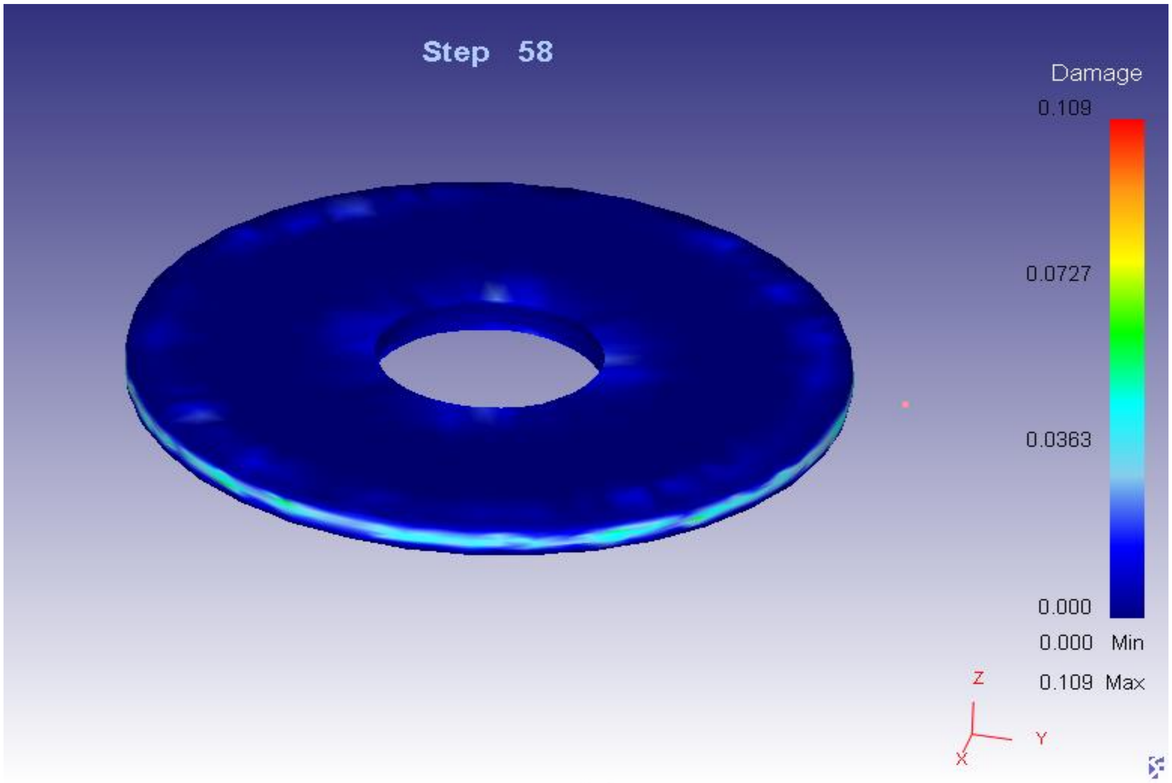

Figure 4. 8 damage for alloyed

When the material is hardened and strong enough damage in deformation becomes reduced. As shown in the above figure 4.8 the maximum damage created due to the applied load 2815 KN is 0.109 which is less than 0.235 that is damage obtained in compression of exsting wheel by the maximum deformation load of 2900KN. And the maximum damage is displayed in red color. It is possible to compare damage obtained between exsting and alloyed wheel as follows. 0.235-0.109/0.235*100=53.6%.

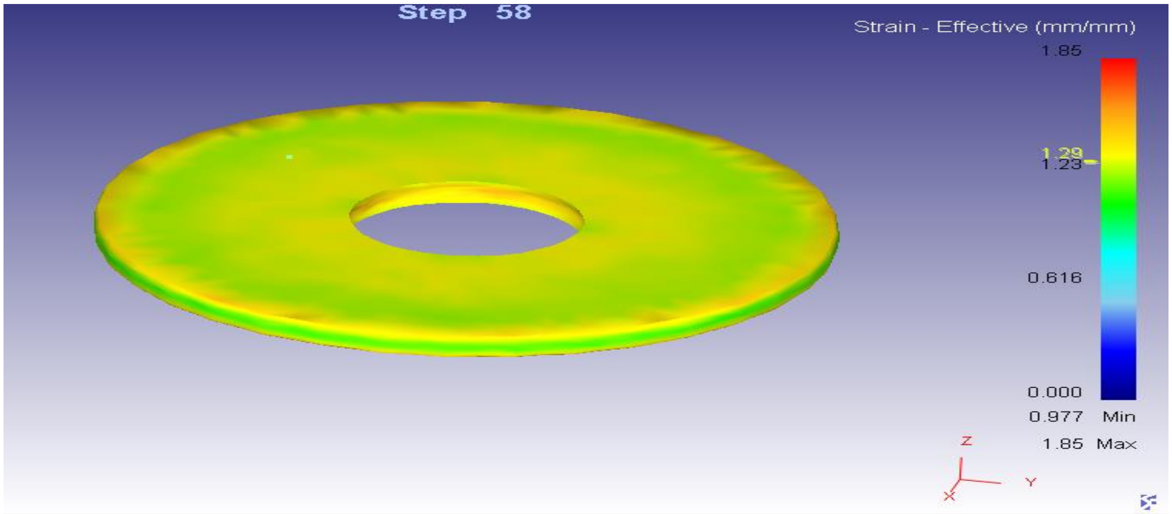

Figure 4. 9 Strain effective for exsting

With the maximum deformation load 2900 KN the minimum and maximum strain-effective values are 0.977 and 1.89 respectively for exsting wheel. This strain rate increment tells how the deformation is increased in case of exsting wheel.

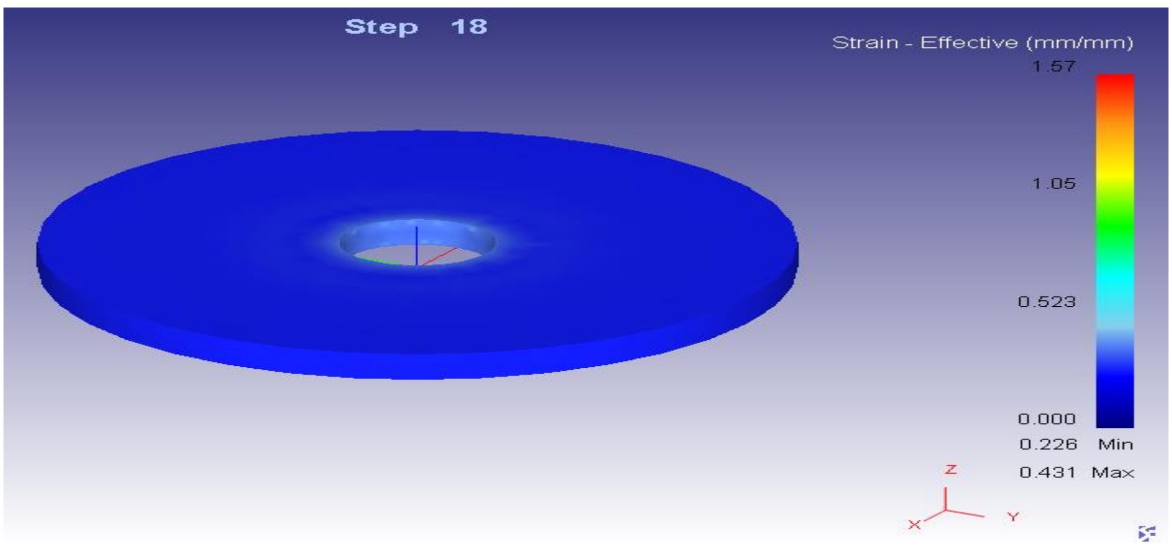

Figure 4. 10 strain-effective for alloyed wheel

The figure 4.10 shown above explaines the minimum load requirement and maximum deformation load is 1500KN, 2815KN respectively and minimum and maximum strain-effective is 0.228 and 1.57 respectively for alloyed wheel.

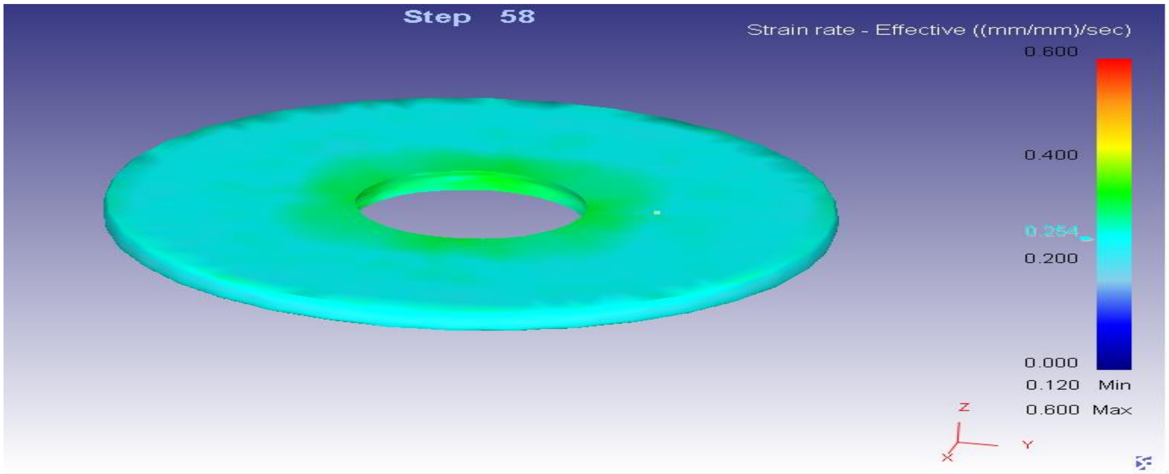

Figure 4. 11 Strain rate for alloyed

The maximum strain rate value is 0.6 (mm/mm)/sec and the minimum value is 0.12(mm/mm)/sec. And the maximum strain rate is increased inwards because of the inner radius is sensitive for friction than the outer.

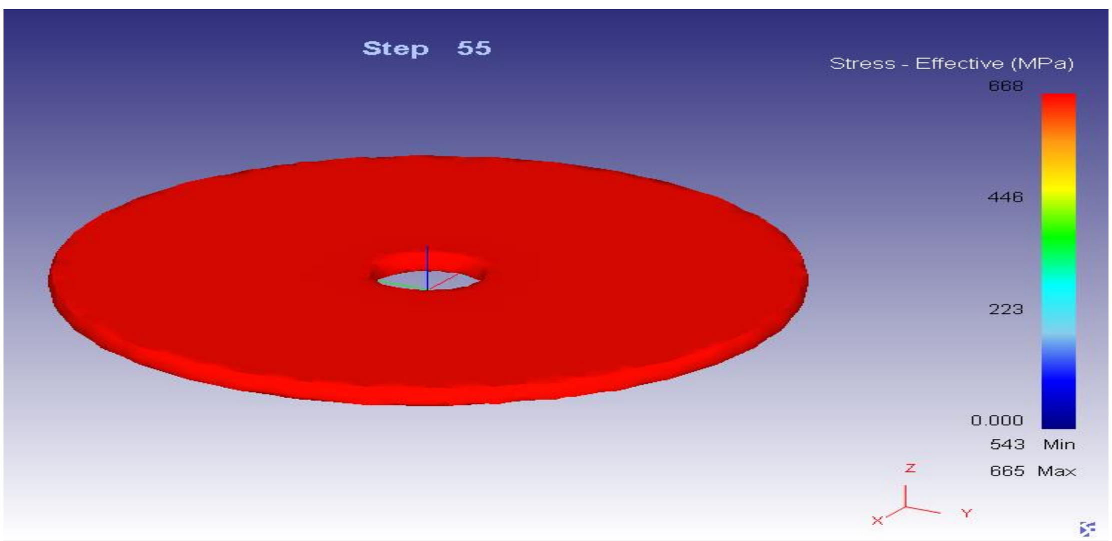

Figure 4. 12 Stress effective for exsting

Due to the maximum compressive load in ring compression test the maximum effective – stress developed on the sample is 668Mpa for exsting wheel.

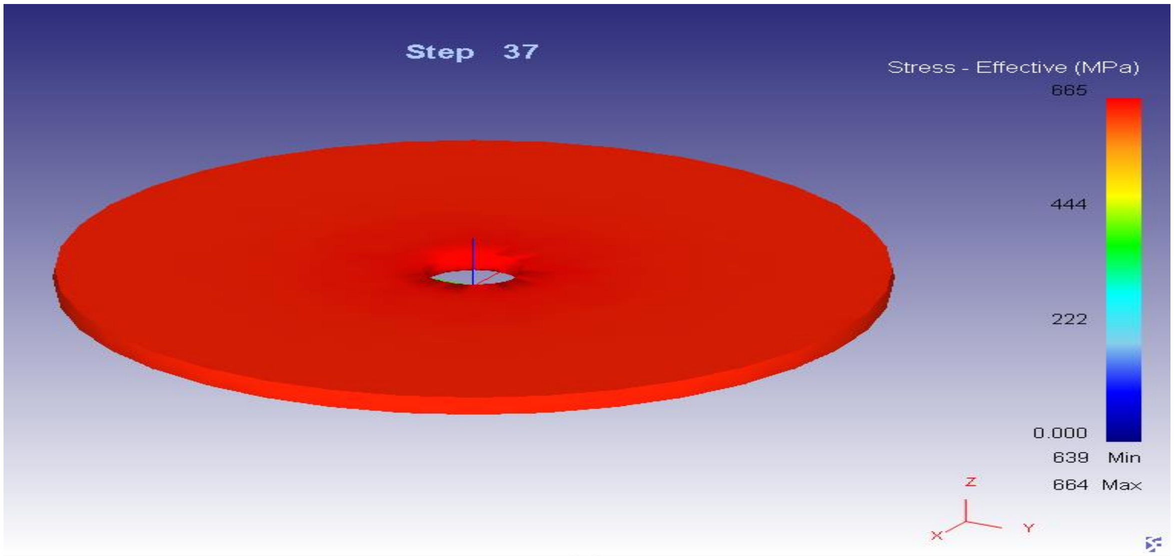

Figure 4. 13 stress-effective for alloyed

The maximum effective stress induced due to the compressive load of 2815 KN which is displayed in red color is 665Mpa. Due to hardening and proper controlling of friction behavior the specimen could carry more loads than exsting one where as maximum stress-effective developed in exsting was 668Mpa which shows material property is enhanced.

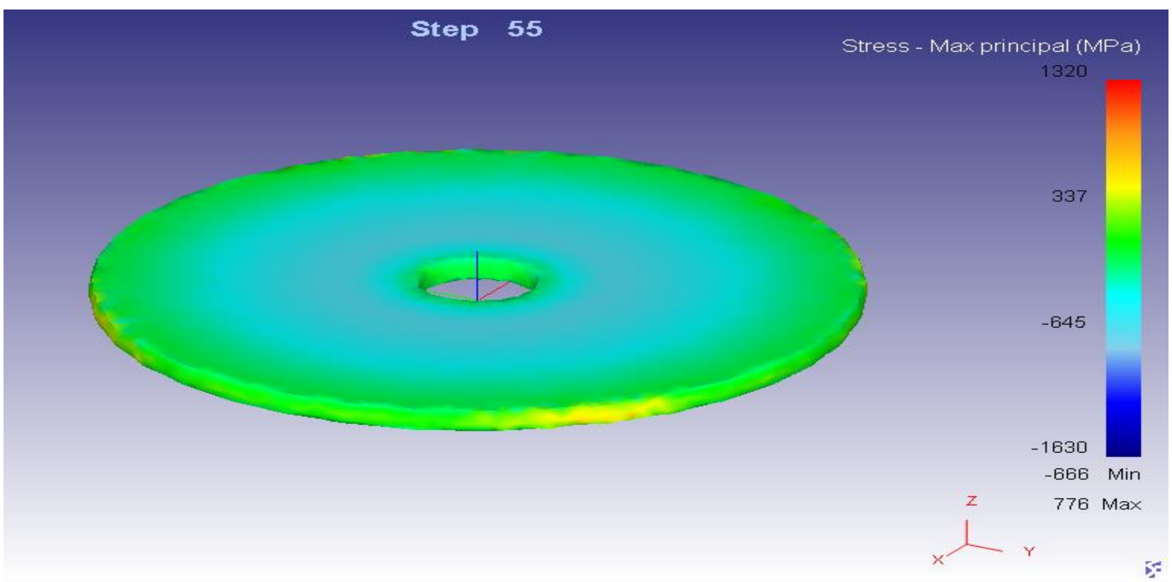

Figure 4. 14 Stress max for exsting

4.3.4. Comparation of Experimental and FEM simulation Result of compression test

Table 4. 6 Validation for ring compression test

Condition	Load(KN)	Max. stress in Mpa		Error%
		experimental	FEM simulation	
Dry	1500	995	946	4.92
	2700	1044.7	1080	3.26
	3040	1146.56	1170	2
Oil	1500	971.13	928	4.44
	2700	1061.9	1130	6.03
	2900	1215.74	1320	7.89
Grease	1500	980.74	897	8.5
	2700	1057.6	1085.5	2.57
	3010	1217.65	1270	4.1

4.4. Ansys result

4.4.1. Stress results for existing Material

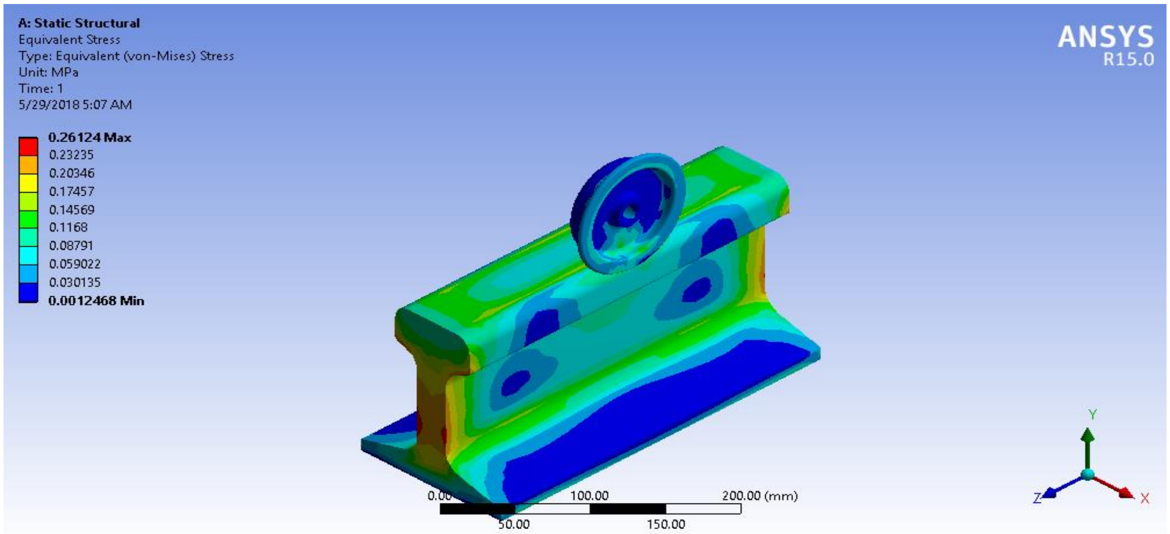

Figure 4. 15 Equivalent (von-misses) stress for existing material

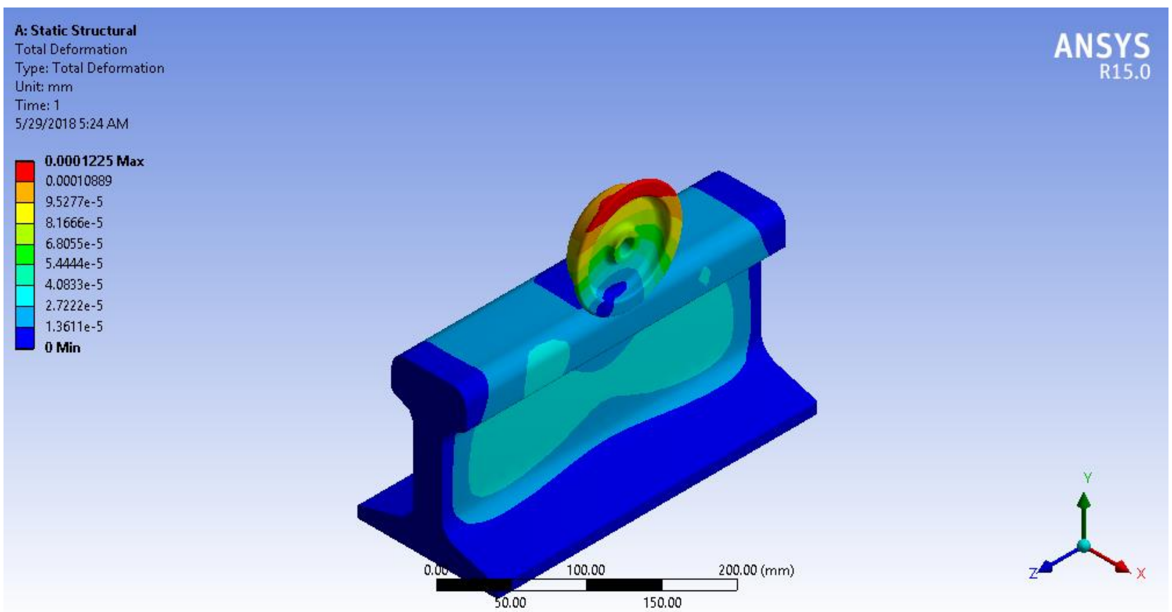

Figure 4. 16 Total deformation for existing

4.4.2. Stress results of alloyed material

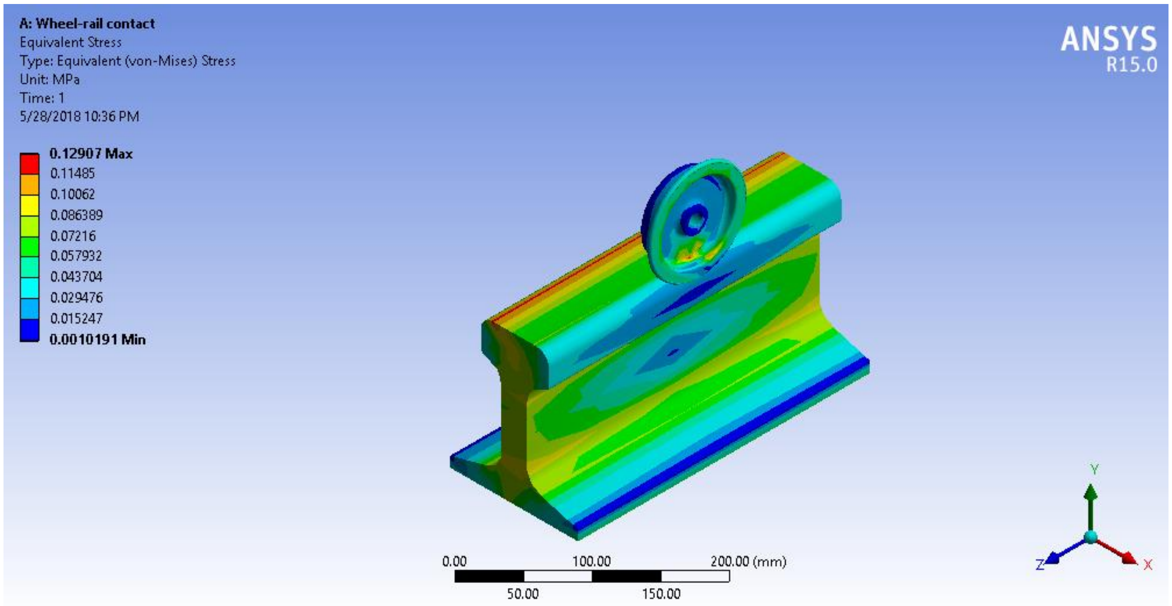

Figure 4. 17 Equivalent (von-misses) stress for alloyed wheel

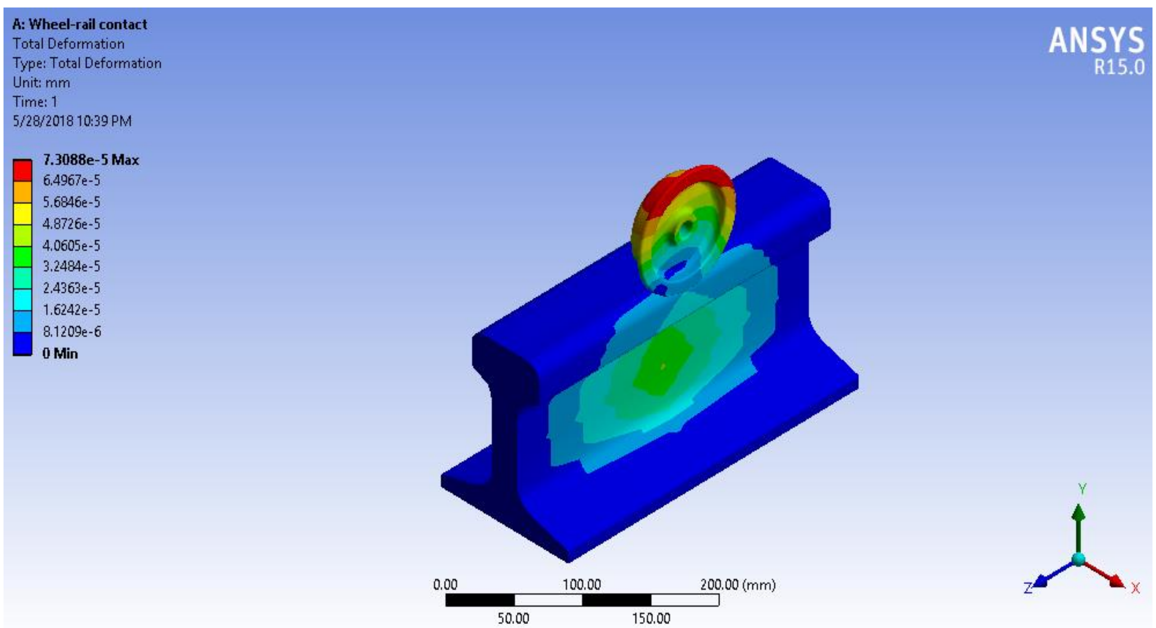

Figure 4. 18 Total deformation for alloyed wheel

The maximum equivalent (von-mises) stress is 0.26124 Mpa for exsting material as shown above in figure 4.13 where as the maximum equivalent (von-misses) stress for alloyed material explained in figure 4.15 is 0.12907 Mpa. With the same geometry, contact area, and applied load equivalent stress less signifies the material can Cary more than the given load.

Therefore we can conclude that the material is improved. Similarly the total deformation was compared between exsting and alloyed one. As explained in figure 4.14 the maximum total deformation for exsting material was 0.0001225mm where as the maximum total deformation for alloyed material is $7.3088e^{-5}$mm. when the two deformations compared, deformation is less in comparation with the exsting. Therefore, the material is improved interms of composition, hardness and alloying.

4.5. Summery

The percentage composition of exsting wheel material constituent elements especially carbon, manganese and silicon are 0.5%, 0.7% and 0.25% respectively. And for alloyed wheel material it has been gained 0.8%, 1.15% and 0.38%. For high wear resistance application carbon, manganese and silicon percentage compostion can be reached up to 0.9%, 1.5% and 0.4% but more than this value leads the product brittle behavior. The hardness value of product has been compared and alloyed wheel becomes harder incomparation with that of exsting one. And the value was 99.7% and 98.88% respectively. From Ansys result it could be summarized as the maximum deformation for exsting and alloyed wheel has been gained 0.0001225mm and $7.3088e^{-5}$mm respectively.

CHAPTER FIVE

5. CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1. Conclusion

Over all, factors which lead to wheel wear at AALRT are triangulated based on results from site inspections/experts, actual wheel data measurements, composition and hardness testing of existing and improved wheel materials. Based on the inspections and wheel data analysis work undertaken for this investigation causes of wheel wear of AALRT vehicles could be considered as a combination of issues related to inadequate friction management, composition and poor track infrastructure. The tight curves at AALRT, mainly in north-south line contribute to high flange wear.

Inadequate friction management at AALRT, in which the lack of rolling stock solid lubricant and inadequate manual based track lubrication on the rail, have led to undesired high friction between the wheel and the rail. Friction condition between the ring and the die interface is one of the most important factors in metal forming operations. Ring compression test is employed in this investigation under both dry and different lubricant conditions to determine the friction coefficient. In general the following conclusions have been drown

- Wheel and rail suffer damages on each of contacting surfaces such as wear, erosion, and plastic deformation
- The wear of the wheel is based on the operating condition of surfaces in which a slight change may influence the wear rate significantly.
- The wheel load that consists of contact stress distribution, sub surface stress, and plastic deformation could led to rolling contact fatigue.
- Oil is the best lubricant for wheel steel and 0.09 is a significant friction coefficient value

5.2. Recommendation

Some simplications of models of the railway system, like ignoring the setting pads in this study decreased the exactness of the solution. This research mainly focuses on the wheel material and its development interms of composition and hardness value for indirect investigation of wheel wear. But it is recommended that during analysis it should be better to consider the rail joints. For similar case engineers can develop the solutions by modification of the geometry of rail joint component part since rail joint is the weakest spots in the railway track and rail joint are used to connect the ends of two rails horizontally and vertically it needs special attention.

5.3. Future work

The present study can be usd as one of the fundamental researches for rolling contact causing fatigue, wear and abrasion. Therefore, improving and pursuing this study can be considered in future works. Directions of the future research are to investigate the influence of pads in nodal forces, stress distribution, and strains created by the wheel on the rail. It is worth to not that pads are also subjected to different types of lateral and vertical loads. Therefore, stresses and strains on pads are needed to be researched out in future studies. The work could be done by considering thermal stresses developed between rail and wheel and by changing the contact length.

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APPENDIXES

A: Interview Questions

1) How serious is the problem of wheel wear at AALRT?

2) What are the adverse conditions and important properties that led to wheel wear at AALRT?

3) Which type of wheel wear is serious for the case of AALRT?

4) What are the maintenance activities carried out on the wheels and rails at AALRT?

5) What facilities are available for testing performance of vehicles?

6) What are the challenges faced due to wearing of wheels?

7) When are the wheels taken in to lath machining?

8) How long where the wheels expected to service before they are worn completely?

9) How suitable is the depot infrastructure?

10) What are the steel grades of wheel and rail that are using in AALRT?

Composition specification gained from AALRT Spec.

Chemical composition (wt. %)	C	Si	Mn	P	Ni	Cr	Mo	V	Fe
CSN12071(rail) (AISI/SAE 1070)	0.7	0.39	1.2	0.05	0.03	0.25	0.002	0.022	97.34
CSN12071(Wheel) (AISI/SAE 1050)	0.65	0.35	0.8	0.035	0.003	0.01	0.001	0.003	98.15

B: Actual wheel data measurements

14	3-7/7/2016	54471	218	1	0.3	659.29	659.59	13.7	16.65	0.24	642.86	643.11	17.65	17.59	39	
				2	0.15	659.29	659.44	14.16	13.86	0.32	643.27	642.96	17.58	17.67	40	
				3	0.01	660.19	660.21	17.08	16.14	0.24	636.55	636.79	19.55	19.72	41	wheel flange thickness
				4	0.16	660.08	659.92	14.11	12.83	0.32	637.96	638.28	17.69	17.78	42	
				5	0.53	659.12	659.65	18.38	18.06	0.03	647.98	647.95	21.11	20.85	43	
				6	0.41	658.94	659.34	16.02	15.26	0.22	648.16	647.94	17.83	17.78	44	
15	08-11/07/2016	47312	215	1	0.44	659.56	660	17.07	17.93	0.31	640.76	641.07	20.97	21.08	45	
				2	0.06	659.79	659.73	15.46	13.46	0.1	642.02	642.12	17.44	17.55	46	
				3	0.09	660.33	660.41	18.05	16.75	0.3	645.14	645.44	19.71	19.94	47	wheel flange thickness
				4	0.18	660.1	660.28	17.09	15.45	0.21	644.17	644.38	18.82	18.81	48	
				5	0.02	659.79	659.81	16.54	16.65	.	.	.	.	.		
				6	0.17	659.79	659.62	16.17	16.03	.	.	.	.	.		
16	13-14/07/2016	22282	207	1	0.19	659.96	660.15	18.63	20.02	0.1	655.17	655.27	19.59	19.84	49	
				2	0.08	660	659.92	18.48	17.54	0.1	654.87	654.76	18.91	18.96	50	
				3	0.01	660.32	660.33	19.54	19.36	.	.	.	.	.		
				4	0.06	660.26	660.32	18.13	18.11	.	.	.	.	.		
				5	0.12	659.98	660.1	19.37	18.82	.	.	.	.	.		
				6	0.06	659.94	660	19.06	17.62	.	.	.	.	.		
17	15-27/07/2016	43452	208	1	0.07	659.43	659.5	16.34	17.53	0.29	637.93	638.21	20.11	20.24	51	
				2	0.22	659.56	659.78	13.45	18.34	0.19	635.4	635.21	17.41	17.75	52	
				3	0.15	660.14	660.29	17.05	15.44	0.1	640.15	640.05	18.58	18.78	53	wheel flange thickness
				4	0.06	660.19	660.12	17.28	14.47	0.23	639.02	638.79	18.3	18.3	54	
				5	0.12	659.67	659.56	18.68	16.96	0.19	645.95	645.76	19.68	19.82	55	
				6	0.2	659.36	659.55	17.09	15.99	0.07	645.78	645.86	18.86	18.9	56	
18	17-18/08/2016	45551	114	1	0.12	659.86	659.74	19.6	20.48	.	.	.	.	.		
				2	0.1	659.85	659.95	20.29	20.47	.	.	.	.	.		
				3	0.25	660.3	660.05	18.52	19.71	0.35	655.78	655.43	18.67	19.38	57	
				4	0.25	660.27	660.02	18.4	19.63	0.58	655.16	655.75	19.35	19.26	58	
				5	0.09	659.88	659.79	19.68	20.34	.	.	.	.	.		
				6	0.12	659.79	659.67	21.11	19.99	.	.	.	.	.		
19	9-22/08/2016	51662	210	1	0.32	659.02	659.34	16.12	16.36	0.29	642.73	642.44	18.99	18.99	59	
				2	0.24	659.44	659.2	16.3	14.39	0.61	642.23	641.63	17.75	18.09	60	
				3	0.23	660.06	660.3	15.52	14.21	0.39	640.74	641.13	17.39	17.46	61	wheel flange thickness
				4	0.21	650.68	650.89	17.51	17.45	0.05	642.57	642.52	18.1	18.44	62	
				5	0.2	659.25	659.45	16.4	16.93	0.15	646.23	646.37	18.02	18.11	63	
				6	0	659.15	659.16	16.38	14.98	0.41	645.96	645.55	17.27	17.58	64	
20	23-25/08/2016	40415	108	1	0.42	659.94	659.52	20.44	20.4	.	.	.	.	.		
				2	0.03	659.67	659.64	19.94	19.66	.	.	.	.	.		
				3	0.21	660.49	660.28	18.59	17.81	0.65	654.65	655.3	18.52	18.82	65	
				4	0.13	660.15	660.28	17.9	16.94	0.23	654.01	654.54	18.54	18.87	66	
				5	0.38	659.94	659.56	19.64	19.67	.	.	.	.	.		
				6	0.37	659.9	659.53	20.05	20.08	.	.	.	.	.		

21	25-30/08/2016	45551	111	1	0.44	659.16	658.73	18.52	18.79	-	-	-	-	-		wheel flange thickness
				2	0.19	658.93	658.74	18.05	18.59	-	-	-	-	-		
				3	0.53	659.83	660.36	17.14	13.11	0.31	636.12	636.43	17.94	17.76	67	
				4	0.56	659.73	660.29	17.26	13.04	0.51	635.31	635.82	17.23	16.99	68	
				5	0.09	659.88	659.79	19.68	20.34	-	-	-	-	-		
				6	0.12	659.79	659.67	21.11	19.99	-	-	-	-	-		
22	05-07/09/2016	54807	110	1	0.22	659.34	659.12	18.71	19.11	-	-	-	-	-		wheel flange thickness
				2	0.23	659.41	659.18	18.86	18.64	-	-	-	-	-		
				3	0.31	659.99	660.31	17.13	14.58	1.1	637.47	636.36	18.33	18.75	69	
				4	0.58	659.8	660.37	17.02	13.09	0.22	636.5	636.28	18.24	18.07	70	
				5	0.5	659.79	659.29	19.71	18.67	-	-	-	-	-		
				6	0.25	659.19	658.95	18.97	18.06	-	-	-	-	-		
23	09-16/09/2016	61474	219	1	0.42	658.83	659.26	13.78	15.73	0.22	632.77	633	18.46	18.34	71	wheel thread scratch & wheel flange thickness
				2	0.11	659.02	658.91	14.12	12.97	0.27	631.54	631.8	17.84	17.87	72	
				3	0.26	659.88	660.15	14.94	14.18	0.96	630.83	630.91	18.84	18.42	73	
				4	0.12	659.95	659.83	14.97	13.22	0.75	631.27	631.42	18.3	17.86	74	
				5	0.52	659.04	659.56	15.01	13.23	0.13	634.26	634.4	17.92	17.96	75	
				6	0.43	658.92	659.36	13.68	12.55	0.19	633.38	633.19	17.94	18.11	76	
24	14-15/11/2016	76430	109	1	0.11	658.81	658.7	18.71	18.59	-	-	-	-	-		wheel flange thickness
				2	0.05	658.86	658.81	19.16	18.28	-	-	-	-	-		
				3	0.49	660.35	659.86	12.45	17.42	0.65	629.45	628.8	17.88	18	77	
				4	0.31	660.17	659.86	13.68	16.42	0.27	629.68	629.41	19.6	19.49	78	
				5	0.19	659.16	658.97	18.65	18.27	-	-	-	-	-		
				6	0.09	658.89	658.8	19.18	18.24	-	-	-	-	-		
25	16-18/11/2016	78624	218	1	0.26	641.85	642.11	13.65	13.97	0.12	618.12	618	18.08	18.17	79	wheel flange thickness
				2	0.12	642.28	642.16	14.71	14.09	0.06	616.53	616.59	20.35	19.53	80	
				3	0.16	612.41	612.25	19.62	19.74	0.16	612.41	612.25	19.62	19.74	81	
				4	0.32	637.64	637.96	13.25	13.07	0.18	609.91	609.73	17.89	18.05	82	
				5	0.04	626.7	626.74	20.9	20.87	0.04	626.7	626.74	20.9	20.87	83	
				6	0.13	647.16	647.03	14.81	14.29	0.11	626.16	626.05	17.99	17.93	84	
26	19to21/11/2016	66522	216	1	0.15	648.92	649.07	16.52	16.1	0.3	623.18	623.48	20	20.09	85	wheel flange thickness
				2	0.07	645.61	645.54	15.96	15.02	0	622.13	622.13	18.46	18.4	86	
				3	0.07	660.03	659.96	17.86	16.84	-	-	-	-	-		
				4	0.15	659.99	659.84	18.15	17.53	-	-	-	-	-		
				5	0.08	647.3	647.22	18.47	16.75	0.05	627.07	627.02	19.69	19.12	87	
				6	0.06	647.24	647.3	16.6	14.75	0.01	625	624.99	18.38	18.36	88	
27	24/11/2016	26848	211	1	-	-	-	-	-	-	-	-	-	-	-	scratch on thread and abnormal wheel flange profile
				2	-	-	-	-	-	-	-	-	-	-	-	
				3	0.06	639.74	639.8	18.86	17.79	0.09	630.25	630.25	19.12	19.3	89	
				4	0.42	634.87	635.29	19.28	18.19	0.2	629.22	629.42	18.16	18.15	90	
				5	-	-	-	-	-	-	-	-	-	-	-	
				6	-	-	-	-	-	-	-	-	-	-	-	

28			217	1	0.06	651.32	651.26	15.26	15.04	0.11	625.02	625.13	19.14	19.36	91	wheel flange thickness
				2	0.01	654.81	654.82	17.26	16.56	0.07	625.34	625.41	20.76	20.74	92	
				3	0.37	640.7	641.07	17.08	16.19	0.02	616.36	616.34	19.46	19.61	93	
				4	0.2	640.46	640.66	14.77	13.67	0.33	614.21	614.54	18.18	18.31	94	
				5	0.36	659.25	659.61	18.39	18.23	0.22	642.37	642.59	20.91	20.84	95	
				6	0.03	659.23	659.26	17.59	15.38	0.14	641.21	641.36	18.53	18.44	96	
29	30/11/2016	69044	115	1	0.37	659.14	658.77	21.41	19.37	-	-	-	-	-		wheel flange thickness
				2	0.06	659.12	659.06	21.15	19.99	-	-	-	-	-		
				3	4.69	635.12	635.91	19.34	15.24	0.32	607.06	607.58	19.63	19.55	97	
				4	0.45	634.9	635.35	18.52	14.09	0.02	605.31	605.33	18.78	18.71	98	
				5	0.23	659.25	659.02	21.45	20.51	-	-	-	-	-		
				6	0.16	658.82	658.66	20.98	19.82	-	-	-	-	-		
30	12/5/2016	57012	220	1	0	659.3	659.3	18.42	17.65	-	-	-	-	-		wheel flange thickness
				2	0.03	659.72	659.3	17.82	16.97	-	-	-	-	-		
				3	0.22	659.89	660.11	17.64	15.57	0	636.33	636.33	19.69	19.83	99	
				4	0.1	659.82	659.92	18.55	18.69	0	636.29	636.29	18.55	18.69	100	
				5	0.33	658.98	659.31	18.23	17.66	-	-	-	-	-		
				6	0.02	659.12	659.1	18.34	16.64	-	-	-	-	-		
31	13-14/12/2016		219	1	0.22	632.52	632.74	20.21	19.32	-	-	-	-	-		scratch on wheel thread
				2	0.23	631.31	631.54	19.67	19.2	-	-	-	-	-		
				3	0.11	630.62	630.73	20.43	19.41	0.07	626.67	626.6	19.34	19.36	101	
				4	0.16	631.11	631.27	19.88	19.85	0.04	628.28	628.32	19.42	19.48	102	
				5	0.02	634.04	634.02	19.75	18.92	-	-	-	-	-		
				6	0.45	633.21	632.76	19.45	19.17	-	-	-	-	-		
32	15-20/12/2016	52732	108	1	0.43	659.65	659.23	21.29	20.63	0.01	653.12	653.13	21.54	21.61	103	scratch on wheel thread
				2	0.04	659.25	659.29	20.87	19.87	0.12	653.12	653.24	20.67	20.74	104	
				3	0.73	654.36	655.09	18.78	18.65	-	-	-	-	-		
				4	0.43	653.65	654.04	18.6	18.04	-	-	-	-	-		
				5	0.32	659.5	659.18	20.71	19.97	-	-	-	-	-		
				6	0.31	659.48	659.17	20.98	20.43	-	-	-	-	-		
33	22-28/12/2016	75028	206	1	0.07	648.45	648.52	17.08	16.77	0.02	625.49	625.48	20.46	20.34	105	wheel flange thickness
				2	0.06	647.39	647.45	16.57	15.74	0.05	623.99	623.93	19.81	19.69	106	
				3	0.15	638.77	638.92	15.41	15.38	0.23	615.7	615.47	19.21	19.21	107	
				4	0.23	637.33	637.56	14.6	14.34	0.02	615.31	615.29	18.44	18.28	108	
				5	0.14	652.58	652.72	16.52	16.09	0.0.15	625.91	626.06	20.72	20.44	109	
				6	0.23	652.36	652.59	16.07	15.47	0.33	625.06	624.73	19.94	19.91	110	
	>>> flange increase indicates the value added on list flange thickness															
	>>> diameter reduction indicates the total amount lathed from pre-measured diameter size															
	>>> factor of diameter reduction the amount of diameter reduction for unit increase or flange thickness															
	>>> pre-measurement refers the measurement before lathing															
	>>> post-measurement refers the measurement after lathing															
	>>> "-" refers wheels those not lathed															

C: Vehicle specification in AALRT

empty load)	≤900 mm
轴距（动力转向架）	1900 mm
Wheelbase (power bogie)	1900 mm
轴距（非动力转向架）	1800 mm
Wheelbase (unpowered bogie)	1800 mm
客室内净高：	≥1980 mm
Clear height of passenger compartment	≥1980 mm
轮径（新轮）	≤660 mm
Wheel diameter (new wheel)	≤660 mm,580 mm minimum,15mm
轮径（最大磨耗轮）	≤600 mm
Wheel diameter (Max. wear)	≤600 mm
客室侧门：	每侧 4 对
Side doors of passenger compartment	four pairs per side
客室门净开度(宽×高)：	≥1300×1860 mm

车辆载客能力 **Rated passenger capacity of vehicles**

乘客数量（人） Number of passengers (persons)	坐席 Seated	站席 Standing	合计 Total
座 席（AW1） Seats (AW1)	65	0	65
定员载客（AW2）（站席 6 人/m2） Rated passenger capacity (AW2) (standing: 6 persons/m2)	65	189	254
超员载客（AW3）（站席 8 人/m2） Overload capacity (AW3)(standing: 8 persons/m2)	65	252	317

D: Chemical compostion test result for exsting wheel

HIBRET MANUFACTURING AND MACHINE BUILDING INDUSTRY

Chemical composition Laboratory Test Result Form

Date: 26/06/10

Requested by: lioul fenta

Sample type: STEEL

Purpose: composition test

	Sample Name	Chemical composition									
		C	Si	Mn	P	S	Cr	Mo	Ni	V	Fe
	Steel ring	0.50	0.25	0.7	0.05	0.05	0.02	0.001	0.005	0.002	98.404

Prepared by: Diribe

Sign:

Date: 26/06/10

Checked by: Alemitu

Sign:

Date: 26/06/10

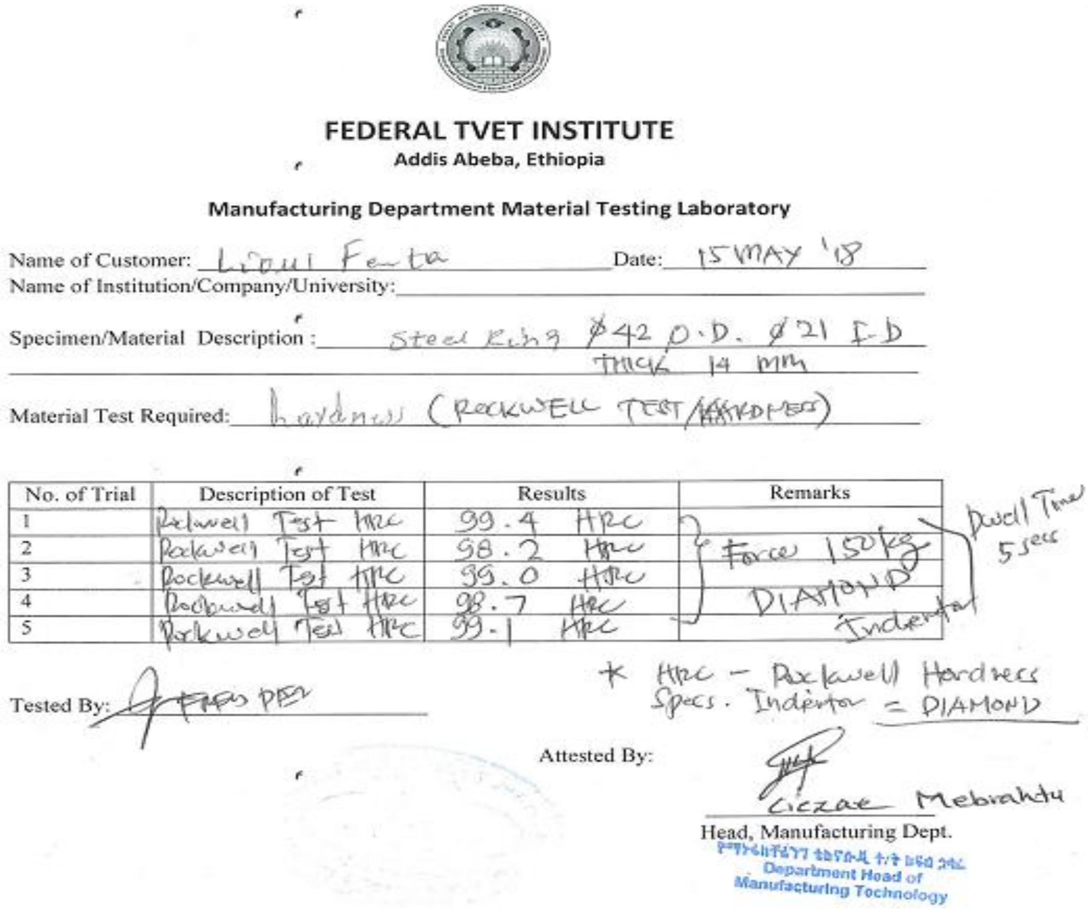
Appr

Sign:

Date:

Metals & ... * Hibret Manufactur...

E: Hardness test result for exsting wheel


FEDERAL TVET INSTITUTE
Addis Abeba, Ethiopia

Manufacturing Department Material Testing Laboratory

Name of Customer: Lioul Fenta Date: 15 MAY '18
Name of Institution/Company/University:

Specimen/Material Description: Steel Ring Ø42 O.D. Ø21 I.D THICK 14 mm

Material Test Required: hardness (ROCKWELL TEST/HARDNESS)

No. of Trial	Description of Test	Results	Remarks
1	Rockwell Test HRC	99.4 HRC	Force 150kg, DIAMOND Indentor
2	Rockwell Test HRC	98.2 HRC	
3	Rockwell Test HRC	99.0 HRC	
4	Rockwell Test HRC	98.7 HRC	
5	Rockwell Test HRC	99.1 HRC	

Dwell Time 5 secs

Tested By: [signature]

* HRC – Rockwell Hardness
Specs. Indentor = DIAMOND

Attested By:
Ciezae Mebrahtu
Head, Manufacturing Dept.
Department Head of Manufacturing Technology

F: Hardness test result for alloyed wheel

FEDERAL TVET INSTITUTE
Addis Abeba, Ethiopia

Manufacturing Department Material Testing Laboratory

Name of Customer: Liaul Fenta Date: 5/16 /2018
Name of Institution/Company/University:

Specimen/Material Description: heith manganiz steel

Material Test Required: Hardness test

No. of Trial	Description of Test	Results	Remarks
1	Rockwell test HRc	99.9 HRc	force 150kg
2	" HRc	99.7 HRc	
3	" HRc	100 HRc	Diamond
4	" HRc	99.1 HRc	Indenter
5	" HRc	99.7 HRc	

Dwell time 5sec

Tested By: PEV

Attested By:

Head, Manufacturing Dept.

G: Ring compressin test

ECAE ኢተምድ	የኢትዮጵያ የተስማሚነት ምዘና ድርጅት Ethiopian Conformity Assessment Enterprise	Document No TLD/F5.10-1	
		Copy No -	Rev No 1
Title:	TEST REPORT ይህ የናሙና ፍተሻ ሪፖርት እንጂ ሰርተፍኬት አይደለም	Page No 1 of 1	Effective Date 1Jan 13

Report No: MTR/2068/18
Test order No: ---

1	Name and address of client	Lioul Fenta Tel: +251-918-29-38-94, Adama
2	Date and place of sampling	Not specified
3	Sampled and submitted by	Client
4	Date sample received	27/06/18
5	Client's sample code	-
6	Laboratory designated sample No.	10290004
7	Type of sample	Steel ring (42*21*14) mm
8	Test method	As per clients agreements
9	Test date(s)	27/06/18
10	Date of Submission of test report	27/06/18

Test result

L.D.S No.	Ser No.	Test Condition	Force(KN)			Dimension change (mm)		
			Force 1	Force 2	Force 3	External Diameter	Internal Diameter	Thickness
1029004	1	Dry	1500	2700	3040	48.1,59.9,60.2	19.85, 17.2,15.3	11.4,7.86,5.71
	2	Oil	1500	2700	2900	48.26,59.20,59.24	19.51,15.89,16.63	9.66,5.70,5.64
	3	Grease	1500	2700	3010	48.1,59.9,60.2	19.85,17.2,15.7	11.4,7.86,5.71

Remark:-

1. This test report relates only to the specific sample product which has been tested by ECAE Testing Laboratory.

Test report authorized by, Name Yohannes Kedir Position Analyst Sign.

✉ 11145 ☎ 011 6 46-05-69, Fax. 011 6 45-97-20, E-mail info-cs@eca-e.com Web site: www.eca-e.com
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ADDISABABA, ETHIOPIA