ADDIS ABABA UNIVERSITY ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF MULTIDECIPLINARY ENGINEERING GRADUATE PROGRAM IN RAILWAY ENGINEERING

Wear Analysis on Track Braking System using FEM

By

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(Railway Stream)

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DECLARATION

I, the undersigned, declare "Wear Analysis on Track braking systemUsing Finite Element Method" is original work of mine and has not been presented for any degree in any university and all the sources of materials used for the thesis have been duly acknowledged.

Kaltoun Mohamed Mahamoud__________________   __________________

Name   Signature   Date

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ABSTRACT

Electromagnetic rail brake (also called magnetic track brake) is a kind of contact friction braking, basing on the track /rail adhesion.

The main purpose of this study is to analyze the wear of the dry contact between rail shoes/rail of the AA-LRT train during emergency braking. CATIA software was used for the modeling purpose. The analysis in this thesis used both numerical and analytical method. The numerical analysis is used to determine the amount of wear. The thermal analysis of the track brake was carried out using ANSIS workbench. In this work, a transient thermal and structural analysis was carried out to investigate the temperature variation on the pad area, total heat flux using ANSYS software. The thermal-structural analysis is then used to determine the stresses established in the rail shoes area.

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Nomenclature

C_p= specific heat

Pr=Prandtl number

Re=Reynolds number

A_d=contact swept area

C_{pa}=specific heat capacity

μ_{Va} =dynamic viscosity

h=convective surface heat transfer coefficient

Q= heat flux

V =wear volume

K=wear coefficient related to the material

W=normal force

H=hardness of the material

μ=friction coefficient

V_{TV}= maximal vehicle speed

L=contact length

k=thermal conductivity

S= sliding distance

t=thickness

t_b =braking time

CHAPTER I. INTRODUCTION

1.1 Background

Train braking is a very complex process, specific to rail vehicles and of great importance by the essential contribution on the safety of the traffic. This complexity results from the fact that during braking occur numerous phenomena of different kinds - mechanical, thermal, pneumatic, electrical, etc. The actions of these processes take place in various points of the vehicles and act on different parts of the train, with varying intensities. The major problem is that all must favorably interact for the intended scope, to provide efficient, correct and safe braking actions.

The purpose of braking action is to perform controlled reduction in velocity of the train, either to reach a certain lower speed or to stop to a fixed point. In general terms, this happens by converting the kinetic energy of the train and the potential one - in case of circulation on slopes - into mechanical work of braking forces which usually turns into heat, which dissipates into the environment.

At first, the rather low locomotives power and traction force allowed braking using quite simple handbrakes that equipped locomotives and eventually other vehicles of the train. As the development of rail transport and according to increasing traffic speeds, tonnages and length of trains, it was found that braking has to be centralized, operated from a single location - usually the locomotive driver's cabin and commands have to be correctly transmitted along the entire length of the train.

As a consequence, along the time, for railway vehicles have been developed various brake systems, whose construction, design and operation depend on many factors such as running speed, axle load, type, construction and technical characteristics of vehicles, traffic conditions, etc.

Among various principles and constructive solutions that were developed, following the studies and especially the results of numerous tests, the indirect compressed air brake system proved to have the most important advantages. Therefore, it was generalized and remains even nowadays the basic and compulsory system for rail vehicles.

The braking effort achievable was limited, and an early development was the application of a steam brake to locomotives, where boiler pressure could be applied to brake blocks on the locomotive wheels. However, it was also unreliable, as the application of brakes by guards depended upon them hearing and responding quickly to a whistle for brakes. [22]

Brakes have been retuned and improved ever since their invention. The increases in travelling speeds as well as the growing weights of cars have made these improvements essential. The faster a rail car goes and the heavier it is, the harder it is to stop. An effective braking system is needed to accomplish this task with challenging term where material need to be lighter than before and performance of the brakes must be improved.[23]

During braking the energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated into the surround atmosphere to stop the rail vehicle, so the brake system should have the following requirements.

- The brakes must be strong enough to stop the vehicle with in a minimum distance in an emergency.
- The driver must have proper control over the vehicle during braking and the vehicle must not skid.
- The brakes must have well anti fade characteristics i.e. their effectiveness should not decrease with constant prolonged application.
- The brakes should have well anti wear properties.

The electromagnetic brakes is one type of operation brake by which according to the direction of acting force may be sub divided.

The force which slowing down or stopping the train, keeping the train speed stability making the train stopped in place even on the slopes is known as brake. The way using electromagnetic effect for braking, is known as the electromagnetic brake. Electromagnetic rail brake (also called magnetic track brake) is a kind of contact friction braking, basing on the track /rail adhesion. The electromagnetic force sucks the magnetic track brake which mounted on bogie and rail. Through the device at the bottom of the magnetic rail wear, the sliding friction between the plate and rails, train the kinetic energy into heat energy and make it escape into the atmosphere, so as to realize the train slowing down or stop.

1.1.1 Track brake

Design and operation of the track brake correspond to an electromagnet. The magnet coil is the essential part of the track brake. When the coil is energized a magnetic field is created. Coil core, flanges and rail shoes are magnetized this way. The rail shoes are the two poles of the magnet system. The air gap between the rail shoes closes the magnetic circuit (observe the magnetic field lines in the figure).When the track brake is located at an adequate distance between the lower edge of the rail shoe and the upper edge of the rail the track brake is pulled on the rail by its own magnetic force (against the low spring force of the two suspensions). Therefore, the rail forms a kind anchor which replaces the air gap of the magnetic circuit and short-circuits it.

When the air gap between rail shoe and rail is small enough, a force of attraction which is usually designated as adhesive force is created. The braking effect is caused by the friction of the rail shoes on the rail; the adhesive force represents a measure for the braking force. The braking force of the track brake is transferred to the bogie and thus to the vehicle via the carriers. The track brake is attached to the bogie in a vertically spring-mounted way. As soon as the track brake is de-energized, the two suspensions of the track brake are lifted from the rail against their residual magnetism and bring the brake back into its initial position.

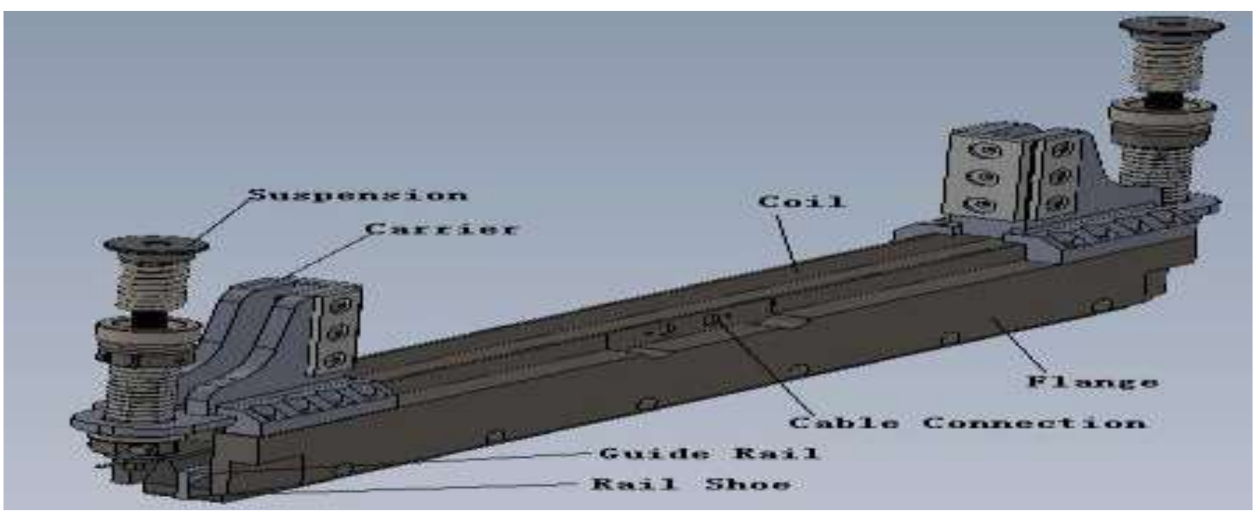


Figure1. Track brake structure

1.1.2 Wear on track

Wear is a process of gradual removal of a material from surfaces of solids subject to contact and sliding. Damages of contact surfaces are results of wear. They can have various patterns (***abrasion, fatigue, ploughing, corrugation, erosion and cavitation***). The results of abrasive wear are identified as irreversible changes in body contours and as evolutions of gaps between contacting solids. The wear depth profile of a surface is a useful measure of the removed material. The definition of the gap between contacting bodies takes into account deformations of bodies and evolutions of wear profiles. The wear depth can be estimated with the aid of wear laws. Derived in this study, constitutive equations of anisotropic wear are extensions of the Archard law of wear. The equations describe abrasion of materials with microstructures.

However a separation or cutting of rail due to friction and abnormal heavy load is called wear. There are three types of wears of rail

1.2 Statement of problem

The track brake is used for emergency case in case of LRT. After many years of services when the train brake system becomes old, the braking performance will decrease or becomes failed. Then the using of track braking will be increased so the contact between the track brake and rail will occur. Hence the wear of the track brake increases due to frequent uses of the track brake system.

The friction forces generated during braking between pad and rail produces high thermal forces on the frictional surfaces such as wear and that causes a braking problem such as wear.

The consequences of this situation will be analyzed and the life time of the track braking system should be predicted in order to make the spaces ready for next service. This study will analyze the wear of track brake and predict the life of the track brake.

1.3 Purpose and scope of this work

1.3.1 General objectives

The main objective of this thesis is to provide a depth study for analyzing the wear of track braking system in AALRT caused by emergency braking action.

1.3.2 Specific objectives

- Study the track brake system in rail vehicle
- To determine the type of wear existing in track brakes
- Modeling track brake using CATIA software
- Analyze the wear using FEM
- To predict the life time of the track braking system

1.3.3 Scope of this thesis

- The researches mainly focus on the wear analysis using finite element method.
- Wear analysis of surface of the rail shoes
- Wear simulation using finite element method
- Rail surface and simulation of heat flux on contact area
- Life time prediction of whole track braking system

1.3.4 Limitation

In this research delimitation are following:

- Experimental analysis of wear track is not possible because lack of materials laboratory
- Experimental measurement of wear doesn't take in this study due to the absence of the material required

1.4. Organization of the paper

This thesis contains five chapters presenting the research study. The content of each chapter is outlined below: Chapter one outlines general information about the research conducted. The background, statement of problem, the general and specific objectives of the research and the scope and limitation are stated out. Chapter two covers the review of journals, articles, proceedings and publications which were referred during the work of the thesis. Chapter three discuss about the material, calculation and modeling of the track brake. Chapter four the results obtained from ANSYS transient thermal and structural analysis of the track brake system results discussion based on these results are included. Chapter five covers conclusions drawn based on the outcome of the analysis, and recommendations for future application. In addition; there are list of points that help to continue the research on the same topic for future work.

1.5. SIGNIFICANCE OF THE RESEARCH

This work shows the wear analysis in a track brake of a rail vehicle during braking. As the brakes slow the vehicle, they transform its kinetic energy into thermal energy, resulting in intense heating of the rail shoes. If the rail shoes overheat, it stops working and, in a worst-case scenario, can melt. In order to protect this problem this thesis gives information on the wear behavioral approach and life time analysis.

1.6. Research Methodology

To fulfill the objectives of the study the following methodology is used:

I. Survey of books, journal articles, proceedings of international conferences, auto manufacturer catalogues, and other relevant literature is done.

II. Data Collection, data regarding the track brake of locomotive vehicle is collected from journals and ERC.

III. Modeling: The finite element model development as well as the corresponding thermal and stress analysis is performed using ANSYS software

.IV. Conclusions, Recommendations and future work.

CHAPTER II. LITERATURE REVIEW

2.1 wear

Wear can be defined as damage to a solid surface, generally involving progressive loss of material, due to relative motion between the surface and a contacting substance or substances. It is an undesired case for machines or mechanisms. Therefore, all over the time, it is tried to be prevented. **[18]**

Wear takes place when surfaces of mechanical components contact each other. The investigated question is, how much of the material will be lost during the given operation time. Wear and plastic deformation cause surface profiles change and pressure distribution is strongly depended on the phenomena. There can be many causes for wear. First of all, it is caused by material fracture under stresses in the process of friction. This widespread type of wear is classified as mechanical wear and is often taken to be a synonym of the word "wear". Among other wear causes, chemical reactions and electrochemical processes can be mentioned. Corrosive wear is an example of this type of surface fracture. It is the main wear mechanism in moving components, operating in a chemically aggressive environment.

Some physical processes can also cause wear. For example, it is known that almost all of the energy dissipated in friction is converted into heat. An increase of the surface layer temperature can change the aggregate state of the material. In such a case the wear is provided because of melting and flowing of the melt out of the interface (ablation wear) or because of evaporation (breaks, high speed guides, plane wheels, etc.). High temperature accelerates diffusion processes which can influence wear in some cases (cutting tools). For these cases, wear occurs at the atomic and molecular levels.

The most important thing about wear is to know that "Wear is not a material property, it is a system response" **[19]**. Therefore there are lots of system parameters to distinguish wear. These parameters can be seen on Table 2-1**[20]**.

Table 2.1 parameter affecting wear

Wear parameters		
Operating parameters	*Material parameters*	*Environmental parameters*
Contact pressure	Hardness, Yield and ultimate tensile strenght	Relative humidity
Sliding speed	Toughness	Heat radiation leve
Sliding distance	Braking distance	
Surface temperature	Thermal conductivity	
Surface finish	Electrochemical potential	
Type of contact	adhesion	

2.1.1 Different types of wear

Wear is described by the material removal mechanisms which are so called wear types. In different applications different types of wear can be dominant. However, generally, there is not only one type wear, but combinations of wear mechanisms are generated together.

It is common to differentiate the following fundamental types of wear according to their physical mechanisms:

• **Abrasive wear** occurs, if two bodies with distinctively different hardness are in contact or the third body contains hard particles

• **Adhesive wear** occurs even in contacts with the same or similar materials as this study

• **Corrosive wear** is associated with chemical modifications of the surface and finally removal of the surface layer

• **Surface fatigue** is caused by repeated loading of the surface either by sliding or rolling, where in every single loading cycle, no noticeable changes in the surface stresses appear **[19]**.

2.1.2 Abrasive wear

For existing abrasive wear, there should be a weaker material. Therefore, this type of wear is commonly seen in manufacturing processes such as milling, honing, etc. During abrasive wear, asperities of harder material penetrate and micro-cut the softer material as shown in Figure 9. In this study there is two steel material contact.

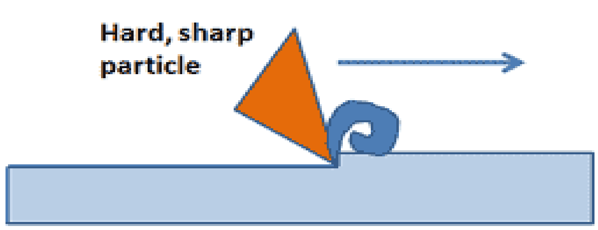


Figure2.1.Abrasive wear mechanism

In order to estimate wear volume in abrasive wear, Archard Wear Equation is used:

$$v = k_{\underline{ab}} \times \frac{w \times s}{H}$$

Where:

V: wear volume (mm3)

k_{ab}: wear coefficient for abrasive wear (dimensionless)

w: normal load (N)

s: sliding distance (mm)

H: hardness value of softer material (MPa)

2.1.3 Fatigue wear

The results of many experiments show that most of the failures are caused by fatigue. For abrasive or adhesive wear, there is no need to be repeated cycles of contact.

However, fatigue wear occurs in cycling loading conditions as in study the repeated using of track brake.

When the number of contact cycles is high, the high-cycle fatigue mechanism is expected to be the wear mechanism. When it is low, low-cycle fatigue mechanism is expected.

It is known that in elastic contact case of rolling elements, the main wear mechanism is high-cycle fatigue [20].

2.2 Track brake system

A track brake magnet is basically an electromagnet or solenoid. It consists of a coil which is wound around an iron core generating a magnetic field when direct current is applied. Soft-iron parts attached to the magnet rule how the magnetic lines of force close about the rail head (see Figure 1

Air gaps between iron parts that carry the magnetic lines of force diminish the magnetic brake force. The largest air gap occurs at the point of contact between the pole shoes and the rails.

The magnetic flux in the brake magnet is generated by the magnetic field of a DC coil. The coil must be suited to the harsh railway environment and withstand all kinds of exposure. It is therefore wound into a box-shaped steel bobbin which is welded up afterwards on all sides.

The magnitude of the magnetic force is ruled by the area of contact between the pole shoes and the rail, and by the number of magnetic lines per square centimeter of contact area.

Given the rail width, the magnitude of the magnetic force is therefore directly dependent on the length of the magnet.

Since the magnetic track brake is usually installed between two wheels of a bogie, the wheelbase and the wheel diameter govern the size of the magnet that will fit there; this in turn rules the magnitude of the brake force

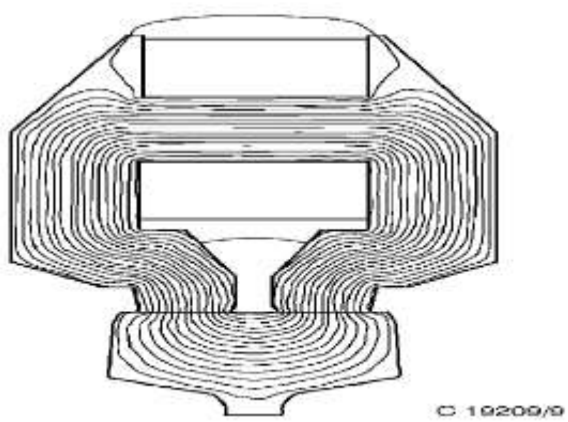
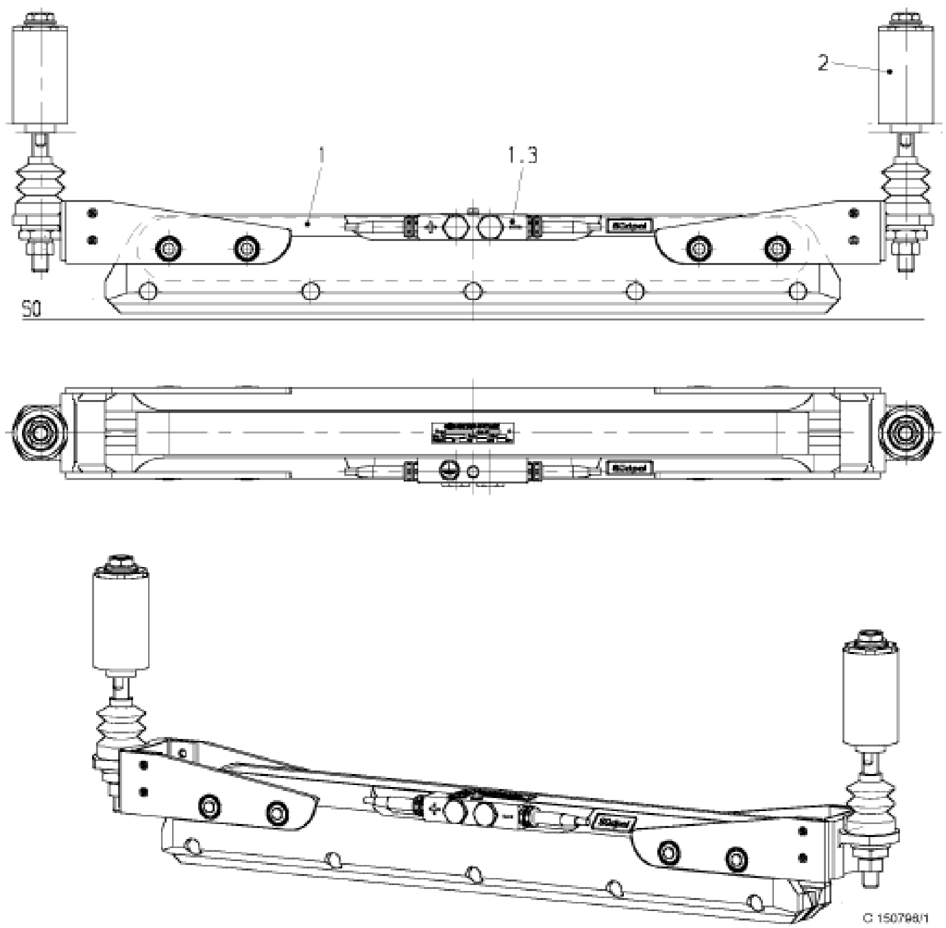


Figure 2.2.Magnetic lines of forces represented symbolically

2.2.1 Working principle of track brake

Once activated, a magnetic track brake is pressed onto the rails by its own magnetic pull. Transmission links fixed in place on the bogie draw the brake magnet over the top of the rail in the running direction.

The braking power is exerted as the kinetic energy of the moving vehicle is gradually transformed and consumed by the magnets which are connected to the rails by the force of the magnetic field. The brake magnets exert an adhesive force of 66 kN ±5%.



1 magnet 1.3 cable connection 2 compression spring suspender

Figure 2.3. Magnetic track brake

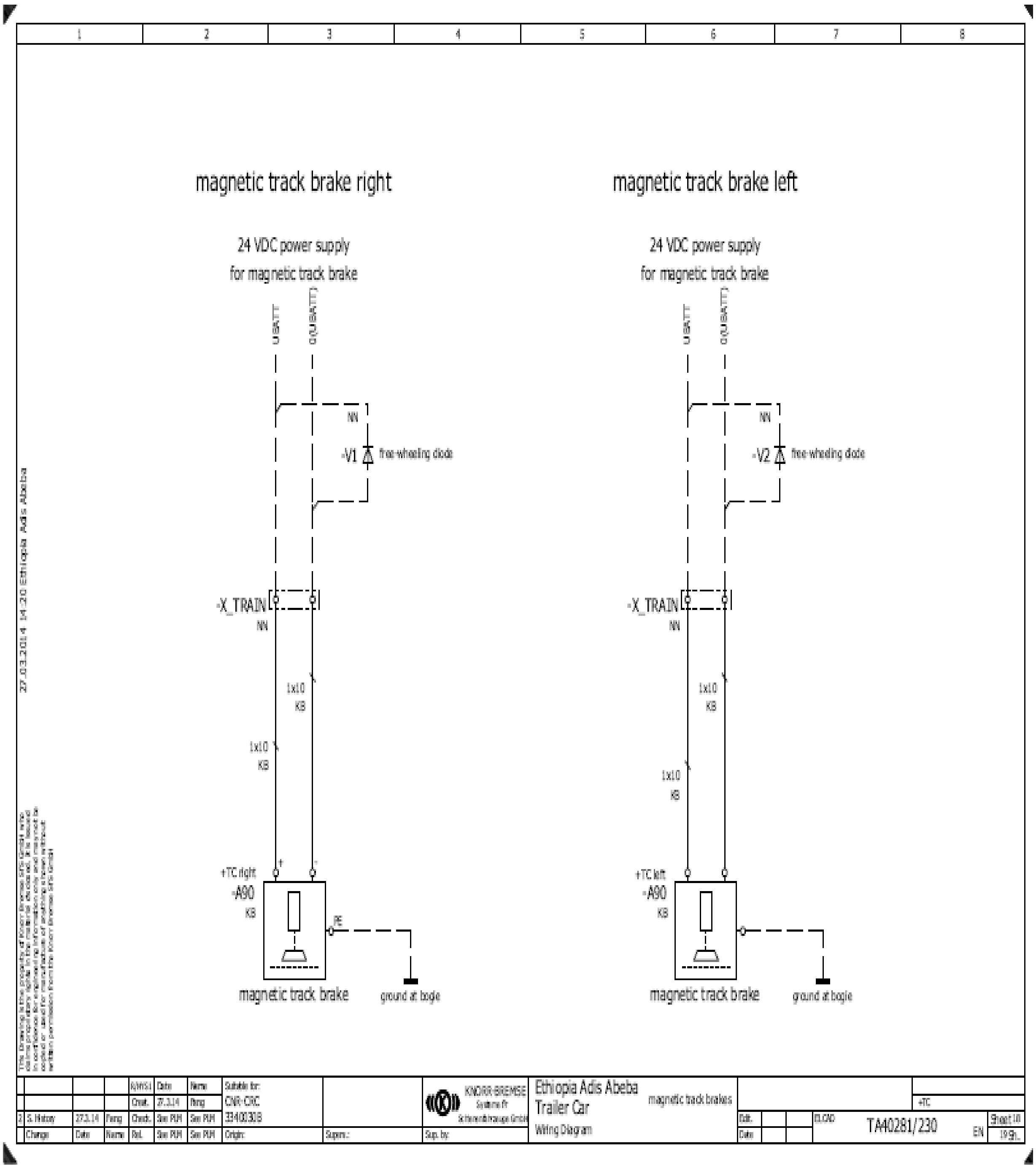


Figure2.4. Electrical drawing parts of magnetic track brake [17]

2.3 Related papers

A series of small-scale laboratory experiments has been carried out in which crushed granite ballast is fed into a rolling–sliding contact. The operation of railway track is likely to involve the presence of solid contaminants on the line at some stage. This may be from the dispersion of freight goods such as coal or minerals, or the presence of ballast stone thrown on to the track either by the passage of the train or during ballast cleaning operations.

A twin-disc testing machine was used to investigate the wear of rail and wheel steel materials during rolling–sliding behavior. The machine was used to simulate the wheel–rail rolling–sliding conditions. Wear debris was collected and weighed and later examined using a scanning electron microscope.

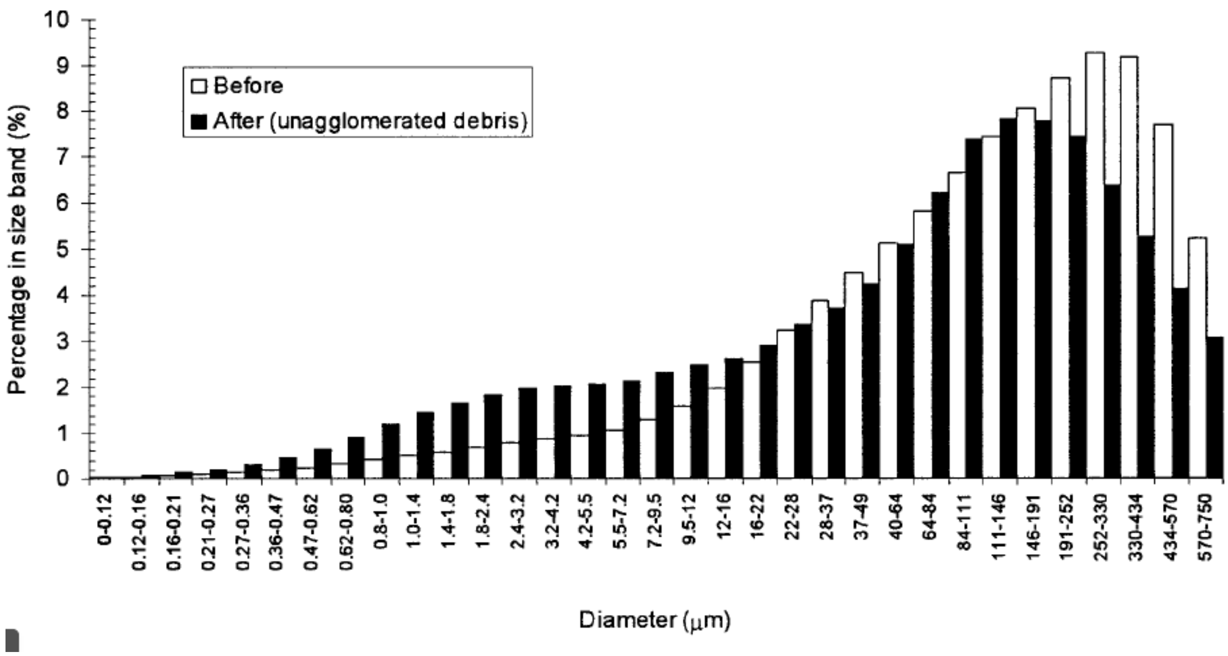


Figure2.5.wear measurement using scanning electron microscope

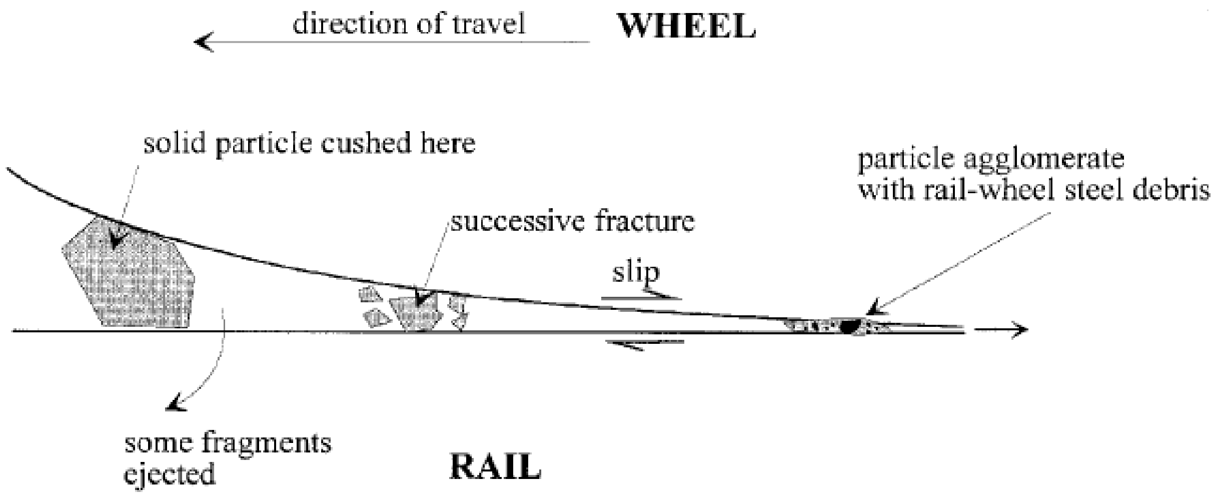


Figure2.6.Removal particles of the contact

All this evidence seems to support the theory that hard contaminants entering a rolling–sliding contact are crushed and then embedded into the softer surface (the wheel disc), thus gouging the harder surface (the rail disc). Agglomeration of the particles and resulting wear debris occurred in the contact. However, to complicate the process further, some surface cracking appears to have occurred **[1].**

The railway section are especially exposed to the abrasive or fatigue wear and the changes of shape as a result of dynamic loads action of cyclical nature, occurring when the track vehicles ride through the switch .The process of a mechanic destruction of the upper layer leads to the undesired change of dimensions and shape of the contacting rolling surfaces of a switch element and a railway wheel. Tribological tests were performed with the application of friction couples interacting in real conditions. The material for the specimens was R260 steel with diverse pearlite morphologyP60 steel was used as a counter-specimen. This type of steel is commonly used in rail wheel rings so its application increased the credibility of R260 steel wear results. The lowering of an annealing temperature results in the increase of tensile strength **[2].**

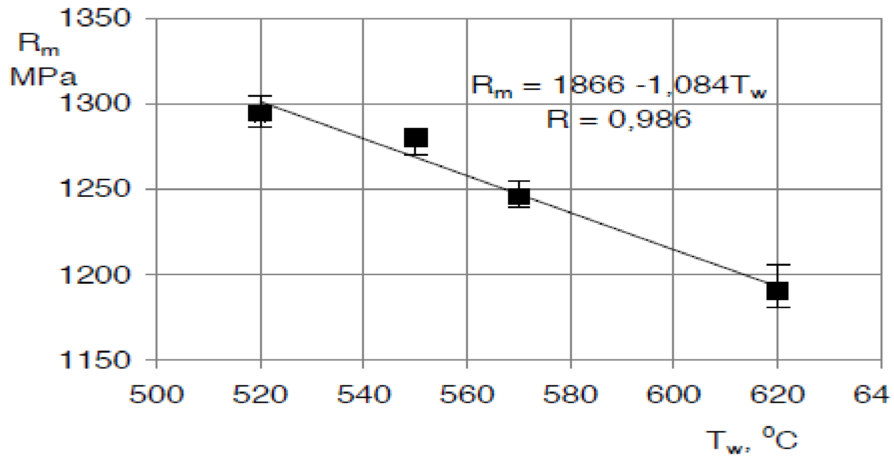


Figure2.7.Tensile strength relatively with temperature

The steel after hot-rolling (lt=0.28 m) was characterized by the lowest resistance to abrasive wear, demonstrating the highest wear for the tested values of pressure. The abrasive wear of rail steel is the more intensive, the larger load at a constant slide is.

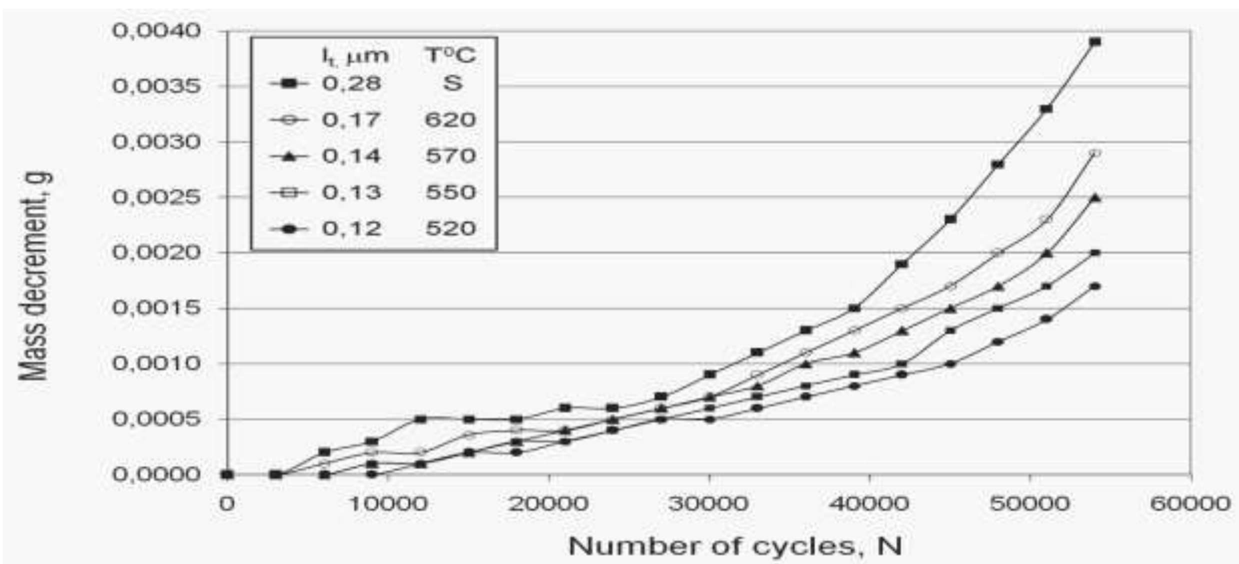


Figure2.8- Number of cycle's relative with the mass decrement

Wear depth is used as a surrogate term for abrasion, or the inverse of abrasion resistance. As the wear curves shift downward on the graph, the mix design shows higher abrasion resistance based on SSART testing. Table 1 summarizes the percentage change in abrasion resistance of various specimen types relative to control specimens **[3].**

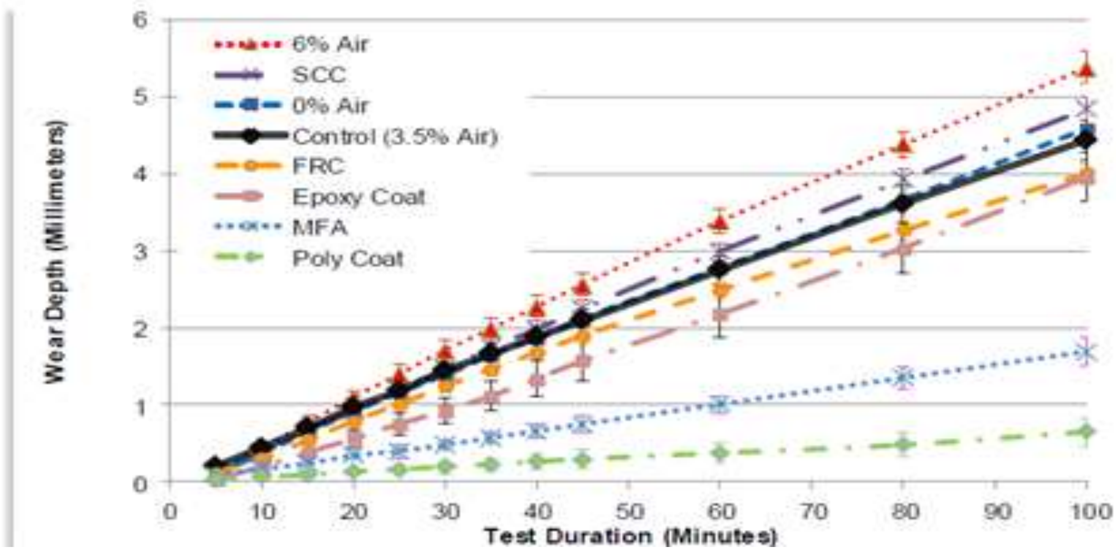


Figure2.9-Time test relative with wear depth

Transient thermal analyses determine temperatures and other thermal quantities that vary over time. The variation of temperature distribution over time is of interest in many applications such as cooling of electronic packages or quenching analysis for heat treatment. Also of interest are the temperature distribution results in thermal stresses that can cause failure. In such cases, the temperatures from a transient thermal analysis are used as inputs to a structural analysis for thermal stress evaluations. Thermal analysis is the primary stage in the study of braking systems, because the temperature determines the thermomechanical behavior of the structure. In the braking phase, kinetic energy transforms into thermal energy, resulting in intense heating of the railway wheel. This generates stresses and deformations, whose consequences are manifested by the appearance and the accentuation of cracks on treads of wheel, and eventually fractures of the whole wheel.

The coefficient of friction has significant effects on the form of the thermal field, as well as on temperature distribution. The existing models for the estimation of the amount of the heat generated during friction processes assume that the energy delivered to bodies in the frictional (or Tribological) contact transforms into heat only due to the friction losses on contact surfaces **[4].**

A railway wheel rolling along a rail gives rise to high surface stresses in the generally elliptical contact area between wheel and rail. Besides the vertical stress component, traction load locally produces additional transverse stresses beneath the wheel tread and the running surface of the rail respectively. Such stresses lead to local plastic deformations of the materials in the surface area if the yield strength of the rail steel is exceeded. Recurrent plastic deformation of the rail surface induces residual compressive forces. Plastic deformation causes strain hardening to occur on the surface, moreover, that leads to the yield strength being raised locally. As a result, the material is initially able to absorb further strains by purely elastic means. This is a precondition for the materials being able to withstand such high stresses in the contact area. Recurrent loading cycles on the rail produces cumulative plastic deformations (ratcheting) as a function of the vertical stress exerted and the friction coefficient. Once the limit of strain hardening (critical deformation) is achieved and adhesive wear on the rail surface is low relative to the degree of ratcheting, cracks form on the surface. These may subsequently lead to flaking or spalling. To prevent this occurring, the cracks can be removed through grinding (artificial wear) [1, 2]. As well as needing to have a sufficient strength, the rail material also has to deliver high resistance to wear whilst also being sufficiently tough if the danger of brittle fracture is to be avoided especially when there are cracks in the rail **[5].**

Figure2.10-Material loss relatively with the pairing material

Steel wheels rolling on steel rails are the principal characteristic that distinguishes railways from other forms of transport. Wheel and rail meet at a contact patch that is small and carries the full wheel load through which all steering, traction, and braking forces are transmitted. This contact patch sees a severe working environment. Stresses normal to the plane of contact can reach values several times the wheel or rail tensile strength, and sometimes shear stresses in the plane of contact can exceed the shear yield stress. Rapid temperature rises, caused by relative slip between the wheel and rail, can reach several hundred degrees Celsius in routine operation, and over 1000°C in extreme circumstances.

These stress and temperature conditions inevitably lead to wear, deformation, and damage to the wheels and rails; and a major goal of railroads is to arrange service conditions and maintenance procedures to minimize deterioration and hence extend component life. This is important because rails — and to a lesser extent wheels — constitute a large part of a railroad's asset base **[6].**

The finite element method (FEM) is a numerical technique for solving problems which are described by partial differential equations or can be formulated as functional minimization. A domain of interest is represented as an assembly of finite elements. Approximating functions in finite elements are determined in terms of nodal values of a physical field which is sought. A continuous physical problem is transformed into a discretized finite element problem with unknown nodal values. For a linear problem a system of linear algebraic equations should be solved. Values inside finite elements can be recovered using nodal values. Two features of the FEM are worth to be mentioned:

- Piece-wise approximation of physical fields on finite elements provides good precision even with simple approximating functions (increasing the number of elements we can achieve any precision).
- Locality of approximation leads to sparse equation systems for a discretized problem. This helps to solve problems with very large number of nodal unknowns.

For a mechanical problem like our case, let us consider a three-dimensional elastic body subjected to surface and body forces and temperature field. In addition, displacements are specified on some surface area. For given geometry of the body, applied loads, displacement boundary conditions, temperature field and material stress-strain law, it is necessary to determine the displacement field for the body **[7].**

The friction between the wheels and rail is extremely important as it plays a major role in the wheel – rail interface process such as adhesion, wear, rolling contact fatigue, and noise generation. Effective control of friction through the application of friction modifiers to the wheel – rail contact is therefore clearly advantageous, although the process has to be carefully managed. The aim of friction management is to maintain friction levels in the wheel – rail contact to give:

- Low friction in the wheel flange – rail gauge corner contact.
- Intermediate friction wheel tread-rail top contact (especially for freight trucks).
- High friction at the wheel tread-rail top contact for locomotives (especially where adhesion loss problems occur).

Loss of friction or adhesion between the wheel and rail is particularly important as this has implications for both braking and traction. Poor adhesion in braking is a safety issue as it leads to extended stopping distances, and also in traction as it may lead to reduced acceleration which will increase the risk of a rear collision from a following train. In traction, however, it is also a performance issue. If a train experiences poor adhesion when pulling away from a station and a delay is enforced, the train operator will incur costs. Similar delays will occur if a train passes over areas of poor adhesion while in service **[8].**

- Table 2.3: Wear coefficient of the different material. **[23]**

Table 1: K values for various materials

Material	K
Mild steel (on mild steel)	7×10^{-3}
α- / β-brass[N 1]	6×10^{-4}
PTFE	2.5×10^{-5}
Copper-beryllium	3.7×10^{-5}
Hard tool steel	1.3×10^{-4}
Ferritic stainless steel	1.7×10^{-5}
Polythene	1.3×10^{-7}
PMMA	7×10^{-6}

2.3.1 Summary

Wear is a major risk at all mechanical contact. The rolling, sliding and friction between wheel/rail or track brake causes a critical damage of abrasive wear.

All of these researchers are focused only on wear on wheel/rail but the wear causes a cost problem on whole railway as an electromagnetic brake. These papers done only the numerical analysis parts or experimental parts that is not enough to improve the influenced parameters of wear on this area.

Most freight trains use track brakes, where the energy dissipation is generated with the friction on track breaking. It is a simple method that avoids the use of more complex systems but the friction generates wear which influences directly the evolution of the track brake. Moreover, novel braking materials which reduce noise generation seem to cause more wear. These braking systems are becoming mandatory following noise reduction policies, but their impact on wear has not been investigated deep enough. The braking action of a magnetic rail brake is due to the adhesion force between the brake and the rail, not the wheel and the rail. The adhesion force appears when the brake is attracted to the rail. The friction caused by that adhesion causes an abrasive wear.

CHAPTER III. NUMERICAL ANALYSIS OF WEAR AND MODELING OF TRACK BRAKE

3.1 Introduction

Any component with to the braking motion is subjected to surface contact due to the loading, friction and thermal effect on the contact zone. Those applied load and relative motion cause removal material or abrasive wear. Wear analysis mostly used by experimental procedure in order to analyze the material loosed relatively with the time. In this research a software simulation of wear analysis will do. The FEM is a common simulation method to analyze wear model Using ABAQUS or ANSYS.

3.2. Analytical method and condition

3.2.1 Dimension

Most freight trains use block brakes, where the energy dissipation is generated with the friction on the contact zone. The magnetic contact to the rail is made by the rail shoes which also serve as friction lining. These braking systems are becoming mandatory following noise reduction policies, but their impact on wear has not been investigated deep enough.

Table 3.2.1: Standard Dimension

(Source: Ethiopia Railway Corporation, Technical specification of vehicle)

Part name	Standard	Material	Dimension
Track brake	EFI core iron	Soft iron	F=66 Kn
Rail	UIC60 900A	Low carbon steel	L=25m

3.2.2 Material selection

A track brake magnet is basically an electromagnet or solenoid. It consists of a coil which is wound around an iron core generating a magnetic field when direct current is applied. Soft-iron parts attached to the magnet rule how the magnetic lines of force close about the rail head. [17] But the friction part is made by metal in general.

- Table 3.1. Mechanical properties of rails shoes material [15]

Yield strength(MPa)	310
Ultimate tensile strength(MPa)	207
Modulus of elasticity (GPa)	220
Resistance at 20˚C (Ω)	0.57
Hardness(HB)	190
Elongation % in 2"	40

- Table 3.2. Thermal properties of rail shoes brake material [16]

Density (lb/cu in)	0.284
Thermal conductivity(W/cm °K)	73
Specific heat capacity(kJ/kg - °C)	0.45

- Table 3.3. Chemical properties soft iron EFI core material[14]

Carbon (%)	Silicon (%)	Chromium (%)	Iron
0.03 max	0.5	12	Bal.

- Table3.4. Mechanical properties of UIC60900A rail material

Yield strength(MPa)	≥880
Elongation (%)	≥10
Hardness(HB)	240-270

3.2.3 Conditions

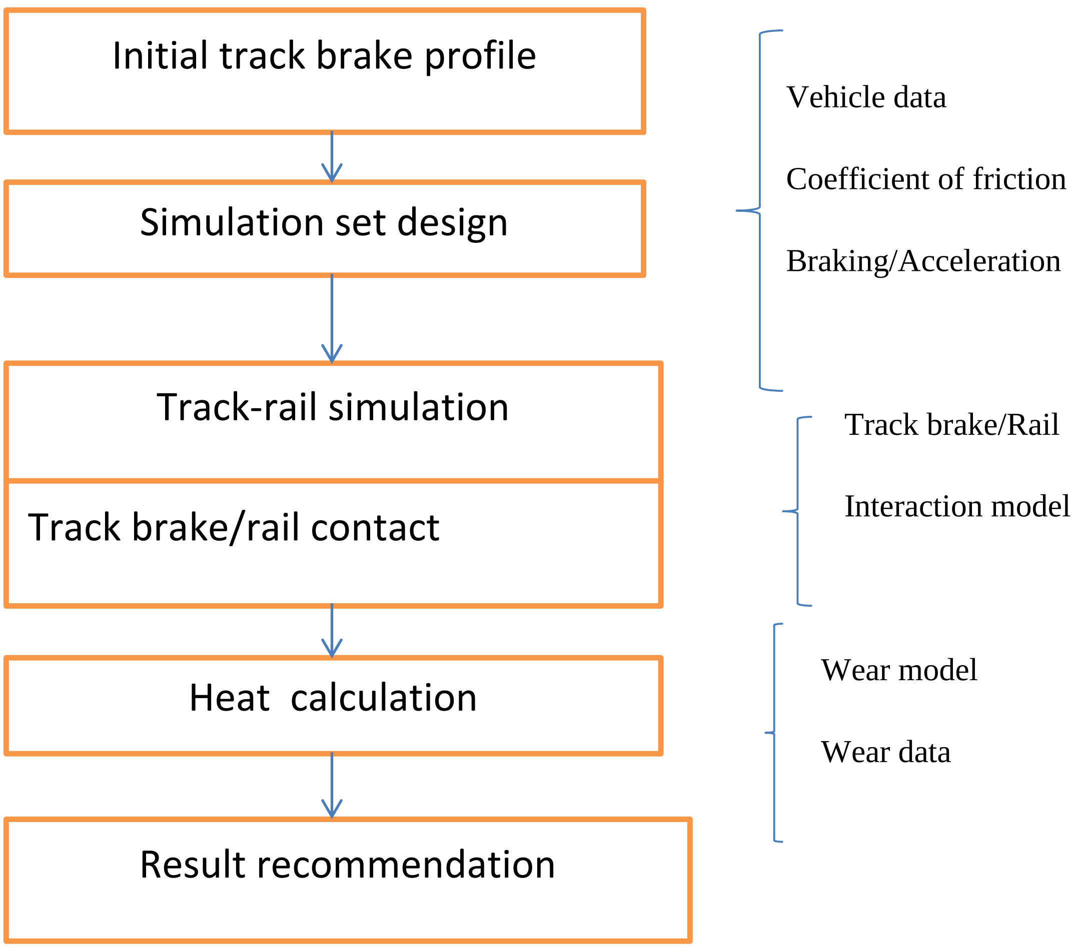
The below table show that the general technical parameters and condition of freight car of the national railway of Ethiopian railways corporation, rolling stocks specification. The deceleration is taken from the light rail transit railway of Addis Ababa of the emergency braking, to see the maximum effect.

- Table3.5.Technical parameters of freight cars for AALRT railway of Ethiopia

Railway gauge	1435mm
Design speed	80km/h
Loading capacity	44t
Continuous speed	70km/h
Maximum electromagnetic braking effort	66KN±5%

3.3. Mechanical contact between track brake/rail

3.3.1 Wear analysis procedure



3.3.2 Braking on a straight track

When braking on a flat surface the train has only kinetic energy of the vehicle. Due to this kinetic energy the heat is developed between rail and pad due to friction. The heat energy during this time is calculated only from the kinetic energy of the vehicle and rotational kinetic energy of the adhesion parts due to the electromagnetic.

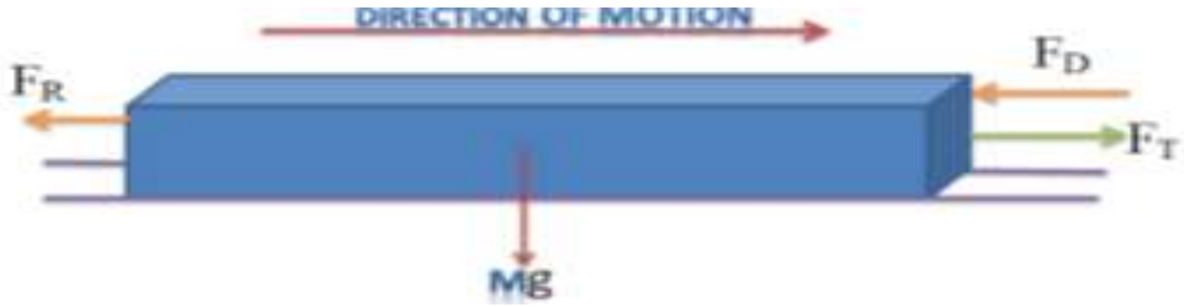


Figure3.1. braking forces

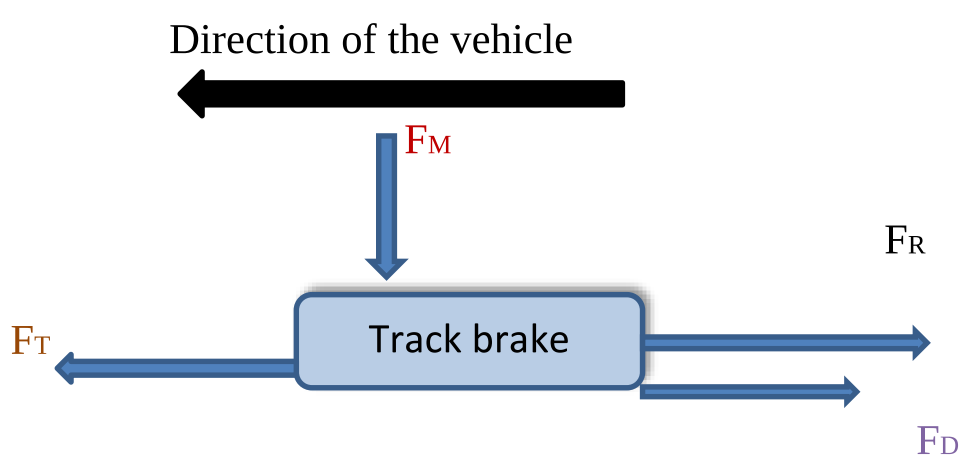


Figure 3.2. Magnetic track braking forces

To simulate a process of braking of railway vehicles it is necessary to define an analytical model of a thermal analysis that describes the heating transfer of the heat generated by friction at surfaces which are in contact, between a rail and rail shoes. Numerical calculation is done for the purpose of input for the ANSYS analysis and used to get thermal result (temperature).The transient thermal analysis will determine the temperature distribution on the pad and the transient structural analysis will determine the wear damaged area. The thermal result is an input for the structural analysis. The analysis is done with the different initial speed.

3.3.3 Numerical Heat flux analysis

Once activated, a magnetic track brake is pressed onto the rails by its own magnetic pull. Transmission links fixed in place on the bogie draw the brake magnet over the top of the rail in the running direction.

The braking power is exerted as the kinetic energy of the moving vehicle is gradually transformed and consumed by the magnets which are connected to the rails by the force of the magnetic field. The brake magnets exert an adhesive force of 66 kN ±5%.

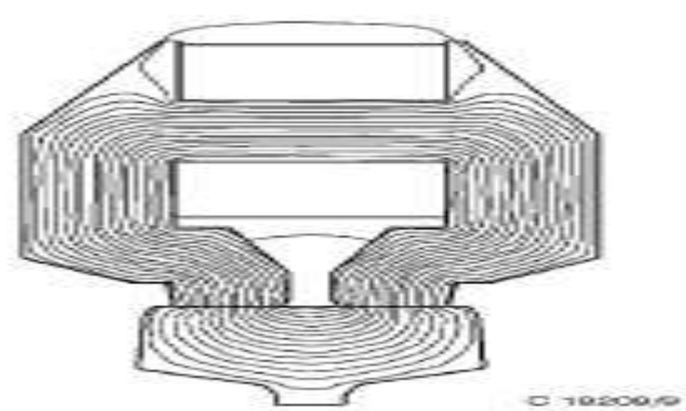


Figure3.3: Magnetic lines of force represented symbolically [17]

The thermal analysis of the braking system of railway vehicles requires a precise determination of the quantity of heat produced by friction, as well as the distribution of this energy between the rail and the pad. When the braking process occurs pad and rail are in a sliding contact. The resulting force resists the movement so the train slows down and finally stops. The friction between the rail and rail shoes always opposes motion and the heat is generated due to conversion of the kinetic energy. This thermal analysis will be done for maximal speed of the freight vehicle.

- **Heat flux**

$$q_{total} = \frac{Q_{gen}}{n \times A_p} = \frac{E_b}{n \times A_p} = \frac{\frac{1}{2} \times m \times v^2{}_i}{n \times A_p}$$

Vehicle mass: $m_v = 44 tonnes$

Passengers mass: $m_p = 318 \times 60 = 19080 kg$

Then; mass= $m_v + m_p = m$ =63080kg

Pad area: $A_p = 900 \times 54.5 = 49050 mm^2$

Number of track brake on each vehicle: n=6

Then, $q_{total} = \frac{63080 \times (19.44)^2}{2 \times 6 \times 49050 \times 10^{-6}} = 4050083229 W/m^2$

$$q_{average} = \frac{q_{total}}{2} = 2025041615 W/m^2$$

The pad absorbs 90% of the average heat. $q_{90\%} = 1822537453 W/m^2$

- **Heat convection**

$$h_c = \frac{k_{air} \times Nu}{D}$$

With,

$$\text{Re} = \frac{D \times V \times \rho_a}{\mu_a} = \frac{0.9 \times 6 \times 19.44 \times 1.17}{1.847 \times 10^{-5}} = 6649806$$

$$P_r = \frac{\mu_a \times c_{pa}}{K_a} = \frac{1.847 \times 10^{-5} \times 1006.248}{0.02601} = 0.715$$

$$Nu = 0.0243 \times \text{Re}^{0.8} \times \text{Pr}^{0.4} = 6103.46$$

$h_c = 29.4 w/m^2$

Where, thermal conductivity k_a=0.02601w/mK, density $\rho_{a=}$1.17Kg/$m^{3,}$,dynamic viscosity μ_{va}=1.847*10^{-5}NS/m^2,length of the contact L=0.9*6=5.4m,vehicle speed v_{TV}=19.44m/s and specific heat capacity C_{Pa}=1006.284J/kg.K , are given for the surrounding (ambient air) air of Addis Ababa.

- **Sliding distance**

$$S = v_0 t + \frac{1}{2} a t^2 = 19.44 \times 8.84 - 0.5 \times 2.2 \times \left(8.84^2\right) = 85.89 m$$

Track braking time $t_b = \frac{v_i}{a} = \frac{19.44}{2.2} = 8.84 s$

- **Wear volume**

In order to estimate wear volume , Archard Wear Equation is used:

$$V = K \times \frac{W \times S}{H}$$

$$V = \frac{0.007 \times 66000 \times 85.89}{70} = 566874 mm^3$$

$$V = A_p \times t \Leftrightarrow t = \frac{V}{A_p} = \frac{566874}{49050} = 11.56 mm$$

$t_{service} = t_{new} - t_{remaining} = 55 - 5.5 = 49.5mm$

$\frac{t_{service}}{t_{wear}} = N_{cycle} \Rightarrow \frac{49.5}{11.56} = 4.3 times$ For one time, the emergency braking will wear from the brake friction material. Accordingly to this friction material, the track brake serves: almost 4 times

Where;

$t_{remaining} = 10\% t_{new}$

$t_{wear\,limit} = 90\% t_{wear}$

V: wear volume in mm3

Kab: wear coefficient for abrasive wear (dimensionless) and in such case K= 0.007 for mild steel as a metallic material. **[23]**

W: normal load (N) is the magnetic load where W=66000N

S: sliding distance (mm)

t: wear thickness

H: hardness value of friction part material H=70 (semi- metallic material)

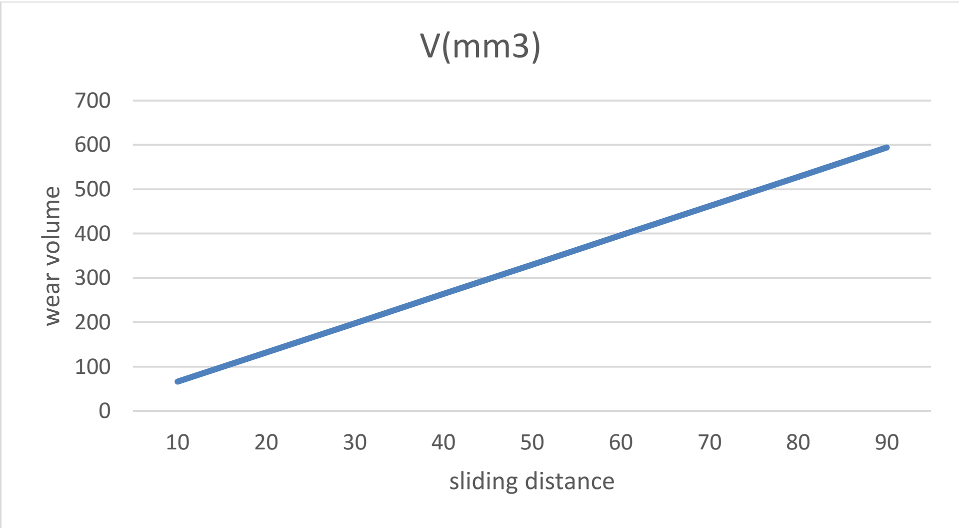


Figure3.4: Wear volume proportional related to the sliding distance

3.4 Modeling of Track braking system

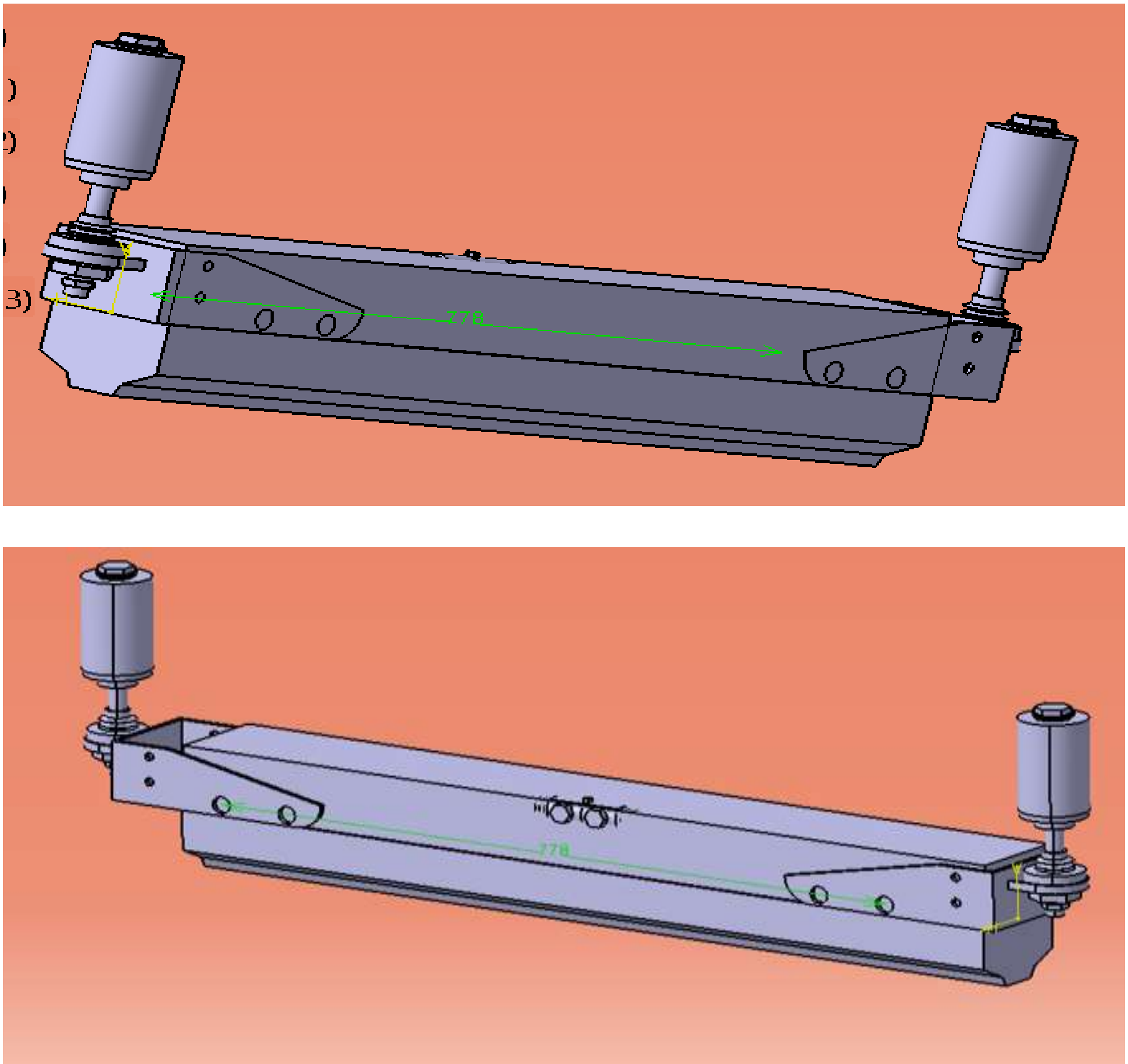


Figure 3.5: Track brake model using Catia V5R19

The full model of track brake-rail is modeled using ANSYS order to analyze thermal stress on the rail shoes in manner to analyze indirectly the wear.

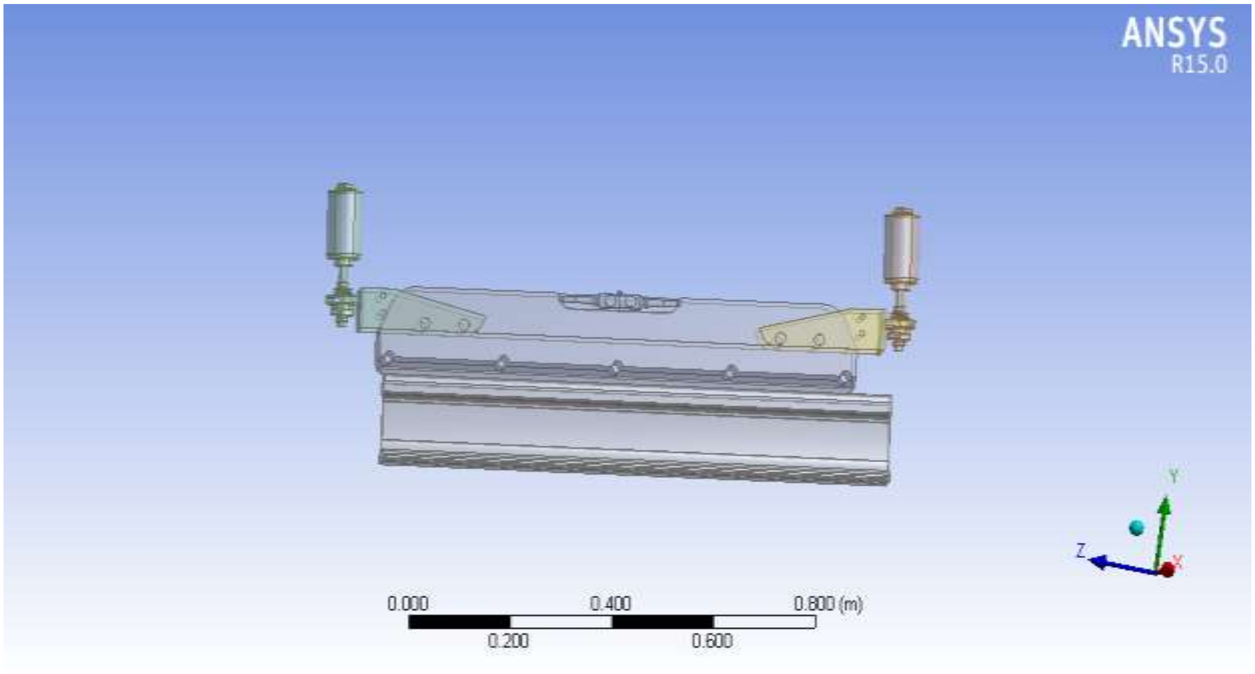


Figure 14. Track brake rail assembly

CHAPTER IV. RESULTS AND DISCUSSION

4.1 Results of Thermal and Structural Analysis

❖ **Meshing**

In the 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 a finite number of points called nodes. A network of these elements is called as a mesh. For this analysis, automatic mesh generating means were used in ANSYS rather than defining the nodes individually, after importing the track brake assembly model to ANSYS workbench [21].

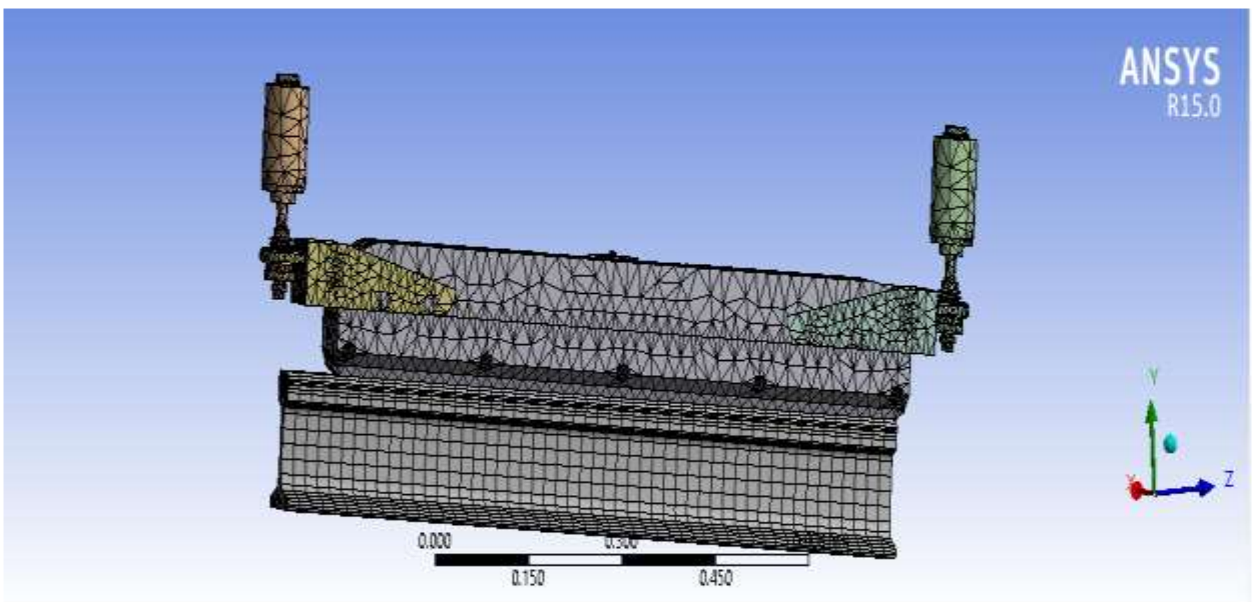


Figure15. Track brake system meshing in ANSYS workbench

❖ **Definition of the boundary condition**

After completion of the finite element model and mesh, it is necessary to apply constraints and loads to the model. The analyzed railway track brake system was subjected to the following loads:

- ✓ The initial temperature of the rail and the pads is 25.5 °C.
- ✓ The surface convection condition is applied at all surfaces of the track brake with the values of the convection coefficient (h) which was calculated before.
- ✓ The heat flux into the brake disc during braking is calculated above.

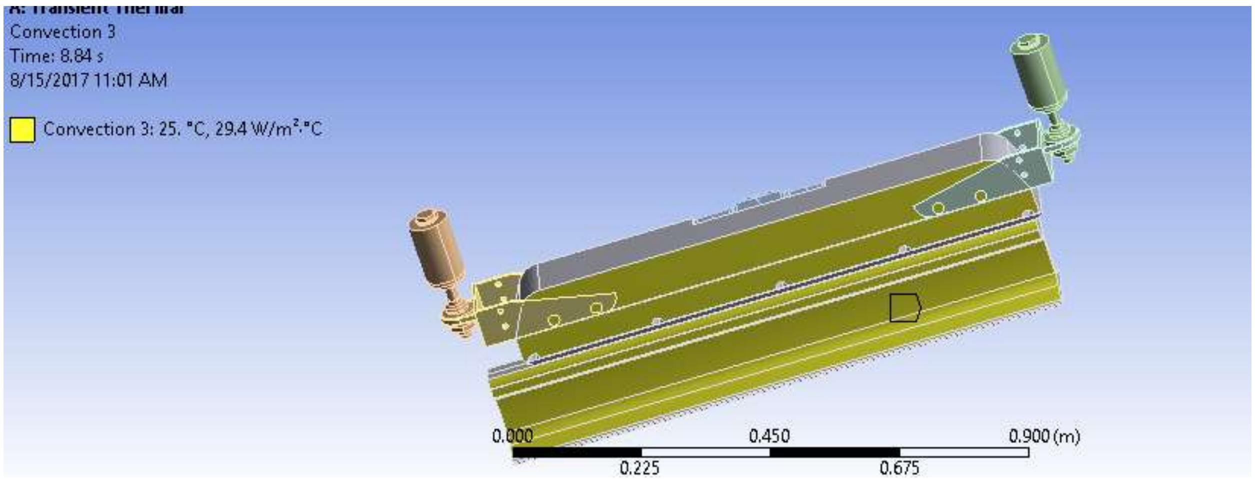


Figure16. Thermal loads and boundary conditions

➢ The heat flux applied on rail shoes surface, is distributed to contact area and is equal to the rail heat flux.

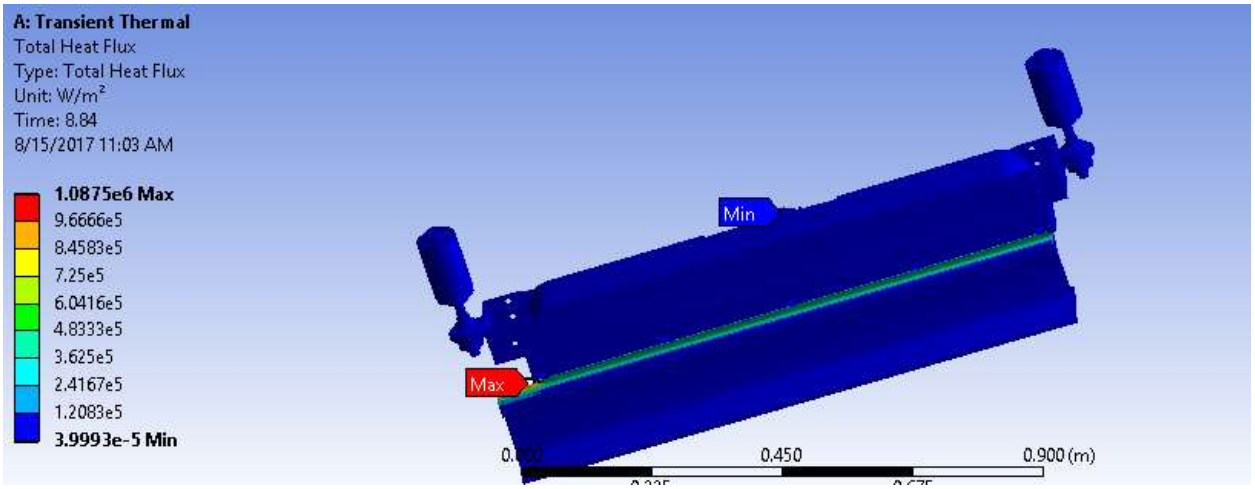


Figure17 .Total heat flux during emergency braking

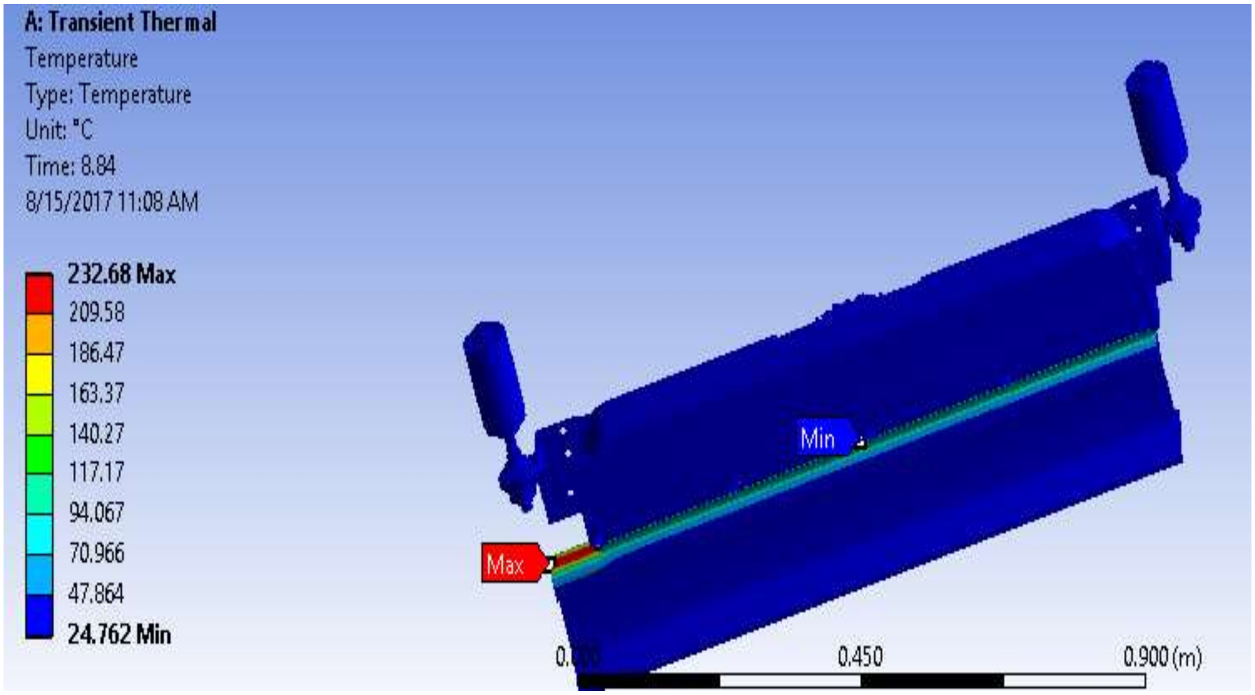


Figure 18. Temperature distributions load

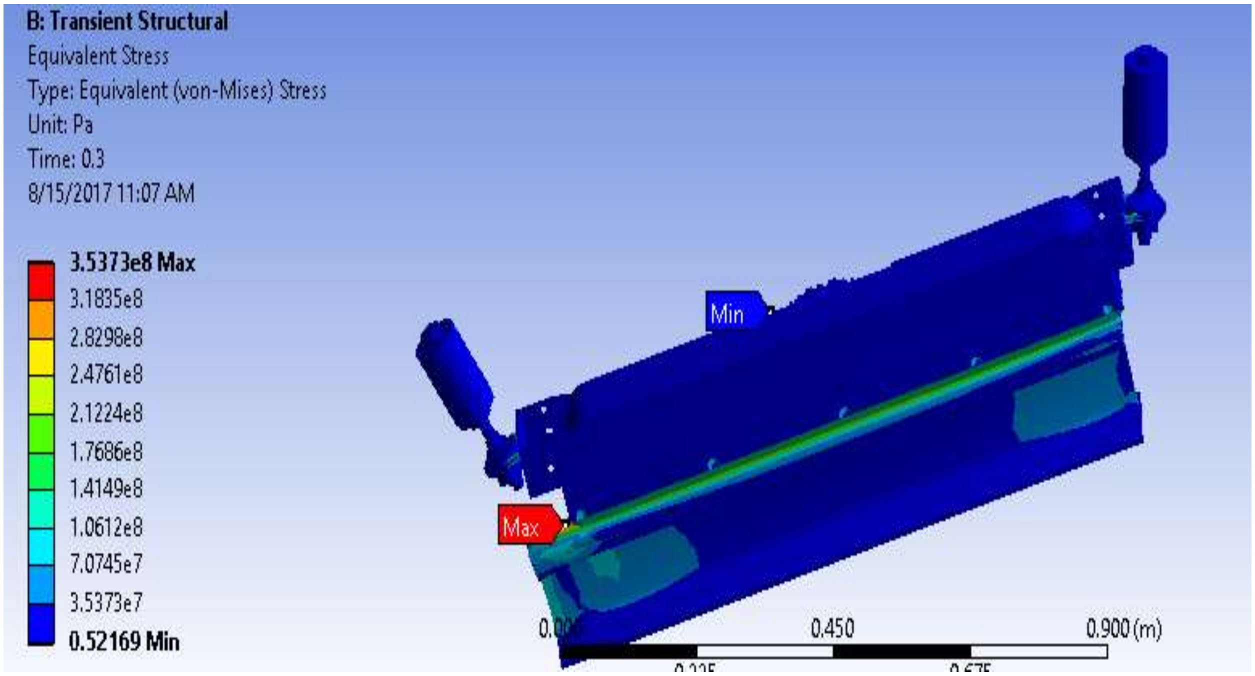


Figure19. Equivalent stress

4.2. Life time analysis

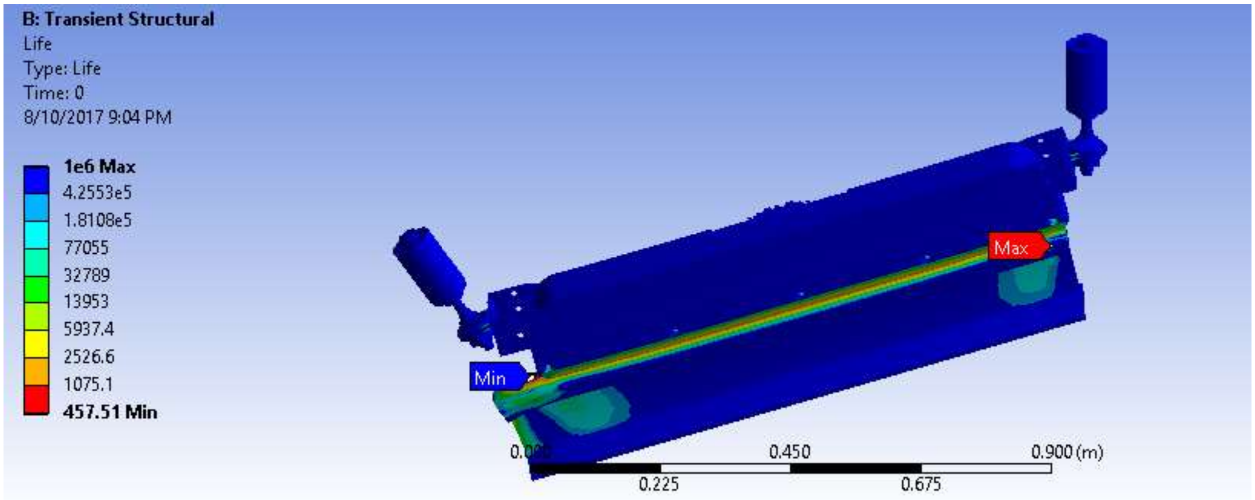


Figure20. Track brake life time

Now a day's railway transportation system is becoming popular in terms of cost and long life operation all over the world including Ethiopia; hence the transportation system should be free of risks that arise due to component failures such as braking system. As temperature and number of cycles of the track break increases the life time of the whole track brake decreases due to repeated cycles. So it better to know the life time of the using material to prevent the critical number of cycles of using. The minimum life of the track brake is the pad area. This damaged part will cause to damage the support first until the whole track brake will be failed.

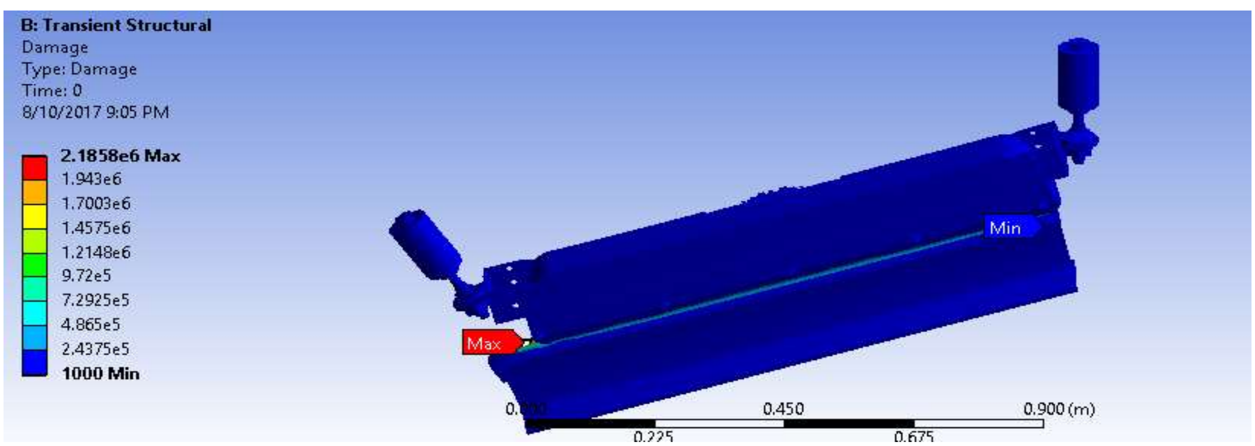


Figure 21. Damaged area

4.3. Discussions

In this thesis study, Archard wear law was used to evaluate wear volume on contacting surfaces because it is the most frequently used method in practical engineering applications.

During braking there is frictional heat produced between rail and rail shoes. The two contact applied material have different chemical composition and property. The rail shoes material is softer than the rail one surfaces move over each other that causes the most critical wear: the abrasive wear, wear will occur in the form of damage to one or both surfaces, generally involving progressive loss of material. Archard's wear equation states that the wear V in any contact is directly proportional to the load applied W and inversely proportional to the surface hardness of the wearing material H.

$$V = K \times \frac{W \times S}{H}$$

We should know the quantity of wear volume determining the number of cycles that might affect the limit of the wear thickness in order to replace the pad.

Due to the heat generation of the rubbing surface, a clear hot annular broadband of heat accumulation is observed in the contact region. The temperature distribution can be observed in the figure 21 above.

The heat flux values generated during contact of materials were analyzed. The heat calculations were done in order to see whether they have effects or not on wear.

In Figure19, it is obviously seen that the resultant stress values on materials during contact are greater with respect to their yield strength. However in this case, the track brake is expected to use in the emergency while the others braking will be failed; the track brake using will increased that means it will repeatedly use.

CHAPTER V. CONCLUSION, RECOMANDATION AND FUTURE WORK

5.1. Conclusion

Magnetic track brakes system is a braking system used in AALRT at the emergency braking purpose as the train's service life is increasing the probability of the failure of the service brake increases accordingly. The wear analysis of the magnetic track brake pad is useful to determine the life time of the pad.

The analysis on this thesis used both numerical and analytical method to determine the wear of the pad, deformation, and stress and damaged area. Ansys software is used to determine the temperature, deformation and stress and the damaged area. The Archard's law was used to determine the wear of the pad material at the emergency brake.

The results shows that during one time emergency braking [11.56mm] of the thickness of the pad. Accordingly as the thickness of the new track braking pad is [55mm] the track braking pad can serve for [4.3] times emergency brakes.

5.2. Recommendation

The emergency braking system has as function to stop the train at the short time at the short distance in every speed. This system is planned for the safety case, so even if the others braking becomes failed we have to minimize or prevent the track braking wear measuring the depth of wear.

5.3. Future Work

The following are suggested for future work as extensions and elaborations of this research.

- Experimental analysis of wear on track braking system
- Experimental measurement of wear depth on track braking pad
- Numerical and experimental analysis of fatigue life time track braking system considering the different speed and slops.

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