



ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

GRADUATE PROGRAM IN RAILWAY ENGINEERING

**DEVELOPING A MATERIAL FOR IMPROVING FATIGUE STRENGTH
OF WELDED BOGIE FRAME OF ADDIS ABABA LIGHT RAIL TRANSIT**

**A RESEARCH PAPER SUBMITTED FOR
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR MASTER OF SCIENCE IN ROLLING
STOCK ENGINEERING.**

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JULY 2017

ADDIS ABABA, ETHIOPIA

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DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

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ACKNOWLEDGMENT

At the head of my intentions to forward my acknowledgement to the ones that deserve it, my heartfelt thanks will be directed to the almighty ALLAH who is the source of my success in my life. I would also like to express my appreciation and thanking's to my advisor Dr. Daniel Tilahun for his unreserved assistance and resource full advise that encouraged me to conduct my research successfully and courageously.

I would like to thank my government to giving a chance to study my master degree on this beautiful UNIVERSITY OF ADDIS ABABA with collaboration with Ethiopian Railway Corporation. I would also want to thank the Locomotive Industry for giving me the necessary technical data's and their collaboration to take the direct measurements. My Special thanks will go to my family especially for my dad who has contributed great deal by suggesting valuable advises and grammatical corrections standing on his research experiences.

Finally I would like to thank all those who stand by my side and giving me their significant advice and motivation throughout the entire progress of my research undertakings.

ABSTRACT

This research paper present develops a material for improving the fatigue strength of the bogie frame of AARLT. The purpose of this research is to compare between the current material and selected material in order to protect the bogie frame from failure. In the analysis of the research ANSYS and FEMFAT software have been used to investigate the difference of these materials. The specimen S.N curve has been used to clearly differentiate the two materials.

On the basis of the modal analysis the following results has been achieved. The equivalent stress of the current material is $2.0091e^8$ and $2.0037e^7$ for the selected material .the minimum safety factor of current is 0.4290 and 0.4302 for the selected one. The total deformation of the two material are 0.0013168 ,0.0013329 which lead to the researcher to say that the selecting material has less deformation than the current .FEMFAT software reveal that the selected material have greater endurance limit and survival probability ,which mean the new material will be more resistant.

Based on that result, it is possible to conclude that the selected material is stronger than the current material .the bogie frame that is the most important part of the bogie will be safe and can withstand the overload. The study is significant and applicable because it introduce a knowledge on the material of the bogie frame in order keep it save by improving the fatigue strength .Therefore railway corporation should give attention on the phenomena.

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NOMENCLATURE

UIC	International union of railways
AALRT	Addis Ababa light rail transit
Se	Endurance Limit
M_v	The mass of car in running order;
P1, P2	the mass of passengers at exceptional loads
	and normal service load cases respectively
C	The wheel loads of the relevant bogie expressed as a%
m_1	Effective car body mass
m^+	the bogie mass
n_b	Number of bogies
FEMFAT	FINITE ELEMENT FATIGUE
S.N	STRESS VERSUS NUMBER OF CYCLE

CHAPTER ONE: INTRODUCTION

1.1. Background

It must be clearly understood that the major difference between a railway vehicle and other types of wheeled transport vehicles is the guidance provided by the track. The surface of the rails not only supports the wheels, but also guides them in a lateral direction. The rails and the switches change the rolling direction of wheels and thus determine the travelling direction of the railway vehicle. In this paper, an automation of fatigue durability analysis for the weld bogie frame of railway vehicles will be realized. After the analysis the result will indicate the way of improving life time of bogie frame of the train for AALRT. A bogie frame of railway vehicles plays an important role in sustaining the static load from the dead weight of a carbody. Quasi-static loads occur periodically during curving and braking operations, and cyclic dynamic loads are caused by an irregular rail surface and relative movement of the attached equipment. Since the majority of the bogie frame is a welded structure which is very susceptible to the fatigue failure under such loads, a fatigue durability analysis to ensure the sufficient fatigue strength of its weldments is a relevant issue [1]. The bogie of railway vehicle is the primary structures, which support the weight of car body and passengers, and under the repeated external loading between rail and wheel. Therefore, in order to have enough strength and stiffness against the external loading, bogie frame were made of solid steel or welded structures based on metal materials such as SM490A. The weight of the bogie makes up approximately 37% of the whole vehicle weight[2].

The wheelsets and the bogies are the components of the rail vehicles that experience the hardest conditions. In particular the bogie frame, due to the dynamic loads induced from the operating condition (train speed, quality of track, and so on), may show initiation of fatigue cracks and eventually fatigue failure. Stresses on bogie frames will be developed as a results of loads, displacement constrains and acceleration effects [3].

1.1.1. Type of bogie frame of AARLT

A. MOTOR BOGIE FRAME

One of the major components of bogie is the frame. The frame adopts welded structure, incorporating steel plates and cast steel parts. It is mainly consisted of side sill, cross beam and end sill. The frame is designed and calculated in compliance with UIC615-4, EN13749 and VDV152 European railway standards. It is welded and examined according to EN 15085 European railway standard. After welding, frame will be subjected to tempering to eliminate residual stress due to welding.[4]

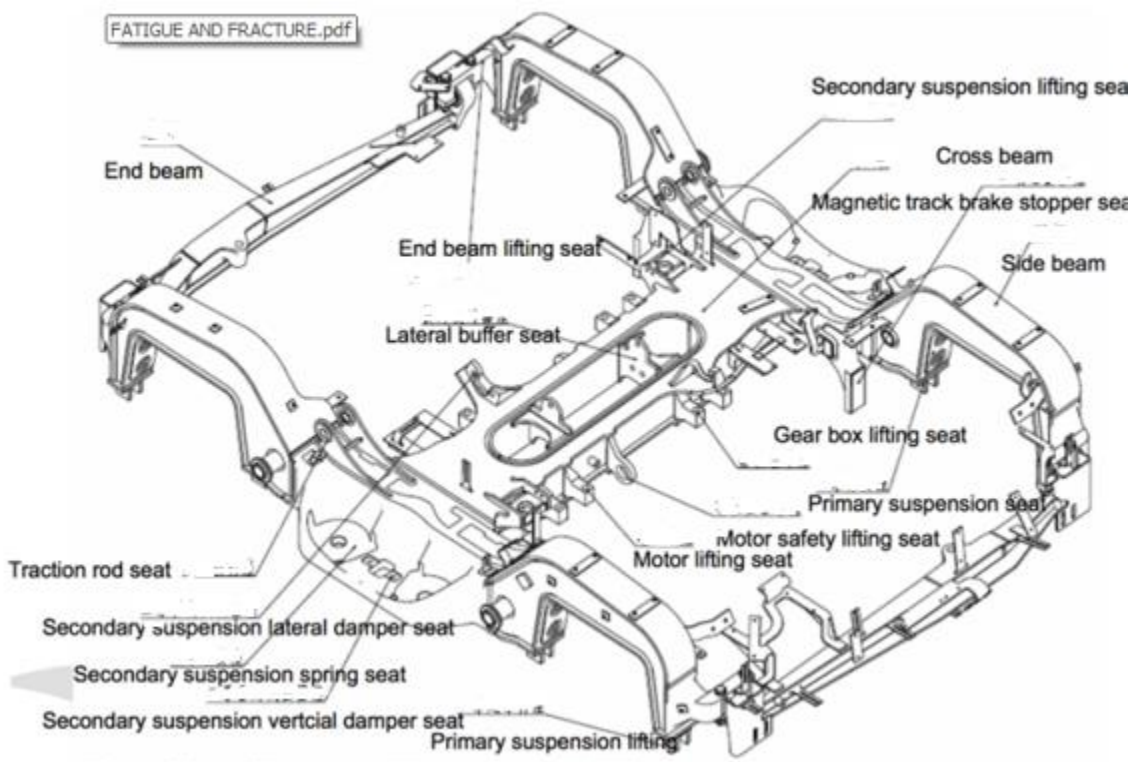


Fig 1.1 motor bogie frame

B: Trailer bogie frame

The frame is H shaped welded structure, and is welded of casting and square boxes. Designed, calculated, welded and examined criterions are same as motor bogie frame. Bogie frames are always subjected to dynamic random loads and consequently fatigue phenomena.

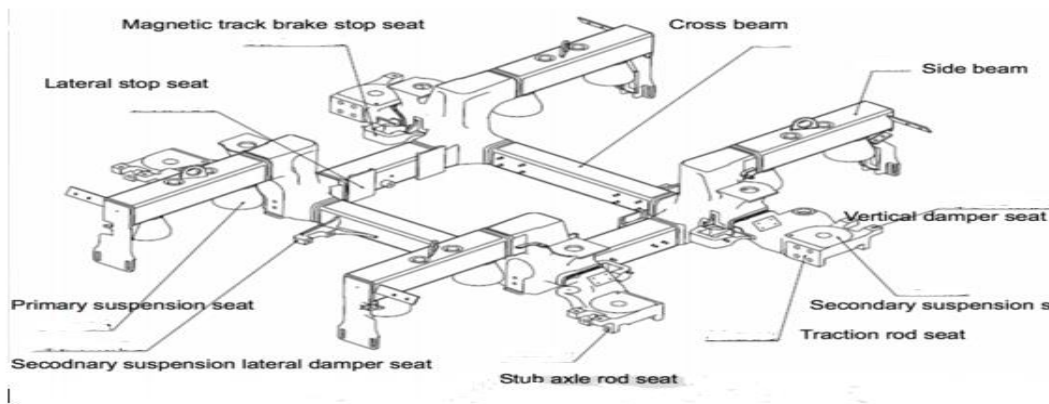


Fig 1.2: Trailer bogie frame

1.1.2. Introduction to fatigue

It is a well-known fact that if the maximum load acting on a structure becomes higher than its material yield strength limit, a failure is assumed in the structure. However, in a structure that undergoes fluctuating loads, even if they are well below the material elastic limit, a failure can be expected after many loading cycles. The latter situation, which is a result of accumulated damages in the material, is known as fatigue failure. In other words, static loading of a ductile material which increases from zero to a maximum, will cause large deformations. In that case, failure of the structure occurs after a single load application with large plastic deformation, whereas, if the same material is repeatedly loaded to stresses well below the elastic limit, fatigue failure may happen after as little as a few hundred cycles or after, say, several million cycles of load application without any large plastic deformation. Fatigue is a progressive process that takes time to initiate and develop. Therefore, the process of fatigue is time-consuming and can only happen as an outcome of a repeated loading. In most cases the crack initiates in a confined small area that is either subjected to high local stresses or suffering from local defects in the material. On the contrary, in adjacent parts, where the stress state is insignificantly lower, no crack would initiate. Hence, fatigue is clearly a much localized process in which the crack originates in a location where several micro-cracks are available and grow together into one dominant crack. The mentioned process of crack formation after a coalescence of several micro-cracks is called the initiation phase of fatigue crack growth and is a result of plastic deformations in a small area in front of the crack tip. The presence of plastic deformations also implies that fatigue is an irreversible process which leaves permanent structural damages. Under normal working

conditions, bogie frame has a life cycle of 30 years. Contrary to the above fact it is quit impossible to maintain normal working conditions due to many reasons all the time. Some of the reasons that could affect the normal working conditions might be:-

1. It is usually observed over loading experience are inevitable in Ethiopia.
2. Unskilled man power involved in the production and lack of modern welding mechanisms can affect the strength of the welded bogie frame.
3. Lack of regular and careful supervision on the bogie frame could be another reason that can affect the normal working conditions.

1.2. Statement of the problem

Rail transport is of great importance for the functioning of the economic system of each country. The efficiency of rail transport indirectly affects the efficiency and functioning of the entire economic system of a country. Many countries are usually being confronted by such a type of problem. Thus economic impact is always the major concern for the Government and the society. Bogies are major parts in the configuration of railway vehicles that directly interact with the rail and track irregularities as a result studding the fatigue durability of bogie frames are imperative. While in motion bogies tolerate severe dynamic loadings. Fatigue in bogie axles, center bowls and frames are unavoidable. So that, the purpose of the research is to develop a material in order to improve fatigue strength of the bogie frame and compare with the conventional material. As consequence of this material, safety in travel will be put in a save situation and the cost of maintaining the train will decrease.

1.3. Objective

1.3.1. General objective

The main objective of this research is developing a material for improving fatigue strength of the bogie frame.

1.3.2. Specific objective

➤ The specific objectives of this research are:

1. To study the fatigue strength of the material of the bogie frame of AARLT.
2. To carry out Fatigue strength modeling for Bogie Frame by ANSYS and FEMFAT software's.
3. Modeling fatigue strength analysis for the bogie frame by ANSYS
4. To select better material in order to improve the fatigue strength by suggesting different ideas on the basis of the results of the study.

1.4. Scope and limitation of research

1.4.1. Scope

The present work focuses on developing a material with better fatigue strength for w bogie frame of AARLT. It predict and compares fatigue life, a make sure of safety and reliability of mechanical structure to compare conventional materials with new material using ansys software and taking into consideration tempering and surface treatment influence factors. The FEMFAT MAX module is another method used to analyze material properties.

1.4.2. Limitation

The limitations that the researcher has encountered are

1. Lack of the required fatigue testing equipment, hence no experimental testing on obtained analytical outcomes was evaluated and compared to numerical results.
2. As the technology on railway engineering is a new one there are no sufficient written documentary sources.
3. In this paper the welding part will not be talked.

CHAPTER TWO: LITERATURE REVIEW

2.1. REVIEW

Few researches have been recently conducted a research to evaluate and improve fatigue life of the bogie frames. Park has estimated fatigue life of some types of bogie frames using FEM. He has also optimized the bogie weight based on the genetic algorithm. A web-based automation of fatigue durability analysis for a welded bogie frame of railway vehicle has been investigated under the multi-agent based engineering framework using JADE software by Bang. The macro program of I-DEAS, the APDL of ANSYS, and an in-house fatigue code are utilized for the parametric geometry modeling and automatic generation of finite element models, the static stress analysis, the fatigue durability analysis, respectively. A multi-agent based engineering framework is implemented on the JADE to integrate the overall process. All engineering programs are integrated by a XML based wrapper. The web based automation of fatigue durability analysis for welded bogie frame of railway vehicles is realized with several kinds of system integration techniques. Sub tasks for the fatigue durability analysis such as the parametric geometry modeling, the automatic generation of finite element models, the static stress analysis, and the fatigue durability analysis is automated with the macro program of I-DEAS, the APDL of ANSYS, and the BFAP. The multi-agent based framework is used to manage the overall process. Developed automation techniques show the significant decrease in man-hours in order to achieve the fatigue durability analysis. Compared with a conventional manual process of fatigue durability analysis, this brought a time reduction about up to 80%. They have got different damage values in deferent positions the damage value at position 3 is much higher 0.28~0.47 and 0.13~0.30 in the case of the Bogie Nominal and Bogie Hot Spot project, respectively. With increasing the MCen, the damage value increases slightly and then decreases significantly after holding with constant value. As two transom support brackets approach each side frame of bogie, resistance to the twist behavior of bogie frame may be increased. Finally they concluded that they are trying to develop the more decentralized engineering framework which has intelligent capabilities such as a dynamic distributed resource allocation, load-balance, fault tolerance, and conflict resolution and to apply it to the optimal design considering mutually interactive physical phenomena in the future [6].

Fatigue strength evaluation for the bogie frame of a Korean tilting train was carried out by J.-S. Kim and N. P. Kim using an experiment based on UIC615-4 standard. They showed that the bogie frame of the tilting train is exposed to more severe loadings compared with the conventional one because of the tilting of the car-body and the high-speed curve negotiation. An automation technique was proposed by Han et al. in order to do fatigue durability analysis for welded bogie frames according to the LJIC-code proposed by using the Model-Center, which enables several tools used in fatigue durability analysis to be integrated. A new method to predict fatigue lifetime based on the combination of frequency domain and time domain calculations, which allow lifetime prediction with reduced computational effort is given by Dietz et al. The benefits of the new approach are demonstrated by application to the bogie of a freight locomotive. J. S. Kim has assessed fatigue strength of the bogie frame for the Korean tilting train. For evaluation of the loading conditions, multi-body dynamic analyses have been carried out and strength analysis has been performed by FE analysis [7].

Bogie frame design in consideration of fatigue strength and weight reduction was carried out by B.H Park and K.Y LEE [11]. They used finite element method who performed for various loading condition according to the UIC standard. They choose as a material for bogie frame SWS490A. The properties of this material have been given yield strength “323MPa”, tensile strength “490”, welding “78”. The fatigue analysis is based on the UIC standard. The service load have been designed to verify the absence of any risk of fatigue cracks occurring under combined of the main force encountered during service. The load case consist of different load scenarios for the bogie frame involving experiencing straight track, curve negotiation, rolling and bouncing effect, and track twist. The maximum load applied by B.H Park and K.Y Lee is 157,06KN.

Structural strength analysis of the bogie frame in Tapei rapid transit system is conducted by C.OYAN. He showed that the bogie frame designed for Tapei rapid system is analyzed in order to confirm the technical strength requirement for static and dynamics loading. The bogie frame that he used for rail transit vehicles in Tapei Red line is welded structure. He has conducted his research by using finite element method strength analysis. The MSC/NASTRAN general purpose commercial finite element has been used. The material that he applied for the bogie frame is a

hot Rolled carbon steel of JISG3114SM50BW grade with better atmospheric corrosion resistance properties [10].

Analyzing bogie frame behavior by using the experimental method and ansys simulation was carried out by YAHIA ZAKARIA. He used the modal simulation in ansys program as a supplementary tool to determine the fatigue strength of a bogie frame. He showed that the bogie frame has subjected to a long fatigue experiment to predict its behavior in exploitation. This study have been include a static analysis and a fatigue strength analysis of the bogie frame by using FEM .There are several standards for strength evaluation of the conventional bogie frame such as JIS E 4207,UIC615 and others. He considers the norm EN 15749 in order to get the possible load configuration in normal operation. The material that he has been chosen is steel S35552G3-STD01W03 [9].

2.2. FATIGUE

In narrow sense, the term fatigue of materials and structural components means damage and damage due to cyclic, repeatedly applied stresses. In a wide sense, it includes a large number of phenomena of delayed damage and fracture under loads and environmental conditions.

It is expedient to distinguish between high-cycle (classic) and low-cycle fatigue. Plastic deformations are small and localized in the vicinity of the crack tip while the main part of the body is deformed elastically, then one has high-cycle fatigue. If the cyclic loading is accompanied by plastic deformation in the bulk of the body, then one has a low-cycle fatigue. Usually we say low-cycle fatigue if the cycle number up to the initiation of a visible crack or until final fracture is below 10^4 or $5 \cdot 10^4$ cycles. In material science, fatigue is the progressive, localized, and permanent structural damage that occurs when a material is subjected to cyclic or fluctuating strains at nominal stresses that have maximum values less than (often much less than) the static yield strength of the material. The resulting stress may be below the ultimate tensile stress, or even the yield stress of the material, yet still cause catastrophic failure

2.3. FATIGUE STRENGTH

Fatigue strength is defined as the maximum stress that can be endured for a specified number of cycles without failure. Low cycle fatigue strength approaches the static strength. When the cycle number exceeds to one limit, the fatigue strength falls to fraction of the static strength.

The fatigue strength is the value of the alternating stress that results in failure by fracture a specific number of cycles of load application. It can also be the ordinate of the σ -n (stress versus number of cycles to failure) curve.

The fatigue behavior of a specific material, heat treated to a specific strength level is determined by a series of laboratory tests on a large number of apparently identical samples of those specific materials. The specimens are machined with shape characteristics which maximize the fatigue life of a metal, and are highly polished to provide the surface characteristics which enable the best fatigue life. A single test consist of applying a known, constant bending stress to a round sample of the material, and rotating the sample around the bending stress axis until it fails. As the sample rotates, the stress applied to any fiber on the outside surface of the sample varies from maximum-tensile to zero to maximum- compressive and back. The test mechanism counts the number of rotations (cycles) until the specimen fails. A large number of tests is run at each stress level of interest, and the results are statistically massaged to determine the expected number of cycles to failure at that stress level.

The cyclic stress level of the first set of tests is some large percentage of the Ultimate Tensile stress (UTS), which produces failure in a relatively small number of cycles. Subsequent tests are run at lower cyclic stress values until a level is found at which the sample will survive 10 million cycles without failure. The cyclic stress level that the material can sustain for 10 million cycles is called the Endurance (EL).

2.4. FATIGUE STRENGTH TESTING

A failure that results from such cyclic loads is called a fatigue failure. Since many structural components are subjected to cyclic loads it is necessary for the design engineer to have some quantitative measure of the material's ability to withstand such repeated loads. Quantitative data for the fatigue properties of a given material are obtained by subjecting a number of standard specimens to cyclic loads until fracture occurs. The objective of the fatigue strength or fatigue limit test is to estimate a statistical distribution of the fatigue strength at a specific high-cycle fatigue life. Among many fatigue strength tests methods, the staircase method (often referred as the up-and- down method) is the most popular one that has been adopted by many standards to asses statistical of a fatigue limit.

In this test, the mean fatigue limit has to first estimated, and a fatigue life test is the conducted at a stress level a little higher than the estimated mean. If the specimen fails prior to the life of interest, the next specimen has to be tested at a lower stress level. Therefore, each test is dependent on the previous test results, and the test continuous with a stress level increased or decreased.

2.5. FATIGUE DAMAGE PROCESS

Fatigue is gradual process of damage accumulation that proceeds on various levels beginning from the scale of the crystal lattice, dislocations and other objects of solid state physics up to the scales of the structural components. Three or four stages of fatigue damage are usually distinguishable. In the first stage, the damage accumulation occurs on the level of grains and intergranular layers. The damage is dispersed over the volume of a specimen or structural component, or at least, over the most stressed parts. At the end of this stage, nuclei of microscopic cracks originate, example, such aggregates of micro cracks that are strong stress concentrators and under the following loading, have a tendency to grow. Surface nuclei usually can be observed visually (at least with proper magnification). At the sizes of these cracks whose depth is small compared with the size of the cross section. At the same time, the sizes of these cracks are equal to few characteristics scales of microstructure, say, to several grain sizes. Such cracks are called small cracks. Most of them stop growing upon meeting some obstacles, but one or several cracks transform into microscopic, “long” fatigue cracks that propagate in a direct way as strong stress concentrators. This process forms the third stage of fatigue damage. The fourth stage is rapid final fracture due to the sharp stress concentration at the crack front and/or the expenditure of the material’s resistance to fracture.

The local stress concentrations domains as well as near the damaged or weakest grains. The initial slip planes and micro cracks in grains are oriented mostly along the planes with maximal shear stresses. Small cracks are inclined, at least approximately, in the small directions. There is example of S-N Curves and the approximation of Endurance limit.

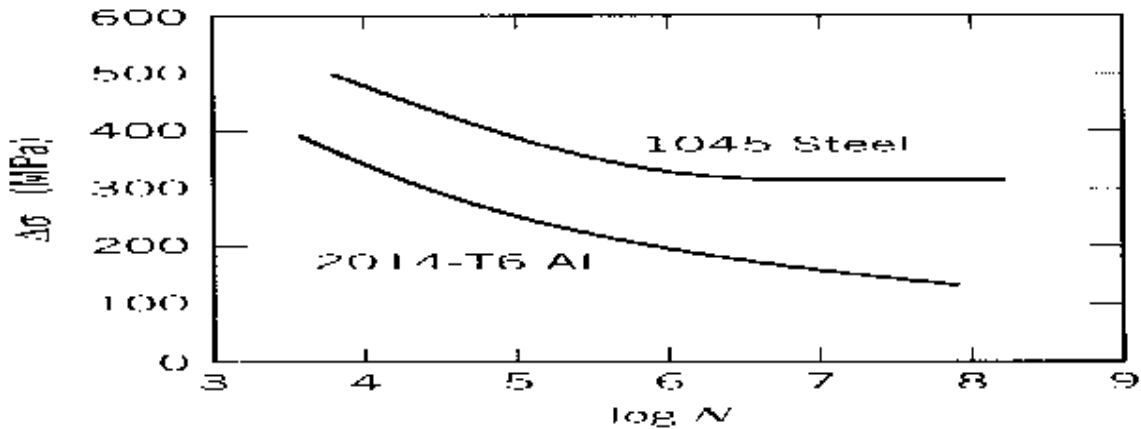


Figure 2: Life Cycle of 1045 Steel and 2014-T6 Al

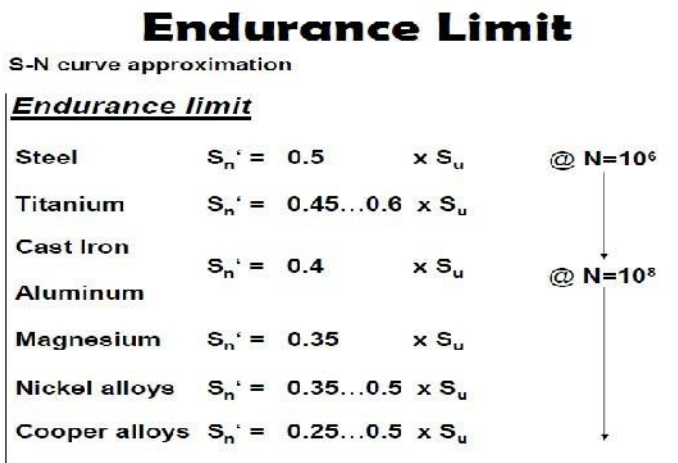


Figure 3: S-N Curve Approximation

2.6. FATIGUE FAILURE

Failure is one of most important aspects of material behavior because it is directly influent the selection of material for certain application, the method of manufacturing and service life of component. The majority of engineering failures are caused by fatigue. Fatigue failure is defined as the tendency of a material to fracture by means of progressive brittle cracking under repeated alternating or cyclic stresses of intensity considerably below the normal strength. Although the

fracture is of a brittle type, it may take some time to propagate, depending on both the intensity and frequency of the stress cycles. Nevertheless, there is very little, if any, warning below failure if the crack is not noticed. The number of cycles required to cause fatigue failure at a particular peak stress is generally quite large, but it decreases as the stress is increased. For some mild steels, cyclical stresses can be continued indefinitely provided the peak stress (sometimes called fatigue strength) is below the endurance limit value.

A good example of fatigue failure is breaking a thin steel rod or wire with your hands after bending it back and forth several times in the same place. Another example is an unbalanced pump impeller resulting in vibrations that can cause fatigue failure.

The type of fatigue of most concern in circuit cards, gasoline, diesel, gas turbine engines and many industrial applications is thermal fatigue. Thermal fatigue can arise from thermal stresses produced by cyclic changes in temperature.

Fundamental requirements during design and manufacturing for avoiding fatigue failure are different for different cases and should be considered during design phase. Fatigue failures almost always begin at the surface of a material. The reasons are:

Suppose that a particular specimen is being fatigue tested. Now suppose the fatigue test is halted after 20% to 25% of the expected life of the specimen, and the surface condition is restored to its original state. Now the fatigue test is resumed at the same stress level as before. The life of the part will be considerably longer than expected. If that process is repeated several times, the life of the part may be extended by several hundred percent, limited only by the available cross section of the specimen. That proves fatigue failures originate at the surface of a component.

Fatigue failure is also due to crack formation and propagation. A fatigue crack will typically initiate at a discontinuity in the material where the cyclic stress is a maximum. Discontinuities can arise because of:

1. Design of rapid changes in cross-section, keyways, holes, etc. where the cyclic stress concentrations occur.

2. Element that roll and/or slide each other (bearings, gears, cams) under high contact pressure, developing concentrated subsurface contact surfaces that can cause pitting from after many cycles of the load.
3. Carelessness in locations of stamp marks, tool marks, scratches, and burrs; poor joint design; improper assembly; and other fabrications faults.

Compositions of the material itself as processed by rolling, forging, casting. Fatigue fracture typically occurs in material of basically brittle nature. External or internal cracks develop at pre-existing flaws or fault of defects in the material; these cracks then propagate and eventually they lead to total failure of part. The fracture surface in fatigue is generally characterized by the term “beach marks”. Examples of fatigue failure can be shown as the following figures:



Figure 4: Example of fatigue failure

CHAPTER THREE: ANALYTICAL METHODS AND CONDITION

The research method for developing a material with a better fatigue strength for bogie frame has considered. The complexity and dynamic associated with the problem that has been dealt in this research, FEM is considered to be an appropriate method for modeling the system structure

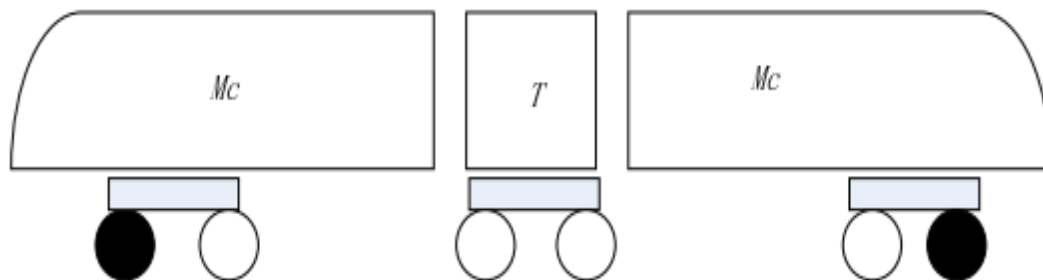
3.1. BOGIE FRAME MATERIAL

A. CONVENTIONAL MATERIAL FOR BOGIE FRAME

The AARLT bogie frame is designed and calculated in compliance with UIC615-4, EN 13749 and VDV 152 European railway standards. These European standards cover a wide variety of different bogies types, according to EN 13749 STD the AARLT bogie will be categorized to bogie category B-IV which is bogies for light rail vehicles and trams.

- Frame; steel UNI 10025 S355J2G3C
- Tensile strength: 612,5
- Yield strength=335MPA

- Axle box =EN-AC-AI-SI-7MG0.6



B. SELECTED MATERIAL FOR BOGIE FRAME

The material that I selected is AISI 4140. It is alloy steel which has high fatigue strength, abrasion and impact resistance, toughness, and torsional strength.

➤ Chemical properties

Table 1: CHEMICAL COMPOSITION OF AISI 4140 STEEL

Element	Content %
Iron, Fe	96.785-97.77
Chromium, CR	0.80-1.10
Manganese, Mn	0.75-1.0
Carbon, C	0.380-0.430
Silicon, SI	0.15-0.30
Sulfur, S	0.040
Phosphorous, P	0.035

➤ Mechanical properties

Table 2: Mechanical composition of AISI 4140

PROPERTIES	METRIC
TENSILE STRENGTH	655MPA
YIELD STRENGTH	415MPA

3.2. DIMENSION

Table 3: Main Technical Parameters of the bogie

Item	Motor bogie	Trailer bogie
Type	CW12	CW13
Maximum operating speed	70km/h	
Maximum test speed	80km/h	
Rail Gauge	1,435mm	
Car body mass (actual)	44,000kg	
distance between the back of the wheel flange	1380 ⁰ ₋₂ mm	1377.7 ⁺² ₋₁ mm
Wheel base	1900mm	1800mm
Axle load	10.5t	11.5t
Wheel diameter (new/worn)	660mm/580mm	
Bogie weight	≤6t	≤4t

Table 4: Main Technical Parameters of the motor bogie frame

Item	Bogie frame
Roll coefficient	$\alpha = 0.1$
Bounce coefficient	$\beta = 0.2$
Mass of bogie frame (actual)	900kg
Mass of bogie (actual)	5631kg

3.3. Methods

This research is specifically conducted on Addis Ababa light rail transit vehicle, by observing the effect of fatigue exhibited on the welded bogie frame, and detail analysis work and it will be carried out in order to verify its effect.

- **Modeling:** - the system will be modeled using FEM with appropriate software such as CATIA, ANSYS and FEMFAT software's.
- **Parameterization:** - the system will be simulated by feeding some known parameters. Analytical Study and Calculation for Fatigue strength of Bogie Frame will be conducted and Research work will be done to improve it.
- ✓ **Fatigue calculation according with EN 13749 for bogie structures**
General methodology: As regards the calculation process, the structural analysis is divided in two phases:
 - ✓ Structural analysis of the bogie frame by FEM calculations;
 - ✓ Structural analysis of the attachments components-bogie frame by FEM calculations.
 For the two verifications above the calculation process for the acceptance procedure requires the following activities
 - Determination of the forces that occur in the interfaces of the structure
 - combination of these forces in load cases representing operation conditions
 - analysis of the stress values caused by the application of every load cases
 - Assessment of the calculated stress values comparing them to the acceptable stress limits.

3.4. Bogie frame calculation

During bogie lifetime several external forces act in the normal service loads on the bogie frame. These forces are coming from the wheel-rail contact points and from the interfaces with the car body and are generated from

- ✓ double sprung masses, including payload;
- ✓ track irregularities;
- ✓ lateral accelerations caused by curve riding;

- ✓ longitudinal accelerations caused by traction and braking;

The forces to apply for fatigue calculation are:-

- vertical forces coming from sprung masses
- transversal forces coming from each axle
- longitudinal forces
- track twist

Frame attachments calculation

- inertial forces due to the masses attached to the bogie frame;
- inertial forces due to the masses attached to the axle box (unsprung masses);
- loads resulting from damper
- loads resulting from braking;
- loads resulting from traction motor;
- load applied on anti-roll system;

The fatigue calculation shall be carried out separately for every support. Two load cases for each calculation have to be performed. Concerning Fatigue Strength analysis techniques the main approaches are the following:

- “Nominal stress” method
- “Hot spot stress” method
- “Effective Notch Stress” method

3. **Nominal stress method:** - The nominal stress approach is the simplest and the most common applied method for estimating the fatigue life of steel structures. The FEM model can be constructed both by employing solid (“brick”) elements or “shell” elements. In both cases, it is important to have a correct simulation of effective welded joint stiffness, as compared to base metal sheet stiffness, as this can affect stress distribution within the different regions of the joint. For fillet welds, this makes it preferable to schematically represent the weld transverse geometry and, in the case of shell models, to insert specific elements having a conventional representative thickness. Of special concern is the mesh size in the weld zone. The nominal stress can usefully be calculated by extracting the forces and

moments transmitted through a weld length of the order of the transverse size and calculating, by simple beam theory relationships, the stresses produced on the corresponding resistant section.

4. **“Hot spot” stress method:** - The hot spot stress approach has been developed to enable evaluating the fatigue strength of welded structures in cases where the nominal stress is hard to estimate because of geometric and/or loading complexities. This approach has been used for the fatigue design of pressure vessels and welded tubular connections. The HSS requires an estimate of the linear component of the stress field at the weld toe. This stress component is best achievable by “shell” element models, which automatically filter the non-linear component.
5. **“Effective Notch Stress” method:** - The fatigue strength of welded joints is heavily depended on their notch properties giving higher stress concentrations which leads to lower fatigue life. The notch stress in welded joints is the total local stress caused by both the component geometry and the local stress raiser, i.e. the weld itself.

3.5. CONDITION

3.5.1. Load cases of the bogie frame

For exceptional loads the effective car body mass m_1 including passengers, corresponding to a particular bogie is

$$m_1 = \frac{(M_v + P_1)C}{100} - nbm^+ \tag{3.1}$$

$$P_1 = \text{mass of passengers} = \text{number of passengers} * \text{average weight} \tag{3.2}$$

$$P_1 = 317 * 60\text{Kg} = 19,020\text{Kg} \dots\dots\dots [12]$$

$$m_1 = \frac{(44,000\text{Kg} + 19,020\text{Kg})95}{100} - ((2 * 5,631) + 3,803)\text{Kg}$$

$$m_1 = 44,804\text{Kg}$$

For normal service loads the effective car body mass m_1 including passengers, corresponding to a particular bogie is

$$m_2 = \frac{(M_v + P_2)C}{100} - nbm^+ \quad (3.3)$$

P_2 = mass of passengers = number of passengers * average weight (3.4)

$$P_2 = 254 * 60\text{Kg} = 15,240\text{Kg}$$

$$m_2 = \frac{(44,000\text{Kg} + 15,240\text{Kg})95}{100} - ((2 * 5,631) + 3,803)\text{Kg}$$

$$m_2 = 41,213\text{Kg}$$

Where:

M_v is the mass of car in running order;

P_1, P_2 is the mass of passengers;

C are the wheel loads of the relevant bogie expressed as a %;

m^+ : is the bogie mass;

n_b : Number of bogies.

3.5.2. General expressions for the basic load cases

Exceptional loads Car body loads:

Longitudinal forces (applied at the center of gravity):

$$F_{xc} = m_1 * a_{xc} \quad (3.5)$$

$$F_{xc} = 44804\text{Kg} * 0\text{m/s}^2$$

$$F_{xc} = 0\text{N}$$

Transverse forces (applied at the center of gravity):

$$F_{yc} = m_1 * (a_{yc} + a_{ycc}) \quad (3.6)$$

$$F_{yc} = 44804\text{Kg} * (3\text{m/s}^2 + 2\text{m/s}^2)$$

$$F_{yc} = 268,824\text{N}$$

Vertical forces :

$$F_{zc} = m_1 * (g+a_{zc}) \quad (3.7)$$

$$F_{zc} = 44804\text{Kg} * (9.81\text{m/s}^2 + 6\text{m/s}^2)$$

$$F_{zc} = 708,352\text{N}$$

$$F_{z1c} = F_{z2c} = \frac{F_{zc}}{2} = \frac{708,352\text{N}}{2} = 35418 \text{ N} \quad (3.8)$$

Bogie frame loads

Longitudinal forces :

$$F_{xb} = m_3 * a_{xb} \quad (3.9)$$

$$F_{xb} = 5631\text{Kg} * 0\text{m/s}^2$$

$$F_{xb} = 0\text{N}$$

Where:- m_3 = bogie weight which is 5631K.g for Mc and 3803K.g for Tp bogies of AARLT

Transverse forces (applied at the center of gravity):

$$F_{yb} = m_3 * (a_{yb}+a_{ycb}) \quad (3.10)$$

$$F_{yb} = 5631\text{Kg} * (5\text{m/s}^2 + 2\text{m/s}^2) \quad F_{yb} = 31497\text{N}$$

Vertical forces (applied at the center of gravity):

$$F_{zb} = m_3 * (g+a_{zb}) \quad (3.11)$$

$$F_{zb} = 5631\text{Kg} * (9.81\text{m/s}^2 + 12\text{m/s}^2)$$

$$F_{zb} = 12281\text{N}$$

Table 5: symbols of Accelerations which are used in load cases.

Acceleration (m/s ²)	Symbol	
	Vehicle body	Bogie (primary spring)
Vertical	a_{zc}	a_{zb}
Transverse (dynamic)	a_{yc}	a_{yb}
Centrifugal (quasi-static)	a_{ycc}	a_{ycb}
Longitudinal	a_{xc}	a_{xb}

Table 6 : 7symbols of Masses which are used in load cases.

Mass (kg)	Symbol
Vehicle in running order	M_V
Vehicle body	m_1
Bogie mass without any secondary spring masses (if present)	m^+
Bogie primary spring mass	m_2
Exceptional payload	P_1
Normal service payload	P_2

Table 8: symbols of forces which are used in load cases.

Force (N)	Position	Symbol		
		Static	Quasi-Static	Dynamic
Vertical	Load applied to bogie	F_z		
	Force on sideframe 1 or sidebearer 1	F_{z1}	F_{z1qs}	F_{z1d}
	Force on sideframe 2 or sidebearer 2	F_{z2}	F_{z2qs}	F_{z2d}
	Force on centre pivot	F_{zp}	F_{zpq}	F_{zpd}
	Force at (vehicle body) c of g	F_{zc}		
Transverse	Load applied to bogie	F_y		
	Force on axle 1	F_{y1}	F_{y1qs}	F_{y1d}
	Force on axle 2	F_{y2}	F_{y2qs}	F_{y2d}
	Force at (vehicle body) c of g	F_{yc}		
	Force due to wind	F_{wl}		
Longitudinal	Force at each wheel	F_{x1}		
	Force at (vehicle body) c of g	F_{xc}		
	Force at (vehicle bogie) c of g	F_x		

3.5 FINITE ELEMENT METHOD MODELING FOR BOGIE FRAME CATIA

The researcher has selected the motor bogie frame for the finite element analysis between the two kinds of AARLT bogie frame.

3.5.3. Modeling using CATIA

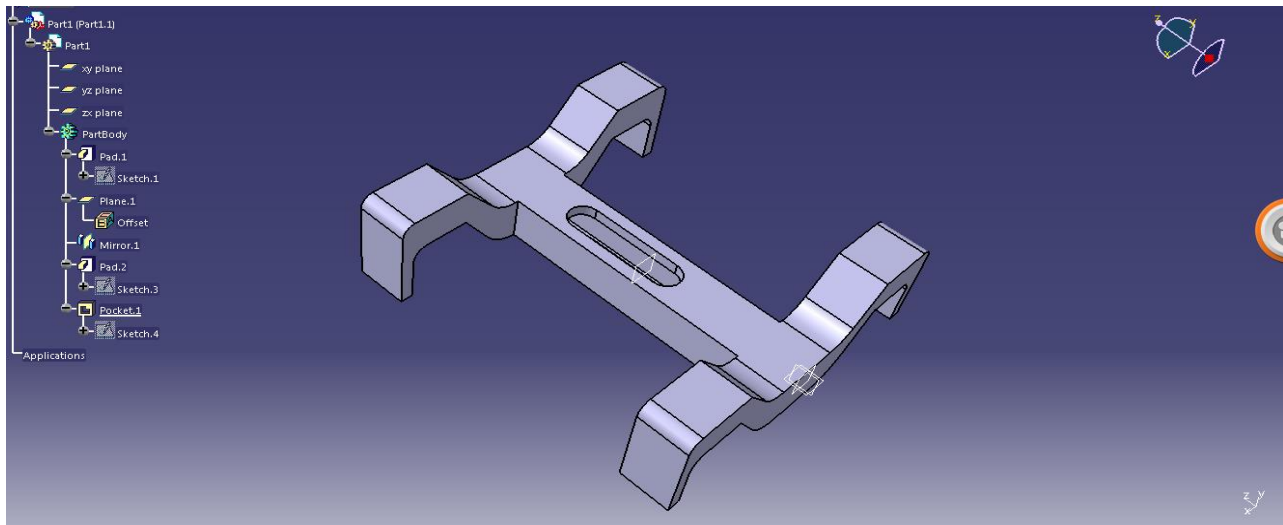


Figure 5: modeling of the bogie fame using catia software

3.5.2 Modeling the bogie frame using ANSYS

Geometry of bogie frame using ANSYS workbench for exceptional load

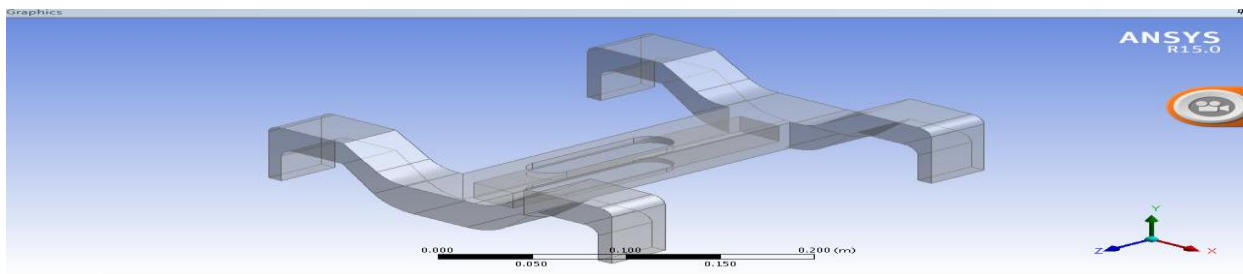


Figure 6: static analysis structure of the geometry of the bogie frame

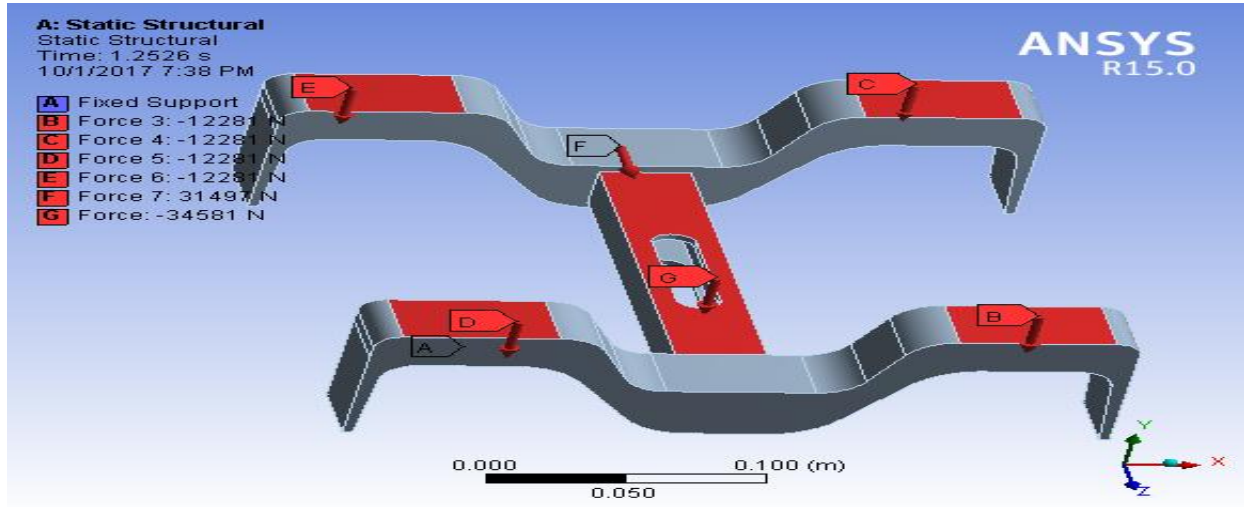


Figure 7: The applied force and the fixed support of the bogie frame

3.6. MATERIALS PROPERTIES

Table 9: materials properties

MATERIAL	POISSON RATIO	ELASTIC MODULUS	YIELD STRENGHT	TENSILE STRENGHT
AISI4140	0.3	210GPA	415MPA	655MPA
steel UNI EN 10025 S355J2G3C	0.27	206GPA	335MPA	612.5

3.7. Fatigue Simulation Process using fatigue simulation program FEMFAT

A simulation tool for fatigue assessment is FEMFAT, developed by the Austrian company Magna Steyr. It is well-established software used by various companies in the automotive and engineering industry. It carries out fatigue assessment based on the results of finite element analyses. The software consists of different modules. The FEMFAT MAX module is used for analyzing components subjected to multi-axial loadings and it allows a superposition of multiple stress states. All analyses within this Thesis were carried out with FEMFAT MAX version 5.0 and whenever it is written FEMFAT in this paper, it is referred to the software tool FEMFAT MAX. In the following section the simulation process for fatigue assessment of the bogie frame is outlined.

I. Material data

In the first step the material data, i.e. the FE-model, has to be imported into FEMFAT. The material properties should be put it to have some result.. It is possible to evaluate 2D and 3D elements but in this Thesis the analyses are limited to 3D elements. By putting the material properties as a input will lead to different result.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1. RESULT

4.1.1. Static analysis result for the selected material

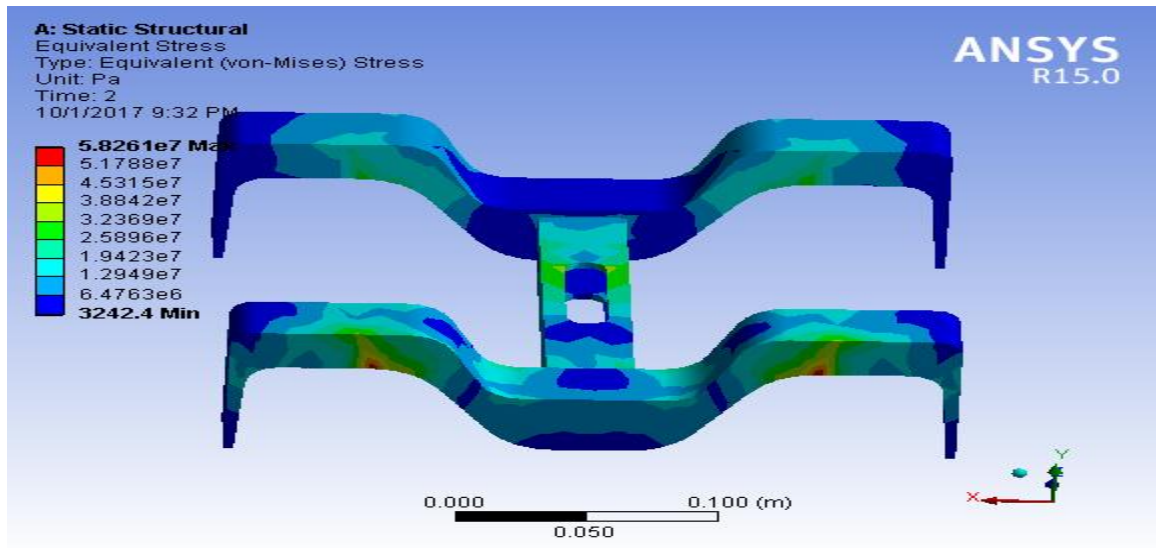


Figure 8: equivalent (von-mises) stress by Ansys

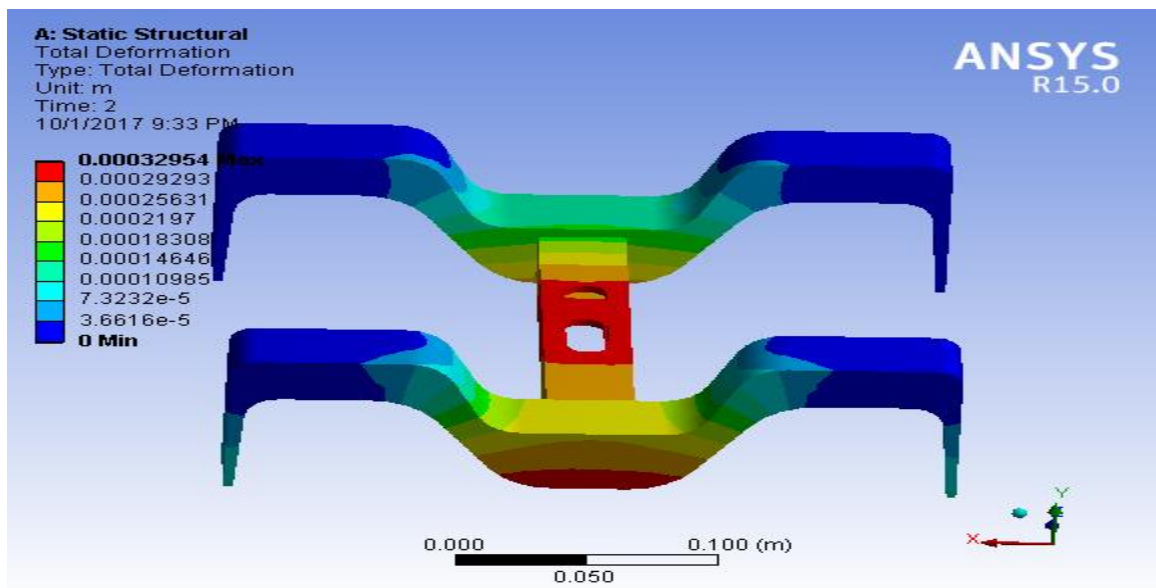


Figure 9: total deformation by Ansys

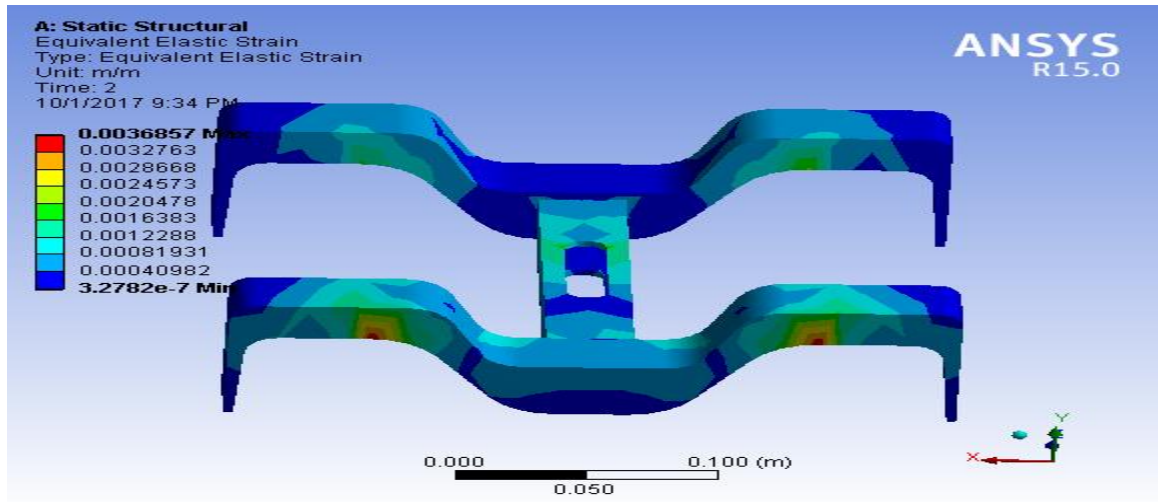


Figure 10: equivalent Elastic strain using Ansys

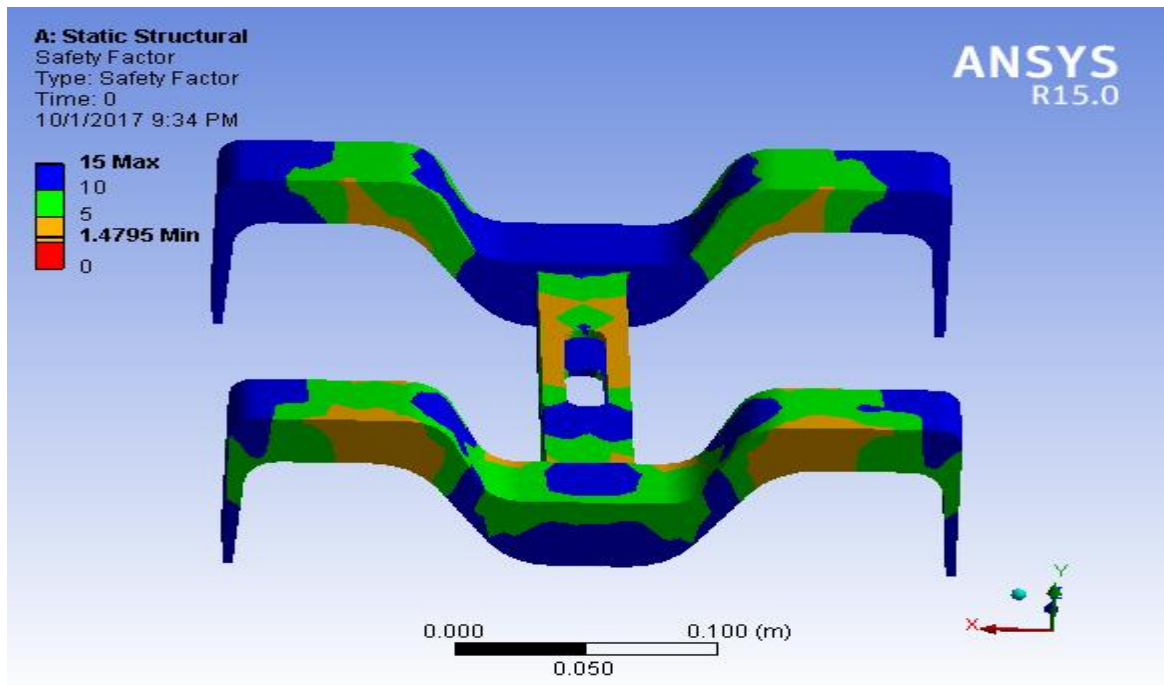


Figure 11: safety factor using Ansys

4.1.2. Static analysis result for the current material

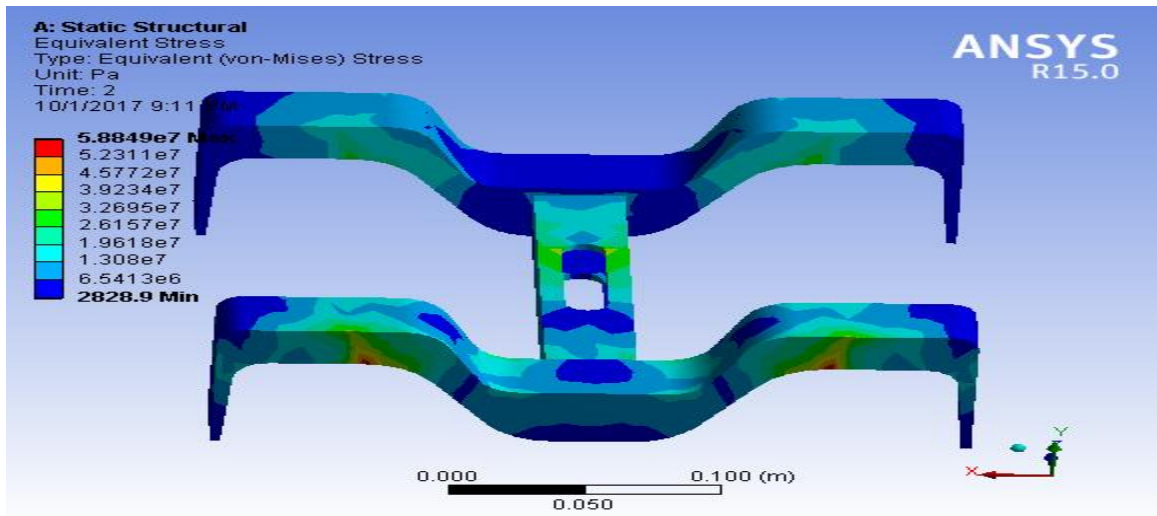


Figure 12: equivalent (von-mises) stress for the current material

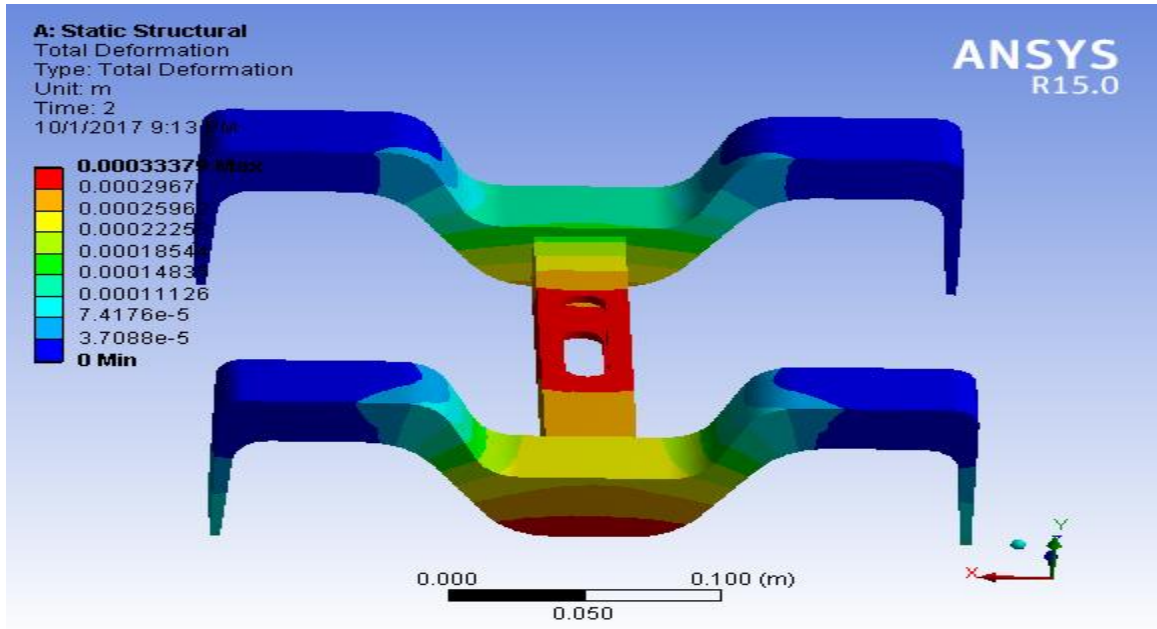


Figure 13: Total deformation for the current material

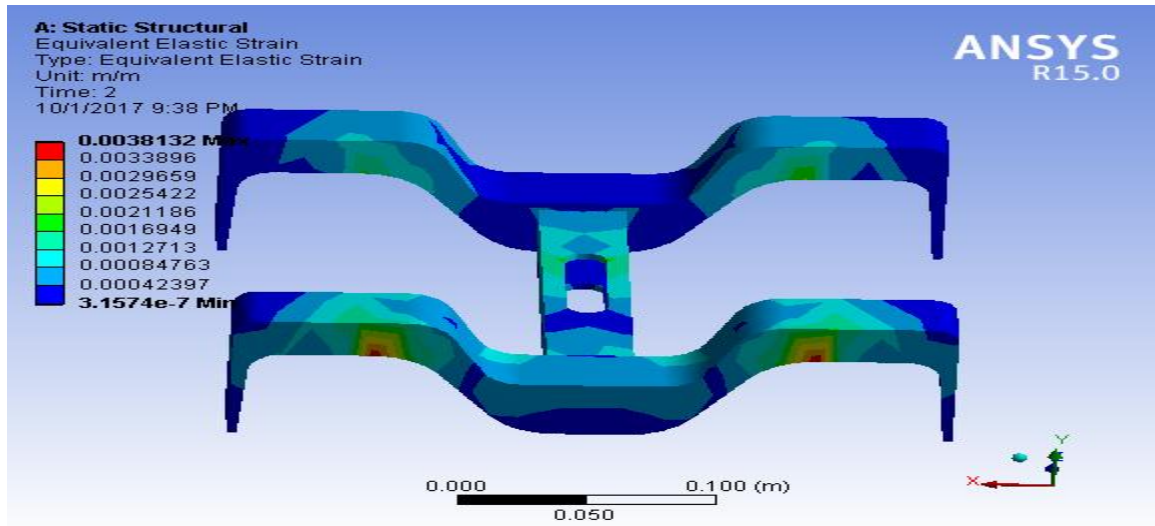


Figure 14: equivalent elastic strains for current material

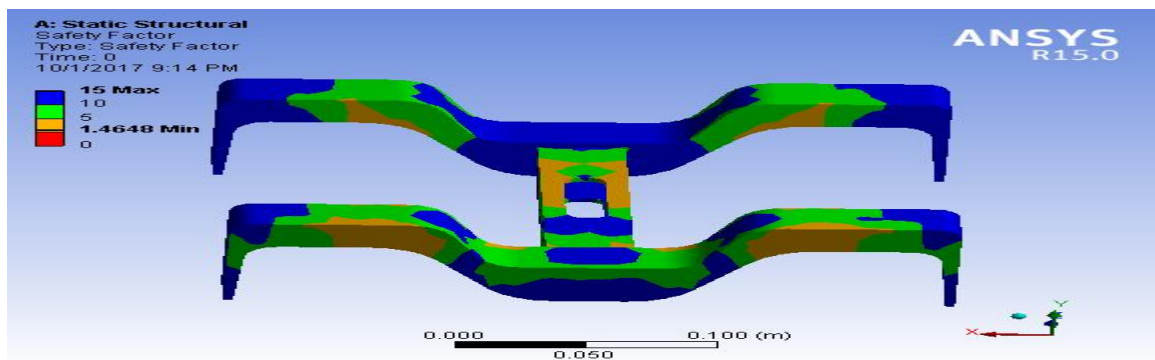


Figure 15: safety factors for the current material

Table 10 : summery of the Ansys result

COMPARISON FACTOR	SELECTED MATERIAL	CURRENT MATERIAL
EQUIVALENT (VON-MIXES) STRESS	5.8226e ⁷	5.8849e ⁷
EQUIVALENT ELASTIC STRAIN	0.0036857	0.0038132
TOTAL DEFORMATION	0.0003295	0.0003337
SAFETY FACTOR	1.4795	1.4648

4.2. FEMFAT RESULT

4.2.1. RESULT OF THE CURRENT MATERIAL

The screenshot displays the 'Material Data' management interface. On the left, a list of materials shows two entries: '1 - UNI EN10025S355J2G3C'. In the center, there are buttons for 'Import', 'New', 'Export', 'Copy', 'Report', and 'Delete'. To the right, the 'Material Generator' section is active, with 'Controlling' set to 'Stress' and 'Standard' set to 'FKM'. Below this are 'Open' buttons for both the generator and 'Defect Definition'. On the far right, three diagrams are shown: an S-N curve, a stress-strain (σ - ϵ) curve, and a Haigh diagram. The bottom section, titled 'Header Lines', contains input fields for 'Material and Specimen Name' (UNI EN10025S355J2G3C), 'Remarks' (Strain data: Calculated from S-N Curve), and 'Data Source' (Source: Material Generator MATGEN (Copyright EC)). A tree view on the left side of the bottom section shows expandable categories like 'General Data', 'Linear Static Data', 'Multilinear Young's Modulus (not used for analysis)', 'Cyclic Stabilized Data', 'Strength Data', 'Tension', and 'Compression'.

Figure 16: inputting material data in FEMFAT FILE

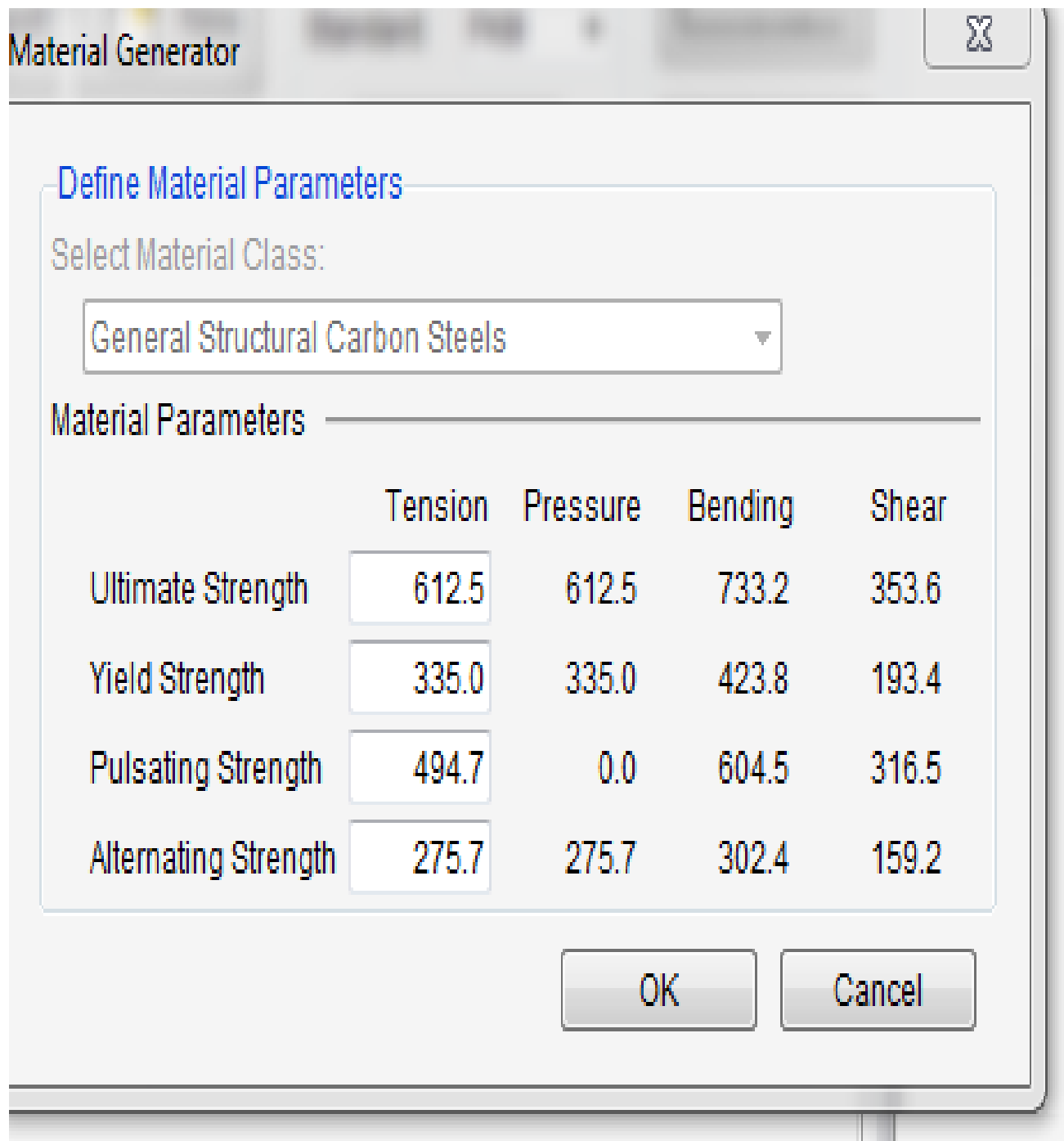


Figure 17 : material parameters

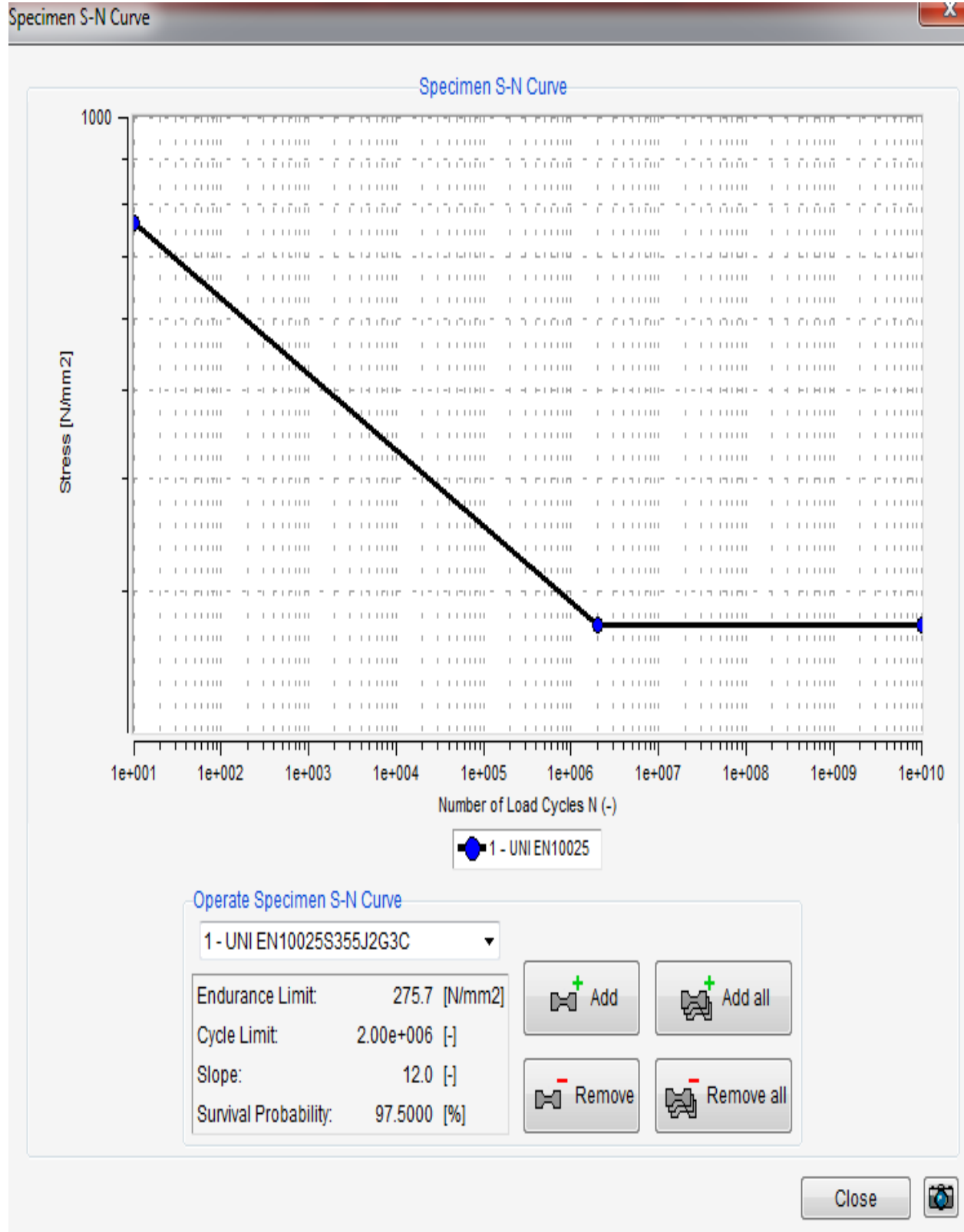


Figure 18: Specimen S-N curve

4.2.2. RESULT FROM SELECTED MATERIAL USING FEMFAT

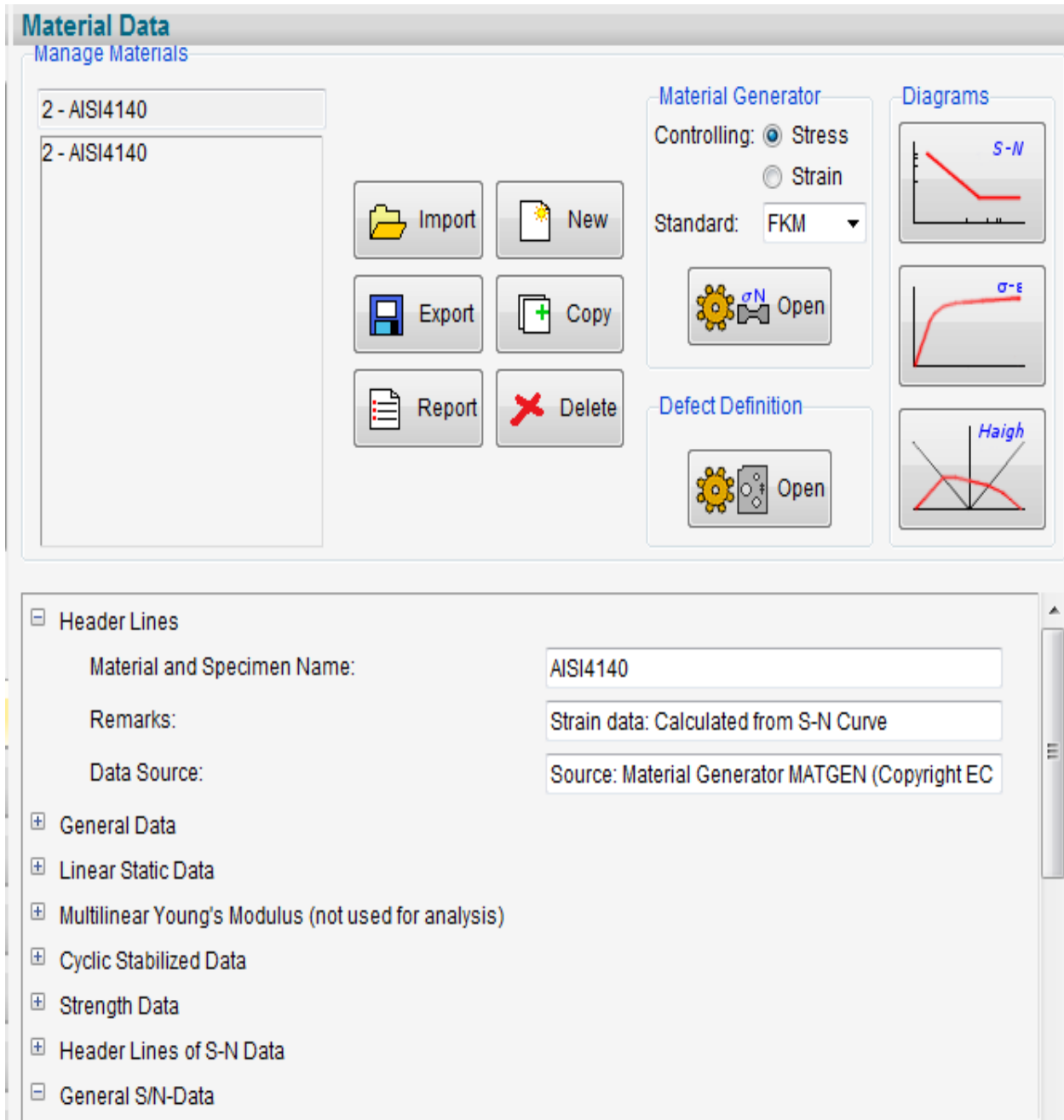


Figure 19: manage materials from selecting material

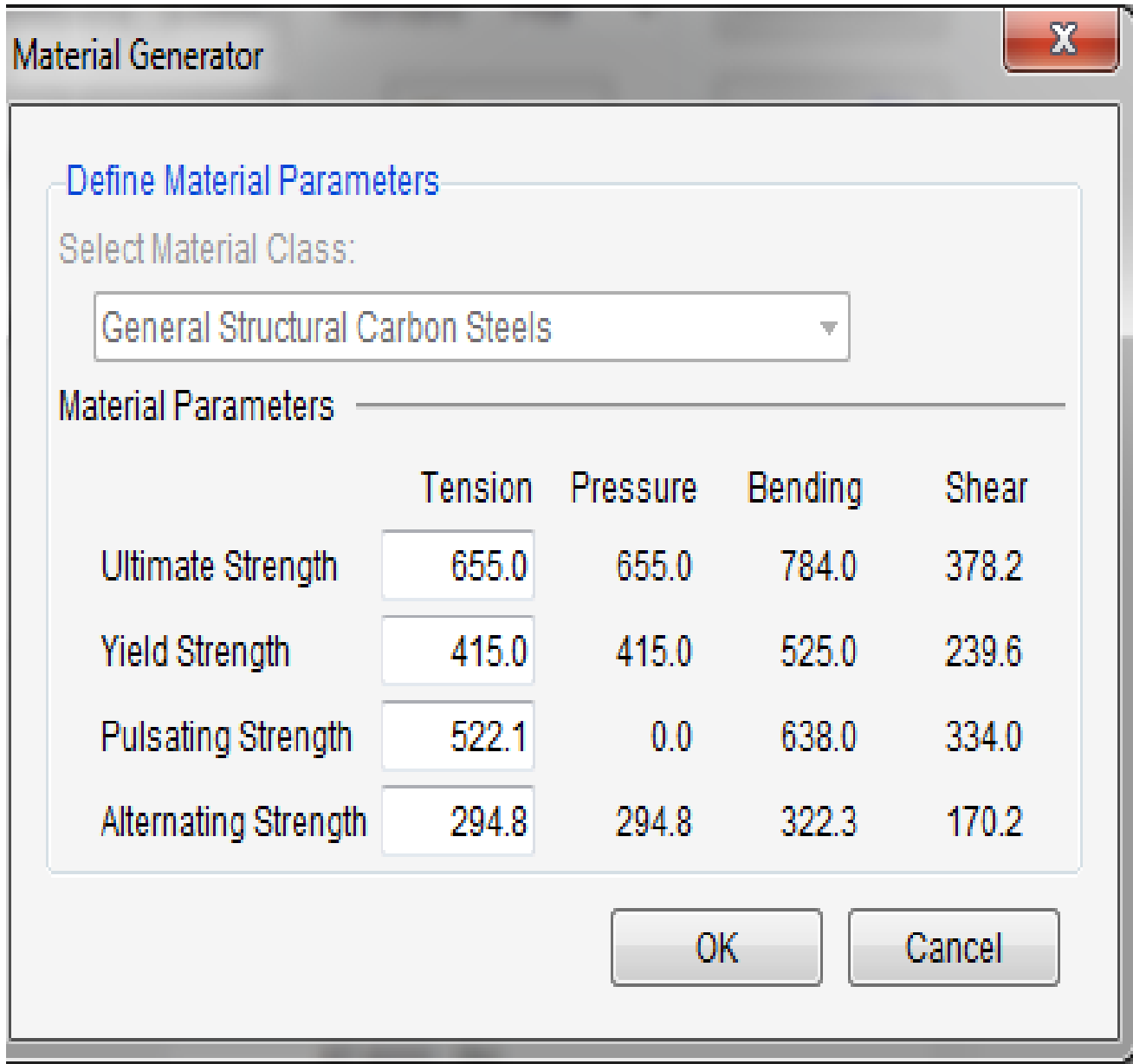


Figure 20: define material parameters

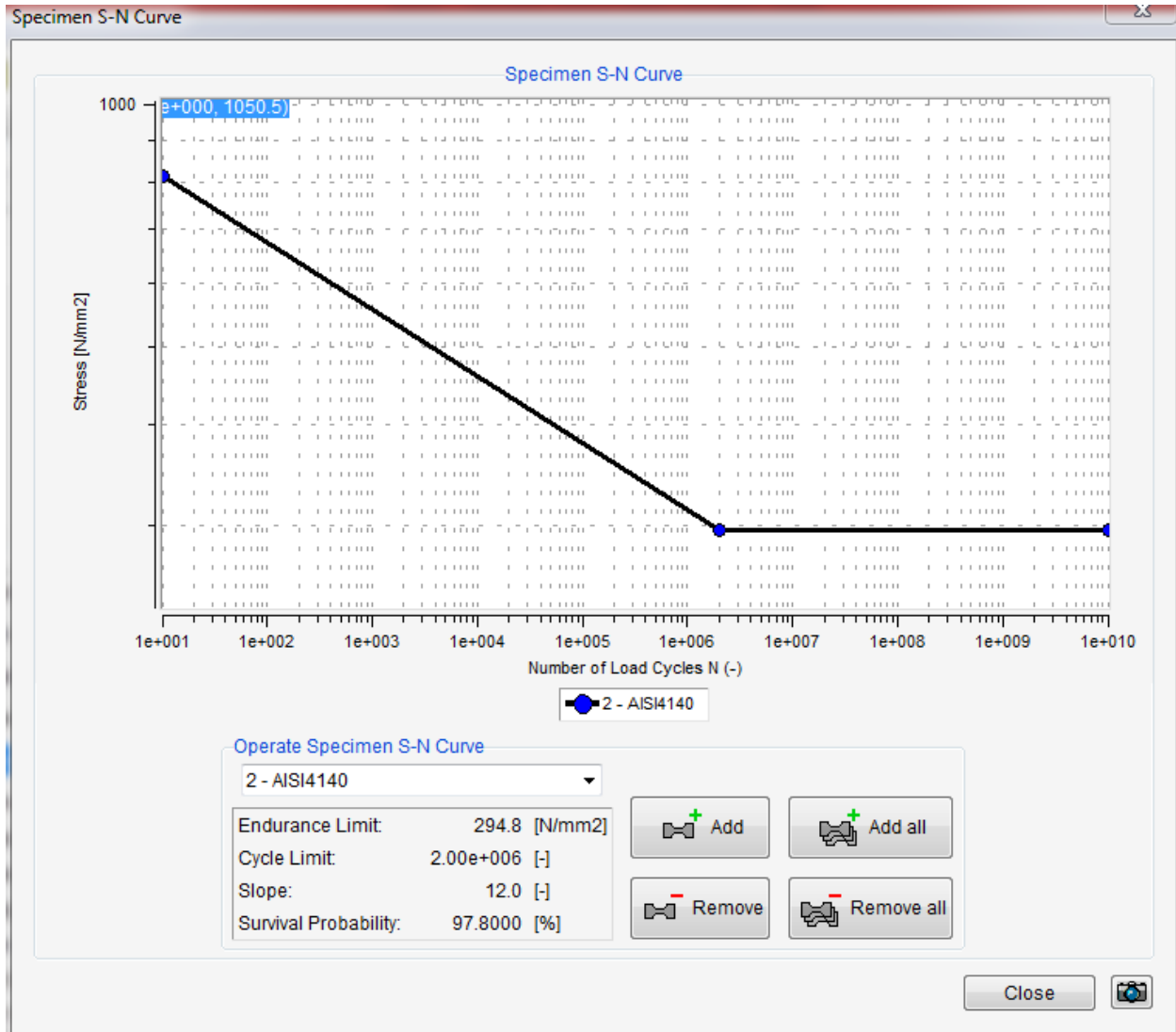


Figure 21: specimen S.N curve from selected material

4.2.3. S.N CURVE OF THE MATERIALS

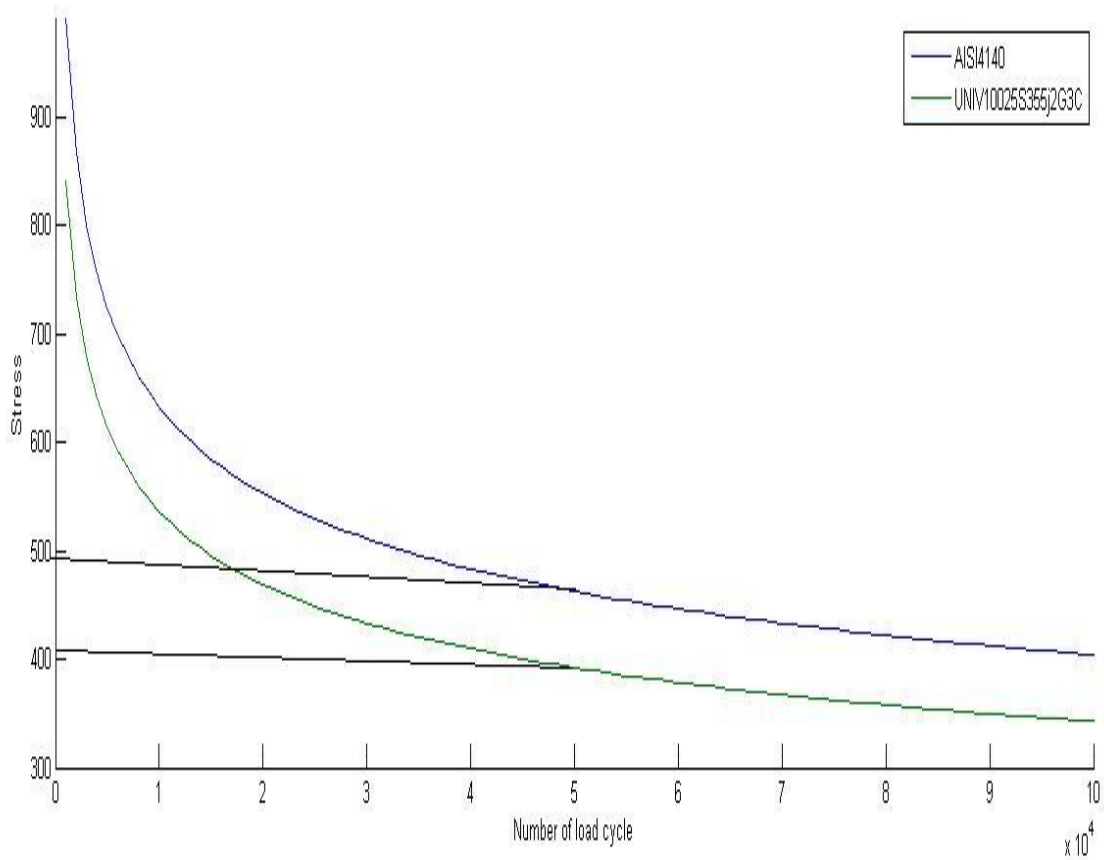


Figure 22: Representation of S.N curve with different endurance limit

4.3. DISCUSSION

The Bogie frame is the main load bearing component of the vehicle , when the vehicle is in motion the process , not only to the bogie frame to withstand load , the bogie frame is subjected to a combination of vertical, longitudinal , lateral and other particular force (roll, yaw) . Result will be stress, strain, total deformation, safety factor. Detailed results are available in the report file discussed above.

Summery table show, that the maximum stress of current material is greater than that maximum selected material with $5.8849e^7$ up to $5.8226e^7$, therefore the possibility of wear or fatigue strength decreasing or damage on the current material is greater than the selected material. In the other hand the result shows that the safety factor of the selected material is greater than the current 1.4795 up to 1.4648 which mean that the selected material can withstand the overload.

Since the research is about to developing the new materials, S.N curve is utilized. FEMFAT (finite element fatigue) software above compare the existing material with develop one by showing different endurance limit and survival probabilities. The conventional material is below than the new material, therefore that developed material will be more difficult to break and stronger than conventional one.

This paper focus on selecting a material for bogie frame in order to improve the fatigue strength and also to withstand the overload.

CHAPTER FIVE: CONCLUSION, RECOMMENDATION, FUTURE WORK

5.1. Conclusion

The purpose of this study is developing a material for improving fatigue strength of the bogie frame of AARLT. In the current simulation processes the ANSYS and FEMFAT software is used to evaluate the fatigue life of the materials. The fatigue life of a member or a structure detail subjected to repeated cyclic loadings is defined as the number of stress cycles it can stand before failure. Stress difference or as most often called stress range is one of the main parameters can influence the fatigue strength. The stress needs to take account for the case of failure in order to get reliable result. THE FEMFAT software has been helpful to compare the two materials by their properties.

On the bases of this discussion the researcher forward the following conclusion. The stress and strain of the current material is higher than the conventional one which leads the possibility to fail. The safety factor of the new material is 1.4795 rather the safety factor of the current material 1.4648. The stress between the two material varies $5.8226e^7$, $5.8849e^7$. the selected material has less deformation. FEMFAT reveal that the selected material has higher endurance limit and survival probabilities than current material.

Based on the result, the new material will carry a load stronger than the conventional material and will be much difficult to break.

5.2. RECOMMENDATION

The research study reveal an optimum stress , total deformation and safety factor for the selecting material and suitable fatigue strength of the bogie frame . On the basis of the result the researcher recommends giving a special attention to the material properties such as the mechanical, chemical, thermal, environmental properties. Also the best recommendation that the researcher suggest is to be familiar with software FEMFAT in order to study the fatigue life of different material and to choose the best material of all component of the train body. Selecting a better material basic on is strength, ductility, toughness will improve the fatigue life of the bogie frame. Additionally the researcher suggests that there should be a skilled man power who can conduct the material properties carefully in order to minimize the failure and increase fatigue life of the bogie frame.

5.3. FUTURE WORK

The future plan of Ethiopian Railway Corporation is intended to produce the whole components of the train; so that manufacturing process needs to be qualified. While we are talking about safety issues concerning the bogie frame conducting a fatigue analysis will be imperative. The Frame is the main bearing component of bogie and the reliability of which directly affects the performance and safety of the locomotive so that conducting a research on the material of the bogie frame for improving fatigue strength is very essential to prove the safety of the train for a long time.

For further research activities the researcher will suggest the following future works:-

- Conduct a practical fatigue test on the welded bogie frame by using fatigue testing machine in the laboratory and compare the results with the analytical one.
- Identify and improve the life of crack initiation and propagation.
- Conduct a fatigue analysis on different kinds of bogie frames including freight trains.
- While conducting the fatigue test avoid the residual stress by using deferent technics i.e. Surface treatment, tempering and etc.

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12. GENERAL KNOWLEDGE ABOUT ROLLING STOCK BY WAKUMA GUTA

