SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

MASTERS OF RAILWAY ENGINEERING

WEAR ANALYSIS OF OVERHEAD LINE CONTACT WIRE USING ANSYS WORKBENCH SOFTWARE

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ABSTRACT

In this thesis, the main objective is analyzing the overhead line contact wire wear rate using ANSYS Workbench software. The wear is defined as the progressive loss of substances from the operating surface of a body occurring as a result of relative motion at the surface. The simulation of contact wire is performed on pin on disc model, where the model is used for sliding contact analysis. The pin made of contact wire materials which are Cu, CuAg, and CuNiSiCr in sliding contact with rotating disc that made of stainless steel. The wear analysis start from modeling pin on disc model to final solution phase is performed on ANSYS Workbench 12.0. Using a displacement boundary condition on pin, disc and holder and applying 617.63 rad/sec rotational velocity on disc the analysis is done. Then by varying the tensile load acted upon the tensile yield strength of the pin material and taking that the region of the pin where maximum equivalent stress occurred is failing or wearing out. The pin model that exhibit maximum equivalent stress has an approximate length of pin that worn out and is taken in order to find the volume of wear material. This process is performed for all sample pin materials taken for wear analysis. Using wear volume the wear rate and wear resistance of material is calculated, those values helps to determine which pin material has high strength to resist the wear from the maximum tensile load. As result of wear analysis, the CuNiSiCr copper alloy has better wear resistance property in comparison to the other sample pure Cu and CuAg materials.

Key word: wear analysis, equivalent stress, wear rate

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NOMENCLATURE

AAIT- Addis Ababa Institute of Technology

AALRT- Addis Ababa Light Rail Transit

OCS- Overhead Contact System

LRT- Light Rail Transits

DC- Direct Current

AC- Alternating Current

Cu- Copper

Ag- Silver

Ni- Nickel

Si- Silicon

Cr- chromium

Zr- Zirconium

Be- Beryllium

Mg- Manganese

ANN- Artificial Neutral Network

OCS- Overhead Contact System

NaCl- Sodium Chloride

L- Length between Pantograph Heads

N- Number of Pantograph Oscillation

FE- Finite Element

FEM- Finite Element Model

FEA- Finite Element Analysis

K- Wear Coefficient

H- Hardness of Tasted Material

P - Applied Pressure

V - The Sliding Speed

APDL- ANSYS Parametric Design Language

F- Applied Force on Pin Holder Top Face

μ- Coefficient Of Friction

f_f - Frictional force on disc surface

V- Running Speed of Rail Vehicle

r- Radius Of Rotating Disc

ω- Rotational Velocity

D- Diameter

OD- Outer Diameter of Disc

ID- Inner Diameter of Disc

L- Length

T- Thickness

ρ- Density of pin materials

E- Elastic Modulus property of material

v- Poison’s Ratio

y- yield strength

H- Hardness Property of Material

V- Wear Volume

W- Wear Rate

R- Wear Resistance

1. CHAPTER ONE: INTRODUCTION

1.1. Background

An overhead line or overhead wire is used to transmit electrical energy to trams, trolleybuses or trains.In 1881 the first tram with overhead lines was presented by Werner von Siemens on the International Electric Exposition in Paris 1881 but the installation was removed after that event. In October 1883, the first permanent tram service with overhead lines was started on tram in Austria. These trams had bipolar overhead lines, consisting of two U-pipes, in which the pantographs hung and ran like shuttles. In April to June 1882, Siemens had tested a similar system on his Electro mote, an early precursor of the trolleybuses. [1]

With the presentation of the world's first electric locomotive in 1879, Werner von Siemens defined a major milestone in transportation, which was quickly followed by other achievements, such as the invention of the pantograph in 1887, the construction of the vertical catenary system in 1905 and the introduction of auxiliary catenary wires as early as 1911. And in 1960 introduced overhead contact lines that were suitable for running speeds of 200 km/h, a development, which have continued with the installation of contact lines for the high speed routes of Rail until today. [2]

Much simpler and more functional was an overhead wire in combination with a pantograph borne by the vehicle and pressed at the line from below. This system, for rail traffic with a unipolar line, was invented by Frank J. Sprague in 1888. Since 1889, it was used at the Richmond Union Passenger Railway in Richmond, Virginia. That was the onset of worldwide use of electric traction.

Overhead line is designed on the principle of one or more overhead wires or rails, particularly in tunnels situated over rail tracks, raised to a high electrical potential by connection to feeder stations at regular intervals. The feeder stations are usually fed from a high-voltage electrical grid.

The main advantage of electric traction is a higher power to weight ratio than forms of traction such as diesel or steam that generate power on board. Electricity enables faster acceleration and higher tractive effort on steep gradients. Other advantages include the lack of exhaust smokes at point of use, less noise and lower maintenance requirements of the traction units. Given sufficient traffic density, electric trains produce fewer carbon emissions than diesel trains.

1.2. Electrification System

A railway electrification system supplies electrical energy to railway locomotives and multiple units so that they can operate without having an on-board prime mover. Railway electrification has many advantages but requires significant capital expenditure for installation.

There are two common type of electrifying trains one is through overhead line or using third rail where the train get its electricity from the rail built in between the two rail tracks.

1.2.1. Third rail system

Third rail systems can be designed to use top contact, side contact or bottom contact. Third rail is more compact than overhead wires and can be used in smaller diameter tunnels, an important factor for subway systems. In practice, all third-rail systems use DC because it can carry 41% more power than an AC system operating at the same peak voltage.

DC systems especially third rail systems are limited to relatively low voltages and this can limit the size and speed of trains and cannot use low-level platform and also limit the amount of air-conditioning that the trains can provide. This may be a factor favoring overhead wires and high voltage AC, even for urban usage. In practice, the top speed of trains on third-rail systems is limited to 160 km/h because, above that speed, reliable contact between the shoe and the rail cannot be maintained.

Figure 1. Third rail electrification system [1]

1.2.2. Overhead line contact system

Overhead contact systems comprise a support system poles, wall and attachments, cantilevers, cross spans, conductors, etc., which may be arranged in one of a variety of configurations and anchorages to tension the conductors. The conductor will be a continuous, energized, un-insulated contact surface suspended above the railway tracks from which electric locomotives can draw power by means of current collectors. This conductor is typically about 6m above the track but can range from 3.5 to 7.3 m above top of rail. In overhead contact use pantograph for current collector whereas contact shoe for third rail system.

In comparison to third rail electrification system the overhead line train electrification is most advantageous through,

- Its simplicity and robustness of its components
- Simplifying installation and maintenance
- The considerable height above the track, reducing the risk of accidental contact.
- The great surface area, improving the system's own refrigeration and lowering the risk of over melting by overheating
- The great conductor section, allowing high current intensities and eliminating the necessity of feeders

In Ethiopia overhead contact system and return current along the running rail used that shall be able to provide safe, reliable, and economical and reasonable power supply, with simple wiring, flexible operating mode, and convenient engineering execution, management and maintenance.

1.3. Means of Contact Wire Failure

The service lifespan of the overhead catenary and collector strips essentially depends on

I. Type of materials at contact;
II. Operating conditions such as sliding speed, contact force and current intensity;
III. Level of sparking or arching
IV. Environmental factors such as catenary in tunnels or in the open space[2]

Conventionally, hard-drawn copper is often used as overhead catenary for traction systems because of its excellent electrical and thermal conductivities and moderately low price but its limitations are low hardness, susceptibility to electrical sliding wear and atmospheric corrosion which lead to shortening of its service life, interruption of the system, and safety problems.

Figure 2. Structure of overhead line and its elements in AALRT

Overhead line is a structure use consists of a conductors contact wires suspended by mast or poles. For certain applications, copper alloy conductors are preferred instead of pure copper, especially when higher strengths or improved abrasion and corrosion resistance properties are required.

Wear and corrosion is the main cause of train overhead failure. A high contact force causes wear at overhead line and pantograph contact strip. In addition, increasing the abrasion of the contact wire or the pantograph strip leads to the arc. The necessary measures should be taken to reduce wearing so that maintenance costs will be reduced as well as the service life of the used equipment will be extended [4]. The wear of overhead catenary materials, and metallurgical study for the wear process, such as the morphology of the worn surface and the debris formed, is very much necessary, the wear arising from friction and arc formation was analyzed in the laboratory environment, and via software.

Corrosion is the electrolytic action of moisture and other dissolved ions of the atmosphere on the metals. The corrosive effects of the outdoor environments, for instance, salty coastal atmosphere, acid rain and icing, present unique challenges to overhead catenary and lead to degradation and eventually to system failure. Therefor the corrosion analysis of train overhead line is necessary for having longer service life and high conductivity.

1.4. Contact wire materials

As stated above on means of contact wire failure the type of material used for manufacturing contact wire is the first and major factor for determining the service life of the wire. The other factors are comes next to materials that provide the required property for seating longer service life of overhead contact wire. Age harden copper alloys are the only material types used in electrifying train. [3]. Copper and copper alloys are widely used in a variety of products that enable and enhance engineering activities. They have excellent electrical and thermal conductivities, exhibit good strength and formability, have outstanding resistance to corrosion and fatigue, and are generally nonmagnetic. Silver(Ag), Nickel(Ni), Silicon(Si), Chromium(Cr) are the most common elements that alloyed with copper for manufacturing overhead line contact wire, those elements provide different mechanical, thermal and chemical property to final copper alloy material.

Copper’s malleability, machinability and excellent conductivity have made it a longtime favorite metal of manufacturers and engineers. Due to its reasonably low tensile strength it become difficult to use pure copper for overhead line contact wire. The addition of nickel to copper improves its strength and durability and also the resistance to corrosion, erosion and cavitation. The alloys show high resistance to stress corrosion cracking and corrosion fatigue [24].

Chromium can be used to replace some of iron content and at one percent or more provide higher strength. Silver is used extensively in the preparation of high temperature superconductor wires, and other configurations in which the silver not only shields the superconducting material from the surrounding materials, but also provides a flexibility and strain relief, as well as stabilization and low resistance electrical contact. Silver is relatively expensive, but at this stage of superconductor development, its unique combination of properties seems to offer the only reasonable means of achieving usable lengths of conductor in rail way electrification system[25].

Eight commercial copper based alloys, including pure Cu, CuZn, CuCr , CuZr, CuCrZr, CuNiSiCr, CuBe, CuBeNi and common CuAg were selected and used for overhead line contact wire electrification system in the present study. On this paper a pure copper, due to its relatively high strength a commonly used copper silver alloy and copper nickel silicon and chromium alloy wear assessment is performed.

Table 1: Composition and properties of Copper and its alloy [3]

Alloy	*Composition*	*Electrical conductivity*	*Density (g/cm^3)*	*Hardness(Hv)*
Cu	0.04% O	100%IACS, 58MS/m	8.90	102
CuCr	1.2% Zr	74%IACS, 43MS/m	8.89	162
CuZr	0.25% Zr	80%IACS, 47MS/m	8.89	132
CuCrZr	1.4% Cr 0.12% Zr	74%IACS, 43MS/m	8.89	168
CuNiSiCr	2.5% Ni 0.8% Si 0.5% Cr	29%IACS, 17MS/m	8.84	234
CuBe	2% Be	23%IACS,13MS/m	8.36	342
CuBeNi	0.4% Be 1.5% Ni	44%IACS, 25.8MS/m	8.83	242
CuAg	0.7% Ag		8.8	219

1.5. Statement of the Problem

In order to provide safe and reliable service of railway on Addis Ababa light rail the overhead line wire need to be wear resistance. The overhead line wire common material is copper that provide excellent electrical and thermal conductivities and compared to others cupper is a low price. However using cupper lack of hardness, strength to electrical sliding wear which lead to shortening of its service life. Therefore it's essential to use an alloy of cupper that can resist the sliding wear.

On this paper it is concerned with analysis of copper alloy material wear assessment. The copper alloy provide different property in respect to pure copper material, it changes the wear rate during electrical sliding, So the analysis of wear rate is very much necessary for reliable electrification of train. In this case the copper alloy used for wear analysis is CuNiSiCr which is rich material better than CuAg alloy for Addis Ababa LRT overhead contact wire, and the wear experimental analysis is already performed by Samrawit at AAIT and I'm interested to validate those result using aid software that can analysis wear and corrosion under differ conditions.

1.6. Objective of the Research

1.6.1. General objective

The main objective of this paper is identifying the wear property of overhead line contact wire materials Cu, CuAg and CuNiSiCr for Addis Ababa light rail transit using aid of ANSYS Workbench software.

1.6.2. Specific objectives

The specific objectives of the research are:

- Studying the copper and its alloy material property
- Determine the load and wear type that exist on overhead line contact wire
- Model wear simulation using ANSYS Workbench geometry software
- Determine the maximum wear depth and stress that cause wear
- Show the relation of wear rate and resistance property of each materials

1.7. Methodology of Research

Some basic procedures that will be followed in order to fulfill the objective of the research paper are stated below:

1. Identifying the copper and its alloy material property and its composition
2. Select Modeling type and model overhead wire using ANSYS Workbench geometry software
3. Analyze wear of the modeled overhead wire using ANSYS software using different operating condition
4. Identifying the equivalent stress, wear rate, wear volume, and wear resistance of sample materials in all three load conditions
5. Identifying the basic similarity and difference of the results and state the cause of difference

Where all of the above procedures will be conducted with application of a specified conditions and constraints that helps to get the suitable and reliable result.

1.8. Significance of the Research

This research paper outcome has a great role for the further analysis and work of overhead line wire. Where the advantage of this research mostly relay on the material analysis in point of strength , wear resistant property, and increasing softening temperature which can lead to high wear due to sliding contact. For newly constructing of Ethiopian light rail way this research provide new point of view and knowledge in electrification system of train. In the future this paper add more knowledge on analysis of wear rate using related software in simplified and effective way. This paper indicates the easy way of analyzing overhead line wire wear and corrosion using different operating conditions.

1.9. Scope of the Research

On this paper the overhead line contact wire material wear analysis is executed using an ANSYS Workbench software. The overhead line contact wire used in analysis is an improved material to that of material used in AA LRT, and the copper alloy CuNiSiCr wear rate will be analyzed with different operating condition and load applications. On this research paper the analysis is performed with free of current flow and under ambient temperature. Finally the result will help to determine which material have high strength and resist wear also the result will be compared with the experimental wear analysis.

1.10. Organization of the Paper

This paper is organized in to five main chapters. The first chapter discusses the introduction of the electrification system and the study. On this chapter background, objectives, statement of problem and methodology is identified. On the second chapter two is the review of literature that includes journals, articles and publications that related to the research paper work. Additionally on this chapter some literature work is also seen that related to field of study to strength the paper. On chapter three the model and wear analysis is discussed on this chapter the contact mechanics and wear mechanisms are analyzed. The requirement for analysis of contact mechanics or wear using related software also studied on the chapter three. On fourth chapter the final result and discussion is performed. The result is obtained from the contact analysis using related software. The software provide basic solutions that helps to determine the require answers for the study based on the results the discussion follows. On the final chapter, conclusion and recommendation of the study is placed. Based on the result of analysis conclusion and recommendation is stated, additionally the possible future work on the field of the study is included on this chapter.

2. CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

There are many journals, articles, thesis papers, books, conference and published study in the world related to overhead line contact wire and wear analysis. Some of them which are considered to be essential and basic are discussed. In those previous works there are different approach used to analyze the wear and corrosion of overhead line contact wire using different materials, and those different approach and methodology will assist the paper that of this paper. There are some papers that do not relate to the wear and corrosion resistance analysis of overhead line contact wire material but give different approach to the current study through providing another way of analyzing wear and corrosion analysis of material using software's.

The rapid increase of railway service the infrastructure need to provide a reliable and safe service, and the one that must be considered in this increased high speed modern locomotive is the electrification system that include the one overhead line contact wire. In current advancement of electrification system of train major efforts have been devoted to increasing lifetime and reducing maintenance costs of the overhead line contact wire and collector strips. The overhead line contact wire need to with stand severe load conditions, environmental effects, high electrical conductivity and able to resist the sliding wear. From many papers some of them are reviewed below.

2.2. Papers Reviewed

F.J. Gonzalez, J.A. Chover, B. Suarez and M. Vazquez [7] this study is to determine the critical wear levels of the contact wire of the catenary on metropolitan lines. The study has focused on the zones of contact wire where localized wear is produced, normally associated with the appearance of electric arcs. To this end, a finite element model has been developed to study the dynamics of pantograph-catenary interaction. The model includes a zone of localized wear and a singularity in the contact wire in order to simulate the worst case scenario from the point of view of stresses.

In order to consider the different stages in the wire wear process, different depths and widths of the localized wear zone were defined. The results of the dynamic simulations performed for each stage of wear let the area of the minimum resistant section of the contact wire be determined for which stresses are greater than the allowable stress. The maximum tensile stress reached in the contact wire shows a clear sensitivity to the size of the local wear zone, defined by its width and depth. In this way, if the wear measurements taken with an overhead line recording vehicle are analyzed, it will be possible to calculate the potential breakage risk of the wire. A strong dependence of the tensile forces of the contact wire has also been observed. These results will allow priorities to be set for replacing the most critical sections of wire, thereby making maintenance much more efficient. The results obtained show that the wire replacement criteria currently borne in mind have turned out to be appropriate, although in some wear scenarios these criteria could be adjusted even more, and so prolong the life cycle of the contact wire [7].

EBRU KARAKOSE AND MUHSIN TUNARY[9] in this study; a condition monitoring and fault diagnosis approach for pantograph catenary system is proposed with improved model, control and analysis methods. There are two main aims of the study. The first is a regular monitoring of the system to determine whether any failure is occur. The second is to reveal the status of fault occurrence in the future. For this purpose, the contact point analysis between the pantograph strip and the catenary is performed. The most wearied points of the pantograph strip and catenary are defined by the method of condition monitoring. High speed trains have a great importance for long distances. The electrical energy for trains must be continuous and uninterrupted. So, the interaction and the mechanical contact between the pantograph and the catenary must be complete.

In electrified rail vehicle it is important to have continuous energy. The quality of the contact force also shows the current collecting quality and quality of the interaction between them. The quality of the contact force depends on the amplitude of the applied force, the operating speed and the vibrations as a result of the contact between the pantograph and the catenary. Very low contact force leads to the formation of arc. An extremely high contact force causes wear at pantograph contact strip and catenary. In addition, increasing the abrasion of the contact wire or the pantograph strip leads to the arc. The necessary measures should be taken to reduce wearing so that maintenance costs will be reduced as well as the service life of the used equipment will be extended [9].

The required software formed with considering the nonlinear pantograph analysis. The wear arising from friction and arc formation was analyzed in the laboratory environment, energized situation and different speeds. The effects of factors comprised the wear and their comparisons were presented. The mechanical structure of the pantograph and catenary system and the resonance event at different speeds with double pantograph were investigated.

In this study; condition monitoring and fault diagnosis methods of PAC system are presented with improved modeling and analysis methods and additional methods. The vast majority of problems can occur due to the wear and deterioration on the surface of pantograph and catenary. The contact which is always at the same point of the pantograph is not reliable. Therefore, the catenary and pantograph surface is divided into specific regions and the situations that might occur for each region are mentioned. In modeling stage, the mathematical model of the system is performed and the simulation is realized. According to the speed of the train and the time, the values of contact points of the pantograph and catenary are received from the model with condition monitoring methods. Then the amount of contacts in the end points of the pantograph and the wear of pantograph strip will be known [9].

TATSUYA KOYAMA [8] in electric railways, electric power is supplied to electric train through current collectors such as pantographs, which directly slides along contact line wires. Overhead conductor rails are generally adopted for underground tracks or tunnel sections because they can be installed in confined construction spaces and there is no fear of wire rupture. Although overhead conductor rail maintenance is generally simple, undulating wear or corrugation, which is in the form of waves, on the sliding surface of conductor rails cause many problems. Once rolling wear begins to appear on conductor rail, more frequent arcing due to contact loss between the pantograph and the overhead rail generates extreme wear on the conductor rail and pantograph contact strip. Gaining insight into the mechanisms causing this type of wear is therefore important to develop a method to prevent such damage.

Electrical wear due to arcs occurring between pantograph heads and the conductor rail is the main causes of the undulating wear formation. The arcs occur when both pantograph heads lose contact with the conductor rail simultaneously. In addition, both pantograph heads tend to lose contact with the conductor rail which has wavelength because both pantograph heads oscillate in phase with each other. Therefore, wavelength of the undulating wear corresponds with L/N, where L-length between pantograph heads, N=1, 2... Furthermore, it was reported that the dynamic characteristics of pantograph also play an important role in formation of wear [8].

2.3. Related Field

Alen John1, Dr. Y.V.K.S Rao, Jerin Sabu, Rajeev V. R[6], on this paper Stress Analysis of Polyoxymethylene which Leads to Wear in Pin on Disc Configuration using Finite Element Method is performed. The simulation of the stresses which leads to wear in pin on disc configuration having the pin made of polyoxymethylene having the NC010-150 designation in sliding contact with the rotating steel disc (AISI 304) was performed using finite element software ANSYS Workbench 11.0. The three dimensional geometry of the required configuration is made by using the modelling software CATIA. Using the boundary conditions the analysis are done. Rotation of 3000 rpm is provided for the disc. Then with analysis software we are analyzing the wear by varying the pressure acted upon the yield strength of the material and assuming that the region of the pin where maximum equivalent stress occurred is failing or wearing out. Then removing the failed elements and again repeating the same process until the material of the pin fails completely, i.e. varying the length of the pin. Along with that the maximum deformation and the maximum equivalent stresses are noted. Then compare the results of deformation and the equivalent stress and concluded that when the length of the pin decreases pin failed more the deformation is decreasing and the equivalent stress is increasing. When the load exceeds tensile yield strength of the material then the material is failed under these circumstances.

P. PRABHU, M.[14], this study's, an attempt has been aimed to predict the wear of the sliding surfaces in the development stage itself which will be results in the increase of durability of the components. The wear for a polymer sliding surface contact in dry condition obtained by creating simulation. There are two inputs are used for determining the wear volume loss over its usage time. One is the nodal pressure value at the contact area for small sliding steps which can be calculated by subjecting the geometrical model to the finite element analysis. ANSYS was used as finite element tool. Another one is the friction coefficient which is obtained by custom designed experiments. For the calculation of friction coefficient, prototype to be subjected to unlubricated pin-on-disc experimental setup. The wear rate is then calculated by graph plotting between pressure and cycles. Swiveling of mirror over the base resulted in the wear. By the above techniques, the wear loss and reliability of the rear mirror is predicted.

PODRA and ANDERSSON [15], have studied the wear simulation approach with commercial finite element software ANSYS. A modeling and simulation procedure was proposed and used with the linear wear law and the Euler integration scheme. A spherical pin on- disc unlubricated steel contact was analyzed both experimentally and with finite element method FEM, and the Lim and Ashby wear map was used to identify the wear mechanism. It was shown that the FEA wear simulation results of a given geometry and loading can be treated on the basis of wear coefficient-sliding distance change equivalence. The finite element software ANSYS was well suited for the solving of contact problems as well as the wear simulation. The actual scatter of the wear coefficient was within the limits of 40-60% led to considerable deviation of wear simulation results. Due to the model simplifications and the real deviation of input data, the FEA wear simulation results was evaluated on a relative scale to compare different design options, rather than to be used to predict the absolute wear life.

KIM ET AL [16]. have proposed a numerical approach that simulates the progressive accumulation of wear in oscillating metal on metal contacts. The approach used a reciprocating pin-on disk tribometer to measure a wear rate for the material pair of interest. This wear rate was an input to a FEA that simulates a block-on-ring experiment. After the simulation, two block-on-ring experiments were performed with the same materials that were studied in the reciprocating pin-on-disk experiments. The results from the FEA were in close agreement with the block on ring experimental results. This approach did not either rely on curve fitting or use the block-on-ring experimental data as model inputs. The FEA were performed by progressively changing nodal coordinates to simulate the removal of material that occurs during surface interaction. The continuous wear propagation was discretized and an extrapolation scheme was used to reduce computational costs of this simulation.

On this study it verify the formation of undulating wear on overhead line through excitation test on type of pantograph used on commercial line. Where the unevenness of the lines' sliding surface was measured using an unevenness measurement device. Unevenness characteristics are as follows; wear on conductor line is not uniform; it is periodic with a wavy pattern, and the amplitude of unevenness forces the pantograph to lose contact with the conductor rail. The specifics periodic unevenness grows selectively and become predominant, mechanical wear stop increasing since pantograph loses contact with the conductor rail. However, arcing causes electrical wear, which bring about further unevenness on the sliding surface of the conductor rail. Therefore the total contact fluctuation of pantograph increase consequently the occurrence of arcs.

C.T. Kwok, P.K. Wong, H.C. Man and F.T. Cheng [3] studies the mechanical wear of overhead line wire using a device called tribometer. A various copper-based alloys in the form of cylindrical pin were forced to slide against a counter face stainless steel disc in air under unlubricated condition at a sliding velocity of 31 km/h under normal load up to 20 N with and without electric current. The worn surface of and wear debris from the specimens were studied by scanning electron microscopy. Sliding wear and corrosion resistance of pure copper Cu and six age-hardened copper alloys CuCr, CuZr, CuCrZr, CuNiSiCr, CuBe and CuBeNi were investigated by a pin-on-disc tribometer and electrochemical measurement.

The C.T.Kwok research determine the wear rate of an overhead line contact wire through an experimental procedure, that require a tribometer that can apply the practical wire and pantograph contact force and operating speed. Conventionally, hard-drawn copper is often used as overhead catenary for traction systems because of its excellent electrical and thermal conductivities and moderately low price but its limitations are low hardness, susceptibility to electrical sliding wear and atmospheric corrosion which lead to shortening of its service life, interruption of the system, and safety problems. Age hardenable copper alloys are dilute alloyed with elements such as Cr, Zr, Ag, Mg and Be etc. with limited solubility. Through age hardening, the mechanical and tribological properties of these copper alloys.

Wear can take place when two or more bodies in frictional contact slide against each other. The significant effect of wear, particularly in friction material of a pantograph and overhead contact wire, is reduction of its life span. Wear of material is a complex process dependent on particle speed, size, angle of attack as well as the behavior of the material. The more the wear, the sooner the friction material needs to be replaced. Removal of material occurs through the processes of micro-plastic deformation or brittle fracture. For ductile materials such as pure metals and alloys, the impact of the hard particles causes severe, localized plastic strain at the impact site on the surface [10]. Material is removed when the strain exceeds the material’s strain to failure.

To conduct wear simulation for saving cost and time, there must be understanding of contact and wear mechanism. First, the contact area in the overhead contact wire and pantograph is analyzed, second the wear loss of material from contact surface is categorized into three regions: mild, severe and catastrophic. Where the wear rate of overhead contact wire and pantograph is categorized under mild because of the consequence of wear is on contact wire is loss of power on the train, failure of railway service and need of extra maintenance cost , time and labor force.

For analyzing wear of a material an experimental studies are often used, but they are quite expensive and time consuming, and usually, they can analyze only limited configurations and load conditions. For that reason, the use of computational modeling is expanding also in this field, but unfortunately, very few published papers present validated wear models to be used.

Simulating the wearing process through finite element enables the prediction of wear behavior of materials under different conditions, which will substitute the need of experimentation, and will enable the identification of constants required for existing analytical models.

The FE simulation model did not include any failure criteria and they made the assumption of plane strain. No direct relation was established between the edge protrusion and the erosion rate. The wear model is implemented by means of FEM.

2.4. Contact Mechanics

The theory of contact mechanics is concerned with the stress and deformation which arise when the surface of two solid bodies are brought into contact. There are two types of contact, first conforming contact when the two surface fit exactly or closely together without deformation and secondly non- conforming contact that the surface or one of the two surfaces, deform when there is a contact area in between them. Central aspect of contact mechanics are the pressure and adhesion acting perpendicular to the contacting bodies’ surfaces, the normal direction, and the frictional stress acting tangentially between the surfaces. However this study mainly focus on normal direction with a friction contact. Contact mechanics provide information for safe and energy efficient design of tribology and indentation hardness.

Hendric Hertz is the first researcher to introduce the contact stress, approached the problem by fmeans of theoretical or numerical solutions based on the Hertz’s theory. In railway service the contact mechanics many applied on the contact between the pantograph and overhead line contact wire and wheel and rail contact, which both are in relative motion contact principle. The Hertz theory have assumptions which are:

i. The radii of curvature of the contacting bodies are large compared with the radius of the circle of contact
ii. The dimension of each body are large compared to the radius of the circle of contact
iii. The contacting bodies are in frictionless contact
iv. The surfaces in contact are continuous and nonconforming

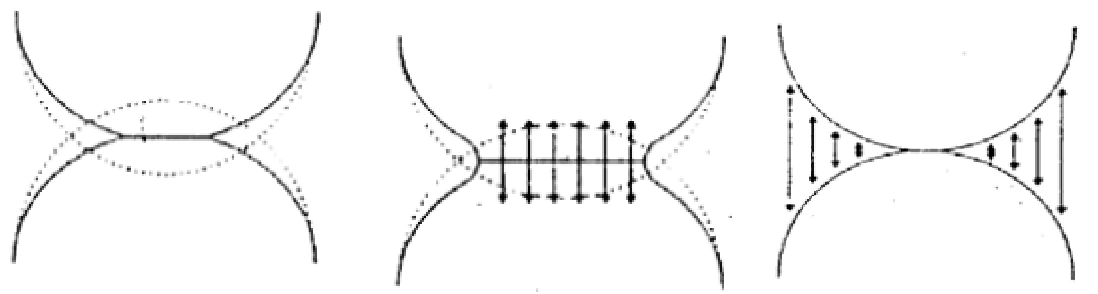

Figure 3.Hertz contact mechanics   Figure 4. Johnson   Figure 5. Bradley

After Hertz contact theory other scientists provide an improved theory. Johnson contact theory the contact is considered to be adhesive. Hence the theory correlates the contact area to the elastic material properties plus the interfacial interaction strength. Bradley's Van der Waals model if the two surfaces are separated and significantly apart. In Bradley's model any elastic material deformations due to the effect of attractive interaction forces are neglected. The Hertz and Johnson contact theory is grouped under fully elastic model which Johnson consider adhesion in contact zone.

2.5. Wear Mechanism

Wear is a complex phenomenon that is not well understood. Humans have been aware of wear for many times. It has been avoided by choosing harder materials for things that are more likely to wear. However, wear is not always something to be avoided, many times it is desired; for example a pencil writes because the lead wears, and metal is polished by wearing the surface smooth.

Wear is not an exact science, its study of incorporate many scientific disciplines and principles whose complex inter-relationships can give rise to considerable area of uncertainty. Wear is the progressive loss of substance from the surface of solid body caused by mechanical action. I.e. contact and relative motion with other body. In this case the wear of contact wire because of relative motion with pantograph. Generally wear rate is higher during running-in, and sliding contact.

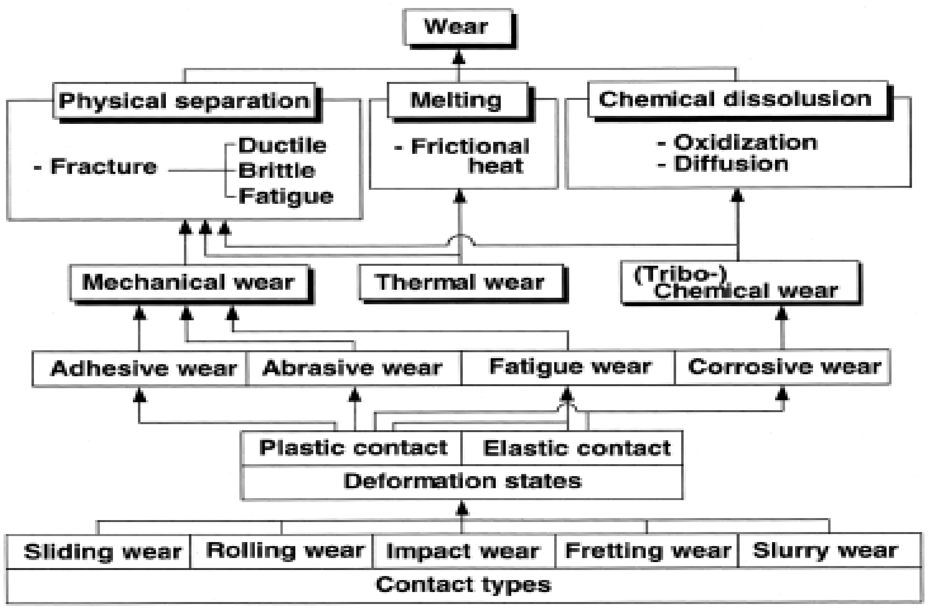

Figure 6. Type of wear and their interaction [13]

Basically wear classified in to two methods, one the conditions in which the wear occurs; and the mechanism by which the wear occurs. Conditions used to classify wear include whether or not there is a lubricant present, and whether or not there are hard, abrasive particles present. If there is a lubricant present, it is referred to as lubricated wear, otherwise it is dry wear. If there are abrasive particles causing wear, then it is referred to as abrasive wear, otherwise it is called sliding wear [17]. The current study of overhead contact wire wear focuses on dry sliding wear.

Wear resistance is not an essential material property, change to surface and near surface structures during wear contact normally significantly alter local material properties, both mechanically and chemically. Many researchers study on developing wear resistance overhead line contact wire most of achieved by increasing the mechanical strength of the wire but in contrary the electrical conductivity decreases which result loss in power. There are many copper alloy that can be used for overhead line contact wire where those alloys have different compositions, electrical conductivity, density and hardness.

Kalker developed FASTIM that is numerical solvers for calculating area and stress using contacts that in non Hertz contact. However both FASTIM and contact are based on Hertz theory and have minor change to overcome some limitations.

The contact between two bodies is divided by rolling and sliding contact, which can be divided into stick and slip regions. In electrically operated rail vehicle there are two basic contact areas one the contact wire and pantograph contact strip and wheel and rail. According to above classifications that contact between contact wire and pantograph contact strip grouped under sliding contact where are wheel and rail contact experience both rolling and sliding contact, that when rail vehicle moves along straight line there is rolling contact and when it moves across curved and braking there is a sliding contact.

There is different phenomena between hertz contact theory and FEM based contact. Hertz contact theory has some significant limitations. FEM has no assumption and obtain more accurate results. In addition computing technology has developed more calculation time decline gradually. In this research we use FEM to obtain more accurate result and predict more accurate wear rate on contact wire of overhead line electrification system.

3. CHAPTER THREE

CONTACT WIRE MODEL AND WEAR ANALYSIS

3.1. Introductions

Any components with to relative motion is subjected to surface contact due to loading and additional thermal effect on the contact bodies. Those applied load and relative motion result high stress and deformation on the contact surfaces which result failure due to wear. Wear analysis mostly performed by experimental procedure in order to analyze the component loss of material with time before and after applying required. In resent research a software simulation of wear analysis is performed by many researchers, a FEM is common simulation method for analyzing wear model using ANSYS or ABAQUS software's.

3.2. Pin on Disc Wear Model and Analysis

3.2.1. Assumptions

The general assumptions that helps to simplify and reduce the simulation process of contact mechanic's on ANSYS WORKBENCH 12.0. The assumptions are start from modeling of wear analysis using software, using pin on disc model instead of contact wire and pantograph contact point.

The following are the assumptions used on this thesis paper to simulate wear analysis on ANSYS WORKBENCH 12.0

- ✓ The assembly contact between pin and disc is bonded contact option of ANSYS without any clearance
- ✓ The analysis conducted is a non linear
- ✓ The analysis of modeled elements are considered as rigid to flexible contact, where one element of model taken as fixed and other as rigid.
- ✓ The attachment for model helps to support and transfer load to analyzed model
- ✓ The contact behavior of modeled elements are taken as asymmetric
- ✓ The coefficient of friction between pin and disc bonded contact is taken 0.3
- ✓ The analysis is performed by assuming the deflection of modeled elements are small and neglected

3.2.2. Method of Wear Simulation

To conduct wear simulation on ANSYS software the contact analysis is performed following five basic steps:

1. Select whether the contact analysis is on ANSYS Parametric Design Language(APDL) or Workbench in this paper the wear simulation is conducted on ANSYS Workbench
2. Create the model geometry and mesh
3. Identify the contact surfaces and material used for each part of model
4. Define solution options
5. Apply boundary conditions and normal force and rotational velocity of disc in case of pin on disc simulation
6. Solve the contact problem

3.2.3. Model Geometry and Mesh

Overhead line electrification is one of the basic critical railway infrastructure, where the rail vehicle gather its power source which is an electrical voltage from power station. The contact type of overhead contact wire and pantograph contact strip is a sliding type, therefore the wear simulation used for sliding contact is pin on disc. In pin on disc simulation the geometric curvature of a disc and a pin that represent the experimental dimensions of experimental Tribometer device.

The assembly model contain Disc that rotates with predetermined velocity, Pin that stays stationary on rotating disc and Holder for holding and applying force on pin. The geometric modeling can be done on Geometry of ANSYS Workbench for creating 3D prototype that used for wear simulation and contact analysis.

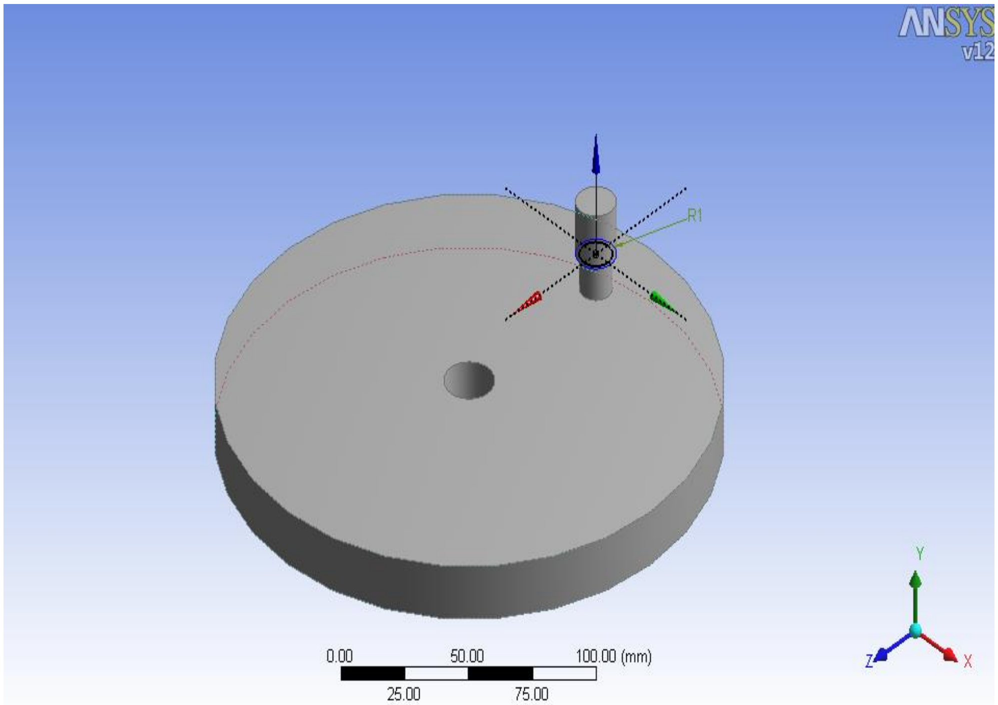

Figure 7. Workbench model of pin on disc

The pin dimensions used for modeling is same as to that of real overhead line contact wire diameter which is 13mm diameter.

Table 2: Dimensions of pin on disc model

Item no	*Description*	*Dimension*
1	Disc	Outer diameter(OD): 200mm Inner diameter(ID): 20mm Thickness(t): >=20mm
2	Pin	Diameter(D):13mm Length(L): 13mm
3	Holder	Diameter(D):16mm Length(l): 20mm

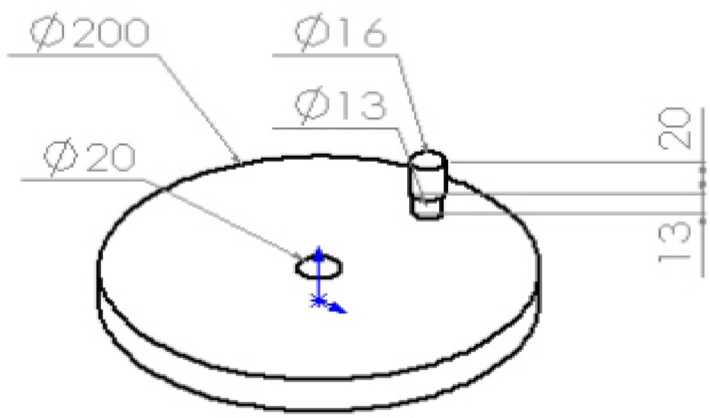

Figure 8. Dimension of pin on disc

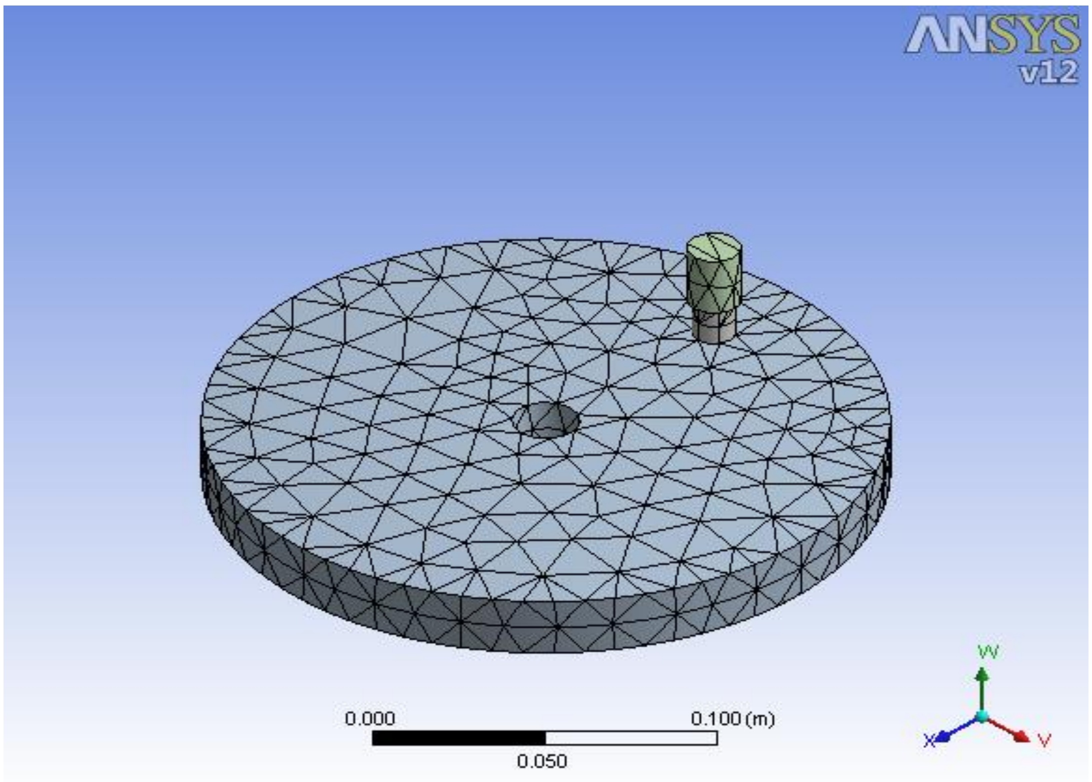

Figure 9. Geometric mesh on WORKBENCH

3.2.4. Contact Surface

Identifying contact surface is a very important part of wear simulation on ANSYS software. The contact and target element are associated with each other via a sheared real constant set. Different contact pairs must be defined by a different real constant set, even if the element real constant values don not change. There is no limit on the number of surface allowed.

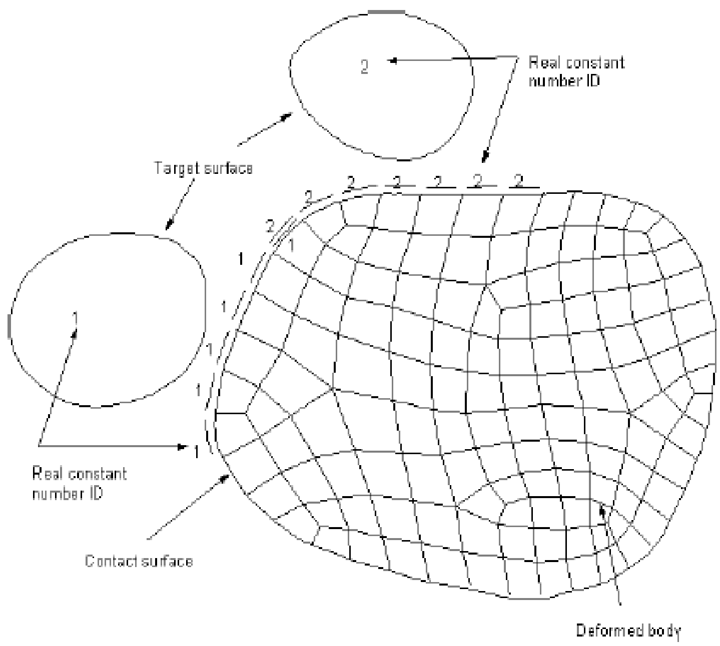

Figure 10. Localized contact zone

The localized contact zone verify nodal nodal number ordering to check contact direction. Depending on geometry of model and potential deformation, multiple target could interact with the same zone of the contact surface.

Contact elements are constrained against penetrating the target surface. However, target elements can penetrate through the contact surface. For rigid to flexible contact, the designation is, the target surface is rigid surface and contact surface is deformed surface. For flexible to flexible contact, the choice of which surface is designated contact or target can cause a different amount of penetration and thus affect the solution accuracy. There is different guideline when designating the surface, but in this paper case the condition or guideline taken are:

- If one surface is stiffer than the other, the softer surface should be the contact surface and the stiffer surface should be the target surface
- If one surface is markedly larger than the outer surface, such as in the instance where one surface surrounds the other surface, the larger surface should be the target surface

These guidelines are true for asymmetric contact; however, asymmetric contact may not perform satisfactorily for any geometric model. Therefore according to above guidelines of contact pair is defined, the disc surface be target and pin be the contact surface.

On stage of defining contact behavior of pin and disc for contact mechanics analysis the type of surface is added. In this paper case a frictional contact between pin and disc surface, with μ 0.3. The frictional force f_f is calculated by the software to add into analysis system.

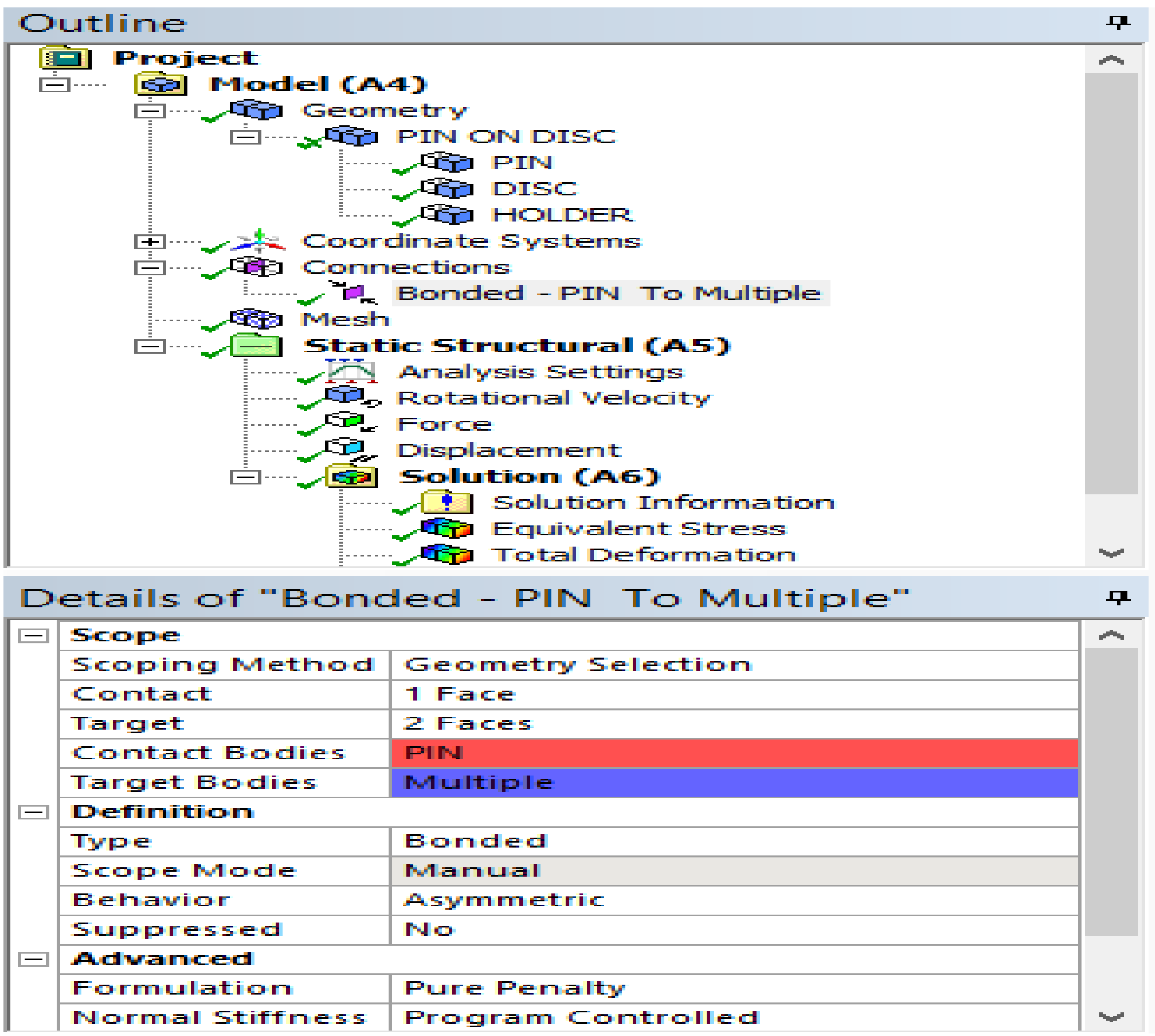

Figure 11. Outline of bonded contact pair

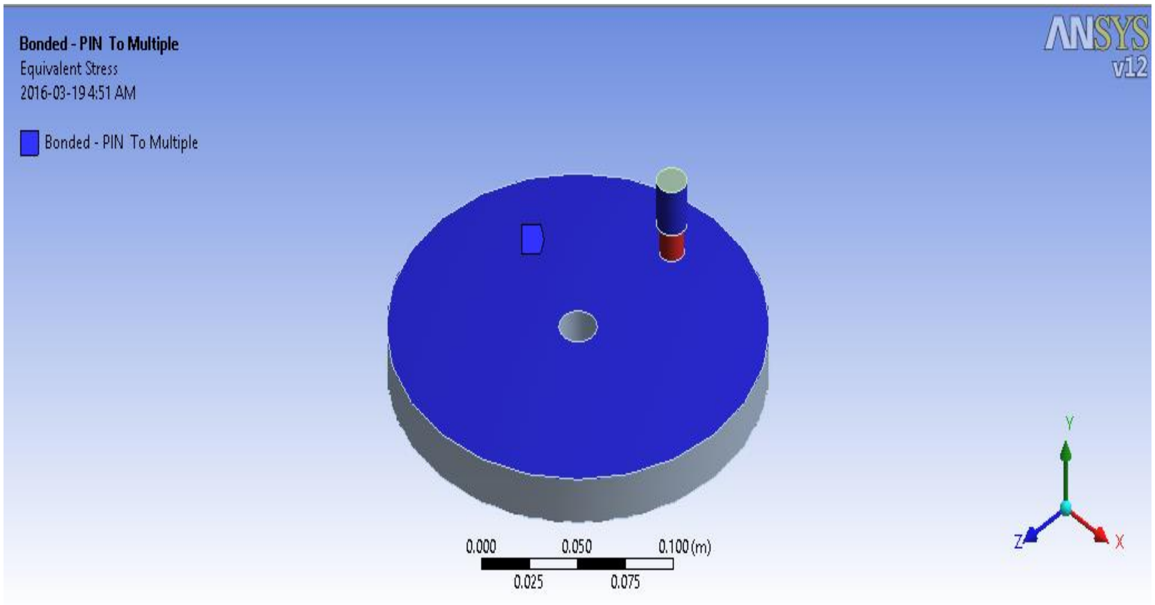

Figure 12 Geometric contact pair

3.2.5. Material Selection

The overhead line contact wire is mostly a copper alloy material that can transmit electricity and that can withstand the variable tensile force applied on it. The contact wire is modeled as pin on pin on disc simulation, where the copper alloy material is specified for pin and a stainless steel is specified for disc and holder material. Stainless steel material is specific material that used for Tribometer device. The specific material property of copper alloys and stainless steel are stated below.

1. Cu material

Table 3: Cu mechanical property [22]

No	*Material Property*	*Value*
1	Density(ρ)	8900Kg/m3
2	Elastic Modulus (E)	$1.17*10^{11}$ pa
3	Tensile Yield Strength	$2*10^{7}$pa
4	Poison's Ratio(v)	0.34
5	Tensile Ultimate Strength	$1.01*10^{7}$pa
6	Compressive Yield Strength	$1.08*10^{8}$pa
7	Coefficient of Thermal Expansion	$2.2*10^{-5}$/c
8	Hardness(H)	35HB

2. CuAg material

Table 4: CuAg mechanical property [26]

No	*Material Property*	*Value*
1	Density (ρ)	8800Kg/m3
2	Elastic Modulus (E)	$1.17*10^{11}$ pa
3	Tensile Yield Strength	$6.2*10^{7}$pa
4	Poison's Ratio(v)	0.3
5	Tensile Ultimate Strength	$1.72*10^{8}$pa
6	Compressive Yield Strength	$1.08*10^{8}$pa
7	Coefficient of Thermal Expansion	$1.7*10^{-5}$/c
8	Hardness (H)	42HB

3. CuNiSiCr material

Table 5: CuNiSiCr mechanical property [23]

No	*Material Property*	*Value*
1	Density (ρ)	8840Kg/m3
2	Elastic Modulus (E)	$1.03*10^{11}$ pa
3	Tensile Yield Strength	$6.5*10^{7}$pa
4	Poison's Ratio(v)	0.3
5	Tensile Ultimate Strength	$1.72*10^{8}$pa
6	Compressive Yield Strength	$1.08*10^{8}$pa
7	Coefficient of Thermal Expansion	$1.7*10^{-5}$/c
8	Hardness (H)	45HB

4. Stainless steel material

Table 6: stainless steel mechanical property [22]

No	*Material Property*	*Value*
1	Density (ρ)	7750Kg/m3
2	Elastic Modulus (E)	$1.93*10^{11}$ pa
3	Tensile Yield Strength	$6.2*10^{7}$pa
4	Poison's Ratio(v)	0.31
5	Tensile Ultimate Strength	$5.86*10^{8}$pa
6	Compressive Yield Strength	$2.07*10^{8}$pa
7	Coefficient of Thermal Expansion	$1.7*10^{-5}$/c
8	Hardness (H)	96HB

The above mechanical property of copper alloy and stainless steel, the value will be added on the engineering data value.

Table 7: Workbench copper alloy mechanical property specification

Properties of Outline Row 4: Copper Alloy

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	8800	kg m^-3		
3	Coefficient of Thermal Expansion				
4	Coefficient of Thermal Expansion	1.7E-05	C^-1		
5	Reference Temperature	22	C		
6	Isotropic Elasticity				
7	Young's Modulus	1.17E+11	Pa		
8	Poisson's Ratio	0.3			
9	Tensile Yield Strength	6.2E+07	Pa		
10	Compressive Yield Strength	1.08E+08	Pa		
11	Tensile Ultimate Strength	1.72E+08	Pa		
12	Compressive Ultimate Strength	0	Pa		

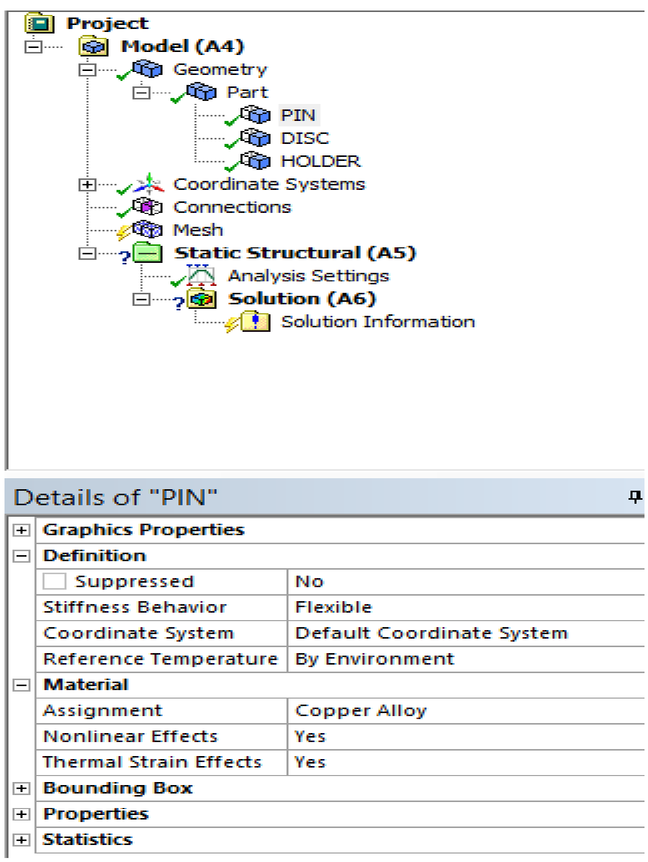

Figure 13. Pin material specifying

3.2.6. Load and Boundary Condition

Boundary condition

The boundary condition is attained for getting accurate and compatible to real condition of contact wire and pantograph contact point. Here the displacement in the X and Z direction of the outer round faces of the pin and holder is arrested, so given the value as zero. At the same time, Y direction displacement given as free, for allowing the movement of pin and holder only in the Y direction. Then displacement in the X and Z direction of the outer round faces of the hollow disc made free at the same time, Y direction displacement is arrested, so given the value as zero, for allowing the movement of hollow disc in the X and Z direction. Now the wear simulation of pin on disc displacement effect is analyzed.

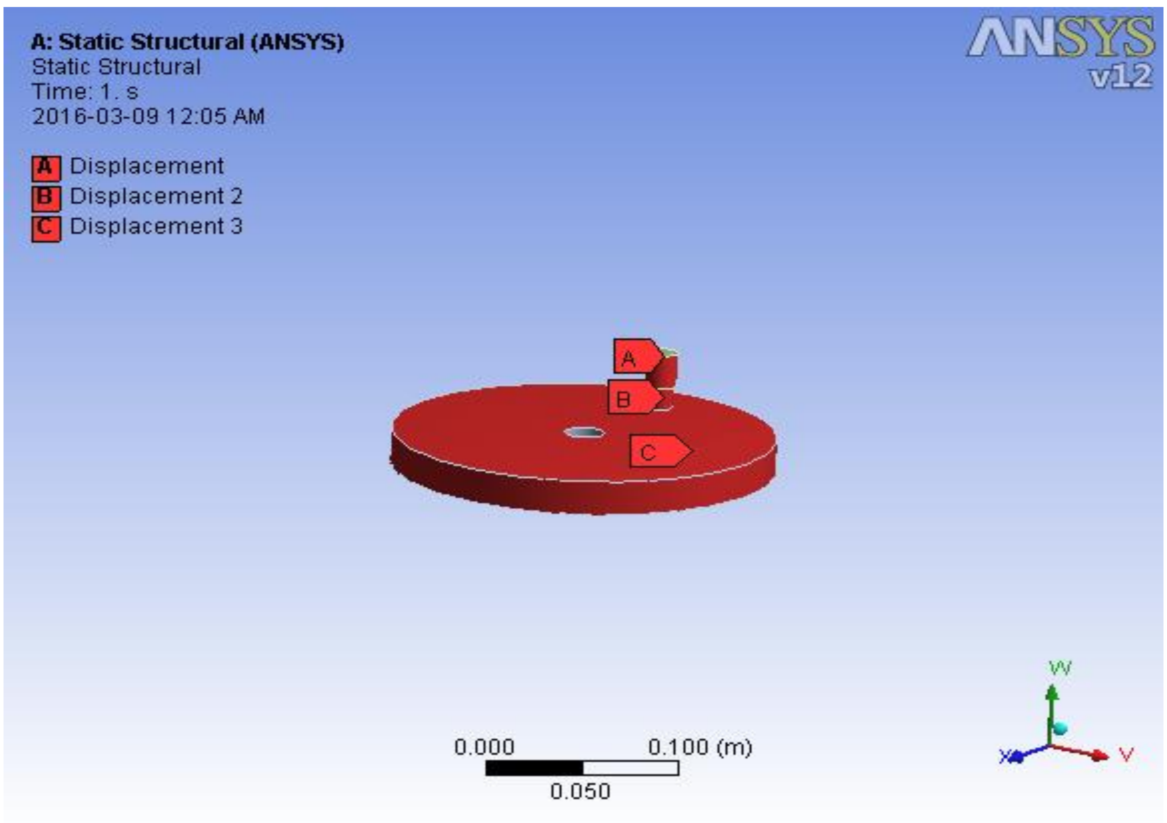

Figure 14. Boundary condition of model

Load

On Tribometer device for conducting wear analysis the vertical downward force is applied on top of pin holder. The process of applying force on ANSYS model is same as to that of real Tribometer device on top of pin holder. The applied force is same force to that tension force exist on real contact wire. The contact wire must have a regulated and evenly distributed tension because the pantograph causes oscillations in the wire. In general, a higher tension means a higher allowed speed. The tension varies between 4.9 kN and 15 kN. To manage an even tension the contact wire system is split into 1.2-1.5 km sections which are anchored in the middle and tensioned in both ends. The wires are tensioned with weights independent of the temperature.

Therefore for simulation purpose a load 4.9kN, 10kN and 15kN force is applied on top surface of pin holder. Force 4.9kN is taken as the lowest possible tension load condition that can exist on real overhead line contact wire due to pantograph oscillation. 10kN is most common load condition occur and 15kN is sever tensile load condition that can occur on contact wire, that taken to find condition of contact wire on worst or factor of safety. The above three load conditions are applied on all copper alloy material of pin and the analysis continues.

The rotational velocity is applied on disc model, the Tribometer device disc rotate with a specified rotational speed which given by the electric motor installed on it. The rotational velocity applied on the model is value that used by Tribometer device manufactured in Mecelakeya Engineering in 2014. But the running speed of rail vehicle is 80Km/hr this cause the pantograph contact strip run with same speed on the contact wire. Therefore the rotational velocity of Tribometer device disc must rotate with running speed of rail vehicle this achieved by installing a variable electric motor.

Rotational speed calculation:

v- Running speed of rail vehicle =80Km/hr, the design speed of AA LRT

r- Radius of rotating disc= 100mm

Therefore the required rotational speed of motor is

$$\omega = {}^{v}/_{r}$$

$$\omega = {}^{80Km/hr}/_{100mm}$$

$$\omega = \frac{80 * {}^{100000}\!/_{3600}\,{}^{mm}\!/_{sec}}{100mm}$$

$$\omega = 222.22rad/sec$$

Where, $1rpm = \frac{2\Pi rad/sec}{60}$

$$\omega = \frac{222.22*60}{2\Pi}$$

$$\omega = 2121.85\text{rpm}$$

Taking maximum possible rotational velocity applied on contact wire by reducing the radius of disc, by half reduction of the disc radius which is 50mm radius the rotational velocity become:

$$\omega = \frac{80 * {}^{100000}\!/_{3600}\,{}^{mm}\!/_{sec}}{50mm}$$

$$\omega = 444.44\text{rad/sec}$$

$$\omega = 4241.73\text{rpm}$$

The rotational velocity that need to be applied on disc of model is 444.44rad/ sec but the Tribometer device motor used a constant speed that rotate with 5898rpm which is greater than the assumed highest rotating speed of disc for sever condition, so it can be applied and get reliable result.

$$\omega = 5898\text{rpm}$$

In order to apply on ANSYS Workbench, rpm must be converted to rad/sec

Therefore $\quad \omega = 5898 * \left(\frac{2\Pi}{60}\right) = 617.63\text{rad/sec}$

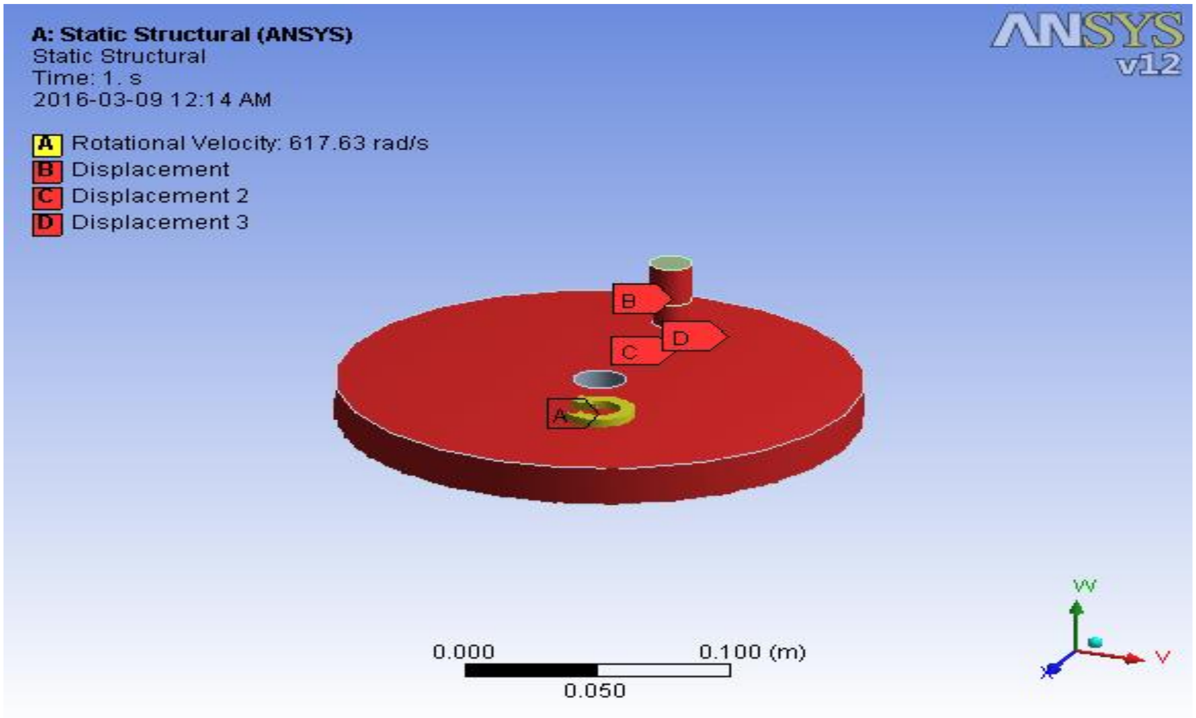

Figure 15. Applying boundary condition and rotational velocity

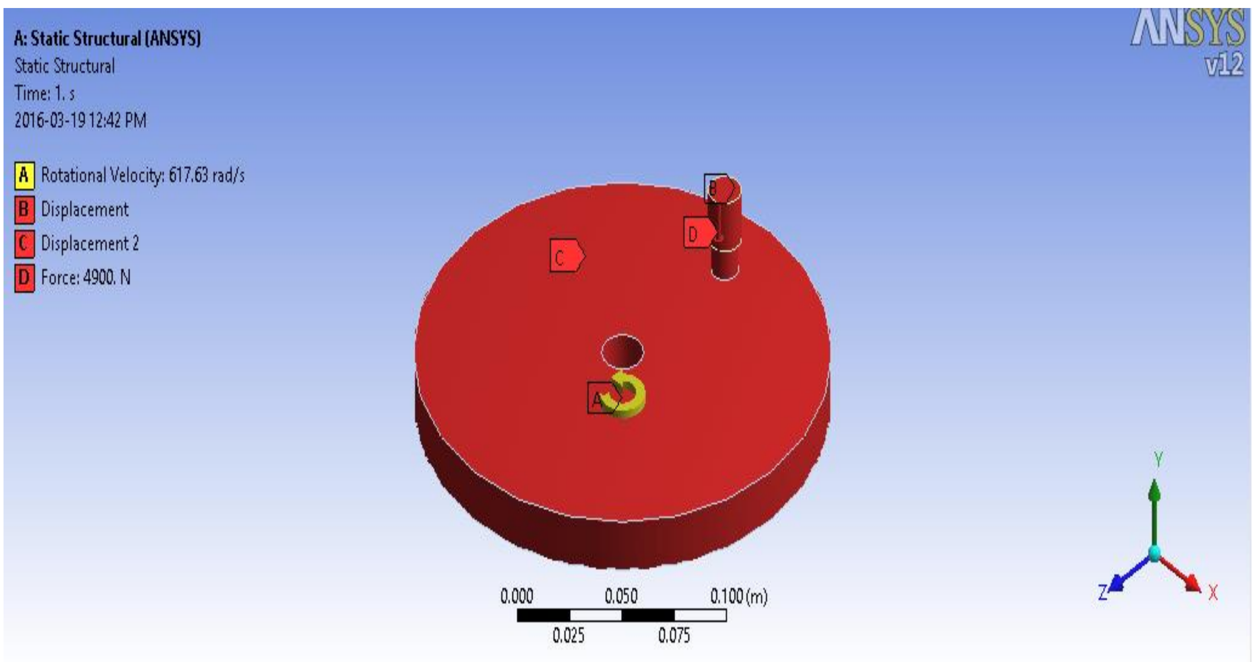

Figure 16. Load applied on model

4. CHAPTER FOUR

RESULT AND DISSCUSSION

4.1. Analysis

The wear model and analysis is performed using finite element method with software ANSYS Workbench that consist of a static structural (ANSYS), static structural (samcef) and others; for purpose of getting the maximum equivalent stress on static structural member a static structural model is selected. The static structural analysis determines the stress, strain, deformation, deflection, safety factor and fatigue wear of structures caused by applied loads that do not involve a significant inertia and damping factors. On this model the location and depth highly stressed zone also determined with implication of red color area. On same boundary conditions and different load applications used to perform the analysis where the model geometry is same as stated above on pin on disc simulations.

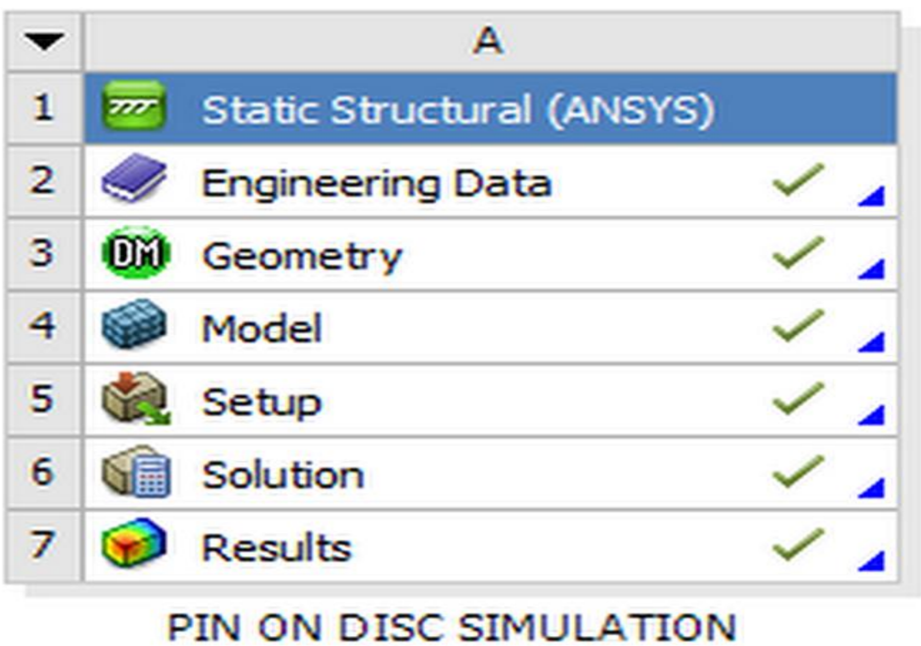

Figure 17. ANSYS static structural analysis system

Where the engineering data helps to input the mechanical properties of Cu, CuAg, CuNiSiCr and carbon strip of pantograph. The stainless steel mechanical property used using default property of the software.

Model is for performing the analysis and get the solution of modeled geometry. The boundary conditions, contact behavior of system, and applying different load cases also performed on this part of FEM analysis. Final stage of analysis on FEM is gating the maximum equivalent stress and maximum equivalent stress locations on pin on disc model.

4.2. Results

The boundary conditions applied on pin on disc model are

- ✓ Displacement on pin, fix X and Z and free Y
- ✓ Displacement on holder, fix X and Z and free Y
- ✓ Displacement on disc, fix Y and free X and Y

A rotational velocity applied on disc with value of 617.63rad/sec as calculated above

A vertical loads applied on top surface of holder are 4.9kN, 10kN and 15kN.

4.2.1. Equivalent (Von-Mises) stress

Using the ANSYS Workbench software, along with the boundary conditions, applied loads is given then we got a value for this load, the values equivalent (von-Mises) stress and deformation. Von Mises stress is widely used by designers, to check whether their design will withstand given load condition and it arises from distortion energy failure theory. Then the maximum and the minimum value is noted and the portion where it's value is obtained, i.e. some portion of the pin showing the maximum equivalent stress. In real condition that portion is worn out and it taken as wear depth.

For the three pin material the equivalent stress maximum and minimum value is taken and then the disc material will be changed to carbon strip and its property applied. Taking the maximum stress and area of worn out area the wear volume calculated.

1. Cu pin material

A. At 4900kN

The equivalent stress for Cu pin material and applying the three load, the tip of the pin is having the maximum stress value

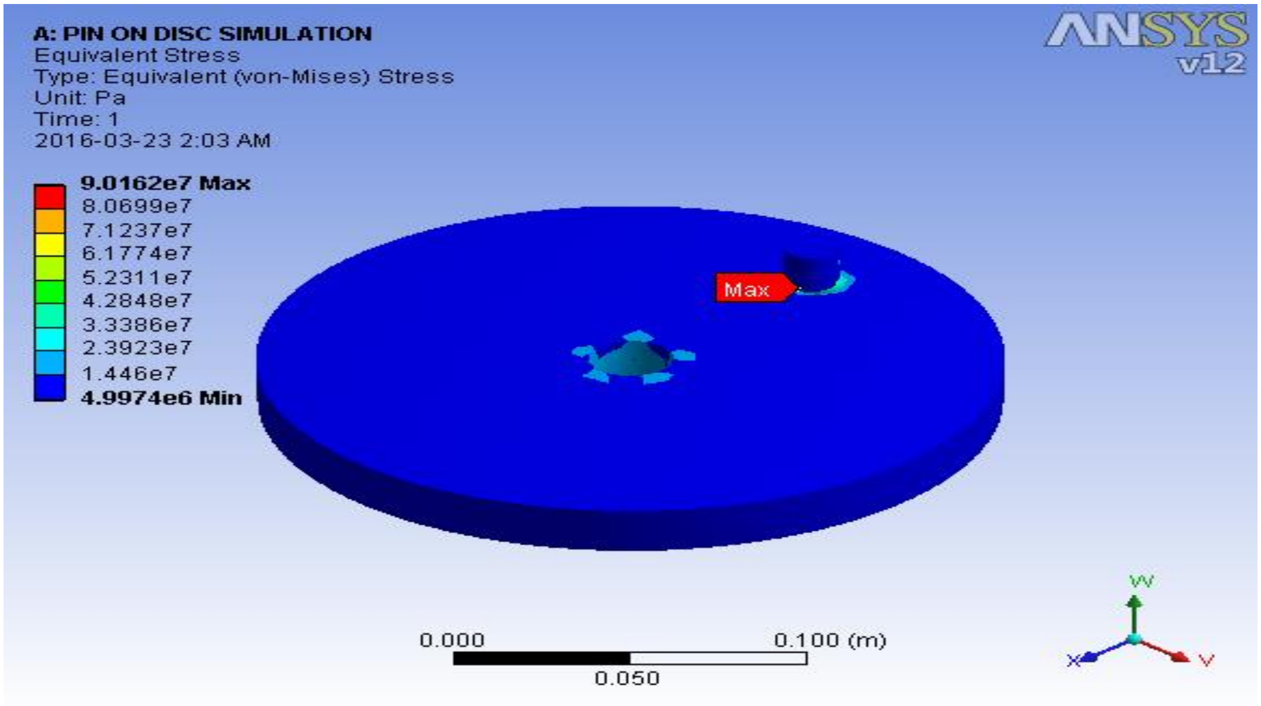

Figure 18. Equivalent stress for 4.9kN applied load

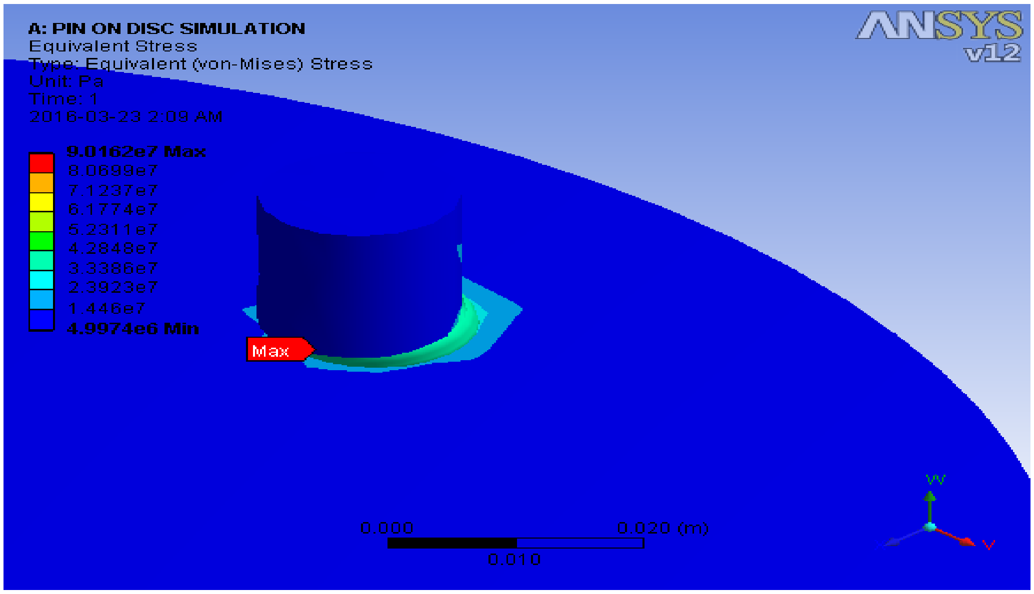

Figure 19. Pin Cu material at 4.9kN

B. At 10kN

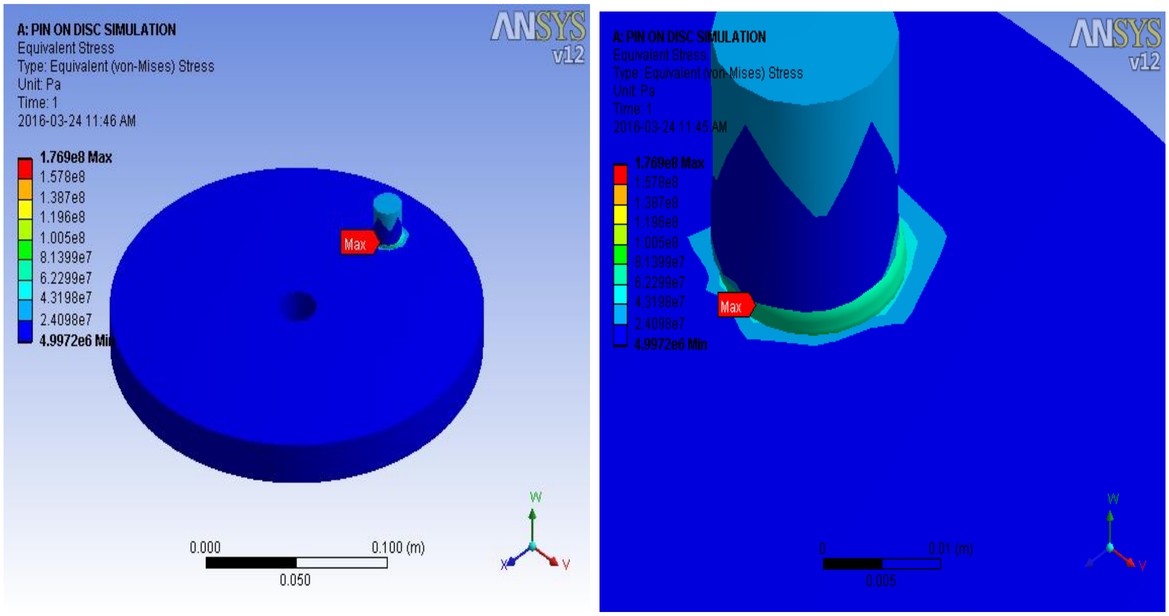

Figure 20. Pin Cu material at 10kN

C. At 15kN

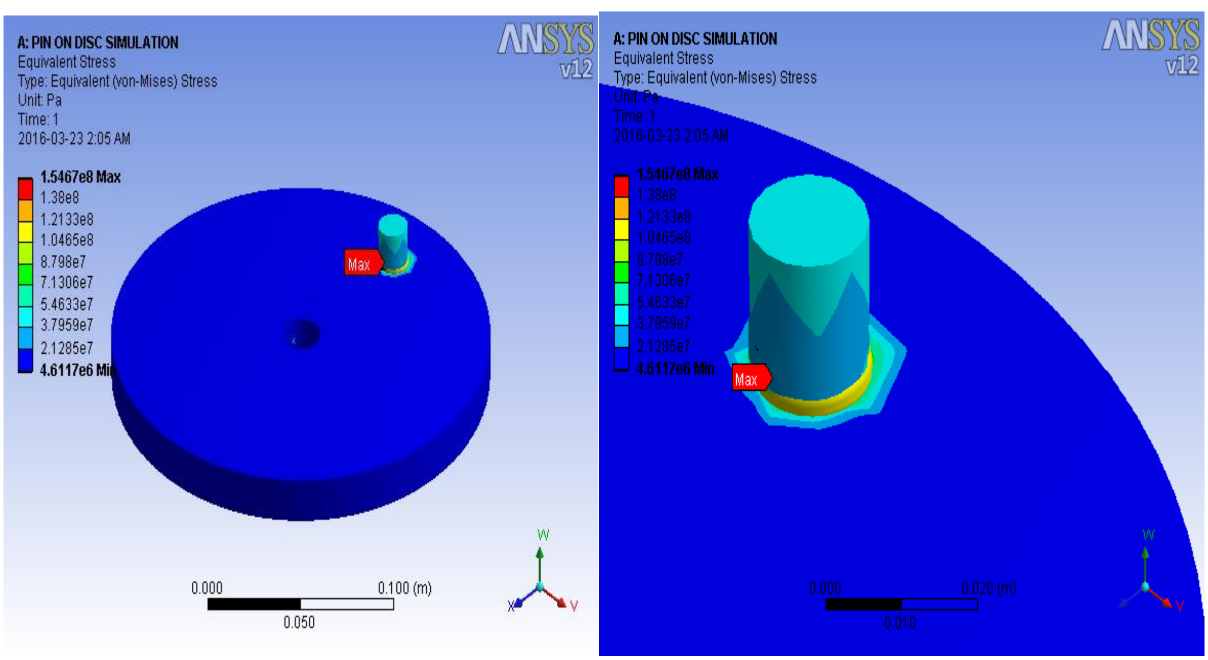

Figure 21. Pin Cu material at 15kN

2. CuAg pin material

The equivalent stress for CuAg pin material and applying the three load, the tip of the pin is having the maximum stress value.

A. At 4.9kN

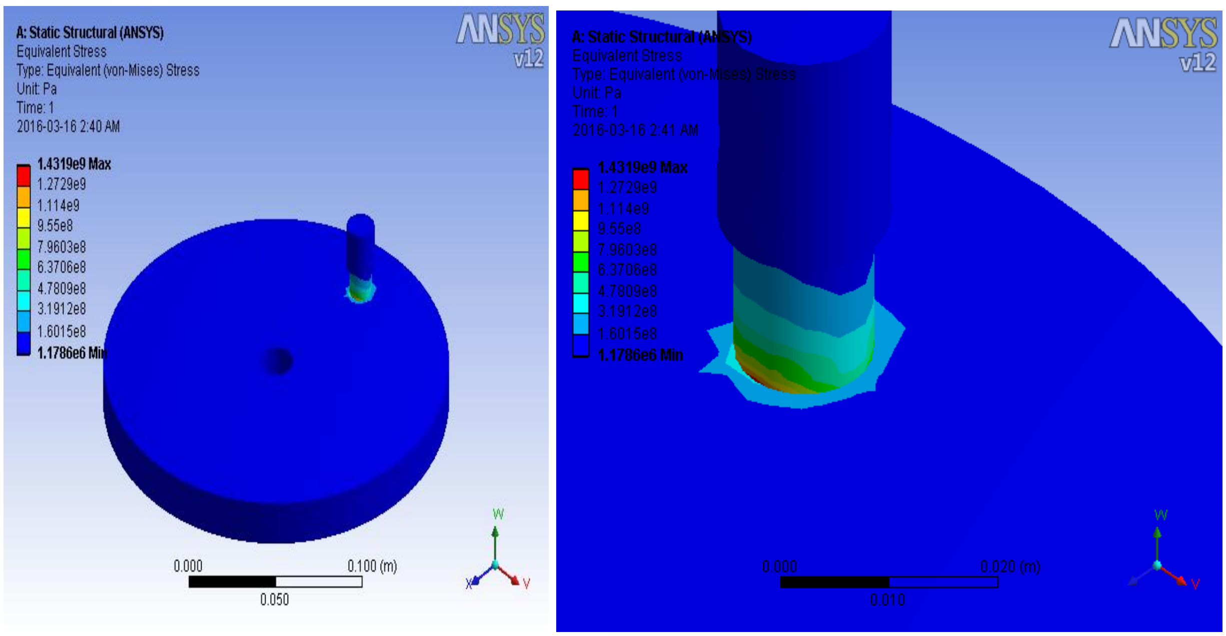

Figure 22. Pin CuAg material at 4.9kN

B. At 10kN

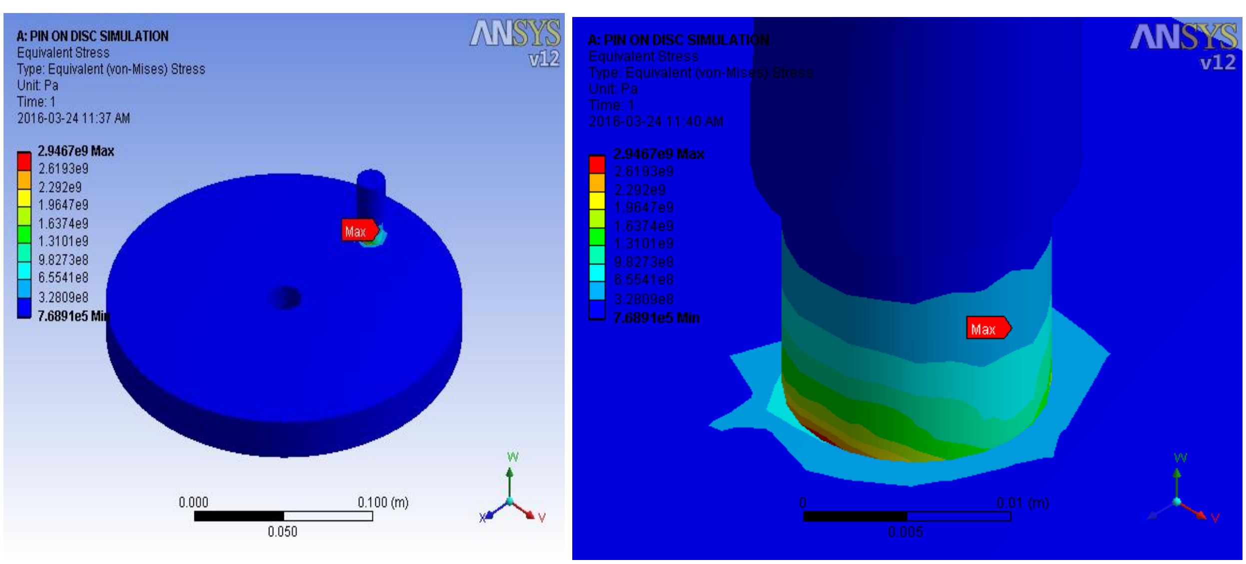

Figure 23. Pin CuAg material at 10kN

C. At 15kN

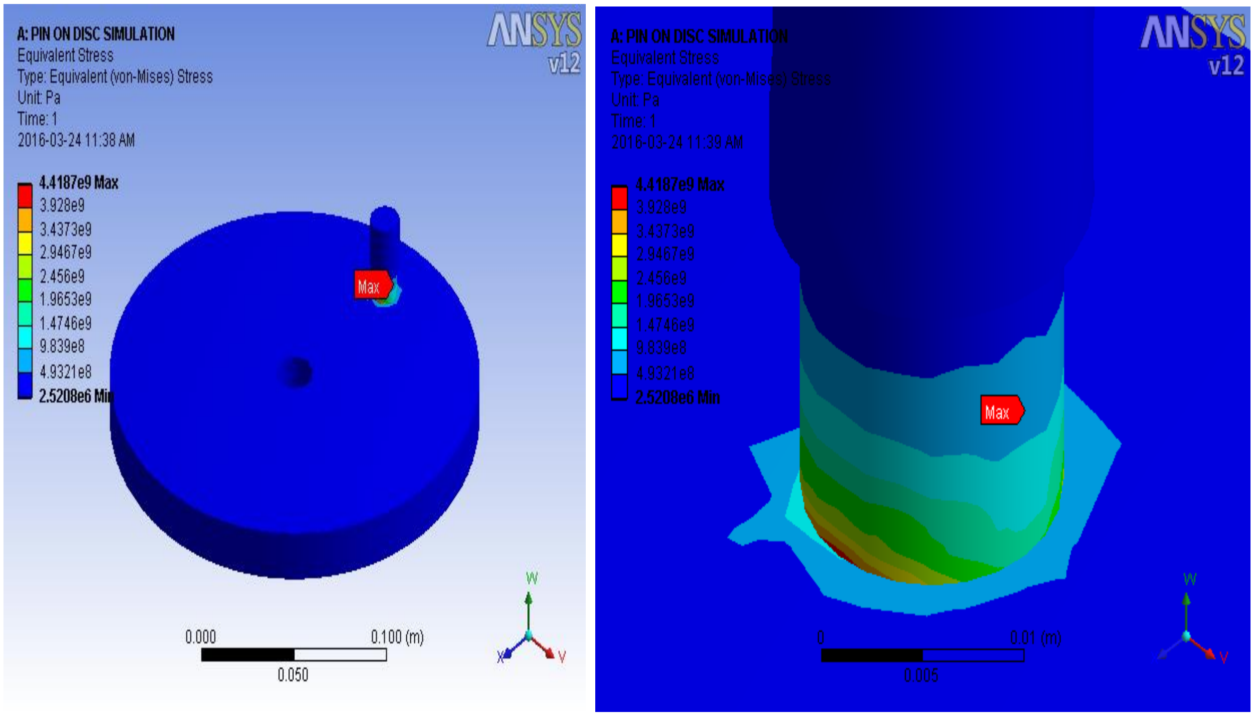

Figure 24. Pin CuAg materila at 15kN

3. CuNiSiCr pin material

The equivalent stress for CuNiSiCr pin material and applying the three load, the tip of the pin is having the maximum stress value.

A. At 4.9kN

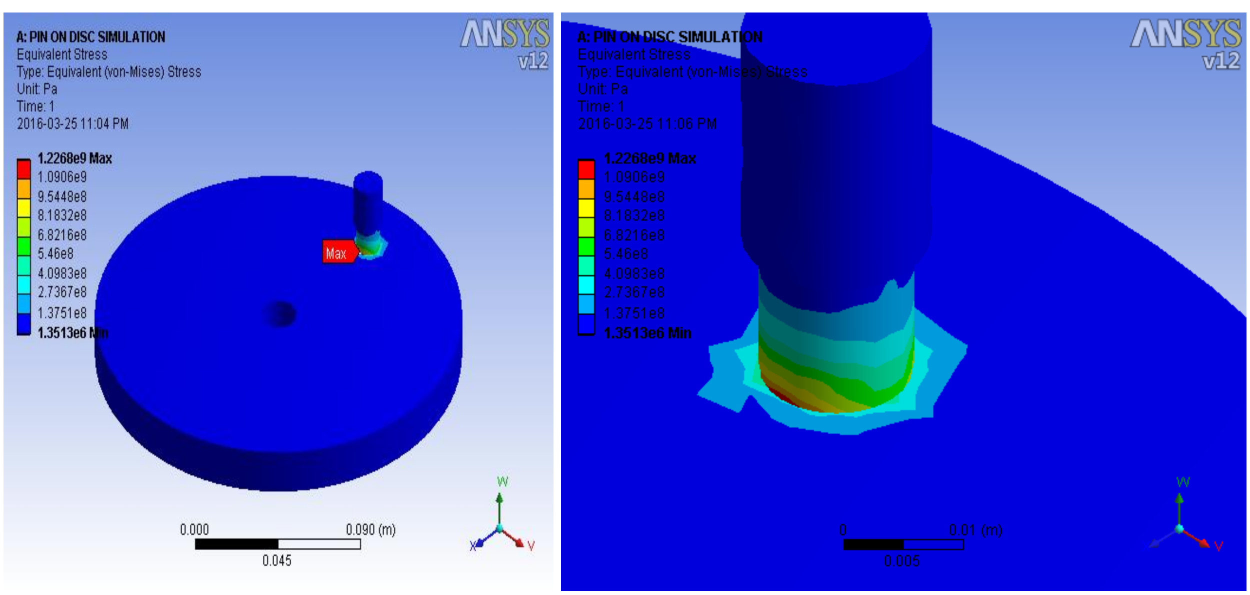

Figure 25. Pin CuNiSiCr material at 4.9kN

B. At 10kN

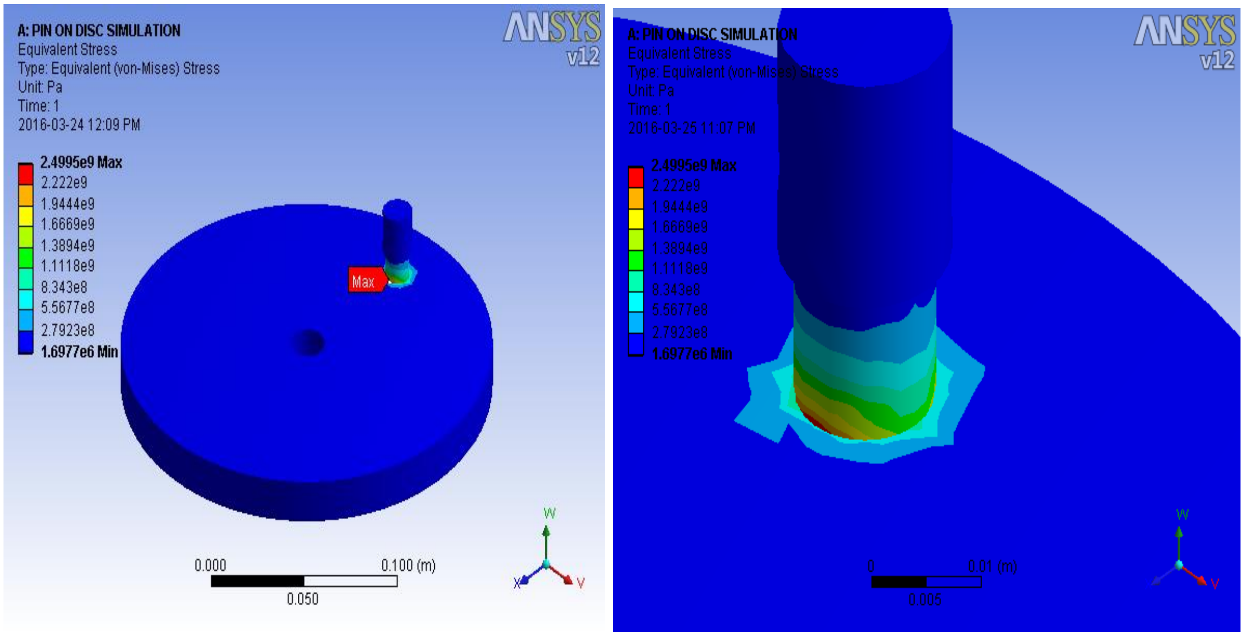

Figure 26. Pin CuNiSiCr material at 10kN

C. At 15kN

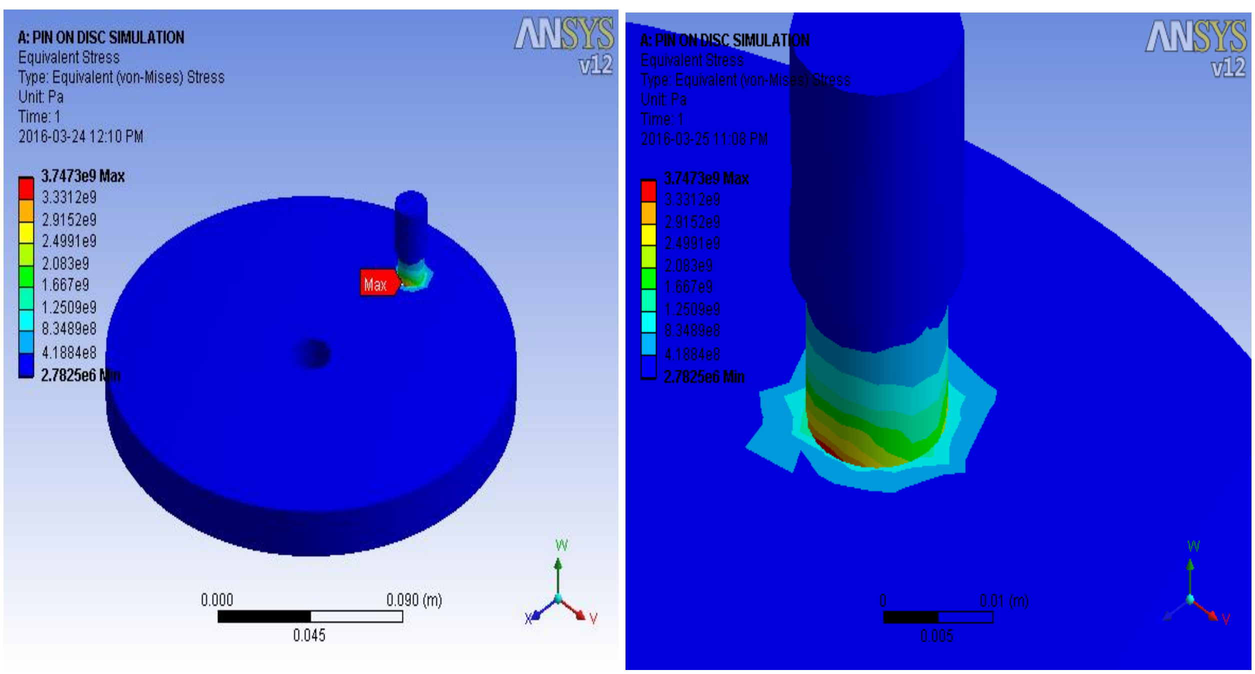

Figure 27. Pin CuNiSiCr material at 15kN

Table 8: Maximum equivalent stress result

Pin material	*Property*	*Loads(kN)*		
		4.9	10	15
`Cu	Max equivalent stress(MPa)	90.16	176.9	154.67
	Min equivalent stress(MPa)	4.99	4.99	4.61
CuAg	Max equivalent stress(GPa)	1.44	2.94	4.48
	Min equivalent stress(MPa)	1.17	7.68	2.52
CuNiSiCr	Max equivalent stress(GPa)	1.22	2.49	3.74
	Min equivalent stress(MPa)	1.36	1.69	2.78

4.2.2. Wear Depth

In order to find the depth of worn out on pin the grid is applied on pin model and the red zone is wear area. Therefore its length is identified using a grid and this helps to find the volume of material that worn out. Where the grid has height of 0.1 inch or 2.54mm.

Taking Cu material for pin model the model is totally deformed in all load cases as shown above.

For contact wire using copper material the contact wire have no strength of resisting the tension load applied by the pantograph contact strip. Therefore by applying grid on pin model of copper material helps to verify the depth of highly stressed height of pin model.

A. Cu pin material

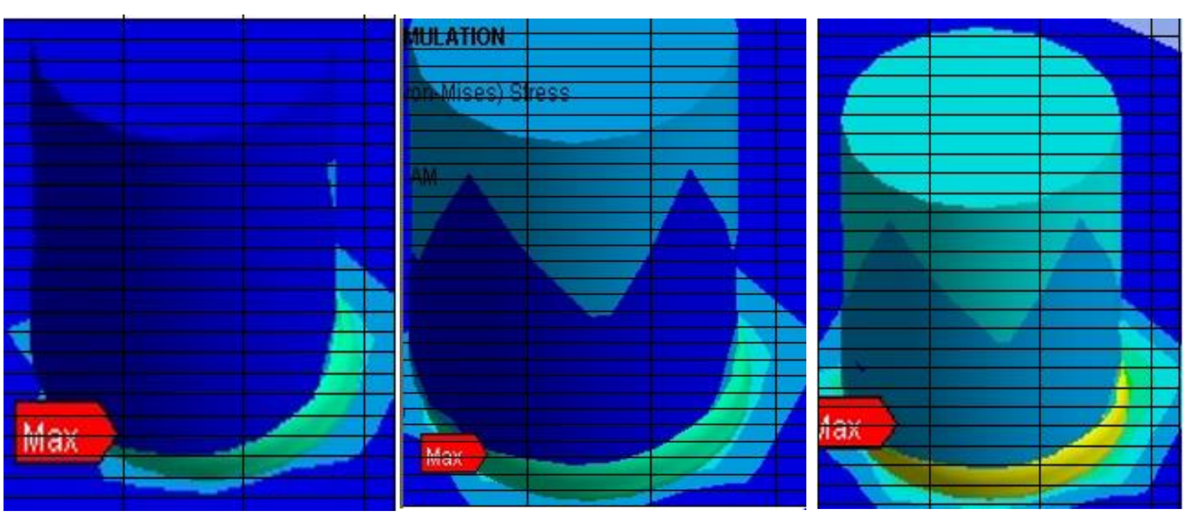

Figure 28. Cu pin material stressed portion in three load cases

Due to low strength of Cu material the overall length of pin is deformed or become out of shape in each three load cases. In the first load case at 4.9kN the copper material pin model deformed but doesn't stressed fully so the wear area is reduced to one third of pin model length. At load case two 10kN show same property to 4.9kN load case but at third load case 15kN the pin model deformed fully and the whole length of pin model stressed that means it will be worn out fully in this sever load condition.

B. CuAg pin material

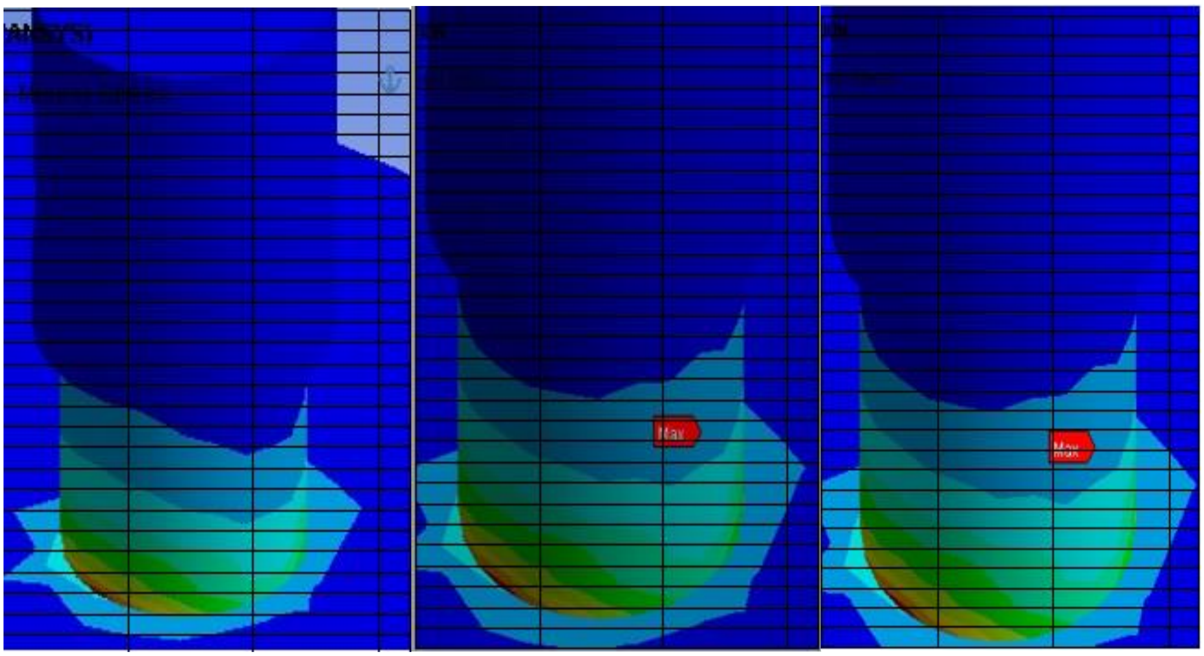

Figure 29. CuAg pin material stressed portion in three load cases

From the above CuAg pin model stress distribution as stated above the tip of pin is stressed highly in every load conditions. The highly stressed area of pin is taken as worn out, therefore this worn out or highly stressed area found by the grid height applied on the model. The depth of highly stress pin model are; in load case 4.9kN the stressed depth is approximately one grid height that is 2.54mm. At load case 10kN the two grid height is identified and on third load case 15kN the highly stressed depth of pin model become two and half height of grid.

C. CuNiSiCr pin material

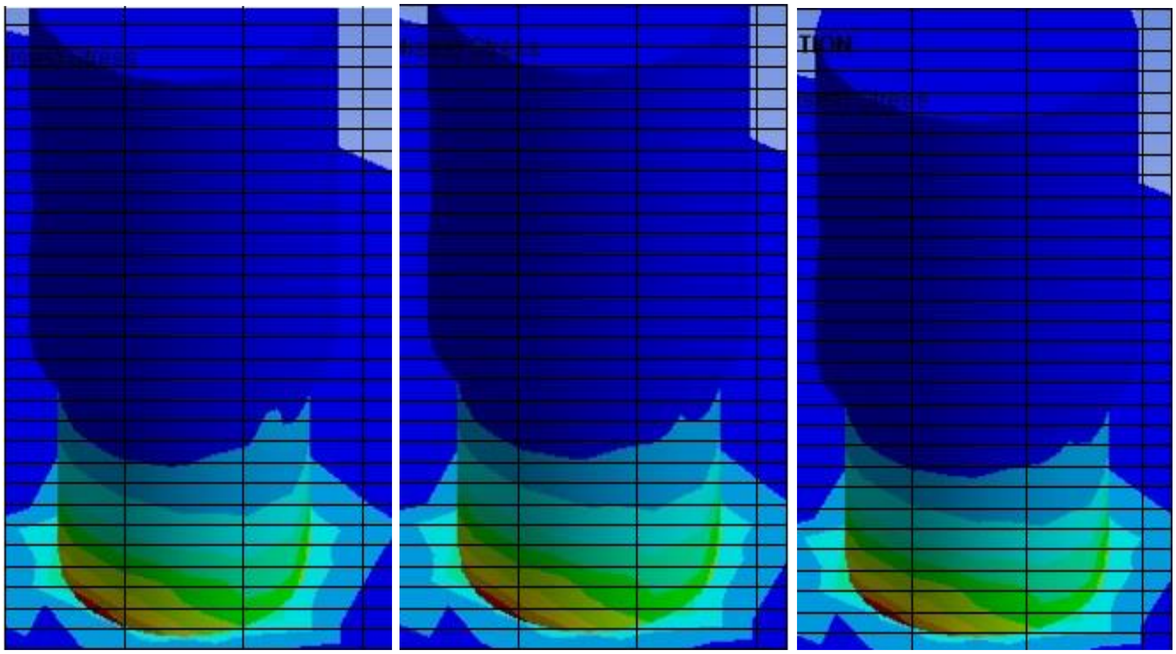

Figure 30. CuNiSiCr pin material stressed portion in three load cases

At load case 4.9kN one of grid depth is highly stressed, on second load case 10kN one and half of grid depth of pin model is stressed. On sever 15kN load case the two grid heights are stressed.

From above specified dimension grid on pin the worn out length due to maximum equivalent stress the material wear volume and wear rate is calculated using grid depth and area of pin model.

Table 9: wear depth

Wear depth(D) in mm

Pin material	Load applied		
	4.9kN	10kN	15k
Cu	6.35	7.62	8.89
CuAg	2.54	5.08	6.35
CuNiSiCr	1.72	3.81	4.23

Table 10: Wear volume

Pin material	*Volume(mm³)V = D*A*		
	Load applied		
	4.9kN	10kN	15kN
Cu	842.89	1011.47	1180.05
CuAg	337.14	674.31	842.89
CuNiSiCr	230.96	505.74	561.49

For calculating wear rate of a material the analysis will be held for some period of time and rate of wear get by wear volume per period of time. In this paper using software ANYS the default time for analyzing contact mechanics is one minutes which is 1/60 hr.

Table 11: Wear rate

Pin material	*Wear rate(W mm³/hr)=V/t*		
	Load applied		
	4.9kN	10kN	15kN
Cu	50.57E3	60.68E3	70.80E3
CuAg	20.22E3	40.45E3	50.57E3
CuNiSiCr	13.85E3	30.34E3	33.68E3

In other case the wear resistance of pin material in each load cases is calculated by time per wear rate value. The wear resistance shows the ability of material to handle the wear existences within a given load applied over period of time.

Table 12: Wear resistance

Pin material	*Wear resistance (R in h/mm³)=1/W*		
	Load applied		
	4.9kN	10kN	15kN
Cu	19.77E-6	16.47E-6	14.12E-6
CuAg	49.445E-6	24.72E-6	19.77E-6
CuNiSiCr	72.20E-6	32.95E-6	29.69E-6

4.3. Pantograph Contact Strip Wear Assessment

The wear assessment of pantograph contact strip is included because of contact wire wear is directly related to it. Contact strip is part of overhead electrification system using pantograph. It directly be in contact with contact wire in order to transmit power to rail vehicle. Contact strip is made of Cu alloy like contact wire to increase conductivity but it additionally include carbon element to resist wear rate and traction force.

There are four common type of contact strip materials PC78A, A0, A1 and C1. The Grade PC78A made by impregnation of copper into porous carbon is used as a standard. The grade A0 are modified from PC78A, and the grade A1 are further improved from A0. Each developed material has an increased content of copper and graphite to increase electrical conductivity. The grade “C1” is made of carbon/carbon composite C/C composite into which Cu-Ti alloy is impregnated. C1 contact strip is most commonly used type of material in recent rail way technology and AALRT also use this material for its contact strip.

Figure 31. Pantograph

Figure 32. Pantograph Contact Strip

The wear analysis of contact strip of pantograph is same as to that of contact wire with some modification to application of parameters. In this case the contact strip material is applied to pin and disc seat as the contact wire material and the rotational velocity added on pin model. The load applied on contact strip is also same as to contact wire tension force because of a mounting bracket Stainless steel of pantograph is directly supporting structure on bottom of panhead and it transmit interaction force between pantograph and contact wire to torsional spring suspension. Therefore the load used are 4.9kN, 10kN, and 15kN.

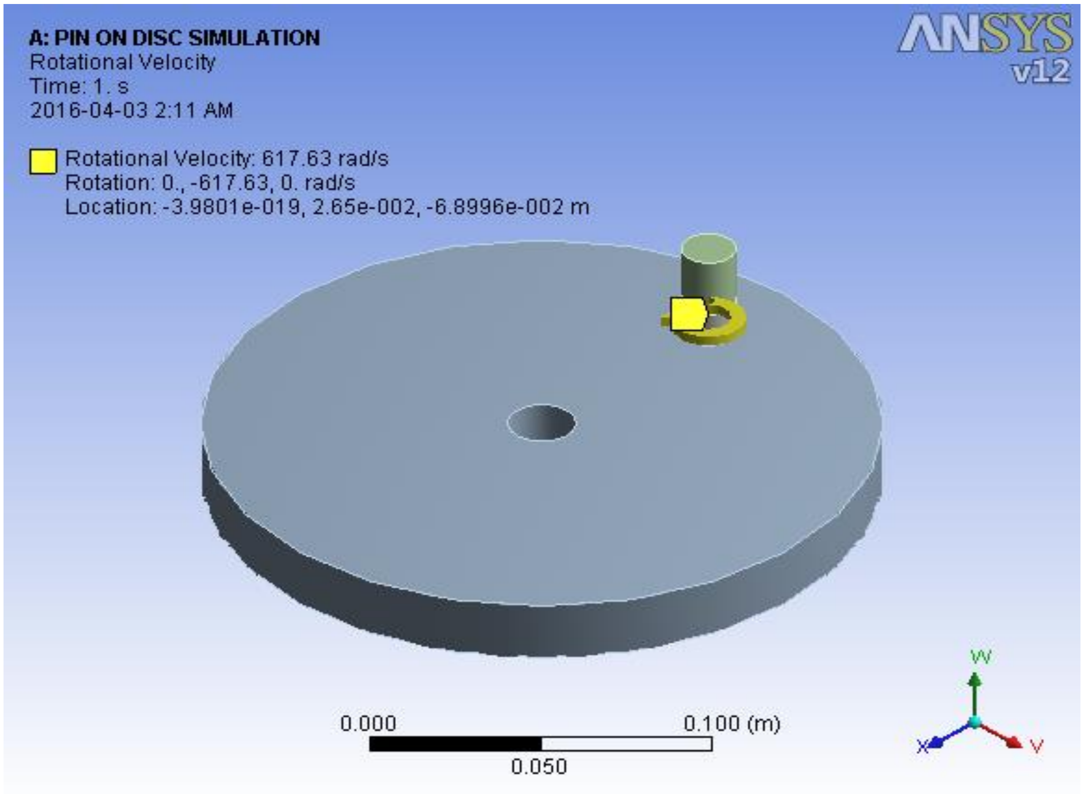

Figure 33. Contact strip wear analysis model

Then the loads applied sequentially on the top face of holder for analyzing the wear rate of pin contact strip material. The equivalent stress result is analyzed and depth of maximum stressed pin region is predicted.

Table13: Contact strip mechanical property[26]

No	*Material Property*	*Value*
1	Density (ρ)	2900Kg/m3
2	Elastic Modulus (E)	$1.93*10^{11}$ pa
3	Tensile Yield Strength	$1.2*10^{8}$pa
4	Poison’s Ratio(v)	0.26
5	Tensile Ultimate Strength	$2.54*10^{8}$pa
	Coefficient of Thermal Expansion	$1.7*10^{-5}$/c
7	Hardness (H)	95HB

For disc applying CuAg material and apply same boundary conditions to contact wire wear analysis.

1. At 4.9kN

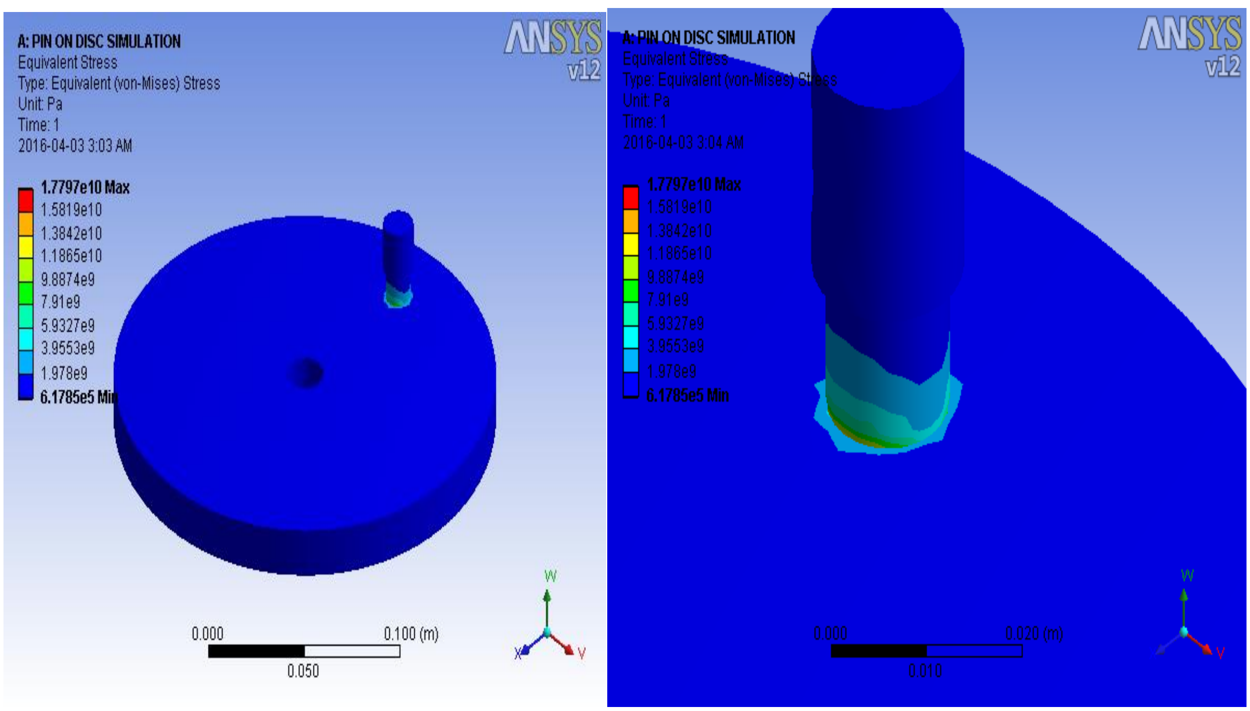

Figure 34. contact strip at 4.9kN

2. At 10kN

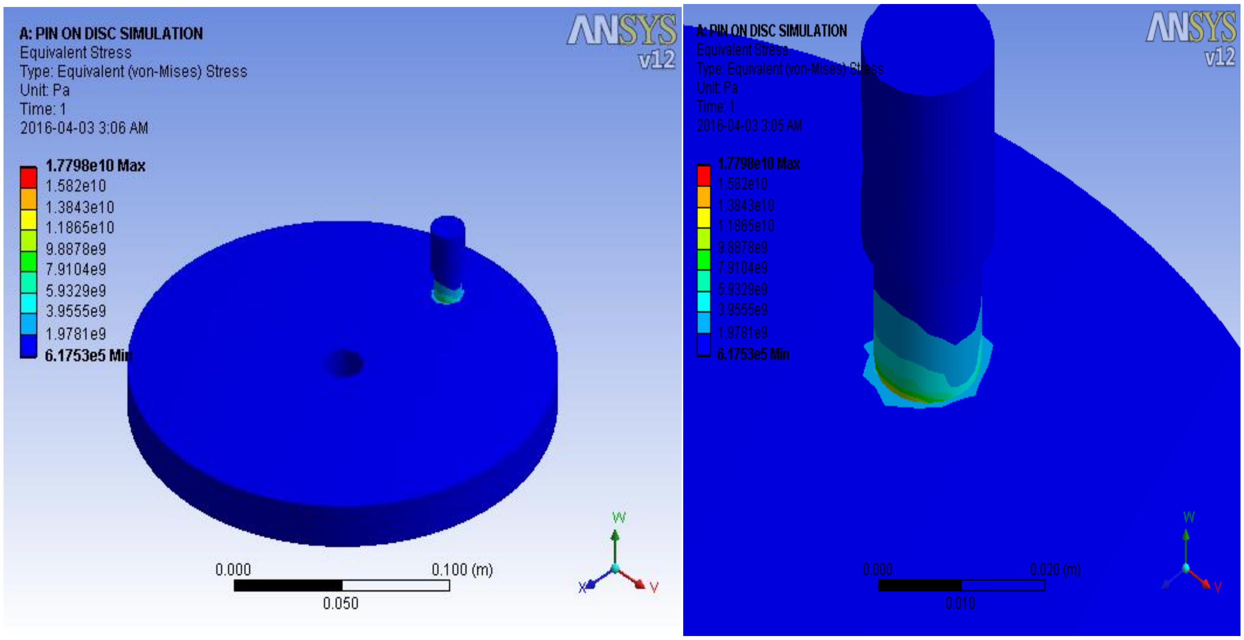

Figure 35. Contact strip at 10kN

3. At 15kN

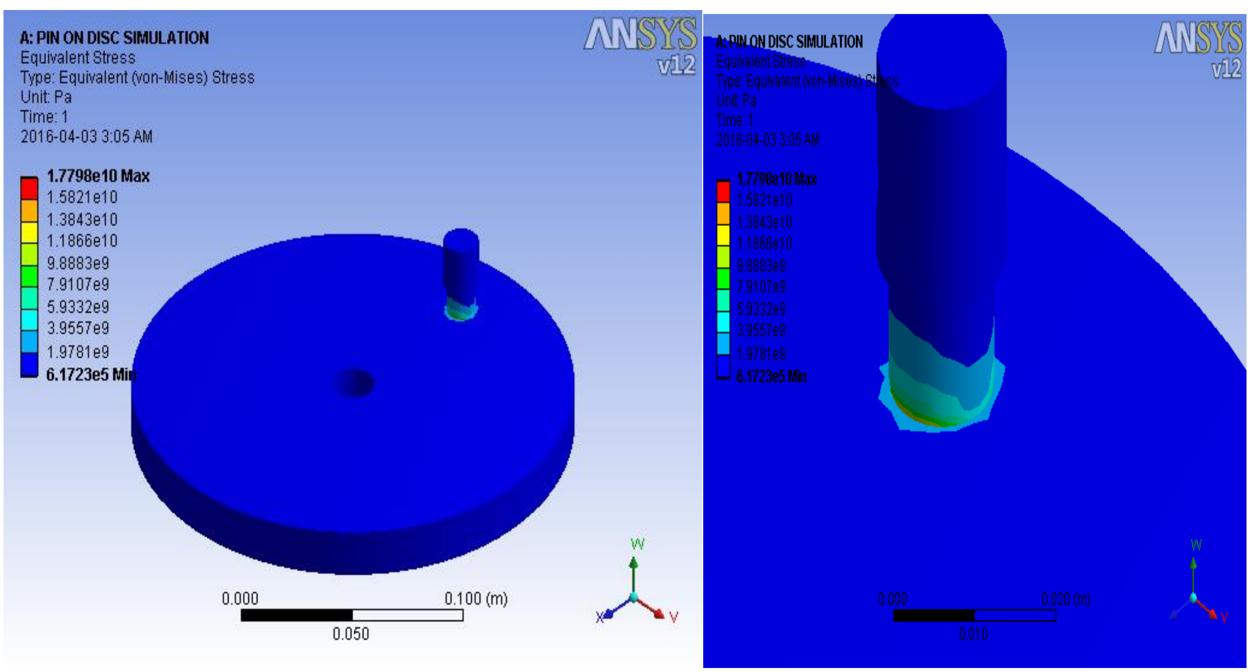

Figure 36. Contact strip at 15kN

Table14: contact strip equivalent stress

Pin material	*Property*	*Loads(kN)*		
		4.9	10	15
	Max equivalent stress(e10)	1.7797	1.7798	1.7798
	Min equivalent stress(e5)	6.1785	6.1753	6.1723

The equivalent stress of contact strip is relatively larger than the equivalent stress of contact wire but the stress concentration on tip of pin is relatively low which is because of the presence of carbon components.

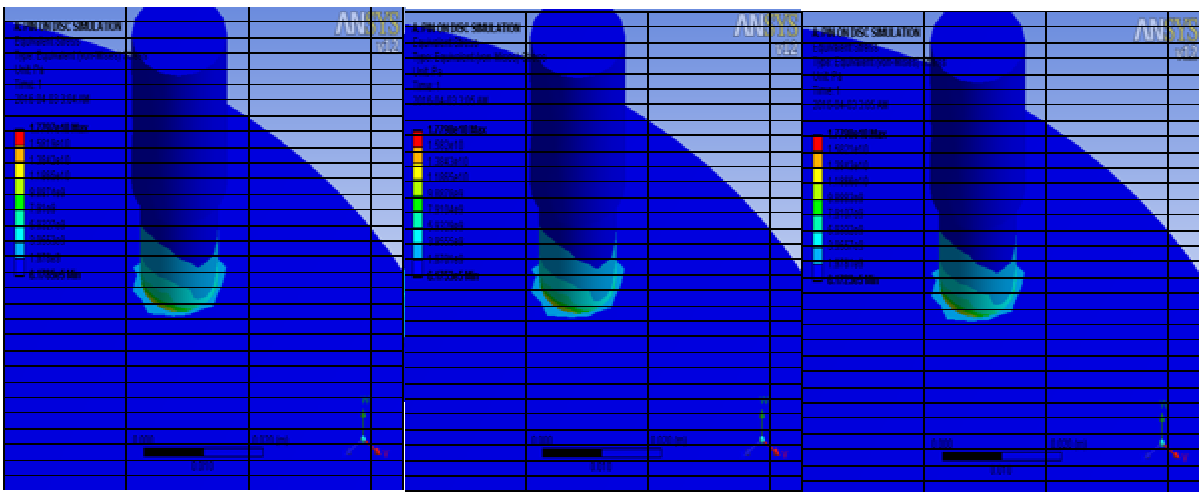

Fig37. Contact strip stressed portion

From the figure deep yellow region on all three load condition are almost the same, which is half on one grid height. From the depth of worn out pin portion the wear volume, wear rate and wear resistance of contact strip is calculated by taking the density 2900Kg/m^3 and wear depth 1.27mm.

Table15: wear property of contact strip wear analysis

Loads	*Wear property*		
	V(volume)	W(wear rate)	R(wear resistance)
	mm^3	mm^3/hr	hr/mm^3
	166.44	9.984e3	100.13e-6

From the above table the result shows that the contact strip have low wear volume and wear rate per hour, and the contact strip has high wear resistance relative to contact strip wear resistance

4.4. Discussion

In this research paper ANSYS Workbench pin on disc simulation models is used for analyzing wear rate of overhead line contact wire sliding contact. Cu, CuAg and CuNiSiCr are materials used for pin model and stainless steel and CuAg used for disc material.

From the simulation result the equivalent stress is taken for assessment of wear on pin model. The maximum equivalent stress value varies from one pin model material to another, where the Cu pin material have higher value than other CuAg and CuNiSiCr in all three normal load conditions. The tensile yield strength of material determine the value of equivalent stress because the tensile yield strength property shows the stress resistance of material during load applied. The change in maximum equivalent stress of pin model is shown in the table below.

Table16: Maximum Equivalent Stress

Pin material	*Property*	*Loads(kN)*		
		4.9	10	15
`Cu	Max equivalent stress(MPa)	90.16	176.9	154.67
	Min equivalent stress(MPa)	4.99	4.99	4.61
CuAg	Max equivalent stress(GPa)	1.44	2.94	4.48
	Min equivalent stress(MPa)	1.17	7.68	2.52
CuNiSiCr	Max equivalent stress(GPa)	1.22	2.49	3.74
	Min equivalent stress(MPa)	1.36	1.69	2.78

The table below shows the volume loss of pure copper, CuAg and CuNiSiCr alloys and for all three pin model materials with the increases applied load the volume loss increase. Whereas relative to each other the materials shows different volume loss value because of their variation in strength, where CuNiSiCr has lowest volume of loss than other pin model materials.

Table17: volume loss

*Volume(mm^3)V = D*A*

Pin material	Load applied		
	4.9kN	10kN	15kN
Cu	842.89	1011.47	1180.05
CuAg	337.14	674.31	842.89
CuNiSiCr	230.96	505.74	561.49

The wear rate of pin model materials increases with applied load and the copper alloy CuNiSiCr has lowest rate of wear than pure copper and CuAg alloy. The wear rate of each material calculated from the volume loss which caused by maximum equivalent stress on tip of pin model. The plot of wear rate with normal load for Cu, CuAg and CuNiSiCr under constant velocity and time is shown in Fig 40 below.

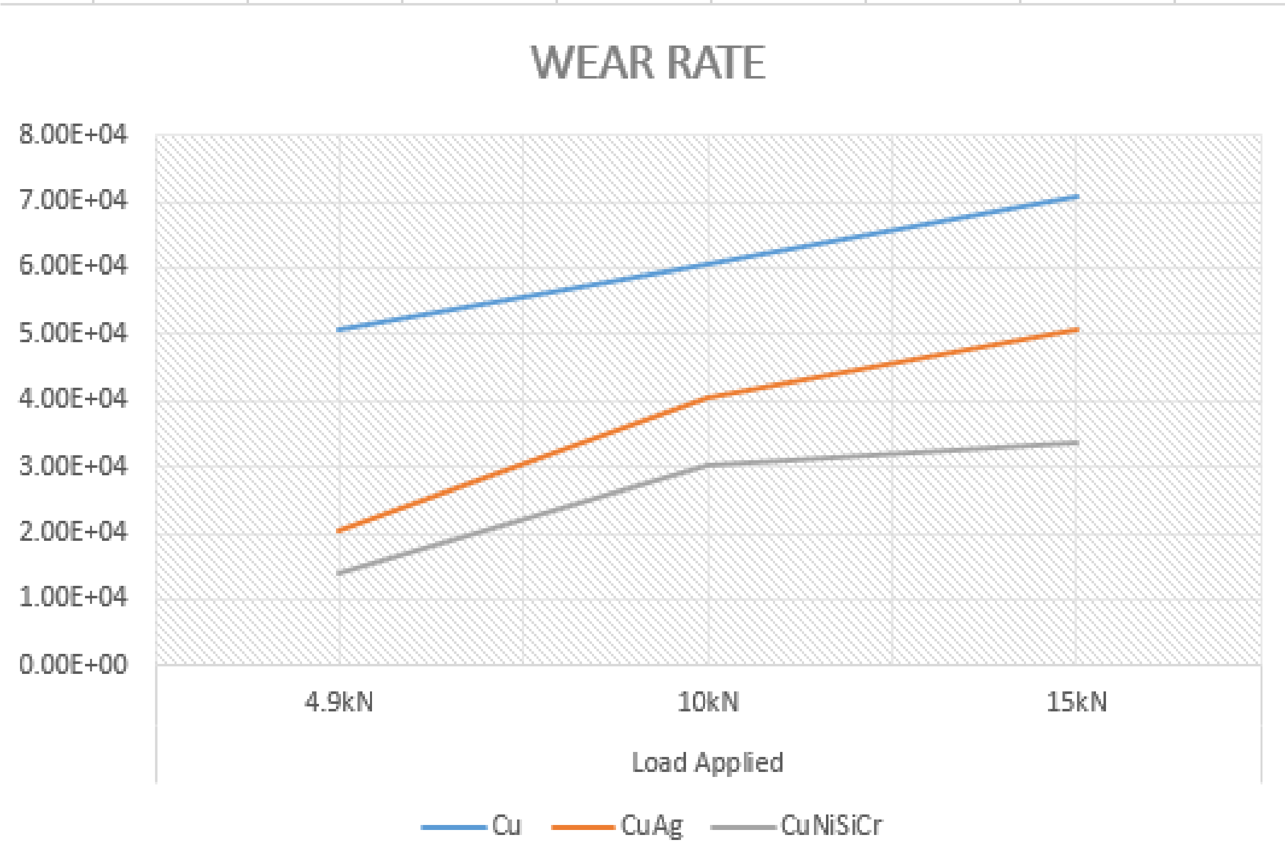

Figure 40. Wear rate graph

The graph of wear resistance with different normal forces under constant velocity and time are shown in Fig.41 below. Among the pure copper, CuAg and CuNiSiCr alloys CuNiSiCr has highest wear resistance and followed by CuAg and pure Cu shows the least wear resistance property.

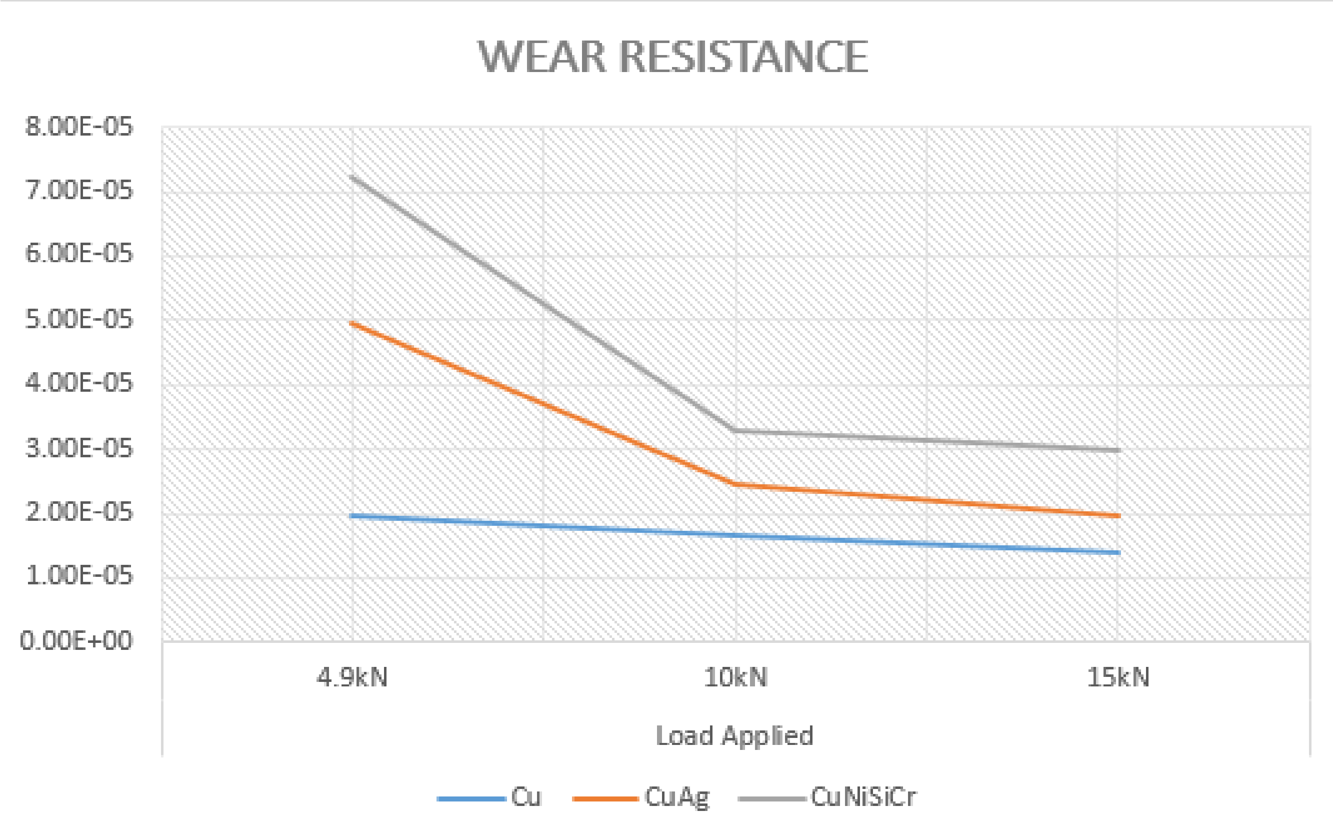

Figure 41. Wear resistance graph

From the graphs shown above CuNiSiCr material have low wear rate and high wear resistance within a period of time and constant normal load applied.

5. CHAPTER FIVE

CONCLUSION RECOMMENDATION AND FUTURE WORK

5.1. Conclusion

The wear of overhead contact wire are modelled and analyzed on ANYS Workbench FEM software. The contact wire is subjected to sliding wear therefore a pin on disc FE modeling is used. When the applied load increases from a value of 4.9kN to 15kN, the corresponding maximum equivalent stresses are increased, at the same time some portion of the bottom face of the pin results the maximum value. Found out that some elements of the pin will fail first, where this property is shown on all three material used for analysis of wear.

From the ANSYS Workbench wear simulation and analysis the following conclusion are made:

- Wear simulation and analysis in FEM is a key to facilitate the assessment of wear analysis of overhead contact wire
- Wear simulation on ANSYS Workbench provide relatively simple method for analyzing of contact wire sliding wear
- With increase tensile yield strength of material, the maximum equivalent stress decrease similarly the wear volume and rate decreases
- CuNiSiCr have minimum wear rate in all load conditions than other pin materials used, it also have high wear resistance property
- The contact strip have high wear resistance property than that of contact wire

5.2. Recommendation

For railway electrification system the reduction of wear on overhead contact wire is essential therefore the material used for wire must be high wear resistance. This paper recommends to AA LRT to use CuNiSiCr alloy material for overhead line contact wire, that can provide better strength for handling tension load applied and longer life span due to high wear resistance than other common Cu and Cu alloy used for contact wire.

5.3. Future Work

On this research paper the wear analysis of overhead line contact wire is analyzed using a related software that used to analyze a contact mechanics. The wear analysis is performed using a FEM on ANSYS Workbench software. The research used for finding the exact rate of wear on contact strip on different materials.

The wear analysis of contact wire require a serious and more attentions because the problem caused by wear lead to high cost and require more time. To minimize those problems and get more accurate and reliable wear assessment on overhead line contact wire, the fallowing recommended future work use as expansion of this paper:

- Analyzing wear using a software that specifically designed for wear analysis and compare with ANSYS Workbench result
- By modifications of pin and disc geometry analyze wear using various materials which can be used for the tribological purposes can also be analysed with these type of analyses.
- Analyzing wear of contact wire with applying current using a related software
- Analyze wear rate of overhead line contact wire by considering heat generated during contact and current flow
- Identifying and studying the possible wear types that can arose on overhead line contact wire
- Analyze the relatedness between the material conductivity and strength that can with stand sever load conditions
- Identify the tension load applied on overhead line contact wire that can cause wear and analyze way to minimize the tension load
- Identifying the rate of corrosion on contact wire using related software

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