ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

GRADUATE PROGRAM IN RAILWAY ENGINEERING

WEAR RATE ANALYSIS OF OVERHEAD LINE CONTACT WIRE BY CONSIDERING CURRENT EFFECT USING ANSYS.

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June, 2017

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.

Taha Ahmed Abdourahman ________________ ________________

Name Signature Date

This thesis has been submitted for examination with my approval as a university advisor.
Dr. Daniel Tilahun ________________ ________________

Name Signature Date

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ABSTRACT

The overhead line and pantograph is the two contacting bodies Wear on overhead line is one of the greatest problems in the railway industry. To overcome the problem of wear on overhead line different studies have been made. A better material selection that can withstand material loss due to sliding is the major solution that has been carried out but the effect of electrical force together with mechanical load is still challenge. In this research, the combined effect electric field and mechanical load is considered on wear of overhead line. In order to analyses overhead line wear rate the electric field effect due to the operational current and mechanical load effect has been under consideration. The modeling of pin-on-disc is made in CATIA software, the structural analysis is done using ANSYS workbench. The structural analysis is then used the stresses of the material of pin. In this cases, the applied load increases with operational current increases then the equivalents stresses increases. The wear rate increases with the operational current increases, so the better material in this researcher is the CuNiCr material because it has good wear resistance. Finally, this paper suggests this material to be used for contact wire material.

Keywords: wear rate, equivalent stress, wear analysis, pin-on-disc, Ansys workbench, Electric field force.

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Nomenclature

OCS: --Overhead Contact System

DC: --- Direct Current

AC: --- Alternate Current

Cu: -- Cooper

Ni: --- Nickel

Cr: -- Chromium

Si: -- Silicon

Ag: -- Silver

Mg: --- Manganese

Be: ---Beryllium

AALRT: -- Addis Ababa Light Rail Transit

FE: -- Finite Element

FEA: -- Finite Element Analysis

FEM: --- Finite Element Method

Gpa: --- Giga-Pascal

Mpa: --- Mega-Pascal

HB --Hardness Brinell

Km: --Kilometer

Hr: -- Hour

Mm: -- millimeter

w: -- rotational speed

V: --- speed

r: -- radius

D: --- Wear Depth

F: -- Load

E: --- Electric field

Fe: --- Electric field force

Q: -- Charge Electric

d: --- Distance

I: -- Current

A: -- Ampere

VDC: -- volt-direct current

W: -- Wear Rate

Wr: -- Wear Resistance

CHAPTER 1: 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-motor, 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. (5) 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. Urban railways are differentiated from regional and intercity railway systems, among other things, by their slower running speed, which is not usually greater than 80 km/h. As lower voltages are required to move the trains, the lines are electrified with direct current at voltages ranging from 600 to 3000 V(2). The vehicle collects the electric current via the pantograph strip, which slides along the contact wire of the overhead line.

As the lines are electrified under low voltage, they demand greater current intensities than other types of railway systems, and this can lead to the overhead line overheating.

1.1.1. Electrification System

A railway system of electrification provides the electric power to the railway engines and with the units multiple so that they can function without having an on- board prime mover. The railway electrification has many advantages but requires significant capital expenditures of investment for the installation.

There is standard of two communal grounds of electrifying trains is by the overhead line or using the third rail where the trains obtain its electricity of the rail built between the two railway tracks.(1)

1.1.2. Third rail system

Most electrification systems use overhead wires, but third rail is an option up to about1.200 V. While use of a third rail does not require the use of DC, 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. Third rail is more compact than overhead wire and can be used in Smaller-diameter tunnels, an important factor for subway systems. Third rail is more compact than overhead wires and can be used in smaller-diameter tunnels, an important factor for subway systems. Third-rail systems can be designed to use top contact, side contact, or bottom contact. Top contact is less safe, as the live rail is exposed to people treading on the rail unless an insulating hood is provided. Side- and bottom-contact third rail can easily have safety shields incorporated, carried by the rail itself. Uncovered top-contact third rails are vulnerable to disruption caused by ice, snow and fallen leaves. The DC systems prevent the use of low-level platforms and are limited to relatively low voltages. A later can limit the size and speed of trains, and limit the power available to passenger comforts, such as air-conditioning.

The low voltage also means that long distance transmission is inefficient and thus frequent transformers are required along the length of the line. 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. (1)

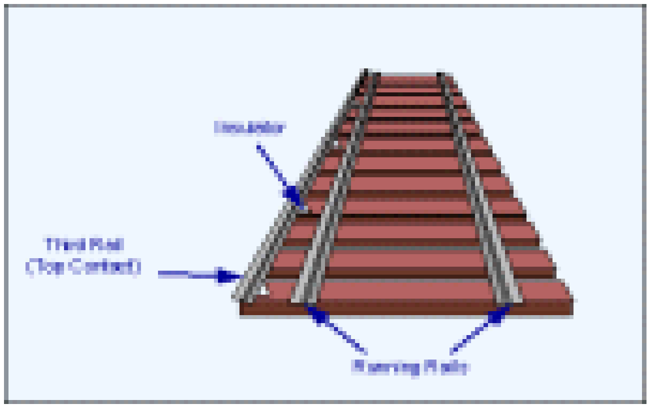

Figure 1: This diagram shows a DC 3-Rail Traction System with the location of the current rail in relation to the running rails. (29)

1.1.3. 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.(1)

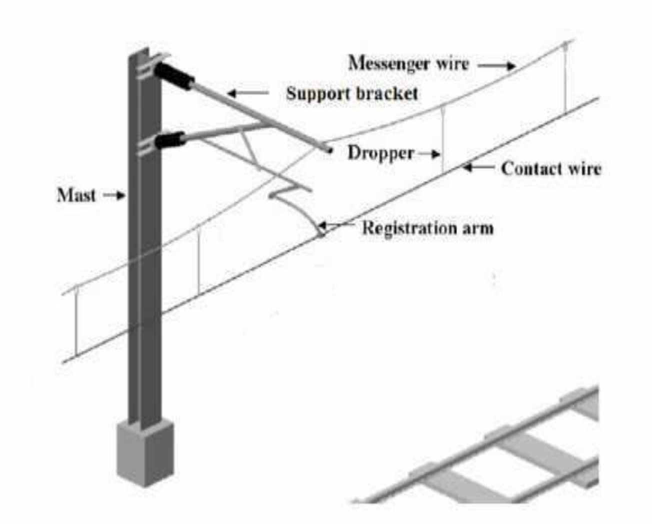

Figure 2: Overhead line

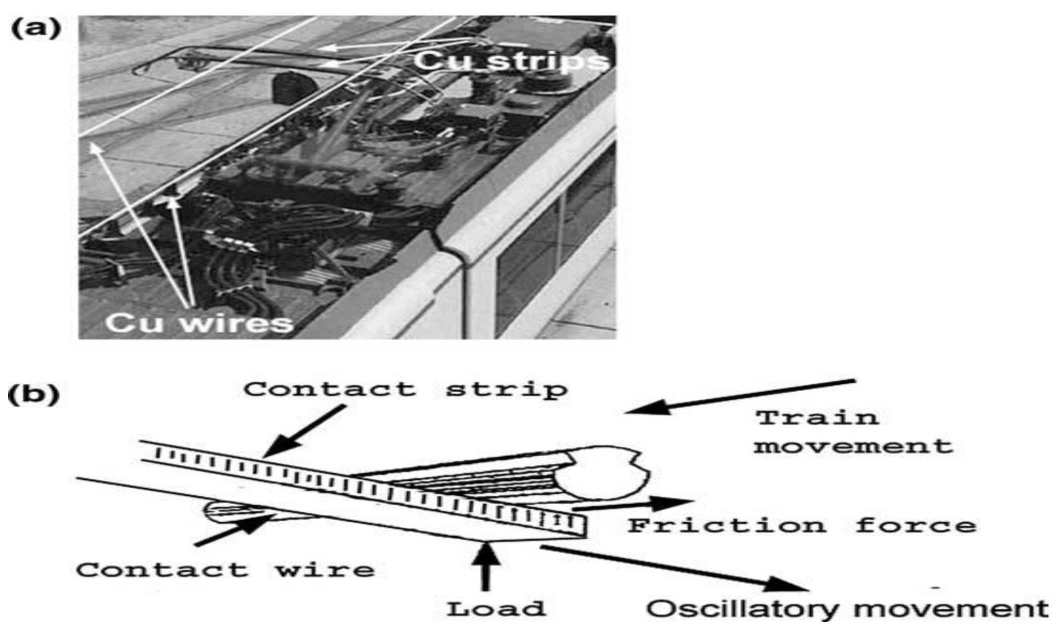

Figure 3: contact between pantograph and contact wire.

1.1.4. Contact Wire Failure

The lifespan of overhead line and collector contact strips are depend on the four given situation if it ignored this challenge the service longer of overhead catenary is less:

I. Type of materials at contact;

II. Operating conditions such as sliding speed, contact force and current intensity;

III. Level of arcing, heat effect and sparking.

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 limitation 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. 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. The effect of electric current on the wear mechanism was emphasized in an action of Joule heat and arc discharge heat [25].Especially, several investigators reported that wear of contact strip materials is related to interface debris generated on contact surfaces [25, 26-28]. With increase in high-speed train, the wear of the collector strip and contact wire materials becomes severer and severer in a pantograph strip rubbing against a contact wire. In order to reveal the effects, influence of electric current and normal force on tribology properties of carbon strip rubbing against copper contact wire is used to investigate damage mechanism of contact materials for pantograph catenary system. 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.

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1.1.5. 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 also the contact wire is a very important element of the electric overhead railway system. 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 becomes 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 [6].

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 super conductor development, its unique combination of properties seems to offer the only reasonable means of achieving usable lengths of conductor in rail way electrification system[7].

Figure 4: Contact wire material

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

Alloy	Composition	Electrical conductivity	Density g/cm3)	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, 13 MS/m	8.36	342
CuBeNi	0.4% Be 1.5% Ni	44%IACS, 25.8MS/m	8.83	242
CuAg	0.7% Ag	None	8.8	219

1.2. Problem statement

The pantograph slides over the overhead line to transmit electric current to the train components due to their sliding motion a frictional force is induced that cause wear between the two bodies with the effect electric field the severity of wear increase. The material of contact wire that the AALRT using are copper alloy which low wear resistance and electrical conductivity, but in order to figure out better materials having high wear resistance and high electrical conductivity copper alloying materials CuAg, CuNiSiCr and CuNiCr are selected in this paper, it considers the wear rate analyses will pursuit to analyze those material with the current in during contact between overhead line contact wire and pantograph. Therefore, after model and detail analysis using software, the relation between wear rate and current of those materials are discussed and recommended better material than CuAg alloy for Addis Ababa LRT overhead contact wire during contact with maximum operational current without corrosion effect.

1.3. Objective of the Research

1.3.1. General Objective

Analyzing the wear rate of overhead line contact wire by considering current effect during contact.

1.3.2. Specific objective

- ✓ Compared the copper and its alloy material property, type of material and select this material.
- ✓ Determine the load, wear type and the operational of current effect to convert electric force as distributed load on overhead line contact wire during contact means sliding moment without arcing effect.
- ✓ Models wear simulation using ANSYS software.
- ✓ Showing the influence between current, the wear rate and resistance for each material.
- ✓ Select the material that has good wear resistance.

1.4. Methodology of research

The methods sections are keys of research to relay in procedures in order to achieve stated of the objectives:

1. Choosing the copper and its alloy material property and its composition
2. Select the modeling type using Catia V5 software for model the material.
3. Analyzing wear of the overhead wire with operational current effect during the contact moment modeling using Ansys.
4. Identified the high operational current and convert to applied electric force between overhead line contact wire and pantograph during contact.
5. Identifying the mechanical resistance (equivalent stress, wear depth, wear resistance, wear rate and wear volume).
6. Determine which material has good wear resistance with operational current.

1.5. Significance of the research

This paper has a big significance for analysis of overhead line wire systems considering the current flow effect. When the capacity current increase the speed of train increase then, the sliding contact of the wire over pantograph increases as this reason the wear rate also increase. This research is providing for Addis Ababa LRT to select material for overhead line and suggests to add something as to perform analysis without considerate the thermal structure occur when contact between materials. And finally it indicates the simplicity of analyzing wear rate in overhead line.

1.6. Scope and limitation of the study

This research paper targeted in the analysis of wear rate in overhead line contact wire using ANSYS Workbench software where my objective will be assigned without cost analysis, corrosion without heat generated due to less of data finding but indicate the material will appropriate to catenary contact wire consideration the effect of operational current. The wear rate will be analyzed at different load, neglect the matrices force applied between wire and pantograph also arcing effect at current transfer but focuses on electric field force during contact moment also combined with normal pressure. In this paper the analysis of this material are required CuAg, CuNiCr, and CuNiSiCr under current at ambient temperature. The results which compared with experiments paper to define the gap, suggested which material has good resistance material of wear and strength.

1.7. Organization of the research

This research paper is organized in to five chapters. The first chapter is the introduction part describes the background of the research, statement of problem, and objective, scope and limitation of the study, significance of this research and methodology. The second chapter two is literature review that contains journals, articles and publications relevant on the research paper work. Also on this chapter is adding some related paper to give strength of paper. Chapter three focused to the model; wear analysis and using to analysis the contact mechanics and thermal effect. The assignments for analysis of wear rate were studied related software. Chapter four was occurred the final result and discussion. The software provide basic solutions that helps to determine the require answers for the study based on the results the discussion follows. Chapter five is all about the conclusion and recommendation and it give future work on this domain of study.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

There are many journals, papers, conference, thesis papers and published study concern in overhead line contact and wear analysis. There are many previous works way a different approach used to analysis wear rate in overhead line contact wire using materials those different approach and methodology will get also in this paper.

2.2. Overhead contact line wire and power supply

Overhead catenary is simplified the traction system of electrical to conductors the power through to sliding pantograph current collectors to supply electrical energy to moving locomotives. The increasing speed of modern high-speed locomotives need more power to improve the efficient of speed then increase of wear brought to reduce the lifespan of material and increase the power needed. In recent technological developments of electric traction systems, major efforts have been devoted to speeding up locomotives, prolonging lifetime and reducing maintenance costs of the overhead catenary and collector strips [2].

F.J. Gonzalez, J.A. Chover, B. Suarez and M. Vazquez (8) : it focus to determine quantity of wear levels of the contact wire of the catenary urban lines. It has focused the contact wire zones where wear is created the creation of electric arcs. The model analysis is doing by FEM issued to indicate interaction developed by pantograph catenary dynamics. Also it has includes a zone of wear and point the contact wire in refer simulation the less case from the stresses. The wear wire processes different depth and widths must knowing in definition wear zone. The outcome of simulation dynamic indicate the step to see of wear section to resistant less than area of the contact wire to supervising which stresses is greater than giving stresses. The tensile stress reached at maximum in wire contact to determine exactly place wear zone to estimate depth and width quantity. If the wear quantity are analyzed an overhead line to recording train, it will be simply to determine the potential risk of wire. Otherwise, the tensile forces dependent of the contact wire are showed. This results giving suggested to change this failure sections of wire, this making better maintenance and efficient. The outcome obtained show the replacement of wire failure, can give some wear problem, adjusted even more and adding life cycle efficient for this wire contact.

Poo Ke Wong (3): This paper studied the electrical sliding wear of cooper based contact wire material for electrical railway in the experiments; the electrical sliding wear suggested of eight cooper-based alloys was showed in pin-on-disc tribo meter. This experiments paper compared alloys and showing which is compatible to overhead line contact wire of wear rate analyzed, this experiences given boundary values under un-lubricated condition at some velocity of sliding as to 31.2km/h and normal load up to 20N with considerate electric current, the experiments taken with various copper in cylindrical rod to forcing with counter face stainless steel disc, another studied with scanning electron microscopic the wear debris and worn surfaces. The different wear studied in the mechanical and electric arc erosive indicates at 50A the mechanisms for the alloy worn. Finally, in the experimental studied with considerations wear resistance and electrical conductivity, cooper alloy as Cu-Cr-Zr is better material of the contact wire for electric railways systems.

Tao Ding, Wenjing Xuan, Qiudong He, Hao Wuand Wei Xiong(14): This paper studied about, Study on Friction and Wear Properties of Pantograph Strip/Copper Contact Wire for High-Speed Train. The service life of pantograph/catenary system mainly depends on the wear life of the pantograph strip and contact wire materials. This experiments work was analyzed in a ring-on- block tester with different operator's condition, lubrication before all test, required time to obtain good contact sliding and showing different mechanical behavior effect in wear properties. Increasing wear service life of the collector strips is a main concern to operators and investigators. From the viewpoint of friction, the wear service life depends on wear mechanisms occurring in the process of electrical sliding friction. A series of experiments on friction and wear properties of carbon strip rubbing against copper contact wire is performed on high-speed friction and wear tester with electric current. The results show that the friction coefficient is generally maintained between 0.24 and 0.37. In the absence of electric current, the coefficient of friction is higher than that in the presence of electric current. The wear rate of carbon strip materials is generally not more than 0.014g/km. In particular, the wear rate under the electric current of 240 A is 14 times more than that in the absence of electric current. By observing the scar of worn surface with optical microscope, it can be found that there are obvious slip scars and arc erosive pits. The dominated wear mechanisms are abrasive wear and arc erosion in electrical sliding frictional process.

C .R. F Azevedo , A. Sinatora (10): in this paper focused to investigated the causes of premature wear of the contact strips of a railway line working under voltage of 1.500 Vdc, current of 1120 A, normal force of 70 N and presence of graphite in the wire/strip interface. In all investigated regions (without apparent wear, moderate wear and severe wear), the presence of cracks in the hardened tribo-surface of the Cu-strip – which is caused either by work hardening or thermal cycling is usually followed by material detachment and production of hard abrasive debris. The presence of hard abrasive particles (such as SiO_2 and Al_2O_3,) and wear debris (Cu_2O and hardened Cu) promotes a regime of severe abrasion. The debris showed preferentially a flake-like morphology, being composed of graphite and highly deformed copper, suggesting the dominant action of mechanical wear mechanisms. The presence of some raindrop-like debris featuring an as-cast microstructure confirmed the occurrence of incipient fusion on the copper strip tribo-interface, possibly caused by electrical discharge (electrical induced wear). The results indicated that the wear mechanism of the Cu strip is divided into different stages. First, there is a mixed wear regime (adhesive and abrasive wear) of the graphite layer associated with lubricated adhesive wear of the Cu strip. After, there is the occurrence of a mixed wear regime between the strip/wire tribo surfaces, with simultaneous action of unlubricated adhesive wear, third body abrasive wear and electrical induced wear (local fusion). Finally, once the graphite has been completely consumed, the wear grooves are parallel to the sliding direction and the center of the strip shows a much more severe wear rate.

A. Bouchoucha , H. Zaidi , E.K. Kadiri , D. Paulmier(16) : this paper discuss the effects of the electric field on surfaces, mechanical properties and tribological behavior. The crossing of the electric current in rail line through a copper/steel sliding contact is associated with an electric field between the sliding surfaces. The electric field increases with the current intensity. the sliding speed and the contact resistance, and it decrease with an applied normal load. An electric field enhances the oxidation of surfaces. and the growth of such an oxide layer increases the electric field. Mechanical wear removes the oxide film and then decreases the electric field. The process of wear in an electrical sliding contact is continuously modified by the electric field according to the current intensity. Surfaces can be damaged by abrasive wear, by oxidation, or by an electric arc through the contact. This paper presents the result of an experimental study of the wear behavior of an electrical sliding contact and its variation in the presence of an electric field. Most paper related to thermal-mechanical approach done by one pin on disc model to represent the sliding system. The main advantage of this approach is that it can be applied to unsymmetrical load to investigate more details about the stability situation in the sliding system (symmetric and asymmetric geometries).

The simulation in the frictional is sliding between a stiff pin and friction disc using ANSYS software. There are three basic types of contact used in ANSYS software: single contact, node-to-surface contact, and surface-to-surface contact. Surface-to-surface contact is the most common type of contact used for bodies small contact area with relative large contact areas.

Alen John1, Dr. Y.V.K.S Rao, and Jerin Sabu, Rajeev V. R(6): On this research paper performed the Stress Analysis of Polyoxymethylene which Leads to Wear in Pin on Disc Configuration using Finite Element Method. Tribological failure is one of the most common problems that limit productivity and its reason is the wear. The pin-on-disc configuration is commonly used for wear tests in laboratories because of its simple arrangement. It consists of a stationary pin under an applied load in contact with a rotating disc. Polyoxymethylene (POM) is an engineering thermoplastic used in precision parts when high stiffness, low friction and excellent dimensional stability are required. POM is characterized by its high strength, hardness and rigidity to ~40 °C. POM can be used for Mechanical gears, sliding and guiding elements, housing parts, springs, chains. It is also used in electrical engineering applications like insulators, bobbins, connectors. For modeling railway parts and in the medical, furniture and construction field also this material is applicable. The analysis is expected to be completed in the finite element analysis software ANSYS Workbench 11.0 with the help of the model made by using CATIA V5R18. 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 modeling software CATIA. Using the boundary conditions the analysis are done. Rotation of 3000 rpm is provided for the disc. Then with analysis software of the wear by varying the pressure acted up to the tensile yield strength of the material and assuming that the region of the pin where maximum equivalent stress occurred is failing or wearing out, since we have no provision for finding out the wear analysis in the available software packages. Then we are moving 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 and this paper focused to explain about analysis of software in pin-on-disc.

Priit Podra , S.Andersson(19): In this paper, the wear simulation was presented in commercial finite elements software ANSYS. The finite elements analysis numerical solution accuracy depends on the model discretization. Finer nodal mesh gives more exact results, but contributes to a long computing time and use of greater disk space. Several additional routines are often needed to enhance the numerical procedure and validate the results. The contact analysis in FEM is a non- linear problem. The FE model discretization and contact stiffness with given loading and constraints are directly related to the iterative procedure's ability to converge. A good configuration has to be found on the basis of experience. The integration time step is a critical parameter regarding the reliability of simulation results. Too long steps cause erratic results and possibly the un-convergence of FEA procedure. Too short intervals take too much computing time. A simple simulation time step optimization routine was developed, evaluating the integration step duration for every solution step individually on the basis of the fixed maximum wear increment. The wear mechanism must be considered and its changes must be foreseen during the simulation process. The Lim and Ashby wear map can be used for steels. Assuming the linear wear law to be valid, the FEA wear simulation results for a given contact geometry and a given load can be treated on the basis of wear coefficient-sliding distance change equivalence and The actual scatter of the wear coefficient being 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 should be evaluated on a relative scale to compare different design options, rather than to be used to predict the absolute wear life.

G-Jia, P.Liu , Feng-Zhang , S-Zhou(12) : This paper reports the study of the sliding wear behaviors of the CuAgCr wire. CuAgCr alloy is a promising contact wire material for high speed electrified railways, which has an excellent combination of mechanical strength and the electrical conductivity. The wear tests were conducted under laboratory with a special sliding wear apparatus, which simulated the tribological conditions of sliding current collectors on overhead wires in the railway systems. The CuAgCr alloy wire was slide against a copper-based powder metallurgy strip under unlubricated conditions. the same strip as those in the train systems were used. worn surfaces , of the CuAgCr alloy wire were analyzed by SEM and EDS. within the studied range of electrical current, normal pressure and sliding speed, the wear rate increased with the increasing electrical current and the sliding distance. Compared with a CuAg contact wire under the same conditions, the CuAgCr alloy wire had much better wear resistance. Adhesive wear, abrasive wear and arc erosion were the dominant mechanisms during the electrical sliding process.

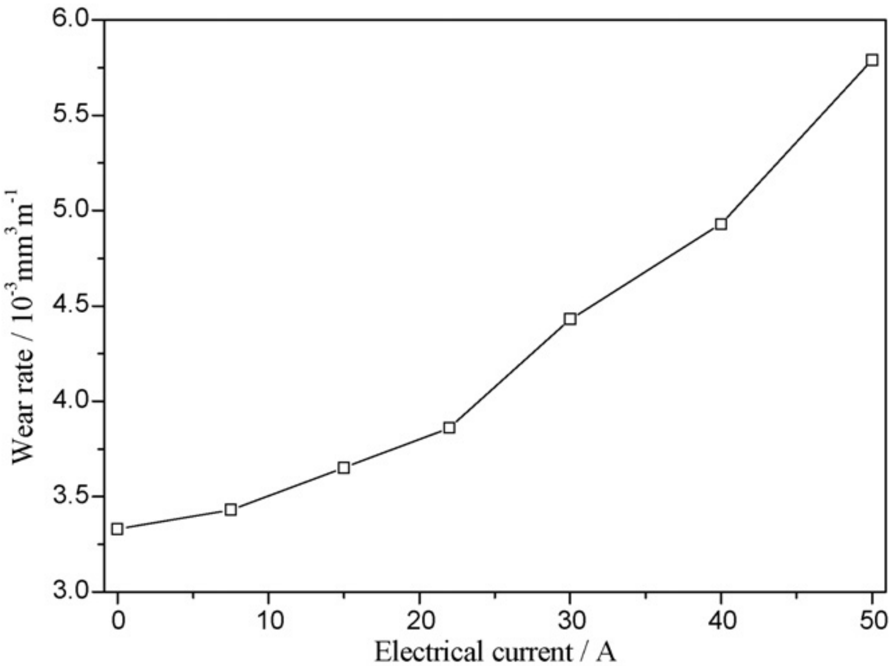


Figure 5: The relation between electric current with the wear rate

This paper is close to my project and the gap can be clearly defined. A selection will be done between three material based on their capacity to withstand the combination of electrical force and mechanical load. In this project case, the current is evaluated as electric force and will be combined with mechanical load. The wear rate of simulation is done by Ansys workbench software with default time of software. This study reports that wear rate increases with increases electric current. In fact, if we increase the intensity of the current, the electric force will increase and the resultant force means combined the electric force with the normal pressure will also increase.

2.3. Sliding Wear

The Wear is the surface damage or the removal of the material from the surface of a solid body as a result of mechanical action of the counter body/sliding, rolling or impact motion/ and is generally accelerated by frictional heating (or thermal means). Many of the wear process at the rail-wheel contact apply also to the overhead line power supply. And electrical transmission- arcing can contribute greatly to wear [6]. The sliding between the contact wire and the pantograph causes wear to both surfaces. For financial and safety reasons, wire wear is more critical than that of the collector strip. Wear is due to mutually related mechanical and electrical factors.

According to [10], the most influential factors are the material , the wire and collector strip are made of, the contact force, the current intensity and the speed of the vehicle. Irregularities in the wire and particularly singular spots with local variations in stiffness, such as the suspension cable anchorage points and the registration arms, cause contact losses between the pantograph and the catenary, [10], [11], [12], and [13].

These contact losses give rise to electric arcs, which cause local overheating, with micro-melting and the evaporation of material, there by accelerating the wear process at a local level, which is wear is not uniform. The rise in temperature accompanying the arc produces an annealing treatment, so the worn wire becomes softer than new wires facilitating surface abrasion [26]. The wear behaviors of tribological pairs with electrical current were different from those without electrical current [8].

The wear of material may be due to the friction of metals against each other, eroding effect of liquid and gaseous media, scratching of solid particles from the surface and other surface phenomena. Wear is composed of the several processes that occur in metal sliding situations. The processes possibly include metal transfer, film formation and removal, debris generation and cyclic surface deterioration. All of these affect the tribological behavior and depend greatly on the sliding materials, the contact geometry, thermal effects (friction and the electric field), and the chemical environment of the contact and the mechanical parameters of the system [15]

Figure 6: Sliding of the contact strip against contact wire.

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 surfaces 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 these studies mainly focus on normal direction with a friction contact. Contact mechanics provide information for safe and energy efficient design of tribology and indentation hardness.

The first pioneer to introduce the contact stress is Hendric Hertz, approached the problem by FEM 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 has assumptions which are:

1. The radii of curvature of the contacting bodies are large compared with the radius of the circle of contact.

2. The dimension of each body is large compared to the radius of the circle of contact.

3. The contacting bodies are in frictionless contact.

4. The surfaces in contact are continuous and non-conforming.

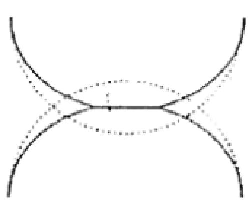
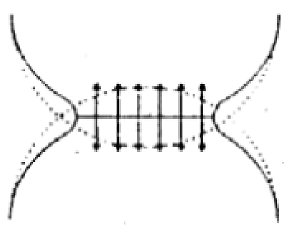
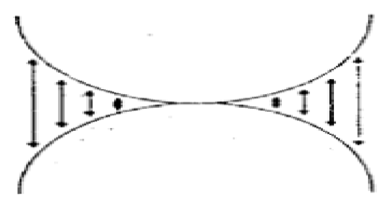




Figure 7: hertz contact Figure 8: Bradley's Van der Waals Figure 9: Johnson contact

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.(21)

2.5. Pin-on-disc

The Arrangement of the load cell the on top of the Pin-on disc. Basically a stationary contact pin hold by an elastic type arm that can be extended to almost half diameter of a disc underneath it. The arm is also connected by high tension string wire attached with a weight holder. The disc is rotated electrically and controlled by motor drive. The disc rotation is measured in RPM. The contact pin is hold into a holder that is attached to an arm that can be slide the arm is fixed with a load cell to detect the sliding force. When the disc is rotating and with a load applied on the pin, the contact between the pin bottoms with the disc surface will cause a sliding force that is detected by the load cell (30).

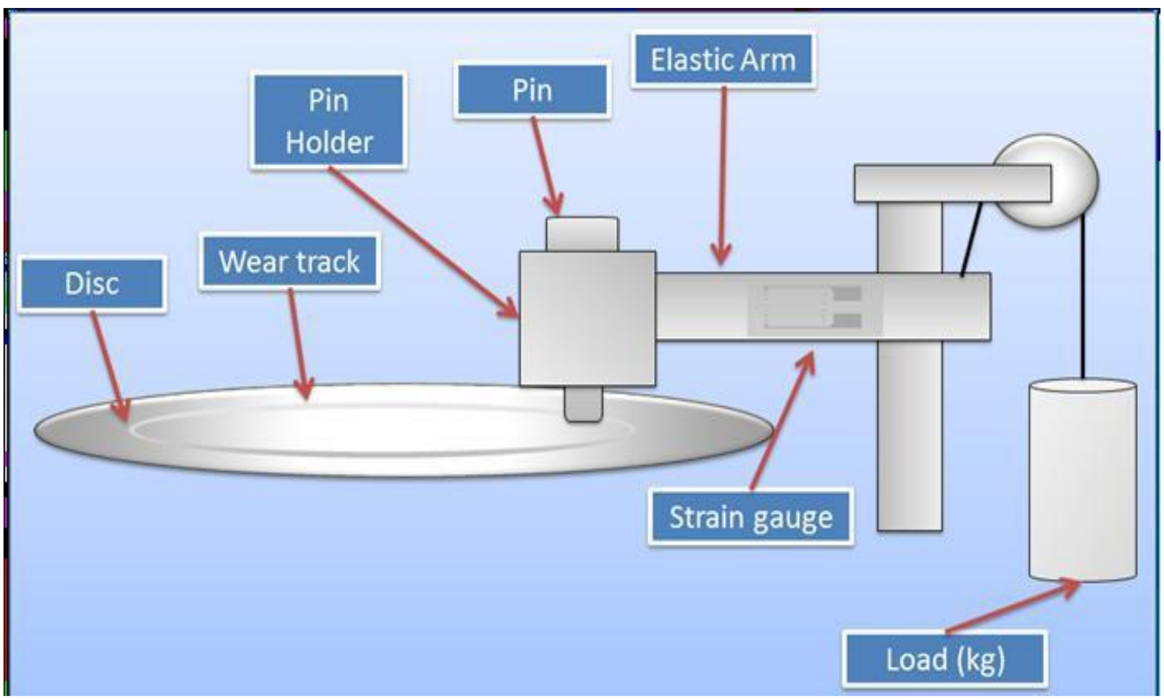


Figure 10: Pin-on-Disc material

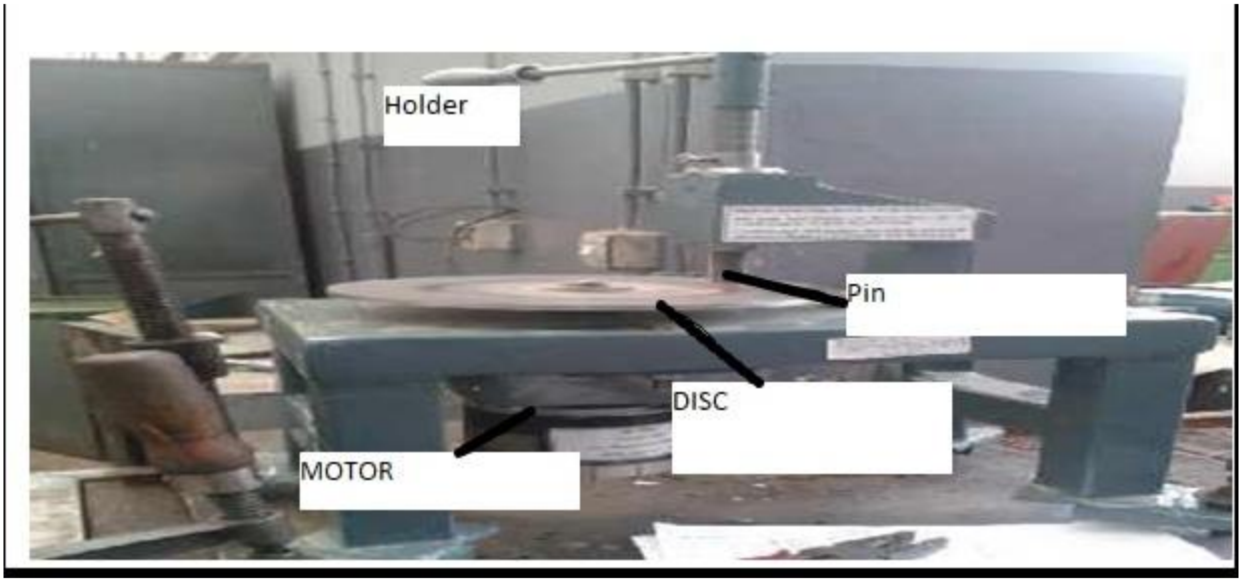


Figure 11: Tribometer Device

2.6. Wear mechanism

Wear has been recognized as meaning the phenomenon of material removal from a surface due to interaction with a mating surface. Almost all machines lose their durability and reliability due to wear, and the possibilities of new advanced machines are reduced because of wear problems. Therefore, wear control has become a strong need for the advanced and reliable technology of the future. Wear map is considered one of the best descriptions of tribological conditions and is useful in selecting materials in a wide range of operating conditions.

In order to design tribo-systems and select materials based on the wear map, an understanding of wear rate, varieties of wear modes, and wear mechanisms is essential.

Wear is the result of material removal by physical separation due to micro fracture, by chemical dissolution, or by melting at the contact interface. Furthermore, there are several types of wear: adhesive, abrasive, fatigue, and corrosive. The dominant wear mode may change from one to another for reasons that include changes in surface material properties and dynamic surface responses caused by frictional heating, chemical film formation, and wear. Wear mechanisms are described by considering complex changes during friction. In general, wear does not take place through a single wear mechanism, so understanding each wear mechanism in each mode of wear becomes important.

"Wear is not a material property. It is a system response." Wear is changing drastically even with a relatively small change in a tribo-system. This is composed of dynamic parameters, environmental parameters, and material parameters. Wear is sometimes investigated from the viewpoint of the types of contact interaction of solid surfaces. There are many different contact configurations in practice. Normal or inclined compression and detachment, unidirectional sliding, unidirectional rolling, reciprocal sliding, reciprocal rolling, and rolling with slip are all different contact configurations classified from the viewpoint of motion of contacting bodies. Furthermore, free solid particles sometimes become unique substances, which attack interacting surfaces. This is also a contact configuration. Wear in these contact types is described as sliding wear, rolling wear, impact wear, fretting wear, or slurry wear. These descriptions of wear are all technical and based on the appearance of the contact type. They do not represent wear mechanisms in a scientific way. In order to focus on the wear mechanisms from the viewpoint of contact configurations, apparent and real contact conditions at the contact interface are introduced without particularizing about these contact configurations. Severity of contact, such as elastic contact or plastic contact, is the simplest and most direct way to think about wear mechanisms, and is a tribo-system response determined by dynamic parameters, material parameters, and atmospheric parameters.(22)

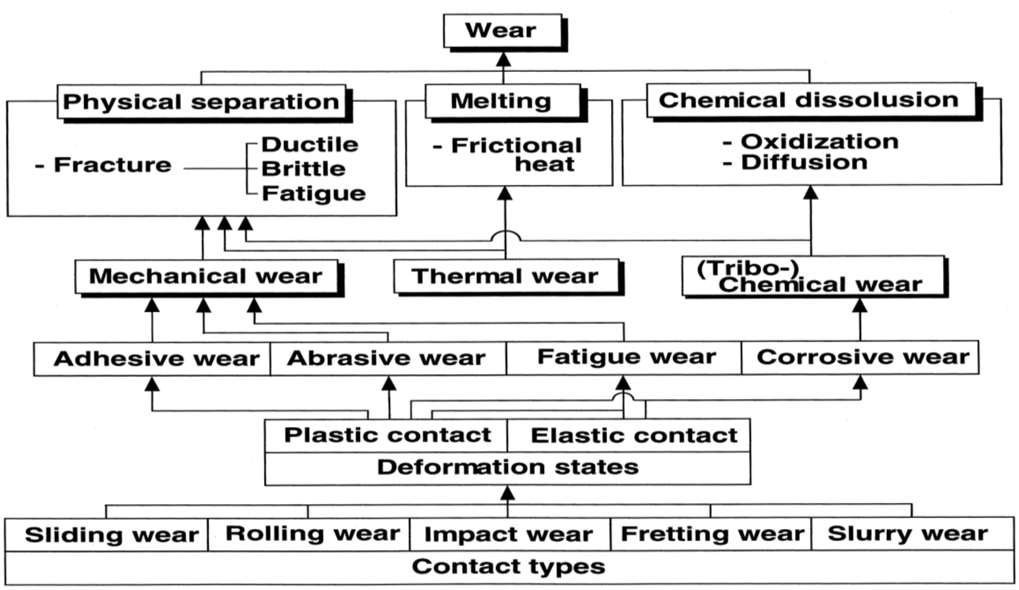


Figure 12: Descriptive key words of wear and their interrelations.(22)

CHAPTER 3: ANALYTICAL METHODS AND CONDITIONS

3.1. Introduction

The motion between components is creating in surface contact due to loading on the contact bodies. When one surface applied load in other surface in motion can be damaged the contact surface provides to wear failure. Mostly wear analysis is performed by experiments has analyzed the material surface was applied some condition. In order to check the deformation of material have used before analysis and after and compare them. At the last, in the decades, many researchers used to simulation in software the wear analysis, using CATIA V5 for modeling also assembling two components. The simulation of wear in finite element method was analyzed imported the model because it's common simulation method for analyzing wear model with using ANSYS software.

3.2. Pin-on-disc wears model and analysis

3.2.1. Assumptions

The general suppositions can be helps to reduce and simplify in procedure of contact's mechanic's on software. The first step is to model wear analysis using Catia V5, for type of contact sliding pin-on-disc modeling related of contact wire and pantograph contact. In this paper, the following point is assuming to simulate wear analysis on ANSYS:

- The contact between pin and disc is sticking in contact without any clearance.
- Pin on Disc contact problem are considered as non-linear because of the stiffness, loads, deformation and contact boundary conditions.
- The analysis of modeled elements, one piece is fixed and other is rigid because the contact as rigid to flexible.
- Transfer load is analyzed model, the contact for model helps to support.
- The behavior of contact is asymmetric
- The coefficient friction is taken 0.3
- Calculate the resultant force as upward force, the electric field force and tension force applied on wire.

3.2.2. Method for software simulation

For wear simulation on Ansys conducted for the contact analysis in five steps:

1. Create model geometry in Catia V5 for Pin-on-Disc.
2. Imported in ANSYS workbench software
3. Selection contact analysis:
   - Ansys parametric design language(APDL)
   - Workbench for inserting the engineering data.
4. Meshing for showing the clearance of contact surface
5. Identifying for each material the contact surface
6. Applied boundary condition.
7. Applied force as resultant force combined electric force as distributed load , tension stress applied on wire and the upward force and rotation of speed for disc simulation pin-on-disc
8. Solve

3.3. Pin-on-disc model and geometry

Overhead line power supply is important for railway. Its distribution for the power source from power station, high electrical voltage passes through it to train, the effect of high current can be damaged the surface of contact also reduce power. As wheel and rail, the contact type between contact wire and pantograph is sliding. Where in tribology in contact surface used for sliding contact is pin-on-disc for wear simulation. The geometric from pin-on-disc represented at the experiments dimension of tribo meter device experimental. The geometric modeling will be done in Catia V5 software after imported in Ansys. The assembly model for disc is rotation but pin is uniform stationary without speed of velocity, where disc is rotating to create slide with pin, also for applying force in pin will be hold by holding.

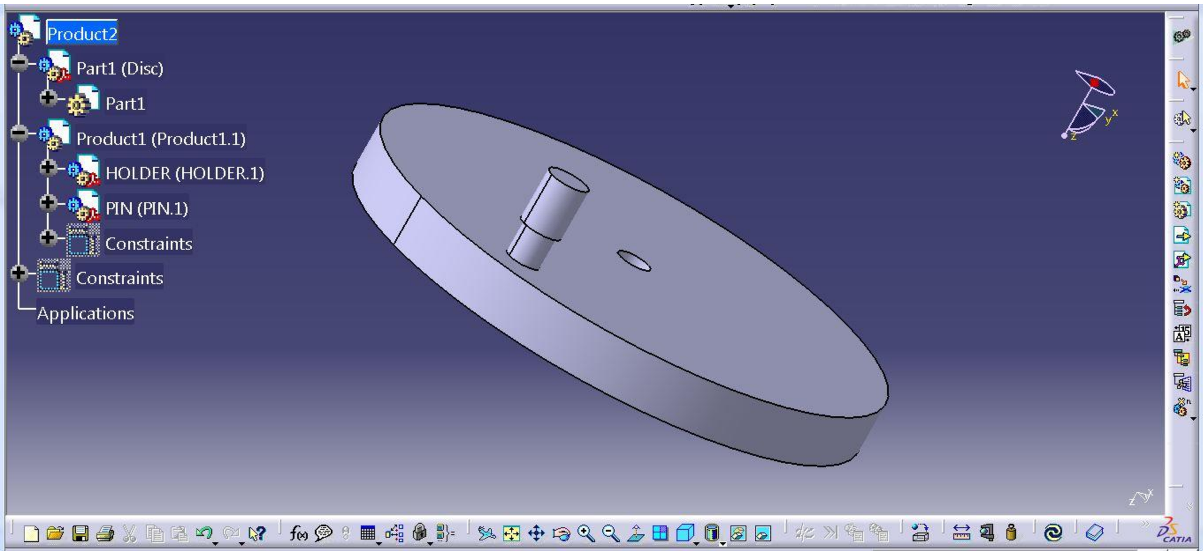


Figure 13: Pin-on-Disc Modeling.

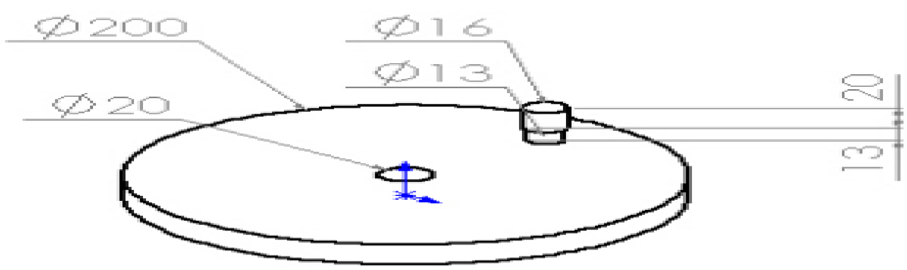


Figure 14: Dimension Part

3.3.1. Modeling and Dimensions

The Specimen Dimension is taken as main dimensions of LRT contact wire has.

Table 2: Main sectional dimensions of LRT contact wire [28]

Size	A(mm)	B(mm) ±2%	C(mm) ±2%	D(mm) + 4% -2%	E(mm)	K(mm)	R(mm)	G(°)±1°	H(°) ±1°

Size	A(mm)	B(mm) ±2%	C(mm) ±2%	D(mm) + 4% -2%	E(mm)	K(mm)	R(mm)	G(°)±1°	H(°) ±1°
150mm2 Cu-Ag alloy	14.40	14.40	9.71	7.24	6.80	4.00	0.40	27	51

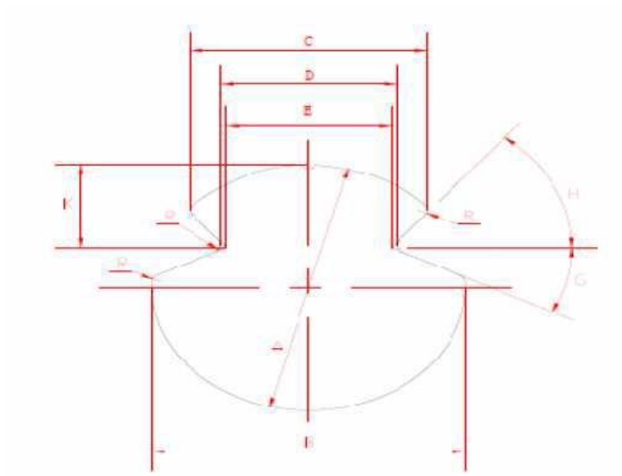


Figure 15: Schematic Diagram and sectional dimension in AALRT

For analysis since the internal diameter of pin holder is 13mm as cyndrical form (CuNiCr, CuNiSiCr, CuAg) are analyzed with a dimension of 13mm diameter and 13mm length.

The table below describes all input data in CatiaV5 for modeling pin-on-disc

Table 3: Dimension Table.

Pin-on-Disc Description	Dimensions
Disc	Outerdiameter:200mm

Pin-on-Disc Description	Dimensions
Disc	Inner diameter:20mm Thickness(t)>=20mm
PIN	Diameter = 13mm Length= 13mm
HOLDER	Diameter =16mm Length= 20mm

3.3.2. Meshing model in Ansys

After imported the model from CATIA V5, the simulation are done in ANSYS from mesh fine to get accurate and reliable deformation on solution.

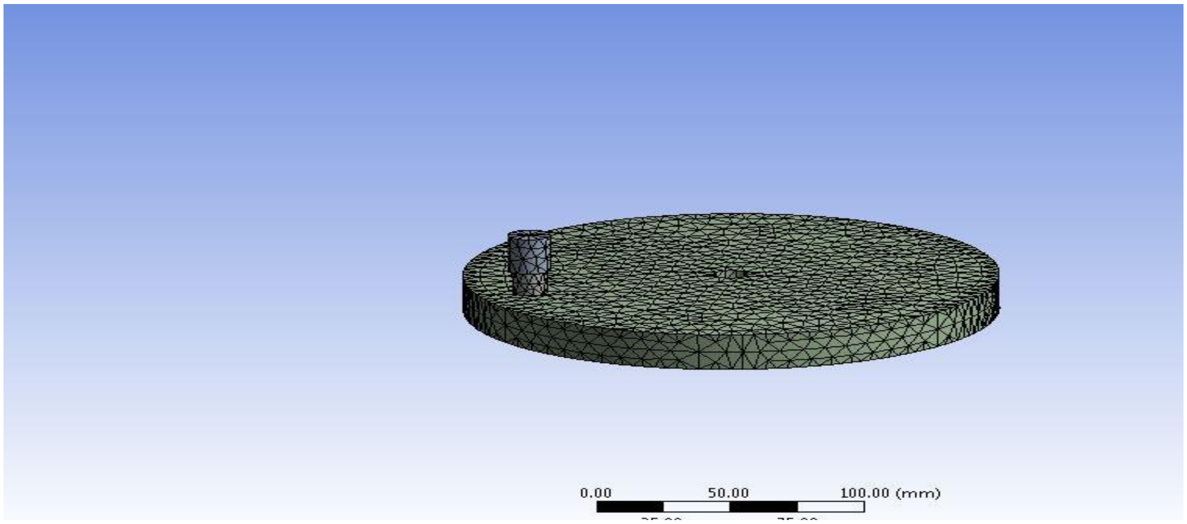


Figure 16: Mesh Part.

3.4. Contact Surface

For analysis simulation identifies of contact surface to simulate in ANSYS software is very important. Where the contact elements and target can create a contact associated between them to share a real constant set. Different contact pairs must be defined by a different real constant even if the element real constant values don't change. There is no limit on the number of surfaces allowed. The localized contact zone is verifying nodal-nodal number in order to check contact direction. Depending on the geometry of the model, the potential deformation and multiple target surfaces 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 obvious: the target surface is always the rigid surface and the contact surface is always the deformable surface.
- 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 following guidelines when designating surfaces and in this paper the guidelines to follow analysis are taken :(24)

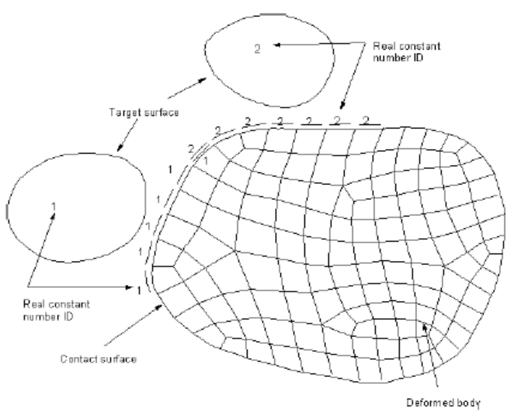


Figure 17: The contact surface

1. 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.

2. If one surface is markedly larger than the other 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 your model.

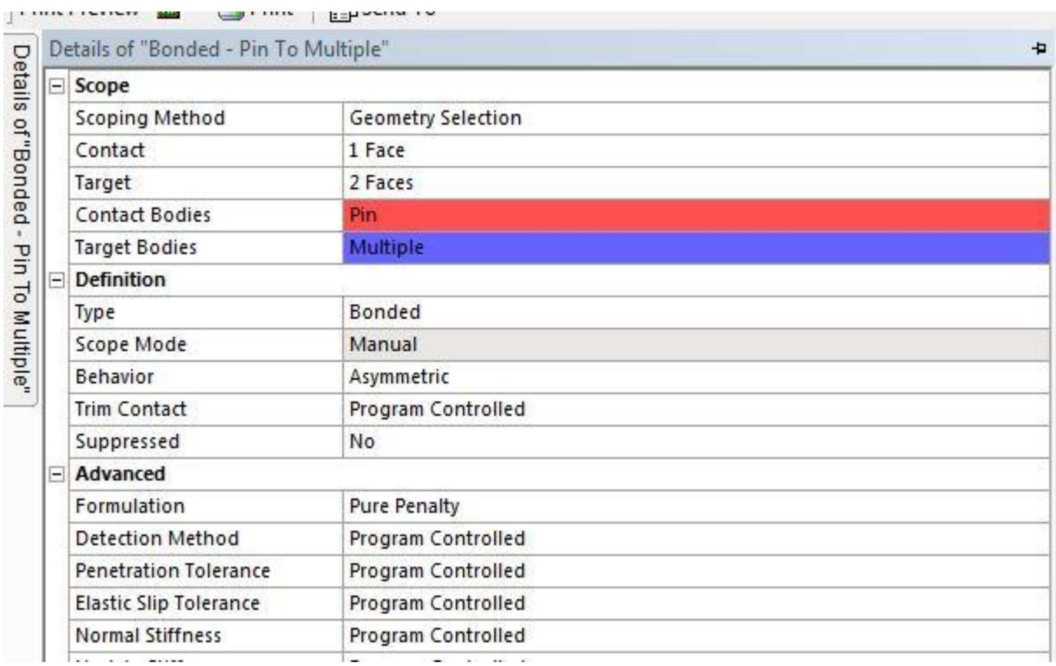
Then in according to guidelines of contact a surface is defined:

- The surface of disc is target
- Pin is contact surface

It's adding in define contact behavior of pin and disc for contact mechanics analysis of the type surface.

In this research paper, the friction contact between pin and disc surface is 0.3.

Where the frictional force Ff is calculated by software add to system analysis.(24)



Details of "Bonded - Pin To Multiple"

Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	2 Faces
Contact Bodies	Pin
Target Bodies	Multiple
Definition	
Type	Bonded
Scope Mode	Manual
Behavior	Asymmetric
Trim Contact	Program Controlled
Suppressed	No
Advanced	
Formulation	Pure Penalty
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Elastic Slip Tolerance	Program Controlled
Normal Stiffness	Program Controlled

Figure 18: Ansys Workbench contact part

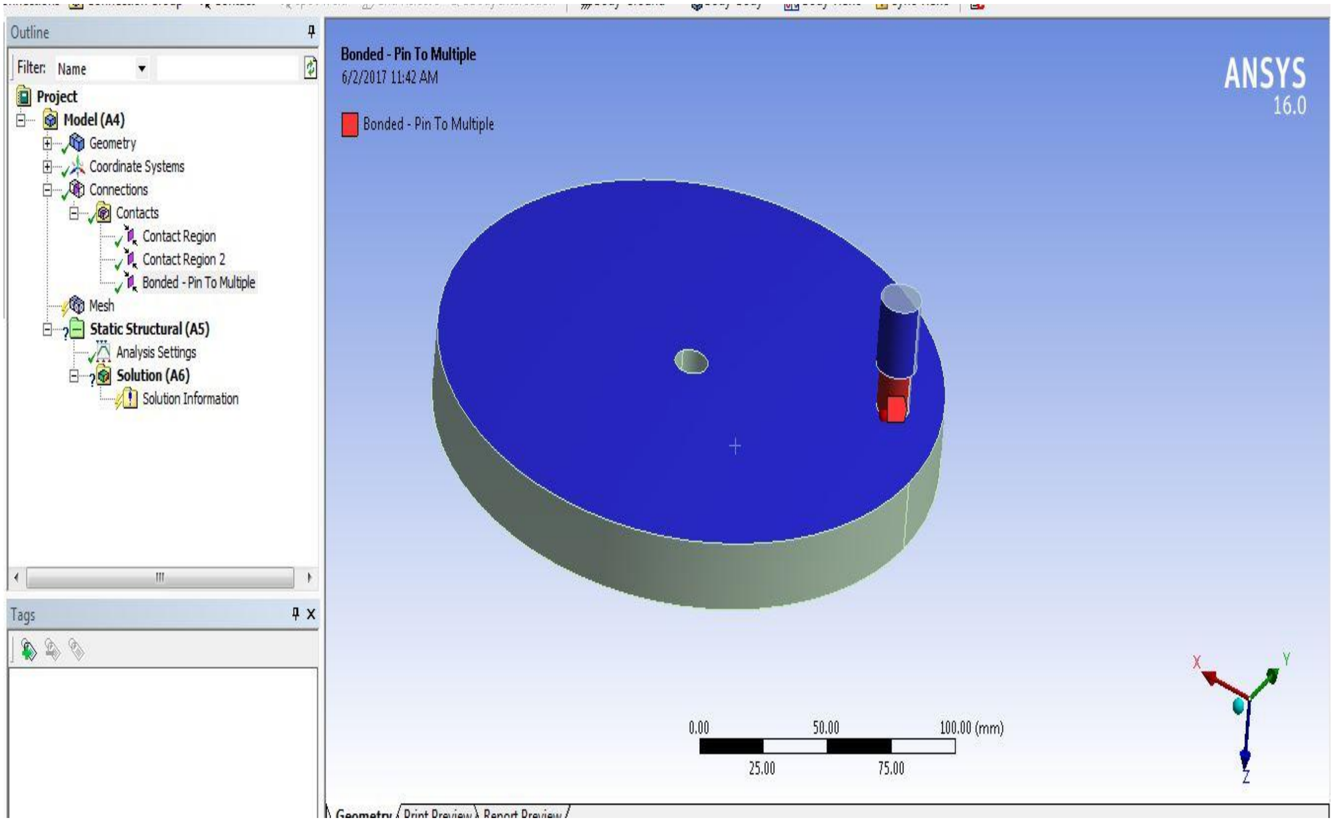


Figure 19: pin-on-disc model

3.5. Material Selection

The selection of a material for an overhead line is very important to take material physical properties and mechanical property; nevertheless mostly overhead line contact is cooper alloy material because it has good electrical conductivity and good resistance, strength and cost.

3.5.1. Material composition

The copper alloys are prepared by melting the industrial grade materials followed by machining process. So the industrial grade material copper, ferrochromium, ferrosilicon and Nickel are used for this research investigation purpose. The materials have chosen by the consideration of their good wear and corrosion resistance property.

Table 4: Comparisons of material selection criteria.

Pin material	Hardness	Wear resistance	Electric conductivity	conclusion
Cooper	Low	Low	Very high	It's selected because high electric conductivity
Chromium	Very high	Very high	Good	High wear resistance then selected
Nickel	High	High	good	High corrosion resistance also good electric conductivity, selected for alloys with
Silicon	Good	Good	Moderate	Flexibility and resistance then selected

Source: Copper Development Association

The chemical composition of the copper alloy is as shown.

Table 5: Chemical composition of copper alloys.

Material	Chemical composition in %					
	Cu	Ni	Si	Cr	Zr	Impurities
Cu -Ni-Si-Cr	96.7 with 0.04%O2	2.4	0.003	0.077	-	<0.78
CuNiCr	98.7 0.04%O2	0.33	-	0.193	-	<0.78

Material	Chemical composition in %					
	Cu	Ni	Si	Cr	Zr	Impurities
CuAg	(99.3Cu-0.08Ag) as per specification of ERC					

3.5.2. Materials properties

The selection of a material for an overhead line is very important to take material physical properties and mechanical property; nevertheless mostly overhead line contact is cooper alloy material because it has good electrical conductivity and good resistance, strength and cost. Also it can transmit the electricity and applied with tensile force. The overhead line contact wire modeled as pin on pin-on-disc simulation also the pantograph as stainless steel modeled as disc then at conclusion the copper alloys materials as pin and the stainless steel characteristic as disc and holder material.

The description of material copper is alloyed with zinc, it is usually called *brass*. Other, it is alloyed with another element, it is often called bronze. Sometimes the other element is specified too tin bronze or phosphor bronze. (23)

The description of material property for cooper alloys and carbon strip material for pantograph contact strip below:

3.5.2.1. Carbon strip for disc selection

The choice of carbon strip is for disc material because it's used by AALRT as the actual material of pantograph contact strip.

Table 6: carbon strip material properties

Material property	**values**
Density (ρ)	2900kg/m^3
Elastic Modulus (E)	193Gpa
Tensile Yield Strength	1.20E7 pa
Poison's Ratio(v)	0.26
Tensile Ultimate Strength	2.54E7pa
Coefficient of thermal expansion	1.7E-5 C^-1
Hardness	95HB

3.5.2.2. CuAg property of material

Table 7:Cu Ag property of material

Materials	Values
Density (ρ)	8800kg/m^3
Elastic Modulus (E)	1.17E11 Pa
Tensile Yield Strength	6.2E7 Pa
Poison's Ratio(v)	0.3

Tensile Ultimate Strength	1.72E8 Pa
Coefficient of thermal expansion	1.7*10^-5/c
Hardness(H)	42HB
Compressive Yield Strength	1.08E8 Pa

3.5.2.3. CuNiCr property of material

Table 8: CuNiCr material properties

Materials	Values
Density (ρ)	8940Kg/m^3
Elastic Modulus (E)	141Gpa
Tensile Yield Strength	1.24E7Pa
Poison's Ratio(v)	0.26
Tensile Ultimate Strength	3.30E8Pa
Coefficient of Thermal Expansion	1.64*10^-5/c
Hardness (HB)	141HB

3.5.2.4. CuNiSiCr property of material

Table 9: CuNiSiCr material properties.

Material property	values
Density (ρ)	8840Kg/m3
Elastic Modulus (E)	103G pa
Tensile Yield Strength	65Mpa
Poison's Ratio(v)	0.3
Tensile Ultimate Strength	172Mpa
Compressive Yield Strength	108Mpa
Coefficient of Thermal Expansion	1.7*10^-5/c
Hardness (HB)	45HB

3.6. Boundary Condition and Load

3.6.1. Boundary Condition

The boundary condition is used to find exactly and precise to the real contact point during contact time between pantograph and contact wire. Once, the train is applied is three displacements as translation means at X-direction, rotational means at Z-direction and pith means Y-direction for different displacements coordinate but in this simulation model in CATIA V5 at YZ-plane then the rotation is given as X-direction.

For the real condition, contact wire is stationary and the pantograph in motion by rotates the train motor as current passes through to train. For simulation, we are taken pin-on-disc tribo meter device for this type of contact point in sliding moment. therefore pin considered as contact wire (stationary) , hold by holder for them the displacements for X and Y-direction for round outer faces is zero means no motion but at same time they displacements at Z-direction give as free then allowing for PIN on holder only in y-direction. Disc considered as pantograph rotate by motor rotational velocity and motion in translation with for the train direction then at same time for pin displacements, the outer round faces of the cover disc is free at X and Y-direction but Z-direction is given as zero finally for hollow disc is allowing the movement in the X and Z direction. The simulation of wear for Pin-on-Disc displacement is given.

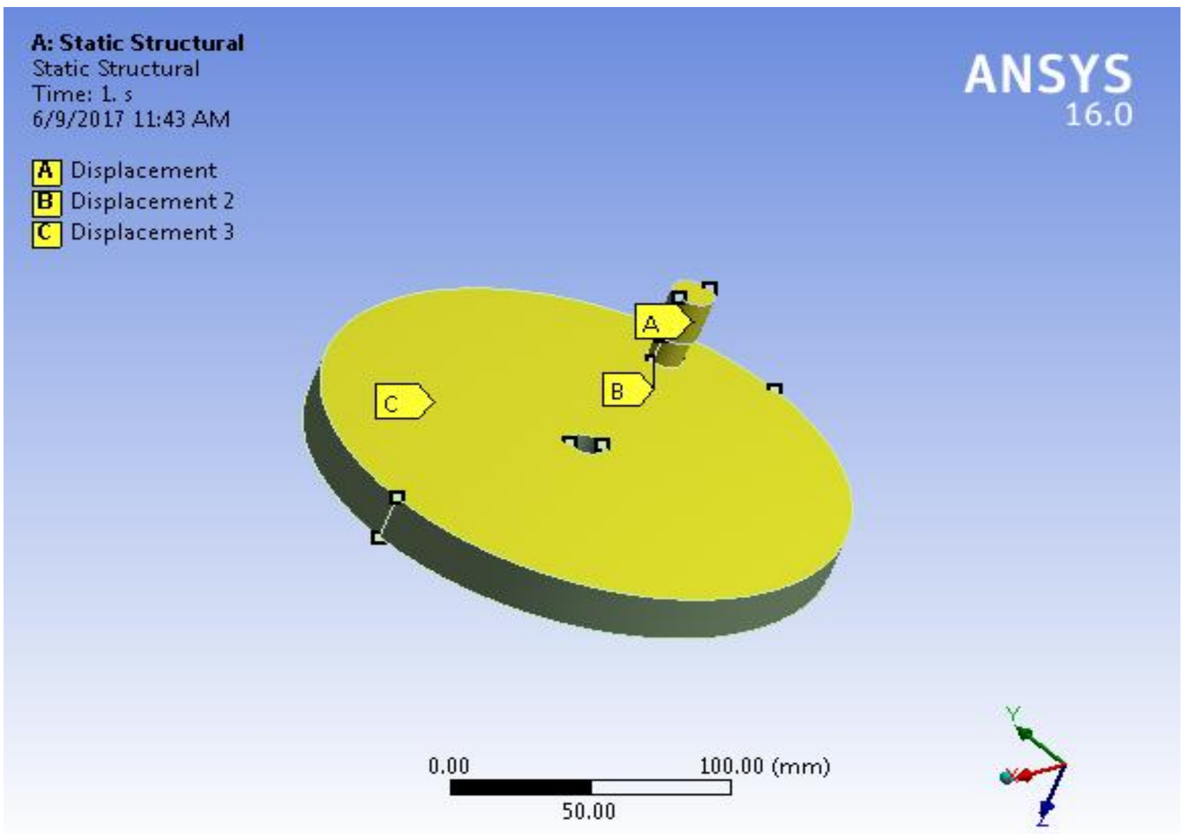


Figure 20: Boundary condition model

3.6.2. Load

For simulation in tribo meter device for analyzing wear analysis with current effect combined in resultant force as Electric force field adding the upward static force of pantograph also the tension of wire. Generally the vertical load will be applied in the top of pin Holder for getting the material support the wear. In reality, the process for applying the force on ANSYS is same like real tribo meter device on top of PIN of holder according to the experiments, for this analysis the resultant force is combined as tension applied in wire and the electric force as distributed load also pantograph static force.

3.6.2.1. Speed rotational velocity

The speed of rotational velocity is applied on disc because the disc is rotating by electric motor with appropriate rotational speed. But the running speed of rail vehicle is 70Km/hr this cause the pantograph contact strip run with same speed on the contact wire. At last, this device has to rotate with the train running speed reached by given a different values electric motor.

v- Train running speed =70Km/hr : the design speed of AA LRT

r- Radius of rotating disc=100mm
Therefore the required rotational speed of motor is

Equation 1: Rotational speed

$$w = \frac{v}{r}$$

$$w = \frac{70km/h}{100mm} = 388.9\text{rad/sec}$$

But, 1rpm= $\frac{2\pi}{60} rad/sec$ therefore, 388.9rad/sec= 2443.53rpm.

The minimum rotational speed at maximum radius of disc but for getting reliable result used to small area of radius for disc because if the radius is small the rotational speed increase.

For tribo meter device used constant speeds estimated highest rotate with 5898rpm for high condition issued form experiments design previous and at X-direction in disc surface in this simulation.

W= 5898 rpm because for w= $\frac{2\pi}{60} * 5898$= 617.5 rad/sec

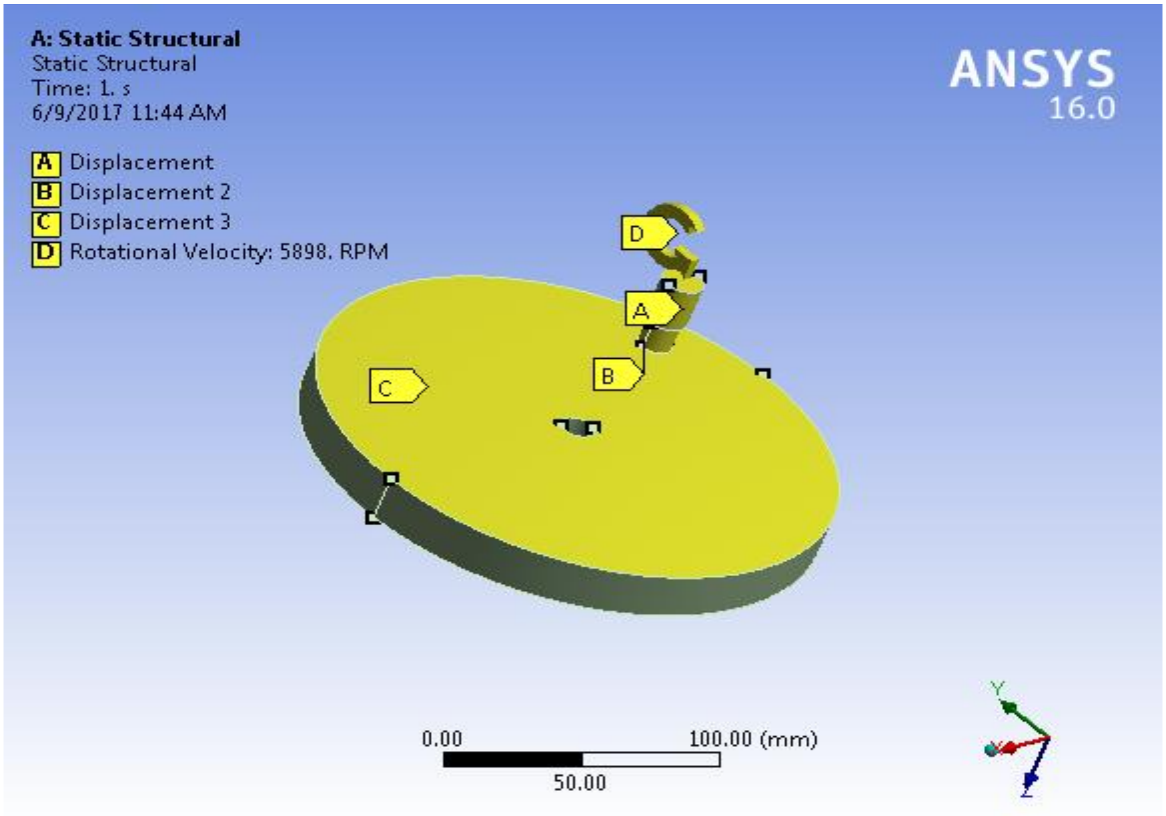


Figure 21: Applying boundary and rotational velocity.

3.6.2.2. Load analysis with current flow.

At the first, the current come from station to messenger wire passing through contact wire to pantograph and 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. otherwise we will estimate to calculate the current effect through the electric force as distribution load for top of surface and determine the charge through the max operational current and normal operational after get this force electric, the normal contact between pantograph (static upward force) and combined the tension happen in wire for accurate the sum of force to input in Ansys.

Table 10: Technical Data (17)

Temperature	-35℃～+65℃
Speed	70km/h
Nominal system voltage	750 VDC
Operational current	1050 A
Max operational current（30s）	Max 1600 A
Static current	Max 460 A
Static upward force for maximum contact	100 N (adjustable 60 to 140N)
Distance managed for wire (standard)	1.2-1.5km

The tension of wire is 15kN is sever tensile load condition that can occur on contact wire, that This three load was combined and applied on all copper alloy material of pin for analyzing the material.

Table 11: Electric force determination

Current / dimension	Low current I= 550 A	Operational current I= 1050A	Max operational current. I= 1600A
Time of operation(s)	30	30	30
Charge electric(c) (Q= I*t)	16500	31500	48000
Distance split max (d) in km	1.5	1.5	1.5
Nominal system voltage(VDC)	750	750	750
Electric field (v/m) (E= V/d)	0.5	0.5	0.5
Electric force (Fe= E*Q) in kN	8.25	15.75	24

The sum of force at 500A:

The tension stress was applied in horizontal direction as taken the max values $Fx = 15KN$

The electric force as distributed load and applied the top of pin and the upward force applied from disc to pin as really application from pantograph to contact wire during contact:

$$Fy = 8.25kN + 0.1kN = 8.35kN$$

Therefore the totally force applied:

Equation 2: Applied load

$\boldsymbol{F = \sqrt{Fx^2 + Fy\text{^}2} = \sqrt{8.35^2 + 15^2}}$ = 17.160kN

The same calculation for another operational current to get the sum force applied therefore the following is the result.

Load/ current	500 A	1050A	1600A
Electric force(KN)	8.25	15.75	24
Upward force(KN)	0.1	0.1	0.1
Tension force in wire(KN)	15	15	15
Totally Load (KN)	17.16	21.82	28

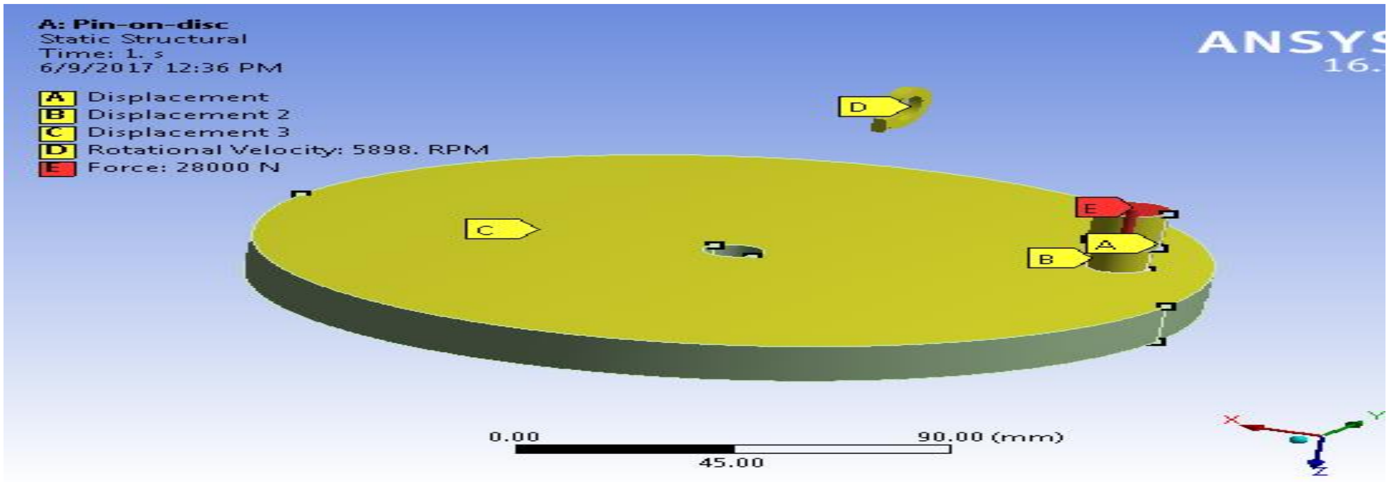


Figure 22: Load applied on model

3.7. Analysis

The wear analysis is performed in Ansys workbench software by using the finite element method otherwise this workbench has many option simulation in this case the static structural performance for getting the maximum and minimum equivalence stress is selected form static structural part of simulation. This workbench determines the stress, deformation, strain and the safety factor of material. In this case the fatigue and damping of wear material caused by loads applied is not required. In this analysis for getting approach of stressed zone and high depth is determine the red color or the maximum zone required for analyzing the wear rate. The boundary condition and loads application determine the significant of analysis. For input data of the material mechanical properties of CuAg, CuNiSiCr and CuNiCr also for pantograph carbon strip material mechanical property. The model Pin-on-disc has modeled using Catia V5 software at YZ-plane to performance analysis. To perform this analysis in finite element method has to give the displacements, the contact behavior between each solid and applied the load as direction of solid. Finally, this analysis solution is to find the maximum equivalent stress and deformation part stress place on this model.

CHAPTER 4: RESULT and DISCUSSION.

4.1.RESULT

The displacements applied on Pin-on-disc model at YZ-plane are:

- Pin considered as stationary only applied in Z-direction because to applied the load and see which for it is resist to wear; For holder same like pin displacements to hold the pin and applied load on it at the top of surface in Z-direction.
- For hollow disc consider as movement only displaced at Y-direction and X-direction.

Finally, For Pin and Holder fix Y and X-direction but at Z-direction free, Disc hollow fix at Z-direction but fix at Y and X. The loads are 17.160KN; 24.82KN and 28KN calculated above according to the current operational values applied at Z-direction as vertical of the top surface of holder.

4.1.1. Result of Material Analysis

In order to use Ansys workbench software, toward with application the applied load and boundary condition is given according to the values loads we found the equivalent stress values and deformation. This theory used by designers to check the failure theory of material arising point according to the load condition. Otherwise the maximum and minimum value of equivalent stress is determine to give the value of pin part worn out and taken this portion as wear depth in real condition. The load of the three materials the maximum and minimum equivalent stress values are taking. For disc considered as carbon strip material property and applied each load. In this paper, taking the maximum area of worn out and the wear volume area then calculated.

Figure 23: ANSYS Static Structural Analysis system

- CuAg pin material

The equivalent stress is of each applied load of this material with having applied of top pin at maximum stress value.

A. At 17.160kN

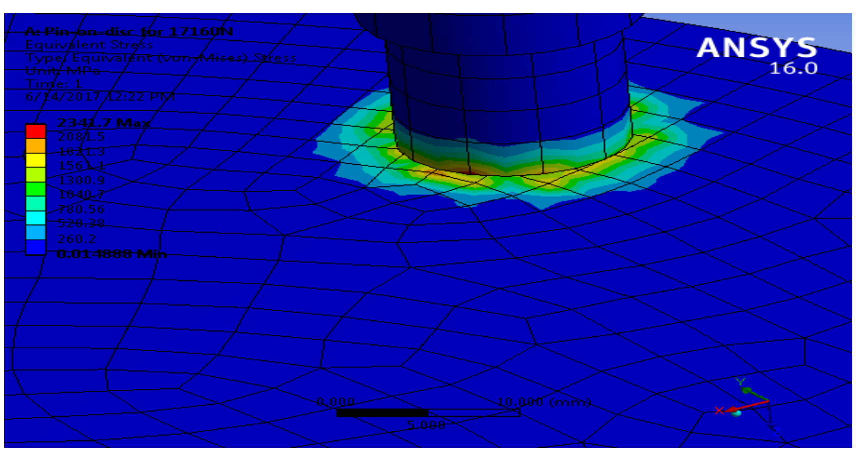


Figure 24: Equivalent stress at 17.60KN applied load.

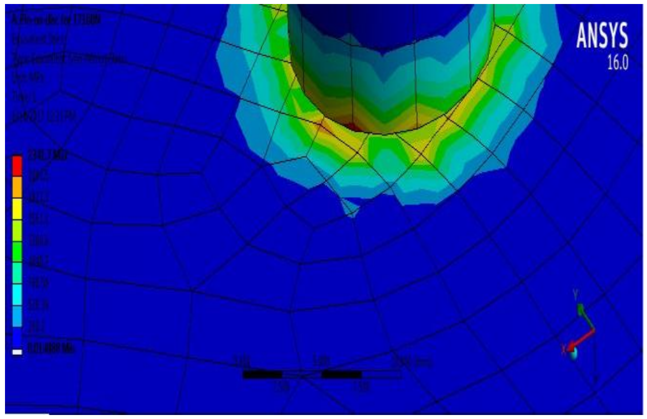


Figure 25: CuAg pin material

B. At 24.82kN

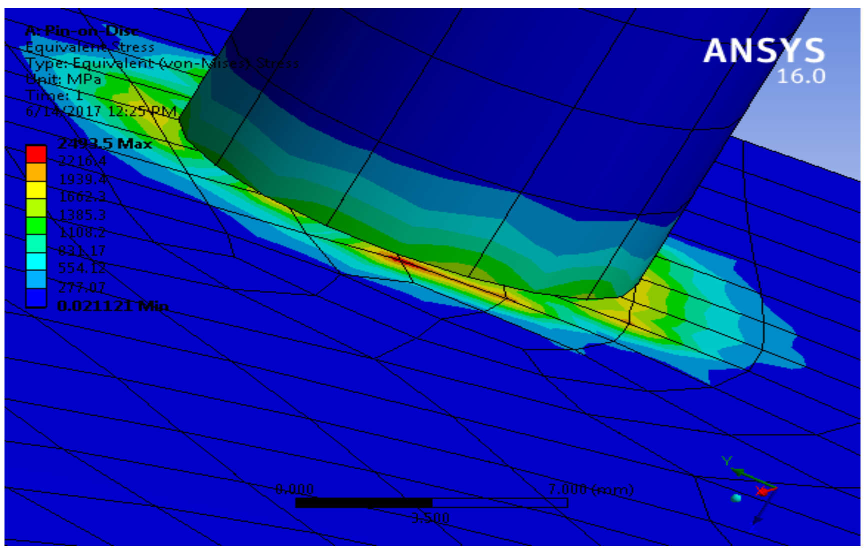


Figure 26: CuAg 24.82 Kn pin material

C. At 28.00kN

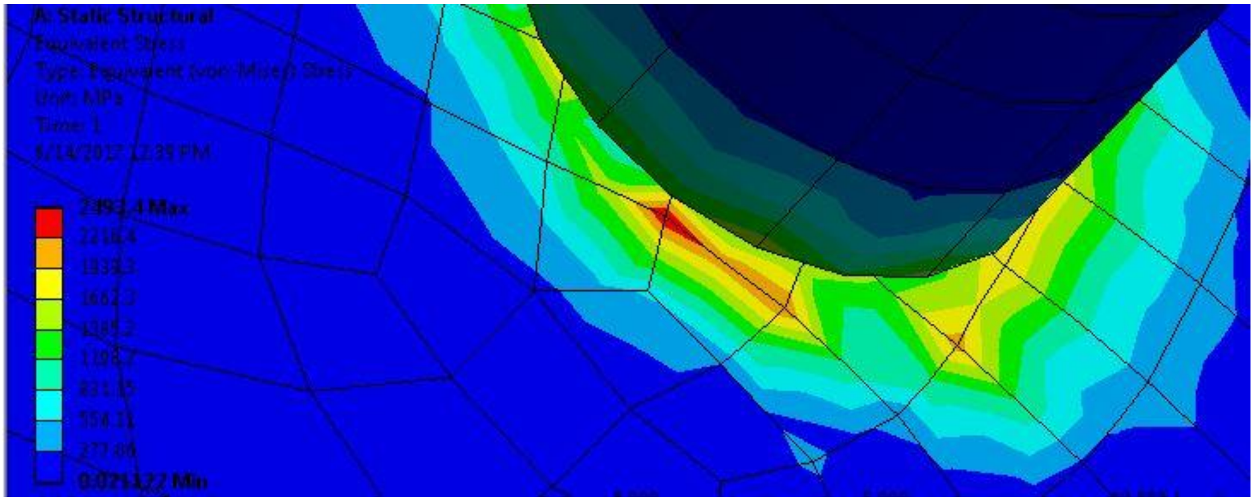


Figure 27: CuAg pin material at 28KN

- CuNiSiCr pin material

The equivalent stresses are applied load of this material with having applied of top pin at maximum stress value.

A. At 17.160kN

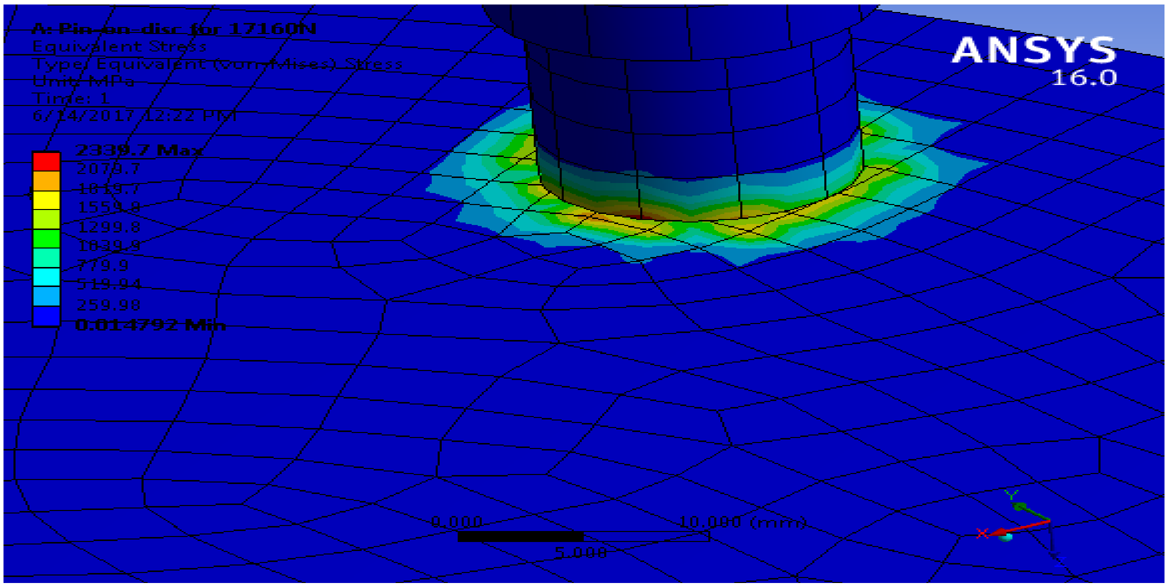


Figure 28: CuNiSiCr pin material 17.60 KN

A. At 24.82 KN

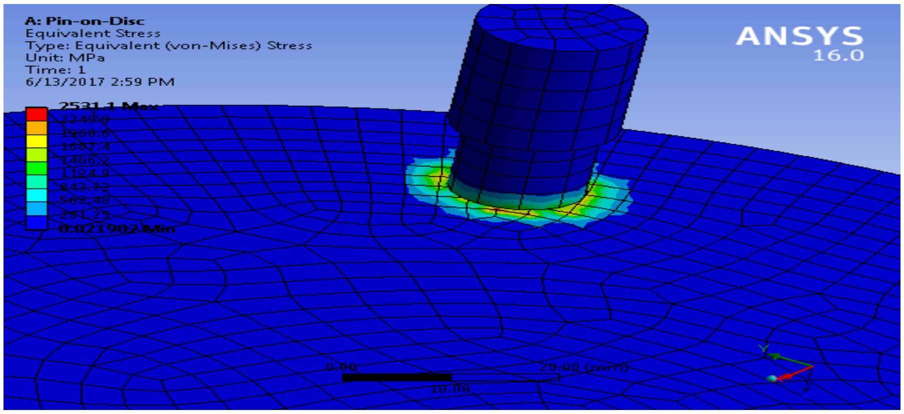


Figure 29: CuNiSiCr pin material at 24.82Kn

C. At 28.00kN

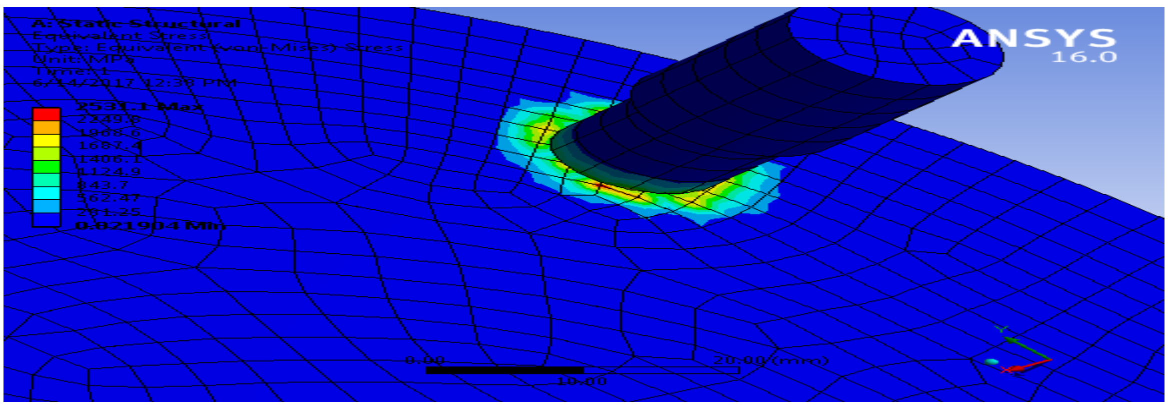


Figure 30: CuNiSiCr pin material at 28KN

- CuNiCr pin material.

The equivalent stress is applied load of this material with having applied of top pin at maximum stress value.

A. At 17.160kN

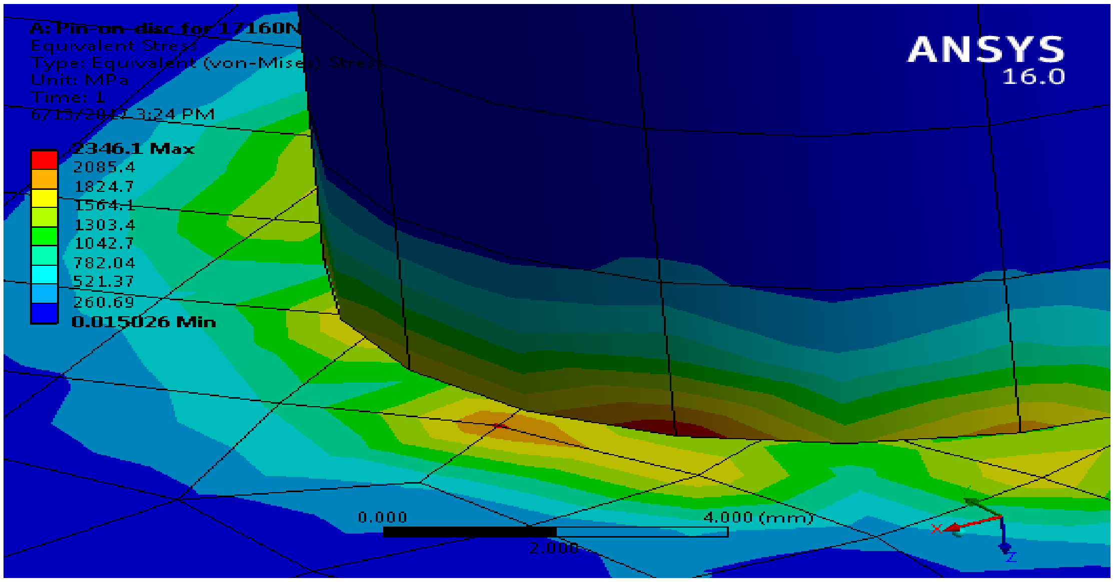


Figure 31: CuNiCr pin material at 17.60 KN

B. At 24.82kN

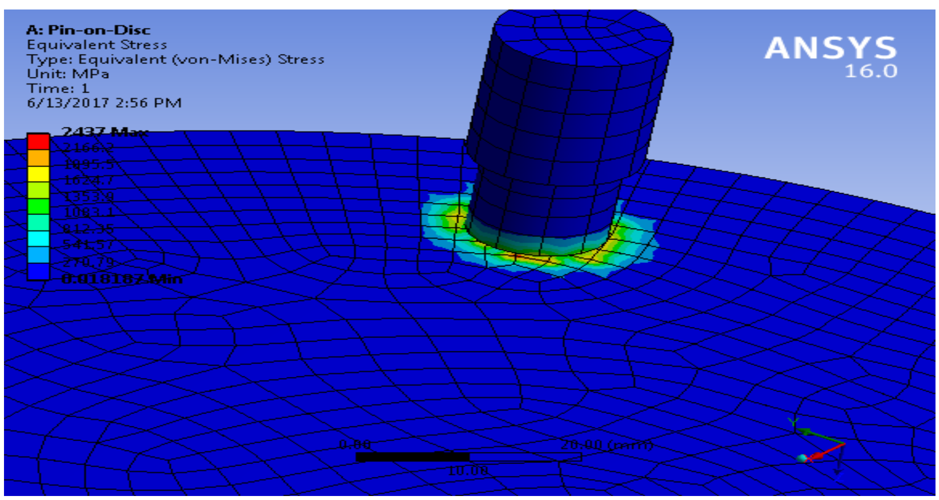


Figure 32: CuNiCr pin material at 24.82

C. At 28.00kN

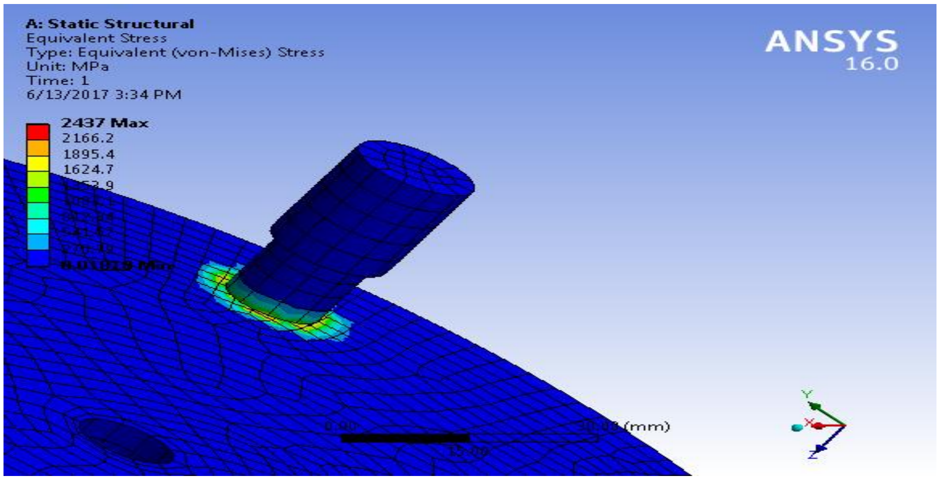


Figure 33: CuNiCr pin material at 28 KN

Finally, the equivalent stress is very quiet at each load and for determine the wear depth, wear volume and wear rate continues then the comparisons will be at the two loads for showing the material resistance according to show the current effect.

PIN material	Equivalent stress	Loads(kN)		
		17.160	24.82	28
CuAg	**Maximum(Mpa)**	2341.7	2493	2493.5
	Minimum(Mpa)	260.82	277	277.07
CuNiSiCr	**Maximum(Mpa)**	2339.7	2530	2531

	Minimum(Mpa)	234.92	280	281.26
CuNiCr	**Maximum(Mpa)**	2346.7	2437.5	2437
	Minimum(Mpa)	234	270.9	270.79

4.1.2. Wear depth

In refer the wear depth of worn out, used grid to determine of stressed at red zone color part meaning wear area. In order to get the length of depth is using the grid height for helps us to find the volume worn out. The contact wire material copper alloy are checking to show the resist one used cooper alloy after applied the combine due to the electric force , static force and tension applied by the pantograph carbon strip. Where applied the grid on pin of cooper alloy helping to find the height of depth part of stressed in pin model. In this case, the grid has height is 2.25mm.

For grid applied on pin for each material:

- **CuAg pin material**

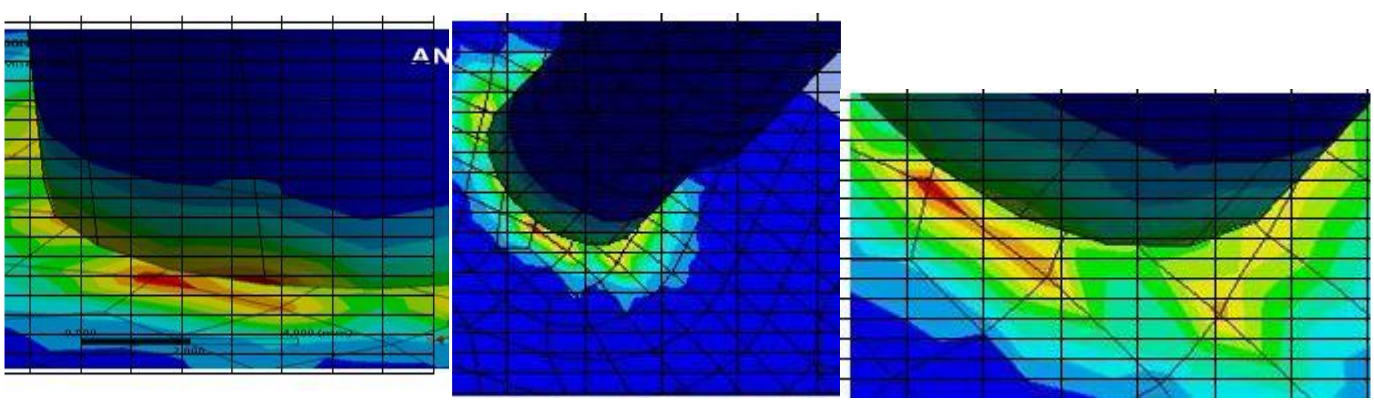


Figure 34: CuAg pin material stresses tip at two load cases

CuAg pin material the stress distribution according to height of grid firstly, for 17.60 KN taken one point and half height of grid, at 24.82KN two point two height of grid very small occur as pin tip then the height of grid and for 28.2 KN is two point five height of grid. The stress is very minimum.

- **CuNiCr pin material**

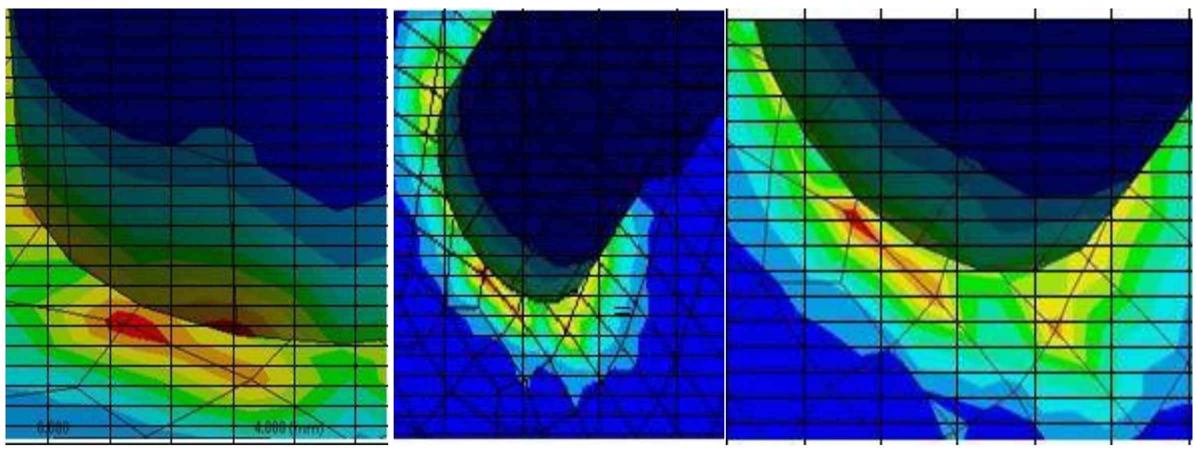


Figure 35: CuNiCr pin material stresses tip at two load cases

For 17.60KN the height of grid depth is one point five are stressed, at 24.82 two of the height grid are stressed and for 28.2KN two point three height of grid stresses part.

- **CuNiSiCr pin material**

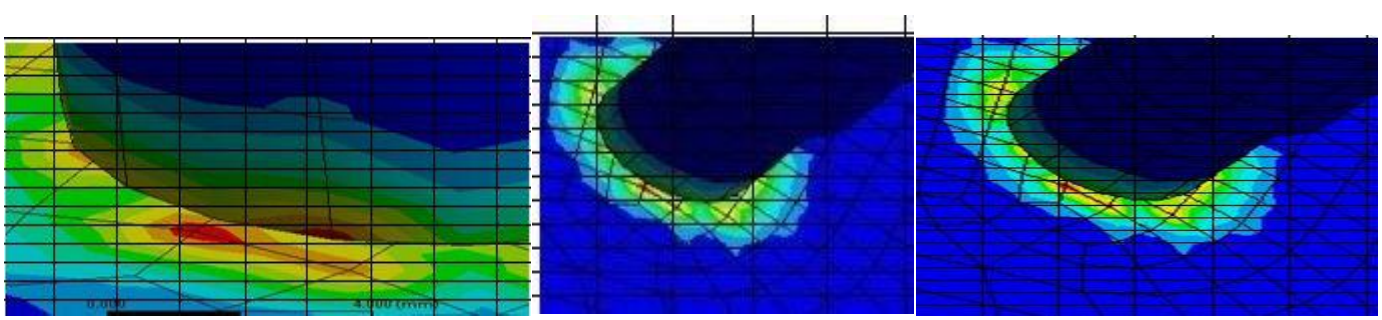


Figure 36: CuNiSiCr pin material stresses tip at two load cases

At load case 17.60 KN one point two of grid height are very stressed, at 24.82kN two point one grid of height and for 28 KN two point four height of grid are high red color .the stressed is very small

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 12: Wear Depth

Material	Wear depth in mm		
	Load(kN)		
	17.160	24.82	28.00
CuAg	3.375	4.95	5.625
CuNiSiCr	2.7	4.725	5.4
CuNiCr	2.25	4.5	5.2

- **Wear Volume**

  The diameter of pin = 13mm then the radius r= 6.5 mm therefore The area of pin is $A = \pi r^2$= π*(6.5)^2= 132,73mm^3

Table 13: Wear Volume

Material	Wear volume V= depth * area pin = D*A		
	Loads(KN)		
	17.160	24.82	28.00
CuAg	447.963	657.0135	746.60
CuNiSiCr	358.371	627.14	716.74
CuNiCr	298.64	597.285	690.2

- **Wear rate**

For evaluating wear rate of a material, we have to take about time with time of current passing. Otherwise the wear rate find by wear volume according to time. In this paper, we will used one minutes thirty second because one minutes is default time of workbench for determine contact and thirty seconds is real operational current time between contact wire.

Therefore to convert 0.0125h.

Table 14: wear rate

Material	Wear rate (mm^3/hr)= V/t		
	Loads(KN)		
	17.160	24.82	28.00
CuAg	35837.1	52561.8	59728.8
CuNiSiCr	28669.68	50171.94	57339.36
CuNiCr	23891.2	47782.8	55215.68

Table 15: Current versus wear rate

Operational current (A)	CuAg	CuNiSiCr	CuNiCr
	Wear rate(mm^3/hr)		
500	35837.1	28669.68	23891.2
1050	52561.8	50171.94	47782.8
1600	59728.8	57339.36	55215.68

- **Wear resistance**

The wear resistance of pin material is period on wear rate. it's given to show the resisting of material according to exist wear with different load.

	Wear resistance = 1/W		
Material	Loads(KN)		
	17.160	24.82	28.00
CuAg	2.790E-5	1.903E-5	1.674E-5
CuNiSiCr	3.488E-5	1.993E-5	1.744E-5
CuNiCr	4.18E-5	2.092E-5	1.81107E-5

4.2.Discussion

In this paper, the wear rate of overhead line contact wire with current effect at sliding moment are analyzing by ANSYS workbench software in pin-on-disc simulation. The pin model material CuAg, CuNiCr and CuNiSiCr and carbon strip for disc material. These materials are showing with electric force applied as distribution load from operational current and the max tensile stress and upward force to pantograph. For this paper, the result of equivalent stress maximum and minimum is taken for evaluating the wear on pin-on-model. the maximum equivalent stress varies according to pin model material but in this case the maximum equivalent stress is to close between two loads as 24.820KN and 28KN because the force is very quiet as determination with high operational current then we are estimated to evaluate with

1050A operational current because only the electric force varies with current ratio according to this current the force is equal 24.820Kn.Therefore the equivalent stress is very close each of them or the material CuNiCr has highest value than CuAg and CuNiSiCr with normal applied load but this material is higher due to tensile yield values. The equivalent stress increase due to the applied load.

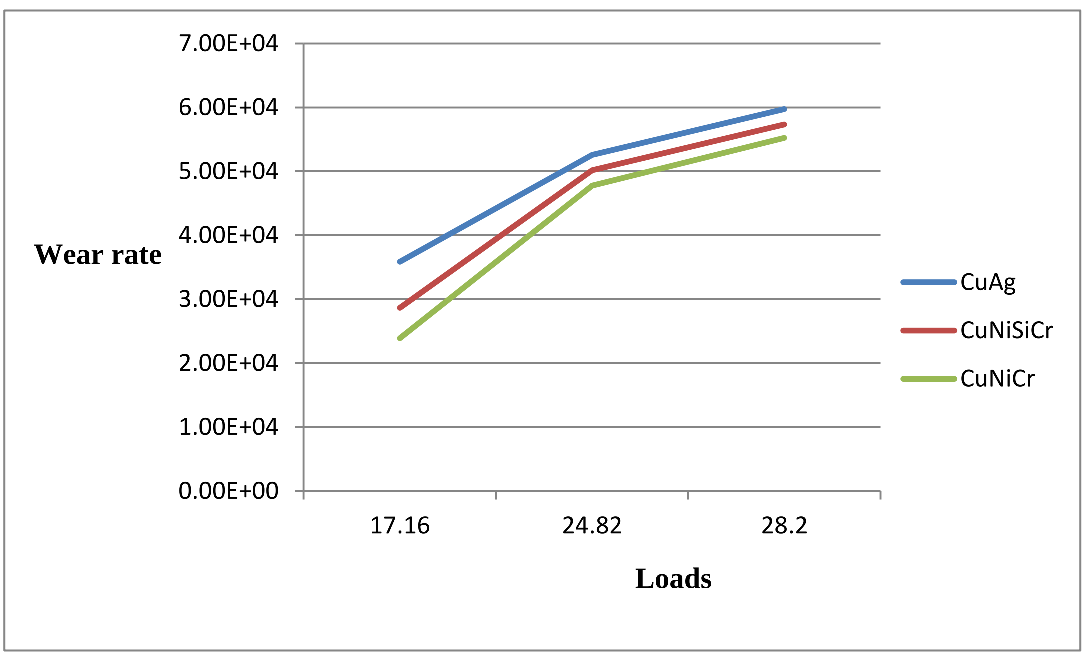
Table 16: The equivalent stress of pin model material

PIN material	Equivalent stress	Loads(kN)		
		17.160	24.82	28
CuAg	**Maximum(Mpa)**	2341.7	2493	2493.5
	Minimum(Mpa)	234.82	277	277.07
CuNiSiCr	**Maximum(Mpa)**	2339.7	2530	2531
	Minimum(Mpa)	234.92	280	281.26
CuNiCr	**Maximum(Mpa)**	2346.7	2436.5	2436.5
	Minimum(Mpa)	234	270	270.79

The volume loss of pin model materials is increase within operational current and normal load. The material CuNiCr has lowest volume than another pin model material due to the strength of material and it has better electrical conductivity.

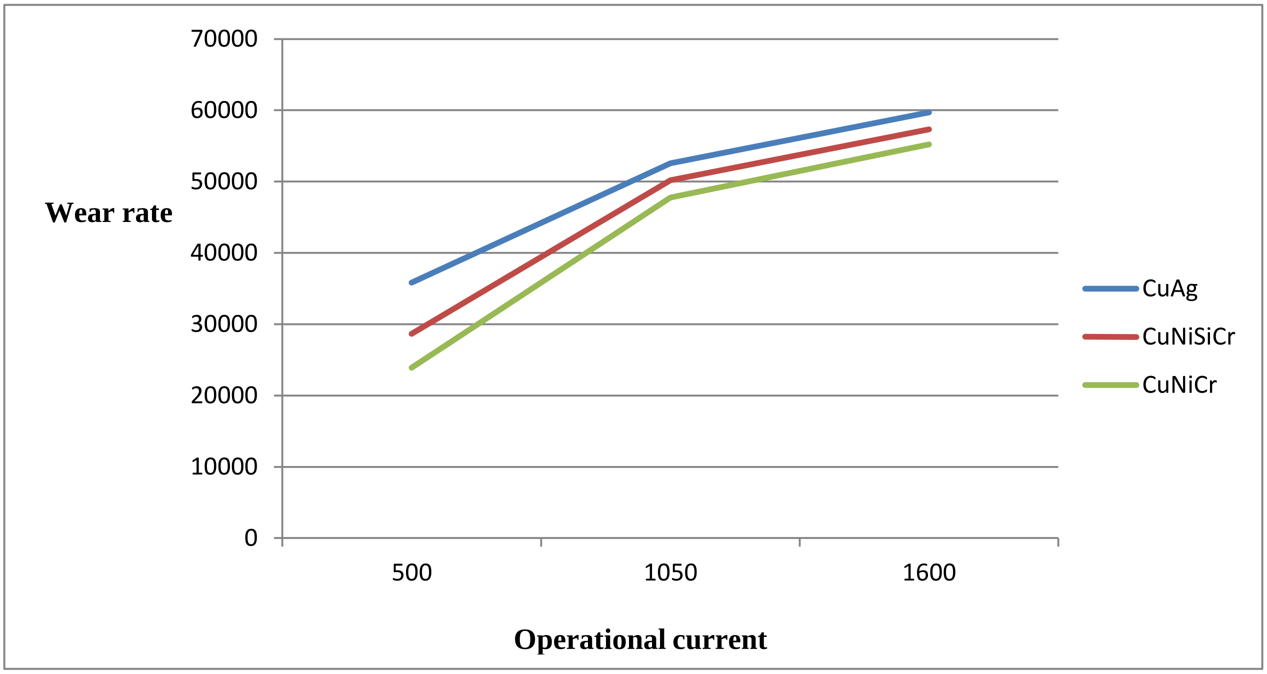
Material	Wear volume V= depth * area pin = D*A		
	Loads(KN)		
	17.160	24.82	28.00
CuAg	447.963	657.0135	746.60
CuNiSiCr	358.371	627.14	716.74
CuNiCr	298.64	597.285	690.2

The wear rate main parameter to determine of this researcher to get which material has lowest wear rate within current effect, therefore the wear rate increase with normal applied load. The copper alloy CuNiCr has lowest wear rate than other.

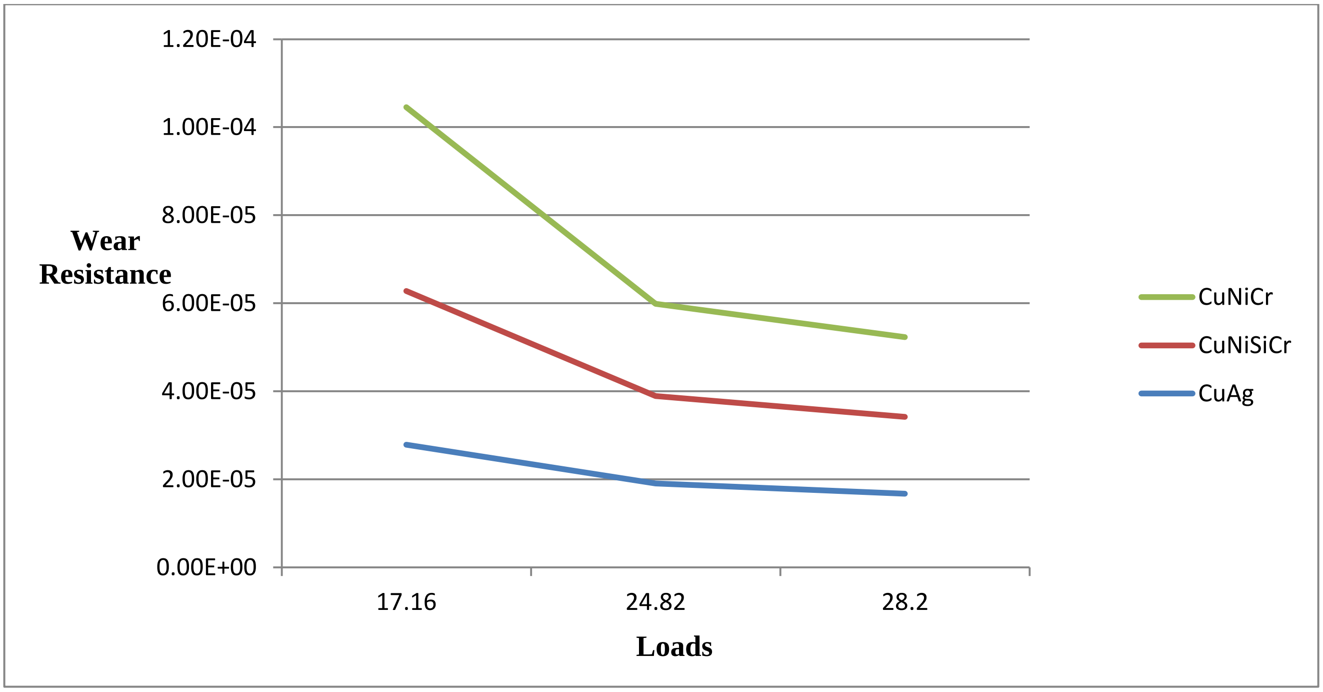


Wear rate vs applied load

The wear rate increases with operational electric.



The plot of wear resistance with 17.160KN and 24.820KN within constant speed and time of operational. The material CuNiCr has highest wear resistance.

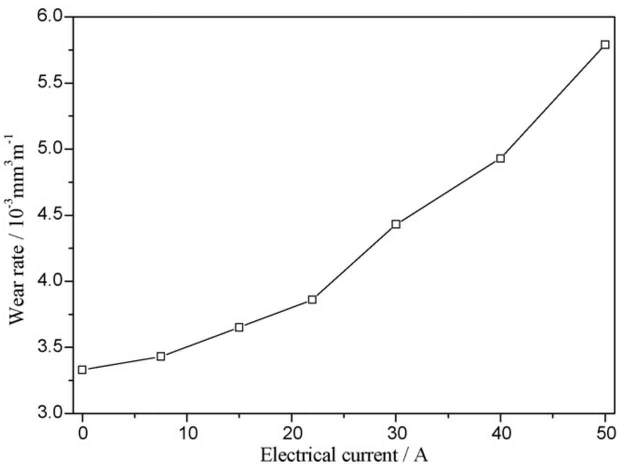


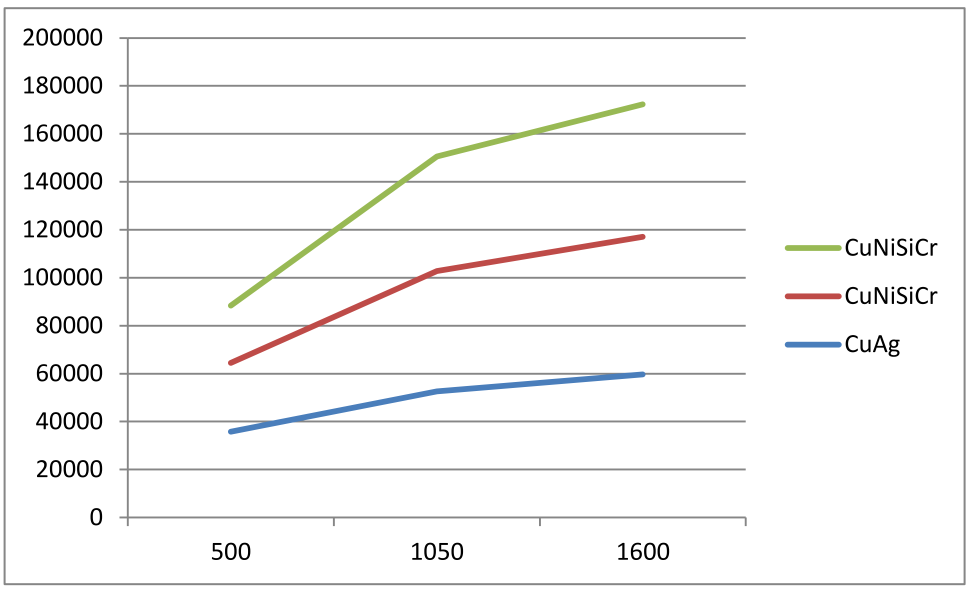
Wear Resistance vs loads

Finally, the material CuNiCr has low wear rate and good wear resistance within period of time and constant speed during contact period under applied load because it has also good electric conductivity.

4.3.COMPARAISONS

In experiments, the effect of the electric current on the wear rate overwhelmed the normal pressure and sliding speed at higher electrical current. This effect contribution has a significant scenario of wear rate in wire. The result the wear rate increased drastically with increasing of current with sliding distance at speed normal at 18km/h and the wear rate of alloy obtain as the wear volume loss per length at sliding pass of strip. In This case, the electric current applied as electric force as distributed load to combined with normal pressure due to wire to find the amount of wear happen during contact between contact wire and pantograph strip taken different copper alloy material but the load applied as resultant force of top surface of holder and the wear rate result of copper alloy material obtain as the wear volume loss per hour taken the default time of software. From the results, as the wear rate is increases with resultant force as operational current increases for any material as graph shown.





- In experiments paper, to find worn out their sliding until 4h with sliding speed at 18Km/h with normal load but in this case the worn out finding at instantly time meaning the default time of software also speed velocity is 70Km/h
- The difference in applied current, because in simulation the current force was combined with normal pressure then applied as resultants force to get the maximum stress but in experiments with normal current of device, they are finding after 4h the significant of wear due to joule heat with electric current.

CHAPTER FIVE: CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1. Conclusion

Wear on overhead line is one of the greatest problems in the railway industry. To overcome the problem of wear on overhead line this paper targeted asses the wear rate based on the effects of the current flow over the overhead line wire using Ansys. The specimen sample is modeled by using Catia V5 software and imported in Ansys workbench software to simulate. The contact arrangement of pantograph and overhead line is the sliding contains, so as to follow the arrangement pin-on-disc geometry in Ansys is used. The analysis considers applied current at 500A, 1050A and 1600A during operational time, but the electric load convert for electric force combined normal pressure load and 17.160KN, 24.82KN and 28KN inputs are given to the analysis. After a detail analysis the equivalent stresses is maximum and concentrated at the bottom face of pin. And finally the following pointes are concluded.

- ✓ The wear rate increases with resultant force due to combined with electric force, normal pressure.
- ✓ CuNiCr has minimum wear rate at different load with current than other pin material in despite the stresses portion is very lowest at pin tip part maybe due to the electric force varies.
- ✓ Finally, CuNiCr has high wear resistance than other material.

5.2. Recommendation

The electrification railway system within operational current issued from station of electric through contact wire passes to pantograph then increase the speed of train related to reduce to less of transport in the city. Select the material wire with high resistance have to require for overhead line contact wire and essential to reduce the wear on this area.

Finally, this paper strongly recommends to AALRT to use CuNiCr alloy material within high wear resistance for wear with operational current as comparing used one.

5.3. Future work

On this paper the wear rate analysis of overhead line contact wire with current using Ansys workbench appropriate a contact mechanics. The paper used to determine with operational current but without heat effect which select the material has low wear rate on contact strip.

The wear analysis need more attentions on contact wire because this effect within current by wear require more time and cost to show what kind force we need to applied within current. Those problems need to accurate values and reliable wear assessment:

- Analysis the wear with analysis software considerate the current effect.
- Analyze wear rate of overhead line contact wire material related software by considering the arcing and heat effect.
- Analyze the wear and fatigue life of contact wire material
- Analyze the relationship between the material conductivity and strength that cause by tensile load.
- Analyze the wear with temperature effect during contact moment.
- Analyze the wear with corrosion effect of material.

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