



**ADDIS ABABA UNIVERSITY**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING**

**DEVELOPMENT OF MATERIAL FOR TRAIN  
OVERHEAD CONTACT WIRE**

*The thesis Submitted to School of Graduate Studies of Addis Ababa University in  
partial fulfillment of the requirement for the Degree of Masters of Science*

**In Railway Engineering  
(Rolling Stock)**

**By  
Ashreka Yenus**

**Advisor  
Dr.Daneil Tilahun**

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## ABSTRACT

This paper presents the development of material for train overhead contact wire. In view of the current Addis Ababa Light Rail Train overhead contact wire with high material cost and low wear resistance ; the copper alloys which has better mechanical wear and corrosion resistance with moderately low cost, are developed. The mechanical properties and electrical conductivities of the prepared copper alloys were investigated by using lab testing machines. Wear tests were conducted by a pin- on-disc Tribometer which simulated the tribological conditions of sliding contact strip on overhead wires in the railway system. The copper-alloys in the form of cylindrical pins were forced to slide against a stainless steel disc with a sliding velocity of 80 km/h at room temperature under unlubricated condition and normal load up to 11N without electric current. In addition to this, the electrical conductivity of the copper alloys were investigated by multimeter . Among the alloys investigated, CuNiCr, which possesses quite good electrical conductivity and relatively high wear resistance (2 times that of Cu Ag) .Also in order to simulate costal and acidic environment, corrosion test is conducted in acid rain, salt solution and in distilled water. The corrosion from the specimens was studied by weight loss measured by analytical balance among the copper alloys Cu Ag is highly corroded and worn surfaces of the copper alloys pin were analyzed by optical microscope from these parallel and continuous scratches in the direction of motion observed. From this experimental investigation the dominated wear mechanisms are abrasive and adhesive wear in mechanical sliding frictional process. Finally the cost analysis of copper alloys per each pin performed and Cu- Ni -Cr takes less cost from others. By considering wear resistance, corrosion resistance, electrical conductivity and cost, Cu Ni Cr is appropriate for Addis Ababa light rail train and future national railway overhead line contact wire.

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**LIST OF ACRONYMS**

Cu	Copper
Ag	Silver
Ni	Nickel
Si	Silicon
Cr	Chromium
Zr	Zirconium
Be	Beryllium
$\rho$	Density
W	Wear rate
$C_m$	Cost per kilo gram
m	Mass of the pin
$\Delta w$	Weight loss
R	Wear resistance
CO <sub>2</sub>	Carbon dioxide
LRT	Light Rail Train
HCl	Hydrochloric acid
NaCl	Sodium chloride
SEM	Scanning electron microscopy
EDS	Energy dispersive X-ray spectrum
IACS	International annealed Copper standard
m	Micro ohm

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# CHAPTER ONE

## INTRODUCTION

### 1.1 Background

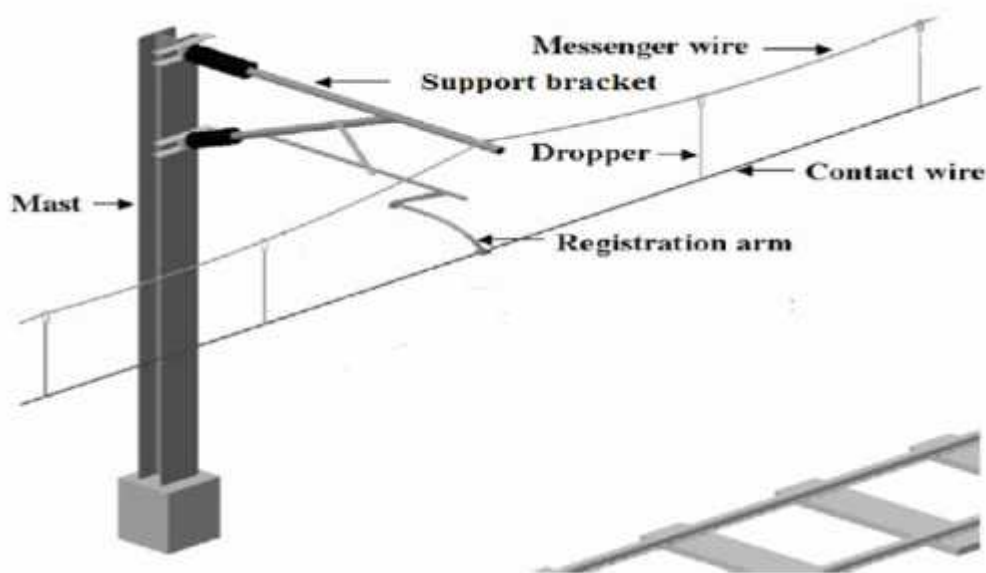
Railway transportation is attracting attention once again as an effective means of modal shift in transportation as this is promoted with a view to higher transportation efficiency and conservation of global environment especially in terms of CO<sub>2</sub> emission, so these systems are becoming key-players in worldwide transport [1].

Electrified railway system has most important environmental advantages which are more and more becoming significant as concern about climate change grows. Shifting freight traffic from the less efficient highway system to the more efficient rail system reduces both carbon emission and transport cost.

Electric trains are cheaper to purchase, and have lower operational and maintenance costs virtually silent (quieter) than diesel trains. It reduce accidents, environmental pollution, use of land, and train deleyance because of all such reason Addis Ababa Light Rail project is on the preparation to implement this transport system. Electricity is supplied to the electric rolling stock through overhead contact lines and rails for operation. Because the rails, which are in contact with the ground, become the return circuit of the feeding circuit, a portion of the return current flows to the ground through the rails [2].

Overhead line is a structure used in electric power transmission and distribution to transmit electrical energy along large distances using sliding contact with pantograph of rolling stock. The contact wire serves as a medium through which electricity is supplied to the train via the pantograph. Both mechanical and electrical considerations have to be acknowledged when choosing material and cross section of the contact wire .The most common material to use for the contact wire is copper, either a solid wire or stranded wire and sometimes with alloy additives. It consists 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 [4].The different parts of

overhead contact lines or catenary system are: contact and messenger wires, droppers and support poles. Figure 1.1 shows different parts of overhead contact lines.



**Figure 1.1:** Different parts of overhead contact lines [23].

Due to its relatively low cost, excellent electrical and thermal conductivities, copper is often used as the overhead contact wires for electric railway systems. However, the low wear resistance attributable to its low hardness greatly affects its application and service lifespan [5].

Copper and its alloy have been known with their moderate ductility and high electrical conductivity, machinability and corrosion resistance. However, relative to pure copper, the higher strength and corrosion resistance benefits that are offered by copper alloys are offset by their lower electrical conductivities [3]. Copper is easily soldered to and has good mechanical characteristics including tensile strength, toughness and ductility. Due to its low coefficient of thermal expansion and high tensile strength, copper finds widespread use in overhead transmission lines [5]. Not all the overhead line is copper; some fittings are stainless steel so that the carbon pantograph strip moves from copper to stainless steel and to copper. Wear depth of stainless steel was lower than copper [6].

For high-speed electric railway traction, the current is collected by one or two pantographs in a sliding contact with the overhead wire, which is supported by means of vertical droppers. High speed trains need a regular current transmission in pantograph-catenary systems. A high quality

current collection is characterized by a continuous smooth contact between the pantograph and the overhead contact wire [8].

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. 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. Maintenance work is hindered by the high density of traffic. On the one hand, wear due to mechanical abrasion increases, while at the same time there is a demand for continuous current consumption, which increases the risk of overheating, which in turn alters the mechanical properties of the material [9].

A crucial problem for railway companies is to prevent damages to the overhead line equipment and to pantographs. A poor contact produces various drawbacks, including bursts of arcing: if they have a long duration, locomotive efficiency may reduce and an excessive wear of the pantograph strips and of the contact wire may lead to maintenance problems, up to crashing of catenary. If a loss in contact with the overhead wire is happen: an electrical arcing may occur causing the overhead wire and the pantograph shoe to deteriorate rapidly [8]. Since our country is introducing this technology in order to reduce the occurrence of such problems, the contact line system shall be characterized of safe and reliable performance, being able for satisfy the operation requirements at the maximum operation speed of 80km/h. The contact line shall adopt overhead catenary and shall satisfy the normal operation of the rolling stock in various environmental conditions, route conditions, and traffic conditions of ADDIS ABABA LRT and future national railway. The structure of the contact line shall be simple, reliable, stable to receive current, to withstand mechanical load and convenient for installation. The last but very important solution is the overhead contact wire material should be good in electro mechanical property to have long service life. In order to realize these solutions the contribution of the respected one must be high.

This study addresses the development of overhead contact wire material with good electro mechanical property and low cost since development of new material is essential to have

performance improvement, cost effectiveness, longer life. Addis Ababa Light Rail Transit uses Cu-Ag contact wire so by considering the current situation of our country, the overhead contact wire materials which have better mechanical property with low cost and good electrical conductivity can develop. The paper emphasize on developing overhead contact wire materials that have relatively better wear and corrosion resistance with a combination of good electrical conductivity and low cost. Finally, the material which has good electrical conductivity and relatively high wear and corrosion resistance also takes less purchase cost is recommended for Addis Ababa light rail train and future national railway overhead line contact wire.

## **1.2. Statement of the Problem**

Now a day's rail way transportation system is becoming popular in terms of cost and long life operating all over the world. With the technological developments of electric railways, speed up of train and reduction of cost to maintain the facilities are strongly required. Major efforts have devoted to solve these issues to meet the expectations of people. The contact wire is one of the factors, which can greatly affect the speedup of the train and the cost of maintenance. To enhance the quality of the contact wire, new materials should be developed. The contact wire made with the new materials should have a low wear rate and better combination of good strength and conductivity . In Ethiopia, currently the railway transport system is on the way to start, since our country is introducing this technology it is new. Therefore, we have to accept this technology with maintenance cost minimization and passenger's safety and comfort. To minimize maintenance cost, to ensure safety and comfort for the passengers and in order to have good ride quality the railway components such as overhead contact wire, Rail, Wheel and axle are free of failure.

A poor contact produces various drawbacks, including bursts of arcing: if they have a long duration, locomotive efficiency may reduce and an excessive wear of the pantograph strips and of the contact wire may lead to maintenance problems, up to crashing of catenary. Excessive wire wear can lead to breakage causing the service to be suspended It will results maintenance cost. The costs linked to a service being suspended can be extremely high, although the most important factor is the repercussion on the passengers affected so it has socio economic impact [9]. In the new network rail transport in Ethiopia if these problems are not analyzed from the start and ignored, it will cost more in incidents, accidents, fatality and excess maintenance cost.

Therefore, it is very important to find a compromise that will allow maximum usage of the wire without entailing any risk of breakage and major efforts have been devoted to prolonging lifetime and reducing maintenance costs of the overhead catenary .Since our country is introducing this technology and Ethiopian Railway Corporation is already on the way to finish the erection process of overhead line system for the future work before this kind of effect happens detail researches on developing overhead contact wire materials that have relatively better wear and corrosion resistance with a combination of good electrical conductivity and low cost must be done.

In this study prediction will be given by analyzing the current overhead contact line wire of Ethiopian Railway Corporation which is ,the copper silver contact wire, which has poor wear and corrosion resistance also expensive relative to the copper alloy material that have good wear , corrosion resistance property and less purchase cost metals like chromium(Cr), nickel(Ni), silicon(Si) etc .To alleviate this property, Cu-Ni-Si, Cu-Cr-Ni and Cu-Ni-Si-Cr copper alloys are manufactured and investigate with lab tests and comparing the alloys according to electromechanical property and cost .Lastly the copper alloy with moderately good electrical conductivity , low cost and good combination of high wear and corrosion resistance is recommended for Addis Ababa Light Rail Train and future national railway overhead contact wire.

### **1.3. Significance of the research**

The study will help to develop the appropriate overhead contact wire for Addis Ababa Light Rail Train and future national railway and identify the problems that are resulted from sliding wear and corrosion resistance of overhead contact wires. These will help for Ethiopian Railway Corporation to promote safety issue that related to wear, corrosion and conductivity failure of overhead contact wire while implementing the project. Furthermore, the research helps for the responsible authorities to see the effect of how sever the issue is, so it contributes to decrease the number of incidents related to this component failure and to reduce the maintenance and interoperability development costs. Such that great attention and participations on any research based on development of Material for train over head contact wire by improving its electro mechanical property will be supported efficiently. In addition, it is also a supporting document for a research on the title. Therefore it will help as a reference for further study in the area of the above mentioned title. So as it will be a good guide for further researches.

## **1.4. Objective of the Study**

### **1.4.1. General objective**

The general objective of the study is developing the overhead contact wire material which has better wear and corrosion resistance with good electrical conductivity and low cost.

### **1.4.2. Specific objectives**

The specific objectives of the research are:

- To manufacture pin test pieces with Cu- Ni- Si, Cu-Ni-Cr and Cu-Ni-Si-Cr copper based alloys.
- To investigate wear and corrosion resistance of the above copper based alloys.
- To conduct electrical conductivity test of the manufactured pins.
- To conduct cost analysis per one pin for each copper alloys.
- To compare the results of cost analysis, wear resistance, corrosion resistance and electrical conductivity tests of Cu-Ag, Cu-Ni-Cr, Cu-Ni-Si-Cr, Cu- Ni- Si.
- To recommend the contact wire material which has better wear and corrosion resistance with low cost and good conductivity for Addis Ababa Light Rail Train and future national railway overhead contact wire material .

## **1.5. Limitation and Scope of the Study**

### **1.5.1 Limitation of the Study**

During the preparation of this document, the writer faced many problems.

- Availability of laboratory grade material and Raw material like Zirconium, Beryllium and magnesium to make pins may not be available as is required.
- Because of unavailability of speed controller the wear rate test is forced to conduct with constant velocity.
- Because of the low capacity of machine the test was performed with normal load to below 11N.
- The operation of Addis Ababa light rail train is on the way to start because of this total maintenance cost of existing and proposed overhead contact wire is not carried out.

### **1.5.2 Scope of the Study**

Geographically, the study covered Addis Ababa Light Rail Train and future national rail way. Conceptually, it is focused on development of material by using manufacturing method with the appropriate raw material and the wear and the corrosion effect is analyzed by using experimental analysis through lab testing machine to different load and environmental condition. Due to low capacity of tribometer machine motor and the absence of constant electric power supply mechanism for pins, the wear test is conducted without electric current under a condition of constant velocity and a load up to 11N.

### **1.6. Organization of the Paper**

This thesis contains five chapters. The first chapter is background and Justification of this thesis work and contains statement of the problem, significance, objectives, limitation, scope and organization of the paper .Following this,the second chapter provides a summary of the available literature in the area of development of material for train overhead contact wire and related ideas. Also in this chapter a brief description of overhead contact wire, sliding wear, corrosion and electrical conductivity is included. Experimental methods and conditions are discussed in the third chapter. The material type, the dimensions of the specimens, conditions of operation and experimental procedures are discussed. This chapter also describes experimental apparatus and cost analysis. The results obtained from the experimental analysis carried out by the specimen for wear, corrosion, electrical conductivity tests and discussions based on these results are included in the fourth chapter. Finally, the main findings of the study are summarized in fifth chapter along with recommendations for application is given. Also propose future work in this field of study.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1. Introduction

Review of literatures reveals that different previous works which are assisting to introduce the current study. Some of them are direct and the others are indirectly related to this work. On the other hand, it is useful to develop the recent idea. This part contains description of overhead contact wire, sliding wear, corrosion and electrical conductivity. There are many books, journals, conference papers, thesis and dissertation are used to support the current paper, and some of fundamentals are discussed on this paper.

#### 2.2. Overhead Contact line Wire

Overhead catenary constitutes an important traction system of electrical conductors used in conjunction with sliding pantograph current collectors to supply electrical energy to moving locomotives. The increasing speed of modern high-speed locomotives becomes a challenging problem in the design of electric traction systems over the world. 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].

Copper has the highest electrical conductivity rating of all non-precious metals; it is an essential property in electrical wiring systems. 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 sliding wear and atmospheric corrosion which lead to shortening of its service life, interruption of the system, and safety problems. Overhead contact wires are designed to give high resistance to wear, corrosion and have good electrical conductivities to provide an optimum balance between them for the expected service life. Copper alloy conductors are preferred instead of pure copper. Age-hardenable copper alloys are dilutely 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 can be enhanced while a high level of electrical conductivity can be preserved [3].

To withstand the harsh service condition in real application, electric contact materials for the overhead catenary and collector strips should possess high hardness and mechanical strength, high sliding wear and corrosion resistance and excellent electrical conductivity. Due to this, many researchers are interesting to do their research around this area to solve the problem related to overhead contact line wire failure due to wear and loosing conductivity also to improve the performance, the service life and maintenance cost of the contact wire. This part deals with previous work related to development of material for contact wire and the sliding wear and corrosion resistance of copper alloys.

Kwok [3]: investigated the sliding wear and corrosion resistance of pure copper (Cu) and Six age-hardened copper alloys (CuCr, CuZr, CuCrZr, CuNiSiCr, CuBe and CuBeNi) by a pin-on-disc tribometer and electrochemical measurement respectively. Various copper-based alloys in the form of cylindrical pin were forced to slide against a counterface 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. Open-circuit potential (OCP) measurement and potentiodynamic polarization test in 3.5% NaCl solution for simulating the coastal environment, open to air at  $23 \pm 1^{\circ}\text{C}$  were performed using a PAR VersastatII potentiostat. The alloys were embedded in cold-curing epoxy resin, exposing a surface area of  $1 \text{ cm}^2$ . By using scanning electron microscopy the worn surface of and wear debris from the specimens were studied and the corroded part mass loss rate was calculated with the aid of a software (Power CORR, V.2.42). The results indicate that the wear resistance of the copper-based alloys increases with decrease in normal load and the increase in hardness. Among the alloys, CuCrZr has the highest corrosion resistance and CuBeNi has highest sliding wear resistance and Adhesive wear, abrasive wear and arc erosion are the wear mechanisms during the electrical sliding which results in metal transfer, film formation and removal, debris generation and surface deterioration.

Finally materials approved by researchers Based on consideration of wear resistance, electrical conductivity and safety, From the following material mentioned in the table 2.1, Cu- Cr- Zr is a promising candidate as the contact wire material.

**Table 2.1:** Composition and Properties of Copper and its Alloys [3] .

Alloy	Composition (Bal .Cu)	Electrical conductivity	Density (g/cm <sup>3</sup> )	Hardness (Hv)
Cu (C11000)	0.04% O	100% IACS, 58MS/m	8.90	102
CuCr (C18200)	1.2%Cr	74% IACS, 43 MS/m	8.89	162
CuZr (C15000)	0.25% Zr	80% IACS 47 MS/m	8.89	132
CuCrZr (C18150)	1.4%Cr 0.12%Zr	74% IACS 43 MS/m	8.89	168
CuNiSiCr (C18000)	2.5%Ni 0.8%Si 0.5% Cr	29% IACS 17 MS/m	8.84	234
CuBe (C17200)	2%Be	23% IACS 13 MS/m	8.36	342
CuBeNi (C17510)	0.4%Be 1.5% Ni	44% IACS 25.8 MS/m	8.83	242

Po Kee Wong [4]: studied electrical sliding wear of copper-based contact wire materials for electric railway. The electrical sliding wear behavior of eight copper-based alloys was investigated by a pin-on-disc tribometer. In air under unlubricated condition at a sliding velocity of 31.2 km/h and under normal load up to 20 N with and without electric current, various copper-based alloys in the form of cylindrical rod were forced to slide against a counter face stainless steel disc. By using scanning-electron microscopy the worn surface and wear debris of the specimens were studied. Mechanical wear and electrical arc erosion were the dominant wear mechanisms for the alloys worn at 50 A. Finally their finding was by Considering both electrical conductivity and wear resistance, CuCrZr is a promising candidate as the contact wire material for electric railway systems.

Jia a [21]: developed Cu–Ag–Cr alloy in order to compare to that of Cu–Ag alloy. The sliding wear behavior of the Cu–Ag–Cr alloy contact wire was studied using a specified sliding wear tester and The Cu–Ag–Cr alloy wire was slide against a copper-based powder metallurgy strip, which was used as a contact strip on a pantograph of an electric railway vehicle in a train system under unlubricated conditions. Worn surfaces of the Cu–Ag–Cr alloy wire were analyzed by scanning electron microscopy (SEM) and energy dispersive X-ray spectrum (EDS). Finally from the test result compared with a Cu–Ag contact wire under the same conditions, the

Cu–Ag–Cr alloy wire had much better wear resistance because of the addition of Cr can markedly increase the wear resistance of the Cu–Ag alloy contact wire .

Mediha I. [22]: studied the effect of aging parameters on properties of powder metallurgy (PM) Cu-Cr-Zr alloy. Cu-1.5wt.%Cr-0.5 wt.% Zr alloy was prepared by powder metallurgy method . Cu-Cr-Zr powders were pressed under 390MPa uniaxial compression and sintered at 1000°C for 2h. After the holding time, samples were immediately taken out of furnace and pressed at 850 MPa. Sintered samples were solution-treated at 1000°C for 15 min and water-quenched. Then, they were deformed 20% at room temperature and aged at 450, 475 and 500°C for 2, 4, 6 and 8 h. SEM investigation revealed that, Cr and Zr particles having limited solubility in the Cu distributed homogeneously in copper matrix and XRD analysis showed that each sample (sintered and aged at 475°C for different times) has same phases: copper and trace Cr<sub>2</sub>O<sub>3</sub>. Finally The relative density of sinter-pressed sample increased from 92% to 94% by cold deformation. The highest micro hardness value is obtained in sample aged at 450°C for eight hours and electrical conductivities ranges 84.9-87.6% IACS depending on increase in temperature.

Tao Ding [24]: study on Friction and Wear Properties of Pantograph Strip/Copper Contact Wire for High-Speed Train .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.

### **2. 3. Sliding Wear**

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, thereby 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 [14]. The wear behaviors of tribological pairs with electrical current were different from those without electrical current [8].



**Figure 2.1:** Sliding contact of the contact strip against contact wire [10].

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].

Friction is the main factor of mechanical wear when the alloys slide without electric current. On the other hand, the combined effects of friction and electric current lead to electro-mechanical wear which includes abrasive, adhesive and arc erosion wear mechanisms. For abrasive wear, the harder body plastically deforms the softer body. On micro-scale, asperities of the harder surface press into the softer surface, with plastic flow of the softer surface occurring around the harder asperities. For adhesive wear, the asperity junction of the sliding surfaces of counter parts under normal contact force adhered together through solid phase welding of asperities. Subsequent detachment from the surface of the weaker phases resulted in loss of material [16].

Different studies, [16], [10] and [11], show that the contact wire wear rate depends on the heat generated on the contact surfaces and the pressure of contact between the wire and the contact strip. This heat is the sum of the mechanical heat associated with friction, Joule heat associated with contact electric resistance, and the heat generated by the electric arcs. In the absence of contact losses, the main wear mechanism is mechanical abrasion, which increases with the friction force, [10]. The wear rate can be influenced by Physico chemical properties of materials, such as composition, microstructure, hardness work hardening characteristics, corrosion resistance, wear strength and Wear conditions such as contact areas, load applied, temperature, presence of lubricants, degree of lubrication, rotational/sliding speed, flow rate of liquid or gas, nature of environment and duration of wear.

## **2.4. Corrosion**

The corrosion of materials causes great loss in the industrial applications, especially under some extreme conditions, i.e. the corrosive atmosphere and high temperature. Corrosion is the electrolytic action of moisture and other dissolved ions of the atmosphere on the metals and it is the destructive attack of a metal by chemical or electrochemical reaction with its environment. 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 [17].

The surface chemical reactions which are beneficial in preventing adhesive wear will, if unchecked, lead to a considerable loss of the underlying material. If a material (metal) is corroded to produce a film on its surface while it is simultaneously subjected to a sliding contact then one of the four following processes may occur [11]: a durable lubricating film which inhibits

both corrosion and wear may be formed; a weak film which has a short lifetime under sliding contact may be produced and a high rate of wear may occur due to regular formation and destruction of the films. The friction coefficient may or may not be low in this instance; the protective surface films may be worn (e.g. by pitting) and a galvanic coupling between the remaining films and the underlying substrate may result in rapid corrosion of the worn area on the surface. The corrosive and wear processes may act independently to cause a material loss which is simply the sum of these two processes added together. The corrosion resistant coatings have attracted many attentions for many years due to its simplicity and efficiency. Copper and copper alloys are materials, which are prone to corrosion. The electrical conductivity of contact materials can be largely reduced by corrosion [18].

## **2.5. Electrical Conductivity**

Of all common metals, copper possesses the highest rating for both electrical and thermal conductivity. High conductivity coupled with intrinsic strength, formability and corrosion resistance make copper alloys unique as conductors of electricity making them ideal for connectors and other electrical/electronic products. Conductivity is the primary characteristic that distinguishes copper from other metals. The electrical conductivity of materials is measured against that of a standard bar of “pure” copper [19].

The thermal and mechanical processing variations used to produce commercial alloys can cause profound changes in their conductivity, and frequently the alloys with the highest strengths have the lowest conductivity. Alloys of higher electrical resistivity ( $R$ ) or lower conductivity will waste more energy, since heat generated due to an electric current ( $I$ ) is proportional to  $I^2$  times the resistance. The heat generated will increase the temperature of the component, with potentially adverse consequences. Higher thermal conductivity alloys allow the designer to dissipate some of that heat, minimizing any temperature rise. Within alloy families, thermal conductivity tends to be related to electrical conductivity that is alloys of higher electrical conductivity will tend to have higher thermal conductivity.

The range of conductivity of copper alloys differs, depending on the alloying elements. High copper alloys made with tellurium, zirconium, magnesium, chromium, and iron provide increased strength with conductivity in the 75% to 90% range. Another alloy group, with

combinations of elements including boron, iron, tin, zinc, cobalt, magnesium and phosphorous, provides good strength with conductivity in the range of 50% to 75% [19].

Additives to the copper generally result in a reduction in its conductivity. The copper is alloyed with small quantities of one or more substances in order to attain specific properties without varying its basic character. Addition of elements such as Cr and Be to copper significantly improves the hardness and the wear resistance. Adding tin, chromium and iron makes the copper stronger. Sulphur or tellurium improves its cutting properties. Adding silver, cadmium, tin or tellurium increases the softening temperature and improves its creep strength. Nickel additions result in great strength and improved resistance to corrosion. Silicon addition improves flexibility and corrosion resistance. Zirconium addition increases corrosion resistance with electrical conductivity since it has a good electrical conductivity and highest corrosion resistance [4].

In Ethiopia, there is a shallow or few researches have been done on railway area. Specifically, on development of material for overhead contact wire, there is a huge gap of conducted research in the area. Therefore this study is expected to reduce this gap in this area.

Finally, in this paper Cu-Ni-Cr, Cu-Cr-Ni-Si, Cu-Ni-Si copper alloys pins developed and investigate the mechanical sliding wear behavior of age-hardened copper-based alloys under different load and environmental conditions. The electrical conductivity test of the alloys performed. In addition, the corrosion behavior of the alloys in 3.5% NaCl solution, acid rain with 5PH solution and distilled water studied. In developed country 5-5.5PH acid value rain because of their industries, cars and others that out harmful gases, but for this thesis the extreme value was taken because of our country low carbon effect.

## CHAPTER THREE

### EXPERIMENTAL METHODS AND CONDITION

#### 3.1. Material

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 3.1:** Comparison of material selection criteria for develop copper alloys

Material	Hardness	Wear resistance	Resistance to corrosion	Electrical conductivity	Cost	Conclusion
copper	low	low	low	Very high	moderate	Because of its high conductivity copper is selected
Chromium	Very high	Very high	good	good	high	Because of its high wear resistance chromium is selected
Nickel	high	high	Very high	moderate	low	Because of its high corrosion resistance nickel is selected
Silicon	good	good	high	moderate	higher	Because of its high corrosion resistance and flexibility silicon is selected

Source: Copper Development Association

The chemical composition of the copper alloy is as shown in Table 3.2

**Table 3.2:** Chemical composition of copper all

Material	Chemical composition in %				
	Cu	Ni	Si	Cr	impurities
Cu -Ni-Si-Cr	96.7with0.04% O <sub>2</sub>	2.4	0.003	0.077	<0.78
Cu-Ni-Si	99 with0.04% O <sub>2</sub>	0.503	0.14	-	<0.317
Cu -Ni-Cr	98.6with0.04% O <sub>2</sub>	0.33	-	0.193	<0.837
Cu-Ag	(99.3Cu-0.08Ag) as per specification of ERC				

Preparation for manufacturing process

### 1. Collecting material

The industrial grade materials are taken from manufacturing industries like akaki basic Metals and Elsewedy cables, Gafat. The industrial grade material is impure than that of laboratory grade material so consider the impurities like as amount of iron in the material. For example to get pure silicon, 45%FeSi (45% silicon in FeSi) have been collect, then calculate amount of pure silicon to add in the composition to be melt.



Chromium



Nickel



Silicon

**Figure 3.1:** The raw material used for manufacturing of pins.

### 2. Amount preparation

After getting the appropriate material for this research to get the needed percentage composition, calculation was needed.

- To get the above chemical composition

Calculate the gram of one pin with dia.13mm xlength13mm.

Where:

$$A = \pi r^2$$

$$V = \pi r^2 * L$$

$$m = \rho * v$$

$$\rho = m/v$$

$$d = 13\text{mm}$$

$$L = 13\text{mm}$$

$\rho$  = density of copper

$$\rho = 8.96 \text{ gm/cm}^3$$

m = mass of pin in gram

A = area of pin in  $\text{mm}^2$

v= volume of pin in  $\text{mm}^3$

d= diameter of pin in mm

$$\begin{aligned} A &= \pi(6.5\text{mm})^2 \\ &= 132.73 \text{ mm}^2 \end{aligned}$$

$$\begin{aligned} v &= 132.73\text{mm}^2 * 13\text{mm} \\ &= 1.726\text{cm}^3 \end{aligned}$$

$$m = 8.96 \frac{\text{gm}}{\text{cm}^3} * 1.726 \text{cm}^3$$

$$m = 15.461 \text{gram}$$

**Table 3.3:** Pin material composition with impurities

Material	Chemical composition in %				
	Cu	Ni	Si	Cr	Impurities
Cu-Ni-Si	99 with 0.04% O <sub>2</sub>	0.503	0.14	-	<0.317
Cu -Ni-Si-Cr	96.7 with 0.04% O <sub>2</sub>	2.4	0.003	0.077	<0.78
Cu -Ni-Cr	98.6 with 0.04% O <sub>2</sub>	0.33	-	0.193	<0.837
Cu-Ag	(99.3Cu-0.08Ag) as per specification of ERC				

Consider 100% copper is equal to 15.461 gram of copper and calculate each element percentage out of 100%.

➤ For Cu –Ni- Cr copper alloy pin

Calculate the gram of 0.193% of chromium out of 100 % ( 15.461 gram) of copper alloy.

$$100\% \text{Cu} = 15.461 \text{ gram}$$

$$0.193\% \text{Cr} = x$$

$$\frac{0.193\%}{100\%} = \frac{x \text{ gram}}{15.461 \text{ gram}}$$

$$x = \frac{15.461 * 0.193}{100}$$

$$x = 0.0298 \text{gram}$$

0.0298 gram of Cr needed to manufacture one pin of Cu-Ni-Cr.

For n number of pins the value can be multiply with number of pin .

For manufacturing nine pins 0.269gram of Cr needed.

Gram of 0.33 % of Nickel out of 100% of copper.

$$\frac{0.33\%}{100\%} = \frac{x \text{ gram}}{15.461 \text{ gram}}$$

$$x = 0.051 \text{gram}$$

0.051 gram of Nickel needed to one pin.

For nine pin 0.4591917gram of nickel needed.

- For manufacture nine pin of Cu-Ni-Cr 139.149gram of copper, 0.051 gram of nickel, 0.269 gram of chromium needed.
- For Cu- Ni- Si-Cr copper alloy pin

Calculate the gram of 0.077% chromium out of 100 % ( 15.461 gram) of copper alloy.

$$100\%Cu = 15.461\text{gram}$$

$$0.077\%Cr = x$$

$$\frac{0.077\%}{100\%} = \frac{x \text{ gram}}{15.461 \text{ gram}}$$

$$x = 0.012 \text{ gram}$$

0.012 gram of chromium needed to one pin.

For nine pin 0.107 gram of chromium needed.

Gram of 2.4 % of Nickel out of 100% of copper.

$$100\%Cu = 15.461 \text{ gram}$$

$$2.4\%Ni = x$$

$$\frac{2.4\%}{100\%} = \frac{x\text{gram}}{15.461\text{gram}}$$

$$x = 0.37\text{gram}$$

0.37 gram of Nickel needed to one pin.

For nine pin 3.34 gram of nickel needed.

Gram of 0.003% of silicon out of 100% of copper.

$$\frac{0.003\%}{100\%} = \frac{x \text{ gram}}{15.461\text{gram}}$$

$$x = 4.64E - 04 \text{ gram}$$

4.64E-04 gram of silicon needed to melt one pin.

For nine pin 4.1745E-03 gram of silicon needed.

- For manufacture nine pin of Cu-Ni-Si-Cr 139.149 gram of copper, 4.1745E-03 gram of silicon, 3.339576 gram of nickel, 0.107 gram of chromium needed.



**Figure 3.2:** Composition of pin material Cu-Ni- Si-Cr before melting process.

- For Cu-Ni-Si copper alloy pin

Gram of 0.5 % of Nickel out of 100% of copper.

$$\frac{0.5\%}{100\%} = \frac{x \text{ gram}}{15.461 \text{ gram}}$$

$$x = 0.08 \text{ gram}$$

0.08 gram of Nickel needed to one pin.

For nine pin 0.696 gram of nickel needed.

Gram of 0.14% of silicon out of 100% of copper.

$$\frac{0.14\%}{100\%} = \frac{x \text{ gram}}{15.461 \text{ gram}}$$

$$x = 0.0216 \text{ gram}$$

0.0216 gram of silicon needed to melt one pin.

For nine pin 0.195 gram of silicon needed.

- For manufacture nine pin of Cu-Si-Cr 139.149 gram of copper, 0.195 gram of silicon and 0.696 gram of nickel needed.

### 3. Melting process

After amount preparation the melting process was carried out by graphite crucible with oil furnace at yalew garage .The materials were prepared by melting high purity cathode copper, ferrochromium, ferrosilicon and Nickel according to their melting temperature. The quality of

the material will depend on melting process and containing materials. It is impossible to produce a material without defects and there will always be some defects like pores, slags and inclusions.

**Table 3.4:** Melting temperature of materials

Material	Melting point in °C
Copper	1083
Chromium	1890
Nickel	1452
Silicon	1430

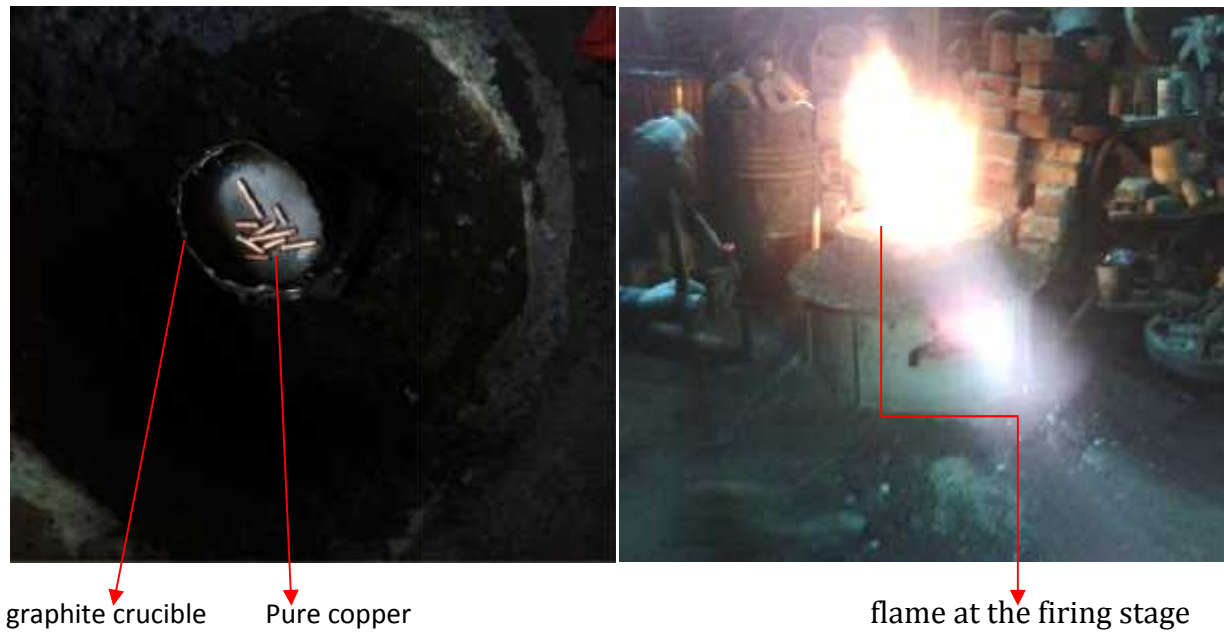


The valve which supply and manage Oil      Air regulator

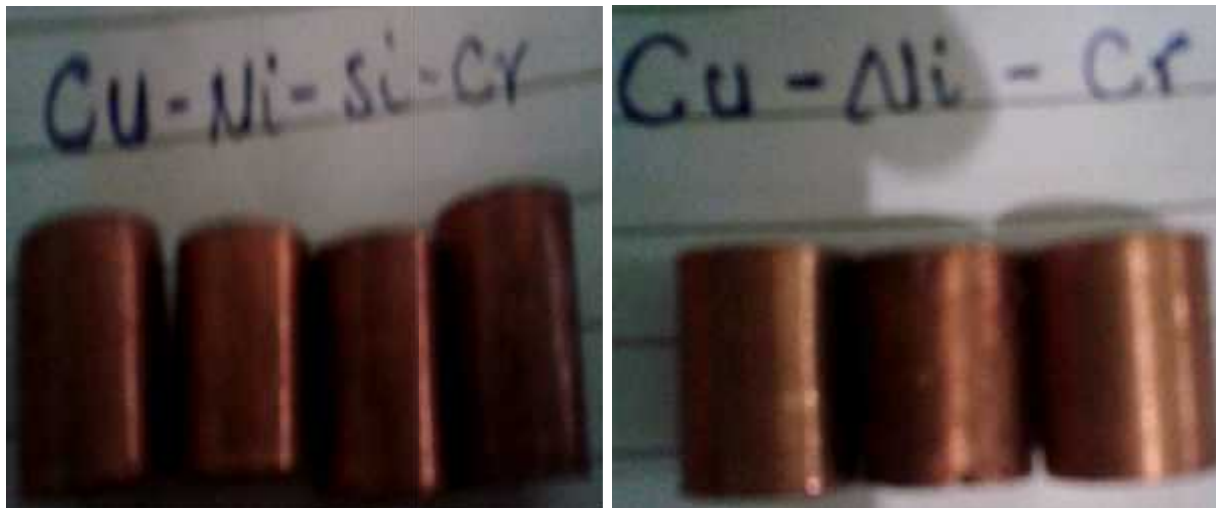
Furnace

**Figure 3.3:** General description of furnace room.

In melting process first melt the base metal of the composition copper, and then add others first chromium, second nickel, third silicon by descending order of their melting point. After melting pour the alloy immediately in hollow cylindrical steel mold, then cooled by air or use water as quenching media .Finally machining process followed to get the necessary shape mentioned in the above.



**Figure 3.4:** Inside part of furnace and crucible.



**Figure 3.5:** The copper alloy pins after melting and machining process.

### After melting process

After melting and machining process the chemical composition and hardness of the specimen tested by lab testing machine, in order to know composition the test was conducted by the spectrometer which is the advanced machine and after three tests the average result taken as a value.

**Table 3.5:** Chemical composition of copper alloy after melting process

Material	Cu	Ni	Si	Cr	Ag	impurities
Cu-Ni-Cr	98 with 0.04%O <sub>2</sub>	0.3	-	0.19	-	<1.47
Cu-Si-Ni	98.8 with 0.04%O <sub>2</sub>	0.49	0.14	-	-	<0.53
Cu-Ni-Si-Cr	97 with 0.04%O <sub>2</sub>	2.4	0.003	0.017	-	< 0.54
Cu-Ag	99.8 with 0.04%O <sub>2</sub>	-	-	-	0.086	<0.074

The hardness test of the copper alloys performed by using vickers hardness testing machine and the hardness value of the alloys shown in table 3.6.

**Table 3.6:** Hardness and Density value of copper alloy

Material copper alloy	Hardness (Hv)	Density (g/cm <sup>3</sup> )
Cu-Ni-Si-Cr	145	8.84
Cu-Ni-Cr	141	8.8
Cu-Ag	130	7.4
Cu-Ni-Si	114	8.26
Disc		
Stainless steel (AISI316L)	151	7800kg/m <sup>3</sup>

### Cost analysis

Cost-effectiveness analysis is a decision-making assistance tool. It identifies the economically most efficient way to fulfill an objective. The cost of overhead line equipment on electrification projects forms a significant pan of the total investment and therefore considerable effort has been devoted to achieving the maximum economy.

### Cost of materials from the market

For comparison purpose, the cost is taken from Agica Ethiopia, Micron international trading house PLC and Niway PLC and let's compare the four copper alloys material that is the current Ethiopian contact wire Cu-Ag and the new materials developed for this research purpose.

**Table 3.7:** Cost of each material per kg

Material	Kg	Price (birr)
Copper	1	1300
Chromium	1	4500
Nickel	1	920
Silver	1	65000
Silicon	1	6000

- The cost  $C$  of the pin is just its mass, times the cost per Kg,  $C_m$  of the material of which it is made.

$$C = mC_m = AL\rho C_m$$

In order to manufacture one pin of copper alloy of Cu-Ag We have pure copper and silver.

- For Cu Ag (Cu=99.8%, Ag=0.086%)

For Copper

$$\frac{99.8}{100} = \frac{x}{15.461}$$

$$x = 15.43 \text{ gram of Cu}$$

$$1\text{kg} = 1000\text{g}$$

$$y\text{kg} = 15.43 \text{ g}$$

$$y = 0.01543 \text{ kg}$$

$$1 \text{ kg of Cu} = 1300 \text{ birr}$$

$$0.01543 \text{ kg of Cu} = W \text{ birr}$$

$$\frac{w}{0.01543\text{kg}} = \frac{1300\text{birr}}{1 \text{ kg}}$$

$$w = 20.059 \text{ birr for } 99.8\% \text{ Cu in one pin}$$

For Silver

$$\frac{0.086}{100} = \frac{x}{15.461 \text{ gram}}$$

$$x = 0.0133 \text{ gram}$$

$$1\text{kg of Ag} = 65000\text{ birr}$$

$$0.0000133\text{kg of Ag} = w\text{birr}$$

$$\frac{w}{0.0000133\text{kg}} = \frac{65000\text{birr}}{1\text{kg}}$$

$$w = 0.8645\text{ birr for } 0.086\%\text{Ag in one pin}$$

**Total cost for Cu -Ag per pin**

$$= 20.059\text{birr} + 0.8645\text{ birr}$$

$$= \mathbf{20.92\text{ birr for one pin of CuAg}}$$

➤ **For Cu Ni Cr (Cu=98.6%, Ni=0.33% & Cr=0.193%**

For Copper

$$\frac{98.6}{100} = \frac{x}{15.461}$$

$$x = 15.245\text{ gram}$$

$$\frac{w}{0.015245\text{kg}} = \frac{1300\text{ birr}}{1\text{kg}}$$

$$w = 19.82\text{birr for } 98.9\%\text{Cu in one pin}$$

For nickel

$$\frac{0.33}{100} = \frac{x}{15.461\text{ gram}}$$

$$x = 0.0000510\text{kg}$$

$$\frac{w}{0.0000510\text{kg}} = \frac{920\text{birr}}{1\text{kg}}$$

$$w = 0.04694\text{ birr for } 0.33\%\text{Ni in one pin}$$

For chromium

$$\frac{0.193}{100} = \frac{x}{15.461\text{ gram}}$$

$$x = 29.83973 \cdot 10^{-6}\text{ kg}$$

$$\frac{w}{29.83973 \cdot 10^{-6}\text{ kg}} = \frac{4500\text{birr}}{1\text{kg}}$$

$$w = 0.1343\text{birr for } 0.193\%\text{ Cr in one pin}$$

**Total cost for Cu Ni Cr per pin**

$$= 19.818\text{birr} + 4.694\text{E} - 02\text{birr} + 0.1343\text{birr}$$

$$= 19.999\text{birr for CuNiCr in one pin}$$

➤ **For Cu Si Ni (Cu=99%, Si=0.14%, Ni=0.503%)**

For copper

$$\frac{99}{100} = \frac{x}{15.461\text{gram}}$$

$$x = 15.30639\text{ gram}$$

$$1300\text{birr} = 1\text{kg}$$

$$= 15.3064 \cdot 10^{-3}\text{kg}$$

$$\frac{w}{15.3064 \cdot 10^{-3}\text{kg}} = \frac{1300\text{birr}}{1\text{kg}}$$

$$w = 19.898\text{birr for } 99\% \text{Cu in one pin}$$

For silicon

$$\frac{0.14}{100} = \frac{x}{15.461\text{ gram}}$$

$$x = 0.021646 \cdot 10^{-3}\text{kg}$$

$$\frac{w}{0.0216456 \cdot 10^{-3}\text{kg}} = \frac{6000\text{birr}}{1\text{kg}}$$

$$w = 0.12987\text{birr for } 0.14\% \text{ si in one pin}$$

For nickel

$$\frac{0.503}{100} = \frac{x}{15.461\text{ gram}}$$

$$x = 0.0778 \cdot 10^{-3}\text{kg}$$

$$\frac{w}{0.0778 \cdot 10^{-3}\text{kg}} = \frac{9200\text{birr}}{1\text{kg}}$$

$$w = 7.154\text{E} - 02\text{ birr for } 0.503\% \text{Ni one pin.}$$

**Total cost for Cu- Ni- Si per pin**

$$= 19.898\text{birr} + 0.12987\text{birr} + 7.154\text{E} - 02\text{ birr}$$

$$= 20.099\text{birr for CuNiSiCr in one pin}$$

➤ **For Cu Ni Si Cr (Cu=96.7 %, Ni=2.4%, Si=0.003 &Cr=0.077 %)**

For copper

$$\frac{96.7}{100} = \frac{x}{15.461 \text{ gram}}$$

$$x = 14.9507 \cdot 10^{-3} \text{ kg}$$

$$\frac{w}{14.9507 \cdot 10^{-3} \text{ kg}} = \frac{1300 \text{ birr}}{1 \text{ kg}}$$

w = 19.436 birr for 96.7% Cu in one pin

For nickel

$$\frac{2.4}{100} = \frac{x}{15.461 \text{ gram}}$$

$$x = 0.371 \cdot 10^{-3} \text{ kg}$$

$$\frac{w}{0.371 \cdot 10^{-3} \text{ kg}} = \frac{920 \text{ birr}}{1 \text{ kg}}$$

w = 0.34137 birr for 2.4% Ni in one pin

For silicon

$$\frac{0.003}{100} = \frac{x}{15.461 \text{ gram}}$$

$$x = 0.046383 \cdot 10^{-3} \text{ kg}$$

$$\frac{w}{0.046383 \cdot 10^{-3} \text{ kg}} = \frac{6000 \text{ birr}}{1 \text{ kg}}$$

w = 0.278298 birr for 0.003% Si in one pin

For chromium

$$\frac{0.077}{100} = \frac{x}{15.461 \text{ gram}}$$

$$x = 11.90497 \cdot 10^{-6} \text{ kg}$$

$$\frac{w}{11.90497 \cdot 10^{-6} \text{ kg}} = \frac{4500 \text{ birr}}{1 \text{ kg}}$$

w = 53.572365E – 03 birr for 0.077% Cr in one pin

**Total cost for Cu -Ni- Si- Cr per pin**

$$= 19.436 \text{ birr} + 0.34137 + 0.278298 \text{ birr} + 53.572365 \text{ E} - 03 \text{ birr}$$

$$= 20.11 \text{ birr for CuNiCr in one pin}$$

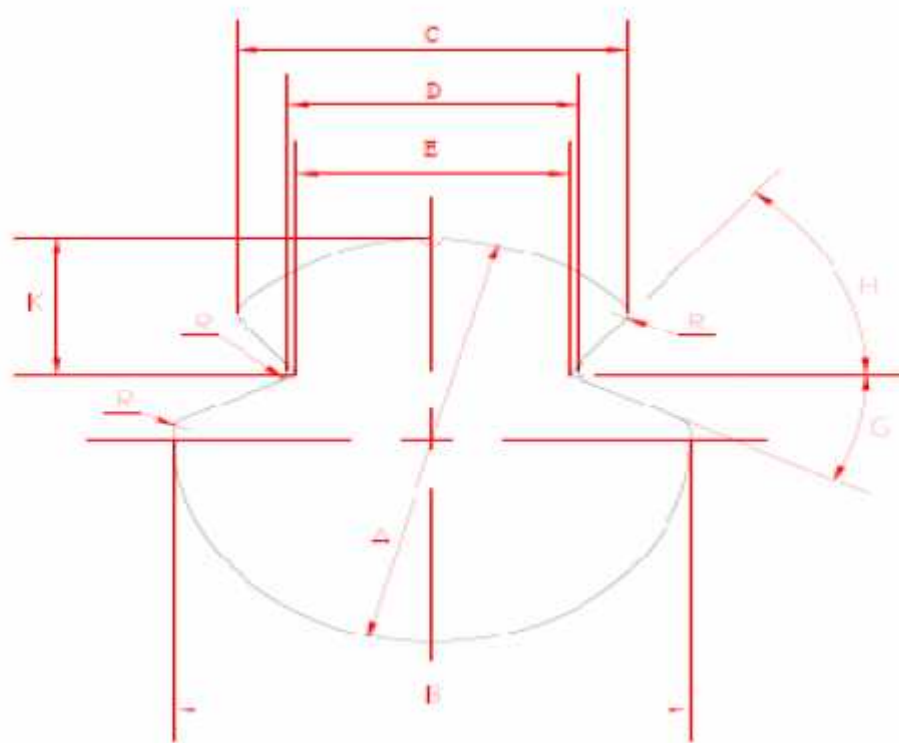
## 3.2. Specimen Dimension

Main dimensions of LRT contact wire as shown in table 3.8.

**Table 3.8:** Main sectional dimensions of LRT contact wire [28]

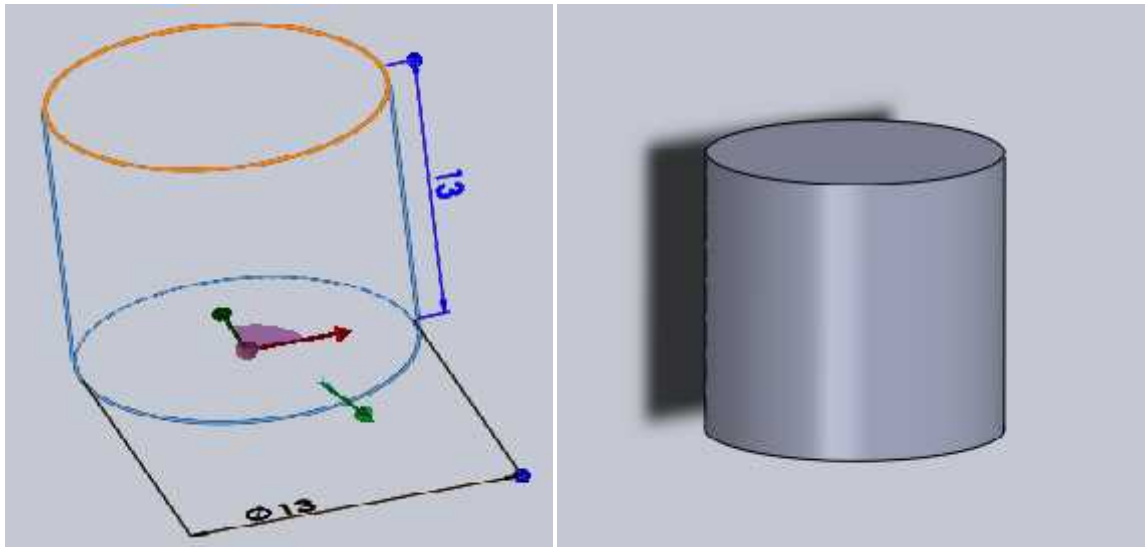
size Type	A(mm) ±1%	B(mm) ±2%	C(mm) ±2%	D(mm)+ 4% -2%	E(mm)	K(mm)	R(mm)	G(°)±1 °	H(°)±1°
150mm <sup>2</sup> Cu-Ag alloy contactwire	14.40	14.40	9.71	7.24	6.80	4.00	0.40	27	51

Schematic diagram and sectional dimensions of LRT contact wire



**Figure 3.6:** Schematic diagram of LRT copper alloy contact wire section [28]

For this experimental analysis since the internal diameter of pin holder is 13mm then the cylindrical specimens (CuNiCr, CuNiSiCr, CuNiSi) are prepared with a dimension of 13mm diameter and 13mm length.



**Figure 3.7:** Feature and dimension of the cylindrical test piece

### 3.3. Experimental Procedure and Condition

The experimental work with wear, corrosion and electrical conductivity testing were evaluated at Addis Ababa Institute of Technology in the department of Mechanical, Chemical and Electrical Engineering laboratory respectively but melting, machining process chemical composition, hardness testing were conducted on private industry and METEC.

#### Electrical conductivity test

After knowing the chemical composition and the hardness test the electrical conductivity test was conducted on Electrical and Computer Engineering Department at power research and development lab.

In this experiment because of the shortage of conductivity meter, at room temperature the resistance value of the four copper alloys measured with the help of multimeter from these values the resistivity and conductivity value of the alloys can be found.

#### Procedure for electrical conductivity test

- Measure the diameter and the length of the specimen by using caliper.
- Disconnect power source before testing.
- Turn the meter ON and press  $\square$  for Resistance Measurement.
- Insert two wires in the jacks Labeled V and COM..
- Measure the two wires resistance value in order to get the accurate value.

- Adjusting the specimen and connecting the two opposite sides to red meter Lead and black meter lead (positive and negative connection).
- Read the electrical resistance value of specimen on digital display.
- After three tests for each specimen take the average value by adding the resistance value of the wires.
- Finally after getting the resistance values from this the resistivity and conductivity value of the specimen can be calculated as follows.

1. Resistivity:- it is defined as resistance and area product per length

$$=RA/L$$

2. Conductivity:- conductivity is a reciprocal of resistivity

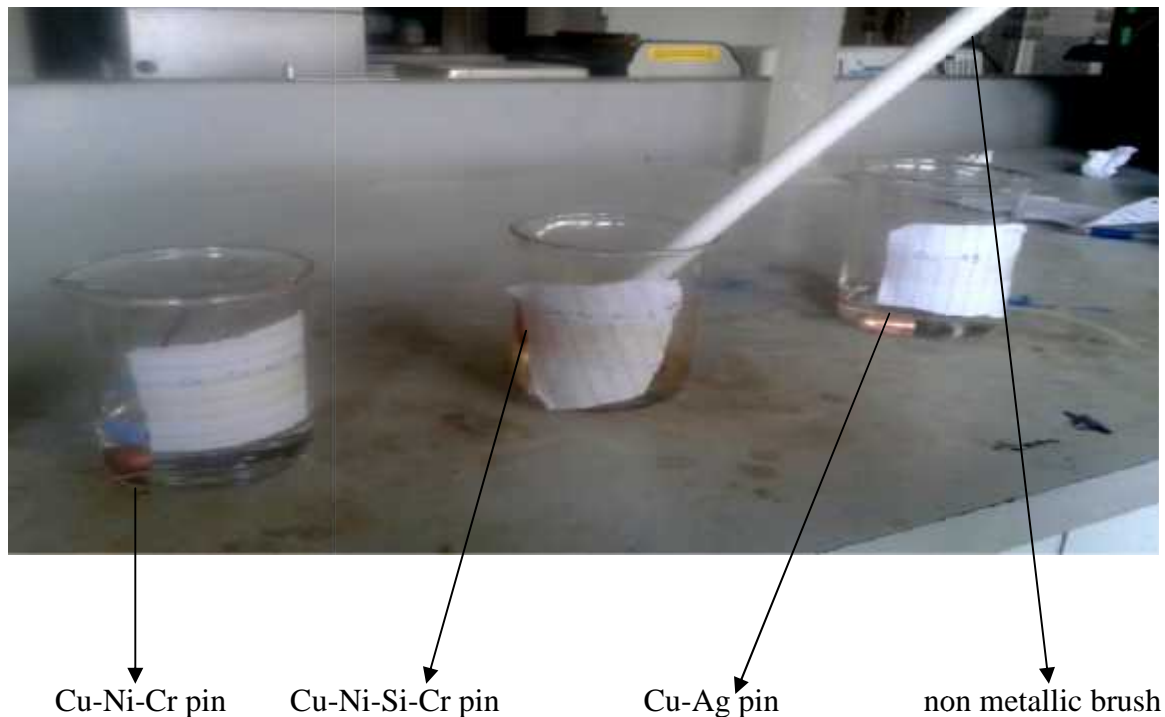
$$\text{Conductivity}=1/\text{resistivity}$$

$$k=1/$$

## Corrosion Test

Laboratory test for corrosion can also be performed by electrochemical test method. The test was conducted by corrosion studies kit and the corrosion resistance is calculated by gram loss.

Test piece of four copper alloy pins (Cu-Ni-Si-Cr, Cu-Ni-Cr, Cu-Ni-Si, Cu-Ag) are used for corrosion testing purpose. Each pin is marked with a unique identification code using a tagging process. Then the solution of 100ml tap water and 0.5 hydrochloric acid (HCl ) was prepared for cleaning process of pins. Each of pins washing under cold tap water and immersed in the specified cleaning solution shown in fig below in a 500-milliliter glass Vickers then the pins are cleaned in the appropriate solution. Following required immersion in the cleaning solution, the pins are removed from the solution.



**Figure 3.8:** Copper alloys in cleaning solution

**Table 3.9:** Cleaning procedure

Copper Alloys	Cleaning solution	Minutes	Temperature	Remark
Cu-Ni-Si-Cr	0.5% HCl & 100ml water	15	Room temperature	Follow with light scrub using non metallic brush
Cu-Ni-Cr	0.5% HCl & 100ml water	15	Room temperature	Follow with light scrub using non metallic brush
Cu-Ni-Si	0.5% HCl & 100ml water	15	Room temperature	Follow with light scrub using non metallic brush
Cu-Ag	0.5% HCl & 100ml water	15	Room temperature	Follow with light scrub using non metallic brush

Clean test piece are wiped with a lint free towel to remove surface water and suspended in a drying oven warmed to 103°C after this preparation of the test solution media conducted by mix 3.5% NaCl with 500ml tap water and prepare acid rain solution with 5PH finally prepare pure distilled water for stress test in each Vickers for each specimen.



**Figure 3.9:** Preparation of test solution media PH value and acid adding process.

Dry pins are removed from the oven, allowed to cool for about 15 minutes, and then weighed to the nearest tenth of a milligram. Finally the test pieces should be immersed and completely covered with solution and touching the bottom of the Vickers.



**Figure 3.10:** Test pieces in different test solution media.

#### Procedure for corrosion test

- Test piece of each alloy to be tested, are engraved with a unique identification code.

- Cleaned the specimen by Washing with 100ml distilled water and 0.5 Hydrochloric acid (HCl) for 15 minutes to remove grease and oxidation films.
- Dry the test specimens with warm oven for 30 minutes at maximum temperature of 103<sup>0</sup>C.
- Extract the specimens from the oven and insert into cooling jar.
- Fill the Vickers with 500ml of water.
- Preparation of test solution media by adding the wet or dry components to water. Make 3.5%NaCl solution, acid rain solution with 5PH and pure distilled water for stress test in each Vickers for each specimen.
- Each specimen is weighted by electronic balance before immersed in the solution and carefully labeled to later identify their initial weight.
- Insert each specimen in to the prepared solution media.
- Leave the specimen for 3 to 10 days.
- After the experiment has been completed, wash the specimen by HCl solution like before test and dry with warm oven and then reweighed.
- Put the gram difference which indicates the corrosion part.

### Test Conditions for Corrosion

In order to simulate acidic and costal environmental conditions the corrosion test was carried out with 3.5%NaCl solution, acid rain solution with 5PH and distilled water under room temperature, while the current supply to the solution ended constant throughout the test.

**Table 3.10:** Corrosion test condition

Copper alloys	Test Conditions		
	3.5%NaCl solution	Acid rain solution with 5PH	Distilled water
Cu-Ni-Si-Cr	3.5%NaCl &500ml water	HCl &500ml water with 5PH	Pure distilled water
Cu-Ni-Cr	3.5%NaCl &500ml water	HCl &500ml water with 5PH	Pure distilled water
Cu-Ni-Si	3.5%NaCl &500ml water	HCl &500ml water with 5PH	Pure distilled water
Cu-Ag	3.5%NaCl &500ml water	HCl &500ml water with 5PH	Pure distilled water

### Wear test

In laboratory tests, wear are usually determined by weight loss in a material and wear resistance is characterized by the loss in weight per unit area per unit time. The test was conducted on a machine called Pin on disc machine as shown in Figure 3.11.



**Figure 3.11:** Pin on disc tribometer when the pin slides on the disc.

The specimen was mounted on pin holder perpendicularly on the revolving disc. When the disc rotates for a particular period of time, the specimen can loaded at the top to press against the disc with the help of a lever mechanism. In this experiment the test can be conducted with the following parameters that are load, speed and time .Speed and time were kept constant while the load was varied from 3.5 N to 11 N.

For each of the sample, test was conducted for 3 times and the average of all the samples was taken as the observed values in each case. Once the parameter is set and work piece is mounted, the test is carried on for the desired time. The wear track so formed on the rotating disc is a circle. After each test only the mass loss of the specimen was considered as the wear.

The wear rate of each sample was calculated from the weight loss, the amount of wear is determined by weighing the specimen before and after the test using precession electronic weighing machine. Since the mass loss is measured it is converted to volume loss using the

density of the specimen. Hence wear resistance, wear volume and wear rate can be calculated as follows.

1. Wear rate:- It is defined as wear volume per unit time

$$\text{Wear rate} = \text{wear volume} / \text{time (h)}$$

$$w = \Delta v / t$$

$$w = \text{mm}^3 / \text{h}$$

2. Wear resistance:- wear resistance is a reciprocal of wear rate

$$\text{Wear resistance} = 1 / \text{wear rate}$$

$$R = 1/w$$

3. Wear volume:- Wear volume = 1000 weight loss / density

$$v = 1000 w / \rho$$

$$\text{Density of specimen} = \text{g} / \text{cm}^3$$

### Procedure for wear test

- Manufacture the copper alloys pin of diameter of 13mm and length of 13mm.
- Check the hardness and chemical composition of copper alloy pins.
- Weight the specimen by electronic weighing machine.
- Mount the specimen on pin holder perpendicularly on the revolving disc.
- Conduct the wear test using pin-on-disc tribometer at a constant sliding speed of 80km/h and at room temperature.
- With the help of a lever mechanism by applying normal load of 3.5N, 5.5N and 7.5N the copper alloy pins are forced to slide against stainless steel disc driven by an electric motor under unlubricated condition.
- For each of the copper alloy sample, test was conducted for 3 times and the average of all the samples was taken as the observed values in each case.
- The test is carried on for the desired time and after each test only the weight loss in (gram) of the specimen was considered as the wear.
- the amount of wear is determined by weighing the specimen before and after the test using precision electronic weighing machine.
- The worn surface and wear debris of the selected specimen analyzed by optical microscopy.

### Test Conditions for Wear

In this experiment the wear test was conducted with constant speed and time under unlubricated condition at room temperature and the load was varied from 3.5 N to 11 N. The wear test conditions of copper alloys are shown in Table 3.11.

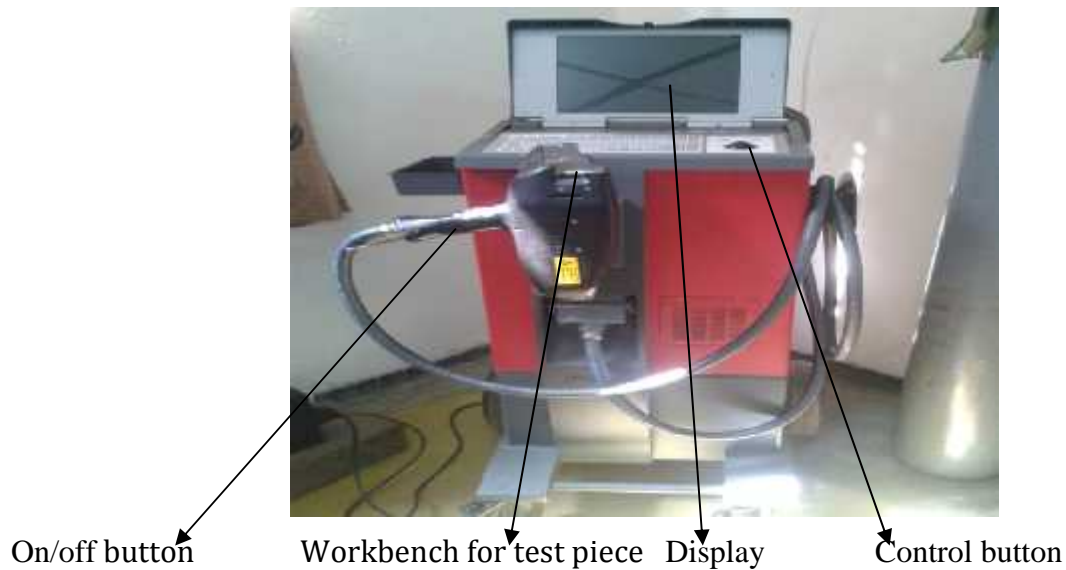
**Table 3.11:** Wear test condition

Test piece	Test Conditions				
	Speed [km/h]	Time minutes	Temperature	Presence of lubricants	Load [N]
Cu-Ni-Si-Cr	80	2	Room temperature	Unlubricated	3.5
					5.5
					7.5
Cu-Ni-Cr	80	2	Room temperature	Unlubricated	3.5
					5.5
					7.5
Cu-Ni-Si	80	2	Room temperature	Unlubricated	3.5
					5.5
					7.5

## 3.4. Experimental equipments used

### Spectrometer

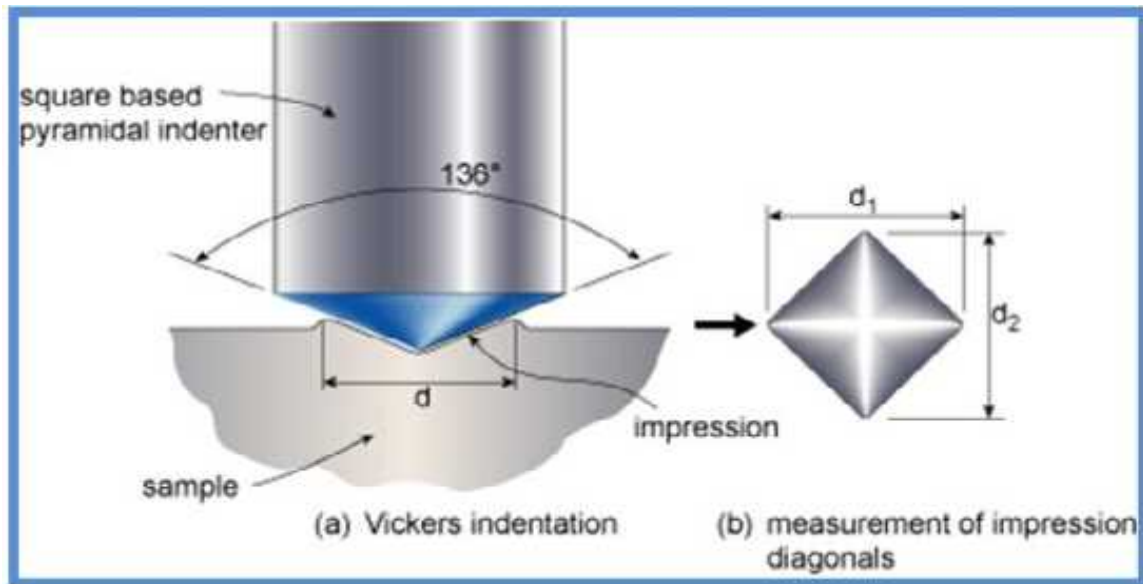
This is an advanced machine used to test chemical composition of the material here the system is computerized and the working principle is by using the buttons the system is restarted and waited about an hour until the spectrometer is refresh after that polish the specimen in order to have smooth surface finish and remove impurities and placing the test piece on bench by pressing the on button until the whole chemical composition is displayed after three testes the average value is taken. For this Experimental analysis the spectrometer which is found on Hebert manufacturing Industry shown in Figure 3.12 is used.



**Figure 3.12:** Spectrometer chemical composition test machine

### Vickers hardness testing machine

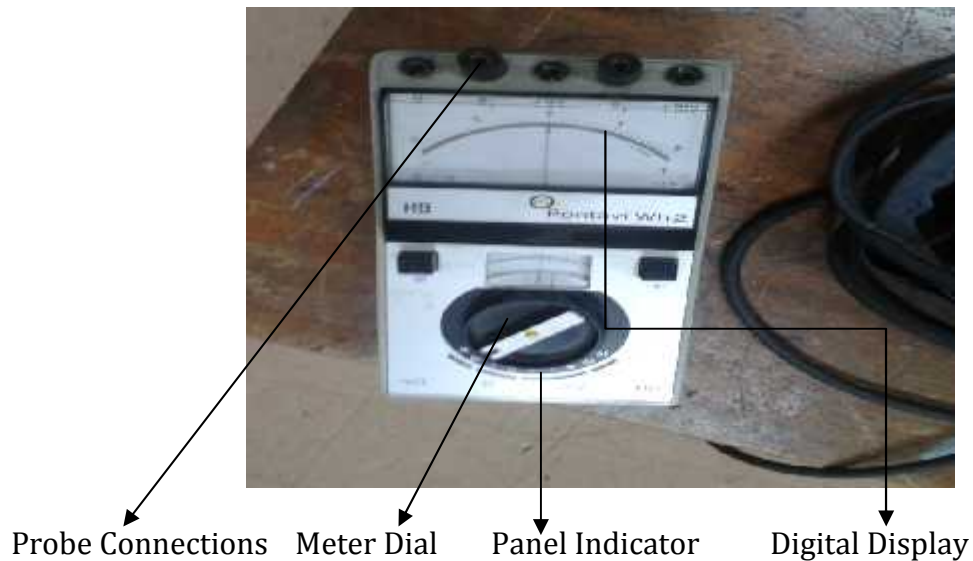
The Vickers hardness test uses a square-base diamond pyramid as the indenter and it is commonly used simple and inexpensive method. The hardness scale of Vickers can be used in all materials, from soft to hard ones and even for carbides. It can be also used both for micro- and macro hardness where A sample is placed in the machine and a pyramidal indenter is pushed with a certain load against the surface of the sample [26].



**Figure 3.13:** Vickers hardness test machine working principle [26].

## Multimeter

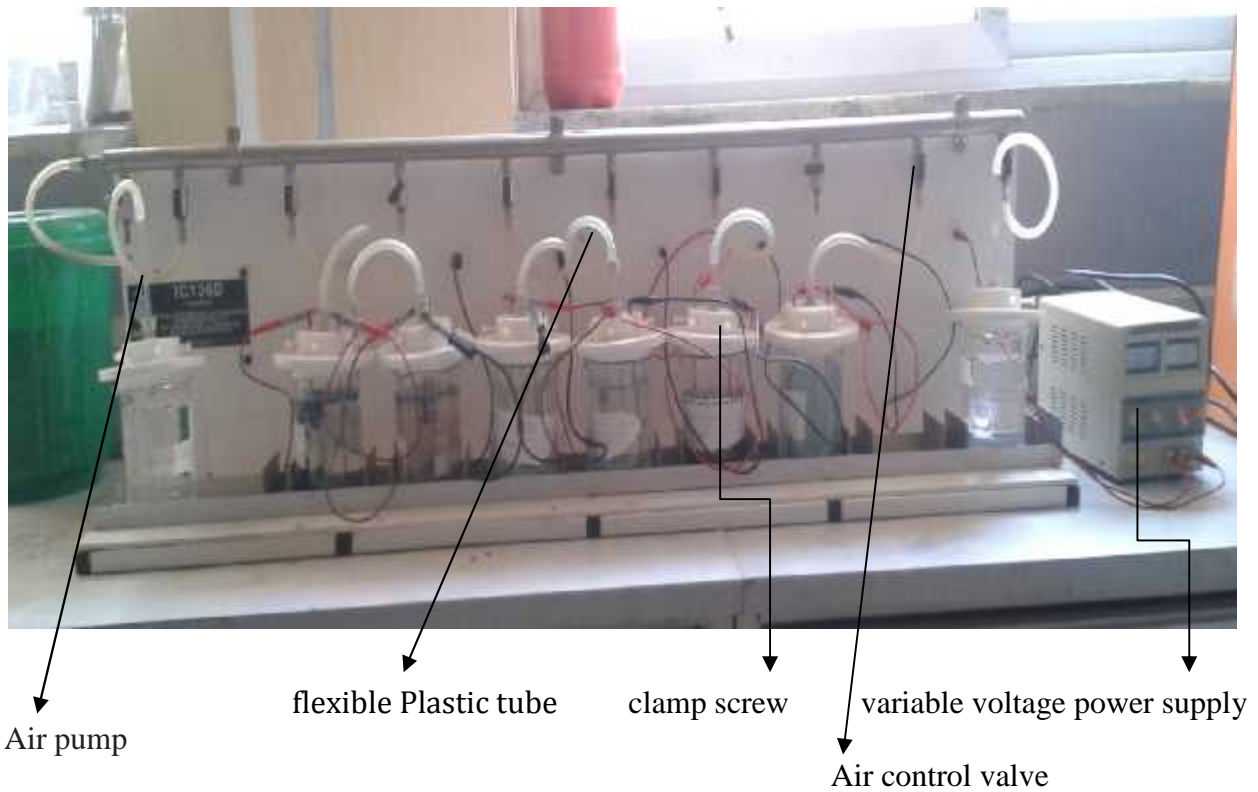
A multimeter is a device used to measure voltage, resistance and current in electronics & electrical equipment. Here for Resistance Measurement first turn the meter ON and press  $\Omega$  and insert two wires in the jacks labeled V and COM. For this experiment the multimeter which is found on Electrical engineering power and research lab shown in Figure 3.14 is used to measure the resistance of a copper alloys.



**Figure 3.14:** Multimeter for electrical resistance value measurement

## Corrosion Study Kits

The Corrosion Study Kits has been designed for students demonstration on how potentially corrosive situations may be recognized and avoided using a simple equipment consisting of a series of test cells. Although the experiments refer principally to steel-water systems, the apparatus is also suitable as a test bench for other chemical systems. The equipment allows for a simultaneous study of up to eight corrosion cells on various materials [25]. All connecting glass and plastic tubing is provided, as are the appropriate supports for the specimens and glass test cells. In this paper for the study of electrochemical corrosion effects the corrosion study kits which is found on Environmental lab shown in Figure 3.15 is used. Voltage supply is included together with all necessary electrical connections.



**Figure 3.15:** Corrosion study

### PH Meter

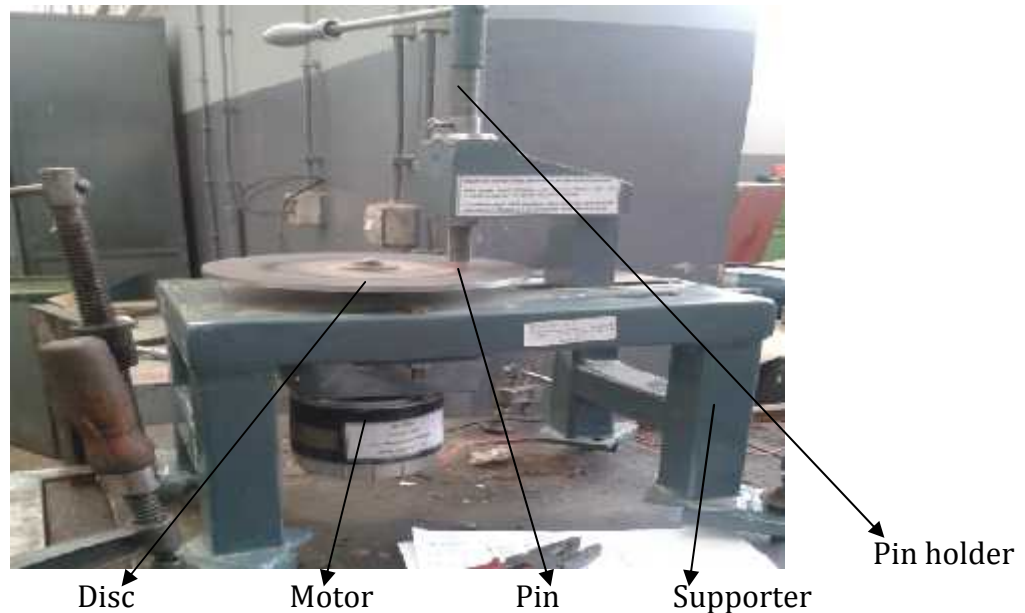
PH meter is an instrument used to read the ph value of the solution. A pH meter is supplied to ensure the correct strength of initial test solutions. In this paper in order to read the PH value of acid rain solution with PH5 the PH meter which is found on Environmental lab shown in the Figure 3.16 is used.



**Figure3.16:** PH meter

### Pin on disc tribometer

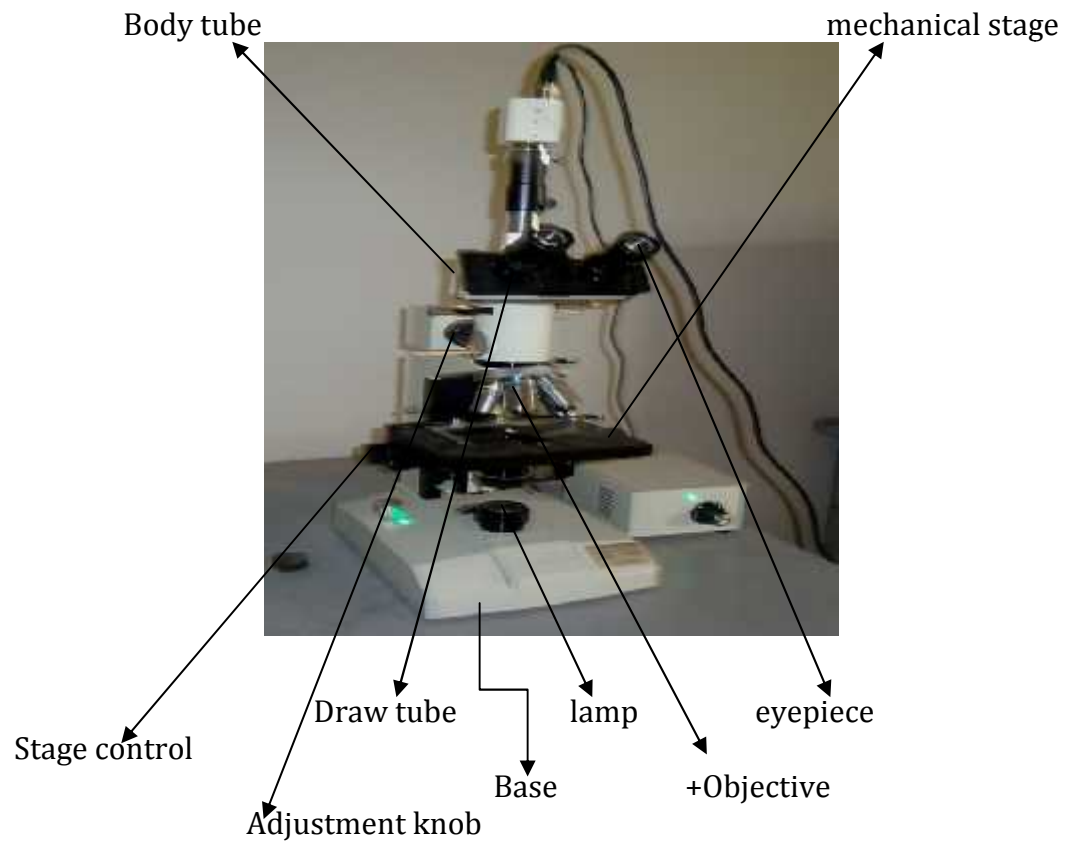
A tribometer is a machine or device used to perform tests and simulations of wear, friction and lubrication. Often tribometers are extremely specific in their function and are fabricated by manufacturers who desire to test and analyze the long-term performance of their products [27]. In this paper in order to test and analyze the wear resistance of the copper alloys the tribometer which is found on mechanical work shop shown in Figure 3.17 is used. The working principle of this tribometer is simply the copper alloy pin mounted on pin holder perpendicularly to the revolving disc and forced to slide against the revolving disc which is driven by an electric motor.



**Figure 3.17:** Pin on disc tribometer

### Optical microscope

Optical microscope is an instrument which is used to magnifying the worn part of the test piece. The eyepiece and objective are responsible for magnifying the image of the specimen and projecting it on to the viewer's retina or onto the film plane in a camera and the job of the condenser lens is to focus a cone of incident light on to the specimen. An illumination system or an external artificial light may direct towards the condenser lens. There is a movable stage which holds the specimen in the optical path and allows the specimen to be moved in and out of the focal plane and even left, right and rotated about the optic. For this experimental analysis the worn surfaces of copper alloy pins were analyzed by optical microscope which is found on mechanical workshop shown in Figure 3.18 is used.



**Figure 3.18:** A schematic representation of the Optical Microscope.

## CHAPTER FOUR

### RESULTS AND DISCUSSIONS

#### 4.1. Result

For wear, corrosion, electrical conductivity test and cost analysis there are some outputs from the experimental and cost analysis. The results found are mentioned below.

##### For wear

From wear test conducted on pin on disc tribometre, in wear truck radius of 70mm at rotational velocity of 5898rpm with the applied force of 3.5 N, 5.5N and 7.5N. The values of weight loss, volume loss, wear rate and sliding wear resistance for copper alloys after 2 minutes or 0.0333h are shown in tables below.

(a)

Material	Specimen gram		weight loss $\Delta w$ (in gram)
	Before test	After test	
Cu-Ni-Si	14.1	14.097	0.003
Cu-Ni -Cr	16.2	16.198	0.0019
Cu-Ni-Si -Cr	13.6	13.599	0.0012
Cu-Ag	16.4	16.396	0.0038

(b)

Material	Specimen gram		weight loss $\Delta w$ (in gram)
	Before test	After test	
Cu-Ni-Si	13.2	13.155	0.045
Cu-Ni -Cr	14.1	14.056	0.044
Cu-Ni-Si-Cr	16.87	16.828	0.042
Cu-Ag	17.8	17.751	0.049

(c)

Material	Specimen in gram		Weight loss $w$ (in gram)
	Before test	After test	
Cu-Ni-Si	14.26	14.197	0.0621
Cu-Ni -Cr	16.21	16.1516	0.0584
Cu-Ni-Si -Cr	13.8	13.753	0.047
Cu-Ag	16.86	16.762	0.098

**Table 4.1:** Copper alloy pins weight loss after wear test for applied load of (a) 3.5 N (b) 5.5 N and (c) 7.5

**Table 4.2:** Volume loss and Wear rate of copper alloys

Material	volume loss $v$ (in $\text{mm}^3$ ) $V = 1000 W/t$			wear rate $w$ (in $\text{mm}^3/\text{h}$ ) $W = V/t$		
	Applied load in [N]					
	3.5	5.5	7.5	3.5	5.5	7.5
Cu-Ni-Si	363.2	5447.9	7518.2	10906.9069	163600.6006	225771.7718
Cu-Ni -Cr	226.2	4977.4	6606.3	6792.79279	149471.4715	198387.3874
Cu-Ni-Si-Cr	113.6	4772.7	5340.91	3411.4114	143324.3243	160387.6877
Cu-Ag	513.5	6621.6	13243.2	15420.42042	198846.8468	397693.6937

**Table 4.3:** Wear resistance of copper alloys under different load application

Material	wear resistance $R$ (in $\text{h} / \text{mm}^3$ ) $R = 1/W$		
Applied load	3.5N	5.5N	7.5N
Cu-Ni-Si	9.2E-05	6.1E-06	4.4E-06
Cu-Ni -Cr	1.5E-04	6.7E-06	5.0E-06
Cu-Ni-Si -Cr	2.9E-04	6.9E-06	6.2E-06
Cu-Ag	6.5E-05	5.0E-06	2.5E-06

### For Corrosion

The corrosion test was conducted on corrosion test kits for successive eight days with 3.5% NaCl, acid rain solution and with distilled water. The gram of test piece before and after the test also weight loss in gram is shown in table below.

**Table 4.4:** Weight loss of the pins after corrosion test

Corrosion medias with 21% oxygen	Copper alloys			
	Cu-Ni Si-Cr	Cu-Ni-Si	Cu-Ag	Cu-Ni- Cr
	Gram of test piece before corrosion			
3.5 % Nacl	16.05	13.83	16.61	15.84
PH5 Acid rain	14.10	14.22	16.9	16.23
Pure distilled water	16.2	13.81	16.7	14.26
	Gram of test piece after corrosion			
3.5 % Nacl	15.94	13.63	16.312	15.74
PH5 Acid rain	13.635	13.674	16.054	15.765
Pure distilled water	16.1899	13.7969	16.686	14.2566
	Weight loss after corrosion in gram			
3.5 % Nacl	0.11	0.2	0.298	0.100
PH5 Acid rain	0.465	0.546	0.846	0.456
Pure distilled water	0.0101	0.0131	0.014	0.0034

## For Electrical Conductivity

Because of shortage of conductivity meter the value of the conductivity found by indirect method. The resistance value measured by multimeter from that the value of the resistance, resistivity and electrical conductivity are shown in Table 4.5.

**Table 4.5:** The value of resistance, resistivity and electrical conductivity

Material	Resistance value in m $\Omega$	Resistivity value in cm $\Omega$	Conductivity value in IACS
Cu-Ag	10	$1.0210 \times 10^{-2}$	97%
Cu-Ni-Si	12	$1.2252 \times 10^{-2}$	82%
Cu-Ni-Cr	13	$1.3273 \times 10^{-2}$	75%
Cu-Ni-Si-Cr	17	$1.8315 \times 10^{-2}$	57%

## Cost analysis

For comparison purpose, the cost of each raw material taken from Agica Ethiopia, Micron international trading house PLC, Niway PLC and the result of the analysis that is the cost of each material per one pin are shown in table 4.6.

**Table 4.6:** The four copper alloy material cost per one pin

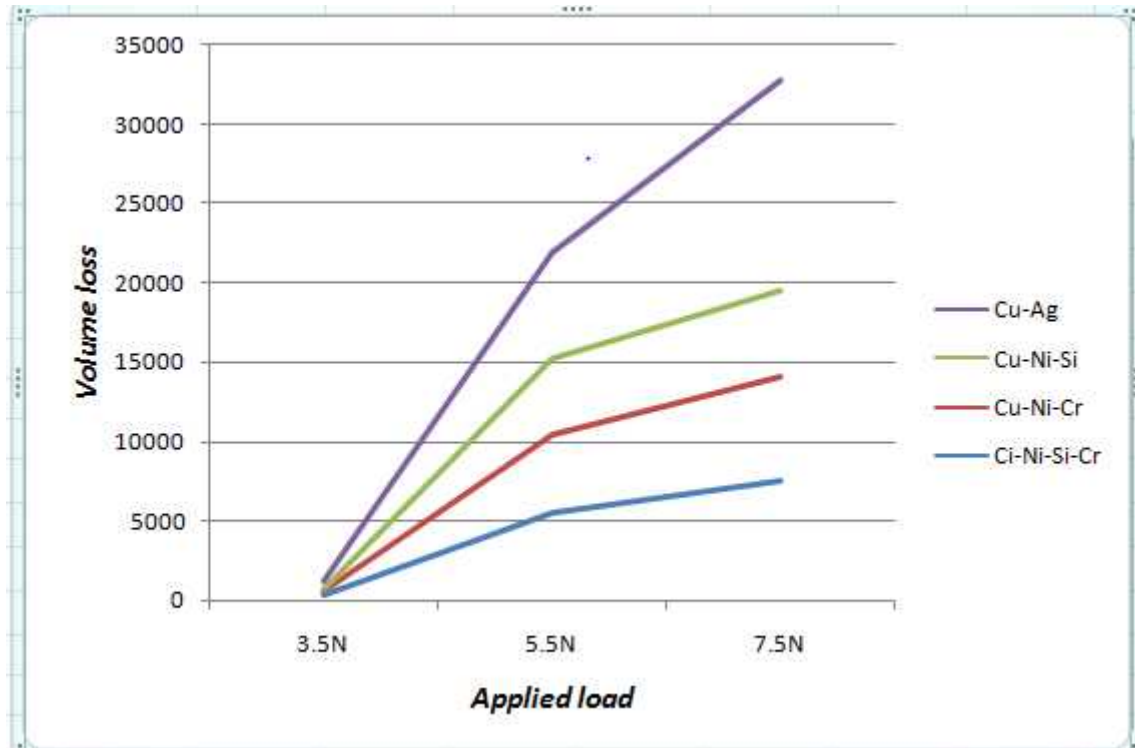
Copper alloy material	Cost (birr) in one pin
Cu-Ag	20.928
Cu-Ni-Si-Cr	20.11
Cu-Ni-Si	20.099
Cu-Ni-Cr	19.999

## 4.2. Discussion

### 4.2.1 Sliding Mechanical Wear Behavior

The plot of volume loss with normal load for copper alloys under constant velocity and time is shown in Fig 4.1. The volume loss of copper alloys increases with applied load and the copper alloy Cu-Ag has highest volume loss. The plots of wear resistance and wear rate with different normal forces under constant velocity and time are shown in Fig.4.2 and Fig .4.3 respectively. Among the copper alloys Cu-Ni-Si -Cr has highest wear resistance followed by Cu-Ni-Cr and Cu-Ni-Si. Cu-Ag possesses the lowest wear resistance. The ranking of sliding wear resistance at

3.5N, 5.5N and 7.5N and at constant velocity in descending order is; CuNiSiCr>CuNiCr>CuNiSi>CuAg. Cu-Ag has highest wear rate followed by Cu-Ni-Si. The copper alloy Cu-Ni-Si-Cr has lowest wear rate. Addition of elements such as Cr, Ni and Si to copper significantly improves the hardness and hence the wear resistance also increases. Compared with CuAg, the wear resistance was increased by 3 and 2 times for CuNiSiCr, and CuNiCr respectively. In general, the wear resistance of the Cu based alloys increases with the increase in hardness.



**Figure 4.1:** Plots of Volume loss with applied load

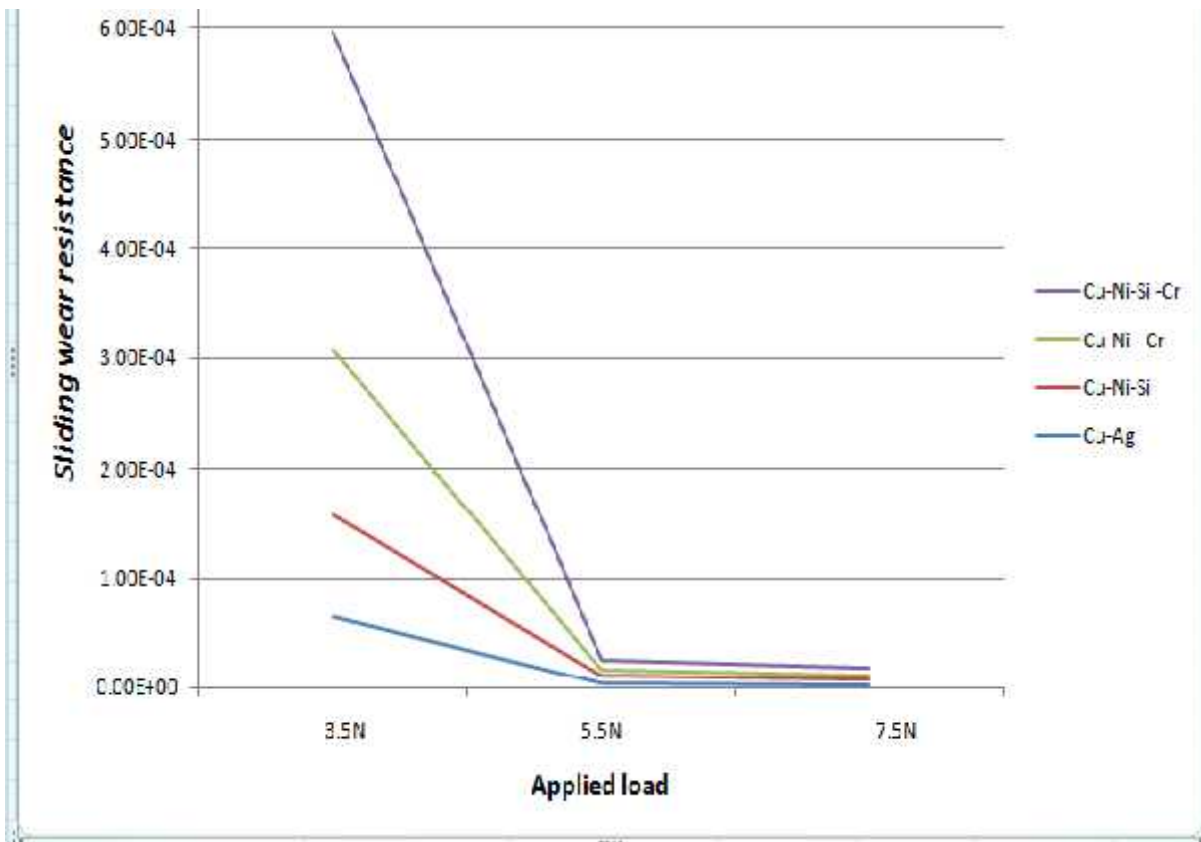


Figure 4.2: Plots of sliding wear resistance of each material versus applied load

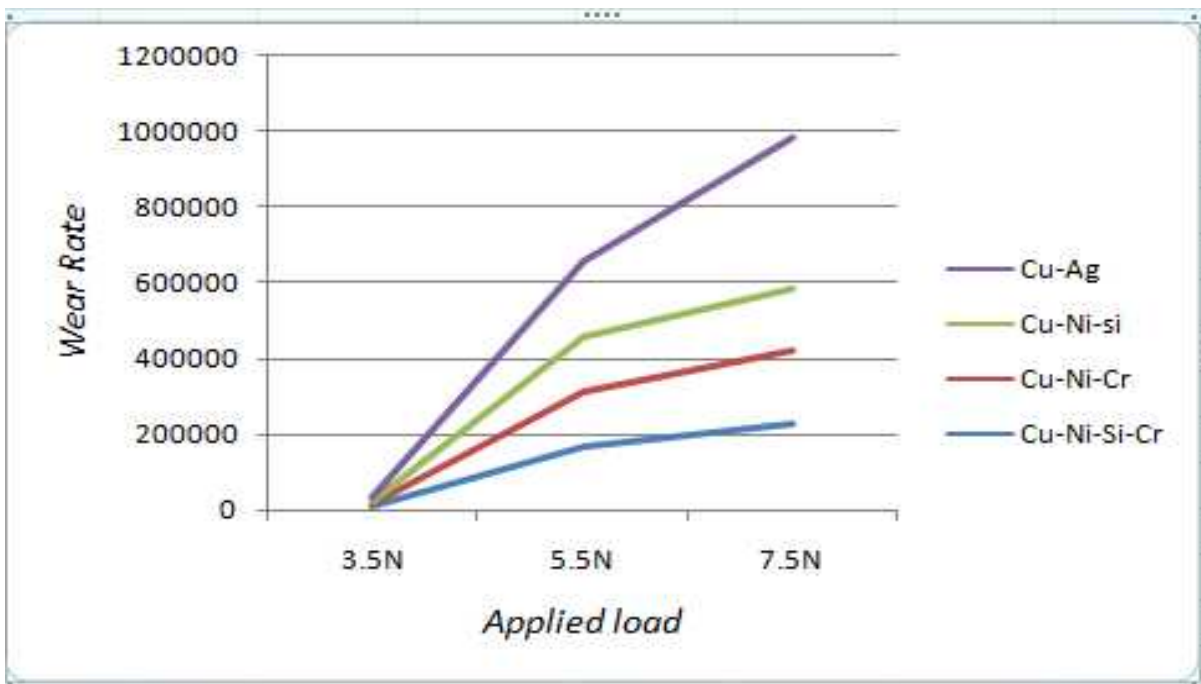


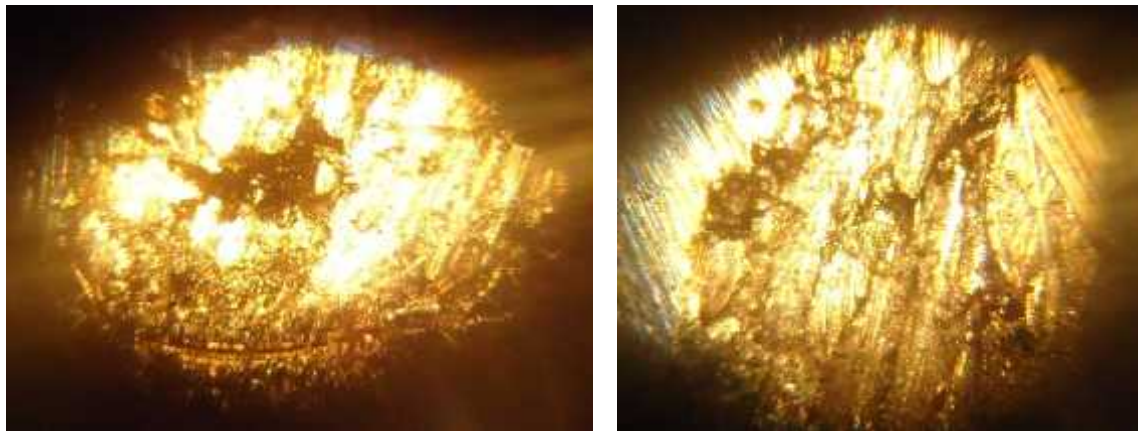
Figure 4.3: Plots of Wear rate versus applied load

### **4.2.2 Effect of Normal Force**

The above figures shows the plots of wear rate, wear resistance with normal force at constant velocity. The effects of normal force on the wear rate  $W$  and wear resistance  $R$  without current can be described. The wear rate is greater and increases with normal force but the wear resistance of the alloys decreases with increase normal load.

### **4.2.3 Mechanism of Sliding Wear**

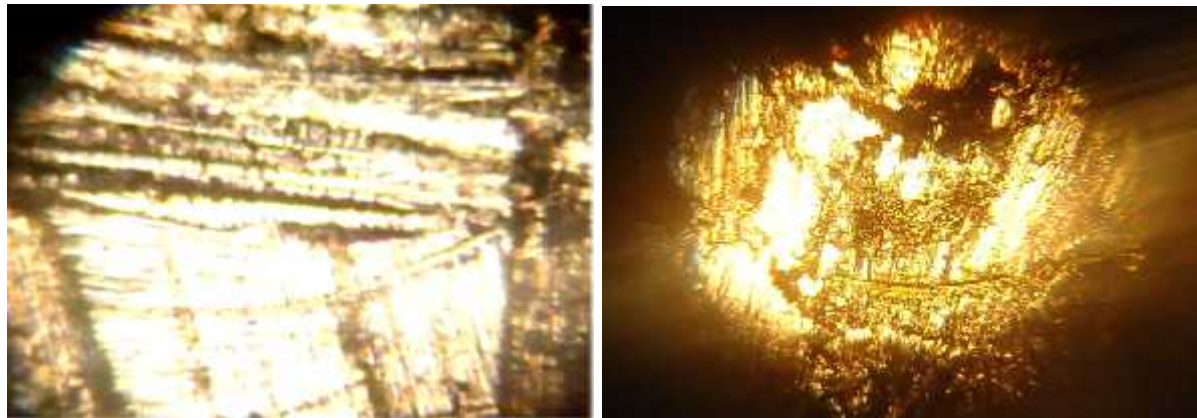
The worn surfaces of the specimens were observed by optical microscope. Figure below show the worn surface of copper alloys without the electrical current under load of 3.5N, 5.5N and 7.5N at the sliding speed of 80km/h for 2 minute respectively. Friction is the main factor of mechanical wear when the alloys slide without electric current which includes abrasive, adhesive wear mechanism. Under dry sliding conditions, friction between the specimens and the disc favored oxidation with increased surface temperature and causes thermal softening of the oxides and the substrate. For abrasive wear, the harder body plastically deforms the softer body. Here stainless steel disc plastically deforms the copper alloy pins. Copper alloys and its oxide are removed with the formation of microchips, there by producing scratches on the softer surface. The presence of parallel and continuous scratches in the direction of motion observed on the surface is due to the action of the worn particles. On micro-scale, asperities of the harder surface press into the softer surface, with plastic flow of the softer surface occurring around the harder asperities. The repeated sliding contact between the disc and pin results in the fracture of the oxide film, which formed between the interfaces. The detached mixture of metal and oxide debris acts as the hard abrasive and causes abrasive wear. For adhesive wear, the asperity junction of the sliding surfaces of counterparts under normal contact force adhered together. Successive detachment from the surface of the weaker part resulted in loss of material. Here also there were small chips on the surface of disc.



(a)

(b)

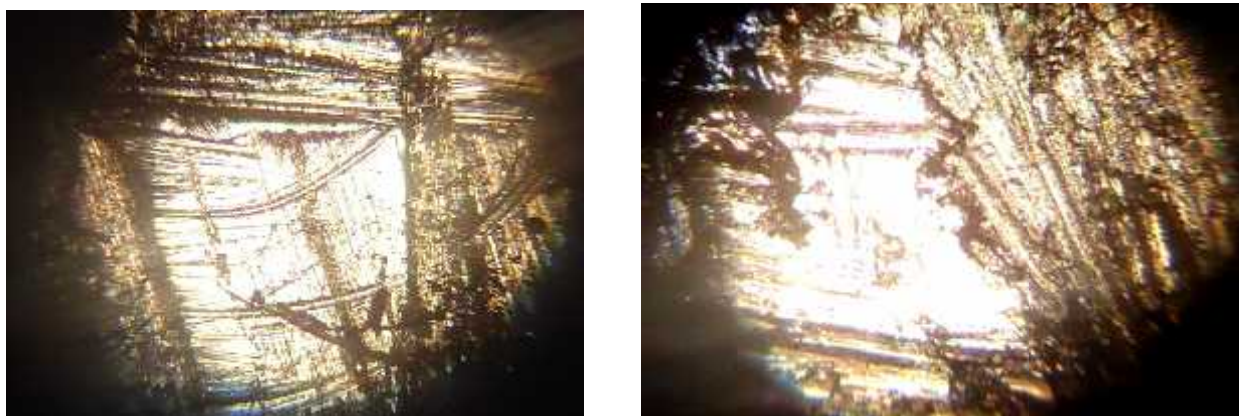
**Figure 4.4:** worn surfaces of Cu-Ag with load of (a) 5.5N and (b) 7.5 N and with 10x100 macroscopic images by optical/metallurgical microscope.



(a)

(b)

**Figure 4.5:** Worn surfaces of (a) CuNiSi and (b) CuNiSiCr with load of 7.5N .With 10x100 macroscopic images by optical/metallurgical microscope.



(a)

(b)

**Figure 4.6:** Worn surfaces of CuNiCr with load of (a) 5.5N and (b) 7.5N .With 10x100 macroscopic images by optical/metallurgical microscope.

In this Experiment, for the harder material which is CuNiSiCr, the size of the wear debris is much smaller as shown from the figure 4.5 (b) and the smaller wear particles were removed from the CuNiSiCr specimen after the wear test and a lower degree of scratch is observed. CuNiCr has also a good wear resistance the size of the fragment is small as shown in Fig 4.6 (b) so CuNiCr harder compare to CuNiSi and Cu-Ag.

#### 4.2.4 Corrosion Behavior

In order to simulate coastal and acidic environment effect on copper alloys, in addition to this to see the interaction of corrosion and mechanical stress to produce a failure by cracking, the corrosion test was conducted with 3.5%Nacl solution, acid rain solution and distilled water for stress corrosion. The gram difference of the pins taken as the corrosion part that means the high weight loss indicates the high corrosion rate. The plots of weight loss in grams with corrosion media are shown Figure 4.7. From the ranking of corrosion resistance for the above corrosion media, Cu Ag is highly corroded followed by CuNiSi. Cu-Ni-Cr has highest corrosion resistance. The corrosion effect is highest at acid rain solution followed by 3.5% Nacl solution.

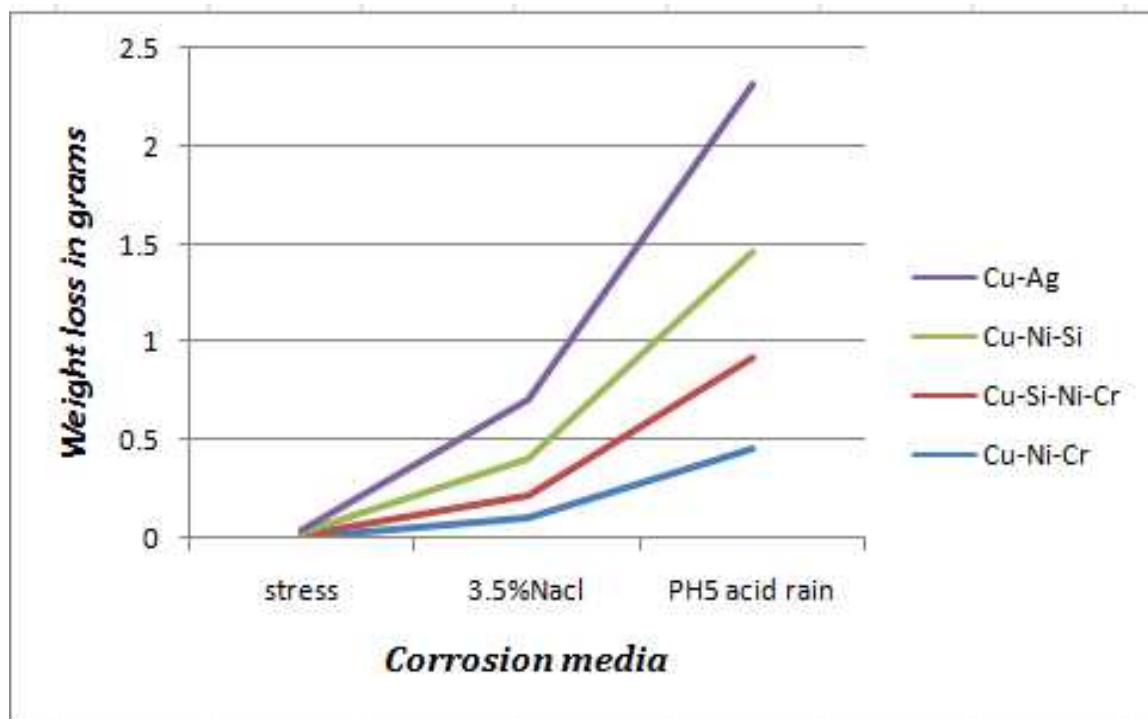
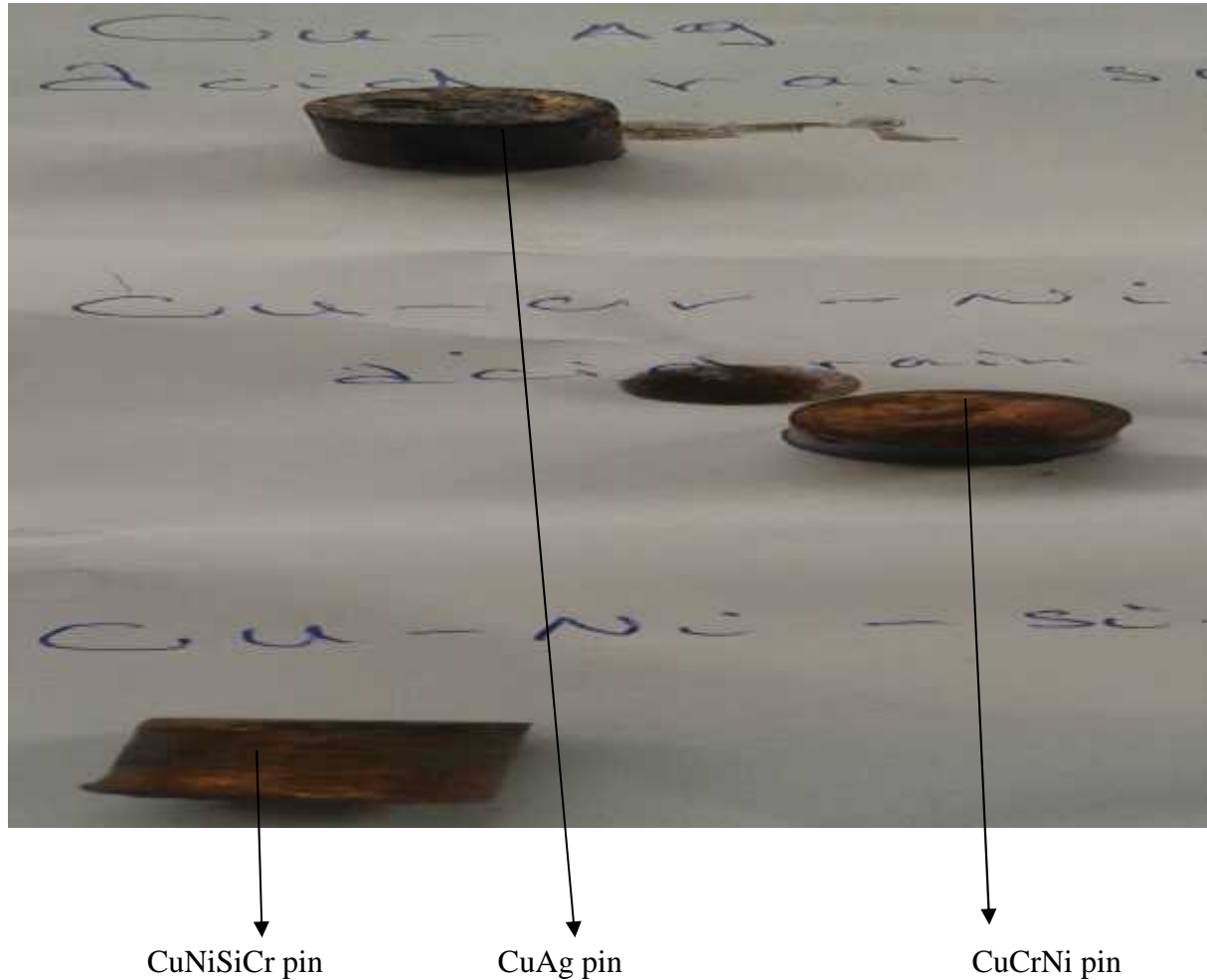


Figure 4.7: Plots of Corrosion media versus weight loss in gram.

#### Picture of corroded specimen in each media

The test pieces are embedded for eight days in different corrosion media after that the test pieces extract from each solution and the corroded specimen at different solution are shown in Figure 4.8 and Cu-Ag is highly corroded.



**Figure 4.8:** Corroded specimen of copper alloys at acid rain corrosion media

### 4.2.5 Electrical Conductivity

The electrical conductivity test is performed with multimeter by measuring the resistance value from that the resistivity value is gained the reciprocal of resistivity is conductivity from the figure 4.9, the electrical conductivity is high in Cu-Ag and low in Cu-Ni-Si-Cr.

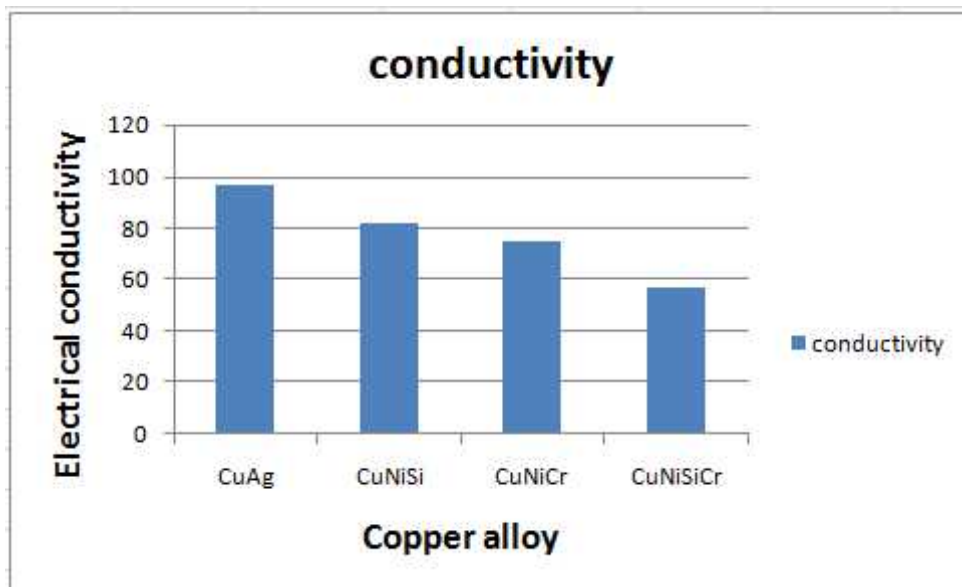


Figure 4.9: Copper alloys versus conductivity value.

#### 4.2.6 Cost of each Material per One Pin

The cost of each material per one pin is calculated that is cost of the pin is just its mass times the cost per Kg of the material of which it is made from. The figure below shows the Cu- Ni -Cr copper alloy takes less cost from others.

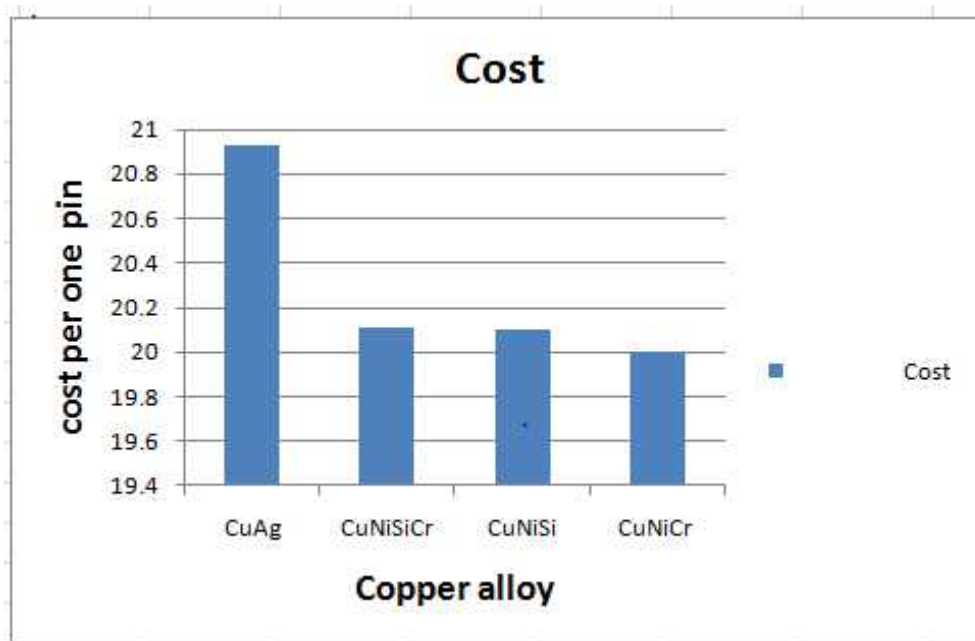


Figure 4.10: Copper alloys versus cost per one pin.

## Selecting an Appropriate Material for ERC Overhead contact wire.

Overhead contact wire used for electrical transmission should have the following properties:

- High electrical conductivity.
- High wear resistance in order to withstand the mechanical loading.
- High corrosion resistance since it is exposed to environmental condition.
- Low cost so that it can be used for long distances.

All the above requirements are not found in a single material therefore, while selecting a conductor material for a particular case a compromise is made between the required mechanical properties, electrical conductivity and cost so by using selection matrix the appropriate material for ERC over head contact wire is selected. Both mechanical and electrical considerations have to be acknowledged when selecting material of the contact wire. The copper alloys with the higher strengths have lower conductivity and wear rate. So wear rate and conductivity have direct relationship but wear resistance and electrical conductivity have inverse relation .As the wear rate increase the durability of the wire decrease that means the maintenance cost increases. Copper and its alloy have good electrical conductivity property but even if it is the highest conductive material it should have good wear and corrosion resistance because fretting wear and corrosion can largely reduce the electrical conductivity of contact materials .As discussed in the literature part the maximum consideration is given to sliding wear resistance in order to maximize the service life of the contact wire .The researchers investigate the sliding wear and corrosion resistance of six age hardened copper alloys with lab testing machine finally on consideration of wear resistance, electrical conductivity and corrosion resistance, they recommend the material which have high corrosion, medium wear resistance and electrical conductivity is an appropriate material as the contact wire . In addition to all the above reasons the objective of this research is to develop the overhead contact wire material which have better wear and corrosion resistance to that of the current AALRT contact wire so from contact wire material selection criterion wear resistance takes the first place or highest weight .electrical conductivity is also a critical property for consideration as electrical contact materials because the higher electrical resistance causes rapid heat-up and softening and results in higher wear loss so electrical conductivity takes the second place .Since overhead contact wire exposed to environmental conditions ,corrosion resistance is also considered last cost. From the selection

matrix below Cu Ni Cr has highest score so that it best meets the criteria that is it is appropriate for Addis Ababa light rail train overhead contact wire.

**Table 4.7:** Selection matrix

Criteria	weight	Cu Ni Cr		Cu Ni Si Cr		Cu Ni Si		Cu Ag	
		Rating	Score	Rating	Score	Rating	Score	Rating	Score
Wear resistance	4	2	8	3	12	2	8	1	4
conductivity	3	2	6	1	3	2	6	3	9
corrosion	2	3	6	2	4	2	4	1	2
Cost	1	3	3	2	2	2	2	1	1
Total	10	10	23	8	21	8	20	6	16

Rating: 3=high

2= medium

1=low

Finally, results of the analysis are summarized in table and discussed based on the outputs of the experimental analysis. Graphically the copper alloys are compared for each case. To elaborate the gap between all of this and to compare the aggregate values the radar diagram is used .Figure 4:10 shows the cumulative value of the results from that the weight loss and the cost has negative value that means the higher the weight loss the lower corrosion resistance and also the higher the cost is expensive here Cu-Ag has higher weight loss and cost. The sliding wear and the electrical conductivity has positive value that means the higher wear resistance means the lower wear rate and the higher conductivity means the lower power loss.

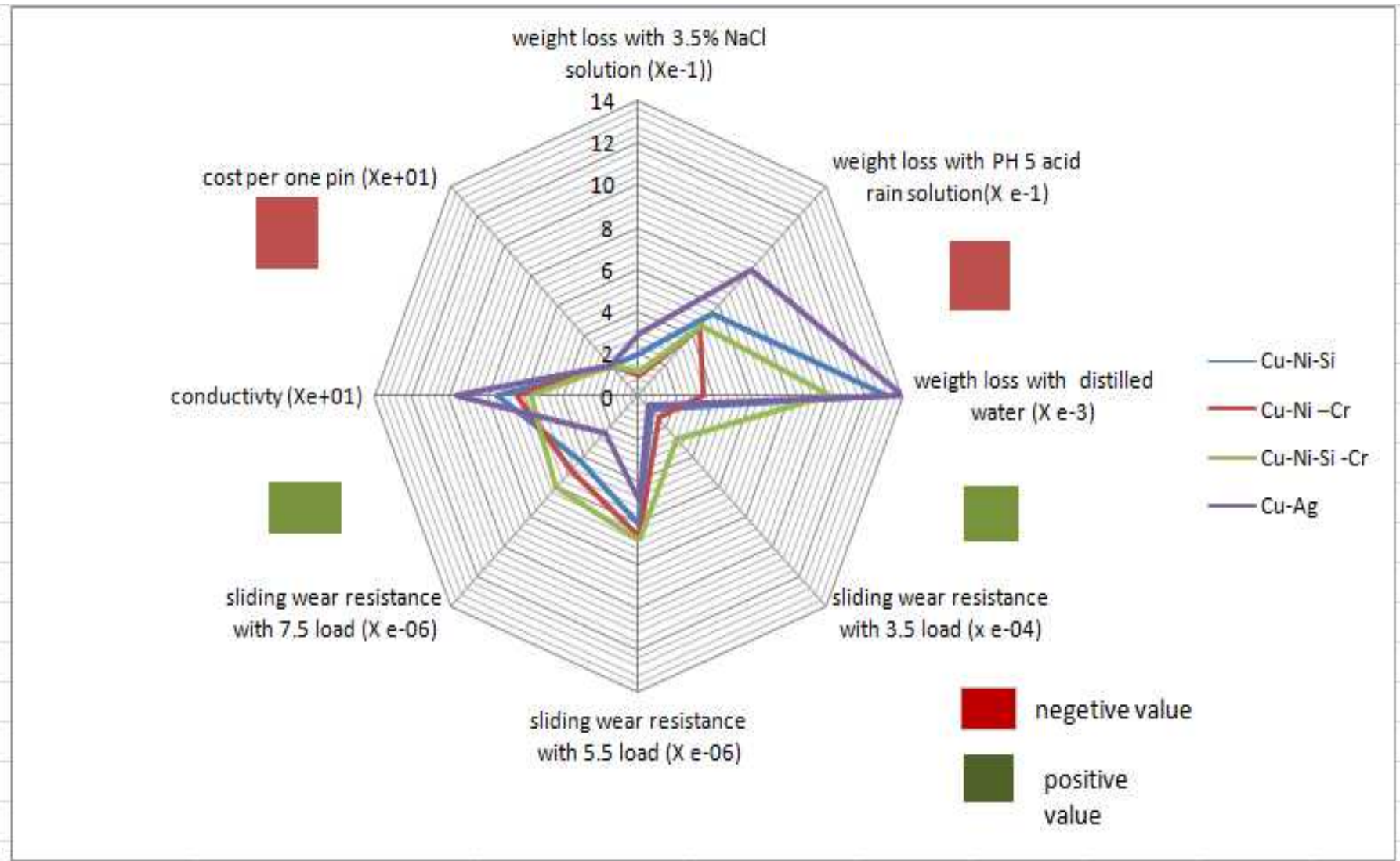


Figure 4.10: Radar diagram to compare the cumulative value

## CHAPTER FIVE

### CONCLUSION, RECOMMENDATION AND FUTURE WORK

#### 5.1. Conclusion

Based on the laboratory test results, the investigation into the electrical conductivity ,the behavior of wear generated by sliding friction (mechanical wear) under conditions of varying normal load and constant sliding speeds and the corrosion behavior of copper alloys under 3.5% NaCl solution, acid rain solution and distilled water by electrochemical method finally have led to the following conclusions.

- The wear resistance of the copper-based alloys increases with decrease in normal load .
- The ranking of sliding wear resistance in descending order is:  
CuNiSiCr>CuNiCr>CuNiSi>CuAg.
- Adhesive wear and abrasive wear are the wear mechanisms during the mechanical sliding which results in metal transfer, removal, debris generation and surface deterioration.
- Addition of elements such as Cr, Ni and Si to copper improves wear resistance, corrosion resistance and reduces electrical conductivity. So among the alloys, CuAg has highest electrical conductivity and lowest wear and corrosion resistance.
- Among the alloys, CuNiCr has the highest corrosion resistance and also take less purchase cost.
- Among the corrosion media, High corrosion effect observed in PH5 acid rain solution.

#### 5.2. Recommendation

Based on consideration of wear resistance ,electrical conductivity, corrosion resistance and each material purchase cost from decision matrix end result Cu Ni Cr is appropriate as the overhead contact wire material for Addis Ababa light rail project and future national railway additionally by making further investigation with the application of electric current, Addis Ababa light rail project can use this overhead contact wire .Also from corrosion test result at

acidic solution the corrosion effect is high so in order to promote safety issue that related to corrosion failure of overhead contact wire while implementing the project it is necessary to suggest to have protected environment beyond the contact wire material property.

### **5.3. Future Work**

During the material development process and experimental analysis of the copper alloys, there are a lot of problems to be solved. On the other hand, because of the shortage of facilities for material development and experimental investigation purpose this paper is limited to develop the materials with Cu, Ni, Si, Cr and conduct its experimental analysis for wear test at constant velocity without electric current under applied load below 11N.

Finally, some suggestions are listed below for future work as extension and continuity of this paper.

- Increase the pin on disc tribometer machine motor capacity and generate a constant electric power supply mechanism for pin and rotating disc to conduct the wear test with electric current and to increase the condition that applies on disc like force and speed.
- For the material developed identify the effect of electrical sliding wear with electrical current.
- For the material developed investigate the wear test under the condition of applied load of more than 11N and with variable speed.
- By changing the chemical composition develop the overhead contact wire.
- For the FE analysis, by using the full licensed ANSYS software conduct wear analysis in Pin on Disc Configuration using Finite Element Method.
- Calculate the Critical wear section of contact wire using dynamic analysis with the help of finite element method.
- Experimental analysis on icing and anti icing of overhead contact wire.
- Corrosion protection mechanism for over head contact wire.

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**School of Mechanical and Industrial Engineering**  
**(Stream: Mechanical Railway Engineering)**

**Master's Program Final Thesis Acceptance Approval Form**

**Thesis Topic: Development of Material for Train Overhead Contact Wire**

By: Ashreka Yenus

Approved By Board Of Examiners:

Dr. Daniel Tilahun  
Advisor

  
Signature

20/05/15  
Date

Mr. Habtamu Tkubet  
Internal Examiner

  
Signature

19/01/15  
Date

Mr. Tsegaye Feleke  
External Examiner

  
Signature

20/05/15  
Date

Dr. Birhanu Beshah  
Railway Head Center

**Birhanu Beshah(PhD)**  
**Head, Railway**  
**Engineering Centre**  
Signature

22/05/15  
Date

