ADDIS ABABA UNIVERSITY

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SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

GRADUATE PROGRAM IN RAILWAY ENGINEERING

Development of Material for the Overhead Contact Line of the Addis Ababa Light Rail Transit (AA-LRT).

A Thesis proposal submitted to the School of Mechanical and Industrial Engineering at Addis Ababa University in partial fulfillment of the requirements for the Degree of Masters of Science in Railway Engineering (Rolling Stock).

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ABSTRACT

The purpose of this research is to develop a better material for the AA-LRT overhead contact line production. So with this in mind, the mechanical wear and corrosion resistance as well as the conductivity and hardness test of Cu-Ag and three other age-hardened copper alloys (Cu-Sn, Cu-Sn-Cr, and Cu-Ag-Sn) were studied using a pin-on-disk tribometer, a Rockwell Hardness Test machine and a Corrosion resistance test apparatus. For a tribological test, the samples were forced to slide against a rotating disk made of a stainless steel at a room temperature under un-lubricated condition with a constant velocity of 80km/h and a vertical load up to 7N (The actual pressing force of the pantograph against the conduct line in real situation is far greater than 7N, however, due to the limitation of laboratory equipments the maximum load used was seven Newton. The worn surfaces of the samples were examined under an optical microscope. Upon examination of the surfaces it was observed that the mechanisms of wear were both abrasive and adhesive. The corrosion resistance test was done by immersion of samples in three different solutions, Na-Cl, PH5 acidic rain, and distilled water. Continuous fresh air was pumped through the fluids and a 30volt DC current was applied for an electrolytic condition. In both the tribological and corrosion resistance test weight difference of the sample alloys before and after the respective test was taken as a measure of their wear and corrosion resistance property. With its high wear and corrosion resistance as well as good conductivity, the Cu-Sn-Cr alloy is an appropriate material for future production of an alternate overhead contact line of the Addis-Ababa Light Rail Transit system.

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LIST OF ABBREVIATIONS and SYMBOLS

AA-LRT---------- Addis-Ababa Light Rail Transit

Ag----------'Argent' Latin for Silver

ASTM ---------- American Standards for Testing of Materials

Be ---------- Beryllium

Cr ---------- Chromium (from Greek word '*khrōma,'* meaning color, due to chrome's ability to produce color in its compounds).

Cl---------- Chlorine

CS----------Clad Steel wire

Cu----------'Cuprum' Latin for Copper

ECAP----------Equal Channel Angular Pressing

EDS----------Energy Dispersive X-ray Spectroscopy

ERC----------Ethiopian Railway Corporation

HCl----------Hydrochloric Acid

HSHC----------High-Strength High-Conductivity

IACS----------International Annealed Copper Standard

Mg----------Magnesium

Na----------'Natrium' Latin for Sodium

NaCl----------Sodium chloride

Ni----------Nickel

OCS----------Overhead Catenary System

OCW----------Overhead Contact Wire

OHCL----------Over-Head Contact Line

POD ---------- Pin-On-Disc tribometer

pH or PH----------Potential of Hydrogen Ion

RHN ---------- Rockwell Hardness Number

RMPCS---------- Resin-Matrix Pantograph Contact Strip

SEM---------- Scanning Electron Microscope

SPD---------- Severe Plastic Deformation

Si----------Silicon

Sn----------'Stanum' Latin for Tin

UFG---------- Ultra Fine Grain

UTS ---------- Ultimate Tensile Strength (N)

Zr---------- Zirconium

Ø---------- Symbol to represent diameter

σ ---------- Conductivity

ρ ---------- Resistivity (electrical), Density (g/cm^3)

Δw ---------- Change in weight (mg)

ΔV---------- Change in volume (mm^3)

m---------- Mass (g)

cm ---------- Centimeter

d---------- Diameter

g ---------- Gram

Kg---------- Kilo-gram

Km/h---------- Kilometer per hour

mm ---------- millimeter

N---------- Newton

V---------- Volume

R---------- Resistance to electrical current or to wear

t ---------- Time

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CHAPTER I: INTRODUCTION

1.1 Background.

The railway system is now one of the widely used and environmentally friendly, means of transportation, despite the competition of buses, cars, ships, and airplanes. It usually is classified as high-speed and non high-speed, freight and passenger type, urban and suburban light rail systems. Early railways used muscle as well as steam engine as a source of power, while the late ones replaced steam with electric power. This type of energy source is cheap and environmentally friendly [1]. Our country is on the merge of completing its light rail transit system in its capital city Addis-Ababa, known as the AA-LRT system. The role of this new and first in Ethiopia, type of transportation will hopefully reduce the traffic congestion including the increase in carbon emission rate in the capital. This transit system gets its power from an Over Head Contact Line (OHCL) using a copper alloy conductor, and the power is collected via a pantograph mounted on, and moving with the train, transmitting power to the electric motors and utility systems within the locomotive or wagons. Due to a sliding friction and other factors, the pantograph-catenary system is exposed to wear which results in power conductance reduction leading to lower performance of the train [2]. The OHCL used by the AA-LRT is an alloy called silver-bronze (Cu-Ag) and has a problem of low wear resistance Fig 1. This paper is about developing an alternate OHCL material, by alloying copper as a base metal with tin and chromium.

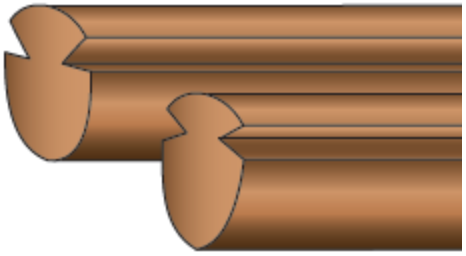

Figure 1 the AA-LRT overhead contact line.

The history of railway transportation began around the year 1550, as the German coal-miners lay on the ground a pair and parallel wooden/iron rail on which coal carrying wagons were hauled or travelled. In doing so, they have noticed that, the power/muscle needed to move those cars on the rails was much less than the one they used to when they drag the same car on the bare ground [3], [4], [5]. The reason for this was the diminishing of frictional force due to reduced area of contact between the wheel of the wagons and the narrow and smooth surface of the rails, which as a result enabled the miners to transport heavier loads with the same or much less effort. The motive power for the wagons was either human or animal mussels. See Fig.2

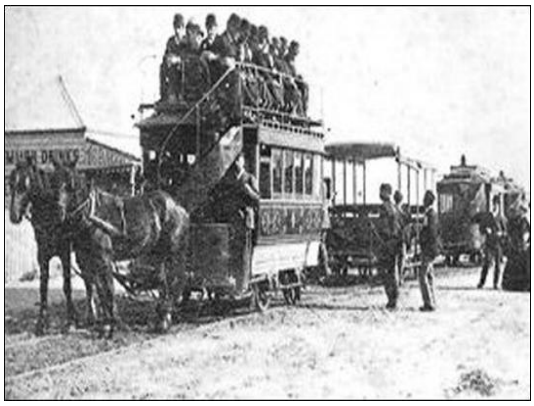

Figure 2 horse drawn carriage.

Around the 1800 with the invention of a steam power the steam engine replaced the horses. The steam engine was used as a source of power for wagons and later for locomotives for almost 125 years, by which time the locomotives weighted as much as 500 tons and reached a maximum speed of 120mph or around 200kph. However this, the only and very powerful source of energy for the trains, found to be coupled with a lot of problems like, huge amount of steam and smoke exhaust which restricted its use in tunnels and towns, the cumbersome maintenance of the engine system and its high cost, the continuous and frequent fueling as well as the need to carry a large container of water supply [6].

In and around 1870, some steam engines began to be replaced by electric motors. These motors at first were powered by batteries and latter by stationary electric generators, and at last by a power supplied from a main power station via overhead contact line / pantograph system.Fig.1. Compared to steam power, the electrically driven locomotives / trains offered higher performance on steep grades and in long tunnels, besides eliminating the smoke exhaust problem. Different countries now in the world like Japan, China, India, the most parts of Europe, and North America, use electric train for freight hauling or passenger transportation.

Figure 3.the earliest (1871) electric locomotive with single phase traction motors. [18]

Due to the importance of its immense power as a hauler, there is an intensive research taking place around many countries on the development and performance of the electric train transport system.

In the near future the rail track trains will be replaced with the newly discovered maglev (magnetic levitation) train. These trains run on a magnetized guide way, which will levitate it to 100mm above the guide way and with a speed of 500kph. These trains have far more efficiency in all aspects of engineering fields than their conventional counterparts [3], [5].

We have so far seen the rise and development of the train starting from hand or horse drawn wagons to steam powered and lastly electrically driven types including the maglev train. Now we will look at the means of providing the needed electric current to the motors and utility systems of the locomotives or cars of the train.

Early in the history of rails like 100 years ago, power delivery to an electric train was via the overhead line and the pantograph, and this same technique is still used generally, except for some technological development, which leads to the increase in voltage and type of the current capacity, as well as speed and safety. See Fig.4, Fig.5.

The overhead line or contact line gets the electric current from the nearby substation, which is supplied by the local electric power station. The pantograph which is mounted on the roof top of the train and always in contact with the contact line collects the power for the motors, lights, and air conditioning, etc., of the train, while it is moving or stationed at terminals.

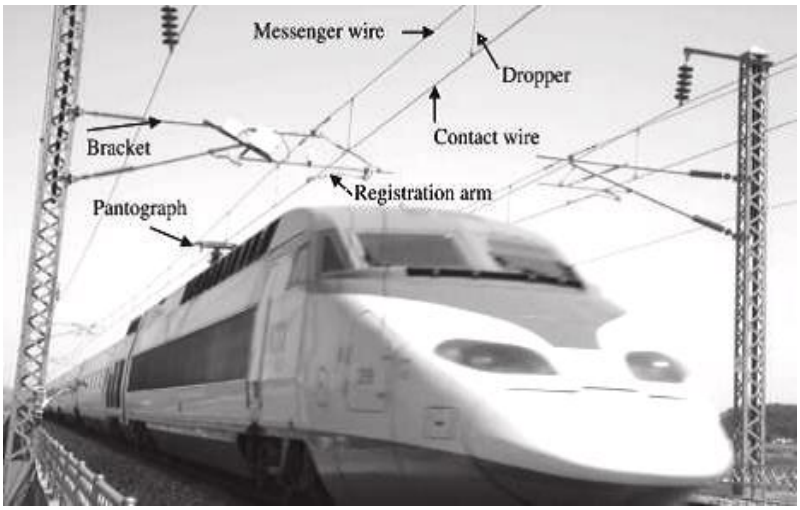

Figure 4 Overall pantograph-Catenary systems.

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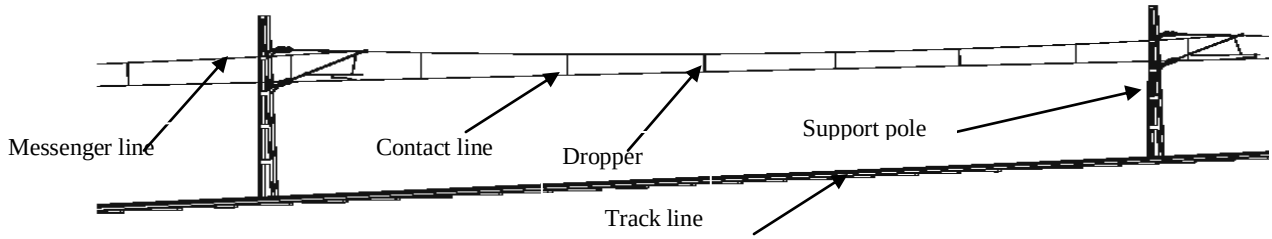

Figure 5 A simple catenary systems.

All overhead contact lines need therefore to have the following specific qualities or properties: -

--Adequate mechanical strength and electrical conductivity

-- Resistance to loads imposed by wind and some reactive substances in the air.

-- Corrosion resistance

-- Uniform and low wear throughout its service life.

These demands resulted from contact wires twin functions:

a- Supply electric power over a particular distance and

b- Provide a sliding contact for the pantograph all the time [7].

1.2 Statement of the Problem

As mentioned early in the above statements, contact lines need to have some quality properties like, good electrical conductivity, corrosion and mechanical wear resistance and also need to be cost effective. So in order to get wires with those properties, different countries use different copper alloy material by combining copper with different kinds of metals. Since the base metal for theses conductors is copper due to its excellent conductivity, the addition of other metals as its alloy reduces its conduciveness to some degree depending on the type and amount of alloying

metal. Copper is alloyed with other metals in order to increase its hardness and mechanical strength to withstand wear. The newly built and currently functioning transit system of the AA-LRT use as its over-head contact line an alloy of copper and silver called silver bronze (Cu-Ag). This copper alloy wire in spite of its high conductivity as seen from experience and test result of some researches [8] has a low wear resistance due to its low hardness value; which leads to reduced performance, poor ride quality and high maintenance cost.

In this study the Cu will be alloyed with different percentage content of Tin (Sn) and Chromium(Cr) in order to replace and/or strengthen the Cu-Ag alloy and increase the hardness value and decrease its cost without significantly reducing its conductivity. Even though in previous times copper bronze had been used as a trolley contact wire, few researches were done to further its use. This research uses this alloy to conduct a test for a future consideration as a production material of alternate contact line for the AA-LRT. Besides, tin (Sn) and Chromium (Cr) have important metallic properties like high corrosion resistance and good conductivity with some degree of hardness that fit for over-head line production.

1.3 Objectives

1.3.1 General Objective

The general objective of this research is to develop an alternate material for the overhead contact line of the AA-LRT.

1.3.2 Specific Objective

Materials selection for test pin production.

Manufacturing and collecting of test samples.

Performing tribological and corrosion resistance test on samples.

Making comparison of samples depending on the data and recommend the alternate material.

1.4 Scope and Limitation

1.4.1 Scope

In this research the wear resistance (mechanical and corrosion), hardness and electrical conductivity test of the above mentioned alloy namely, Cu-Sn, Cu-Ag-Sn, Cu-Sn-Cr and Cu-Ag will be performed under different load and medium with constant time and velocity.

1.4.2 Limitations

- Collection of materials for the preparation of alloy samples took long due to the scattered locations of resource centers.
- Due to lack of information (there was an electric furnace in the AAU-AIT mechanical work shop) the melting of alloy metals was done at a private center with an open and oil-burner furnace which was likely to increase the impurity level.
- Wear debris were not analyzed according to the rule because of unavailability of the SEM and EDX equipments.
- Because of shortage of test apparatus the corrosion test was done in two phases instead of at one time.
- Due to repetitive testing and wear-out the POD tribometer at the shop is limited to applied load of 7N.

- Accuracy of micro scales and electrical measurement instruments is insufficient.

1.5 Organization of the Paper

This paper is consisted of five chapters. The first chapter introduces with the railway mode of transportation and its historical background, statement of the problem of pantograph-catenary system frictional interaction due to the relative motion between them, also gives the general and specific objectives of the research in addition to the scope of it including some limitations or problems occurred during the process. The final section of this chapter gives the outline chapters of the paper in sequence. Chapter two reviews some literatures connected with the railway overhead power supply system the cause and result of its malfunction. The main concern of this research which is wear is defined and different and major types of wear are defined. The use of copper and its alloys as the main choice of overhead contact line materials is briefly discussed. Finally the research work of different persons on similar research is reviewed while in its last statement the aim and type of alloys for this study is addressed. The third chapter addresses all of the methods for accomplishing the test for this research. Included in this chapter are: material selection, test piece dimension, condition and types of tests to be conducted as well as percentage calculation for mixing the alloys and cost analysis of each sample alloys are explained. Chapter four is about the results of tests in tribological, hardness and corrosion resistance as well as conductivity level of each sample. Following the result is the discussion part which looks at and analyzes the data collected in each categories of the test. The last chapter which is chapter five summarizes the test and gives the conclusion and recommends the alternate material for future use as a contact line for the AA-LRT. This conclusion and recommendation is based upon

comparison of materials property proofed by the values collected after the samples passed through similar mechanical and electro chemical tests under them same condition. Some areas not covered by this research are addressed under the future work section. At the end of this paper references are listed in alphabetical order, these references are the works of some scientific researchers who in the previous time did similar studies in alloying copper with different metals as well as the detail study and investigation of the wear process. Next to this, the appendix section presents some international standards and regulations followed by this and other researches.

CHAPTER II: LITERATURE REVIEW

2.1 Introduction

This literature review explores some of the main concerns when selecting a material for the production of railway contact line, like the corrosion, wear, conductance of electric current and hardness, etc. In addition to this previous research works on similar case will be reviewed.

2.2 The pantograph-catenary system

The overhead contact line together with the pantograph (the pantograph-catenary system) is the main power supply and collection system to the LRT. The performance of the train depends upon the intensity and uninterrupted current flow. In order to accomplish this task the OHCL should be a highly conductive and wear resistant wire. The contact wire is worn by sliding of pantograph strip. The wire is worn out at different rate in different locations along the track line. For example F.Okimotto, et al has noticed that, especially, contact wires at stations are rapidly worn at points where trains stop. Thus, the wire has rough contact surfaces at these points and this causes contact loss between contact wire and running pantograph. For these reasons, reducing wear of contact wire at stations and along the track is very effective not only for extending the life time of contact wire but also for reducing the contact loss of pantographs of passing high speed trains and also LRT's. Sometimes the contact line separates from the pantograph, which results in the loss of contact, leading to the interruption of energy supply with arcing between the collector bow of the pantograph and the contact wire, which is another cause of deterioration of the functional conditions of the two systems and passenger discomfort [9].

The increase of the average contact force would improve the energy collecting capabilities but would also lead to a rapid wear of the registration strip of the pantograph and of the contact wire. Considering that all the power needed to drive the train is transmitted through the small area of contact between contact wire and collector strip, it is fundamentally important to ensure a proper contact force is used without causing sever frictional damage/wear to the wire or the strip . The consideration of the quality of the current collection becomes more critical as train speed increases, but is not exclusively confined to high speed only. Other conditions such as the operation of multiple pantographs at distances close to span length need to be carefully considered, because at the junctions different kind of metal than that of the main contact line is used and this leads to wear rate differences at these intervals, since different metals wear at different rate.

Due to continuous sliding contact and friction between the overhead conductor and the pantograph, the wear of both materials is the main concern of modern day high speed/light rail trains. Wear of the system leads to low quality of performance and high maintenance cost. Wear is defined as a system property rather than that of a material, since some other factors also contribute to the wear rate, besides its natural property. These factors can be weather related like humid or dry air, ambient temperature, presence of lubrication, and a load which compresses the two materials together plus relative sliding speed between them [10],[11] .

Even though wear is defined as a surface material removal due to a relative motion of two bodies in contact under normal load, the cause and effect of different kinds of wear has its own role.

Since the pantograph system is exposed to all or some kinds of wear types, we should have some brief view on the types and causes of those wears.

2.2.1 Wear modes and mechanisms recognized as fundamental and major:

a) Adhesive

b) Abrasive

c) Fatigue

d) Corrosive wear.

a) Adhesive wear: Defined as wear by transfer of material from one to another between surfaces which are in contact under pressure and in relative motion. Generally metal surfaces are not as smooth as they appear. They are all covered with microscopic high and low points called asperities. When two smooth surfaces come in to contact their contact area actually is divided in to two types:

-The apparent area of contact

-The true area of contact

It is in the true area of contact that the wear mechanism takes place Fig.6. Since the two surfaces only contact at asperity points the static load contributes to their deformation until the true contact area increases to support the load. As a result an oxide film, which always is present on all surface materials by nature, is removed. Upon the introduction of a relative linear movement of the surfaces, plastic deformation of the asperities will occur subsequently resulting in their

fracture which results in adhesive wear fragments. Besides, if the adhesive force between the two contacting materials exceeds the strength of either metal, bonding of the two surfaces leads to adhesive wear [12], [13], [14].

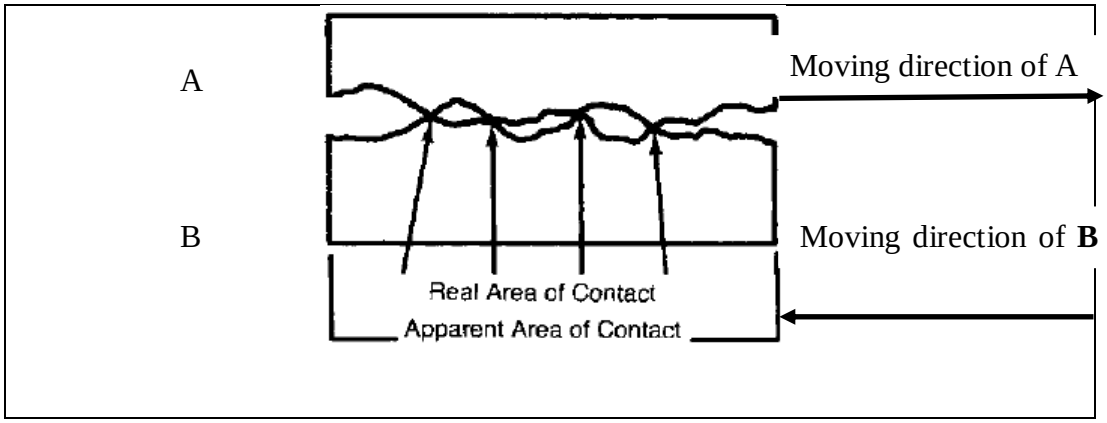

Figure 6 real and apparent contact surfaces of two relatively sliding bodies.

b) Abrasive wear: When two relatively moving surfaces are in contact and differ in hardness value, the harder material ploughs or cuts in to the softer material surface, as a result a certain volume of surface material is removed and an abrasive groove is formed on the softer material and this is called a two-body contact abrasive wear. See Fig.7.

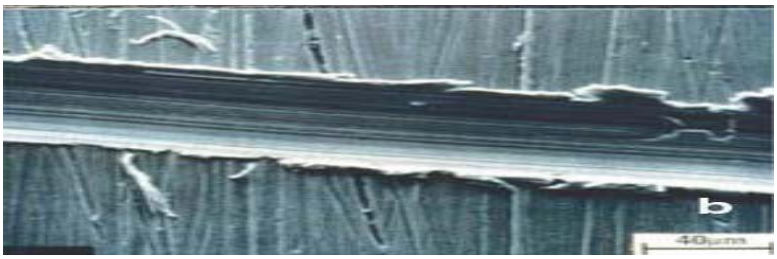

Figure 7 an example of abrasive wear.

Also this is the case most of the time, a loose hard particle between the two mating materials also can be the cause of an abrasive wear, since it cuts in to one of the metals and removes some surface material from it. This type of abrasive wear is referred as a three body contact abrasive wear. In order to minimize abrasive wear, mating surfaces should be as hard as possible or must have similar values of hardness and the lubricating fluid between them must be as freer as possible from foreign materials or from wear particles [15].

c) Fatigue wear: Repetitive contacts between asperities with very high local stress during sliding or rolling under dry or lubricated condition results in a severe plastic deformation. This causes the subsurface crack initiation and growth toward surface followed by a fracture of surface material as a result of which fatigue wear is created Fig.8. This kind of wear causes a chunk of material from one of the mate to be removed causing a sudden or abrupt malfunction of the part. For example, part of a flange is thrown out of a wheel of a wagon.

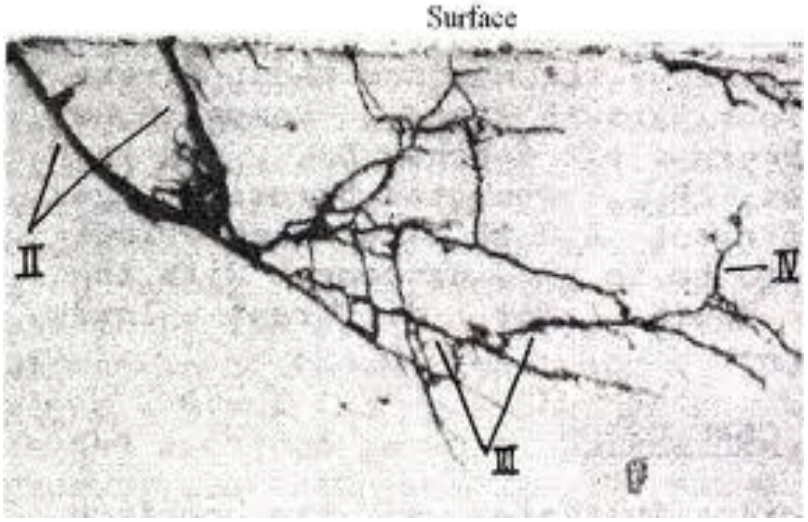

Figure 8 shows propagation to surface of sub-surface-initiated cracks.

d) Corrosive (Tribo-chemical) wear: When two metallic surfaces in contact are in a relative sliding motion and the surrounding medium is considered as corrosive, tribo-chemical reaction takes place and the reaction layer is produced on the surface. This layer however is removed by friction and the process repeats itself resulting in the wear of the surfaces called corrosive wear. In general corrosive wear is caused by a chemical reaction between the two interfacing surfaces involving the lubrication, material and/or environment, activated by frictional heating. Copper and copper alloys are materials, which are prone to corrosion Fig.9.

Figure 9 an example of a corrosion type called Pitting caused by chloride attack.

The electrical conductivity of contact materials can be largely reduced by corrosion and in order to avoid corrosion, protective surfaces must be used. There are basically two groups of materials, which can be employed for corrosion protection of electrically conductive surfaces. The first group includes noble metals such as gold, silver and palladium. The second group comprises of corrosion resistant so-called passive metals such as tin and nickel. These metals are basically ignoble and they derive their corrosion resistance from the presence of a thin oxide film on the surface, called the passive film, which acts as a protective barrier between the metal and its

environment. The passive film inhibits deeper corrosion, and is usually an oxide or nitride with a thickness of nanometers [16].

Since copper is the best conductor next to silver, the overhead contact line of all electric trains is made up of copper based alloys of different metals. In order to prevent or minimize the different kinds of wear corrosion stated above, a research is continuously taking place to make the suitable material for contact line wire and its coating out of copper and its alloys, according to the speed of the train, the contact force, the voltage, and environmental circumstance.

2.2.2 The use of copper and its alloys as a conductor.

Since the dawn of history, mankind was using copper for different purposes in his social life as a monetary means for exchange, as homemade materials for utensils, for art and decoration works, as well as for weaponry. When electricity was discovered in the 1800s and was used as a means of power supply, the best conductor next to silver found to be was copper. Since then the use of copper in this field is enormous and incomparable. One of the great advantages of copper is that there is a wide selection of alloys available, combining excellent electrical properties with good mechanical properties Fig. 10 [17]**.**

So to come up with a contact wire material suitable for a specific type of service, there was a lot of research done on those different types of copper alloys. C.T.Kwok, et al by far performed the multi types of copper alloys in one time experiment on the electrical sliding wear and corrosion resistance test, of pure copper (Cu) and six other copper alloys (CuCr, CuZr, CuCrZr, CuNiSiCr, CuBe and CuBeNi) on a pin-on-disc tribometer [18]. After doing the research the CuCrZr was

found to possess good electrical conductivity and comparably high wear resistance which is like 7 times that of copper.

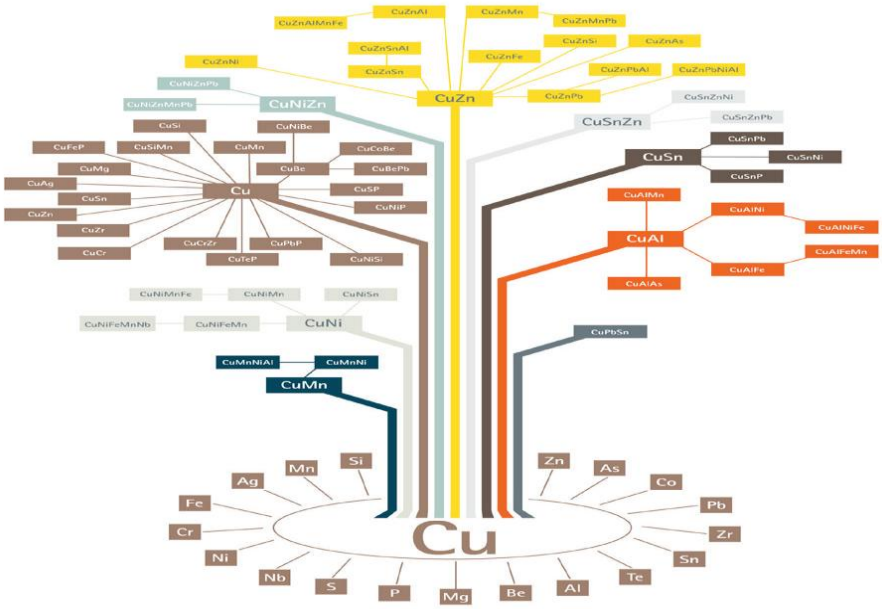

Figure 10 the copper alloy tree with more than 400 alloy combinations possible. [17]

At the same time the CuBeNi and CuBe alloys with their high wear resistance but low electrical conductivity and their toxic property due to the presence of beryllium, were proved to be of less use for catenary wire production.

In another similar test condition Ping Liu, et al, conducted a test comparing Cu-Ag with Cu-Ag-Cr. The electrical sliding wear of this alloy was studied by sliding it against a copper-based sintered alloy strip, which was used as the contact strip of an electric railway pantograph. Due to

the influence of microstructures of the material because of the addition of Cr resulting in finely dispersed precipitate Cr particles, there was a noticeable difference between the Cu-Ag and Cu-Ag-Cr alloy. At the conclusion it was stated that the Cu-Ag-Cr alloy wire has the combination of high strength and high conductivity relative to the Cu-Ag alloy. This alloy also has a higher arc erosion and mechanical wear resistance, which indicates that the addition of Cr could greatly improve the wear resistance of the Cu-Ag alloy contact wire [19].

Y.Sakai et al. demonstrated that by using a new method one still can change the property of the Cu-Ag alloy. By cold working and intermediate heat treatment which is repeated 3-4 times at 350-450°C for 1-2 hours had been possible to produce an optimized Cu-16 at.%Ag alloy wire with a tensile strength of 1000MPa (2.5 times that of Cu-Ag) and an electrical conductivity of 80%IACS at room temperature [20]. Due to continuous development of high-speed electric railway, copper alloys of exceptional strength and conductivity are needed. In order to produce those kinds of materials it is not enough just to combine copper with different types of metals though this so called conventional method worked well for so long and still is, but in the present time to come up with those high demanding types of alloys various kinds of advanced metallic materials are desired.

Aibin Ma et al. used a method called equal-channel angular pressing (ECAP) to produce ultrafine-grained (UFG) Cu-0.2wtMg alloy contact wire with high mechanical/electrical performance, aimed to overcome the wave propagation problem of high-speed trains by maximizing the tension and improving the power delivery. The Cu-Mg alloy after different severe-plastic-deformation (SPD) and multi-pass ECAP at a temperature of 200°C obtained

ultrafine grains with higher strength and expected conductivity. In conclusion the grain refinement via continuous SPD processing can increase the alloy's strength and good conductivity characteristics, which are the needed qualities of contact wires of high-speed trains [21].

Since the tribo-electrical wear process of a pantograph-catenary system is consisted of the sliding interaction of those two parts, it is sometimes necessary to do some research on the pantograph strip in order to make a compatible material with the existing catenary wire. Some properties of the strip materials can and will greatly affect the safety and power delivery capability of the contact line.

TU Chuan-jun et al. demonstrated an experiment to develop a pantograph contact strip and came up with a type of material called RMPCS (resin-matrix pantograph contact strip), which has excellent abrasion resistance with electrical current and friction-reducing function far better than those traditional contact strips with high maintenance cost, high wear rate with electrical current and severe damage to the contact wire [22].

Combining just the right amount of a specific metal with copper produces an alloy significantly stronger than copper with a little decrease in conductivity.

F.Pupke compared and evaluated four different copper alloys currently used as over-head catenary system (OCS) and concluded that A wire made of the copper-magnesium alloy Cu-Mg0.2-0.5 in cold work-hardened condition is characterized by significant higher strength, high electrical conductivity (82% IACS). The electrical conductivity still can be increased by using

different and new methods of metal working process and will be possible without reduction of the required tensile strength to produce a wire with 13% energy saving potential [23], [24]. But in this experiment even though using the magnesium alloy produced good material for production of contact wire materials, the volatile nature of magnesium restricts its use only in certain areas.

The wave propagation phenomenon in the railway transport system is a main concern when newly manufactured high-speed trains arrive to the service. In order to avoid this problem or to control its effect on the power supply system, contact wires with high tensile strength are needed.

Shin-ichi KATAYAMA et al. made an experiment and a field study after making an alloy which is called Copper Clad Steel wire (CS). The alloy was developed by dipping a steel core of certain diameter into a molten oxygen-free copper bath with a purity of 99.6% or greater. The tensile strength of CS contact wire is almost double that of hard-drawn copper contact wire the same cross sectional area. Since the wire is covered with pure copper and has a core of steel, it could be installed with high tension load which will greatly control the wave propagation velocity and its frequency [25].

The properties of copper alloys can be enhanced following different methods of alloying process as explained previously, this being a known fact for long the discovery of those new methods is still fascinating to review. A.O. Olofinjana, K.S.Tan presented a result of his research after demonstrating an experiment using a method called rapid solidification [26]. This experiment aimed at producing a high-strength-high conductivity (HSHC) alloy by diluting copper with chromium metal. The methodology involved in taking an already prepared Cu-Cr alloy and

melting it with a rapid solidification in the as-cast ribbon to gain a high cooling rate which resulted in super saturated solid solution of Cu-Cr. The best combined strength and conductivity was obtained for 4%wtCr alloy with hardness of 350HV and conductivity of 80%IACS.

S.G.Jia et al. did a tribological study after alloying the Cu-Ag wire with zirconium (Zr) [27]. The test was conducted under laboratory conditions with a specified sliding wear tester that simulated train motion under an electrical current applied across the sliding surfaces. The sample wire was slid against a copper-based powder metallurgy strip used in railway systems under unlubricated conditions. Worn surfaces were studied and analyzed with different proper instruments and it was found that compared with a Cu-Ag contact wire under the same test conditions, the Cu-Ag-Zr alloy wire has much better wear resistance.

On a paper entitled ‘the electrical conductivity of CuCrZr alloy after SPD processing [28] M. Lipinska et al. published about a possibility to improve mechanical strength while preserving high electrical conductivity. Due to the subjection of the alloy to a series of thermo-mechanical treatments, which includes solution annealing and water quenching, SPD processing (using hydrostatic extrusion and ECAP) as well as aging in order to improve mechanical strength. The CuCrZr alloys are now used as electrical wires or overhead contact wires for fast railway. Those properties of excellent mechanical strength with very high electrical as well as thermal conductivity needed for contact wires are attained due to the application of different heat treatments and manufacturing processes involving almost every known strengthening mechanism.

One of the main and common alloying elements for copper alloy is tin. When copper is alloyed with tin the product is called bronze. This alloy has been known for so long it even has a period of time in the history of civilization known as the Bronze Age. In the present time this material is used in many thousands of applications including as an electrical conductor and production of parts with high wear and corrosion resistance. In the past few years, the use of bronze is growing in many fields due to in addition to the previously mentioned properties excellent thermal and electrical conductivity, self lubrication ability and wear resistance [29].

J.Zhang et al. have been able to produce an ultrahigh electrical conductor from Cu-Sn alloy by subsequently using different kinds of metal processing like, casting, normalizing, cold work and annealing. Using these procedures at the same time of the research they could be able to find a conductor material with a resistivity of 1.55 and 1.26μΩ cm [30].

The strength of metals can be improved in following different and common methods of like grain size refinement, strain hardening, solid solution hardening, quench hardening, dispersion strengthening and precipitation hardening. By using the newly emerging technique called spinodal hardening S. Ilangovan and R. Sellamuthu found that the hardness of an alloy increases when the amount of Sn increases from 4% to 8% in the solution heat treated conditions and the peak aging time is found to decrease with an increase in the Sn content, which is good to obtain an alloy ready within short period of time. The Sn content within this material induced a significant increase in hardness which resulted in increase to wear resistance [31].

J.X. Hou et al. produced an alloy $Cu_{75}Sn_{25}$ and used a Rapid Solidification process to get a material with high corrosion and wear resistance plus good conductivity [32].

In summarizing, it can be stated the fact that all those previous researches are done using either a very complicated metal working method or repeatedly using the same materials for alloying with copper, however this research will use tin, chromium and silver for a new types of alloys.

The European Copper Institute has published about a copper and tin alloy in the range of 0.2-0.55% tin addition with good and high mechanical and electrical properties connected with high wearing resistance (Werke AG 2015). This material has higher than pure copper softening temperature and good creep, stress relaxation fatigue resistance, while it permits good corrosion resistance and without stress cracking corrosion.

On this paper CuSn0.3% will be produced for comparison with the present contact line alloy of the AA-LRT (Cu-Ag) and at the same time this contact line material will be alloyed with the 0.3% Sn as well as the Cu-Sn-Cr is produced in order to compare the effects of Sn and Cr all in all. In the reviews cited above we have seen how the addition of Cr to the Cu-Ag alloy improved the wear resistance of it and with an expectation of similar or near to similar results the copper bronze will be diluted with chromium. As an alloying compound, adding chrome provides color, hardness, hygiene, permanence, strength and resistance to corrosion, decay, temperature and wear. Chrome's corrosion resistance makes steel stainless. In contact with air, chromium spontaneously forms a very thin, continuous and stable oxide film on the steel's surface. This renders the surface inert to chemical reaction and is passive [33].

CHAPTER III: METHODOLOGY

3.1 Material

The alloy materials selected for this research are:

a. Cu-Sn b. Cu-Sn-Cr

c. Cu-Ag-Sn d. Cu-Ag alloy.

The Cu-Ag alloy conduct wire will be collected from the ERC and melted after which ,tin is added to come up with a Cu-Ag-Sn alloy metal with a diameter of Ø13mm and a length of 13mm. Some of the melted metals like chromium and tin are collected from Akaki metal factory and copper from Elsewdy cables, found not far from Addis-Ababa. The materials collected will be melted at Yalew garage in Addis-Ababa around Nifasilk1 and at the AAU-AIT mechanical work shop. In order to get our sample in a desired dimension of 13mm we have to cast the melted metal in a twenty mm metal pipe and let the work piece go through a turning machine process until we get a 13mm diameter rod Fig.11, after which it is prepared for the test. The materials are selected for their hardness, conductivity and corrosion resistance property. Compositions of alloy materials are shown in Table 1.

Figure 11 the raw alloys go through machining process on a lathe machine.

Table 1.Material composition of test samples to be prepared.

Test sample alloys' Composition in Percentages.					
Material	Cu	Sn	Si	Cr	Impurities
Cu-Sn	98.6 with 0.04% O_2	0.3	_	_	≤1.060
Cu-Sn-Cr	98.6 with 0.04% O_2	0.3	-	0.193	≤0.98
Cu-Ag-Sn	99.3 with 0.08-0.12Ag as per specification of ERC	0.3	-	-	≤0.40
Cu-Ag	(99.3% Cu-(0.08-0.12Ag)) as per specification of ERC.				

3.2 Test pieces dimension

Test pieces are prepared as solid type with cylindrical shape. All together there will be 24 of them and will have a dimension of Ø13mm by 13mm length (L). The diameter (Ø13mm) is chosen to represent the actual diameter of the OHCL of the AA-LRT Fig.13.

Figure 12 some sample alloys with Ø13mm x 13mm (L).

In order to manufacture the pins, calculate in prior the amount of Copper needed as a base metal and then the mass of the other alloying elements as a percentage of the copper mass in one pin. For all sample pins, the volume of each will be calculated using the formula:

$$V = \pi r^2 \times L \quad \ldots\ldots (1)$$

Where: V = volume,

r = radius,

L= length of one pin

$$V = 3.1416 \times 6.5^2 mm \times 13mm = 1725.52\text{mm}^3 = 1.726\text{cm}^3$$

Using the equation of density and mass relation with volume, the mass of the copper within a pin can be calculated as:

$$\rho = m/v \qquad (2)$$

$$\rho = density\left(\frac{g}{cm^3}\right) = 8.96, \qquad m = mass\,(g), and \;\; v = volume\,(cm^3) = 1.726\text{cm}^3$$

Since 100% pure copper has a density of 8.96g/cm³, for a 98.64% copper with impurities will have a density of: $\rho = 98.64\% \div 100\% \times 8.96\text{g/cm}^3 = 8.84\text{g/cm}^3$

From equation (2) the mass of copper within a pin will be:

$$m_{Cu} = \rho \times v \rightarrow \frac{8.84\text{g}}{\text{cm}^3} \times 1.726\text{cm}^3 = 15.26\text{g}$$

And for 12 samples the amount of copper needed will be: $m_{c\,u} = 12 \times 15.26\text{g} = 183.06\text{g}$

The percentage of metals in each alloy was calculated as follows.

A. Tin amount For: Cu-Sn and Cu-Sn-Cr alloy pins

To prepare one pin of these alloys with 0.30% of tin out of the mass of copper we need:

$$m_{Sn} = 0.30\% \div 100\% \times 15.26\text{g} = 0.04575\text{g}$$

For six samples of each: $m_{Sn} = 2 \times 6 \times 0.04575\text{g} = 0.549\text{g}$

B. Chromium amount for Cu-Sn-Cr pin with a 0.193% Chromium out of the mass of copper:

$$m_{Cr} = 0.193\% \div 100\% \times 15.26\text{ gm} = 0.0294\text{g}$$

For six samples: $m_{Cr} = 6 \times 15.26\text{ gm} = 0.1766\text{g}$

And 0.30% of tin out of the mass of copper is the same amount for the Cu-Sn; 0.04575g.

C. For: Cu-Ag-Sn

To prepare this alloy, a piece of Cu-Ag wire was taken and then melted with a 0.3%wt tin. In order to find the percentage of tin, first the mass of copper within the Cu-Ag contact line was calculated the following way:

100% pure copper has a density of 8.96g/cm³, but according to the ERC Cu-Ag wire has 99.3% copper content, the rest being Oxygen and Silver including other impurities.

So if 100% = 8.96g/cm³; Then 99.3% = x, from where:

$$\mathrm{X} = 99.3\% \div 100\% \times 8.96\mathrm{g/cm^3} = 8.897\mathrm{g/cm^3}$$

The volume of one pin is 1.726cm³; then mass of copper from equation (2) is:

$$m_{Cu} = 8.897\mathrm{g}/cm^3 \times 1.726cm^3 = 15.357\mathrm{g}.$$

The amount of tin will be: $m_{Sn} = 0.30\% \div 100\% \times 15.357 = 0.0461\mathrm{g}.$

For six samples: $m_{Sn} = 6 \text{ x } 0.0461 = 0.2764\mathrm{g}.$

All the samples were prepared following the above material composition and analyzed using a spectrometer; after repetitive tests the results were summarized and shown in table 2.

Table 2 Material composition of Test pins.

Material	Cu%	Sn%	Si%	Cr%	Impurities%
Cu-Sn	98.4 with 0.04% O_2	0.298	_	_	≤1.262

Cu-Sn-Cr	98.1 with 0.04% O_2	0.298	-	0.128	≤1.434
Cu-Ag-Sn	98.7 with 0.077% Ag	0.299	-	-	≤.884
Cu-Ag	(99.3% Cu-(0.08-0.12Ag)) according to the specs.of ERC.				

3.2.2 COST OF EACH SAMPLE ALLOYS:

One of the engineering design principles is production of materials or equipments in a cost effective way. So the cost effectiveness of producing each sample was is taken in to comparison. The current market values of each metal from Micron International Trading House in A.A around Mexico Square, and from a website called www.infomine.com: is shown in Table 3. Using these values cost analysis was done.

Table 3 Market price of Alloying elements (metals) of the sample pins.

MATERIAL	PRICEPER KILOGRAM in birr/kg	PRICE PER GRAM in Birr/g
Copper (Cu)	1170	1.170
Silver (Ag)	58500	58.50
Chromium (Cr)	4050	4.050
Tin (Sn)	7900	7.90

So following the values in Table 2 and Table 3 a cost of production of each sample is calculated using the percentage of each material in the test pins and its market price per gram.

3.2.2.1. for **Cu-Sn:**

Total mass of copper (Cu) in each pin is: **mcu = 15.25g**

Percentage of copper in Cu-Sn is: 98.4%

Mass of copper (Mcu) in this pin is:

$$M_{Cu} = 98.4\% \div 100\% \times 15.25 = 15.006\text{g}$$

The price \$Pcu of copper per gram is: 1.17birr/g and for 15.006g the cost will be:

$$C_{Cu} = \$\text{PC}_\text{U} \times \text{MC}_\text{U} = 1.17\text{birr/g} \times 15.006\text{g} = 17.55\text{birr}$$

Percentage of tin is: 0.298%

Mass of tin will be:

$$MS_n = 0.298\% \div 100\% \times 15.25\text{g} = 0.14945\text{g}$$

The price \$PSn of tin per gram is: 7.90birr/g; and for 0.14945g the cost will be:

$$C_{Sn} = \$\text{PS}_\text{n} \times \text{MS}_\text{n} = 7.90\text{birr/g} \times 0.14945\text{g} = 1.18\text{birr.}$$

Total cost for one pin of Cu-Sn alloy is:

$$TCC_{u\_}S_n = C_{Cu} + C_{Sn} = 17.55\text{birr} + 1.18\text{ birr} = 18.73\text{birr.}$$

3.2.2.2 for **Cu-Sn-Cr**

%Cu = 98.1%, Mcu = 14.96g, $Pcu = 1.17birr/g and the cost of copper for this sample is:

$$C_{Cu} = 1.17\text{birr/g} \times 14.96\text{g} = 17.50\text{birr.}$$

%Sn = 0.298%, Msn = 0.14945g, $Psn = 7.90birr/g and the cost of tin for this pin is:

$$C_{Sn} = 7.90\text{birr/g} \times 0.14945\text{g} = 1.18\text{birr.}$$

And %Cr = 0.128%, Mcr = 0.01952g, $Pcr = 4.050birr/g, so the cost of chromium for one sample is:

$$C_{Cr} = 4.050\text{birr/g} \times 0.01952\text{g} = 0.0791\text{birr.}$$

Total cost for one Cu-Sn-Cr alloy pin:

$$TCC_u\_S_n\_C_r = 17.50 + 1.18 + 0.0791 = 18.76\text{birr.}$$

3.2.2.3 for **Cu-Ag-Sn**

mcu = 15.357g

%Cu = 98.7%, Mcu = 15.16g, $Pcu = 1.17birr/g,

$$C_{Cu} = 1.17\text{birr/g} \times 15.16\text{g} = 17.73\text{birr.}$$

%Ag = 0.077%, MAg = 0.0118g, $PAg = 58.50birr/g,

$$C_{Ag} = 58.50\text{birr/g} \times 0.0118\text{g} = 0.6918\text{birr.}$$

%Sn = 0.299%, Msn = 0.0459g, $Psn = 7.90birr/g,

$$C_{Sn} = 7.90\text{birr/g} \times 0.0459\text{g} = 0.3627\text{birr.}$$

Total: $TcCu\_Ag\_Sn = 17.73birr + 0.691birr + 0.3627birr = 18.78birr.$

3.2.2.4 for **Cu-Ag**

mcu = 15.357g

%Cu = 99.3, Mcu = 15.2495g, %Pcu = 1.17birr/g, Ccu = $Pcu x Mcu = 17.84birr.

%Ag = 0.08%, MAg = 0.0123g, $PAg = 58.50birr/g, CAg = $PAg x MAg = 0.7187birr.

Total: $TcCu\_Ag = 17.84birr + 0.7187birr = 18.56birr.$

3.3 Methods

The overall testing procedure is consisted of four categories:

1. Hardness

2. Conductivity

3. Tribological

4. Corrosion Resistance test

In each test categories samples will go through three times, and average value of their test result will be calculated and recorded.

3.3.1 Hardness Test:

Hardness is the property of a material that enables it to resist penetration and wear by another material, generally a resistance to deformation. Hardness is directly related to the mechanical properties of the material. Factors influencing hardness include microstructure, grain size, and strain hardening, etc. Generally as hardness increases so does yield strength and ultimate tensile

strength (UTS), thus specifications often require the results of hardness tests rather than tensile tests. The most popular methods are Brinell, Vickers and Rockwell hardness tests for metals and alloys. Hardness tests can be used for many engineering applications to achieve the basic requirement of mechanical property [34].

The alloy samples' hardness is tested as per ASTM E 110 – 82 (Reapproved 1997) , using the Rockwell Hardness testing machine at the AAU-AIT mechanical workshop. Fig.14.

.

Figure 13 The Rockwell Hardness Testing machine.

This test machine is the widely accepted due to its speed, freedom from personal errors, ability to distinguish small hardness difference, and a small size of indentation. The hardness is measured according to the depth of indentation, under a constant load. In order to do the Rockwell Test the following procedures must be followed:

- Position the specimen to be tested close to the indenter.
- Apply the minor load to establish a zero reference position.
- Apply the major load for a specified time period called a dwell time, in this case 60seconds.
- Release the major load leaving the minor load applied.

  The Rockwell number represents the difference in depth from the zero reference position as a result of the applied major load [34].

3.3.2 Electrical Conductivity Test:

Test specimens were checked for their conductivity in the Electrical Machines Laboratory of the AAU-AIT Electrical and Computer Engineering Department. Before the conductivity test specimens were cleaned with a wire brush and polished to remove dirt from their surfaces and measured for their diameter and length, in order to calculate the resistivity of them after reading their resistance from a digital volt meter. Once the resistance R is found then calculating the resistivity will be possible using the formula:

$$\rho = (R \times A) \div L$$

Where: ρ = resistivity; R = resistance in ohm; L= length of the test pins in mm(35)

And the conductivity is calculated as:

$$\sigma = 1 \div \rho$$

And this will be compared to the International Annealed Copper Standard and the value is expressed in %IACS. See Appendix D.

3.3.3 Tribological test:

The tribological test will be done on a pin-on disk tribometer, at the AAU-AIT mechanical workshop/laboratory. This machine is capable of producing up to 10N compressing force produced by a helical spring located within a cylindrical screw, used to press against a rotating disk powered by an electric motor, underneath the test pin.Fig.15.

Figure 14 the pin-on-disk tribometer for the wear test, and some sample alloys.

3.3.4 Corrosion Resistance test:

The corrosion test is done using a corrosion resistance test set up in the environmental laboratory at the AAU-AIT Chemical Department Fig.16.

Figure 15 the corrosion resistance test set up and 30volt DC current supplier.

3.4 Condition:

After collecting raw materials for the alloy samples and manufacturing is completed through a melting process, samples will be shaped by machining and cutting process to the required length and cylindrical shape. All the samples go through pretest cleaning, measuring, and weighing steps. The tribological, hardness, and conductivity tests are done under normal atmospheric pressure and an ambient temperature in a dry condition, however the corrosion resistance test is done in three types of mediums: 3.5%NaCl, 0.5%PH value acid rain, and pure distilled water. Corrosion is the electrolytic action of moisture and other dissolved ions of the atmosphere on the metals. These solutions are chosen as a representation of real average atmospheric conditions like salty coastal atmosphere, acid rain, and icing [36].

This testing process was accomplished under a continuous supply of air which passes through the fluid mediums and a 30 volt DC current for enhancing the electrolytic action.

3.5 Testing:

The tribological test was done on the pin-on-disk tribometer described previously at a radius circle of 65mm at a rotational velocity of 3266rpm, at a constant sliding speed of 80km/h for one minute 0.0167hr. The test was conducted without lubrication and no electrical current, under loads of 3, 5, and 7 Newton, applied by a compression spring. Each sample's weight was taken and recorded using an electronic balance with a precession of 0.01 of a mili gram. All sample alloys have gone through the test three times for each type of load and their weight after the test recorded. The difference in their weight before and after the test was considered as a wear rate in time for each sample.

The weight loss Δw (in g) of the specimen in wear time t was recorded by an electronic balance of 0.01 of mg precision. The volume loss Δv (in mm^3) was calculated as:

$$\Delta v = 1000 \Delta w \div \rho \ldots\ldots\ldots\ldots\ldots (1)$$

Where: ρ is the density of the alloys in g /mm^3.

The wear rate W (in mm^3/h) and the wear resistance R (in h/mm^3) are solved as follows:

$$w = \Delta v \div t \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$R = 1 \div w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

(37)

The worn surfaces of the selected specimen were observed under an optical microscope and analyzed. Fig.16and 17.

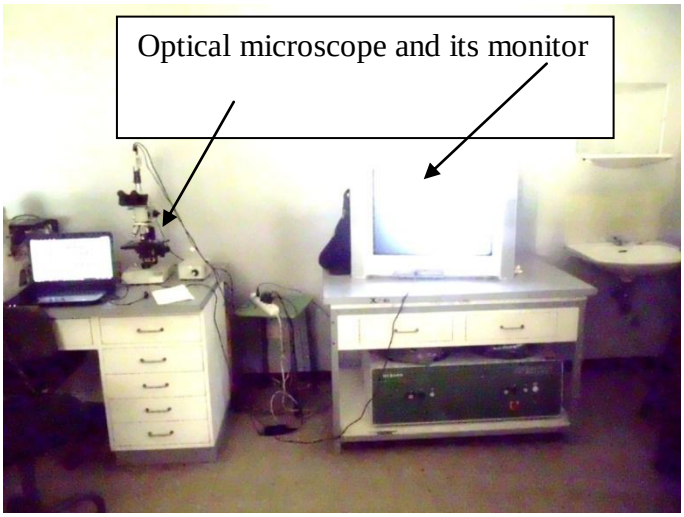

Figure 16 an optical microscope with observing monitor.

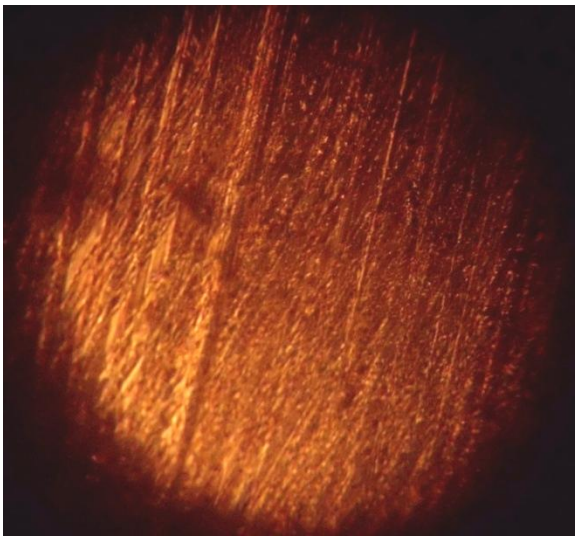

Figure 17 the tip of a specimen after a tribotest seen under the optical microscope X100.

CHAPTER IV: RESULS AND DISCUSSION

4.1 Results:

After conducting the Hardness, Conductivity, tribological and corrosion resistance test, the following results were obtained Tables 4, 5, 6, 7 and 8:

4.1.1 Hardness test result:

Table 4 Hardness and Density of each sample alloys.

MATERIAL	HARDNESS (RHN)	DENSITY (g/cm^3)
Cu-Ag	48.33	8.53
Cu-Sn	45.67	10.14
Cu-Sn-Cr	50.67	9.30
Cu-Ag-Sn	47.80	8.38

4.1.2 Conductivity test result:

Table 5 Conductivity test result of each sample alloys.

MATERIAL	Resistance in Ω	RESISTIVITY (ρ) in(Ωm) ρ=RA/l	CONDUCTIVITY (σ=1/ρ) in (S/m)	IACS in % ρ/1.7241e-8 x100%
Cu-Ag	1.72	1.7575e-8	5.6899e7	98.10
Cu-Ag-Sn	1.87	1.9157e-8	5.2201e7	90.0
Cu-Sn	2.09	2.1391e-8	4.6749e7	80.6
Cu-Sn-Cr	2.22	2.2686e-8	4.4081e7	76.0

4.1.3 Tribological test result:

Table 6 Results of a Wear test for applied loads of 3, 5, 7 Newton, (a, b, c).

(a)

MATERIAL	LOAD (N)	PRETEST WEIGHT (gm).	POSTTEST WEIGHT (gm).	CHANGE IN WEIGHT (ΔW) (gm).
Cu-Ag-Sn	3	13.7632	13.7600	0.0032
Cu-Sn-Cr	3	13.0190	13.0172	0.0020
Cu-Ag	3	16.8015	16.8010	0.0050
Cu-Sn	3	14.1014	14.0980	0.0034

(b)

MATERIAL	LOAD (N)	PRETEST WEIGHT (gm)	POSTTEST WEIGHT (gm)	CHANGE IN WEIGHT (ΔW)
Cu-Ag-Sn	5	13.1375	13.0875	0.050
Cu-Sn-Cr	5	14.7082	14.6882	0.0200
Cu-Ag	5	13.7855	13.7255	0.0600
Cu-Sn	5	14.1415	14.1115	0.0300

(c)

MATERIAL	LOAD (N)	PRETEST WEIGHT (g)	POSTTEST WEIGHT (g)	CHANGE IN WEIGHT (ΔW) (g)
Cu-Ag-Sn	7	13.1390	13.0690	0.070
Cu-Sn-Cr	7	14.7000	14.6700	0.0300
Cu-Ag	7	13.7795	13.6935	0.0860
Cu-Sn	7	14.1388	14.0908	0.0480

Note: The tribological test was done under those specified loads due to the limitations of the test machine, which has a minimum of 3N and a maximum of 7N load application with a strong vibration as it runs so that using fractional increments was not used as it gives a wrong result due to the vibration effect.

Table 7 Volume loss and Wear rate of Test pin alloys under different loads.

MATERIAL	Volume loss Δv= 1000ΔW/ρ, (mm^3)			Wear rate W= Δv/t, (mm^3/hr)			Time for total Loss
	APPLIED FORCE IN (N)						$t = \frac{1725.5mm^3}{w}$
	3	5	7	3	5	7	For 7N
Cu-Ag-Sn	0.381862	5.966587	8.353222	1.06E-04	1.66E-03	2.32E-03	7.44E+05
Cu-Sn-Cr	0.193548	2.150538	3.225806	5.38E-05	5.97E-04	8.96E-04	8.3E+08
Cu-Ag	0.058617	7.033998	10.08206	1.63E-05	1.95E-03	2.80E-03	2.96E+11
Cu-Sn	0.335306	2.95858	4.733728	9.31E-05	8.22E-04	1.31E-03	2.25E+14

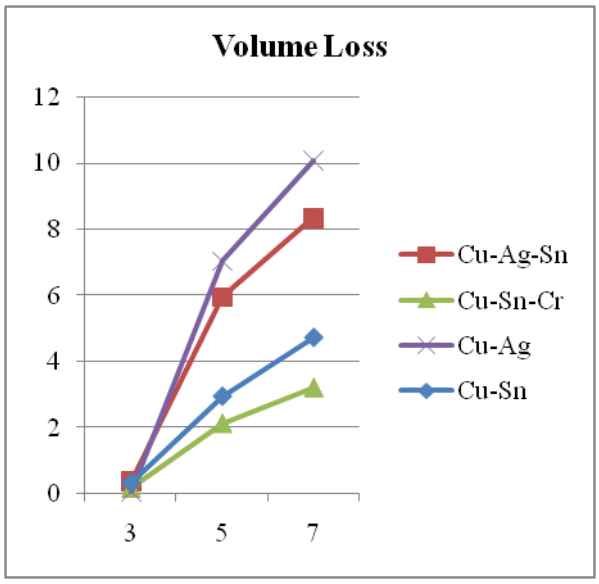

Figure 18 Plots of Cumulative volume loss vs. applied load.

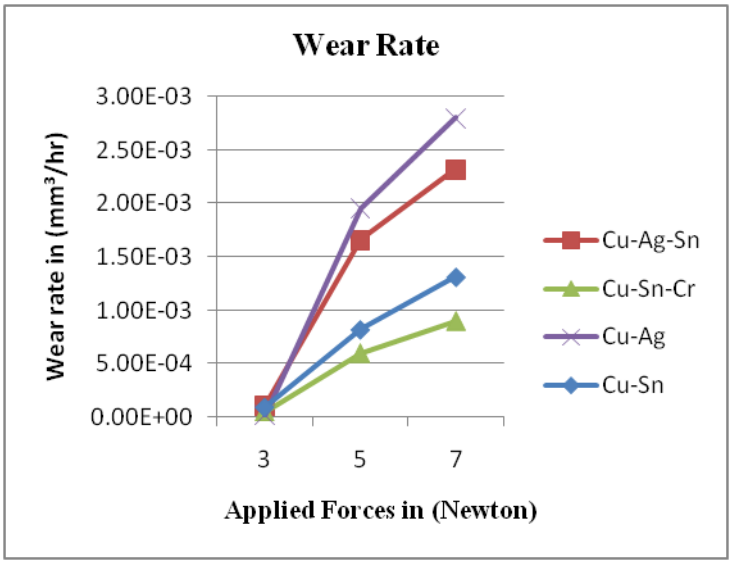

Figure 19 Plots of wear rate of copper alloys vs. applied load.

Table 8 Wear resistance of test pins under different load application.

The wear resistance R (h/mm³), Where: R= 1/W			
Applied Forces			
MATERIAL	3	5	7
Cu-Ag-Sn	9.43E+03	6.03E+02	4.31E+02
Cu-Sn-Cr	1.86E+04	1.67E+03	1.12E+03
Cu-Ag	6.14E+04	5.12E+02	3.57E+02
Cu-Sn	1.07E+04	1.22E+03	7.60E+02

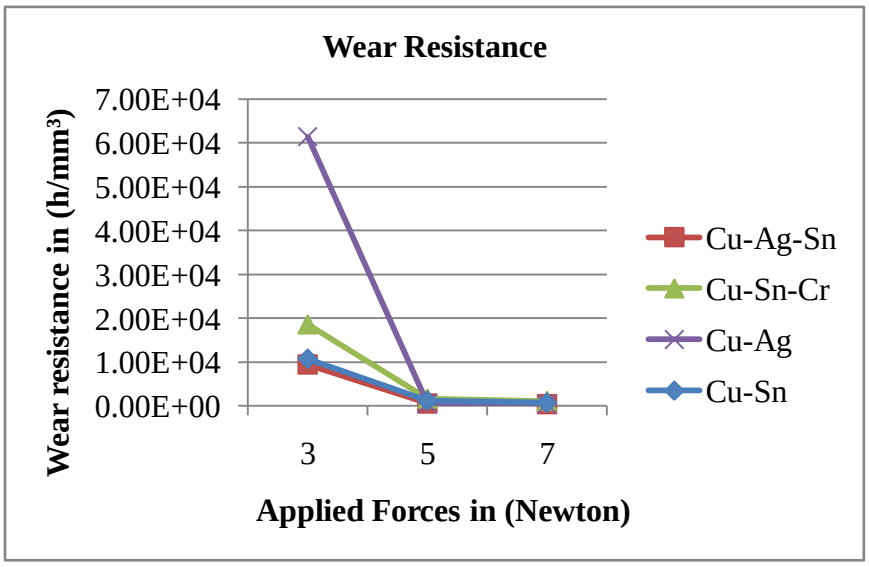

Figure 20 Sliding wear resistance vs. applied load

4.1.4 Corrosion Resistance Test Result:

Table 9 shows results after alloys have gone through the test and Fig.21 depicts in graph the weight loss of each sample in each corrosive media.

Table 9 Corrosion Resistance Test results of Test Pins.

CORROSION MEDIAS	Test samples and their Start Mass (gm).			
	Cu-Ag	Cu-Ag-Sn	Cu-Sn	Cu-Sn-Cr
3.5%NaCl	13.35	12.50	14.60	13.74
PH5 Acid rain	13.131	14.25	16.77	13.99
Distilled water	12.38	11.40	13.88	13.93
CORR0SION MEDDIAS.	Test samples and their Finish Mass (gm).			
	Cu-Ag	Cu-Ag-Sn	Cu-Sn	Cu-Sn-Cr
3.5%NaCl	13.05	12.23	14.20	13.54
PH5 Acid rain	12.63	13.95	16.30	13.74
Distilled water	12.34	11.37	13.81	13.91
CORROSION MEDIAS	Test samples weight loss = Start Mass – Finish Mass (gm).			
	Cu-Ag	Cu-Ag-Sn	Cu-Sn	Cu-Sn-Cr
3.5%NaCl	0.3	0.27	0.40	0.20
PH5 Acid rain	0.501	0.30	0.47	0.25
Distilled water	0.04	0.03	0.07	0.02

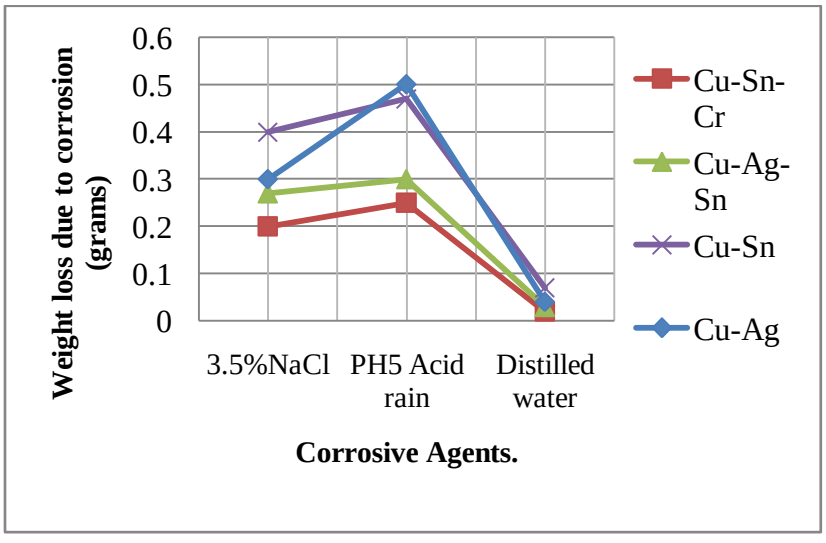

Figure 21 Plots of weight loss vs. corrosive media for the copper alloys.

4.1.5 Cost of each sample alloy (test pin)

The cost of the sample pin is calculated from current market price of the metals in each alloy. The price list for each metal is taken from Micron International Trading House in Addis-Ababa around Mexico Square and compared with international current metal price taken from WWW.mineinformation.com. The result is shown in Table 10.

Table 10 sample pins and their costs.

TEST PIN SAMPLE	COST (birr)
Cu-Sn	18.73
Cu-Sn-Cr	18.76
Cu-Ag-Sn	18.78
Cu-Ag	18.56

4.2 Discussion

4.2.1 The sliding wear

The graph of volume loss vs. applied load for copper alloys of different metals under constant time and velocity without current and no lubrication is shown in Fig.4.2.1. We can see the trend of an increase in volume loss for each alloy with an increase in applied force. According to the graph the Cu-Ag sample alloy has the greatest volume loss while Cu-Sn-Cr has the least, due to the presence of the chromium, which gives to the sample a harder surface coating. Since the sample pins slide against the rotating stainless steel, imitating the actual pantograph-catenary relative movement to each other under an upward pressing force of the pantograph strip, the type of wear between them is a sliding wear under a normal force. The mechanics of wear for this

type of contact and pressing force is abrasive. The asperities of the hard surface of the rotating disk/pantograph strip dig through the soft mating surface of the copper alloy/contact line. The wear rate of these sample alloys is plotted and shown in Fig.4.2.2. The wear rate of each material increases with an increase in applied load due to an increase in friction between the test pins and the disk.

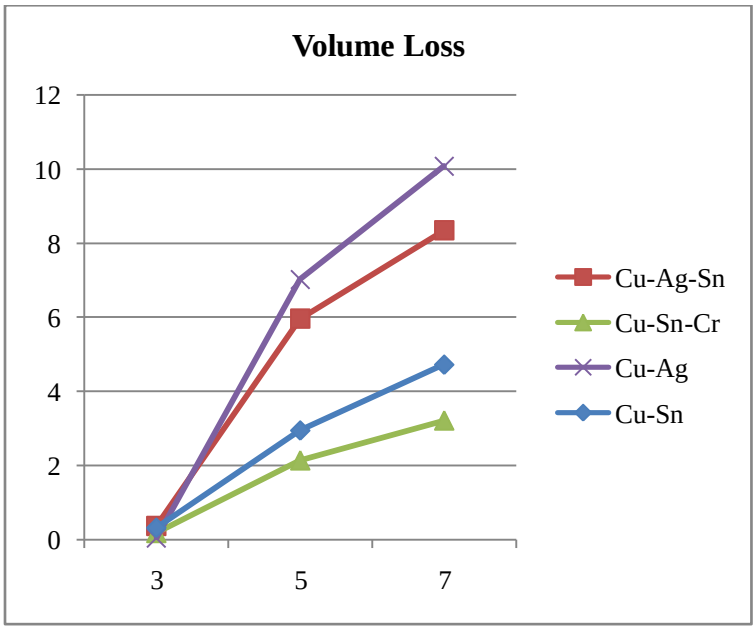

Figure 4.2.1 Cumulative volume loss vs. applied load.

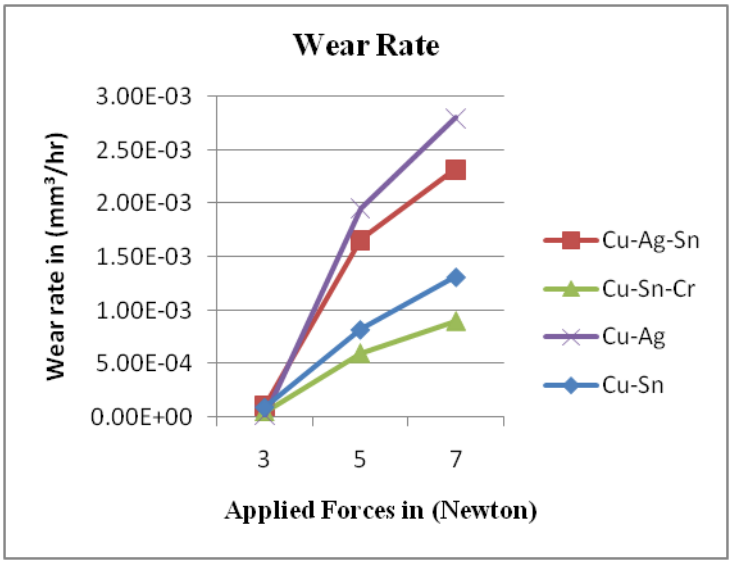

Figure 4.2.2 Plots of wear rate of copper alloys vs. applied load.

The wear resistance which is the inverse of wear rate is shown in Fig.4.2.3. The higher the wear rate of a material the less is its wear resistance under same conditions. In the graph we notice that the Cu-Ag alloy has the less wear resistance since it has the highest wear rate Fig.4.2.2. The Cu-Sn-Cr alloy has the highest wear resistance followed by Cu-Sn and Cu-Ag-Sn pin sample. Cu-Ag possesses the lowest resistance. At the start of the load application the Cu-Sn alloy and others have a significant level of resistance to wear, however when the applied load starts exceeding the 5Newton boundary the resistance falls dramatically. The list of wear resistance at 5 and 7 Newton at constant velocity and time in descending order is Cu-Sn-Cr > Cu-Sn > Cu-Ag-Sn > Cu-Ag. Addition of elements like Cr, and Sn to copper and its alloy like Cu-Ag increases its

hardness resulting in its wear resistance. The addition of Sn and Cr rather than Ag to copper increases its wear resistance by 3.5 times.

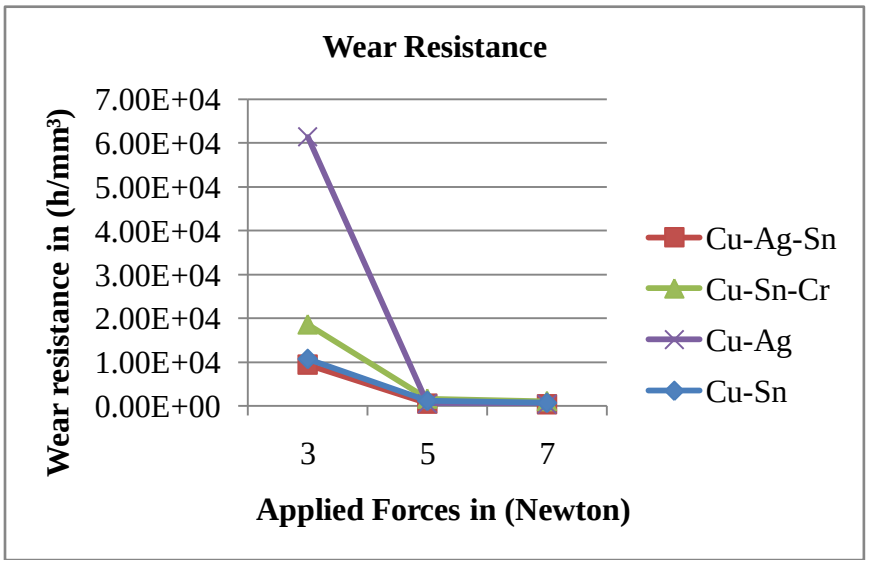

Figure 4.2.3 Wear resistance of sample alloys vs. applied load.

After completion of the tribological test under a specific applied load, the surface of each sample was observed under an optical microscope with a magnification of 100xs at the AAIT mechanical work shop and pictures were taken with a digital camera for analysis. Some of these pictures of worn surfaces of tested alloys with a load of 7N are shown in Fig.23 a, b, c, and d.

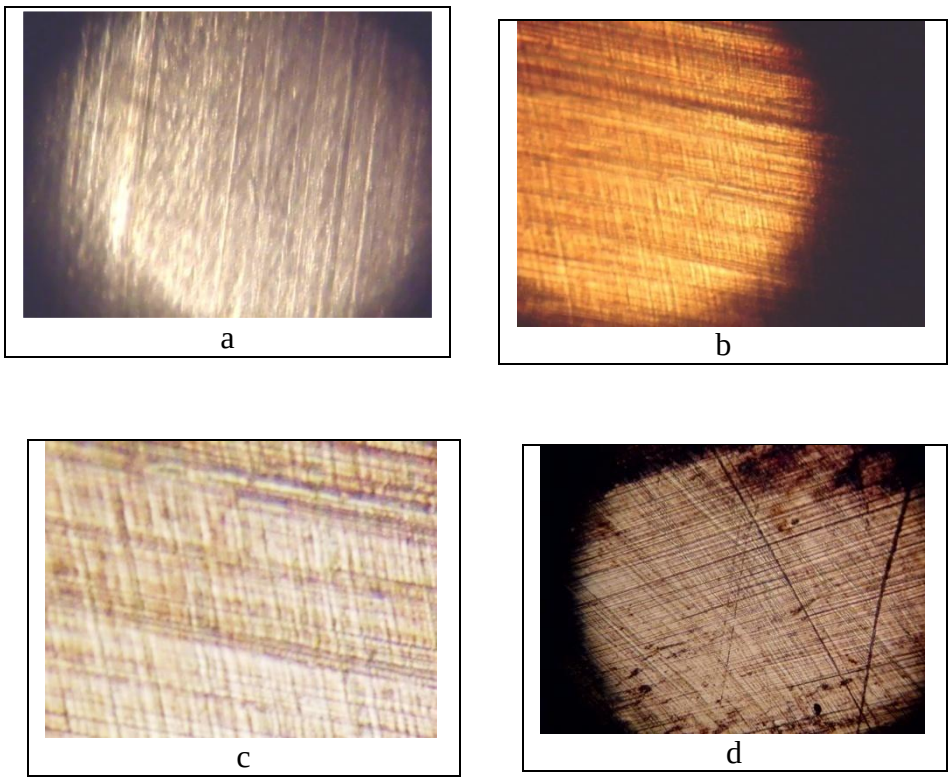

Figure 22 Picture of a worn surface of (a) Cu-Sn; (b) Cu-Ag; (c) Cu-Ag-Sn; (d) Cu-Sn-Cr under a load of 7N.

Since this experiment was done without current and lubrication, the main cause of the wear of the surfaces is friction. The main mechanisms of wear in this type of situation are abrasive and adhesive. For the abrasive wear to occur the asperities of the harder surface; the rotating stainless steel disk/the pantograph-strip in this case, must dig through the softer body; the copper alloy sample pin/the overhead contact line; thereby removing some material in shallow depth which is seen as a scratch on the surface. The particles removed in this process produce a continuous and parallel scratch line along the direction of motion of the harder surface.Fig.4.2.3. The mechanism

of the adhesive wear is the result of heat due to the friction created between these bodies in motion in a parallel and opposite direction under normal contact force plus the bonding of the asperity junction of both surfaces resulting in micro-scale welding of asperities. On the next cyclic movement of the parts the welded particles/ asperities brake off or detach and move in the direction of motion of the main sliding part there by leaving a pit like surface (adhesive wear) and making further a scratch (abrasive wear) on the softer surface. Upon analysis of the picture of the worn surfaces of Cu-Ag-Sn, Cu-Ag, and some part of Cu-Sn, Cu-Sn-Cr, Fig.23 a, b, c and d, the presences of dark spots tell a removal of some material from the surfaces of this alloy pins confirm the occurrence of the adhesive wear mechanism. In addition the friction which is created due to the sliding motion of parts under pressing force, in this case the test pin and the rotating disk accelerated the oxidation due to an increase in surface temperature which results in thermal softening of the substrate. The increase in temperature under dry and repeated sliding motion results in weakening of the oxide films and their fracture. In general the mechanisms of the sliding wear are the abrasive and the adhesive types. Therefore this type of wear causes a metal transfer, a metal oxide film formation and its removal, in addition to a cyclic surface deformation of this copper alloy test pins. The wear resistance of Cu-Ag is lower than that of Cu-Sn, Cu-Ag-Sn, and Cu-Sn-Cr as indicated by the more deformed surface as shown in Fig.23. When we look at the picture of the harder Cu-Sn-Cr worn surface, the size and depth of the grooves is much smaller.

From previous graphs of volume loss, wear rate, and wear resistance of sample alloys we could observe that with the increase of the applied load on test pins against the rotating disk of the

POD tribometer under constant velocity in time, volume loss and wear rate increase while the wear resistance decreases. The influence of an applied force on the wear rate W with zero current can be explained following the Archard's wear rate calculation formula: W=kFvH, where k is coefficient of wear, F = the applied force, while v=the sliding speed and H=the hardness of the sample. So if we hold constant all the variables and vary the value of F, then W (the wear rate) increases in direct proportion. From this we can conclude that, the magnitude of force applied on two relatively sliding surfaces controls in part the wear rate of one or both of the materials. The higher an applied force the higher is the wear rate and the less the wear resistance.

4.2.2 The Corrosion Resistance

The graph of weight loss of the copper alloys in different corrosive media against time is shown in Fig.4.1.4. The test pieces were tested for corrosion by immersion method in a 3.5% Na-Cl to represent sea shore environment, PH5 acid rain to imitate cities' climate with a lot of factory and vehicle emissions, and distilled water for normal water vapor saturated surroundings. The test was conducted for 7 consecutive days and 24 hours a day at room temperature and normal atmospheric pressure with a 30 volt DC current applied to the solutions to expedite the electrolytic process. One thing in common for all the alloys is that they have the maximum weight loss in PH5 acid rain environment with the least in distilled water.

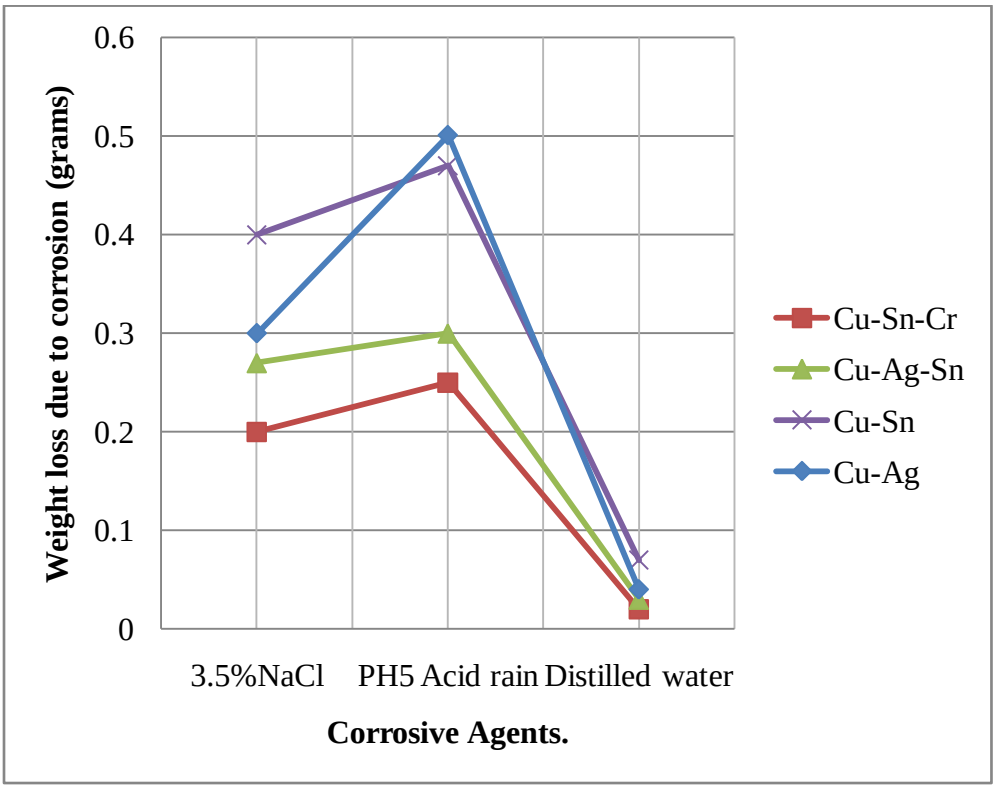

Figure 4.1.4 Plots of weight loss vs. corrosive media for the copper alloys.

The Cu-Sn-Cr alloy though has the minimum weight loss in all the media due to the presence of the Chromium metal. Cu-Ag has the least resistance to corrosion followed by Cu-Sn. If all the samples are presented in accordance with the magnitude of their resistance to those corrosive agents, the following will be their order of sequence:

Cu-Sn-Cr>Cu-Ag-Sn>Cu-Sn>Cu-Ag

The addition of 0.193% Cr in Cu-Sn-Cr is the case for this alloy to have a higher resistance to corrosion which shows that it can efficiently perform in salty and acidic rain environment. Due

to its better corrosion and wear resistances plus good conductivity, the Cu-Sn-Cr copper alloy is an alternate material for developing a catenary wire for electric trains.

4.2.3 Conductivity

It's known that copper is the best conductor next to silver, however due to some of its mechanical properties it usually is alloyed with some other metals in order to increase its strength and hardness. One problem though with alloying it is that, reduction of its conductivity level always is associated with an increase in those desirable mechanical properties. This fact is seen in those samples tested in this research. The current overhead contact line of the AA-LRT system the Cu-Ag alloy with a 98% IACS when alloyed with tin (Sn) improved its wear and corrosion resistance property but with some loss of conductance. When copper is alloyed with tin also increased its mechanical as well as chemical qualities in resisting wear or corrosion, the same is when Cu-Sn is alloyed with metal chromium, it increased in its hardness but still with a lower value in its conductivity. So when we put those test samples in the order of electrical conductivity we get the following hierarchy:

Cu-Ag >Cu-Ag-Sn >Cu-Sn >Cu-Sn-Cr

4.2.3 Hardness

Hardness is generally considered as resistance to penetration. The harder the material is, the greater the resistance to penetration. Hardness is directly related to the mechanical properties of the material. Factors influencing hardness include microstructure, grain size, strain hardening, etc. Generally as hardness increases so does yield strength and ultimate tensile strength (UTS), thus specifications often require the results of hardness tests rather than tensile tests [38]. So in

order to increase hardness of copper and its alloys in this research we used tin and chromium as diluting metals to alter some areas in the microstructure and grain size of those materials. As a result of this research we could be able to increase the hardness of copper and its alloys in this test by alloying it with tin and chromium. Summarizing the result according to hardness test result, the test samples of this experiment could be arranged as:

Cu-Sn-Cr>Cu-Ag>Cu-Ag-Sn>Cu-Sn

CHAPTER V: CONCLUSION AND RECOMMENDATION

5.1Conclusion

If we put the sample alloys in the order of their resistance to wear from highest to lowest they will be presented as follows: Cu-Sn-Cr > Cu-Sn > Cu-Ag-Sn > Cu-Ag. The wear resistance of these copper based sample alloys increased with decrease in normal force and the increase in their hardness. The wear rate and volume loss of all samples increased in some proportion with an increase in applied load. Sliding motion between parts without lubrication causes the rise in coefficient of friction there by creating a rise in surface temperature resulting in high wear rate. The adhesive wear (bonding of asperities and detachment of surface materials) and abrasive wear (the plowing of the asperities of the harder material through the surface of the softer) are the means of wear during this mechanical sliding in dry condition and with no current. During the process, film formation and removal, metal transfer, debris collection and surface deterioration was observed. Of all the sample alloys the Cu-Sn-Cr alloy has the best wear and corrosion resistance.

5.2 Recommendation

According to the results of all wear tests and its conductivity the Cu-Sn-Cr alloy has good qualities that are needed to be properties of an overhead contact wire material. Since our cities have the least or none toxic substance contaminated rain the AA-LRT can use this alloy for its contact wire production.

5.3 Future Works

- Upgrade the present tribo-test machine by redesigning the force applying compression spring so that a load more than 10N can be used during testing.
- Create a means for supplying constant electric power to the test piece and the rotating disk at the same time to imitate the real condition in the pantograph-catenary wire contact system.
- Do researches on the effect an arc discharge has upon wear rate and corrosion resistance of alloys.
- Modify the rotating disk so that the test sample is winded around its circumference and pressed against the pantograph strip sample at its radial end.
- Vary the content percentages of materials in each alloy and do similar research.
- Simplify the load application by finding a way so that different blocks of known weights can be loaded on to and against the rotating disk through the sample pin instead of using a compression spring.
- Perform the research similar to this or others using a finite-element or an appropriate kind of software.
- Choose one of the metal working techniques or methods cited in this research paper and conduct an experiment with similar or different materials used in this study, verify if any effect a metal working type has on its electro-mechanical properties.
- Find a way so that the temperature of the test pin and the coefficient of friction at any time can be known.
- Do this or other kind of similar test with a lubricated condition.

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APPENDIX A

ASTM GI

Standard Practice for Preparing, Cleaning, and Evaluation Corrosion Test Specimens

Designation: G 1 —90 (Reapproved 1999) a1

Specimens:

This standard is issued under the fixed designation G I the number immediately following the designation indicates the year of original adoption or, in the case of revision. The year of last revision is a number in parentheses that indicates the year of last reapproval. A superscript epsilon je) indicates an editorial change since the last revision or reapproval. €‘Nom—Editorial corrections were made throughout in January 1999.

Scope

1.1 this practice covers suggested procedures for preparing bare, solid metal specimens for tests, for removing corrosion products after the test has been completed. and for evaluating the corrosion damage that has occurred. Emphasis is placed on procedures related to the evaluation of corrosion by mass loss and pitting measurements.

1.2 This standard does not purport to address all of the safety concerns if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

This practice is under the jurisdiction of ASTM Committee G.l on Corrosion of Metals and is the direct responsibility of Subcommittee GOl.05 on Laboratory Corrosion Tests.

Methods for Preparing Specimens for Test

2.1 For laboratory corrosion tests that simulate exposure to service environments, a commercial surface, closely resembling the one that would be used in service, will yield the most meaningful results.

2.2 It is desirable to mark specimens used in corrosion tests with a unique designation during preparation. Several techniques may be used depending on the type of specimen and test.

2.2.1 Stencil or Stamp—most metallic specimens may be marked by stenciling, that is. imprinting the designation code into the metal surface using hardened steel stencil stamps hit with a hammer. The resulting imprint will be visible even after substantial corrosion has occurred. However, this procedure introduces localized strained regions and the possibility of superficial iron contamination in the marked area.

2.2.2 Electric engraving by means of a vibratory marking tool may be used when the extent of corrosion damage is known to be small. However, this approach to marking is much more susceptible to having the marks lost as a result of corrosion damage during testing.

2.2.3 Edge notching is especially applicable when extensive corrosion and accumulation of corrosion products is anticipated. Long term atmospheric tests and sea water immersion tests on steel alloys are examples where this approach is applicable. It is necessary to develop a code system when using edge notches.

2.2.4 Drilled holes may also be used to identify specimens when extensive metal loss, accumulation of corrosion products, or heavy scaling is anticipated. Drilled holes may be simpler and less costly than edge notching. A code system must be developed when using drilled holes. Punched holes should not be used as they introduce residual strain.

2.2.5 When it is undesirable to deform the surface of specimens after preparation procedures, for example, when testing coated surfaces, tags may be used for specimen identification. A metal or plastic wire can be used to attach the tag to the specimen and the specimen identification can be stamped on the tag. It is important to ensure that neither the tag nor the wire will corrode or degrade in the test environment. It is also important to be sure that there are no galvanic interactions between the tag, wire, and specimen.

2.3 For more searching tests of either the metal or the environment, standard surface finishes may be preferred. A suitable procedure might be:
2.3.1 Degrease in an organic solvent or hot alkaline cleaner. (Sec also Practice G 31.) Ultrasonic cleaning may be beneficial in both pre-test and posttest cleaning procedures.

2.3.2 Pickle in an appropriate solution if oxides or tarnish are present. In some cases the chemical cleaners described in Section 6 will suffice.

2.3.3 Abrade with a slurry of an appropriate abrasive or with an abrasive paper (see Practices A 262 and Test Method D 1384). The edges as well as the faces of the specimens should be abraded to remove burrs.

2.3.4 Rinse thoroughly in hot air, dry and store in desiccators.
2.4 When specimen preparation changes the metallurgical condition of the metal, other methods should be chosen or the metallurgical condition must be corrected by subsequent treatment. For example, shearing a specimen to size will cold work and may possibly fracture the edges. Edges should be machined.

2.5 The clean, dry specimens should be measured and weighed. Dimensions determined to the third significant figure and mass determined to the fifth significant figure are suggested. When more significant figures are available on the measuring instruments, they should be recorded.

3. Methods for Cleaning After Testing
3.1 Corrosion product removal procedures can be divided into three general categories: mechanical, chemical, and electrolytic.

3.1.1 An ideal procedure should remove only corrosion products and not result in removal of any base metal. To determine the mass loss of the base metal when removing corrosion products replicate uncorroded control specimens should be cleaned by the same procedure being used on the test specimen. By weighing the control specimen before and after cleaning, the extent of metal loss resulting from cleaning can be utilized to correct the corrosion mass loss.

3.1.2 The procedure given in 3.1.1 may not be reliable when heavily corroded specimens are to be cleaned. The application of replicate cleaning procedures to specimens with corroded surfaces will often, even in the absence of corrosion products. result in continuing mass losses. This is because a corroded surface, particularly of a multiphase alloy, is often more susceptible than a freshly machined or polished surface to corrosion by the cleaning procedure. In such cases, the following method of determining the mass loss due to the cleaning procedure is preferred.

3.1.2.1 The cleaning procedure should be repeated on specim ens several times. The mass loss should be determined after each cleaning by weighing the specimen.

3.1.2.2 The mass loss should be graphed as a function of the number of equal cleaning cycles as shown in Fig. I. Two lines will be obtained: AB and BC. The latter will correspond to corrosion of the metal after removal of corrosion products. The mass loss due to corrosion will correspond approximately to point B.

3.1.2.3 To minimize uncertainty associated with corrosion of the metal by the cleaning method, a method should be chosen to provide the lowest slope (near to horizontal) of line for removal of corrosion products. Removal can often be confirmed by examination with a low power

microscope (for example, 7X to 30X). This is particularly useful with pined surfaces when corrosion products may accumulate in pits. This repeated treatment may also be necessary because of the requirements of 7.1.2.1. Following the final treatment, the specimens should be thoroughly rinsed and immediately dried.

3.1.4 All cleaning solutions shall be prepared with water and reagent grade chemicals.

3.2 Chemical procedures involve immersion of the corrosion test specimen in a specific solution that is designed to remove the corrosion products with minimal dissolution of any base metal. The choice of chemical procedure to be used is partly a matter of trial and error to establish the most effective method for a specific metal and type of corrosion product scale.

3.2.1 Chemical cleaning is often preceded by light brushing (non metallic bristle) or ultrasonic cleaning of the test specimen to remove loose, bulky corrosion products.

7.2.2 Intermittent removal of specimens from the cleaning solution for light brushing or ultrasonic cleaning can often facilitate the removal of tightly adherent corrosion products.

3.2.3 Chemical cleaning is often followed by light brushing or ultrasonic cleaning in reagent water to remove loose products.

3.3 Electrolytic cleaning can also be utilized for removal of corrosion products.

3.3.1 Electrolytic cleaning should be preceded by brushing or ultrasonic cleaning of the test specimen to remove loose, bulky corrosion products. Brushing or ultrasonic cleaning should also follow the electrolytic cleaning to remove any loose slime or deposits. This will help to minimize any deposition of metal from reducible corrosion products that would reduce the apparent mass loss.

3.4 Mechanical procedures can include scraping. Scrubbing, brushing, ultrasonic cleaning, mechanical shocking, and impact blasting (for example, grit blasting, water-jet blasting, and so forth). These methods are often utilized to remove heavily encrusted corrosion products. Scrubbing with a nonmetallic bristle brush and mild abrasive-distilled water slurry can also be used to remove corrosion products.

3.4.1 Vigorous mechanical cleaning may result in the removal of some base metal; therefore, care should be exercised. These should be used only when other methods fail to provide adequate

removal of corrosion products. As with other methods, correction for metal loss due to the cleaning method is recommended. The mechanical forces used in cleaning should be held as nearly constant as possible.

4. Assessment of Corrosion Damage

4.1 The initial mass of the specimen and the mass lost during the test are determined. The average corrosion loss may then be obtained as the difference in weight.

NOTE: This is an excerpt from the original standard; to put the whole information on this paper will be lengthy and exhaustive. So for detailed information this manual can be downloaded from the web.

APPENDIX B

ASTM G99

Standard Test Method for

Wear Testing with a Pin-on-Disk Apparatus.

Designation: G 99 – 95a (Reapproved 2000) e1

This standard is issued under the fixed designation G 99; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (e) indicates an editorial change since the last revision or reapproval. e1 NOTE—Editorial corrections were made throughout in May 2000.

1. Scope

1.1 This test method describes a laboratory procedure for determining the wear of materials during sliding using a pin-on-disk apparatus. Materials are tested in pairs under nominally non abrasive conditions. The principal areas of experimental attention in using this type of apparatus to measure wear are described. The coefficient of friction may also be determined.

1.2 The values stated in SI units are to be regarded as standard.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Summary of Test Method

2.1 For the pin-on-disk wear test, two specimens are required.

One, a pin with a radiuses tip, is positioned perpendicular to the other, usually a flat circular disk. A ball, rigidly held, is often used as the pin specimen. The test machine causes either the disk specimen or the pin specimen to revolve about the disk center. In either case, the sliding path is a circle on the disk surface. The plane of the disk may be oriented either horizontally or vertically.

NOTE 1—Wear results may differ for different orientations.

2.1.1 The pin specimen is pressed against the disk at a specified load usually by means of an arm or lever and attached weights. Other loading methods have been used, such as, hydraulic or pneumatic.

NOTE 2—Wear results may differ for different loading methods.

2.2 Wear results are reported as volume loss in cubic millimeters for the pin and the disk separately. When two different materials are tested, it is recommended that each material be tested in both the pin and disk positions.

2.3 The amount of wear is determined by measuring appropriate linear dimensions of both specimens before and after the test, or by weighing both specimens before and after the test. If linear measures of wear are used, the length change or shape change of the pin, and the depth or shape change of the disk wear track (in millimeters) are determined by any suitable metrological technique, such as electronic distance gauging or stylus profiling. Linear measures of wear are converted to wear volume (in cubic millimeters) by using appropriate geometric relations. Linear measures of wear are used frequently in practice since mass loss is often too small to measure precisely.

If loss of mass is measured, the mass loss value is converted to volume loss (in cubic millimeters) using an appropriate value for the specimen density.

2.4 Wear results are usually obtained by conducting a test for a selected sliding distance and for selected values of load and speed. One set of test conditions that was used in an interlaboratory measurement series is given in Table 1 and Table 2 as a guide. Other test conditions may be selected depending on the purpose of the test.

2.5 Wear results may in some cases be reported as plots of wear volume versus sliding distance using different specimens for different distances. Such plots may display non-linear relationships between wear volume and distance over certain portions of the total sliding distance, and linear relationships over other portions.

3. Significance and Use

4.1 The amount of wear in any system will, in general, depend upon the number of system factors such as the applied load, machine characteristics, sliding speed, sliding distance, the environment, and the material properties. The value of any wear test method lies in predicting the relative ranking of material combinations. Since the pin-on-disk test method does not attempt to duplicate all the conditions that may be experienced in service (for example; lubrication, load, pressure, contact geometry, removal of wear debris, and presence of corrosive environment), there is no insurance that the test will predict the wear rate of a given material under conditions differing from those in the test.

4. Apparatus

4.1 General Description— see Fig.

4.2 *Wear Measuring Systems*—Instruments to obtain linear measures of wear should have a sensitivity of 2.5 μm or better. Any balance used to measure the mass loss of the test specimen

shall have a sensitivity of 0.1 mg or better; in low wear situations greater sensitivity may be needed.

5. Test Specimens and Sample Preparation

5.1 *Materials*—This test method may be applied to a variety of materials. The only requirement is that specimens having the specified dimensions can be prepared and that they will withstand the stresses imposed during the test without failure or excessive flexure. The materials being tested shall be described by dimensions, surface finish, material type, form, composition, microstructure, processing treatments, and indentation hardness (if appropriate).

5.2 *Test Specimens*—The typical pin specimen is cylindrical or spherical in shape. specimen diameters range from 2 to 10 mm. The typical disk specimen diameters range from 30 to 100 mm and have a thickness in the range of 2 to 10 mm.

6. Test Parameters

6.1 *Load*—Values of the force are expressed in Newton at the wearing contact.

6.2 *Speed*—The relative sliding speed between the contacting surfaces in meters per second.

6.3 *Distance*—The accumulated sliding distance in meters.

6.4 *Temperature*—The temperature of one or both specimens at locations close to the wearing contact.

6.5 *Atmosphere*—The atmosphere (laboratory air, relative humidity, argon, lubricant, etc.) surrounding the wearing contact.

7. Procedure

7.1 Immediately prior to testing, and prior to measuring or weighing, clean and dry the specimens. Take care to remove all dirt and foreign matter from the specimens. Use non-chlorinated, non-film-forming cleaning agents and solvents and dry the materials.

7.2 Measure appropriate specimen dimensions to the nearest 2.5 μm or weigh the specimens to the nearest 0.0001 g.

7.3 Insert the disk securely in the holding device so that the disk is fixed perpendicular to the axis of the revolution.

7.4 Insert the pin specimen securely in its holder and, if necessary, adjust so that the specimen is perpendicular to the disk surface when in contact, in order to maintain the necessary contact conditions.

7.5 Add the proper mass to the system lever or bale to develop the selected force pressing the pin against the disk.

7.6 Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disk.

7.7 Begin the test with the specimens in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted or restarted.

7.8 Remove the specimens and clean off any loose wear debris. Note the existence of features on or near the wear scar such as: protrusions, displaced metal, discoloration, micro-cracking, or spotting.

7.9 Remeasure the specimen dimensions to the nearest 2.5 μm or reweigh the specimens to the nearest 0.0001 g, as appropriate.

7.10 Repeat the test with additional specimens to obtain sufficient data for statistically significant results.

8. Calculation and Reporting

8.1 The wear measurements should be reported as the volume loss in cubic millimeters for the pin. While mass loss results may be used internally in laboratories to compare materials of equivalent densities, this test method reports wear as volume loss so that there is no confusion caused by variations in density. Take care to use and report the best available density value for the materials tested when calculating volume loss from measured mass loss.

8.2 Use the following equation for conversion of mass loss to volume loss.

Volume loss, mm^3

Mass loss, g

Density, g/cm^3 x 1000.

8.3 Adequate specification of the materials tested is important. As a minimum, the report should specify material type, form, processing treatments, surface finish, and specimen preparation procedures. If appropriate, indentation hardness should be reported.

NOTE: This is an excerpt from the original standard; to put the whole information on this paper will be lengthy and exhaustive. So for detail information this manual can be downloaded from the web.

APPENDIX C

ASTM E18 – 02

Designation: E 18 2000

Standard Test Methods for

Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials1,2

Designation: E 18 2000.

This standard is issued under the fixed designation E 18; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (e) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 These test methods cover the determination of the Rockwell hardness and the Rockwell superficial hardness of metallic materials, including test methods for the verification of machines for Rockwell hardness testing (Part B) and the calibration of standardized hardness test blocks (Part C).

1.2 Values stated in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

3. Terminology

3.1 *Definitions:*

3.1.1 *calibration*—determination of the values of the significant parameters by comparison with values indicated by a reference instrument or by a set of reference standards.

3.1.2 *Rockwell hardness number, HR*—a number derived from the net increase in the depth of indentation as the force on an indenter is increased from a specified preliminary test force to a specified total test force and then returned to the preliminary test force.

3.1.2.1 *Discussion—Indenters*—Indenters for the Rockwell hardness test include a diamond spheroconical indenter and ball indenters (steel or tungsten carbide) of several specified diameters.

3.1.2.2 Discussion. Rockwell hardness numbers are always quoted with a scale symbol representing the indenter and forces used. The hardness number is followed by the symbol HR and the scale designation. When a ball indenter is used, the scale designation is followed by the letter 'S' to indicate the use of a steel ball or the letter 'W' to indicate the use of a tungsten carbide ball.

3.1.2.3 Examples.64 HRC = Rockwell hardness number of 64 on Rockwell C scale. 81 HR30N = Rockwell superficial hardness number of 81 on Rockwell 30N scale. 72 HRBW = Rockwell hardness number of 72 on the Rockwell B scale measured using a tungsten carbide ball indenter.

3.1.3 Rockwell hardness test. An indentation hardness test using a verified machine to force a diamond spheroconical indenter (diamond indenter), or a ball indenter (steel or tungsten carbide) under specified conditions, into the surface of the material under test in two operations, and to measure the difference in depth of the indentation under the specified conditions of preliminary and total test forces (minor and major loads, respectively).

4. Significance and Use

4.1 The Rockwell hardness test is an empirical indentation hardness test. Rockwell hardness tests provide useful information about metallic materials. This information may correlate to tensile strength, wear resistance, ductility, and other physical characteristics of metallic materials, and may be useful in quality control and selection of materials.

4.2 Rockwell hardness testing at a specific location on a part may not represent the physical characteristics of the whole part or end product.

4.3 Performance verifications of Rockwell hardness indenters and hardness machines shall be made using test blocks calibrated traceable to the Rockwell standards maintained by NIST when primary reference test blocks are available from NIST for the specific Rockwell scale.

5.2 Description of Machine and Method of Test. The tester for making Rockwell hardness determinations is a machine that measures hardness by determining the difference in penetration depths of an indenter under two specified forces, called preliminary and total test forces.

5.2.1 There are two general classifications of the Rockwell test: the Rockwell hardness test and the Rockwell superficial hardness test.

5.2.2 In the Rockwell hardness test the preliminary test force is 10 kgf (98 N). Total test forces are 60 kgf (589 N), 100 kgf (981 N) and 150 kgf (1471 N). In the Rockwell superficial hardness test the preliminary test force is 3 kgf (29 N) and total test forces are 15 kgf (147 N), 30 kgf (294 N), and 45 kgf (441 N). The indenter for either test shall be of a spheroconical or spherical configuration. Scales vary by a combination of total test force and type of indenter.

5.2.3 The difference in depth is normally measured by an electronic device or by a dial indicator. The hardness value, as read from the instrument, is an arbitrary number which is related to the difference in the depths produced by the two forces; and since the scales are reversed, the higher the number the harder the material.

5.2.4 In accordance with the operating procedures recommended by the manufacturer of the hardness tester, the test is started by applying the preliminary test force causing an initial penetration of the specimen. Since measurement of the difference in depth starts after the preliminary force has been applied, the dial gage pointer is set to zero if the instrument is a dial indicator model. On a digital readout instrument, the zero point is captured by the electronics automatically. The instrument shall be designed to eliminate the effect of impact in applying the preliminary test force.

5.2.5 The additional force is applied for the required dwell time and then removed. The return to the preliminary test force position holds the indenter at the point of deepest penetration yet allows elastic recovery to occur and the stretch of the frame to be factored out. The test result is displayed by the testing machine.

5.3 Indenters:

5.3.1 The standard indenters are the diamond spheroconical indenter and steel ball indenters having steel or tungsten carbide balls 1.16 , 1.8 , 1.4 , and 1.2 in. (1.588, 3.175, 6.350, and 12.70 mm) in diameter.

5.3.2 The diamond indenter shall conform to the requirements prescribed in 13.1.2.1.

5.3.3 Indenter balls can be either tungsten carbide or hardened steel; however, tungsten carbide balls are recommended to reduce errors associated with the tendency of steel balls to flatten with use. Indenter balls shall conform to the requirements prescribed in 13.1.2.2.

5.3.4 Dust, dirt, grease, and scale shall not be allowed to accumulate on the indenter as this will affect the test results.

5.4 Anvils. An anvil shall be used that is suitable for the specimen to be tested. The seating and supporting surfaces of all anvils shall be clean and smooth and shall be free from pits, deep scratches, and foreign material. If the provisions of 6.3 on thickness of the test piece are complied with, there will be no danger of indenting the anvil, but, if it is so thin that the impression shows through on the underside, the anvil may be damaged. Damage may also occur from accidental contacting of the anvil by the indenter. If the anvil is damaged from any cause, it shall be replaced. Anvils showing the least visible dent will give inaccurate results on thin material.

5.4.1 Cylindrical pieces shall be tested with a V-grooved anvil that will support the specimen with the axis of the V-groove directly under the indenter or on hard, parallel, twin cylinders properly positioned and clamped in their base.

5.4.2 Flat pieces shall be tested on a flat anvil that has a smooth, flat bearing surface whose plane is perpendicular to the axis of the indenter.

6. Test Piece

6.1 The test shall be carried out on a smooth; even surface that is free from oxide scale, foreign matter, and, in particular, completely free from lubricants. An exception is made for reactive metals, such as titanium, that may adhere to the indenter. In such situations, a suitable lubricant such as kerosene may be used. The use of a lubricant shall be reported on the test report.

6.2 Preparation shall be carried out in such a way that any alteration of the surface hardness (for example, due to heat or cold-working) is minimized.

12. General Requirements

12.1 Before a Rockwell hardness testing machine is verified, it shall be checked to ensure that:

12.1.1 The machine is properly set up.

12.1.2 The indenter-holder is properly seated in the plunger.

12.1.3 When the indenter is a steel ball, the holder is fitted with a new ball that complies with 13.1.2.2. A new ball is not required when a tungsten carbide ball is used.

12.1.4 When the indenter is a diamond indenter, it must be free from defects which may affect the accuracy of the test (See 13.1.2.1).

12.1.5 The test force can be applied and removed without shock or vibration and in such a manner that the readings are not influenced.

13.1.2 Verification of the indenter.

13.1.2.1 Diamond Indenter:

(1) The diamond indenter shall be free from surface defects (cracks, chips, pits, etc.) and polished to such an extent that no unpolished part of its surface makes contact with the test piece when the indenter penetrates to a depth of 0.3 mm for Rockwell hardness testing and 0.2 mm for Rockwell superficial hardness testing.

(2) The verification of the shape of the indenter can be made by direct measurement or by measurement of its projection on a screen. The verification shall be made at not less than four approximately equally spaced sections.

(3) The diamond indenter shall have an included angle of 120□ ‹ 6 0.35.

(4) The angle between the axis of the diamond indenter and the axis of the indenter holder (normal to the seating surface) shall not exceed 0.5‹.

(5) The spherical tip of the diamond cone shall have a mean radius of 0.200 6 0.010 mm. In each measured section the radius shall not exceed 0.200 6 0.015 mm and local deviations from a true radius shall not exceed 0.002 mm. The surfaces of the cone and spherical tip shall blend in a truly tangential manner.

(6) The hardness values given by the testing machine do not depend only on the dimensions given in 13.1.2.1 (c-e), but also on the surface roughness and the position of the crystallographic axis of the diamond and the seating of the diamond in its holder. For this reason, a performance test is considered necessary. The indenter shall be used in a standardizing machine in which the test force applied and the measuring device can be verified by fundamental measurement. Tests shall be made on a minimum of two standardized blocks, that comply with the requirements of Part C, one from each of the minimum and maximum ranges specified in Table 16. Three test impressions shall be made on each of these blocks.

16.5 The maximum deviation in flatness of the surfaces shall not exceed 0.0002 in. (0.005 mm).

16.6 The maximum error in parallelism shall not exceed 0.0002 in. per in.(mm per mm).

16.7 The test surface shall be free from scratches which interfere with the measurement of the indentation. The mean surface roughness (Ra) shall not exceed 12 ƒÊin. (0.0003 mm) center line average.

16.8 The bottom surface shall have a fine ground finish.

NOTE: This is an excerpt from the original standard; to put the whole information on this paper will be lengthy and exhaustive. So for detail information this manual can be downloaded from the web.

APPENDIX D

The International Annealed Copper Standard

The International Annealed Copper Standard (IACS) establishes a standard for the conductivity of commercially pure annealed copper. The standard was established in 1913 by the International Electro-technical Commission. The Commission established that, at 20°C,commercially pure, annealed copper has a resistivity of 1.7241x108ohmmeter or 5.8001x107Siemens/meter when expressed in terms of conductivity.

For convenience, conductivity is frequently expressed in terms of percent IACS. A conductivity of 5.8001x107S/m may be expressed as 100% IACS at 20°C. All other conductivity values are related back to this standard value of conductivity for annealed copper. Therefore, iron with a conductivity value of 1.04 x 107 S/m, has a conductivity of approximately 18% of that of annealed copper and this is reported as 18% IACS. An interesting side note is that commercially pure copper products now often have IACS conductivity values greater than 100% IACS because processing techniques have improved since the adoption of the standard in 1913 and more impurities can now be removed from the metal. Wire of high purity has been produced having a conductivity of slightly over 103% IACS, which is very near the value expected for copper without any impurity.

A Brief History on the IACS

Prior to the establishment of the IASC standard in 1913, there was a lack of uniformity in the values for annealed copper adopted in various countries. These conditions led the Standards Committee of the American Institute of Electrical Engineers to request the U.S. Bureau of Standards to make an investigation of the subject. This was done and resulted in the establishment of standard values based on measurements of a large number of representative samples of copper from 14 important copper refiners. Resistivity measurements were made on samples of copper wire one meter in length and one square millimeter in cross-section.

This investigation led to the adoption of the IACS by the International Electro-technical Commission. The IACS standard was documented in Publication 28 of the International Electro-technical Commission in March of 1914. Publication 28 which is titled, International Standard of Resistance for Copper, states:

The following shall be taken as normal values for standard annealed copper:

1. At a temperature of 20°C the resistance of a wire of standard annealed copper one meter in length and of a uniform section of one square millimeter is 1/58 ohm, which in decimal terms is 0.017241ohm (meter,mm 2).

2. At a temperature of 20°C the density of standard annealed copper is 8.89 grams per cubic centimeter.

3. At a temperature of 20°C the constant mass temperature coefficient of resistance of standard annealed copper, measured between two potential points rigidly fixed to the wire, is 0.00393 per degree centigrade.

4. As a consequence, it follows from (1) and (2) that at a temperature of 20°C the resistance of a wire of standard annealed copper of uniform section one meter in length and weighing one gram is 1/58 x 8.89, which equals 0.15328 ohm (meter, gram). Please note that the unit for resistivity was expressed as 0.017241ohm (meter,mm2) reflecting the units of the length and cross-section of the wire standard. To reduce confusion, the cross-section unit of millimeters is converted to the length unit of meters and the resistivity of the IACS is now typically expressed as 1.7241x108ohmmeter. Also note that the units of volume resistivity and mass resistivity are interrelated through the density, which was taken as 8.89 grams per cm3 at 20° C, by the International Electro technical Commission.

For additional information see, the National Bureau of Standards Circular No. 31 (1914 Edition), which is available online at openlibrary.org. Note: Publication No. 28 of the International Electro technical Commission, "International Standard of Resistance for Copper (March 1914) is included in Appendix V of this document.