ANKARA YILDIRIM BEYAZIT UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

SILICON CARBIDE REINFORCEMENT SILVER METAL MATRIX NANOCOMPOSITE COATINGS ON COPPER BY DIFFERENT ELECTRODEPOSITION METHODS AND AMOUNT OF SILICON CARBIDE

M.Sc. Thesis by

Ece Gürcan Başkaya

Department of Materials Engineering

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SILICON CARBIDE REINFORCEMENT SILVER METAL MATRIX NANOCOMPOSITE COATINGS ON COPPER BY DIFFERENT ELECTRODEPOSITION METHODS AND AMOUNT OF SILICON CARBIDE

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled "SILICON CARBIDE REINFORCEMENT SILVER METAL MATRIX NANOCOMPOSITE COATINGS ON COPPER BY DIFFERENT ELECTRODEPOSITION METHODS AND AMOUNT OF SILICON CARBIDE" completed by ECE GÜRCAN under supervision of Assoc. Prof. RAMAZAN KARSLIOĞLU and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Ass. Prof. Dr. Ramazan KARSLIOĞLU

Supervisor

Prof Dr. Aytunç ATEŞ

(Jury Member)

Prof Dr. Hakan ATEŞ

(Jury Member)

Prof. Dr. Ergün ERASLAN

Director
Graduate School of Natural and Applied Sciences

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ABSTRACT

Silver is the most preferred materials metal between others in electronic and electrical industry because it has the highest electrical conductivity at room temperature. It has some intrinsic qualities such as great electrical and thermal conductivity. So, silver can be used for coating applications for electrical and electronic conductors. However, there are some weak properties for example low mechanical properties. Therefore, silver electrical contact materials can be reinforced by the second phase such as silicon carbide and carbon nanotube. In this study, silicon carbide has chosen as second phase for nanocomposite coating because of its unique mechanical and chemical properties.

Unreinforced silver and various amounts of nano-sized silicon carbide reinforced silver metal matrix nanocomposite coatings were obtained by using electrodeposition technique to improve electrical properties. Different types of current which are direct current, pulse current and pulse reverse current were used. The influences of different types of current and various amount of nano-sized silicon carbide on the morphology, crystallographic orientation, mechanical and electrical properties were investigated with Scanning Electron Microscope, X-Ray Diffraction methods, Vickers's Micro Hardness test and electrical contact test respectively. Taking into account all of these, the best mechanical property was obtained with reinforced Silver by silicon carbide which were used 1 g/L amounts by pulse reverse current electrodeposition method. Also, the best electrical contact performance was obtained with reinforced by silicon carbide which were used 1 g/L amounts by direct current electrodeposition method.

Keywords: Silver, Silicon Carbide, Electrodeposition, Electrical Contact Material

SİLİSYUM KARBÜR GÜÇLENDİRİCİLİ GÜMÜŞ METAL MATRİX NANOKOMPOZİT KAPLAMALARIN BAKIR ÜZERİNE FARKLI ELEKTRODEPOZİSYON YÖNTEMLERİ VE FARKLI MİKTARLARDAKİ SİLİSYUM KARBÜR TAKVİYESİ İLE ELDE EDİLMESİ

ÖZ

Oda sıcaklığında en yüksek elektrik iletkenliğine sahip olan Gümüş, elektrik ve elektronik sektöründe diğer metaller arasında en çok tercih edilen metaldir. Ayrıca iyi korozyon direnci, mükemmel elektriksel iletkenlik gibi bazı doğal özelliklere de sahiptir. Bu nedenle gümüş, elektrik kontak parçaları gibi elektronik iletkenlerin kaplama uygulamalarında kullanılabilir. Gümüşün düşük mekanik özellikler gibi bazı zayıf özellikleri de vardır. Bu nedenle, gümüş ideal bir elektrik kontak malzemesi olabilmesi için ikinci faz takviyesi ile güçlendirilebilir. Bu çalışmada silisyum karbür eşsiz mekanik mukavemeti ve kimyasal özellikleri nedeniyle nano kompozit kaplama elde etmek üzere takviye malzemesi olarak seçilmiştir.

Saf gümüş kaplamalar ve silisyum karbür takviyeli gümüş metal matris nano kompozit kaplamalar, bakır elektrik kontak malzemelerinin özelliklerini geliştirmek için elektrodepozisyon tekniği kullanılarak elde edilmiştir. Nano kompozit kaplamalar üretmek için doğru akım, darbe akımı ve darbe ters akımı gibi farklı akım türleri ve farklı miktarlarda silisyum karbür eklenerek doğru akım kaplama yöntemiyle kaplanmıştır. Farklı akım türleri ve farklı miktarlardaki silisyum karbür eklenen kaplamaların özellikleri, Taramalı Elektron Mikroskobu, X-Işını Kırınım yöntemleri, Vickers' ın Mikro Sertlik testi ve elektriksel kontak testi ile incelenmiştir. Tüm bunlar dikkate alındığında, en iyi mekanik özellikler darbe ters akımı elektrodepozisyon yöntemiyle silisyum karbür kullanılarak güçlendirilmiş gümüş kaplama ile elde edilmiştir.

Anahtar kelimeler*:* Gümüş, Silisyum Karbür, Elektrodepozisyon, Elektrik Kontakt Malzemeler

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NOMENCLATURE

Ag	Silver
Cu	Copper
Ni	Nickel
Al	Aluminum
SiC	Silicon Carbide
DC	Direct Current
PC	Pulse Current
PRC	Pulse Reverse Current
MMNC	Metal Matrix Nanocomposites
CMNC	Ceramic Matrix Nanocomposites
PMNC	Polymer Matrix Nanocomposites
° C	Celcius
$AgNO_3$	Silver Nitrate
KCN	Potassium Cyanide
SDS	Dodecyl Sulfate Sodium Salt
CVD	Chemical Vapor deposition
PVD	Physical Vapor deposition
SEM	Scanning Electron Microscopy
EDS	Energy Dispersive Spectrometer
XRD	X-ray diffractometer

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CHAPTER 1

INTRODUCTION

Many undesirable situations occur on surface of engineering material such as surface friction, wear and fatigue that directly affect the performance of the material. For this reason, besides the traditional coating, metal matrix composite coatings gain properties such as dimensional stability, fatigue resistance, corrosion resistance and high strength to the material [1]. In this study, copper which is used in almost all engineering fields today, but decrease the performance of the material due to negative effects such as corrosion, abrasion, friction, coated with silver metal matrix Silicon Carbide (SiC) nanocomposite by electrodeposition method [2].

Silver is the best candidate for electrical and electronic applications in the other materials and their alloys because it has highest conductivity (at room temperature), high reflectivity, and high ductility. Nowadays, with the advance of nanotechnology, silver matrix nanocomposites coatings are mostly used in electrical contact systems because of their excellent electrical and thermal properties. With the nanocomposite coatings technology, mechanical properties are measured up. Nano-size particle reinforced metal matrix nanocomposite coatings have main role to extend function life and to enhance surface quality and mechanical properties [3].

In addition to traditional coating, nano-size particle reinforced metal matrix nanocomposite coating has become a very efficient production method to obtain metal matrix nanocomposite coating.

Especially right choice reinforcement materials in terms of usage area are much more ahead of traditional methods. The outstanding example for these reinforcement materials as a ceramic one is silicon carbide, which step forward with its mechanical properties. Recently, SiC has found application of industrial furnaces, which has refractory for heating elements, rocket engines and wear resistant parts, also for semiconducting substrates. It can be used for electrical conductors as heating resistance, electronic components and flame igniters. Also, its wear and structural wear applications are continually developing. Due to well-known mechanical properties, SiC is a successful coating material. Therefore, SiC is a good applicant as a second phase addition to silver for electrical contact applications [2], [3]. Nano SiC reinforced to silver metal matrix is hoping further improve the mechanical performance. There are many application areas of these nanocomposite materials. Electrical contacts have many important factors in each system, which has transfer or electricity. In the literature, a few study on nano SiC reinforced metal matrix nanocomposite [4].

Electrical contact materials are a class of metals, which are used as the electrical interfaces for electrical connectors. These materials must exhibit mechanical, physical and chemical properties such as high hardness, high corrosion resistance and high electrical and thermal conductivity. In addition, they have to be produced from environmentally friendly materials. During life service, break operations, arc erosion occurs at make and also welding is a phenomenon frequently encountered problems [4]. In contact areas, coating can promote form any rewarding properties such as it can protect and improve surface quality, also, can enhance mechanical properties. The improved properties can differ from materials and production methods.

In this study, the desirable coating was obtained by electrodeposition method which well-known conventional surface modification process to enhance the surface properties such as functional and decorative characteristics. Ag as a matrix materials and SiC as reinforced materials can be used in metal matrix composites for electrical contact applications due to the highest conductivity of Ag at room temperature and high mechanical properties of SiC. Ag-SiC metal matrix nanocomposite exhibit mechanical, physical and chemical properties such as high hardness, high corrosion resistance and high electrical and thermal conductivity [5]. DC (direct current)

electrodeposition method has been generally used to obtain deposition of metal matrix for many years. Recently, PC (pulse current), and PRC (pulse reverse current) electrodeposition methods which can improve mechanical and corrosion properties of coating have drawn much attention [6]. Under favor of this technique, some parameters that are like time, temperature, ph of the bath, coating layer thickness and surface morphology can be easily controlled [7].

The main purpose of this experiment is to produce nanocomposite coating by using electrodeposition method to improve mechanical properties and surface qualities. In this experiment, silver was used as a matrix material and nano-sized Silicon Carbide particles are added to the nanocomposite coatings as a second phase. Nanocomposite coatings deposited on the copper substrate and copper electrical contact buttons with various types of current and various amount of SiC added to coating bath in order to determine their effect on microstructural, mechanical and chemical properties of metal matrix nanocomposite. Scanning electron microscope examinations and X-ray diffraction analysis were executed for characterization and also hardness measurements was obtained as mechanical tests, also, the tests was applied to coated contact materials to perform electrical contact performance. In the literature, there are some studies about SiC reinforced Silver Metal Matrix Nanocomposite coatings for electrical contact materials by produce powder metallurgy, spray pyrolysis etc. However, there are no study in literature any PC or PRC electrodeposited SiC reinforced silver metal matrix nanocomposite coatings for electrical contact applications. This is originality of our studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Composite Materials

Composites are combined materials, which are produced two or more materials or phases. Composite materials are selected to obtain some unique physical properties such as strength, stiffness, and chemical properties for example high-temperature performance, corrosion resistance. As another choosing reason is light weight of composite materials. Composite materials are composed of two or more distinct phases, which are called matrix phase and reinforced phase. The matrix phase has a continuous character. It is also usually less hard phase and more ductile. It holds the reinforcement and shares the load with it.

The second phase (or phases) which are reinforcement is embedded in the matrix phase with the discontinuous form. Reinforcing phase is usually stronger than the matrix. Although many of common materials properties are similar to those of their base constituents, as they have neglected amount of dispersed phases in their structures, they are not thought as composite materials [8].

2.1.1 Classification of Composites Materials

2.1.1.1 Polymer matrix composites

Polymer Matrix composites have a matrix that consists of resin and other thermoset and generally fibers are used as reinforcement for this type. These types are most widely used in technological applications [9]. Strong and brittle fibers incorporated into a soft and ductile polymeric matrix. Therefore, fibers provide high strength and matrix resin provides lightweight and hold together the fibers. There are

long and short fibers exist. Due to length of fiber, composite properties can be changed. GFRP, CFRP, Aramid fiber reinforcement (AFRP) are widely used examples of PMC. Not only resins are used but also thermoset and thermoplastics can be used as matrix materials [10].

2.1.1.2 Ceramic Matrix Composites

Ceramic matrix materials are generally useful for high temperature and severe-stress applications that possess refractor properties, high hardness but brittle and low fracture toughness. To improve fracture toughness CMC can be developed by using particulates, fibers or whiskers of another ceramics into matrix ceramic. Generally, reinforcements are zirconium, alumina or silicon carbide. Especially whiskers of SiC and Si_3N_4 inhibit crack propagation by

- Deflection of crack tips
- Formation of bridges across crack faces
- Absorption the energy that during pullout as the whiskers deboned from the matrix
- Causing a redistribution of stresses in regions adjacent to the crack tips.

Also, CMC has thermal shock resistance and high temperature creep behavior [9]

2.1.1.3 Metal Matrix Composites

MMC composites represent beneficial properties of metals such as high conductivity, high ductility and strength. But incorporated reinforcements improve their weak properties. By using of reinforcing materials, specific stiffness, strength, corrosion, abrasion and wear resistance, thermal conductivity and stability of dimensions can be improved. Because of higher costs of MMC, their application number is lower than PMC. Generally, super alloys are used as matrix material like silver, aluminum, magnesium, titanium and copper. Reinforcement materials are form in particulates, fibers and whiskers. They are classified in Figure 2.1.

For MMC, at high temperatures, matrix-reinforcement system can be highly reactive and this cause of degradation and decreasing in improved properties. To eliminate this producing surface coating on reinforcement or modifying the matrix generally used matrix metals are;

- Aluminum Matrix Composites,
- Magnesium Matrix Composite,
- Titanium Matrix Composite,
- Silver Matrix Composites,
- Copper Matrix Composites [9].

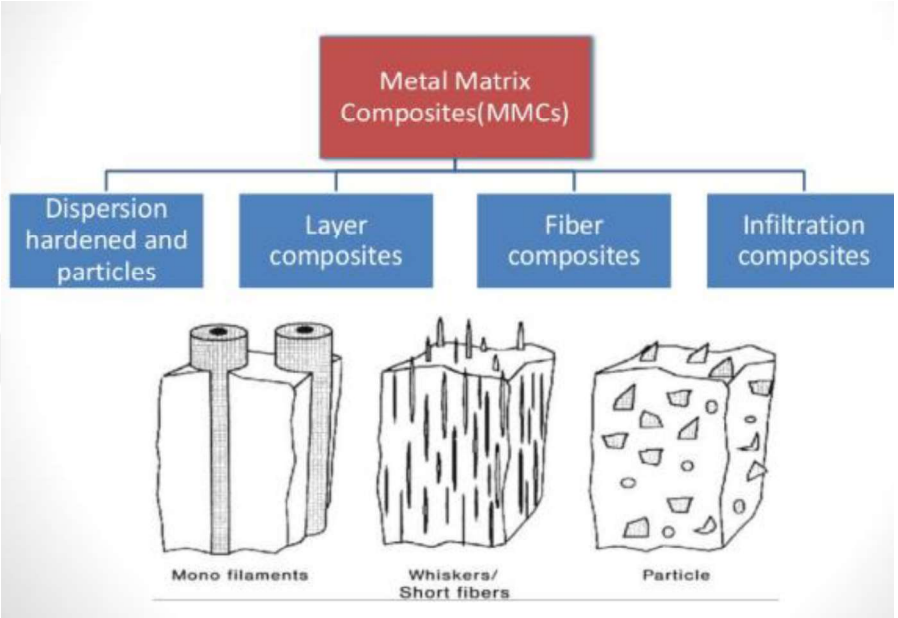


Figure 2.1 Classification of metal matrix nanocomposites [11].

2.1.2 Matrix Materials of Composites

The matrix material holds the reinforcing material, gives the shape of composite component and determines the composites surface quality. A matrix material can be chosen as polymeric, ceramic or metallic. Nowadays, polymer matrix types are the most widely used for high-performance in aerospace applications. Ceramic and metal matrix materials can be used in high temperature applications, such as engines [12]. Alloys are preferred initially for generation of MMC matrix materials. As time has

progressed, special matrix materials have been developed to use in composites though they are tailored. In addition, many other metals are used as matrix materials such as silver, copper, magnesium, lead and super alloys. The properties of composite materials are depend on the manufacturing process in which metals are elastic–plastic materials [13].

For some applications, silver matrix is preferred using with dispersed materials like ceramics and CNT. By this composing, the silver becomes stronger and durable to high temperatures. Their high electrical conductivity is important especially used for a contact material. The typical properties of silver matrix composites are high electrical conductivity, high corrosion resistance, high strength, good thermal properties [14].

2.1.3. Reinforcement Materials of Composites

Reinforcement is the second phase of composite. It is embedded into the matrix in a discontinues form. Reinforcement is usually stronger than the matrix. In addition, it is called as dispersed phase [8]. They affect the specific properties of composites.

2.1.3.1 Particle Reinforcements

Reinforcement particles are liable to restrict the movement of matrix phase in the closeness of each particle as seen in Figure 2.2. The matrix phase transmits some of applied load to the particles. Strong bonding at the interface of matrix particle affects the quality of mechanical properties. Particle size can be lower as micro sized or nanosized. At atomic level, particle matrix interaction provides strengthening of system. Matrix phases bear the large fraction of an applied load and small-dispersed particles hinder the motions of dislocation. Therefore, plastic deformation can be restricted. Metal and metal alloys can been strengthened and hardened by fine particle reinforcement, which is hard and inert. For metallic matrix, reinforcement phase can be metallic or non-metallic. There are dispersion strengthening can be observed, where particles interact with dislocation but it is not called as precipitation hardening. Because in composites there are not any heat treatment is done [9].

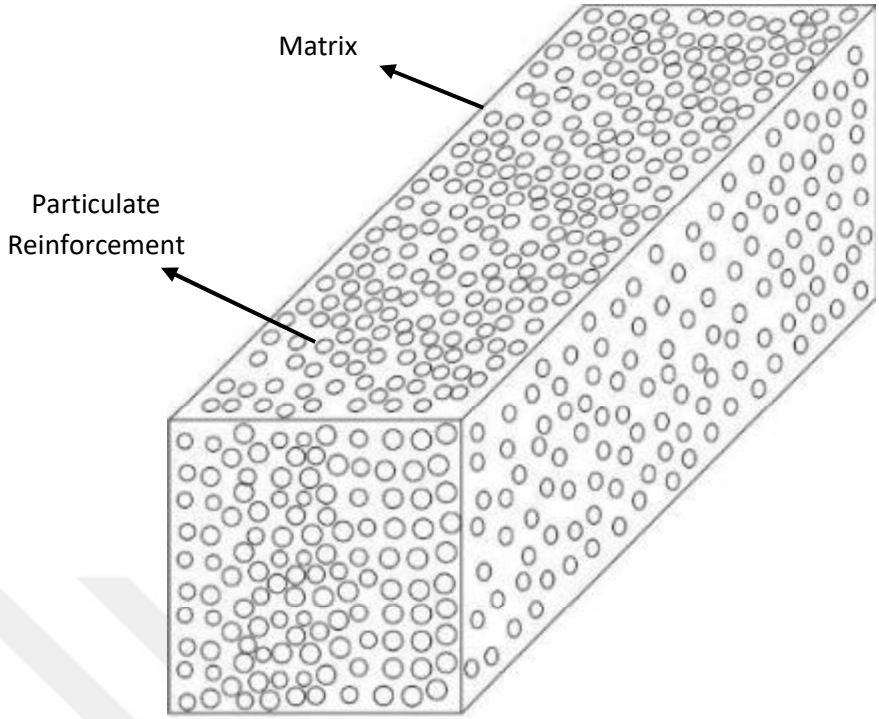


Figure 2.2 Particle reinforcement composite [15].

2.1.3.2 Fiber Reinforcements

Fibers are widely used as reinforcing phase for composites as seen in Figure 2.3 because of their lightweight, stiffness and strong structure. Besides, they represent different properties instead their bulk form. That is why the preferential orientation of molecules along the fiber direction and the number of defects available in a fiber as opposed to the bulk material. Because of different properties, fibers can be determined as their length, strength or chemical composition. If properties of length are considered, they are divided into short, long, or continuous fibers. Aside from they can be taken into account of strength as low, medium, high, and ultrahigh modulus. The most common inorganic fibers are carbon, glass, ceramic, boron. Used organic fibers in composites are polymeric [8].

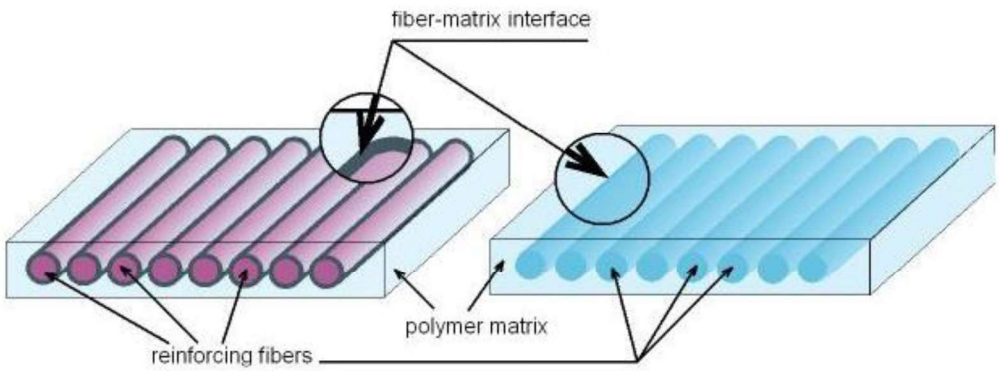


Figure 2.3 Representation of fiber reinforcement [16].

2.2 Application Areas of Composite Materials

Using of composites can provide unique advantages instead of traditional common materials such as metal and wood. The most important advantage is the adoption of the lightweight properties. In transportation, composites are generally preferred to save more fuel improved acceleration because o its less weight. In sporting equipment, lightweight composites allow faster swings and longer drives in golf. In the energy sector, the less a blade weighs means the more turbine power. The primary support from composite materials has come for the aerospace industry as airframe and spacecraft structures [17].

General application examples of metal matrix composites are partial short fibers reinforced light metal dieses piston, cast brake disk particle of reinforced aluminum, disk brakes caliper for passenger cars of an aluminum matrix composite material and conventional cast-iron. In addition, metal matrix composites are used for electrical contact materials production [18].

2.2.1 Electrical Contact Materials

Electrical contacts phenomena, which provides the continuity of electric circuit are defined as the touching of the current-carrying members in electrical devices. Called solids as contact members or contact parts are used for manufacturing the current-carrying members. The contact members are connected to the negative and positive circuit clamps, which are called respectively the anode and cathode [19].

The electric and electrical contact parts are significant components for switching devices. They have to sustain their function from the starting point of working process to the end of the functional life of the devices. There are some requirements on contacts, which are broad such as;

- High arc erosion resistance
- Low contact resistance
- High resistance against welding
- Good arc extinguishing capability
- Good arc moving properties

In the contactors, the main function of contacts is the switching mechanism. During this process, electrical current passes with a certain resistance when a pair contacts each other. The properties of contact materials are depend on structure of surface, time contact and surface chemistry; if an insulating gap separates the pair, the current cannot arise between the pairs. When the pairs contact, the switch is called closed; when the contacts are separated, the switch is called open. The gap must be an insulating material, such as vacuum, air, oil [20].

Electrical contacts can be classified as their nature, surface geometry, kinematics, current load, application, design and technology features, and by others means. Generally, electrical contacs are examined into two basic categories: fixed and moving. Figure 2.4 shows the most general classification of electrical contacts according to contact kinematics, functionality, and design features.

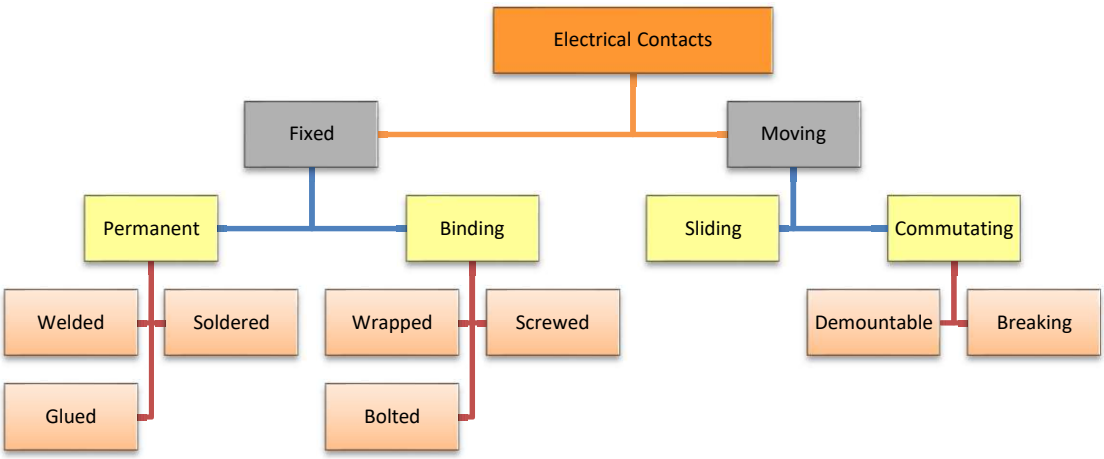


Figure 2.4 Electrical contacts classification [19].

In the fixed contacts phenomena, contact members are connected statically or elastically to the steady unit of a device to provide the constant joint. Fixed contacts are classified into permanent (welded, soldered, and glued) and clamped (bolted, screwed, and wrapped). These contacts can be used in all voltage and current values, for example large bus bars to crimped or screwed wiring connections and on low voltage printed circuit boards. The most important properties of these materials are abrasion resistance and the ability to cut off the electric current when it is necessary [21]. The nature of clamped and permanent contacts are different because there is no physical interface between conductors in the all-metal contacts, however, in clamped contacts the interface is controlled by the ability of the material to undergo plastic deformation and the contact pressure. The lower specific resistance and hardness of a material, the higher its corrosion resistance and, consequently, the lower the contact transition resistance. So that, contact surfaces are usually covered with tin, silver, cadmium, or similar materials, which are soft, corrosion-resistance materials. If the proper materials cannot be chosen, in the case of contact resistance under permanent load on contact materials, increasing of temperature generates corrosion and oxidation. So, the sudden fail will be unavoidable.

In moving contacts, at least one contact unit is connected to the moving device rigidly or elastically. These contacts can be divided into two categories which are commutating (separable and breaking) and sliding. In electrical circuit systems, they are operated for opening and closing for example in different switches, contactors, relays, and similar devices. There are great varieties of commutating contacts due to in breaking power, current, and voltage. Demountable contacts are not exposed to arcing as they are not intended to make or break the connection under load. Many demountable connections remain to work for years without being disturbed [19].

Sliding contacts are required to function as either static or moving. Without any intended separation in the third dimension, the contact members move in the x or y directions relative to each other. Sliding contacts are also categorized as high speed, heavy current types such as rings, slip, generators, and brushes, current pick up contacts in electrical transport light current types and low speed. High sliding speed are examined as the main problem for these kinds of contacts. During sliding the surfaces weld together, arc erosion caused an arc because of high friction is also generated as seen in figure 2.5 and very rough surfaces and causing high wear in system. The coating of the friction surfaces with graphite particles could be the best choice to improve the wear resistance for this type of contacts. [22].

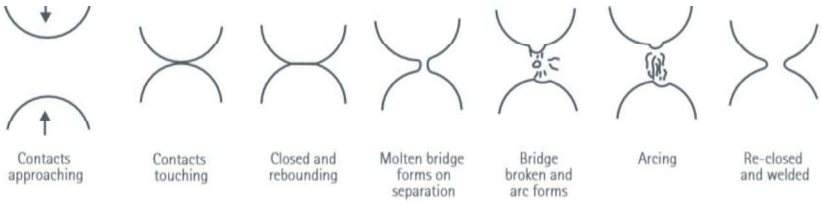


Figure 2.5 Arc erosion and metal transfer on breaking process [21].

Because of all these mechanical and electrical problems material selection is playing most important role. Electrical contact materials should be chosen with properties that can overcome these kinds of problems or improve mechanical and electrical properties of materials by coating or lubricant processes to preserve contacts functionality.

Electrical contact materials are usually manufactured from metals as seen in figure 2.6 have high electrical conductivity also, silver, copper, gold, platinum, and palladium are in general the mostly used metals for contact alloys. Electrical contacts used as proper materials used can be divided into the following groups based on their composition and metallurgical structure:

- Pure metals
- Alloys
- Composite materials [23].

Figure 2.6 Electrical contacts parts [24].

Pure metals

Silver is the most useful one from this group for switching devices in the higher energy technology. Gold and platinum which are other precious are only used in the applications of information technology as form of thin surface layers. Metal tungsten is used as a non-precious for some specific applications such as automotive horn contacts. In some cases, if pure copper pair to a silver-based contact material is used

Alloys

Apart from these pure metals, huge number of alloy materials is used as contacts that are made by melt technology. An alloy is classified by the fact that its compositions are completely or partially soluble into each other in the solid state. Phase diagrams

for multiple metal compositions show the number and type of the crystal structure as a function of the temperature and composition of the alloying components.

They define the parameters of solidification and demonstrate the verges of liquid and solid phases. At the expense of changing materials properties, alloying allows to foster the properties of a material. As an example, while the electrical conductivity decreases with even small additions of these alloying components at the same time the hardness of a base metal can be increased.

Composite materials

Composite materials have great importance for electrical contacts that are used in switching devices that are composed to higher electrical currents. They can be called as heterogeneous materials that are composed of two or more uniformly dispersed components in which the largest part consists of a metal. The properties of composite materials are mainly dependent to properties of their individual components. Hence, combining of tungsten which has the arc erosion resistance and high melting point with copper which has the good electrical conductivity and low melting point is possible, or the weld resistant metalloid graphite with the high conductivity of silver.

2.3 Problems Encountered During Connection

Contact between two engineering bodies occurs at discrete spots produced by the mechanical contact of asperities on the two surfaces. For all solid materials, the area of true contact is a small fraction of the nominal contact area. The types of deformation of contacting asperities are either elastic, plastic, or mixed elastic–plastic depend on local mechanical contact stresses and on properties of the materials, such as hardness and elastic modulus. In a bulk electrical interface in which the contacting components are metals, the mating surfaces are often covered with oxide or other electrically insulating layers. In a bulk electrical connection, the electric current lines happen increasingly damaged as the contact interface is approached and the flow lines bundle together to pass through the separate contact spots. Problems can be examined with four main topics that are encountered during contact as following;

- Electrical contact corrosion,
- High contact erosion,
- Dust Contamination,
- High electrical contact resistance [25].

2.3.1 Electrical Contact Corrosion

For a contact material, its electric current and contact resistance must be preserved during its life. Contact materials work ambient atmosphere where there pollutants in atmosphere can cause the contacts corrode. During corrosion action, the organic or inorganic species found in environment cause contamination and chemical changes on metallic surfaces. By the way, metals are very active elements that have a high affinity to occur oxides, carbides or nitrides. In addition, there are inorganic pollutions are observed. These cause of dramatic changes on contact surface. Therefore, accelerated corrosion tests are essential for design of metallic applications.

Clean surfaces of metals have always a tendency to oxidize quickly and to form a protective film on surface. These also called as tarnish, which formed in air at ambient temperature. They are composed of oxides, sulphides, carbonates and sulphates. There are a solid and a gas react to occur a new solid. This reaction rate depends on coating reactants and permeability. In addition, porosity is important consideration for this process. Porous corrosion protective layer is less protective than non-porous layers. This porosity formation depends on composed materials of layer. Ignoble metals have porous structure and noble metals have non-porous structure.

There are different types of corrosion by following:

- Pore corrosion, there corrosion products are transported from metal to the hole in the plating to contact surface. There are synergistic effect between chlorides, oxygen and sulfates.
- Creep corrosion occurs when a reactive metal such as silver and copper is brought in a physical contact with a noble metal or noble alloy. After that, creep observed between them. In this process dimensional changes are occurred.

There is another harassment process is metallic electro migration which is involved as transport of metals to a non-metallic medium under the influence of an electric field. This is cause of an electrochemical phenomenon. Under high humidity environment, especially silver and copper migration can be seen. This is a moisture process. Or a galvanic corrosion can be cause of contamination as seen in Figure 2.7. In the high frequencies of electrical field between contacts, metallic electro migration van be seen.

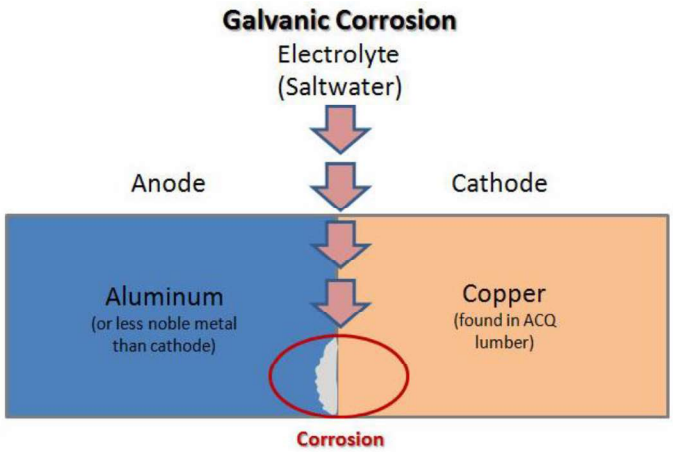


Figure 2.7 Corrosion of different metals, the more anodic metal as substrate [26].

2.3.2 Dust Contamination

Dusts contained on electrical contacts are big problems for connection. They can be cause of contact material failure. Dust particles can be occurred from various different types of particles and so different properties. In addition, their inherent characteristics affect the failure. Dusts can increase the contact resistance [27]. Effect of dust contamination: Especially in the middle of 20th century, because of industrialization and air pollution, there are much number of dusts in air and this cause of failure especially in telecommunication applications. By decreasing of air pollution, dust contamination events also reduced. Especially in China, this problem is very common. Dust contamination cause of high porosity at surface and this varies the contact resistance. In addition, these cause of erosion and corrosion. When this problem is completed, then it can be more harmful. Dust particles have unique chemical, physical and mechanical properties and when they are gathered on surface, they represent their

own properties. Moreover, when they are entrapped, corrosion species can be attached with them and this increase corrosion rate. Humidity and temperature can increase attachment effect. In addition, after this complex effect, contact resistance is enhanced.

Dust contamination is generally observed on relays and connectors. Relays have open and close movements. Connectors are static but have lateral movements. Most of connectors exposed to air and so dusts. Then corrosion is generated and micro movements from external vibration and this cause of failure. There are various shaper of dusts like spherical, multilayered, and polyhedral. In addition, both inorganic and organic dusts are existing. Dusts can be water-soluble salts which effective for corrosion. In that, salts release into positive and negative ions. In addition, they can attract water, vapor and water molecules onto contact surface.

Dust contamination can be a result of arc between surfaces. There organic dusts can be agglomerated from air by organic vapors from outside or inside of components. These organic contaminants can be adsorbed to contact surface and occur polymer structures under the influence of friction between two switches. Moreover, these organic contaminations reduce life of contacts. While discharging of contacts at minimum values of current and voltage, there a strong arc is seen and this can crack the agglomerated dusts by pyrolysis. Another mechanism is about vaporization and deposition of organic molecules near the contact. While arcing, there high temperature is observed and organic particles vaporized and deposited on contact surface. These particles can be not only organic molecules; also, can be minerals [28].

2.3.3 High Contact Erosion and Arcing

Arc Interruption: Arc contamination is especially seen at two-point contact, which interrupts flow of current. They can be also switching devices in electrical insurance. In addition, arc is about high degree of erosion on surface of contact material [28]. During arc, there are very high temperature is occurred and this leads to formation of plasma phase on surface atoms. Plasma phase can be considered as the mixture of electron and positive ions. The thermal energy released during electrical conduction is high enough to cause plasma formation. This ionized plasma gas burns contact points. This occurrence is called as electrical arc. Oxygen and nitrogen atoms which are

contained in air, ionize at about 6500 K. At 20000 K, all atoms are ionized. In the circuits, contact point temperature is range between 6000 K and approximately 20000K due to arc current and other factors arises from design of switching elements.

Electrons are accelerated towards open contact that contain air between them and collide with air atoms. Electrons drift toward the anode and gain energy before they collide with gas molecules. Their energy depends on voltage and current. This procedure occurs during long gap breakdown. There also vacuum and short gap breakdown types exist. Erosion is also complicated with other mechanical effects like impact on closing. Switch mechanism stresses affect the contact erosion as manufacturing of it. Arcing occurs on the contacts come together by the breakdown of the contact gap before they touch each other. Once the contacts touch, they may bounce apart again and an arc will form between them. For AC circuits, contacts not need to be switching too rapid. Nevertheless, for DC circuits, it is rapid. When a voltage is impressed across and open contact gap there two important periods that are called as statistical time lag and formative time lag. During statistical time lag, first electron becomes available to begin breakdown process. Formative time lag is the time that required for discharge to become established. So arc is observed while the contacts burn. If the circuit current is higher than a minimum value, the same way, voltage can be higher than a minimum value. So there an arc is seen and it always initiates in metal vapor on contacts. Cathode contact provides the electrons, the fuel that allows the arc to continue burning between the contacts. The main causes of arc are thermal energy from ions and bombardment, kinetic energy from ions and chemical reactions. In addition, arc affects erosion occurrence at surface of contacts [28].

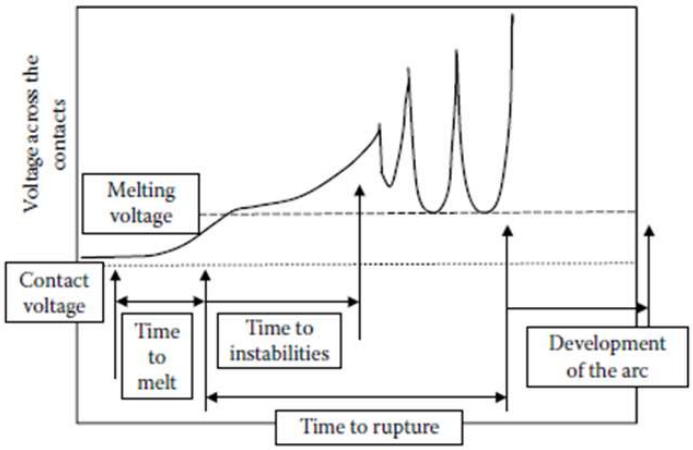


Figure 2.8 The initial voltage drop across a pair of closed electrical contacts as they begin to open [25].

2.3.4 Electrical Construction Resistance

Thin films which deposited on contact surface can be conductive or insulator due to application. Especially this application is important for semiconductor and MEMS-NEMS technology where are required to control current. In that, this affects the surface resistivity as contact resistivity. Conductive layers can be applied on insulator surface and conductive surface or insulator surface can be deposited onto conductor surface and insulator surface. Presence of a thin layer on contact material effect contact resistance. This is achieved by varying a-spot properties. Hardness change of surface due to film formation may affect contact resistance. Good electrical contact can be achieved if the film is insulator or weak conductor and mechanically disrupted to allow formation of metal-to-metal junctions. So, electroplates are often minimize the electrical contact resistance. In addition, it provides from formation of electrically insulator oxidation film, tarnishing, mechanical deformation and contamination, wear and corrosion.

For a small scale of solids, electric current is not continuous as seen in Figure 2.9, but irregular motion of electrons as they collide with lattice imperfections, defects and other dislocations in the conductor interface. During constriction of current lines, scattering occurs [25].

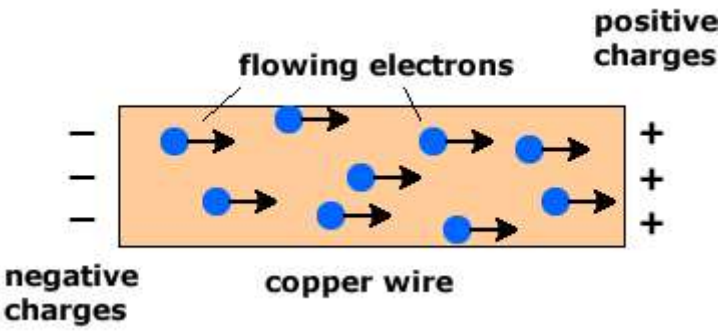


Figure 2.9 Classical electric flow through a constriction [29].

Deterioration of connector is occurred because of relationship between contact zone and environment. Nevertheless, for a well-designed contact material, this rate is slow. First stage of this process, there is not any notable changes for a long time. In that, a-spots are not sensitive for these small changes. But when temperature rise, a self-accelerating of these spots' deterioration is achieved. During degradation, temperature, mechanical stresses and chemical activations are complicated. And resulting this degradation increase the contact resistance due to decreasing contact points [30].

2.4 Nanocomposite Electrical Contact Materials

Nano composites are defined as a composite where at least one of the phases demonstrates dimensions in the nanometer range (1 nm = 10^{-9} m). Nanocomposite materials have emerged to cope with limitations of monolithic and micro composites. However, they are posing preparation difficulties because of the control of elemental composition and stochiometry in the nanocluster phase. Because of design uniqueness and property combinations that are not found in conventional composites, they are called the materials of 21st century [31]. Importance of nanocomposites cannot be over-emphasized due to the high corrosive nature of metals used in oil, gas pipelines, and contact materials and failure rate of conventional materials. In as much as nanocomposites have nanoscale structure that improve macroscopic properties of materials. Nanocomposite materials are different from conventional composite materials in mechanical terms as the exceptionally high surface to volume ratio of the reinforcing phase and its exceptionally high aspect ratio. The reinforcing material can be composed of sheets, particles or fibers. Classification of nanocomposite materials

is the same with micro composites having been classified according to their matrix materials, in three categories. Metal matrix nanocomposites (MMNC), ceramic matrix nanocomposites (CMNC) and polymer matrix nanocomposites (PMNC) as shown in Table 2.1.

Table 2.1 Classification of Nanocomposite.

Class	Examples
Metal	Fe-Cr/Al2 O3 , Ni/Al2 O3 , Co/Cr, Fe/MgO, Al/CNT, Mg/CNT
Ceramic	Al2 O3 /SiO2 , SiO2 /Ni, Al2 O3 /TiO2 , Al2 O3 /SiC, Al2 O3 /CNT
Polymers	Thermoplastic/thermoset , polymer/layered silicates, polyester/TiO2 , polymer/CNT

Mechanical and electrical properties of electrical contact materials are very significant for long-range properties. Corrosion and wear resistance, conductivity and mechanical strength properties have great impacts on contact materials. Electrical contacts materials properties can be improved by nanocomposite coating.

2.4.1 Electrical Nanocomposite Coating Matrix Materials

Many metals can be used a matrix material for electrical contacts. Most common metals that have been used are aluminum alloys, copper, gold and nickel.

Copper, is mostly used metal for electrical contact materials. In that, copper has some significant properties such as high electrical and thermal conductivity. On the other hand, it has poor mechanical properties. These poor mechanical properties limited its usage life. However, the addition of proper reinforcement material improves mechanical properties of copper.

Nickel, In electrical applications nickel coating is most preferred metal because it has high corrosion resistance. In addition, nickel has decorative appearance.

Gold, and its alloys are another matrix nanocomposite coating metal. Like low digital signals connectors, gold alloys coatings are operated with relatively nominal contact forces in particular highly miniaturized electrical contacts. The using of gold coating happens essential for safetc components those which in highly standard. Adhesive wear is the major issue in sliding contact application of using gold. Using of Ni, Co, cu, Ag and Pd elements can be solution for this problem. [22].

Silver, is one of the metals discovered after gold and copper, which with its history dates back to 3000 BC. It was used by Egyptians in 3100 BC, and by Persians and Chinese in 2500 BC. It is known that silver coins were used by the Lydian's in 700 BC. Silver is a precious metallic element, the symbol of which is Ag (in the Latin word argentums). It is bright, malleable, reflects light very well. The atomic number is 47, and the atomic weight is 107.87 grams. Its melting point is 961.9 ° C, boiling point is 1950 ° C and its specific weight is 10.5 g / cm^3. Silver is highly resistant to acids and corrosion. Silver has many application areas (as seen in figure 2.10) such as photography industry, coin production, ornaments and jewelry, alloys, dentistry and water purification industry. It is also used in the making of mirror glazes, in making batteries. The health-used version of silver is called "colloidal silver". It is a compound of silver with various proteins and is a powerful antiseptic. Silver-containing chemicals are used in many healthcare products, such as bandages, infectious drugs and supplies, which are used in medicine because of their germicidal properties as seen in Figure 2.10. Silver ions are known to strengthen bones and have protective effects against radiation. It is known to prevent or destroy bacteria, virus and fungal growth [32]. Silver and its alloys are broadly used in electrical applications such as electrical contacts, circuit relays, coatings and slide bearings because of their high electrical and thermal conductivity, high strength and wear resistance and high chemical stability.

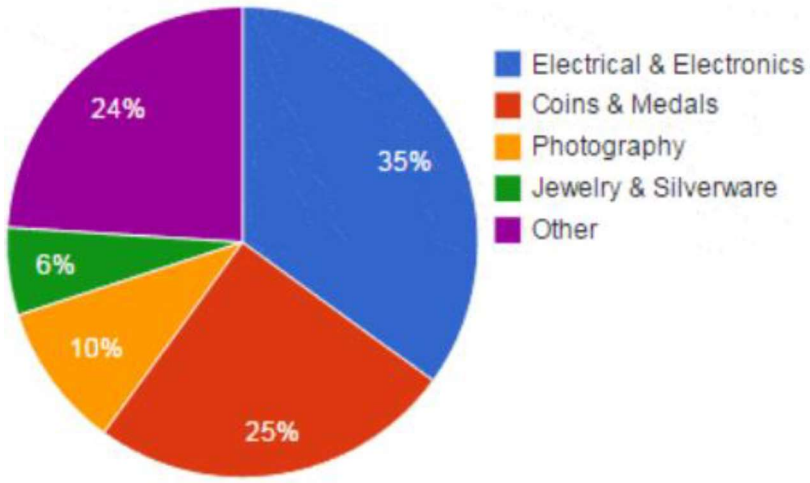


Figure 2.10 Application areas of silver [33].

Silver is a ductile metal. In the technical applications of silver, it is supplied to tribological conditions, mechanical loads, contact temperature and vibration of contact movements. In these conditions, silver and its alloys develop adhesive bonds at 150°C. So, wear, corrosion and plastic deformations can be observed. These disadvantages can be avoided with addition of dispersed phase of ceramics. By addition of this reinforcement to them improve their hardness, corrosion resistance, adhesive wear resistance and eliminate sparking. Therefore, silver matrix composites are a good choice for electrical applications. During work of electrical components, arcing, mechanical deformation and plasticity can be observed. Pure Ag cannot withstand these extreme working conditions, so reinforcement is required for Ag electrical contacts. If Ag matrix composite is produced with reinforcement, its resistance and strength can be increased, deformability can also be decreased but its electrical and thermal properties are decreased. Oxide and carbide particles such as Al_2O_3, ZnO, TiO_2 and SiC have high hardness. Properties of silver nanocomposite can be varied due to properties and quality of reinforcement. According to J. Wieczorek's study, by addition of hard ceramic reinforcement into Ag matrix improve both wear resistance and hardness of Ag matrix [27]. On the silver surface during corrosion, there are not exile layer is formed like copper or nickel. However, silver oxide has a tendency to compose at 150^0C in the air. It is generally reacted with reduced sulphide species like H_2S, S_8 and reactive halides such as fluorine, chlorine and bromide. But chlorine corrosion have no adverse effect on reliability due to the unique properties on silver

like softness of film. Its film formation is linearly kinetic and this means formation never slows down. Generally, during usage of power equipment silver contacts have turned black with time while working. This black appearance cause of silver sulphide and silver chloride compounds which polluted from environment. Nevertheless, it continues to perform reliably [25].

2.4.2 Electrical Nanocomposite Coating Reinforcement Materials

There are various types of reinforcements for nanocomposite composite materials such as ceramic particles, carbon-based particles (carbon nanotube and graphite) which are strengthen the matrix material.

SiC, Silicon carbide is a compound of silicon and carbon element, also its chemical formula is SiC. By the chemical reaction of sand and carbon in high temperature, SiC is obtained. Silicon carbide is a very good abrasive material and has been produced as sanding discs and other abrasive products for more than a century. Today, this material has been developed with very good mechanical properties, as a technically high-quality ceramic material. Silicon carbide crystal consists of carbon tetrahedral and silicon atoms with a strong bond in the lattice. The most prominent feature of SiC is that it is crystalline. Silicon carbide is available in two different forms which are cubic in "β" form at 1400- 1800 ° C, hexagonal and rhombohedra in "α" form above 2000 ° C. SiC has many advantages to use many industrial applications. They can be summarized as below;

- ✓ Low density
- ✓ Low thermal expansion
- ✓ High strength
- ✓ High hardness
- ✓ High thermal conductivity
- ✓ Superior chemical inertness
- ✓ Excellent thermal shock resistance [34].

SiC has a high hardness and it is used in various applications like diodes, astronomy applications, cutters, heating elements and jewelry. In addition, they are widely used in composites as reinforcement phase. A non-oxide compound has properties to cope with extreme environment conditions and has a high melting temperature, a low thermal expansion coefficient and good thermal shock resistance [35]. The properties of SiC are represented at the Table 2.2. SiC is the attractive reinforcement in terms of its high stiffness and strength and low density, combined with good thermal conductivity and thermal stability. In addition, it has a structure similar to diamond. Along it can be manufactured in large quantities in crude from such as powder, it is easier to produce than diamond [36].

By addition of SiC in ductile metal matrix, the ductility of metal can decrease and its hardness and strength increase. Because SiC particles which are incorporated into metal matrix, there is a dispersion strengthening seen which distort the structure and so hinder dislocations. Therefore, increment on mechanical properties seen. However, there are a threshold value exist. In addition, the shape and size of SiC reinforcement affect the properties. SiC is a semiconductor. Addition of SiC can reduce conductivity of metals [37].

Table 2.2 Properties of SiC [38].

Density	3.16 $g \cdot cm^{-3}$
Hardness	24.5HV
Elastic Modulus	410Gpa
Tensile Strength	137.9 Gpa
Thermal Conductivity	120W/mK
Electrical Conductivity	$10^{-10}\Omega-1 \cdot m-1$
Melting Temperature	2,830 °C
Electron Mobility	~900 cm2/V·s

Alumina is a ceramic particle which can improve the strength and hardness of metal matrix contact materials. It is commonly used as reinforcement material in MMC. Thermal stability, good strength, and hard structure of alumina make it a good

candidate for reinforcement material in metallic matrix nanocomposites. It is also available because it is oxide form of aluminum. Its particles produced by ceramic processing methods. Especially nano-sized powders of them reflect excellent properties as reduce dislocations. Its optimized amount addition gives a good hardness and a smoother topographical surface on contact materials. However, it is an electrical insulator and reduces conductivity of matrix material. So its amount should be optimized. Another advantage of alumina is that they are available materials and easily processed with ceramic processing methods. In addition, it has a high melting temperature 2072°C, so it can reduce arcing onto contact material [39]. Because of these properties of alumina, when it incorporated into metal matrix contacts, they improve stiffness, strength, wear, corrosion erosion resistance and thermal stability. However, during production, particle cracking, reduction of cohesion and reinforcement stresses can be observed. Nevertheless, generally electrodeposition methods reduce these disadvantages of alumina reinforcement [40].

Carbon Nanotube (CNT), are one of the allotropes of carbon, which has a cylindrical structure. Because of their unusual properties, they are used in biotechnology, electronics, nanotechnology and other materials science applications. Carbon nanotube has a nano-sized diameter and a long length where the length-to-diameter ratio of them is very high as 132,000,000:1. They have chiral structure and this affect also their properties. Due to rolling angle of sheets, their electrical properties can vary between metal and semiconductor. They can be single walled or multi walled. Carbon nanotube has highest strength and stiffness in terms of tensile strength and elastic modulus. Because of covalent bonds between each carbon atoms, they have high strength. In addition, they have very high electrical conductivity and mobility. Because of their nanoscale cross-section, electrons propagate only along axis of tube. They are one-dimensional conductors [41]. Because of these good properties, carbon nanotube is used as reinforcement material for composite contact materials. These composites are low cost productions; provide homogeneous nanotube dispersion in metal matrix and it leads strong interfacial adhesion between metallic matrix and carbon nanotube dispersions. This type of composites can be deposited onto contacts by electrodeposition. Addition of carbon nanotube into metal matrix for contact materials increases tensile strength and elastic modulus, and resistance to corrosion, wear and

erosion. Nevertheless, because of agglomeration of carbon nanotube agglomeration, reduce these improved properties. By the way conductor carbon nanotube are good candidates to selection of reinforcement for composite contact materials [42].

Graphene, is an allotrope of carbon, which consists of one layer of hexagonal arranged carbons. The schematic representation of graphene and its different representation can be seen in Figure 2.11. It is two-dimensional material and the strongest material ever tested and efficiently conducts heat and electricity. In addition, it is nearly transparent. In can be extracted from graphite layer. Graphene contain sigma and pi bonds. These bonds are responsible to electrical conductivity on them. It has very high melting point as 5727°C. Its young's modulus is as high as 1 TPa [43]. Besides, of these good advantages of graphene, homogeneous dispersion, fabrication problems and chemical reactions occurrence between graphene and metal matrix is exist. Their oxide compounds can be used during fabrication of graphene reinforcement MMC. According to G. Tong's study, addition of graphene reinforcement in ductile matrix materials increases tensile strength and reduces ductility. In addition, graphene reinforcements reduce grain size so; increase the corrosion resistance and strength of matrix metal. Graphene reinforced metal matrix composites produced by various processing methods. For electrode coatings, generally electrochemical deposition is a better way. In an electrode, which contain metal salts, graphene reinforcements can be deposits incorporated with metal matrix. By this method, very uniform dispersion of graphene in the matrix can be achieved and there are nearly no damage to graphene during deposition. Because of excellent properties of graphene, the properties of metal matrix can be improved by addition of graphite. With hardness, also wear resistance, stiffness and strength can be improved. There are three main strengthening mechanisms of graphene reinforcement, filler strengthening, dislocation strengthening and fine grain strengthening. Moreover, they improve conductivity of base metal. Therefore, they are a good candidate to reinforcement selection of metal matrix of composite contacts [44].

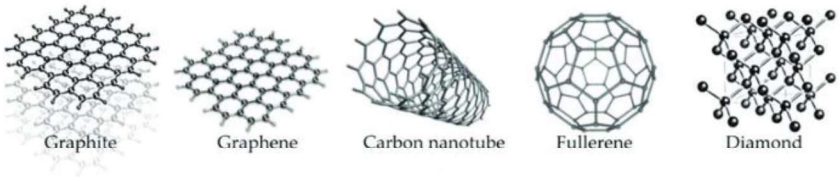


Figure 2.11 Graphene plane structure [45].

2.4.3 Nanocomposite Electrical Contact Materials Production Methods

There are many nanocomposite electrical contact materials production methods which are Chemical Vapor Deposition (CVD), Physical Vapor Deposition Method (PVD), Thermal Spray Coating, Cold Spray Coating Method, Powder Metallurgy and Electrodeposition [46]. Chemical Vapor deposition is very old technique and widely used to obtain thin film deposit. Coating almost of any metallic or ceramic compound, metals and their alloys and inter-metallic compounds, CVD method can be used [47]. The other method of metal matrix nanocomposite production is physical vapor deposition. Deposition in case of forming of coating layer causes not only much thinner layer but also higher adhesion strength [48]. In this method, the positive charged sputter a nanoparticle those which a carrier gas from the target and it is bombarded them with a high energy level to the substrate with negative electrical charge [49] [50]. The other method is Thermal spray. It is defined as the system of applying of melted or molten spray material through to the prepared substrate surface at high speed. Coating raw material is melted by a heat source. This liquid or melted material is propelled through to the substrate by process gases and deposited then the propelled liquid solidifies onto the substrate surface a form a solid thin film [51]. The cold spray process allows the production of dense coatings by spraying solid particles at very high speed and low temperature without melting [52]. The sprayed particle temperature during the cold spray process is very low, but the spray velocity is very high. Differences can be observed depending on the process types and the used gun type in the process and the used gas compositions [53]. Powder metallurgy is the other nanocomposite electrical contact materials production method. They usually can be metal-based, as well as ceramic and polymer-based. It is the method and technique of producing difficult parts with starting from raw materials in powder form, economically, with high strength and minimum tolerance [54]. Generally, it is based

on the sintering of metal powders under a melting temperature after compression in a mold [55].

2.4.3.1 Electrodeposition

Electrodeposition or electroplating is a process where reduced metal cations are produced by using of current and oxidation of anions on a substrate to formation of deposits. By this process, surface properties and components can be changed due to a required process. Especially for electrical applications, this method is used. Not only metal ions but also nanocomposites can be formed on substrate by electrodeposition. There are two main parts; anode and cathode. Anode is metal part, which is deposited on substrate. Cathode is the plated substrate. These components are immersed into electrolyte liquid where ions in move and by applying electricity, ions are transmitted from anode to cathode. In electrolyte, there are dissolved salts. In this process, Direct Current, Pulse Current or Pulse Reversed Current was used where generated by a power supply. At cathode surface, dissolved metal ions are reduced at cathode surface and forms into a thin film. At same rate, metal ions are oxidized from anode surface, which are transmitted to cathode. The weight of cathode increases by time while the weight of anode decreases because of mass transportation. In the electrolyte solution that includes metal salts, cations are associated with anions. By reduction of these cathodes, zero valance metal atoms are deposited on cathode. These cations come from oxidation of anode metal. For example, as represented in Figure 2.12 copper anode oxides to Cu^{+2} in electrolyte by electricity. In addition, on the metallic anode, Cu^{+2} is reduced to Cu and deposited on its surface [56].

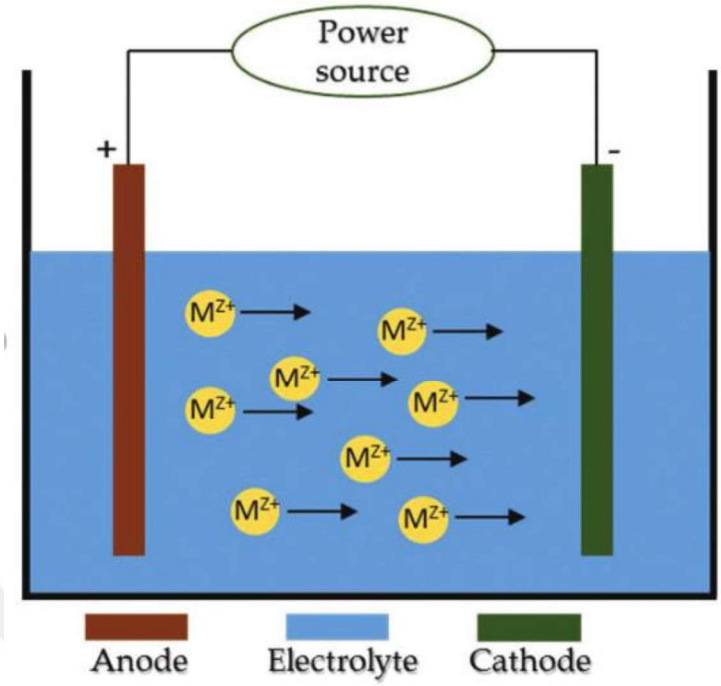


Figure 2.12 Schematic representation of electrodeposition process [57].

Different shape particles such as spheroid, tubular, fibrous or lamellar particles can be deposited as nanocomposite layers on surfaces. Convection of particles towards the cathode surface is conducted with reinforcing of these particles as seen in Figure 2.13. During composite material formation, particles can be agglomerated or well dispersed. Especially quality of bath affects this dispersion mechanism. There are five steps of nanocomposite deposition by following;

- Charged particle formation due to ions and surfactants adsorbed on particle surface,
- Through a convection layer physical transport of particles,
- Mass transport by concentration diffusion layer,
- Migration driven by potential gradient across an electrical double layer,
- Physically embedding of particles into metal deposit that grows.

In addition, there are some parameters to achieve a successful deposition process as following;

- Particle characteristics (size, shape, surface charge etc.),
- Electrolyte (composition, concentration of additives, pH, surfactants, temperature etc.),
- Types of current (DC, PC, PRC, time) [58].

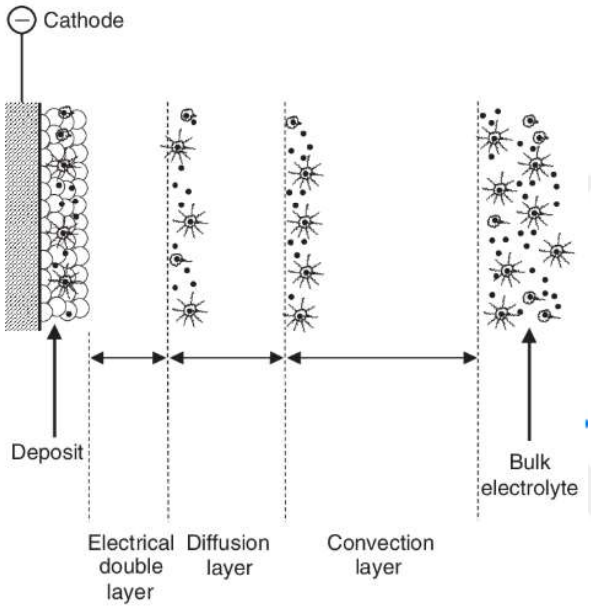


Figure 2.13 Schematic representation of incorporation of particles in metal matrix by electrodeposition [59].

Even though the current type of DC electrodeposition method as seen in Figure 2.14 is very practical by applying constant current along the process, they are sometimes known with coating flaws and slower deposition rates, which there are some undesirable microstructure. Nowadays, the electrodeposition methods of pulse current (PC) and pulse reverse current (PRC) have been considerable important for better corrosion and mechanical properties.

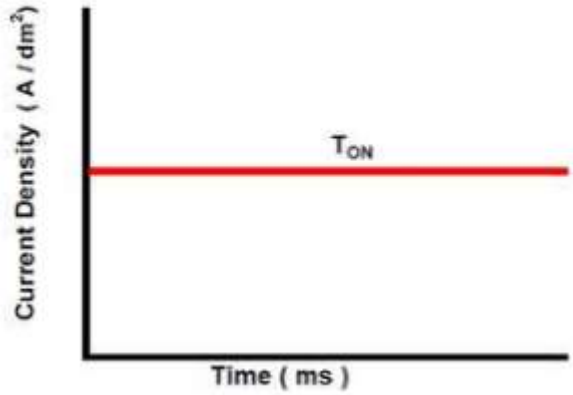


Figure 2.14 Typical Direct Current DC wave [1].

In the methods of PC and PRC, the periodically changes were conducted between two values: for PC from positive to zero; for PRC from positive to negative as seen in Figure 2.15. The electrodeposition type of pulse current and pulse reverse current lead to occur electric double layer and better penetration of ions on cathode surface. [60].

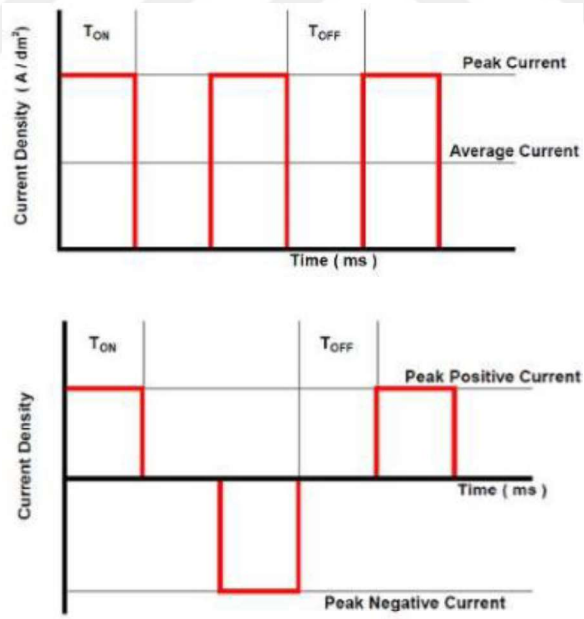


Figure 2.15 Typical Pulse Current PC and Pulse Reverse Current PRC waveforms [1].

Firstly, incorporation of particles increases sharply initially with increase of current density until it reaches maximum value. After this, it decreases sharply. The composite films hardness depends on combined effect of both grain refinement and dispersive

strengthening. At lower current densities, metal ions are dissolved and transported at lower rates and this cause of inadequate deposition on cathode. Therefore, there is too much time required and a weak deposit is obtained at lower concentrations of metal ions. However, in higher current densities, metal ions are dissolved and transferred faster. Nevertheless, this rate can be faster than mechanical agitation. The cause of decreasing is deposition of particles and hardness of coating. Therefore, proper current selection is essential [61].

2.5 Review of Related Works

Silver and its alloys are broadly preferred for electrical applications such as electrical contacts, circuit relays, coatings and slide bearings because of their high electrical and thermal conductivity. In addition to very high thermal conductivity of the silver, life cycle can be spanned with obtaining of silver matrix nanocomposites for electrical applications. Therefore, this field of study attracts much attention. In this chapter summarizing of conducted studies producing nanocomposite coating by electrodeposition method were examined.

Reddy et al. [62] fabricated Ni–Si3N4 nanocomposite thin films by different types of electrodeposition method, which are direct current (DC), Pulse current (PC) and Pulse, reverse current (PRC). They analyzed the surface morphology and structure and mechanical properties of these thin films by Scanning Electron Microscope and XRD. In addition, they evaluated corrosion properties of Ni–Si3N4 nanocomposite by electrochemical method. They indicated that the sample produced by PC method has smaller size rather than the sample produced by DC method (as seen Figure 2.16) Also PRC method provided smaller and more uniform grain size compared to DC and PC methods. They also reported that addition of Si_3N_4 improved micro hardness compared to pure nickel coatings obtained by DC, PC and PRC methods and the highest micro hardness value was obtained by PRC method (as seen Figure 2.17). This increasing of micro hardness can be explained with more content of Si_3N_4 reinforcement in the coating during the PRC process and incorporation of Si_3N_4 caused to decrease the grain size of the coating. Besides they stated that corrosion behavior of Ni–Si_3N_4 composites was better than pure nickel coatings in all electrodeposition methods, also Ni–Si_3N_4

composites obtained by the PRC method showed more corrosion resistance properties than all other coatings produced DC and PC methods. They realized these corrosion properties with using of Taffel curves (as seen figure 2.23).

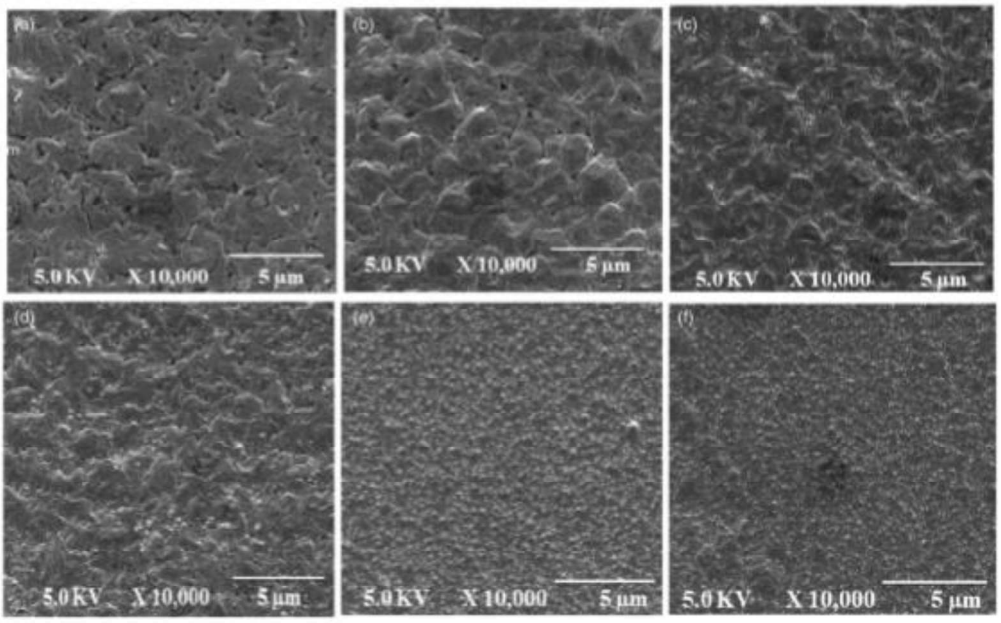


Figure 2.16 Surface morphology of Ni and Ni–Si_3N_4 deposits produced under DC, PC and PRC conditions; (a) DC; Nickel, (b) PC; Nickel, (c) PRC; Nickel, (d) DC; Ni–Si_3N_4, (e) PC; Ni–Si_3N_4, (f) PRC; Ni–Si_3N_4 [62].

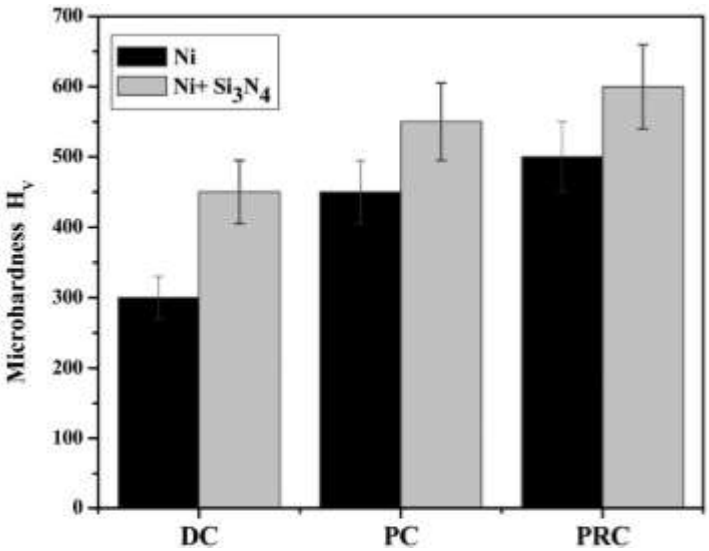


Figure 2.1712 Microhardness of the Ni and Ni–Si3N4 deposits produced under DC, PC and PRC conditions [62].

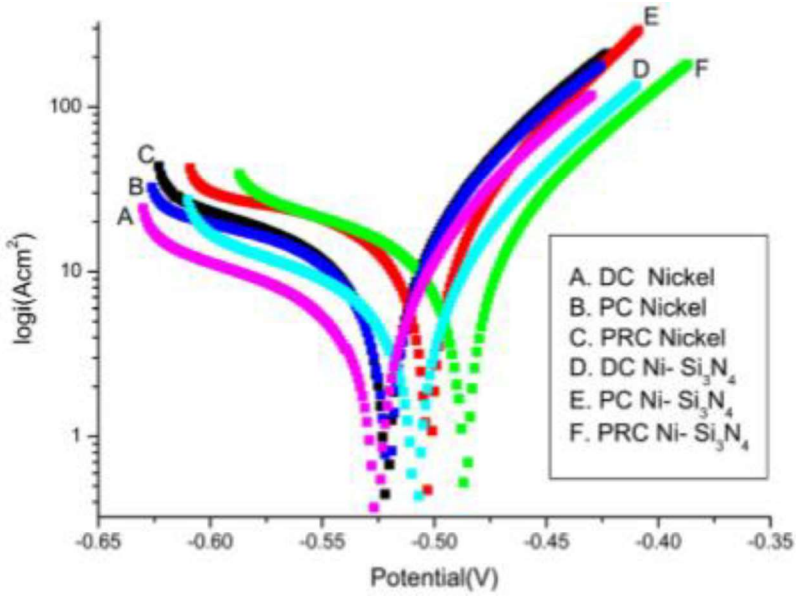


Figure 2.18 Taffel curves of Ni and Ni–Si3N4 deposits produced under DC, PC and PRC [62].

Borkar et al. [60] revealed comparative results and they obtained pure nickel and nickel composite coatings (Ni-Al_2O_3, Ni-SiC and Ni-ZrO_2 by different types of current which are DC, PC and PRC. Fabricated Ni composite coating which produced by PC method resulted uniform and finer microstructure of coatings. They also discussed that, the improvement of hardness for pure nickel coating by produced with PC and PRC deposition conditions was very small because of change in crystallographic condition texture with deposition conditions. This order of deposition conditions resulted increased with addition of reinforcement. Due to increasing of reinforced particle with PC and PRC method, improving of hardness was observed clearly.

Wang et al. [63] characterized microstructure and hardness values of Ni-ZrO_2 coatings that were prepared by PC and PRC methods. They indicated that PC composite coating exhibited most compact micro-surface and smoothest morphology and amongst the others. PRC composite coatings micro-surface morphology was coarsest. They also reported that, remarkable increasing of hardness value of Ni-ZrO_2 composite coating was obtained from PC to PRC method. They attributed this situation to Hall-Petch strengthening and Orowan strengthening.

Vaezi et al. [64] prepared Ni-SiC nanocomposite coating with different amount of SiC in relation cathode current density, temperature of coating bath and stirring rate by

electrodeposition methods. They reported that increasing of current density at higher temperature resulted with increasing of electrodeposited nickel and also, increasing weight percentage of SiC nanoparticles increased the micro hardness of the coating. They also mentioned that, since SiC nanoparticles act as barrier against to corrosion, more incorporation of SiC nanoparticles improved the corrosion resistance of the coating.

Chang et al. [65] not only investigated the behaviour of arc erosion of silver matrix composites with reinforced SiC particles by using tests of single-spark and static-gap but also examined having produced samples by different content and SiC particles with hot pressing process and electroless plating. They reported that, melting, flow, severe splash of molten silver of SiC particles were present on the surfaces of eroded composites, which contain low volume percents of large particles. As the number of particles increased and their size decreased, the flow and splash of silver and the particle segregation were less serious, exhibiting a better erosion resistance.

Lujain et al. [22] has investigated graphene reinforced material affect for silver matrix, she has observed type of current, and amount of graphene reinforcement affect in deposition bath for arc erosion behavior. She has used electrodeposition method to obtain graphene reinforced silver nanocomposite coating. She has observed that arc erosion behavior of pure Ag coating was significantly affected by different type of current and amount of graphene content. She noticed that coated Ag-Gr by PRC method has demonstrated less erosion pits compared to coated Ag-Gr by PC and DC electrodeposition method. She also emphasized that coated Ag-Gr with 2g/L graphene exhibits uneven surface with high deformation areas.

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 Preparation of Samples and Electrodeposition

3.1.1 Preparation of Samples

Silver and SiC were used as respectively matrix and reinforcement materials to observe the efficiency of SiC reinforcement in silver nanocomposites, these electrical silver contacts were used. Electrodeposition method was used to obtain SiC reinforced Ag nanocomposite coating. As an anode material, high purity silver plate and as cathode material, two kind of copper substrates were used. Copper was choosen as substrate material to carry out electrical conductivity with silver coating. The first one was hot rolled copper rods, which were prepared as a cylindrical shape with 8 mm × 3 mm diameter, and length, respectively as seen in Figure 3.1. The other one was electrical contact buttons HDC6 as seen Figure 3.2. Metallographic surface preparations were carried out by different grade size SiC papers which are respectively 400, 800, and 1200 grid. Then each cylinder was washed with distilled water and rinsed with acetone. After these procedures, copper wires were to ungrinded side of the samples. The surfaces, which are not deposited, were polished with a nail lacquer to hinder undesirable effects. After sufficient time for drying of polisher, contact surfaces were cleaned with acetone.

Then Watt type bath has been used for electrodeposition process. During electrodeposition process, current applied was 10 mA and pH of the bath was adjusted to 10-12. Electrodeposition process was applied by BARAKUDA electroplating device. It has been utilized not only used as a power source, but also used as a different current types supplier such direct current (DC), pulse current (PC), and pulse-reverse current (PRC) that had been applied within deposition processes. During all electrodeposition process, magnetic stirrer was not ceased to abstain from agglomeration of used powders.

Figure 3.1 Copper rod samples [22].

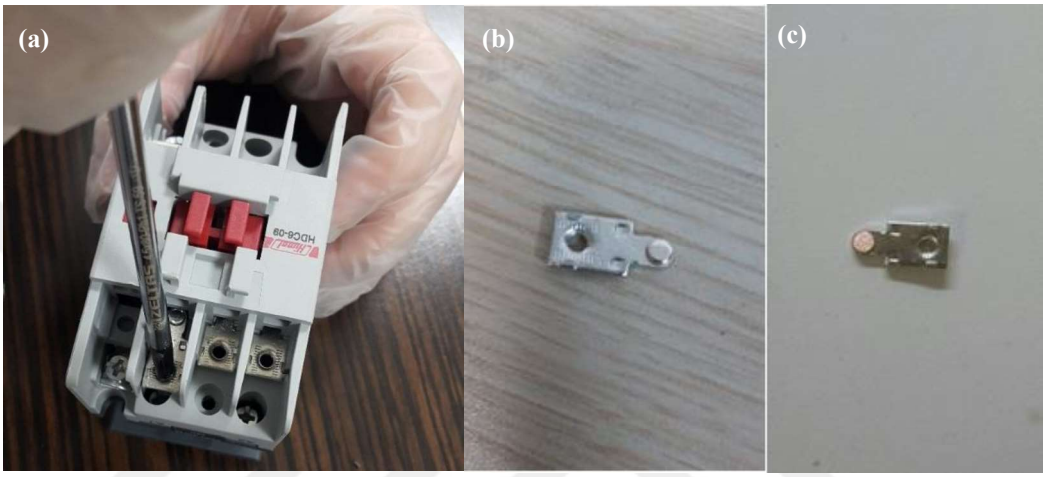


Figure 3.2 Dissembling of contact materials from electrical contactors (a), and disassembled (b) and grinded (c) contact material.

Electrical contact materials that had been dissembled from electrical auxiliary contactors as shown in the Fig. 3.2 obtained electric contact button substrates. Basic silver coatings were grinded with manual grinder machine also acquiring of a flat and smooth surface was aimed. After grinding of silver coating, the copper surface was obtained which has a surface area of 100.5 mm². This procedure was applied on all contact materials respectively. Following this step, each substrate was washed with distilled water and rinsed with acetone. The surfaces, which are not deposited, were polished with a nail lacquer to hinder undesirable effects. After sufficient time was waited to dry of polisher, contact surfaces were cleaned with acetone.

3.1.2 Preparation of Coating Baths

In this part of experiment, two types of silver bath were prepared for electrodeposition, first one was pure silver coating bath and second one was silver-SiC nanocomposite coating bath. General coating bath parameters were shown in Table 3.1. Pure silver coating bath was composed of silver nitride, potassium cyanide and distilled water. The silver nitrate had the duty of being silver source. The deposition molecules would take the silver ions both from not only electrodeposition bath but also from the silver plate, which would be placed across the sample. To dissolve the Silver Nitrate, Potassium Cyanide were added. The Dodecyl Sulfate Sodium Salt (SDS) was applied to prevent the agglomeration. Sulfite ions have been considered as a reducing agent to prepare silver nanoparticles in aqueous solutions. The other bath had consisted the same chemical components with the additional of different amount of reinforcement material that were SiC. Both of them were prepared in 100 ml glass beaker as seen in Figure 3.3.

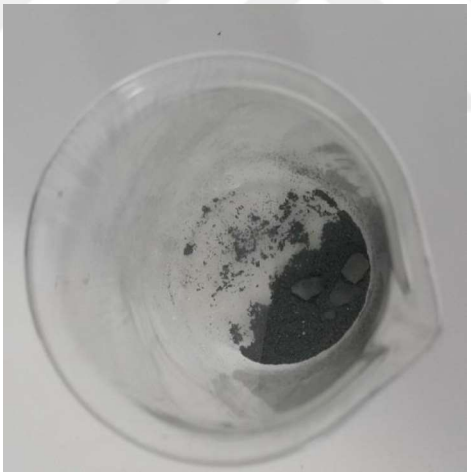


Figure 3.3 Powders of SiC, KCN, $AgNO_3$.

Table 3.1 Coating bath parameters.

Parameters	For Pure Silver Coating	For Silver-SiC Nanocomposite Coating
$AgNO_3$ (g/L)	10	10
KCN (g/L)	10	10
SiC (Reinforcement Material) (g/L)	-	0.5 ,1.0 , 2.0, 4.0
Current	10 mA	10 mA
Current Type	DC,PC,PRC	DC, PC, PRC
PH	9	9
Temperature	50 ^{0}C	50 ^{0}C
Magnetic Stirring	150 rpm	150 rpm
Cathode	Copper	Copper
Anode	Silver	Silver

Because of the SiC's being nanoparticles, the solutions were mixed into the Ultrasonic Homogenizer device as shown in Figure 3.4 for 45 minutes and at 90 °C with magnetic stirrer. The Ultrasonic Homogenizer device provides small particles for increasing the homogeneity of the solution. A reduction of the mean diameter of the particles caused increment of the number of individual particles. This situation leads to reduction of the average particle distance and increase the particle surface area. If the particle size is similar for the majority of the particles, the tendency to agglomerate is reduces [66]. In shortly, ultrasonic homogenizer is a mixing, disruptive machine. After removing of baths from ultrasonic homogenizer, they were individually stirred on magnetic stirrer to obtain a well-dispersed solution and waited sufficient time to decrease temperature to 50^{0}C while magnetic stirrer was turned on and it mixed the solution.

Figure 3.4 The ultrasonic homogenizer equipment.

3.1.3 Electrodeposition Process

Electrodeposition method was used to obtain SiC reinforced Ag coating layer on copper material by using of electrolyte of silver ions and silicon carbide nanoparticles. Different current type and different amount of SiC content affect was observed. In that, pure silver coatings were obtained with different types of current, which are DC, PC, PRC to investigate SiC affect. Also SiC reinforced silver nanocomposite coatings were achieved by changing two parameters, which were type of current and different content of SiC nanoparticles in the deposition bath. Firstly, SiC reinforced silver nanocomposite coating were obtained with using different types of current, which were direct current (DC), pulse current (PC) and pulse reverse current (PRC) to observe different type of current. The second coatings were acquired by different amount of SiC content by DC electrodeposition process to investigate different amount of SiC content.

During electrodeposition process, pure silver ingot was used as anode and contact buttons and cylinders were used as cathode. The pure silver ingot and substrate were placed as facing each other as seen in Figure 3.5. The baths that have 1.0 g/L SiC nanoparticles were connected with DC, PC and PRC power supply. In addition, the other types of bath, which have different SiC nanoparticles amount that are 0.5 g/L, 2.0 g/L and 4.0 g/L were, connected DC power supply. When 50^0C temperature was achieved, DC power supply was applied by a constant (10 mA) current. In PC electrodeposition, 20 mA as Ton was applied for 10 ms and 0 mA as Toff for 10 ms respectively to apply current fluctuation. The average current was calculated as mean of current amount during Ton and current amount of Toff. In the PRC method, 30 mA as Ton for 10 ms and 10 mA as -Ton for 10 ms respectively to obtain 10 mA average current. 10 mA average current was calculated to obtain optimum coating thickness and homogeneous texture. The electrodeposition process was activated and magnetic stirrer was not ceased to avoid agglomeration during electrodeposition process as seen in Figure 3.6. The average current becomes 10 mA in PRC. Structural and tribological improvements were expected on the coating surface due to applying of different amount reinforcements and types coating.

Figure 3.5 The samples to be coated with the silver piece across to each other.

Figure 3.6 The electrodeposition process set-up.

3.2 Characterization Methods

3.2.1 SEM Analysis

The surface of coatings was examined with scanning electron microscopy. In this examination, Tabletop Microscope TM4000Plus SEM was used as seen in Figure 3.7. Each coated contact materials were placed the examination tables of SEM. Materials were attached with carbon adhesive plasters respectively. The settings of SEM were set as represented in Table 3.2. Each SEM visuals were saved.

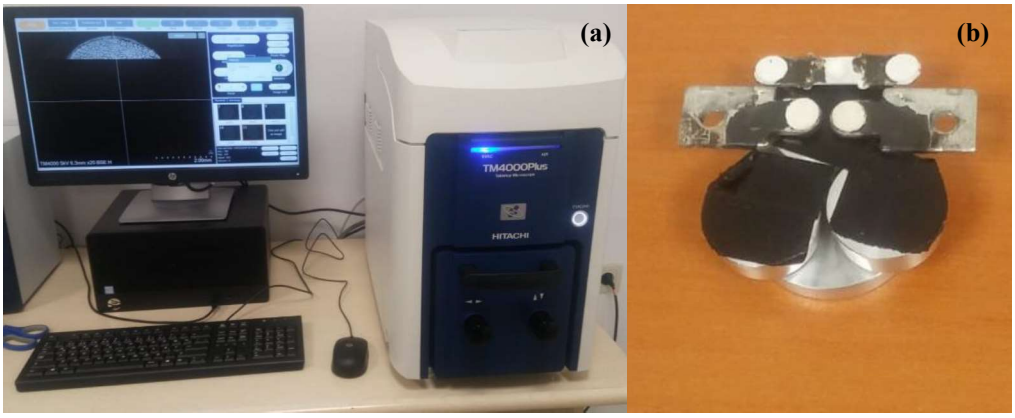


Figure 3.7 (a) SEM instrument, (b) Setting the samples on SEM analysis place.

3.2.2 XRD Analysis

Each contact materials were examined with XRD instrument to obtain information about crystal structures of coatings. Ag-SiC, nanocomposite coatings were analyzed by powder X-Ray diffraction (XRD) using with CuKα radiation. The CuKα radiation of wavelength is 1.54059 Aº. Scanning was done due to 1° increasing in each minute as 2θ range between from 35^0 to 90°. In addition, the intensity values of each 2θ values were collected and plotted by XRD graph.

3.2.3 Hardness Test

The hardness values of each coating were examined with SHIMADZU HMV-G microvicker's hardness device as shown in Figure 3.8. 100 g load was applied for 6 seconds on coated cylinders. For each coating four hardness examinations applied and are took their average as hardness value. There only four cylinders was used for this characterization. Samples and hardness values are represented in table.

The diamond tip was pressed onto surfaces of each coatings and the instrument measured indentation of tip due to time and load. After that, gave a hardness value of each sample. Then a graph was plotted.

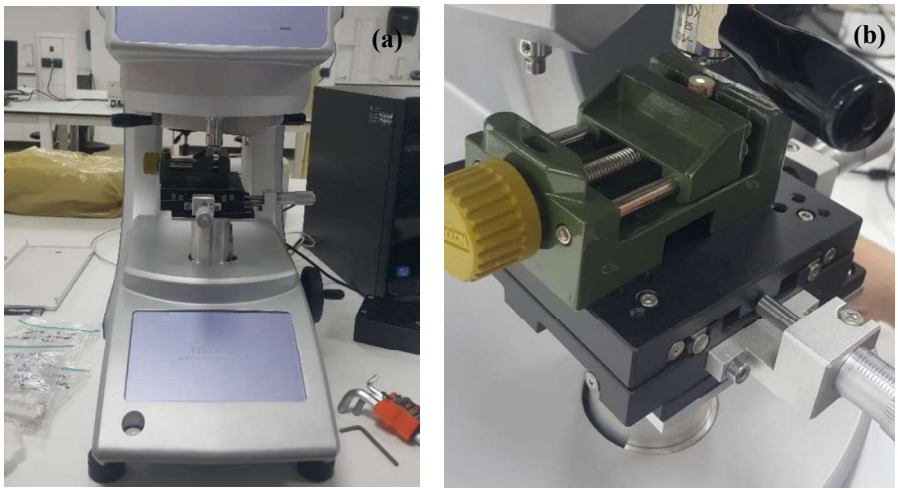


Figure 3.8 (a) Hardness test instrument (b) Vickers hardness test process.

3.2.4 Measurements of Rate of Deposition and Cross-Section Analysis

Cylinder samples were cut with Low-Speed Saw apparatus and then they were mounted with the Bakelite by hot mounting machine to analyze coating thickness and cross-section growth of coating. After that, samples were grinded by SiC sandpaper 600, 800, 1000 and 1200 grinding sizes. Then, 3 µm diamond suspension was used to polish the surfaces on the MD Mol to reach the mirror like surfaces finish. After the preparation of sample, SEM images and EDS analyses were obtained to analyze the growing of Ag-SiC nanocomposite coatings on the copper substrates and calculate the thickness of coating.

3.2.5 Electrical Contact Test

This test's performances were carried out Handmade electrical contact test device have been established in Yildirim Beyazit University laboratory for examining the electrical contact performance of all prepared coatings as seen in Figure 3.10 and also Figure 3.11 shows schematically electrical contact test. Contact tests were carried out at a constant load of 4 kW with a current of ~18 A /DC, and voltage of 220 V. Each contact parts coated pairs were tested for 10000 operation cycles. Operating frequency with 2 seconds for both Ton and Toff was selected. Electrical contact test was applied for analyzing arc erosion, melting and breakdown of the coated contactors. The surface

morphologies of all contacts after the test is completed were characterized by (Hitachi TM-400) scanning electron microscope.

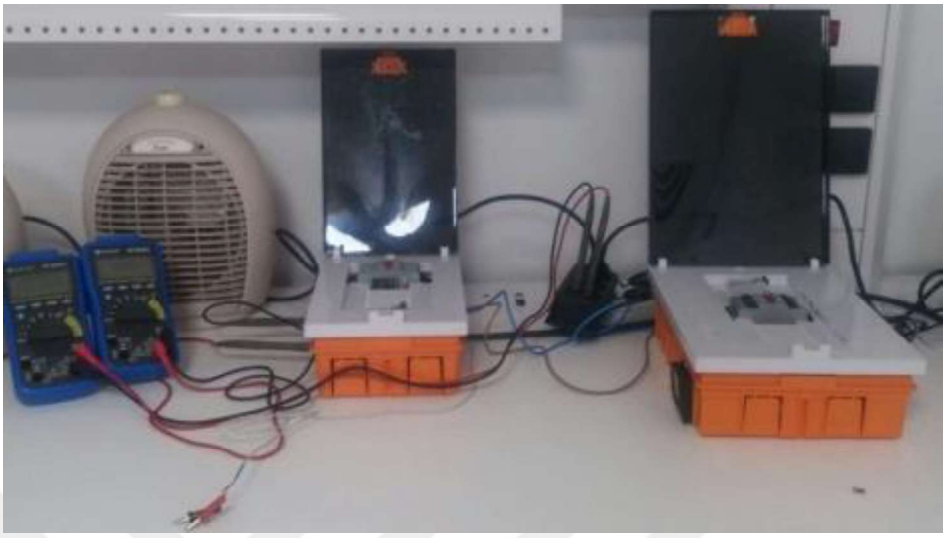


Figure 3.9 Electrical contact test device.

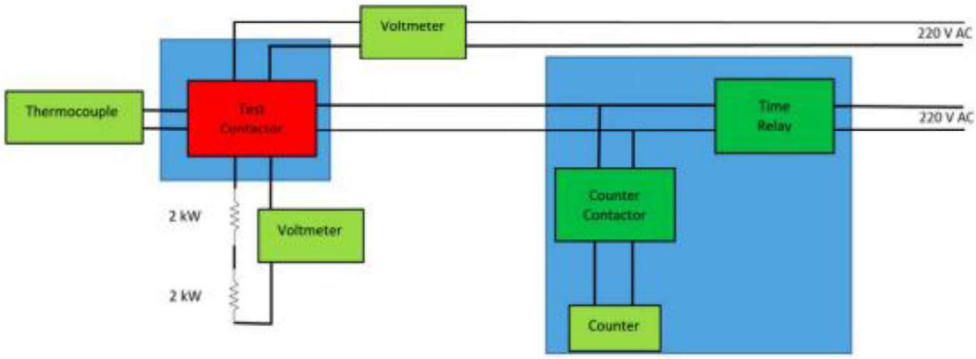


Figure 3.10 Schematic representation of electrical contact test [22].

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Structural Analysis

4.1.1 Microstructural analysis

There are influences of different amount of SiC reinforcement addition to coating bath and different types of current on the mechanical, structural and electrical properties for coating. Scanning electron microscope showed us addition of SiC reinforcement to the silver coating bath has some different morphological properties than pure silver coating in Figure 4.1. If we examine pure silver coating in itself, different types o current (DC, PC, PRC) affects the surface properties. Have produced with DC current type surface has relatively bigger grain size and irregular polyhedron crystal with less compacted structure than have coated with PC and PRC techniques because PC and PRC electrodeposition methods causes more nucleation growth as a result grain structure is finer and also has better uniformity as can be seen in Figure 4.2. Reddy et al. [62] has observed that PC and PRC samples show more uniform morphology than DC electro deposition method when they produced Ni–Si_3N_4 composites with different electrodeposition methods.

For Ag-SiC nanocomposite coating by different applied currents (DC, PC, and PRC method), the SEM images as seen in Figure 4.1 were demonstrated with low magnifications and in Figure 4.2 with high magnification for all. It can be clearly understood that morphologies of coated surfaces were changed by changing of type of electrodeposition methods. Also, Ag crystals have still shown polyhedron morphology but smaller than pure Ag coated surface as can be seen in Figure 4.2. Significant increment of SiC content was observed by PC and PRC methods because of periodically current fluctuation of PC and PRC electrodeposition methods. As can be seen from Figure 4.2. DC deposited SiC reinforced silver nanocomposite coatings results in some agglomerations and heterogeneous texture therefore irregular crystals was observed compared to PC and PRC methods with. The PC and PRC deposited SiC

reinforced silver nanocomposite coatings demonstrate more uniform crystal structure than DC electrodeposition method. PC method deposition gave less agglomeration and more homogeneous texture than DC method deposition. PRC deposited SiC reinforced silver coatings gave the highest homogeneous texture and least agglomeration as seen in Figure 4.2. In the light of these in formations and SEM images, it can be observed that the flattest coating surface belongs to PRC deposited SiC-silver nanocomposite coatings. This situation can be explained by significant increasing of co-deposition SiC content in the coating by PC and PRC comparing with DC method. Because the periodically current density fluctuation of PC and PRC methods (from positive to zero for PC, from positive to negative for PRC methods) results with more co-deposition of nano particles with PC and PRC electrodeposition method than DC deposited nanocomposite. Mohan Reddy et al. [62] have carried out similar study about different electrodeposition methods of production of nanocomposite coatings and they found same results.

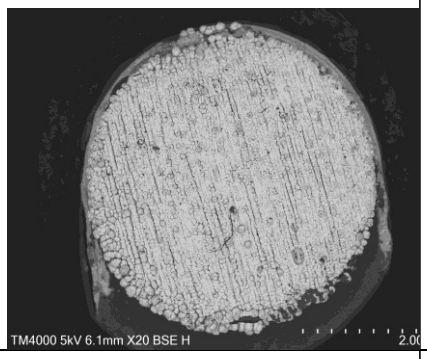
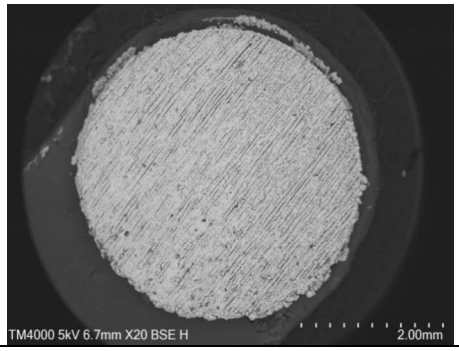
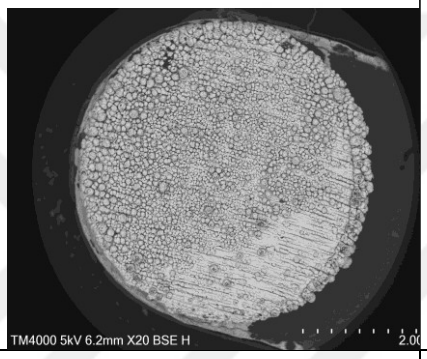
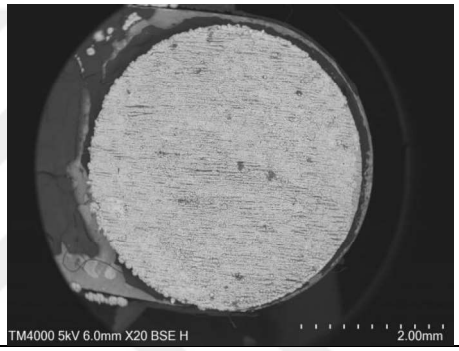
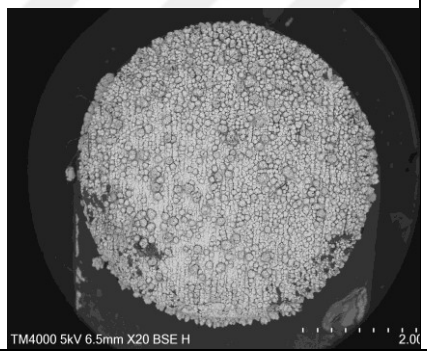
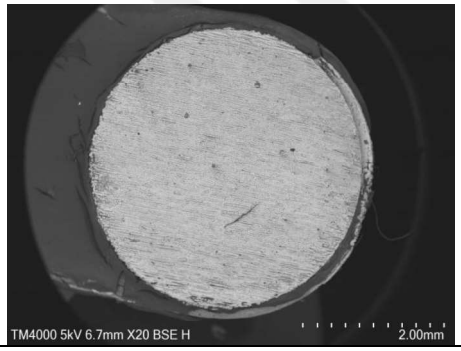
Current Types	Pure Ag	Ag/SiC
DC		
PC		
PRC		

Figure 4.1 Surface morphologies of pure Silver and Silver-SiC nanocomposite coating deposited by DC, PC, and PRC current methods with low magnification.

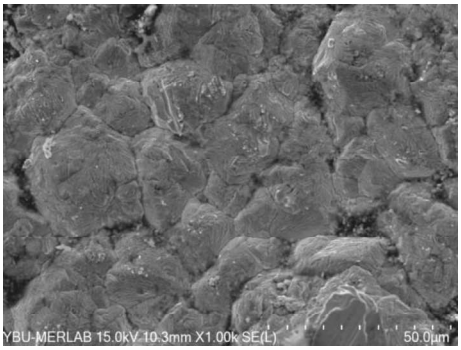
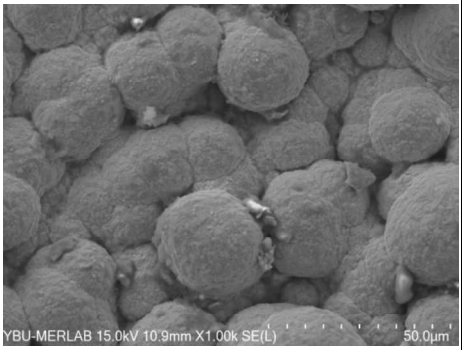
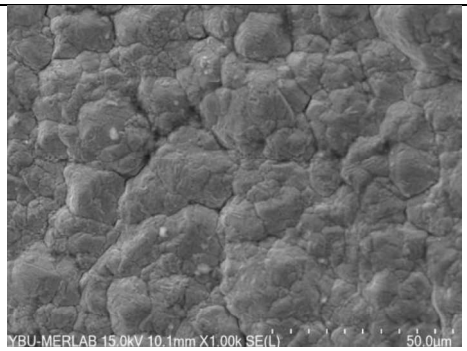
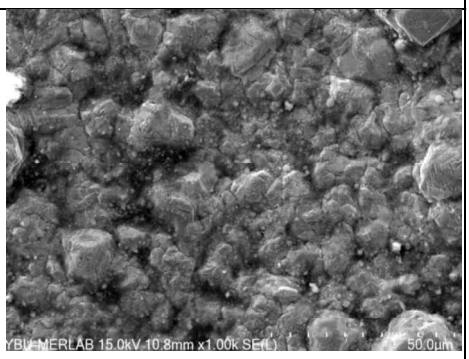
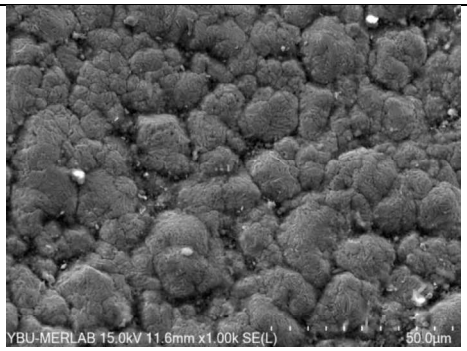
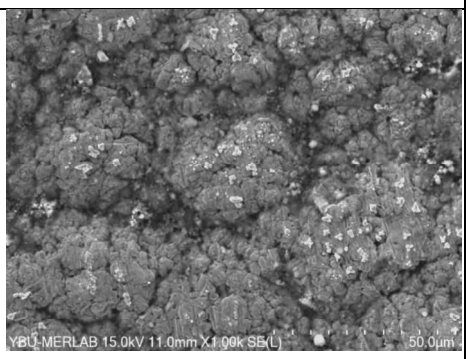
Current Types	Pure Ag	Ag/SiC
DC		
PC		
PRC		

Figure 4.2 Surface morphologies of pure Silver and Silver-SiC nanocomposite coating deposited by DC, PC, and PRC current methods with high magnification.

Have been deposited Ag-SiC nanocomposite coating by different amount of SiC nanoparticles and pure silver coating have observed with Scanning Electron Microscope (SEM). Electrolyte baths difference each other in terms of amount of SiC which were composed of 0.5 g/L, 1.0 g/L, 2.0 g/L and 4.0 g/L SiC. All of them were deposited by using of DC current. The surface morphologies were shown in the Figure 4.3. with low magnification and Figure 4.4. with high magnification. According to

these visuals, there is a rough structure of Ag-SiC nanocomposite coatings' surface by 0.5 g/L to 4.0 g/L. In addition, increasing of SiC nanoparticles amounts resulted with more inhomogeneous because of coarse grain features because of increasing of nano particles caused agglomeration. In terms of figures, pure Ag deposition has high agglomeration amounts and coarse particle formation. At the same time, because of none of SiC dispersion, very little black regions were occurred.

The sample, which contains 0.5 g/L SiC concentration in nanocomposite of Ag/SiC, has a same appearance with pure Ag. Therefore, the amount of SiC was very low to achieve specific SiC regions. On the other hand, the amount of agglomeration and particles sizes are smaller than pure Ag coating. Because SiC particles incorporated into crystals and grain boundaries, also that situation resulted with reducing of agglomeration.

As seen in Figure 4.3, for the nanocomposite deposition, which deposited with 1g/L SiC concentration in Ag matrix, agglomeration size and amount were much reduced. In accordance to some studies [64], this particle restriction can be because of adding of the nano-sized reinforcing material. SiC particles are acting a barrier at odds grain growth of matrix material. Similar results can be seen in the study of Borkar et al. [60].

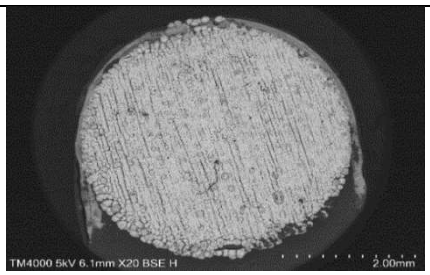
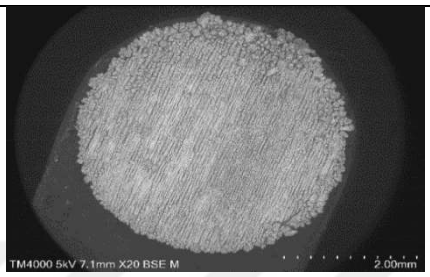
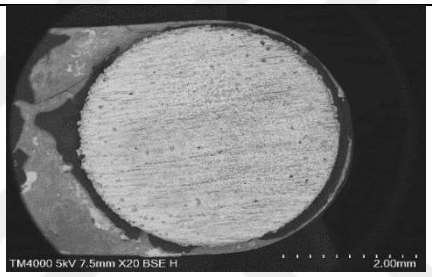
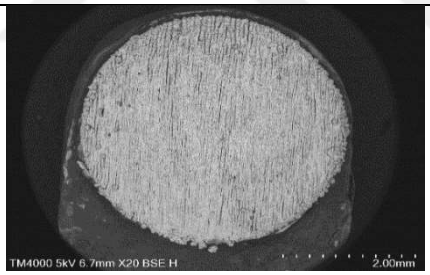
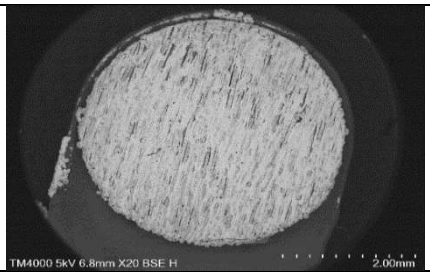
Amount of SiC	Ag-SiC
None	
0.5 g/L	
1.0 g/L	
2.0 g/L	
4.0 g/L	

Figure 4.3 Surface morphology of pure Silver and Silver-SiC nanocomposite coating deposited by different amount of SiC nanoparticles with low magnification.

By the increasing of SiC content up to 4.0 g/L concentrated, SiC-Ag nanocomposite coatings has become less flatness and has demonstrated less homogeneity of surface. As the amount of SiC increases, SiC nanoparticles are spreading to all grain boundaries of silver, forming a very distinct network and grains penetrated at high SiC percentages [67]. The maximum surface roughness has observed in the Ag-SiC nanocomposite coating, which contains 4g/L of SiC amount in electrolyte bath. There were some black regions and agglomerations of SiC as seen in Figure 4.4. With increasing of SiC nanoparticles amounts, surface roughness of nanocomposite coatings has increased. Because of SiC particles were incorporated to crystals and grain boundaries. Homogeneity was relatively decreased and dispersion was reduced because of agglomeration in grain boundaries. The incorporation of SiC nanoparticles caused in decreasing the grain size because of acting of nanoparticles as a physical barrier inhibit the grain growth of Ag matrix. Vaezi et al. [64] carried out same study and they found similar improvements of number of nanoparticles.

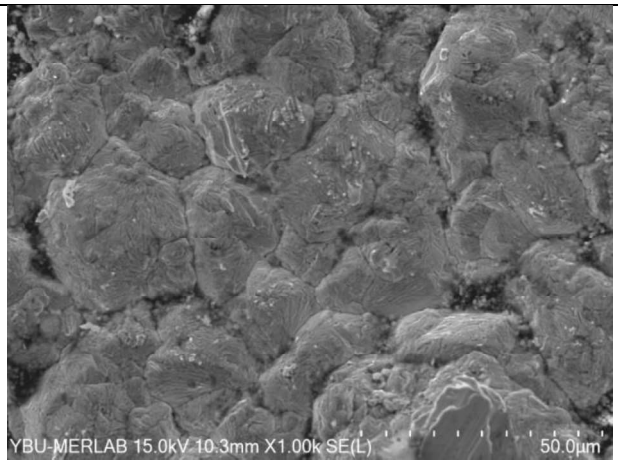
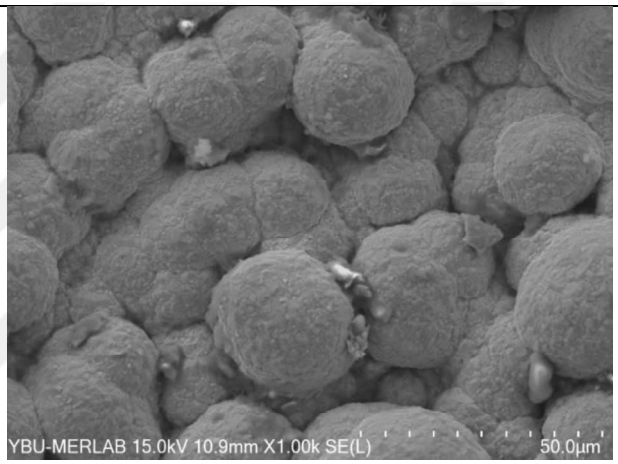
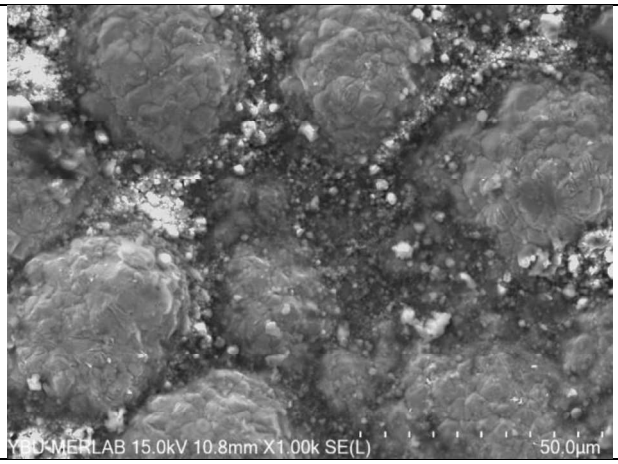
Amount of SiC	Ag-SiC
None	
1.0 g/L	
4.0 g/L	

Figure 4.4 Surface morphology of pure Silver and Silver-SiC nanocomposite coating deposited by different amount of SiC nanoparticles with high magnification with DC.

4.1.2 Energy Dispersive Spectrometer (EDS) Analysis

On the pure coating and nanocomposite coatings, the elements and their ratios were examined by Energy Dispersive Spectrometer. This characterization technique can be seen in some studies [60], [62]. This technique was used to obtain effects of type of electrodeposition methods and different amount of SiC nanoparticles in the coating bath on weight percentage of Si. EDS Map Sum Spectrum of pure Ag coating, which was produced by DC electrodeposition method, is exhibited in Figure 4.5. Borkar et al. [60] and our results show the same direction of the effected reinforcement wt% by different types of current and various content of reinforcement in the bath.

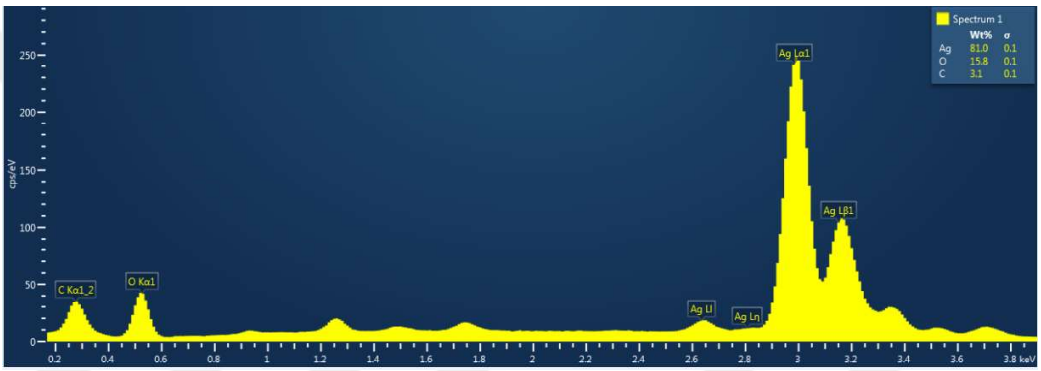


Figure 4.5 EDS map sum spectrum of pure silver coating which was produced by DC electrodeposition method.

Figure 4.6 represents that energy dispersive spectrum for the variation of SiC in deposition of Ag-SiC metal matrix nanocomposite coatings that were produced by DC, PC and PRC electrodeposition methods. Also, the samples which were obtained from cross-section method were analyzed with EDS to observe the growing of Ag-SiC nanocomposite coatings produced by different electrodeposition methods on the copper substrates. It can be clearly understood that from Figure 4.7. coatings are homogeneous and uniform. The presence of SiC was affected by three different electrodeposition methods and the reinforcement contents were increased with respectively PC and PRC electrodeposition methods. While the highest amount of Si was produced by PRC method, the lowest amount of Si was obtained by DC method. It can be explained with the periodic alternation of current (from positive to zero for PC, and from positive to negative for PRC) constitutes better penetration of

nanoparticles is allowed. In addition, it can be observed that, the coating thickness increased from DC (68.9 µm) to PC (72.8 µm) but the deposition rate of PRC (62.8 µm) was the lowest one of the other deposition rates. Mohan Reddy et al. [62] reported that the substrates produced Ni-Si_3N_4 by PC and PRC electrodeposition methods showed high penetration because of periodic alternation. On the other hand, DC electrodeposition method provides continuous current application and this situation results nucleation of SiC nanoparticles in the matrix rapidly. In addition, mechanical properties were affected such as with PRC electrodeposition method, highest hardness value was obtained.

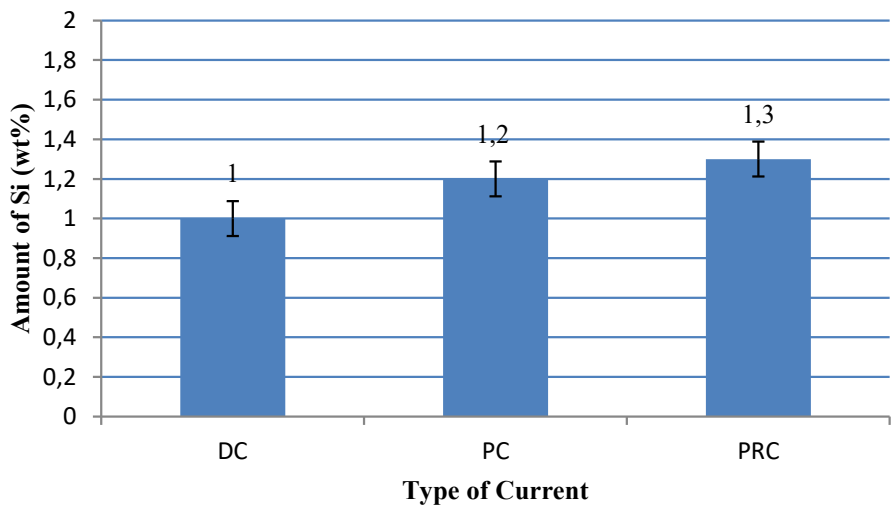


Figure 4.6 Weight percentage of Si in Ag-SiC coatings produced by DC, PC, and PRC deposition methods.

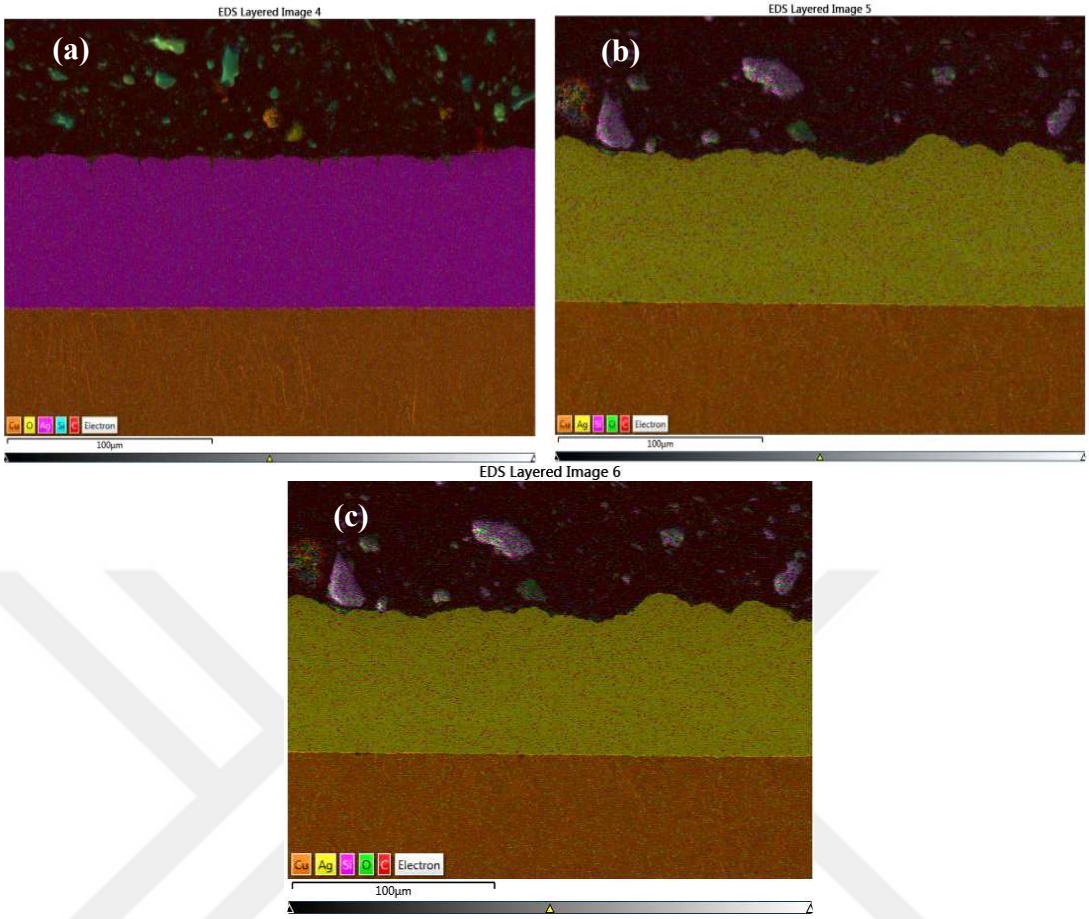


Figure 4.7 EDS analysis of cross-sectional samples electrodeposited with (a) DC, (b) PC and (c) PRC.

EDS results of Ag-SiC nanocomposite coatings were shown in Figure 4.8 with the ratio of Si as a function of different amount of SiC nanoparticles in the bath produced via DC electrodeposition method. Also, the samples which were obtained from cross-section method were analyzed with EDS to observe the growing of Ag-SiC nanocomposite coatings produced by different SiC amounts. It can be clearly understood that from Figure 4.9. coatings which reinforced with 0.5 g/L SiC is homogeneous and uniform but with increasing of SiC amounts to 4 g/L agglomerations were observed. The presence of SiC was affected by different amount of SiC nanoparticles. It can be clearly clarified that the ratio of Si was gradually increased from 0.5 g/L to 4 g/L with the addition amount of SiC. In addition, it can be observed that, the coating thickness increased from amount of 0.5 g/L SiC (70.4 µm) to 4 g/L SiC (95.1 µm). It can be stated that the weight percentage of Si increased with the

increasing of amount of SiC nanoparticles in the bath. The increasing of SiC particulates content results with co-deposited nano particulates in the electrolyte and thus higher concentration of SiC particulates in the electrolyte enhanced the adsorption rate. Kastrubai et al. [68] found similar results and they explained this situation by Guglielmi's (1972) two-step adsorption model. EDS dot map analysis of Ag-SiC nanocomposite coating which was prepared with 1 g/L and 4 g/L amount of SiC and DC method was respectively shown in Figure 4.10.

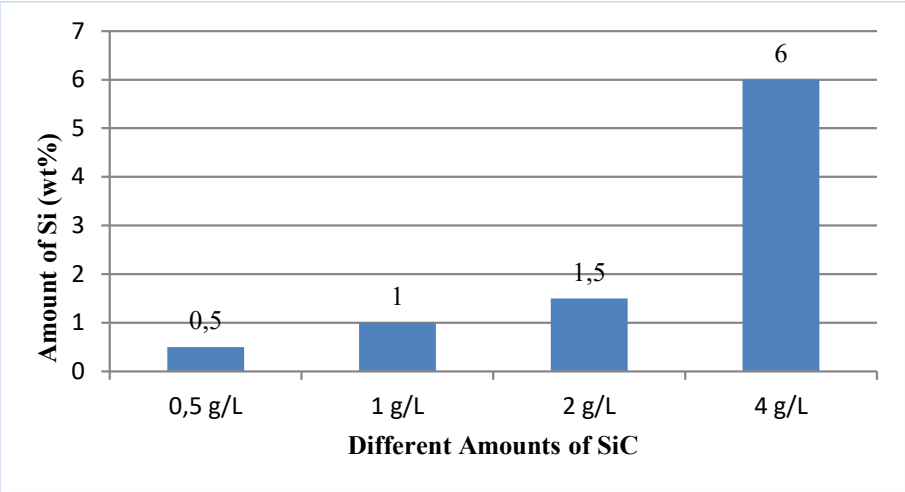


Figure 4.8 Weight percentage of Si in Ag-SiC coatings produced with different amounts of SiC.

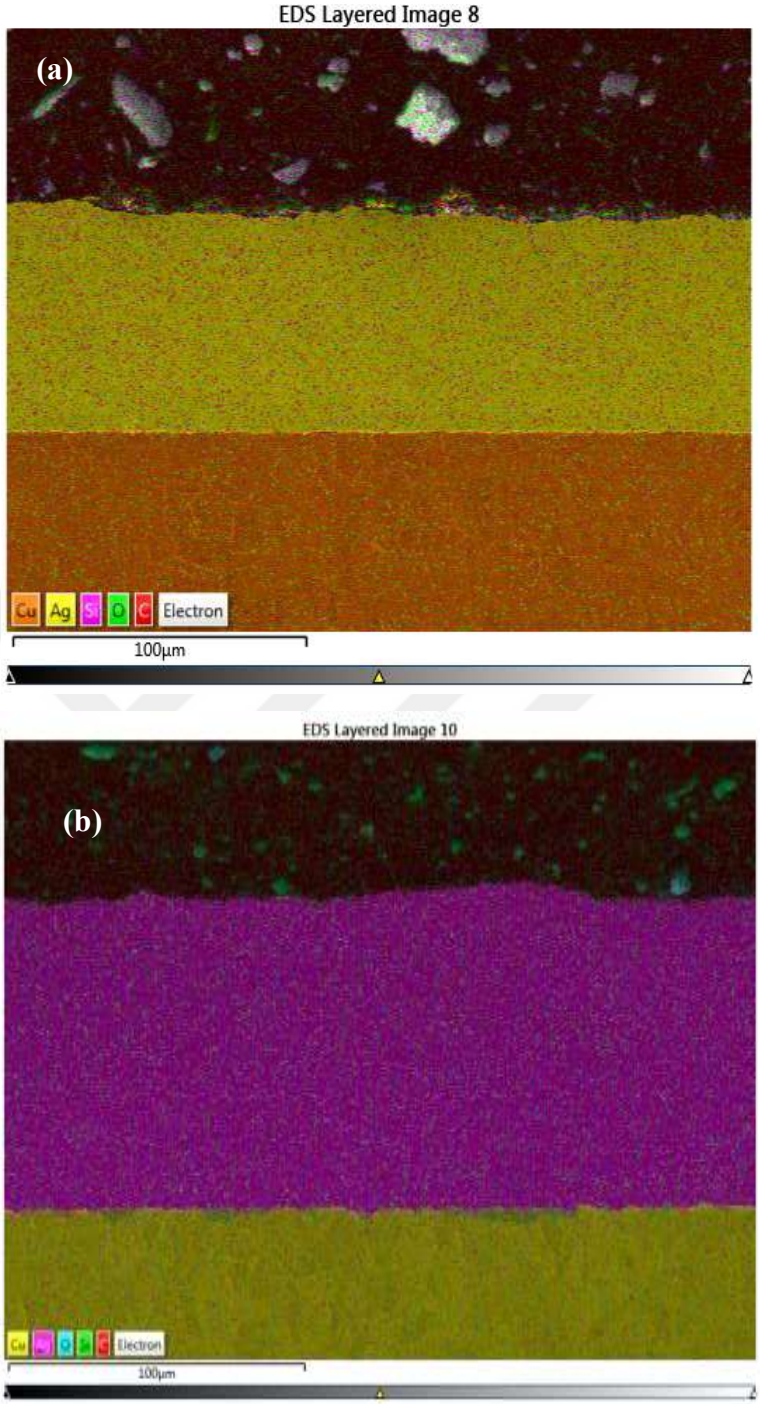


Figure 4.9 EDS analysis of cross-sectional samples electrodeposited different amount of SiC (a) 0,5 g/L, (b) 4.0 g/L.

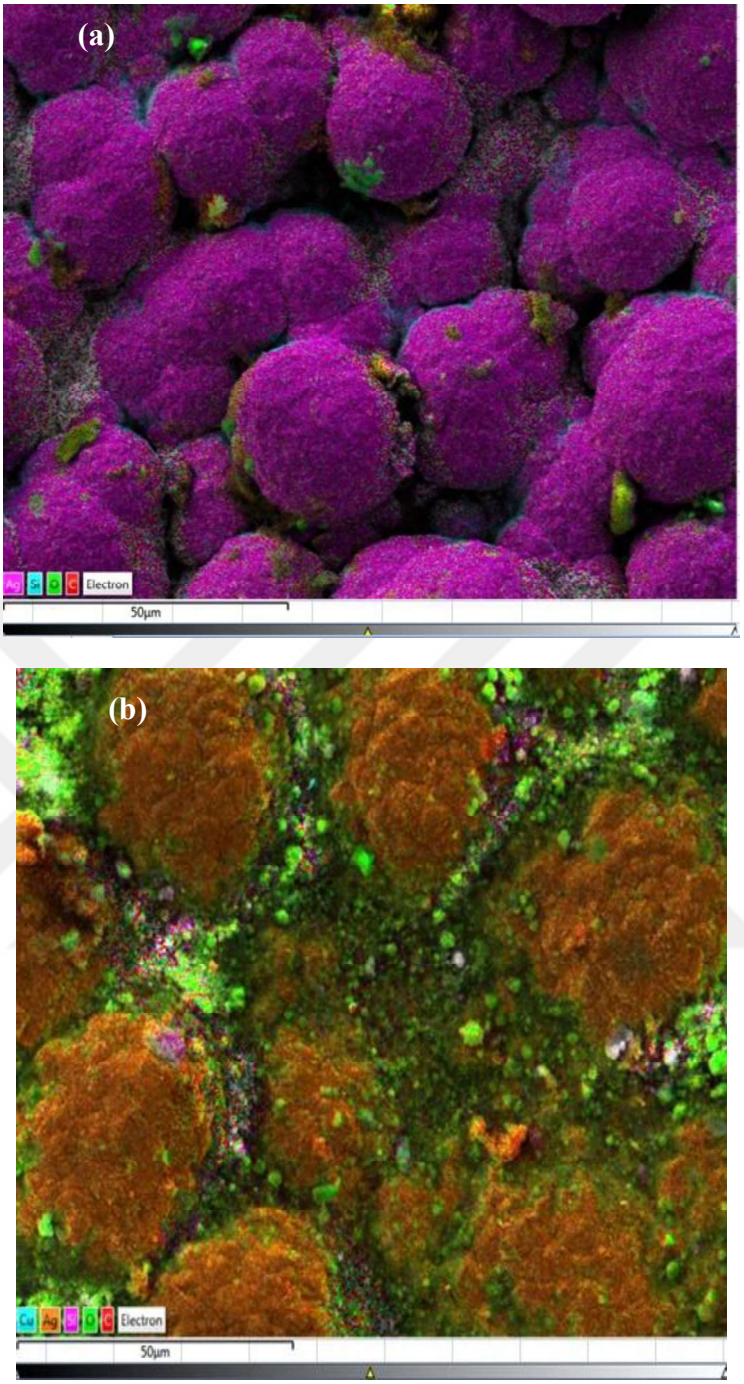


Figure 4.10 EDS dot map analysis of Ag-SiC nanocomposite coatings which includes (a) 1 g/L amount of SiC produced by DC and (b) includes 4 g/L amount of SiC produced by DC.

4.1.3 X-Ray diffraction analysis

XRD analysis was used to examine crystallographic structure of pure Ag and Ag-SiC nanocomposite coatings. As a wavelength beam of X-Ray 1.54059 was selected. As shown in the Figure 4.11, XRD patterns demonstrates pure silver nanocomposite coating by using of DC, PC and PRC electrodeposition method. JPDS card number used in the analysis was 00-004-0850.

If DC electrodeposition method for pure Ag coating is observed, it can be clearly understood that there are four main peaks at $2\theta = 37.87^{\circ}$ and $2\theta = 44.05^{\circ}$, $2\theta = 77.16^{\circ}$, $2\theta = 81.29^{\circ}$; when PC electrodeposition method for pure Ag coating, four main peaks at $2\theta = 38.14^{\circ}$, $2\theta = 44.31^{\circ}$, $2\theta = 77.45^{\circ}$ was observed, and the peaks at $2\theta = 38.25^{\circ}$, $2\theta = 44.42^{\circ}$, $2\theta = 77.49^{\circ}$, and $2\theta = 81.64^{\circ}$ for pure Ag coating obtained by PRC electrodeposition method. For these three different current types corresponds to (1 1 1), (2 0 0), (3 1 1) and (3 3 1) crystallographic orientations respectively. They have given sharp characteristic peaks at the specific intensities and 2θ degrees. These peaks are the individual pattern of pure Ag. For each samples the highest intensity and sharpest peak was observed at (1 1 1) crystallographic plane, which valid for FCC materials When electrodeposition method of Ag nanocomposite coating was changed from DC to PC and PRC, the intensity of (2 0 0) peak has increased and, (3 1 1) peak has decreased but there was no significant change for (2 2 0) and (2 2 2) peaks. The falling off for PC and PRC electrodeposition methods mean grain size refining and more random crystallographic arrangement because greater crystal growth rate was obtained in PC and PRC electrodeposition methods. Chen et al. [69] has observed similar effects of PC and PRC electrodeposition methods.

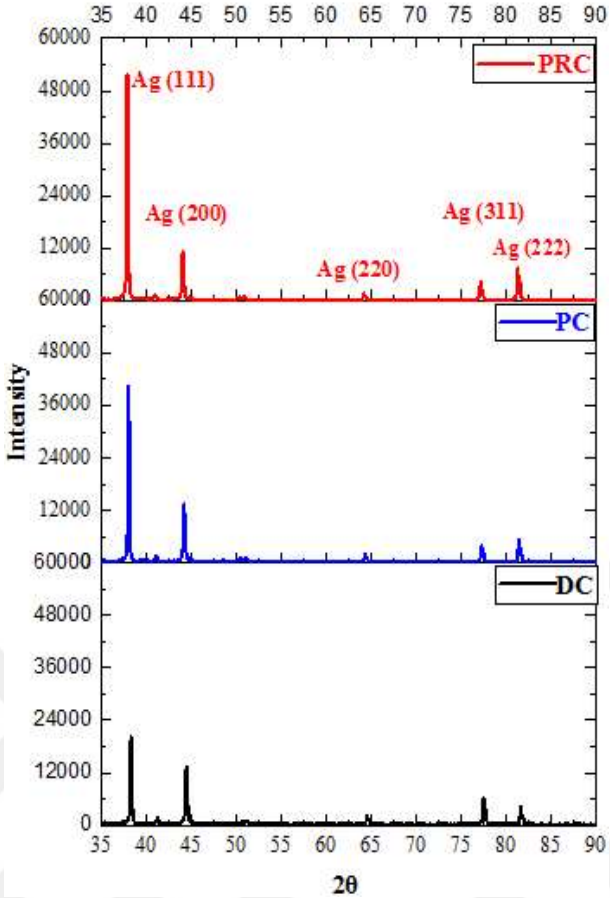


Figure 4.11 XRD peaks of pure Ag coating by different type of electrodeposition methods (DC, PC and PRC).

X-Ray diffraction patterns were observed for Ag-SiC nanocomposite coatings, which contains with 1 g/L SiC nanoparticles in the bath by coated with DC, PC and PRC. In addition, they have been represented in Fig. 4.12. Bragg reflections which belong to silver were observed and they correspond to (1 1 1), (2 0 0), (2 2 0), (3 1 1), and (3 3 1) reflections of silver. XRD peaks did not demonstrate the corresponding reflections of SiC due to small amount of reinforcement into the silver matrix. Even though there were not any XRD peaks correspond to SiC, being a reinforcement of SiC clearly demonstrates some influences, also the intensities of peaks have changed due to applied reinforcement with different deposition methods as seen in the Fig.4.11.

The addition of SiC reinforcement was caused decreasing in (1 1 1) and (2 0 0) peak intensity when it was compared with pure silver and significant decreasing of intensity for (3 1 1) and (3 3 1) peaks were observed as seen in Figure 4.12.a. When SiC nanoparticles were used as reinforcement into Ag matrix, the preferred orientation was influenced because of resisting grain growth and refining of grain size. Vaezi et al. [64] has carried out similar study and they explained this orientation change with same reason. Therefore, the addition of SiC nanoparticles into electrolyte bath induced refining of Ag matrix and decreasing of intensity peaks of XRD. The highest peak for reflection (1 1 1) belongs to PC due to coarse particles. However, when PC and PRC methods were compared, from PC to PRC the (2 0 0) peak has increased. This situation caused distortion of available lattice structure so preferred crystallographic orientation had changed as DC, PC and PRC methods. Borkar and Harimkar study also reported the similar results on the nanocomposite coatings [60]. In coatings, when reinforcement was deposited by DC, PC and PRC current types, emerging of stress was observed because of dispersion of silicon carbide in silver matrix. This situation can be determined by the broadening in the (1 1 1) peak which is shown in the Figure 4.12.b because of the shifting of peak demonstrates the occurring of macro stresses in the lattice. In addition, this shifting can be attributed to decreasing of grain size Ag-SiC nanocomposite coating by adding SiC nanoparticles. By changing of electrodeposition method from DC to PC and PRC, more SiC nanoparticles incorporated into to the silver matrix because of fluctuation of current. As a result, SiC nanoparticles caused to nucleate hence retarding grain growth was observed. Borkar et al. [60] have carried out similar study with some different reinforcement materials and they have applied DC, PC and PRC electrodeposition methods. As a result, they have found similar results.

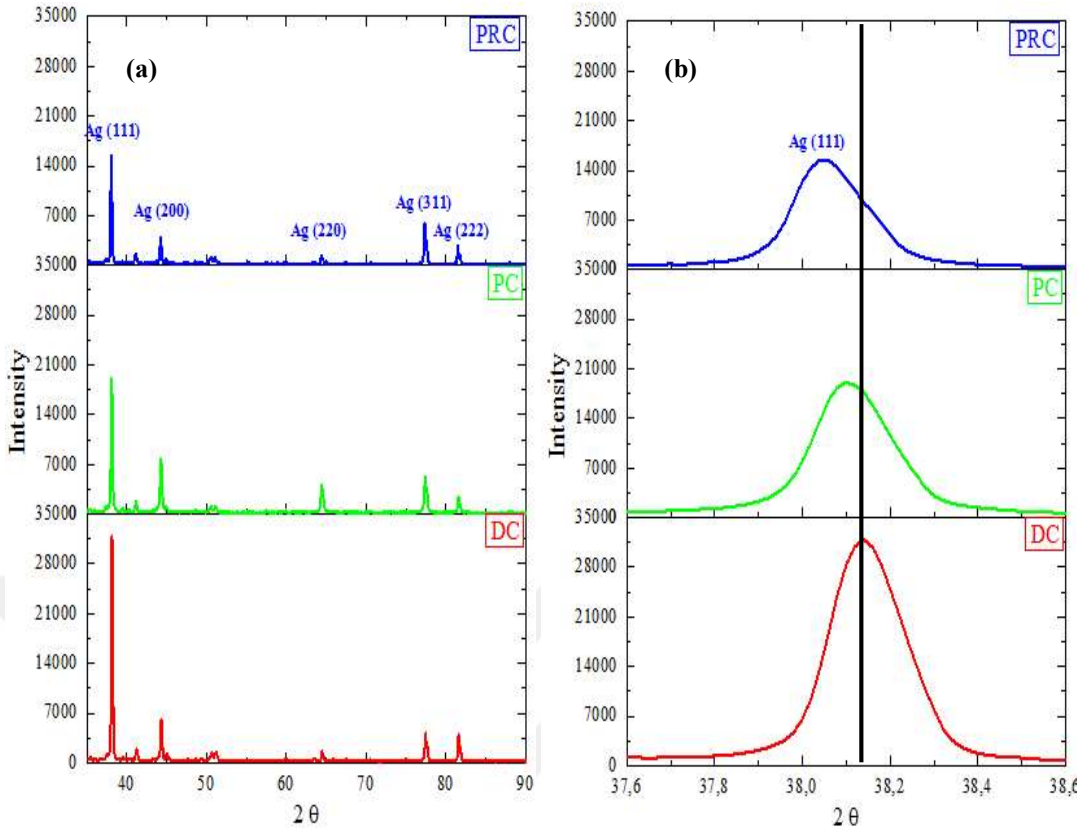


Figure 4.12 (a) XRD peaks of ag-sic nanocomposite coatings deposited by different type of electrodeposition methods (DC, PC and PRC), and (b) detailed (111) diffraction of Ag-SiC coatings.

X-Ray diffraction patterns were observed for Ag-SiC nanocomposite coatings which contains different amount of SiC nanoparticles 1 g/L, 2 g/L, 3 g/L and 4 g/L in the bath by coated with DC. In addition, they were demonstrated in Figure 4.12.a. In the XRD patterns of each samples, there are (1 1 1), (2 0 0), (3 1 1) and (3 3 1) crystallographic orientations and they gave sharp characteristic peaks at specific intensities and 2θ degrees. For each samples the highest intensity was achieved at (1 1 1) crystallographic plane. In this analysis, characteristic SiC peaks were not observed. Because SiC amounts for each sample were not enough to give peak. However, increasing of SiC amount from 0.5 g/L to 4 g/L caused significant decrease of (1 1 1) peak intensity. According to Figure 4.11.a, especially intensity amounts were varied for each crystallographic plane. The highest intensity was observed at 0.5 g/L concentration sample at (1 1 1) plane. In addition, the lowest intensity values were observed at 1g/L concentration sample.

According to detailed analysis of XRD patterns for Ag-SiC nanocomposite coating via addition of different amount of silicon carbide the highest intensity plane of (1 1 1) 2θ angle shifted as seen in the Figure 4.13.b. In Figure 4.13.a, pure Ag coating had nearly 38.3 º at the value of 2θ. For 0.5 g/L concentrated coating shifted to 38.15 º for the same angle. Moreover, by addition of SiC, for 1g/L concentrated sample shifted to 38.26º. In addition, 2 g/L concentrated coating shifted to 37.99 º. Finally, 4 g/L sample shifted to 38.09º. With black line represented in Figure 4.13.b eases the sliding amounts of each SiC reinforced samples. The smallest and lowest peak intensity was conducted with addition of 4 g/L SiC. Decreasing of peak intensities and the shifting of peaks occurred thanks to distortion by more addition of SiC. Because, embedding of SiC nanoparticles into the silver matrix has changed texture of preferred mode. Lujain et al. [22] has found similar results by adding graphene nanoparticles into the silver matrix.

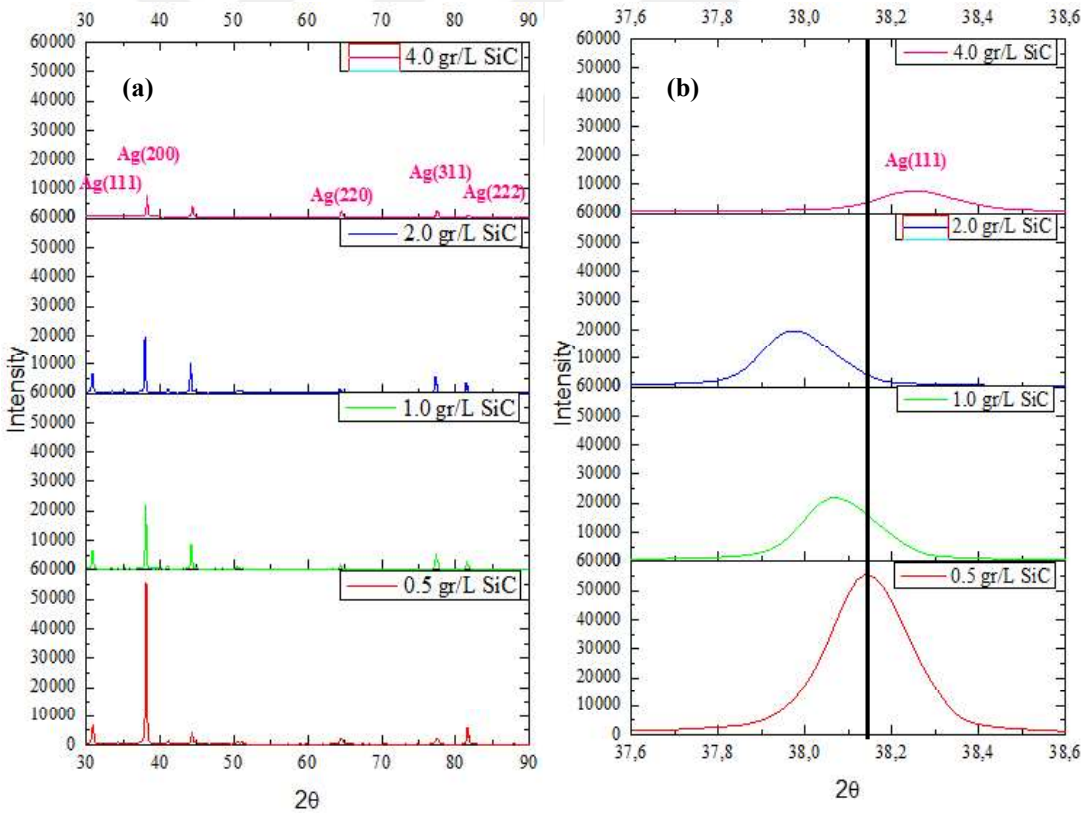


Figure 4.73 (a) XRD peaks of Ag-SiC nanocomposite coatings deposited by different amount of SiC nanoparticles, (b) detailed diffraction of (111) peak of Ag-SiC coatings.

4.2 Analysis of Hardness Coatings

The Vickers' micro hardness test was applied to cross section of samples for pure silver coating) and to the SiC reinforced silver nanocomposite coatings (deposited by DC, PC and PRC) and SiC reinforced silver nanocomposite coatings with different amounts of SiC deposited by DC electrodeposition methods. The hardness values of coatings were shown in the Figure 4.14. The increasing of the hardness for Ag coatings by using of PC and PRC deposition methods can be explained with the finer crystalline size and changing of crystallographic grain growth orientation.

It can be observed that the hardness value of SiC reinforced Ag matrix nanocomposite coatings are higher than Ag nanocomposite coating without reinforcement for different deposition methods (DC, PC and PRC). It can be concluded that, hardness of the coatings was improved through the co-deposition of adding SiC due to fine SiC particles as a second phase because they incorporate within silver matrix and blocks motion of dislocations so there will be observed grain refining and dispersive strengthening effects [70].

When Ag-SiC reinforced coatings produced by DC, PC and PRC methods were observed, type of electrodeposition method has significant influence on coating. The highest Vickers Microhardness value of 86.1 HV of Ag-SiC nanocomposite coating was obtained thanks to use of PRC current method. The hardness value of SiC-silver nanocomposite coatings was increased via applied deposition currents. The value of micro hardness of DC coated SiC-silver nanocomposite was 82.3 HV and it was increased to 83.1 HV with PC deposition current. The value of hardness with PRC method also is higher than PC method. As discussed earlier, this situation is explained by increasing content of reinforced particles. It means that, PRC electrodeposition methods that are applied current from positive to negative allow better distribution of ions in the electrolyte and increasing content of reinforced particles rather than DC and PC current type. Borkar et al. [60] reported a similar effect of current types.

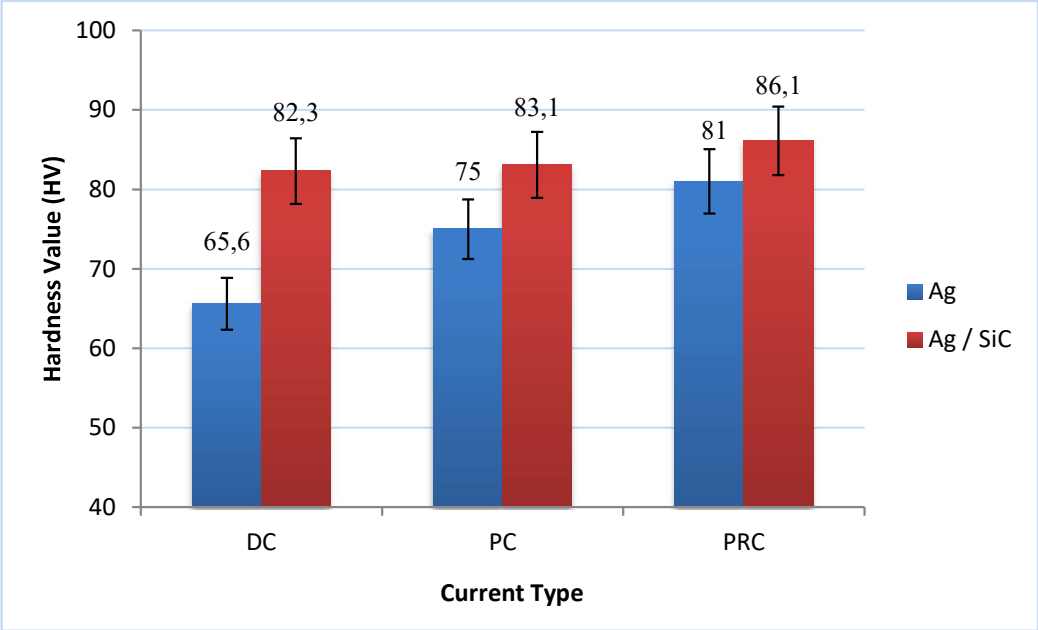


Figure 4.14 Hardness variation of Ag and Ag-SiC nanocomposite coatings with respect to DC, PC, and PRC current types.

Hardness results of silver metal matrix nanocomposite coatings reinforced with different amounts of SiC deposited by DC electrodeposition methods are shown in Figure 4.15. We can clearly illustrate that increasing of amount of SiC content affected on the hardness of the coating of nanocomposite coating. It is clearly understood that the highest hardness value was obtained with the addition of 2 g/L of SiC reinforcing materials in to the silver metal matrix. It can be concluded that, hardness of the composite coatings are improved through the co-deposition of SiC due to grain refining and dispersive strengthening effect, SiC nanoparticles deposited in silver matrix can restrict of growth of silver grains and plastic deformation under the loading. Adding of 4 g/L amount caused to decreasing of hardness of nanocomposite because 4g/L concentration nanocomposites contain excess amount of SiC and coarsening is observed. This leads to an incoherent dispersion. Vaezi et al. [64] reported similar effects with the similar results.

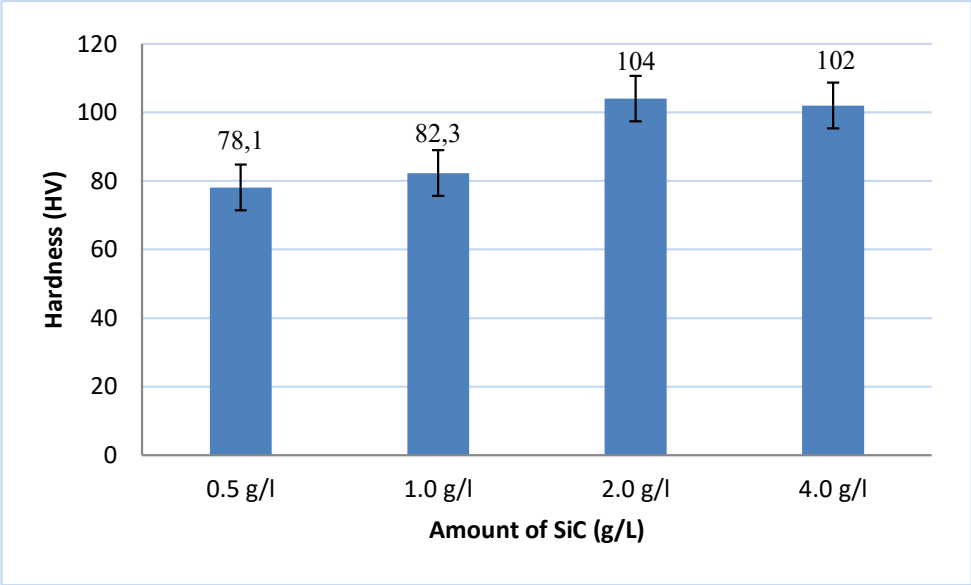


Figure 4.15 Hardness variation of Ag-SiC nanocomposite coatings according to different amounts of SiC.

4.3 Electrical Contact Resistance and Electrical Resistivity Analysis

The electrical resistivity of the coated samples was measured by electrical contact test device that is handmade. The test parameters were the same for all coated samples, which were adjusted at a constant load of 4 kW, double load capacity (18 Amphere), 220 AC voltage and 10000 operation cycles. Having been coated with Ag-SiC nanocomposite coatings contactor buttons, which were demoulded from contactor, was applied electrical contact test. Then the test results were investigated for resistivity as a function of temperature on the same condition of cycle. In addition, two-point electrical resistivity test was applied to the coated substrates to support the results of electrical contact test. Electrical resistivity of contact buttons that was coated with pure Ag coatings using DC, PC and PRC methods and electrical resistivity of contact buttons that was coated with Ag-SiC nanocomposite coating by using DC, PC and PRC methods differ from each other. The results were represented as a graph in Figure 4.16. It can be clearly understood that, the average resistivity of pure Ag coatings are less than Ag-SiC nanocomposite coatings. The incorporation of SiC nanoparticles into the Ag matrix caused increasing of resistivity. In that, the incorporation of addition of nanoparticles into the pure silver increase electrical resistance by distorting the lattice. The electrical conductivity of a metal mainly depends on the movement of electrons

in its internal structure. SiC particles used as reinforcement components in the silver matrix distort the structure, preventing the movement of electrons, thus decreasing the electrical conductivity of the composite with increasing amount of SiC. Gözde Efe et al. [67] have carried out similar study with SiC nanoparticles and they found increasing of electrical resistivity by addition of SiC.

Ag-SiC nanocomposite coated by DC, PC and PRC contactor buttons demonstrated different ranges of resistivity as a function temperature. Figure 4.17 demonstrates that electrical contact resistance behavior of Ag-SiC nanocomposite coating with using of DC, PC, and PRC electrodeposition methods. It can be clearly observed that increasing of operation cycles caused to increase of electrical resistance of Ag coated buttons because of formation of oxide films due to process of arc between contact pairs [67]. Similar study was carried out by Lujain et al. [22], same result has found, and they emphasized that the resistivity fluctuation cannot be dissociated.

On the other hand, coated sample with DC and PC methods show less resistivity than PRC electrodeposition method. In that, PRC electrodeposition method which were applied respectively from positive to negative current allow better distribution of ions in the electrolyte has supplied finer grain size because more SiC particles can be contributed with this electrodeposition method. Every contributed particle block electron motion [67], [22].

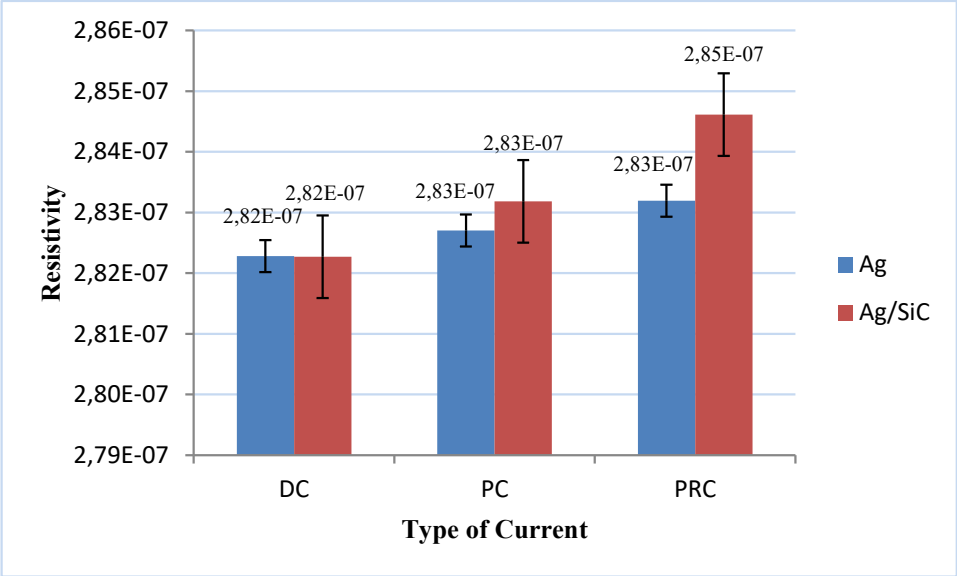


Figure 4.16 Electrical contact resistance analysis of Ag-SiC nanocomposite coating produced with DC, PC, PRC methods.

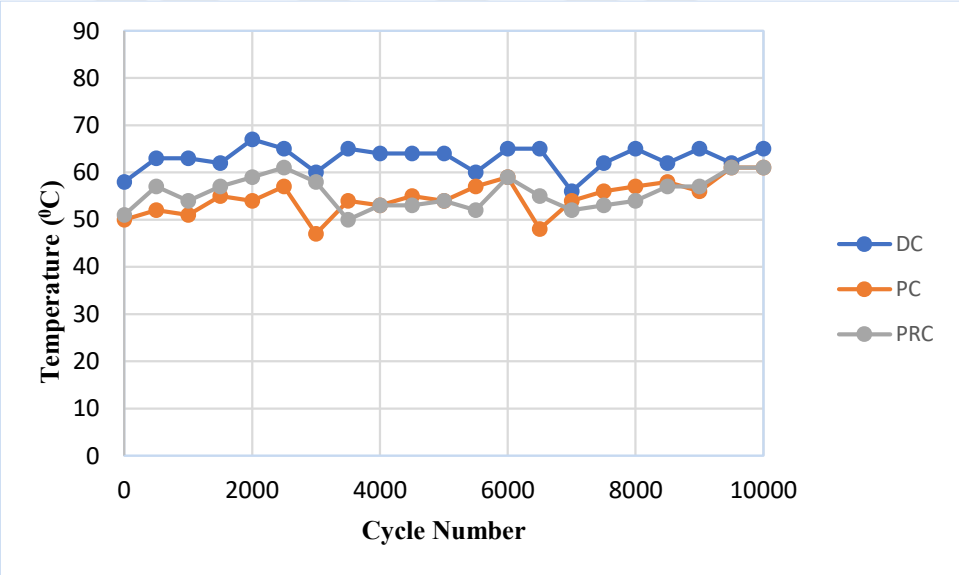


Figure 4.17 Electrical contact resistance analysis of Ag-SiC nanocomposite coating produced with DC, PC, PRC methods.

Figure 4.18 shows the effect of SiC addition amounts which are 0.5 g/L, 1 g/L, 2 g/L and 4 g/L into the Ag-SiC deposition coatings, which are prepared by DC electrodeposition method. It can be easily understood that, increasing of SiC nanoparticles amount into the coating bath and increasing of operation cycles caused the higher resistivity. In that, addition of SiC nanoparticles caused a reduction of grain

sizes with increasing of grain boundaries, which has high defect structure, and this situation resulted with disordered structure. The increasing of temperature can be explained by the increasing of resistivity. Similar resistivity increment was observed by same reason by Bakonyi et al [71]. In addition, because of incorporated particles into the pure silver electrical resistance increased by distorting the lattice structure and more addition of SiC nanoparticles caused more concentration of SiC nanoscale. Therefore, more grain boundaries were obtained and they act as defect the movement of electrons caused to increase of resistivity and temperature [22]. The electrical conductivity of a metal mainly depends on the movement of electrons in its internal structure. SiC particles used as a reinforcing component in the silver metal matrix caused distortion the structure, preventing the movement of electrons, thus reducing the electrical conductivity of the composite with increasing amount of SiC. Similar results were obtained by Gözde Efe et al. [67].

As can be seen in Figure 4.19, coated substrate with Ag-SiC nanocomposite coating with 1 g/L amount of SiC has the highest electrical resistivity among the all. In that, the increasing or reinforcement amount causes the increasing of resistivity. This situation can be explained by reduction of grain size causes the increasing of volume fraction of grain boundaries, which have highly disordered structure. This structure disorders also caused to resistivity and grain boundaries act as a barrier to the motion [71]. In addition, over-increasing of addition of reinforcement into the matrix phase cause agglomeration.

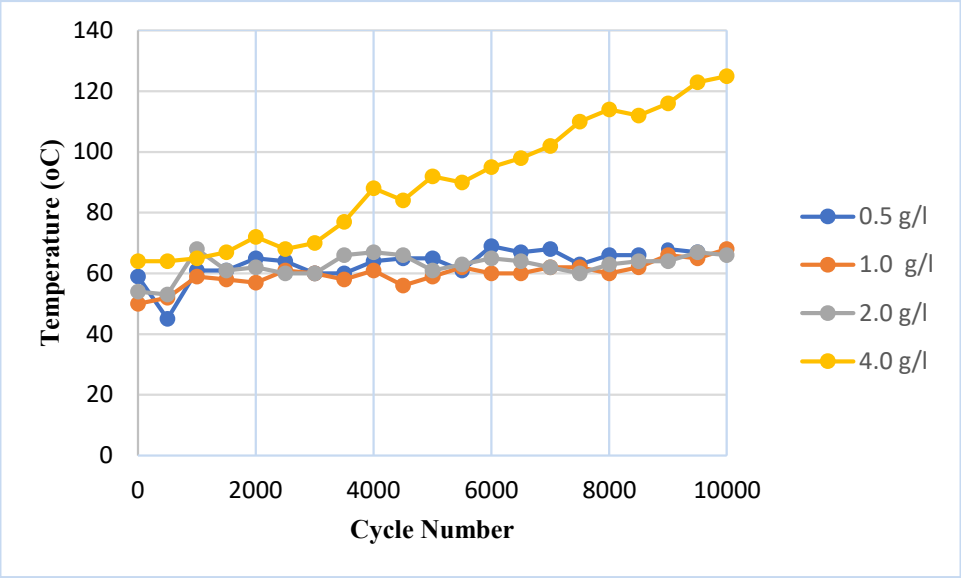


Figure 4.18 Electrical contact resistance analysis of Ag-SiC nanocomposite coating produced with the amount of 0.5 g/L, 1 g/L, 2 g/L and 4 g/L SiC.

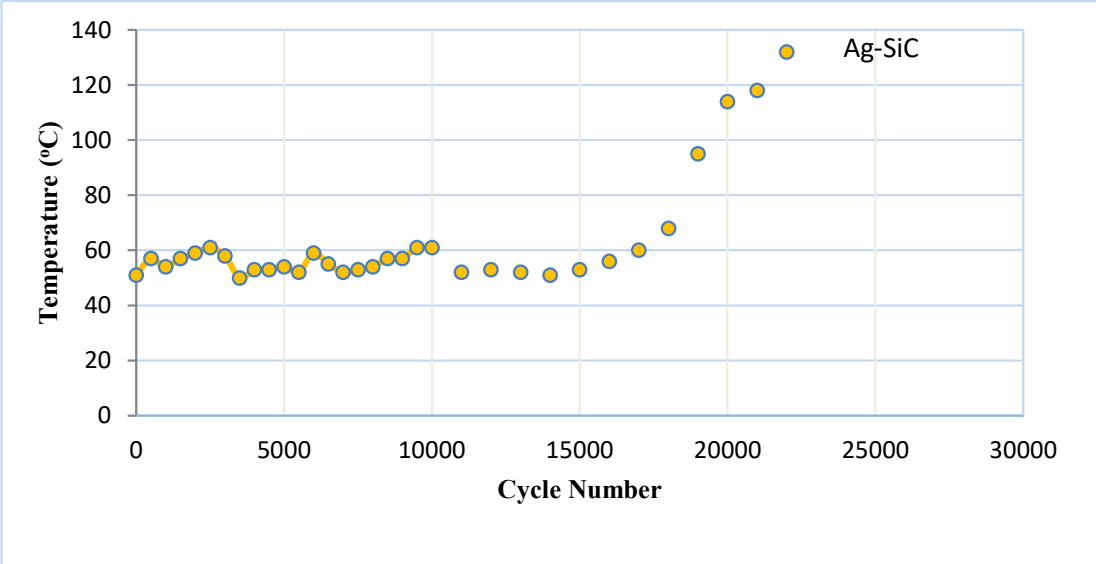


Figure 4.19 Electrical contact resistance analysis of Ag-SiC nanocomposite coating produced with 1 g/L SiC.

4.4 Arc Erosion Morphology

Arc erosion performances for Ag-SiC coated contacts by produced DC, PC and PRC electrodeposition methods were carried out by handmade electrical contact test device have been established in Yıldırım Beyazıt University laboratory for examining the

electrical contact performance of all prepared coatings. The contact pairs were positioned as up and down parts into the contactor. These pairs used as the stationary contact and movable contact were exposed to these pairs during operation in respectively. Contact tests were carried out at a constant load of 4 kW with a current of ~18 A /DC, and voltage of 220 AC. Each coated contact pairs were tested for 10000 operation cycles. Operating frequency with 2 seconds for both Ton and Toff was selected. Electrical contact test was applied for analyzing arc erosion, melting and breakdown of the coated contactors. The surface morphology of arc erosion was represented in Figure 4.20 and 4.21. Similar study was applied by Lujain et al. [22] and she reported that, reinforced Ag coating showed better arc erosion behavior than unreinforced Ag coating. She also mentioned that, the surface of contact coatings produced via PRC current type shows decreasing in erosion pits with more even surface morphology compared to DC and PC coatings surfaces.

It has been observed that Ag-SiC coatings produced with DC, PC and PRC methods have an important effect on arc erosion behavior of both movable and stationary contact surface after 10 000 operations. Since the coating that was produced by the PRC method, has more mechanical resistance, it is expected to experience less material loss. However, when it comes to the strength of the contact materials, high temperature stability and low electrical resistance properties rather than hardness properties are noticeable. On the light of all of this information, it has been observed that the material loss, higher erosion pits and occurring melting in the coatings obtained with the PRC method, which we observed that it is higher than DC and PC production methods as can be seen in Figure 4.20. Therefore, this higher arc erosion occurring in the coating obtained by the PRC method paves the way for the melting and evaporation of silver. Although it enables us to obtain lower grains and increases its mechanical strength to the most preferable level, it is observed that the temperature resulting from the high electrical resistivity confronts us with the effects mentioned above, such as melting and evaporation in the silver matrix. Lujain et al. [22] has observed coated substrate by PRC method increased erosion pits and melting deformation on contact surface and they associated this increment with high contact resistance and concomitant surface temperature.

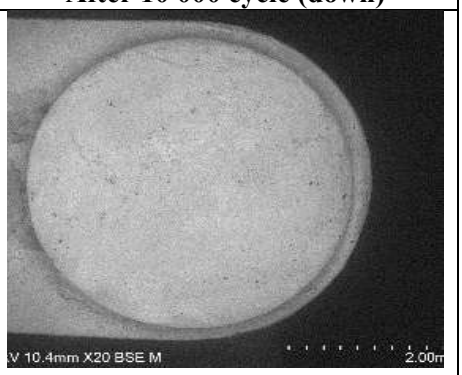
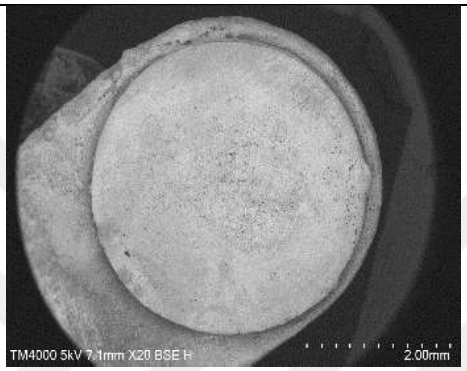
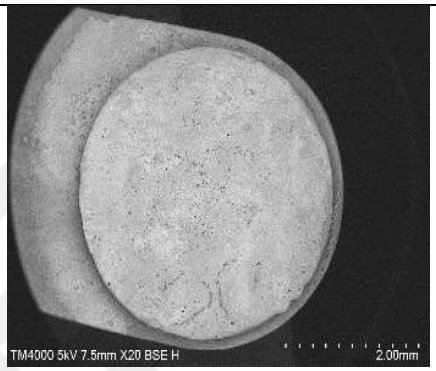
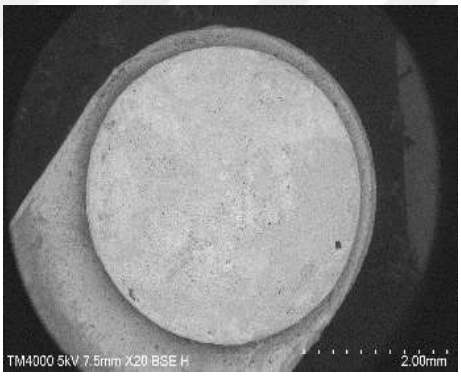
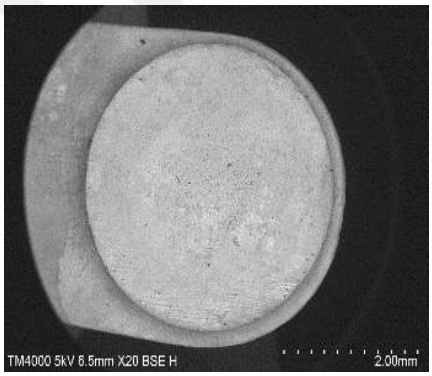
Current Types	After 10 000 cycle (up)	After 10 000 cycle (down)
DC Ag/SiC		
PC Ag/SiC		
PRC Ag/SiC		

Figure 4.20 Effect of current type on Ag-Gr electrical contact performance.

The influences of SiC amount into Ag-SiC nanocomposite coating for electrical contact materials produced by DC electrodeposition method on the arc erosion behavior have been observed. Coated electrical contact substrates with Ag-SiC nanocomposite with addition of different SiC amounts which are 1g/L, 2g/L and 4 g/L into the silver matrix have been conducted the same conditions and cycle numbers with investigation of type of current. After the contact tests, arching morphology has been observed for each substrate with SEM. Along with the increasing operation cycle, high

temperatures caused by arc formation and high electrical contact caused the melting of silver. It was observed that the melted silver flowed and splashed. Silver flow and splashes were greatly reduced with addition of 1 g/L SiC content. Therefore, higher erosion resistance was observed with Ag-SiC coating with 1 g/L than others due to the increased particle content. The reason for this was that the increase for SiC nanoparticles added as the second phase increased the viscosity of the molten silver by increasing the mechanical strength, thus preventing the silver flow, splash and erosion damage. However, increasing of SiC content (2 and 4 g/L) caused agglomeration of these particles so they could not act as a barrier for flowing and splashing of melted silver as seen in figure 4.21. In addition, as increasing of resistivity, melting of silver has been unavoidable and SiC nanoparticles could not avoid flowing of molten silver because viscosity was hidden by agglomeration of SiC nanoparticles. Ag-SiC coating prepared with 1.0 g/L amount of SiC and with PRC electrodeposition method exhibited least erosion pits and lower deformation areas rather than 2.0 g/L and 4.0 g/L amount of SiC. Chang et al. reported that developed SiC reinforced silver matrix composite by electroless method provides good arc erosion resistance with increasing of particle content because of high viscosity of liquids ceased with low flowing and splashing of melted silver [65].

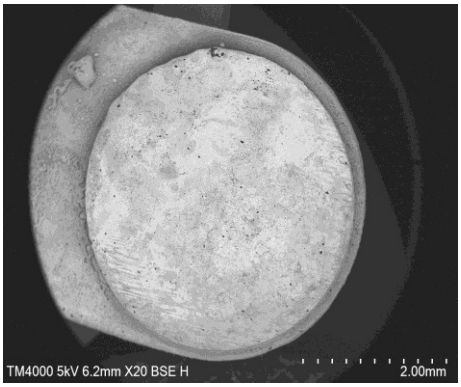
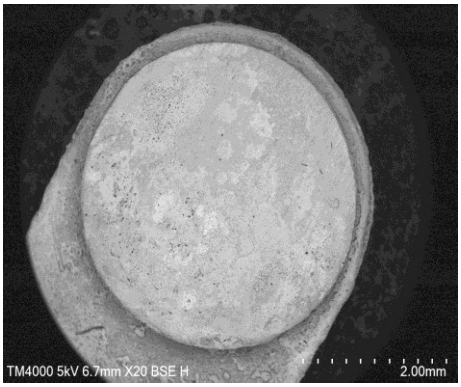
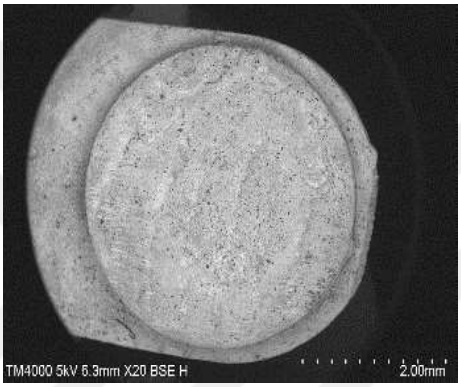
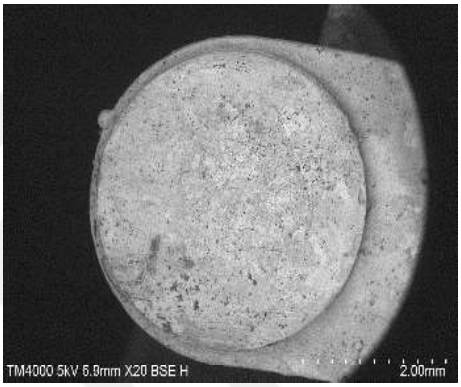
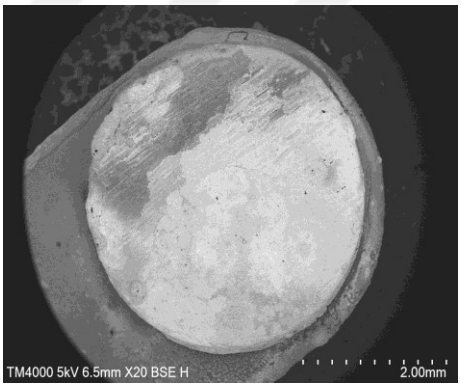
Amount of SiC	After10 000 cycle (up)	After10 000 cycle (down)
DC Ag + 1.0 g/l SiC		
DC Ag + 2.0 g/l SiC		
DC Ag + 4.0 g/l SiC		

Figure 4.81 Effect of amount of SiC on Ag-Gr electrical contact performance.

4.5 Corrosion Resistance Properties

Corrosion resistance tests were conducted with % 3.5 NaCl and speed of test was 0.5 mV/s in same conditions for all coated substrates. Anodic potentiodynamic polarization curves were obtained from electrolytic corrosion experiments and they were represented with Tafel plots. The corrosion resistance properties of Ag-SiC

nanocomposite coatings by DC, PC and PRC methods were determined. In addition, influences of SiC amount, which were 0.5 g/l, 1 g/L, 2 g/L and 4 g/L on corrosion resistance properties of coatings were investigated. The polarization curve of Ag-SiC nanocomposite coatings obtained by DC, PC and PRC electrodeposition methods were shown in Figure 4.22. As it can be clearlys stated that, the corrosion potential of Ag-SiC coatings shifted to more positive potential from DC to PRC. It means that, PC and PRC electrodeposition methods gave more corrosion resistance than DC coating method. It can be explained with the co-deposition of SiC reinforcement nanoparticles in the silver matrix, which can be succeded by PC and PRC methods, improved the corrosion resistance. Inasmuch as PC and PRC electrodeposition methods enable high incorporation of SiC as a second phase into the silver matrix. The incorporation of reinforcement nanoparticles contributes to hasten the passivation process of the metal matrix [72]. Mohan Reddy et al. [62] reported that the substrates produced Ni-Si_3N_4 by PRC electrodeposition method showed high corrosion resistance behaviour.

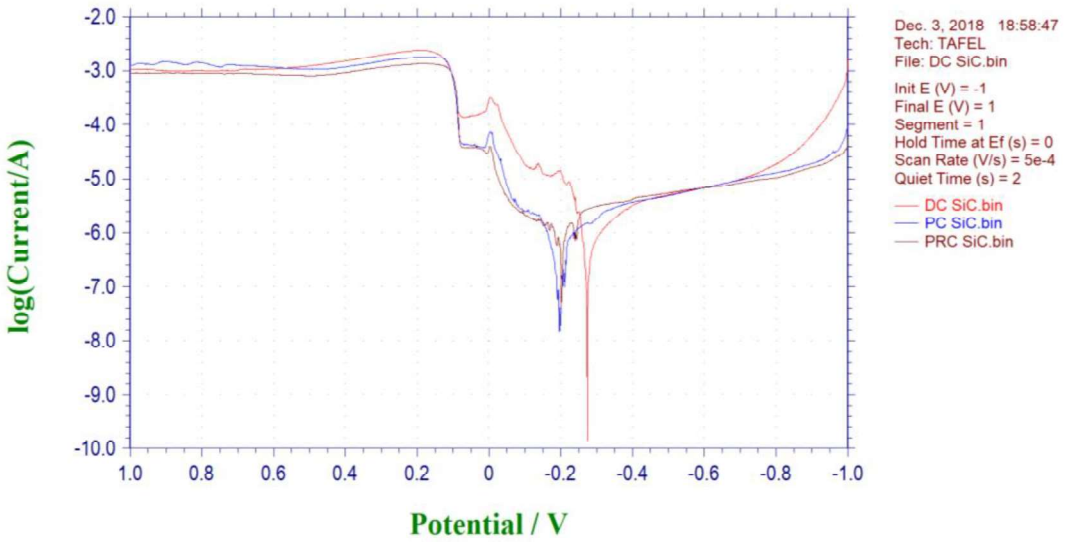


Figure 4.22 Potendiodynamic polarization curves of Ag-SiC nanocomposite coating produced with DC, PC, PRC methods.

The corrosion resistance properties of Ag-SiC nanocomposite coatings by DC, PC and PRC methods were determined. influences of SiC amount, which were 0.5 g/l, 1.0 g/L, 2.0 g/L and 4.0 g/L on corrosion resistance properties of coatings were investigated. The polarization curve of Ag-SiC nanocomposite coatings obtained by different

amount of SiC were shown in Figure 4.23. Incorporation of 1.0 g/L and 2.0 g/L SiC amount into the Ag matrix coating shifted the corrosion ptential to the positive direction. It is obvious that increasing amount of SiC content enhance the the composite coatings as more noble potential. This potential shift towards to positive direction shows the noble characteristic of SiC nanoparticles into the Ag metal matrix. In other words, inclusion of SiC nanoparticles into Ag matrix improved the corrosion resistance behaviour due to filling the defect of surface for instance porosities and pinholes and also the co-deposited nanoparticles behave as an inert chemical barrier to the origination of defect corrosion. Özkan et al. [73] reported that the Ni-SiC nanocomposite coatings produced by electrochemical codeposition of SiC by different amount of SiC showed some different corrosion resistance behaviour. Also they emphasize that increasing of SiC content provides better corrosion resistance. In addition to this finding, Vaezi et al. [64] indicate that, cathodic polarization potential of Ni-SiC plate increases with SiC concentration in the deposition bath. On the flip side of the coin, even though the nanocomposite coating prepared by amount of 2.0 g/L SiC displayed best corrosion resistance, after above 2.0 g/L of SiC nanoparticles showed the least corrosion resistance properties than others because of the agglomeration of particles caused to loosely bound to the Ag metal matrix and this could result with easily removing of particles from the surface [74].

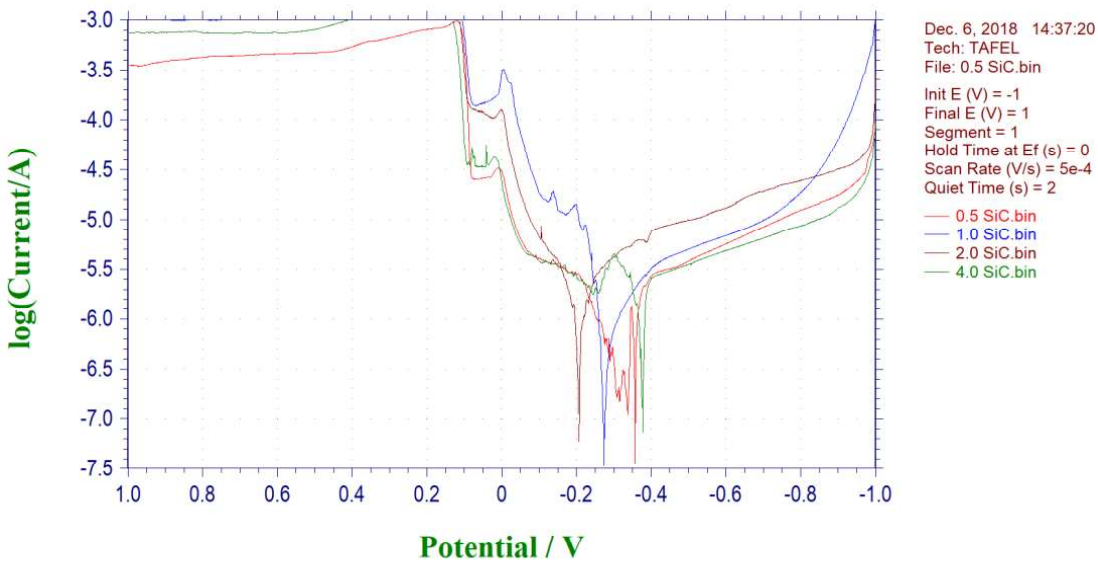


Figure 4.23 Potendiodynamic polarization curves of Ag-SiC nanocomposite coating produced with different amount of SiC.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this study, two categories of copper substrates were deposited with pure silver and SiC reinforced silver metal matrix nanocomposite with electrodeposition method. The first category of copper substrate was cylindrical specimens, which were used for characterizing mechanical and micro structural analysis of the coatings. The second one of copper substrate was electrical contact buttons, which were demoulded from contactors, were used for investigating electrical properties and arc erosion behaviors of nanocomposite coatings.

During these examinations, two parameters affects were examined which were type of current and amount of SiC nanoparticles in the bath. For this reason, pure Ag and Ag-SiC nanocomposite coatings were produced by different types of current, which were DC, PC and PRC. Also, to examine influences amount of SiC nanoparticles in the bath, different content of SiC were added into the coating bath, which they were 0.5 g/L, 1.0 g/L, 2.0 g/L, 4.0 g/L. The effects of these parameters were examined and results were demonstrated as following:

- Pure Ag and Ag-SiC nanocomposite coatings that were obtained by PC and PRC methods have demonstrated more homogenous as micro structural properties. In addition, high amount of Si contents and finer grain size were obtained by PC and PRC electrodeposition methods.

Ag-SiC nanocomposite coatings which were obtained by different content of SiC reinforcement additions were examined for surface morphology, increasing of SiC reinforcements exhibited rougher surface and Ag-SiC coating obtained by addition of 4.0 g/L SiC demonstrated highest surface roughness because of agglomeration of SiC.

EDS analysis results demonstrated that amount of SiC in the coating bath and type of current effected the amount of SiC ratio.

According to XRD graphic, we can understand that Ag matrix has a polycrystalline structure and SiC has amorphous structure because SiC nanoparticles cannot be seen in graphics. There is not any chemical compound occurring between them. The effects of three different type of currents used in electrodeposition method were observed for crystallographic texture for pure Ag and Ag-SiC nanocomposite coatings. In addition, different amount of SiC contents were examined by XRD method. The effects of different current types were examined and results were demonstrated as following:

- The preferred growth of silver (111) was observed and addition of SiC reinforcement effected peak intensity of (111) plane. The highest and sharpest peak were examined in the Ag-SiC coating produced by PC method deposition due to coarse particles. The peak broadening was observed for Ag-SiC coatings produced by PC and PRC methods due to more fine particles. The peak intensity of (200) plane was increased and the peak intensity of (111) plane was decreased by PRC method with respect to the PC method.
- With the addition of 0.5 g/L, (1 1 1) plane was expanded, (2 0 0) was compressed briefly but with addition of 1.0 g/L SiC, all peaks were reduced and planes were compressed. Further addition of SiC such as 2.0 g/L and 4.0 g/L, peaks were increased and planes were expanded. So a uniform lattice strain was observed because dispersed phase apply strain to crystal structure of silver.

Hardness value of Ag-SiC coatings is higher than pure Ag coating. The hardness values were increased by different types of currents. In addition, as amount of SiC contents increased, the hardness values have increased. The highest hardness value is observed in PRC method Ag-SiC nanocomposite coatings due to less agglomeration, and highest homogeneous texture and distortion as expected. In addition, different amount of SiC incorporation into Ag matrix changed the hardness value of surface. The highest hardness value was obtained Ag-SiC coatings obtained with 1 g/L addition of SiC. 0.5 g/L addition into the coating bath, SiC amount was insufficient to hinder

dislocations and for further addition of SiC as 2.0 g/L and 4.0 g/L decreased hardness value because of coarsening of the reinforcement particles.

The electrical resistivity was examined by changing type of currents an increasing of amount of SiC content, also as incorporation of SiC reinforcement into the Ag matrix increased, the resistivity has increased. Three different types of current and different amounts of SiC reinforcement also changed the electrical resistivity. Ag-SiC coating produced by PRC electrodeposition method exhibited highest electrical resistivity rather than DC and PC methods. Ag-SiC coating produced by addition of 4.0 g/L exhibited highest electrical resistivity.

When the coatings were examined as arc erosion behavior according to electrical contact test, different types of current and different amount of SiC effected the behavior. Because of the increasing of both temperature and electrical resistivity, the material loss has been observed and higher erosion pits and occurring melting in the coatings obtained with the PRC method, which we observed that it is higher than DC and PC production methods. Ag-SiC coatings obtained with different content of SiC were examined for arc erosion behavior. Ag-SiC coating prepared with 1.0 g/L amount of SiC and with PRC electrodeposition method exhibited least erosion pits and lower deformation areas rather than 2.0 g/L and 4.0 g/L amount of SiC.

The corrosion resistance properties of Ag-SiC nanocomposite coatings by DC, PC and PRC methods were determined. In addition, influences of SiC amount, which they were 0.5 g/l, 1.0 g/L, 2.0 g/L and 4.0 g/L, on corrosion resistance properties of coatings were investigated. PC and PRC electrodeposition methods gave more corrosion resistance than DC coating method. It is obvious that increasing amount of SiC content enhance the composite coatings as more noble potential. This potential shift towards to positive direction shows the noble characteristic of SiC nanoparticles into the Ag metal matrix.

5.2 Future work

- Ag/SiC nanocomposite and pH change effect of electrolyte can be examined due to micro hardness and microstructure change of samples.
- The particle size effect of SiC incorporation can be examined due to micro hardness and microstructure of Ag matrix electrodeposition coating on Cu substrate.
- This experiment can be done with different current densities to examine changes at hardness and structure of coating.
- With electrodeposition process, Ag-SiC nanocomposite can be studied and changes on hardness and structure of coating can be investigated.
- While the electrodeposition process is being studied in this experiment, different chemical additions and agent effects can be examined due to hardness and structure changes.

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