

**The present work was submitted to the Faculty of Engineering**

**CHEMICAL AND PHYSICAL PROPERTY OF COPPER POWDER AND ITS  
PRODUCTION POSSIBILITY**

**Bachelor Thesis**

by

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Ulaanbatar/Nalaikh, May/16/2022

## Statutory Declaration

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

### CHEMICAL AND PHYSICAL PROPERTY OF COPPER POWDER AND ITS PRODUCTION POSSIBILITY

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Ulaanbaatar May/16/2022

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Signature

## **Acknowledgement**

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## **Abstract**

Powder metallurgy is an engineering discipline that examines the manufacture of powders and their uses. It's also been characterized as a shaping technique that involves molding powdered materials into regular or irregularly shaped components for use in a variety of applications.

Metal component applications are increasingly being produced via powder metallurgy in the industry nowadays. Powder metallurgy is extremely cost-effective in terms of manufacturing and material utilization. Low production costs, improved energy efficiency, and the ability to combine elements that are known to be incompatible are some of the advantages powder metallurgy has over conventional manufacturing techniques such as casting and forging. Powder metallurgy has become popular for treating both traditional and modern materials due to these advantages.

This thesis work is limited to an experimental work with inducted coupled plasma spectroscopy (ICP) and X-ray diffraction analysis (XRD) in order to determine flow rate, particle size, density and oxygen content with following copper content on copper powder sample. Inducted coupled plasma spectroscopy is a sophisticated chemical analysis approach that can identify tiny levels as well as significant concentrations of practically all components in sample, In material science, XRD's purpose is to determine the material's crystallographic structure. XRD technique involves irradiating the material with incoming X-rays afterwards determining the intensity and scattered the angles of the X-rays that exit the substance.

Based on the chemical and physical properties of powdered copper, the purpose of this thesis work is to find a way to produce domestically produced, value-added products in Mongolia and to increase exports to expand gross domestic product.

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## 1 Introduction

### 1.1 Background of this study

As of 2021, the total revenue of our state budget was MNT 14,255.2 billion, from this 29.6% (MNT 4,114.4 billion) of it was generated by the mining. Mongolia's mining sector alone constitutes 24% of the gross domestic product, also in industrial sector 69%, 77% of foreign investment and 93% of exports conforming to the Ministry of Mining and Heavy Industry(1). Coal, which accounts for around 50% of our country's export, was exported for \$ 2.12 billion in 2020, while copper is Mongolia's third-largest exporter, ranking ninth in the world for a total of \$ 1.78 billion. National Statistics Office claimed that in 2020 the total revenue from mineral exports was \$5.26 billion which is down by 17.6% from the previous year, due to the decline in coal exports(1,2). On the current situation between China and Australia that China doesn't import the coal from Australia, the coking coal price will remain stable on the other hand iron ore would fall. However copper prices hit a new record high of \$10,512 per ton on May 9th 2021 making a 130% increase since March 2020(3).

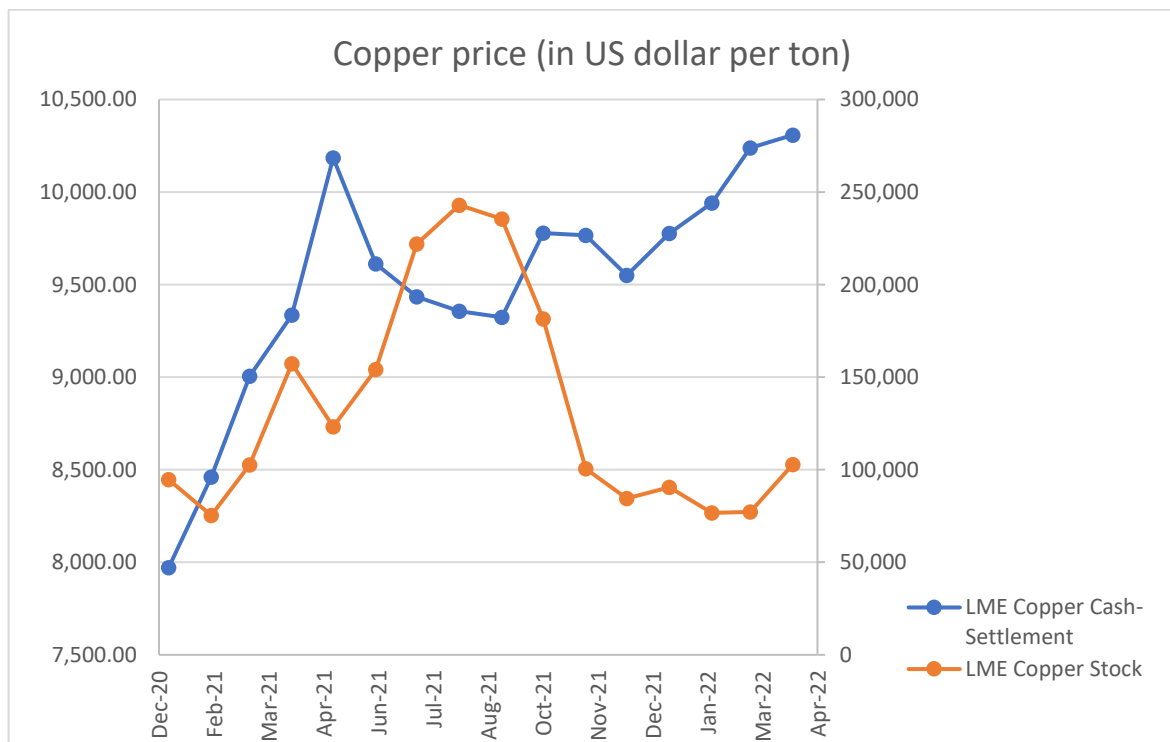


Figure 1. Copper price on London Metall Exchange (LME) from Jan/2021 to Apr/2022

The growth of the copper price was primarily driven by the top consumer demand of China and India, along with post-pandemic economic recovery. Furthermore, it is predicted that tend to rise by because of population, and it is a widely used metal in energy, transmission, constructions, automobile manufacturing and telecommunication and its usage in medical sectors(4).

Powder metallurgy refers to a set of advanced procedures for synthesizing, treating, and shaping a variety of materials which consists of the generation of a powder and its transformation into a compact solid product, was originally inspired by ceramics processing. Powder manufacture can be done in a variety of ways, including electrolytic (e.g., electrolysis) and non-electrolytic (e.g., atomization)(5).

For many years, copper alloy powders been used in industrial application. Copper has established itself as a popular conductive material due to its electrical high conductivity, relatively higher melting point, great solderability, minimal electrochemical migration behavior, and inexpensive material cost(6). Copper nanoparticles are attracting a lot of attention in chemistry and material science right now. Small copper particles have been studied for their conducting, photonic, and catalytic capabilities, as well as their potential applications(7). Copper powder is used in electrical parts, conductive epoxy, metal-bonded cutting tools and abrasive wheels, and airplane brake systems. It is also utilized as a catalyst in chemical formulations and for synthesis of copper compounds. Metal injection molding, electronics, ceramics, and thick or thin film applications were among the new development options presented by ultra-fine copper powder(8,9). According to the rapid advancements in the electronic industry, there is a huge, unprecedented need for high-strength, high-conductivity materials. In the fabrication of electronic devices which is hybrid integrated circuits and multilayer ceramic capacitors, the technology of creating conductive thick films from high purity crystalline copper powders is critical(10). One of the most major application for copper powder is self-lubricating bearing which handles 70% of the copper powder usage(6). Powder metallurgy has a significant cost advantage over conventional forming techniques such as forging and casting. Powder metallurgy is a method of condensing powders at temperatures beneath their melting points, therefore It produces items that are very similar to the shape and dimensions that were designed, obviating the necessity for machining(5).

## 1.2 Hypothesis

The aim of this thesis is to investigate and comprehend copper powder production processes and derivativity. I intend to do a chemical and physical analysis of copper powder to determine the key chemical and physical parameters, like particle size, chemical composition, flow, and density. In addition, my thesis topic will analyze water atomization and electrolyzing types of copper powder processing and their economic effectiveness, as well as the international use of copper powder industry, trends, and characteristics. The thesis predicted outcome is to discover a method for producing a value-added copper product.

## 1.3 Objectives of this study

The sole purpose of this thesis is to characterize the chemical, physical and mechanical properties of the copper powder from GGP Metal Powder AG. In order to accomplish the aim, the following sub-objectives must be fulfilled:

- Literature review on the production of metal powder with with existing technologies to investigate and comprehend copper powder production processes and derivativity.
- Chemical, physical and mechanical characterization of copper powder from GGP metal powder to determine key parameters of the process such as particle size, chemical composition, flow and density.
- Discussion of the main findings and determination of copper processing routes

## 2 State of the art

### 2.1 Key economic figures

The mineral sector accounts for 28.9 % of Mongolia's general budget revenue, at the end of 2021 amounted to 14,255.2 billion MNT, in comparison to the prior year there is an increase of MNT 3,853.3 billion or 37.0 %. Out of this, the revenue collected from the mineral resources sector reached 4,114.4 billion MNT. In comparison to the same time period, of the previous year, it increased by 1,441 billion MNT or 53.9 %. Data and percentage of collected revenue are shown by sector.

- Mining and extraction 3,845.5 billion MNT or 27.0 %,
- Crude oil 198.1 billion MNT or 1.4 %,
- License fee 32.8 billion MNT or 0.2 %,
- Other income 38 billion MNT or 0.3 %.

Table 1 Number of licenses, area size of by type of mineral, March/2021(12)

	Mining License		Mining area size	
	Number	%	Number	%
<b>Total</b>	1701	100%	1,710,379.1	100%
<b>Gold</b>	528	31%	238,279.9	14%
<b>Coal</b>	303	18%	798,452.7	47%
<b>Copper</b>	18	1.1%	84,900.5	5%
<b>Copper, Molybdenum</b>	8	0.5%	14,328.3	0.8%
<b>Copper, Gold</b>	5	0.3%	8,807.4	0.5%

The mining sector pays MNT 3,845.5 billion in taxes and fees to the state budget. From this copper amounted to MNT 2,421.8 billion made an increase of MNT 1,299.3 billion which is 2.2 times higher than compared to the year 2020. Other minerals, such as iron, zinc, fluorspar, and gold, increased slightly, however coal fell 23.1 % from the previous years the amount accumulated in the state budget.

Coal, copper concentrate, iron ore, zinc concentrate, fluorspar, molybdenum concentrate, crude oil, crude or semi-refined gold, silver, mining products such as copper and alloys accounted for 93.3 % of Mongolia's total exports.

**Exports of copper concentrate:** In 2021 total of 1,282.5 thousand tons of copper concentrate was exported that valued by USD 2,899.9 million. In terms of prices from the same term of the last year, it increased by USD 1,121.9 million or 63.1 %, but

decreased in physical terms 112.5 thousand tons or 8.1 %, due to the copper price hit the all-time high. Copper concentrate 100 % were exported to China. As for the cathode copper 9,849.0 tons of cathode at the end of 2021, valued at USD 88.5 million, cathode copper exports increased by 201.6 tons or 2.1 % in physical terms compared to the same period of the previous year. Although, 1 ton of cathode copper the average export price reached USD 8,990.6, increasing by USD 2,841.8 or 46.2 % causes the increases the value by USD 29.2 million or 49.3 % respectively.

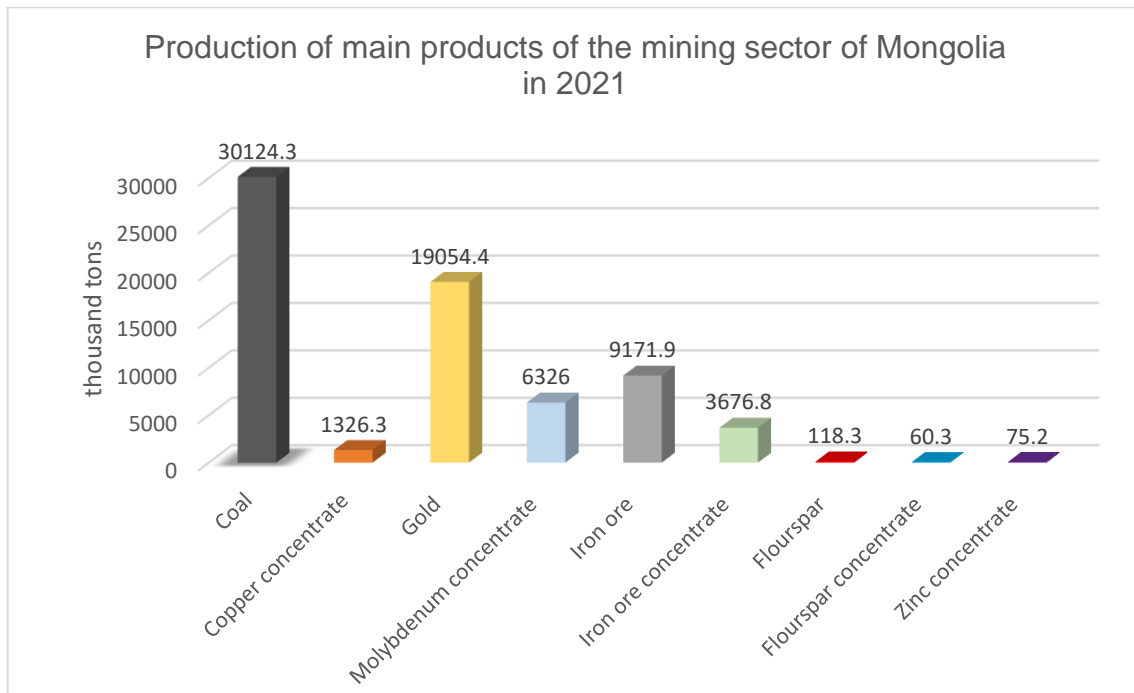


Figure 2 Production of main products of the mining sector of Mongolia in 2021

At the end of 2021, the total industrial output was MNT 18.5 trillion, an increase of MNT 1.8 trillion (10.7%) compared to the same period of the previous year. Coke and crude oil processed productions and other vehicles equipment production fell by 8.2% and 7.8%, respectively. Other industries, such as chemicals and chemical products, and non-metallic minerals manufacture and metal processing production, machinery and equipment other metal products has an increase compared to 2020(1).

## 2.2 Introduction to copper

Copper is present in the crust of the world, most typically as copper-iron-sulfide and copper sulfide minerals as chalcopyrite ( $\text{CuFeS}_2$ ) and chalcocite ( $\text{Cu}_2\text{S}$ ). These minerals have a low concentration in an ore body. Copper ores typically contains 0.5 % to 1-2 % copper in underground mines, forms as the action of enriched supergene with

other mineral components, typically has Isometric crystallography with 2.5 to 3 hardness and 8.7-8.9 kg/m<sup>3</sup> density. The most important applications are in electronic industry and ingredient for gold alloys. Concentration, smelting, and refining are the most common methods for producing pure copper metal from these ores. Copper is used in roughly 22 million tonnes per year around the world. About 18 million tonnes originate from new mining output, with another 4 million tonnes coming from recycled end-of-use products and manufacturing trash(11).

Minerals, like all other natural substances, must be categorised properly in order to be studied and used effectively. The chemical composition and internal structure of a mineral determine its physical and chemical qualities. The following table indicates the copper mineral ore and their properties with corresponding applications.

Table 2 Mineralogical descriptions of sulphide minerals

Minerals	Occurrence	Properties	Application
Chalcopyrite CuFeS <sub>2</sub>	Magmatic, hydrothermal, sedimentary.  Association: Galena, pyrite, sphalerite, tetrahedrite	Crystallography: Tetragonal  Crystal habit: Cubic Tetrahedral crystals;  Color: Brass-yellow  Fracture: uneven;  Hardness: 3.5-4 Specific gravity: 4.3;	Important copper ore
Bornite Cu <sub>5</sub> FeS <sub>4</sub>	Magmatic hydrothermal, sedimentary, in skarns and pegmatites	Crystallography: Tetragonal  Crystal habit: Pseudo-cubic;  Color: Copper-red;  Fracture: Uneven;  Hardness: 3  Specific gravity: 5-6;	Important copper ore
Enargite Cu <sub>3</sub> AsS <sub>4</sub>	Hydrothermal in medium to low temperature.	Crystallography: Orthorhombic  Crystal habit: Tubular, prismatic;  Color: Greyish black to black;  Fracture: Uneven;	Copper ore

		Hardness: 3 Specific gravity: 4.5;	
Covellite CuS	Found in oxidation zone; associated with chalcopyrite, chalcocite, bornite	Crystallography: Hexagonal  Crystal habit: Hexagonal tubular crystals massive;  Color: Indigo-blue  Fracture: uneven;  Hardness: 1.2-2 Specific gravity: 4.7;	Medicine, used as a natural super-conductor
Chalcocite Cu <sub>2</sub> S	Hydrothermal sedimentary, metamorphic and secondary oxidation deposits. Association: Pyrite, chalcopyrite, bornite	Crystallography: Monoclinic  Crystal habit: Prismatic to tabular crystals;  Lustre: Metallic,  Fracture: Conchoidal;  Hardness: 2.5-3 Specific gravity: 5.8;	Cu ore

As for the chalcopyrite, chalcocite, covellite and bornite extracted by the process of froth floatation, smelting, roasting in air. It is mostly employed in the electrical and vehicle industries due to its ductility and high tensile strength and thermal, electrical conductivity.(12).

### 2.3 Water Atomization

The size, shape, and size distribution of metal powder utilized in the production process must all be acceptable. One of most significant features to consider is particle size, as employing finer resolution powder improves the accuracy of the work piece. Atomization is a pioneer among the most promising and cost-effective procedures for the manufacture of powders. The disintegration of liquid into a thin spray of droplets by high-velocity fluids is a regularly used atomization method(13). Due to its advantages, such as high flexibility, high capacity for both elemental and pre-alloyed powder production, and capabilities for rapidly solidified metal powder manufacturing, powder production utilizing an atomization process has been widely explored and implemented in industry. Fine microstructure, chemical homogeneity, extended solid solution, and

metastable phase development are common characteristics of rapidly solidified metal powders. As a result, metal items made from quickly formed metal powders have better mechanical qualities. In theory, any force that causes the metal melt to become unstable will break it down into smaller bits or droplets. Figure 1 depicts the melt disintegration mechanism.

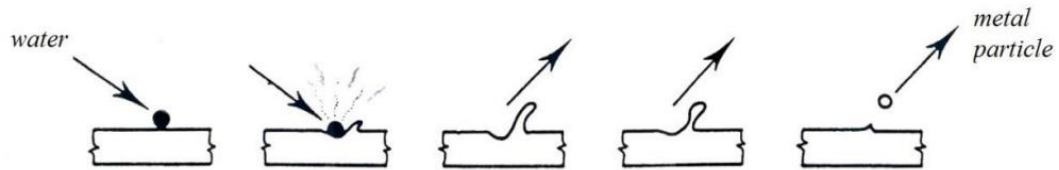


Figure 3 The "scrape" mechanism of water atomization is shown schematically.

Metal melting is the first step in atomization. From a tundish nozzle, liquid metal flows through a sized aperture. A high-velocity stream of water impinges on liquid flow. This causes the liquid stream to break up into little particles that harden quickly. The atomizing medium, pressure, and flow rate all have a significant impact on particle size and shape(14). Liquid copper is superheated to around 1,150 to 1,200 °C for commercial manufacturing of copper powder, with flow rates of 27 kg/min or greater. Water pressure of 10 to 14 MPa is typically used to make -100 mesh (-149 micron) copper powder. Atomization can take place in either an air or a nitrogen-free environment. With the atomization process, the normal yield of creating -325 mesh (-44 micron) powder is between 25 and 80 %. Water atomization at high pressure can produce fine powder. The particle size tends to get finer and particle size distribution tends to become broader as the atomization water pressure increases(13).

### Leaching particle size selection

The size of the particles is significant for two reasons:

- The finer the particles, the more surface area is accessible to touch the lixiviant, increasing the leaching kinetics.
- The finer the particles, the less energy is required by the agitator to keep them in suspension in the leach reactors.

As the particle size grows larger, more energy is required to keep the material from settling. Any settling in the reactors is a big problem with a relative density of roughly 7. The only option to clean the reactor once the solid materials have settled is

to empty it and dig out the solids. Obviously, if the process were to settle, it would result in significant inefficiencies (15).

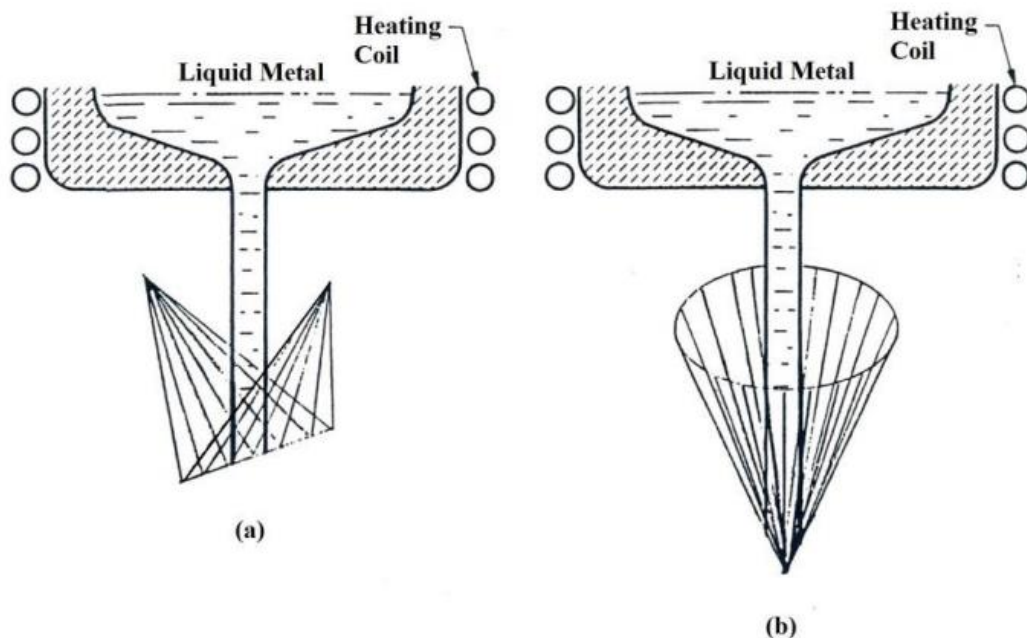


Figure 4 In the water atomization process, there are two types of water jets: (a) V-jet and (b) Cone jet.

Grandzol (1973) demonstrated a simple relation between particle size and the water velocity which Grandzol and Tallmadge later adjusted to yield.

$$D = \frac{S}{(V_w \sin \alpha)} \quad \text{Eq.01}$$

Where

- $D$  Particle size ( $\mu m$ )
- $S$  Normal velocity component ( $m/s$ )
- $V_w$  Water velocity ( $m/s$ )
- $\alpha$  Angle between the water jet axis and the molten metal stream axis (13).

The atomized slurry can be piped directly to leach tanks or to a dewatering system, which can produce either a thickened slurry at 20% moisture or a wet solid at 5% moisture, depending on the moisture content as Figure 3 shown. If water balance is

crucial, this can be fed to leach tanks. Drying consumes a lot of energy and money, yet it's necessary if a smelter is selling to a refiner.

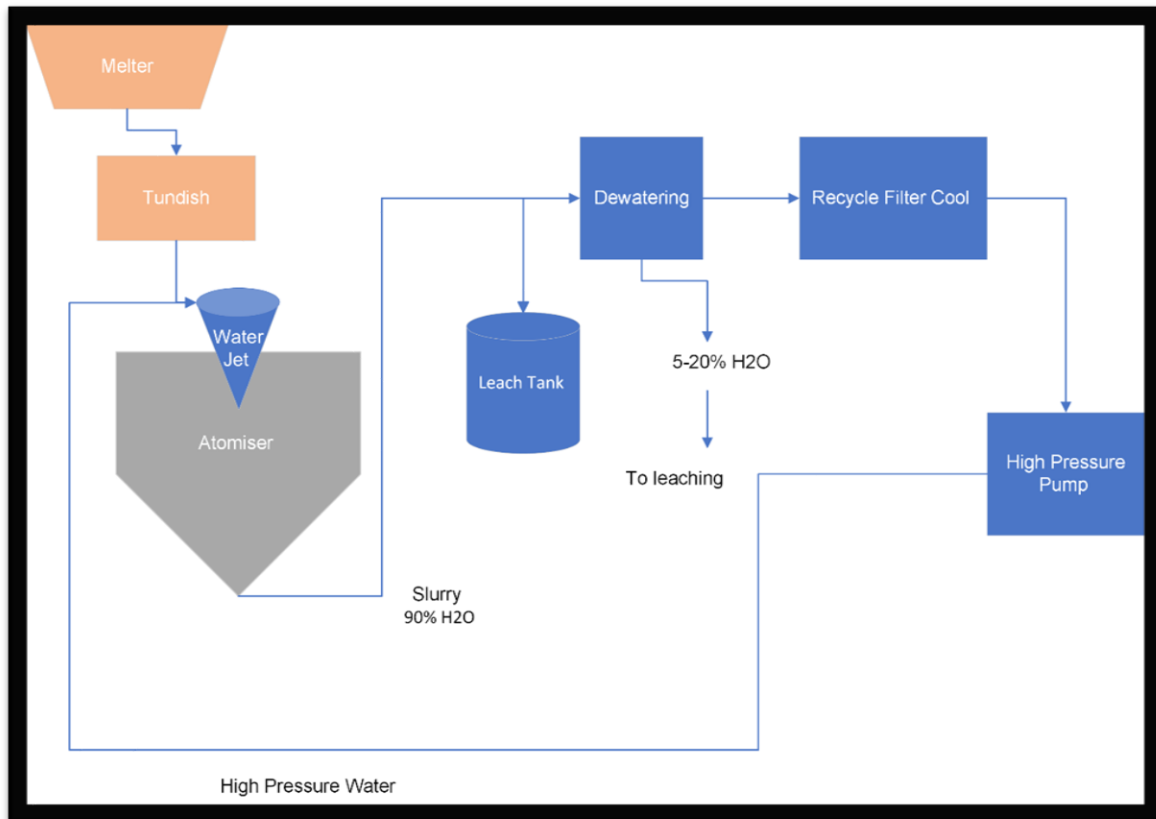


Figure 5 Flowsheet of Water Atomization

Atomization at a water pressure of 20 MPA (a typical high-end operation) typically uses roughly 20 kWh/t of energy. Given that a medium-sized smelter might the energy consumed from atomization, which produces roughly 1 t/h of alloy, is anticipated to be lower than the energy consumed by the several 30 kW motors that maintain the solids suspended in the leaching. It's more cost-effective to create the small particle sizes that emerge from water atomization at 20 Mpa water pressure because the agitators' power consumption will be reduced. The power to the agitators could rise by as much as 50–60% as the mean particle size increases over the range of particle sizes considered(15).

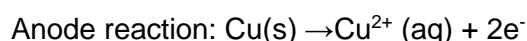
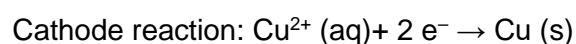
## 2.4 Electrodeposition process

The synthesis procedure has an impact on the form of copper powder particles. Copper particles occur in four different shapes: almost perfect microspheres, irregular rough particles, dendrites and dispersed flower like. Dendrites are the most common

particle shape, and produced by electrolysis(6). Water atomization produces irregular particles, whereas the gas atomizing process produces spherical particles(16). Electrochemically produced copper powders are employed in metallurgy, chemistry, electrical engineering, and other industries. They are commonly employed in electrical engineering to make copper graphite connections, in chemical production as a catalyst, and in hydrometallurgy as a cementing agent (17).

The electrodeposition of copper powders from a copper sulphate electrolytic solution is the most commonly suggested method since it is the most effective, environmentally safe, and cost-effective. Simple operation, great flexibility, low contamination, easy availability of equipment, and no requirement for vacuum systems to generate pure product are all advantages of the electrochemical approach (18,19). When obtaining copper powders, the specificity of the reaction in the electrodes is thoroughly examined. The effect of other electrochemical parameters of the electrolyte composition on the reduction of copper (II) ions at the cathode and the formation of copper powders (20).

Electrolytes based on aqueous solutions of cupric sulfate ( $\text{CuSO}_4$ ) and sulfuric acid ( $\text{H}_2\text{SO}_4$ ) are the most commonly used for copper electrodeposition (19). The procedure of depositing a thin layer using electrodeposition of metal onto an electrically conductive surface using electrolytic cells. The cell made of two electrodes that are held apart from one another and are usually constructed of metal. An electrolyte is used to submerge the electrodes (a solution). When the current is applied, positive ions in the electrolyte migrate to the cathode, a negatively charged electrode. Positive ions are atoms that are missing one electron. As they approach the cathode, they interact with electrons and lose their positive charge. Negatively charged ions migrate to positive side of electrode, known as the anode, at the same time. Atoms having one extra electron are known as negatively charged ions. They move their electrons to the positive anode and lose negative charge when reach it (21).



## 2.5 Relationship between fracture toughness and apparent density

The quality of a powder metallurgy component is determined by the green compact quality. The apparent density and strength of metal powder compacts are the

two most important qualities. Powder compacts are the end result of a well-defined process that includes powder transfer, ejection, compaction, and post-ejection management. A powder might develop cracks at any point in the process, although the chances are higher during compaction, when the particle interaction is weak or non-existent, also during ejection, when the established bonds are disrupted. The most common cause of fracture failure in service are cracks in metal compressed components. Fracture toughness is a metric used by engineers and material scientists to forecast a component's capability to resist fracture failure in the presence of cracks (22).

The modified diametrical compression test (MDCTT) used to evaluate the fracture toughness of metal powder compacts tested were made using the integrated uniaxial compaction of a set amount of loose powder method. As the density of powder increases, the rate of in-plane crack propagation slows down. The fracture toughness for copper powder compacts were observed to increase as the powder density increased. This means that as densification improves, the rate of crack propagation in compacts lowers. The devised mathematical formula,

$$\frac{1}{K_{Ic}} = Q \frac{1}{(1 - \ln(\rho_{powder}))^2} - Q_{powder} \quad \text{Eq.02}$$

Where:

- $K_{Ic}$  – fracture toughness
- $\rho_{powder}$  – relative density
- $Q_{powder}$  – constant which indicates metal powder property

It has the potential to define more useful features of copper powder compact by relating the mode II fracture toughness for the metal powder investigated to the apparent density (23).

The following analyzing techniques are examined the copper powder to my thesis work in order to get required physical and chemical properties. As for the ICP-MS and ICP-OES determining the metal content from copper powder analysis made at Central Geological Laboratory, also the average particle size have been determined by Lased Diffraction spectrometry, flow meter has used in order to get flow rate and oxygen content values have been determined by ELEMENTRAC OH-p 2 elemental analyzer. These devices provided me with data from my first supervisor Dr. Undrakh.N as a standard sample of a “Steppe Metal Powder” LLC.

## **2.6 Inductively coupled plasma spectrotoscopy**

### **2.6.1 Inductively coupled plasma-mass spectroscopy (ICP-MS)**

The ICP-MS detects how much of a given element is present in the material under analysis. The concentration of each element is calculated by comparing the counts observed for a particular isotope to an external calibration curve for that element. Most elements are can be measured by the ICP-MS device, which has detection limits of less than one part per trillion (ppt). The majority of analyses done on this apparatus are quantitative, although it can also be used as a semi-quantitative tool. An unknown sample can be examined for 80 elements using a semi-quantitative method, yielding results that are within  $\pm 30\%$  of the quantitative values.

#### **Working principle:**

Samples are introduced into an argon plasma as aerosol droplets. The plasma evaporates the aerosol, dissociates the molecules, and afterwards eliminates an electron from the components, leaving singly-charged ions to be transported into a mass spectrometer. Most industrial ICP-MS devices use a quadrupole mass spectrometer to rapidly scan the mass range. At any given time, just one mass-to-charge proportion will be able to flow through the mass spectrometer from entry to exit. When the ions collide, a cascades of electrons is released, which is amplified until it becomes a quantifiable pulse. To determine the element's concentration, the program compares the intensities of the observed pulses to those from standard, which form the calibration curve. Due to the ratio of isotopes, or natural abundance, is established in nature, only one isotope is usually required for each element examined. The quantity and relative abundance of the element's natural isotopes, which is frequently referred to as the element's isotopic fingerprint. ICP-MS can measure specific isotopes of each element, which is useful for laboratories specialized in one particular isotope or the ratio of multiple isotopes of an elements (24).

#### **The following are the components of an ICP-MS:**

- The sample introduction system: which consists of a nebulizer and a spray chamber, allows samples to be introduced into the device.
- ICP coil and torch – creates argon plasma, which is used as the ICP ion source.
- Interface - connects the ICP ion source at atmospheric pressure to mass spectrometer at high vacuum.

- Detector, Ion optics and quadrupole require high vacuum, which is provided by the vacuum system.
- Collision/reaction cell - this device comes before mass spectrometer and is used to filter out interferences that could compromise the detection limits.
- Ion optics - directs the appropriate ions into the quadrupole while ensuring that neutral particles and photons are ejected.
- Mass spectrometer – used to select ions according to their mass-to-charge ratio.
- Individual ions departing the quadrupole are counted by the detector.
- Data handling and system controller - manages all aspects of instrument management and data processing in order to produce final concentration values (24).

### **2.6.2 Inductively coupled plasma-optical emission (ICP-OES)**

ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy) technique for determining the amount of particular elements in a sample. The ICP-OES approach relies on the fact of ions and atoms can absorb energy and use it to transfer electrons from a ground to an excited state. The source of such energy in ICP-OES is energy from an argon plasma operating at 10,000 kelvin. As excited atoms move to low energy level, the ICP-OES concept depends on them releasing light at certain wavelengths (25).

#### **Working principle:**

In atomic spectroscopy, inductively coupled plasma-optical spectroscopy emission (ICP-OES) is employed, and the sample is decomposed by extreme heat into a cloud of exhaust gasses containing free atoms and ions of the elements of interest during measurement. A nebulizer converts an aqueous sample into aerosols. The aerosols are carried to the inductively coupled plasma, which is a hot zone (8,000–10,000oC). The analytes are heated to various (atomic and/or ionic) states, resulting in distinct optical emissions lights. The wavelengths of these emissions are separated, and the intensities of these emissions are measured. The concentrations of analytes are proportional to the intensities in the aqueous sample. The quantification is done by comparing the intensity of an unknown sample's emission to that of a reference sample using an multipoint linear standardization. Single- and multielement primary standard solutions are used to make multi-element calibration standard solutions. In other forms

of analysis where chemical speciation is important, ICP-OES only evaluates total elemental concentration.

**The following are the steps in an ICP-OES analysis:**

- The elements to be measured in the sample are chosen. For example phosphorus, sulfur or lead.
- The samples' solutions are made using traditional quantitative chemical analysis techniques.
- There is a collection of calibrating solutions ready. The concentrations of the analyte components S, Pb, and P are precisely known in each solution. Each element's concentration range is chosen to encompass the predicted concentration of that element in the sample solutions.
- Delivering the calibrating and sample solutions into the plasma and detecting the intensities of light in ICP-OES analysis.
- The emissions intensity of the measuring solutions are used to create calibration graphs for each element.
- The calibration graphs are used to determine the element concentrations in each sample solution. From the measured concentrations of the components in the sample solution and the determined dilution factor, the concentrations in the sample are estimated. The results of an ICP-OES study list the concentrations of the elements, usually in g/L or mg/L (26).

**2.7 Particle size distribution by Laser diffraction spectrometry**

Laser diffraction spectrometry (LSC) is used to determine the sizes of particles in a substance. Particle size is calculated using the angle of light scattered by particles as they move through a laser beam. Multiple light detectors are used in a laser diffraction analyzer, with more sensor elements improving size limits and sensitivity. Particle size measuring limits are also influenced by the light source employed by a laser particle size analyzer; short wavelength violet and UV lasers are more suited to measuring submicron-sized particles over red lasers. Three processes can determine the intensity of the measured signal: absorption, diffraction and scattering. The structure, size, and composition of the particles influence scattered light, which is made up of reflected and refracted waves. Diffracted light is caused by edge phenomena and is only affected by the particle's geometric cross-section; consequently, diffraction is unaffected by the particle's composition or refractive characteristics. Light is absorbed

as it interacts with particles and is transformed to various types of energy, reducing its intensity. Particle size and composition have an impact on absorption. LDS can detect all three of these actions, although it is often confined to light detected at low scattering angles.

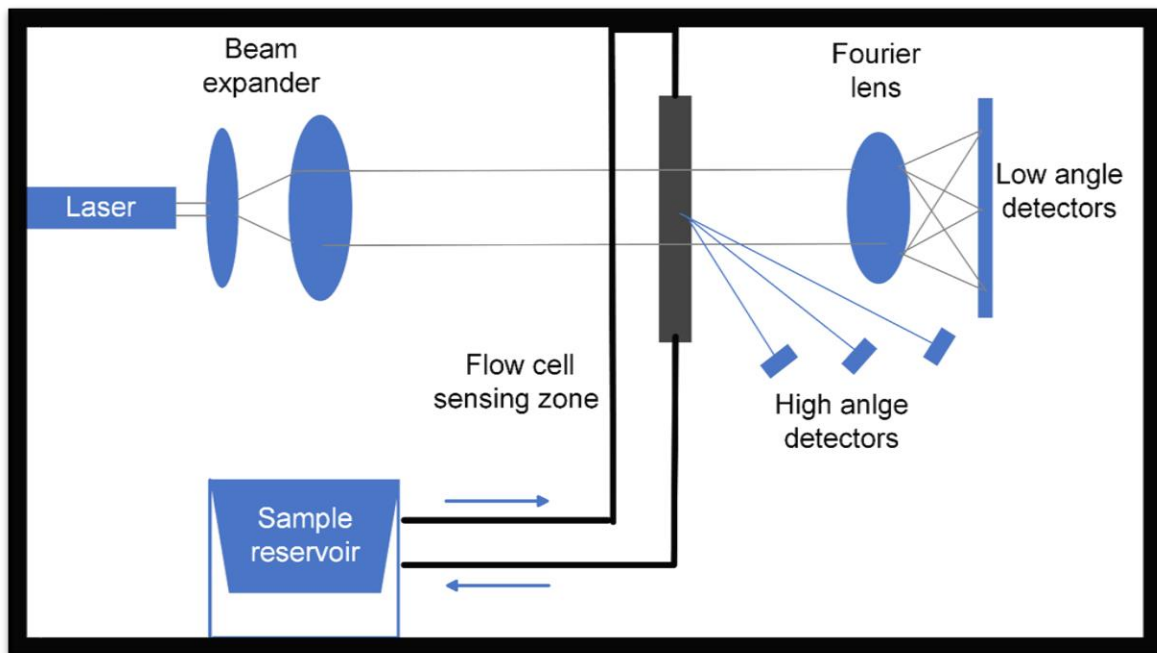


Figure 6 An optical system schematic for a typical laser diffraction spectrometer with the a liquid flow cell

For the investigation of diffraction spectra, there are two main optical models: Mie and Fraunhofer. The Mie theory defines scattering by arbitrary-sized homogeneous spheres. Mie calculates a volume weighted approximate for non-spherical particles. The Mie theory has been used to analyze particles with diameters ranging from several hundred micrometers to around 100 nanometers, with inconsistent results. Manufacturing, quality control, and product development are just a few of the applications for laser diffraction analyzers. Laser diffraction analyzers are commonly employed in industrial settings because they can constantly monitor particle sizes over a wide range of sizes, from 10 nm to 3 mm (27).

## 2.8 Flowmeter

A flow meter (flow sensor) is a device that measures the linear, nonlinear, mass, or volumetric flow rate of liquids or gases. The flow rate is inferentially determined with liquid flow monitoring tools by evaluating the change in kinetic energy

of the liquid. The liquid velocity is determined by the differential pressure that forces it through a pipe. Because the cross-sectional area of the pipe is constant, the average velocity is an indication of the flow rate.

In such instances, the relationship for measuring the liquid flow rate is:

$$Q = kA * \sqrt{gh} \quad \text{Eq.03}$$

Where:

- $Q$  flow rate
- $A$  area between tube wall and float
- $k$  constant
- $g$  gravity force
- $h$  pressure drop

Flowmeter also can be classified as a differential pressure device, by measuring differential pressure units. The float starts to rise when liquid enters the tube's bottom. The float is chosen to have a density greater than the fluid, and its position varies in direct proportion to the flow rate. Its precise location is where the weight of the float is balanced by the pressure difference between the top and bottom surface. Also, no additional flow-reading devices are required because the flow rate can be read directly on a scale mounted next to the tube.

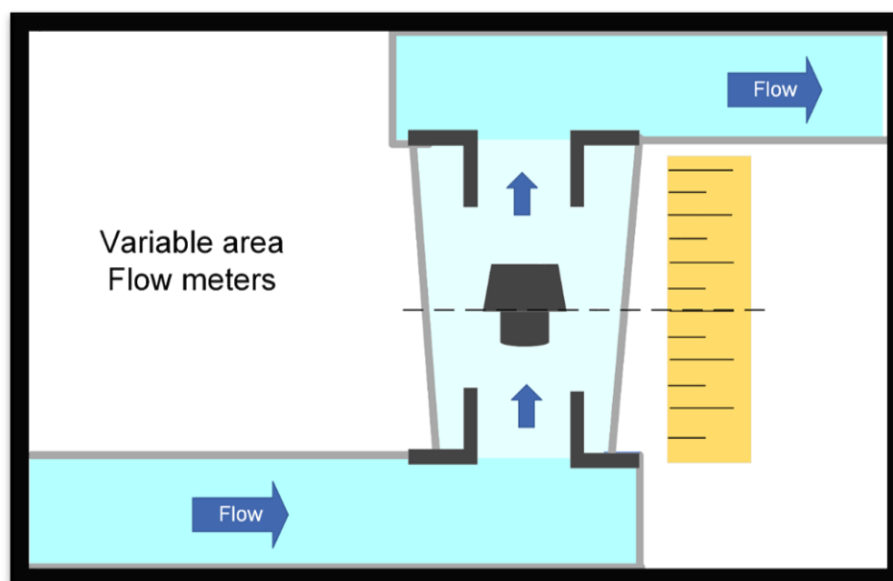


Figure 7 Schematic of vertical flow meter

## **2.9 Elementric oxygen content analysis**

The ELEMENTRAC OH-p 2 elemental analyzer is a powerful and reliable instrument for measuring oxygen, hydrogen concentrations in inorganic samples such as copper, iron, ceramics, and steel. Non-Dispersive infrared radiation (NDIR) and thermal conductivity detectors with high sensitivity reliably detect element concentrations ranging from low ppm to high percentages. The elemental analyzer's measuring principle provides for a large measuring range. The sample is weighed accurately on the sample port to be analyzed, tests quantities ranging from a few milligrams to 2 grams. A capsule that does not need to be sealed is recommended for elemental analysis of powders. After that flushing the furnace with carrier gas avoid oxygen from entering. To avoid contamination, the graphite crucible is outgassed in analyzer's impulse furnace. The sample is put into the crucible and melts after a stabilization phase. Carbon monoxide is created when carbon in the graphite crucible reacts with oxygen in the material. The elemental form of hydrogen is released. Before entering the Schuetze reagent, the carrier gas (nitrogen) and sample gasses travel through a filter, which reduces CO to CO<sub>2</sub>, but leaves hydrogen in its elemental form. The elements analysis is then started using the ELEMENTS program by placing the empty graphite crucible on the lower electrode. All subsequent process steps are controlled by the program. CO<sub>2</sub> is monitored using infrared cells and then chemically eliminated. In the thermal conductivity cell, the hydrogen content is then determined (28).

## **2.10 Copper Powders In Mongolia and In World Market**

In 2022, "Steppe metal powder" LLC has opened their first powder metallurgy plant in Mongolia which will recycle cathode copper and scrap copper with a capacity of 3000 tons of powdered metal annually. Mongolia produces 200 tons of copper waste per month. Therefore, raw materials and products are sufficient, says the industry experts. In addition, the plant is the first in Mongolia to use 99 % of its raw materials and recycle up to 90 % of its water. In addition, it will produce not only copper powder, but also brass, bronze, tin and other metals and export them to the European Union, China, Japan, South Korea and India (16).

Copper Powder was the 900th most traded product in the world in 2020, with a total trade of USD 961 million. Copper Powder exports fell by 38.6% between 2019 and 2020, from USD 1.57 billion to USD 961 million. Copper Powder trade accounts for 0.0057% of global trade, also in the Product Complexity Index, ranked 316th. Malaysia

which is total USD 400 million, and for Germany USD 92.3 million, Japan, Hong Kong, and the United States total of USD 48.2 million, were the major exporters of copper powder in 2020, as for the top importers were: China USD 411 million are the biggest importer, following after South Korea, Japan, Germany, and Chinese Taipei total of USD 44.1 million imported.

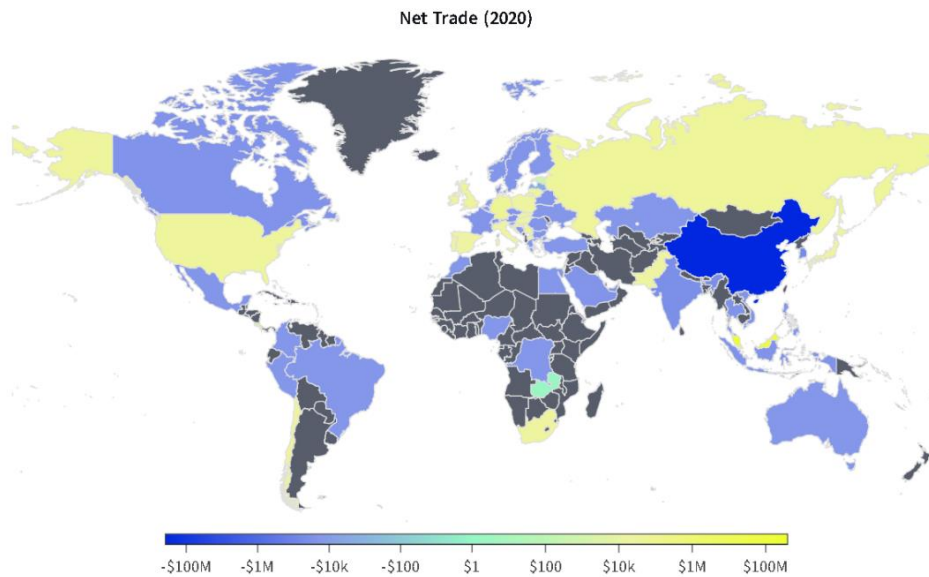


Figure 8 Net trade value of copper powder in world market 2020 (29)

### 3 Material and Methods

#### 3.1 Material

Currently, Steppe metal powder LLC uses water atomized copper powder from GGP metal powder AG as their standard sample. Therefore, this thesis work's sample is based on the water atomized copper powder from GGP Metal powder AG which totally weighs 235gr.



Figure 9 Water Atomized copper powder sample

#### 3.2 Sample preparation

Before doing the sieve analysis I have used cone and quartering sample preparation method which was firstly, make into a conical shape and then turns into cake by flattening, divided into four parts after that two opposing quarters are merged.

#### 3.3 Sieve analysis

A total of 233.48 g of powdered copper was sampled and on 170 g was analyzed using a wet sieve. The layer of sieves with various grades of sieve opening widths is used in this sieve analysis approach. Every layered sieve is placed above it in increasing order sieve size, with the finest sized sieve at the bottom. To evaluate the distribution of weight of these particles, commercial sieve analyzers weigh each individual sieve from the stack. This instrument's base is a shaker, which makes filtering easier. Also a dry sieve was also used to confirm the test results, in order to determine the particle size distribution. Whereas the particle size distribution can affect

a wide range of qualities, such as concrete strength, mixture solubility, and surface area properties, sieve analysis is useful for assessing materials.

**Apparatus for Sieve analysis:**

- pH meter
- Dry oven
- Weigh scale with accuracy of 1gm
- Metal trays
- Wire bush
- Sieves (  $75\mu m$ ,  $53\mu m$ ,  $38\mu m$ ,  $20\mu m$  )

**Measurement procedure:**

Firstly, pH value were measured on 50 g sample mixing with 100 g water with buffer solutions of pH-4 and pH-7, in order to prevent corrosion of sieve. Due to the reason of corrosion rate decreases as pH rises, implying that corrosion rate is proportional to acid concentration in the solution, therefore the result was 8.12 which is very weak base that don't react with metals.



Figure 10 pH value for copper powder

Wet sieving took total of 65 minutes, It was set at 60 amplitudes for 50 minutes, however the amplitude was set to 80 due to water came out of some areas of the blockage. Extra 15 minute with 60 amplitude was added, considering the particles below -20 micrometers had not yet been screened, and the water in the bucket was observed and waited for fresh water to emerge.



Figure 11 Wet sieving set up

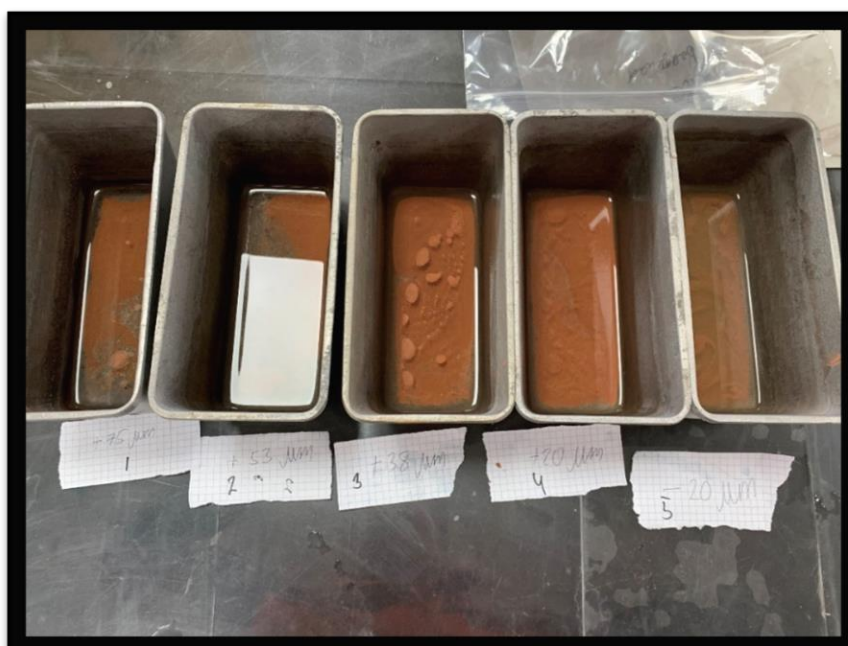


Figure 12 Particle size distribution after wet sieve

After making the wet sieve, it was completely dried in the oven every 24 hours because it contained a certain amount of water.

Lastly, from dried after 24 hours and weighed, samples went through dry sieve for 15 minutes within the same sieve sizes and weighed with the purpose of confirm the test result.

### **3.4 X-Ray Diffraction analysis method**

This analysis took a place at Mongolian Academy of Science, Institute of Physics and Technology, I gave it all copper powder samples to get analyzed, the test results were received by e-mail two days later.

X-ray diffraction (XRD) is a flexible, non-destructive quantitative method for determining material properties such as phase crystal structure, phase composition, texture, and many others in powder, solid, and liquid samples. The phases are determined by evaluating the X-ray diffraction pattern acquired from an unknown material to patterns from a reference database received from the International Centre of Diffraction Data (ICDD).

The following are the key subjects of X-ray diffraction:

- Phase examination of pure compounds, both qualitative and quantitative.
- Temperature and other non-ambient factors such as humidity and applied pressure are investigated.
- For polycrystalline materials, microstructure analysis includes features such as preferred orientation effects, crystallite size, and residual stress.

#### **3.4.1 The powder diffractogram**

The sample in X-ray powder diffraction is made up of an endlessly large number of tiny crystallites that are ideally randomly oriented in relation to one another. Due to all orientations are present, changing the angle of incidence and the angle of diffraction is all that is required. The detected intensity is counted as a function of the angle between the incident and diffracted beams to produce a powder diffractogram. The scattered intensity vs the Bragg angle ( $2\theta$ ) is displayed on a powder diffractogram, which contains a number of reflections. The position, intensity, and contour of the reflections all have a role in powder diffractogram.

### 3.4.1.1 The reflection's position: Bragg law

Diffraction and interference of X-rays in a crystal were characterized by W.H. Bragg and W.L. Bragg in 1913 as reflections at the atomic planes of the crystal lattice. The optical path differences  $2s$ , with  $s=d\sin\theta$  between two reflected rays at neighboring interplanar spacings, are used to calculate the positions of the reflections. Maximas are formed for integer multiples of  $\lambda$ , just as they are in visible light optics.

$$2d\sin\theta = n\lambda \quad (\text{Bragg Law})$$

which consists:

- $d$  interplaner spacing ( space between the planes )
- $\theta$  Bragg angle  
 $2\theta$ : angle between reflected beam and incident
- $n$  Order of interference
- $\lambda$  Wavelength

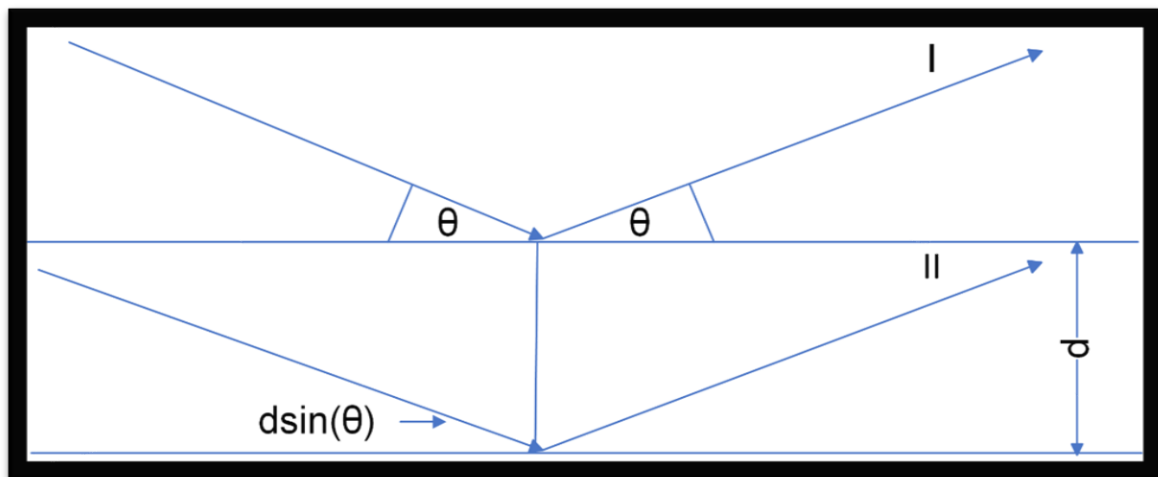


Figure 13 Bragg's law is illustrated graphically.

Coherent scattering of X-rays at the atoms leads in constructive interference at particular well-defined angles as a result of the regular arrangement of atoms in solid. This behavior is similar to the diffraction of visible light at gratings with nm-scaled spacing around the wavelength of the light. When the wavelength of the incoming X-ray photon is of equal size, a crystal can be seen as a three-dimensional grating with a spacing of a few diffraction effects can be detected.

The tube's X-rays travel through primary optical components, irradiate the sample, are diffracted by the sample phases, and then pass through secondary optical components before entering the detector. The intensities of a diffractogram are recorded by adjusting the diffraction angle by moving the tube or sample and detector.

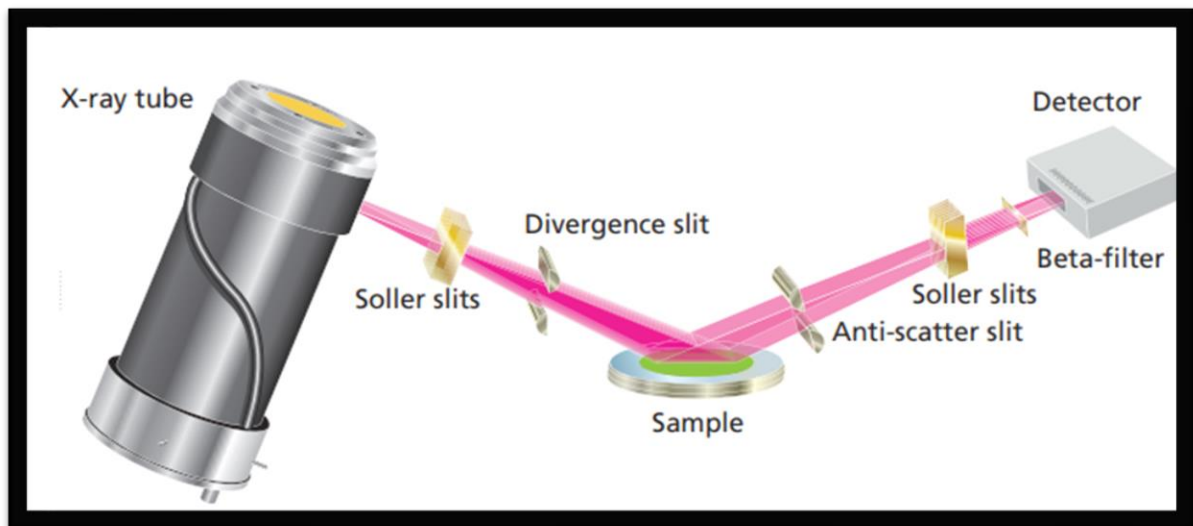


Figure 14 With components for reflection measurements, a powder diffractometer is set up in Bragg geometry.

A reference database of empirically determined d-values and intensities or derived patterns from crystal structure data is compared to the observed diffractogram with peak table and profile. The ICDD (International Centre for Diffraction Data) provides such a reference database (30).

#### 4 Results and Discussion

The following graph shows particle size distribution on copper powder sample with P80 value. Water atomized copper powder sample has a 47.3 $\mu\text{m}$  average particle size, also graph indicates for wet sieving on 52  $\mu\text{m}$  particle size 80% of the sample will pass, as for the dry sieving P80 value was 57  $\mu\text{m}$ .

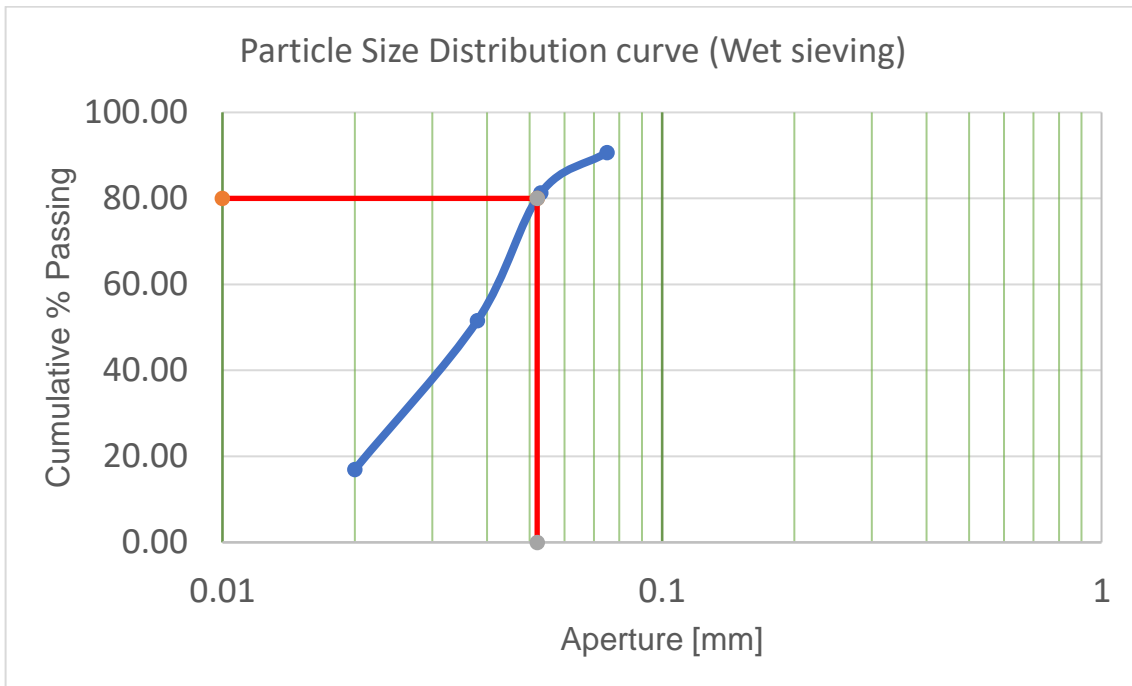


Figure 15 Particle size distribution curve for wet sieving

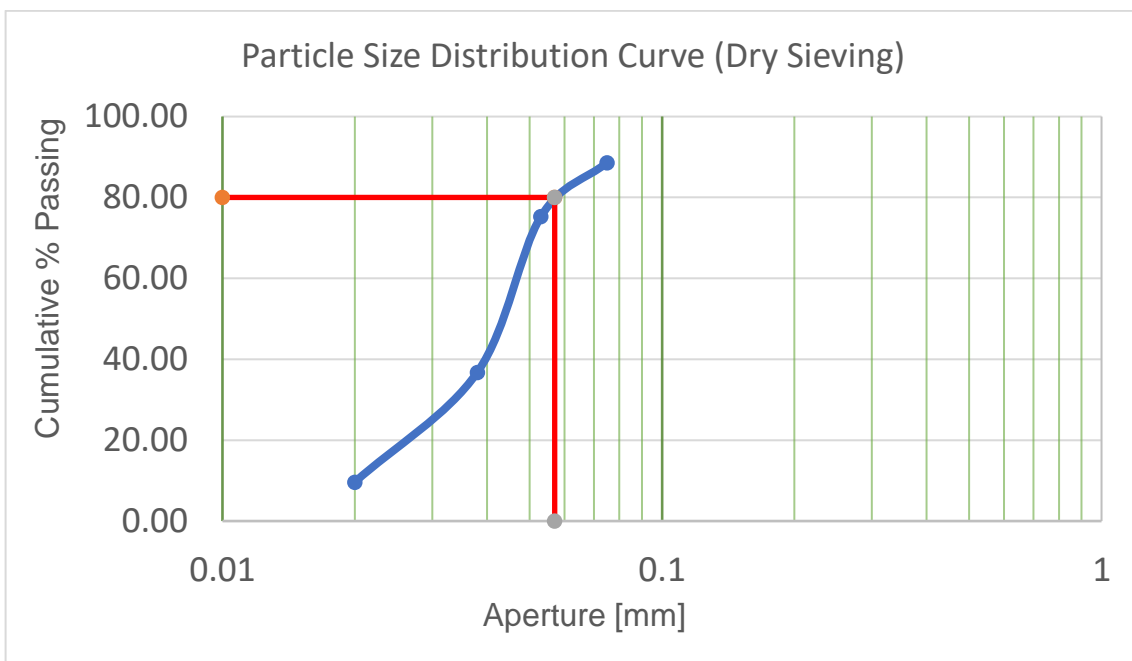


Figure 16 Particle size distribution curve for dry sieving

The apparent density of a copper powder is determined by the solid material's density, particle size, particle shape, individual particle surface area and roughness and particle arrangement. Particle size has a significant impact on apparent density, It generally lowers as particle size falls, decreases as particle shape becomes less spherical and more irregular, drops as surface roughness increases, and it is frequently regulated by mixing different particle sizes. In general, decreasing particle size reduces apparent density. The bigger the specific surface of the powder, the smaller the particles. The friction between particles increases as a result of this phenomena, lowering the apparent density.

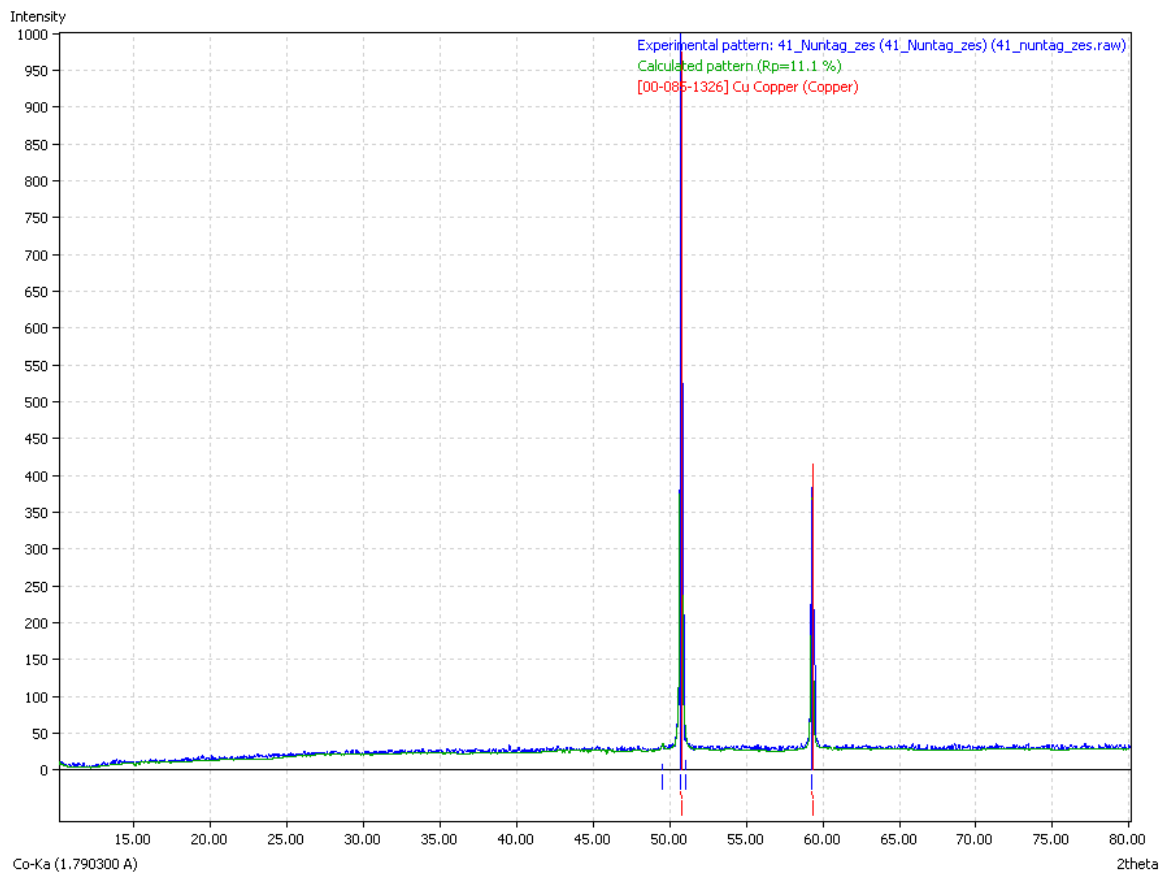


Figure 17 Intensity vs 2theta XRD graph

The graph illustrates that copper powder is indeed crystalline with the sharp peaks. The crystal structure of copper powder is cubic which is isometric crystal system where can the unit cells are in the cube shape with space group of Fm-3m (225) regarding with cell parameter  $a = 3.615 \text{ \AA}$ . The values match precisely with the International Centre of Diffraction Data (ICDD). Some peaks are high in intensity at around  $51 2\theta$  degree and  $59 2\theta$  degrees, due to the fact that there is more periodicity than the other directions. The peak height will be high if there is a preferred crystal

orientation, however if crystals are arranged in a random order than the peak height will be low. Peak intensity represents the atomic position in the crystal structure.

The results of the analysis of the Central Geological Laboratory, calculated the copper content by the difference between the metal content detected by the ICP-MS and the ICP-OES analyzers equipment. Our standard sample has 99.54% copper concentration following highest concentrated elements are Iron (Fe) 0.15% Zinc (Zn) 0.056% Phosphorus (P) 0.051% from the table 5 in appendix.

A minimum copper percentage of 99.3 % is required for pure copper, the standard sample remains pure copper powder with high apparent density  $3.76 \text{ g/cm}^3$  along with 0.0918 % oxygen content as shown in the table 6 from appendix. Comparing between the electrolytic copper powder and water atomized copper powder, electrolytic copper powder used in wide range of application. Due to its oxygen content and crystal structure that influences the thermal and electrical conductivity.

Water atomized copper powder has not acceptable to use in electrical and thermal conduct application purposes, since this process uses smelted copper which is oxygen is added. Copper powder with a higher oxygen content may become embrittled during brazing as a result of hydrogen's reaction with oxygen. Hydrogen diffuses through copper and interacts with copper(I) oxide ( $\text{Cu}_2\text{O}$ ) inclusions to generate water ( $\text{H}_2\text{O}$ ), which forms pressured bubbles at grain boundaries. Hydrogen embrittlement is a phenomenon that occurs when grains are literally driven away from one other, as if cracks are forming. Therefore, copper that is oxygen-free has been processed to reduce the amount of oxygen in the metal, increasing conductivity and oxidation resistance. Industrial applications for oxygen-free copper include electrical generators, in which the wire is regularly exposed to high temperatures and vibration, and video cabling and audio, where the enhanced conductivity is thought to better low-frequency transmission.

On the other hand, electrolytic copper powder acceptable for use in chemical industry, considering its dendritic crystal structure it makes very well suited for blending with other powders like hard metal powders. Moreover, fine powders or powders with a higher specific density, in particular, can be kept between dendrite arms. There is no quenching of a melt with electrolysis, and the free growth of dendrites in crystallographic orientations produces a rather soft material ideal for pressing. Because of the clamping action caused by the dendritic structure, great green strength can be

achieved. Also, electrolytic copper powders have a strong sinter activity because to their high surface area, and high sintered strengths can be obtained starting with high green strengths.

Regarding to the water atomized copper powder's spherical particles, irregular morphology, high apparent density with 0.092% oxygen content and 99.54% copper concentration, these are the following recommended applications:

- Sintering
- Brake and friction lining
- Welding rod

#### 4.1 The metal sintering process

The process of sintering involves combining fine powdered components and compressing them into a desired form. After the appropriate shape has been achieved, the compacted portion is heated in a controlled atmosphere, causing the material to bond. Sintering process commonly used method in powder metallurgy processes, also the following three steps are the main:

- Blending
- Compaction
- Sintering (33)

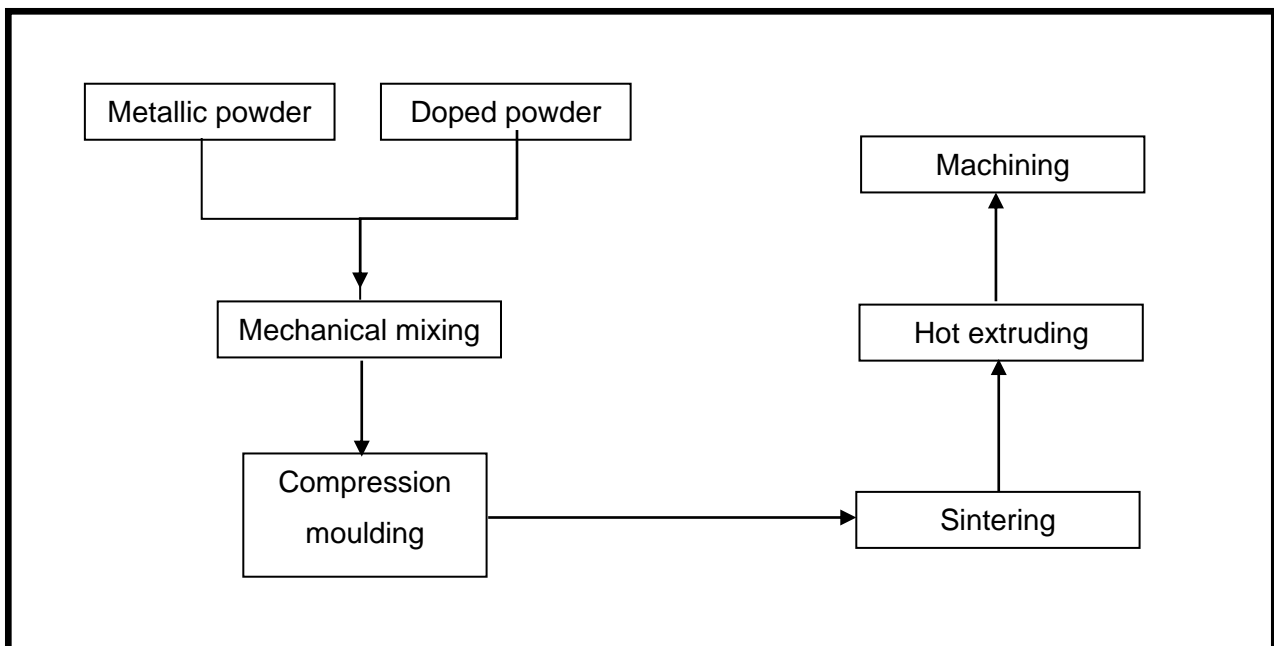


Figure 18 Flow chart of the Cu-based powder sintering process using hot pressing.

## **Blending**

Blending powdered metals is the first step in the process. The first material in metal sintering is an iron-based powder combination. Alloying materials and additives are added to the mix based on the qualities required. The solid lubricant is also included in powder blends. This lubricant is required to reduce resistance between powder mass and the tool's surface during compaction. In the powder metallurgy process, blending allows for the development of a homogenous mixture, the provision of required material qualities, and the reduction of friction during the compaction step.

## **Compaction**

The compaction step uses carbide and steel tools, with the load applied axially. The amount of powder required is calculated ahead of time and given to the tool by gravity. The powder metal is delivered to the die cavity by a filling shoe and compressed with a force ranging from 400 MPa to 800 MPa. The 'green' component created after the initial compaction has a density of roughly 85 % to 95 %. This method allows complex pieces to be pressed in a single operation while maintaining a high production rate - often up to 25 parts per minute. The part to be created has its desired shape after compacting, but not its final dimensions. As a result, concessions for shrinkage during the sintering stage of the process are made. It's worth noting that powder compaction allows for a wide range of radial characteristics and design flexibility.

## **Sintering**

Parts must be sintered in order for the 'green' component created during the compression step of the process to achieve the appropriate mechanical qualities. Sintering is a heat treatment procedure that is usually done in a controlled environment on a belt conveyor furnace. The pieces are now heated in the furnace to below melting point of a powdered metals used in the mixing step of the process. Heating times vary based on the final part's application, the materials utilized, and the physical requirements. During in the sintering, the 'green' part's powder grains grow together and connect through a diffusion process, improving the part's mechanical qualities.

Minor shrinkage occurs during sintering (for which allowances were made during the compaction process), providing the part its final size. The rate where the part is allowed to cool can be changed to modify its qualities (31).

#### **4.1.1 Pros and cons of sintered metal**

The following are some of the benefits of the metal sintering process:

- The capacity to create net forms.
- The requirement for secondary machining processes is reduced.
- Dimensional precision is great in sintered metal products.
- The sintering process is exceedingly reproducible and reliable.
- It's a low-cost and quick way to make precision metal parts in medium to high volumes.
- The method enables for precise control of tolerances.
- The sintering technique can be applied with a variety of powdered metals.
- The material utilization factor of the process is quite high.
- The method creates a nice surface finish.

Sintered Metal's Disadvantages:

- The pressing tonnage at the compaction step limits the size of the component generated.
- The remaining porosity reduces the physical and mechanical qualities of the finished component.

#### **4.2 Processing welding rod**

Thin metal wire forms the electrodes core, most often the core is made of carbon or stainless steel. Firstly, wires go through a machine that simultaneously spins and bends it evenly reshaping the wire until its completely straight, four metal rollers are then push and guide the wire into guillotine. The blade chops the wire into segments that will become the electrode course, these segments range from 25 to 40cm long. There is variety of metals and minerals in the coating, the metals are often nickel, manganese and iron as for the mineral's its aluminum, magnesia, limestone and copper and colorant is can be added. After that, all ingredients mixed with glue and so it turns into consistency of wet sand then went into compressing section forms it into solid slugs with a hole in the middle. Now to put the powder coating on the wires in extrusion press, it will apply 120 tons of pressure on the slugs, to shoot the powder

through nozzles that will coat the wires as they pass through the slugs hole. The coating drives at room temperature for up to 72 hours, to cure the coating the electrodes heated up to 500 degrees Celsius in furnace for up to five hours after those electrodes cooled and ready to use.

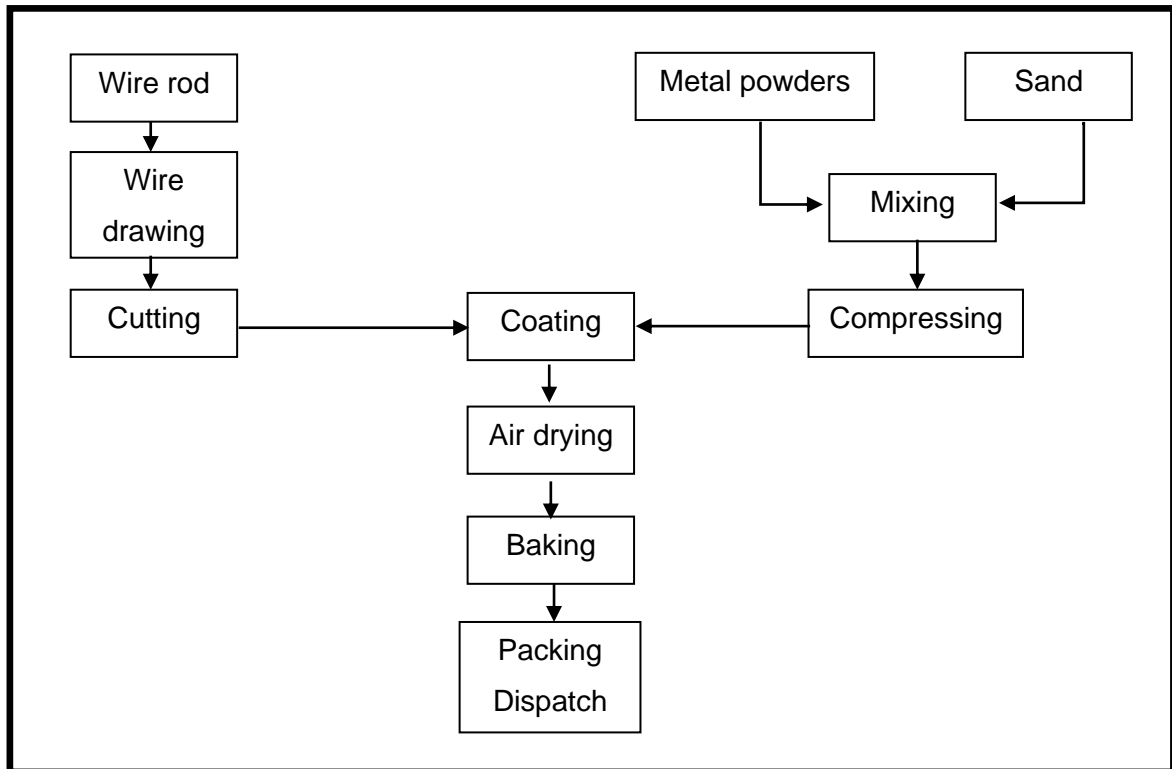


Figure 19 The process flowsheet of copper coated welding electrodes (34)

### 4.3 Processing brake and friction lining

The pad manufacturing process comprises the parallel development of friction material and metal backing plate mixtures. This begins with the preparation of combinations of numerous components (between 20 and 30 components are utilized to manufacture one pad), which are selected from a variety of over 100 different materials. Each of these components has a distinct purpose in the friction material to which they are introduced, such as resins that hold the other components together, abrasives such as aluminum oxides or silicon that generate friction, lubricants such as graphite and Sulphur that limit wear by forming a protective layer between pads and disks, metals such as iron and copper that aid in heat dissipation, at the same time metal backing plates are cut into their final shape following this the back plates are sandblasted and degreased to ensure that the adhesive sets properly (32). Following the application of the adhesive to the backing plates, a dust-free compound is applied

to form the substrate as well as a mix for the friction substance. The entire device is then placed in an oven for the next stage of pressing, during which heat is adjusted to allow the pads to solidify and achieve the desired mechanical and friction properties. After removing the pads from the oven, the places where they will come into contact with the discs are machined to guarantee even mating and shorten bedding times. The pads are then entirely rust proofed save for the area that comes into direct contact with the disks, and any sections that need rounding off cutting are handled with at this stage to improve performance and comfort. The installation of anti-noise shims where indicators and any springs to the calendars is the next step. The ID marks, manufacturer's name, homologation number, and other traceability data are applied on the calipers in the final stage.

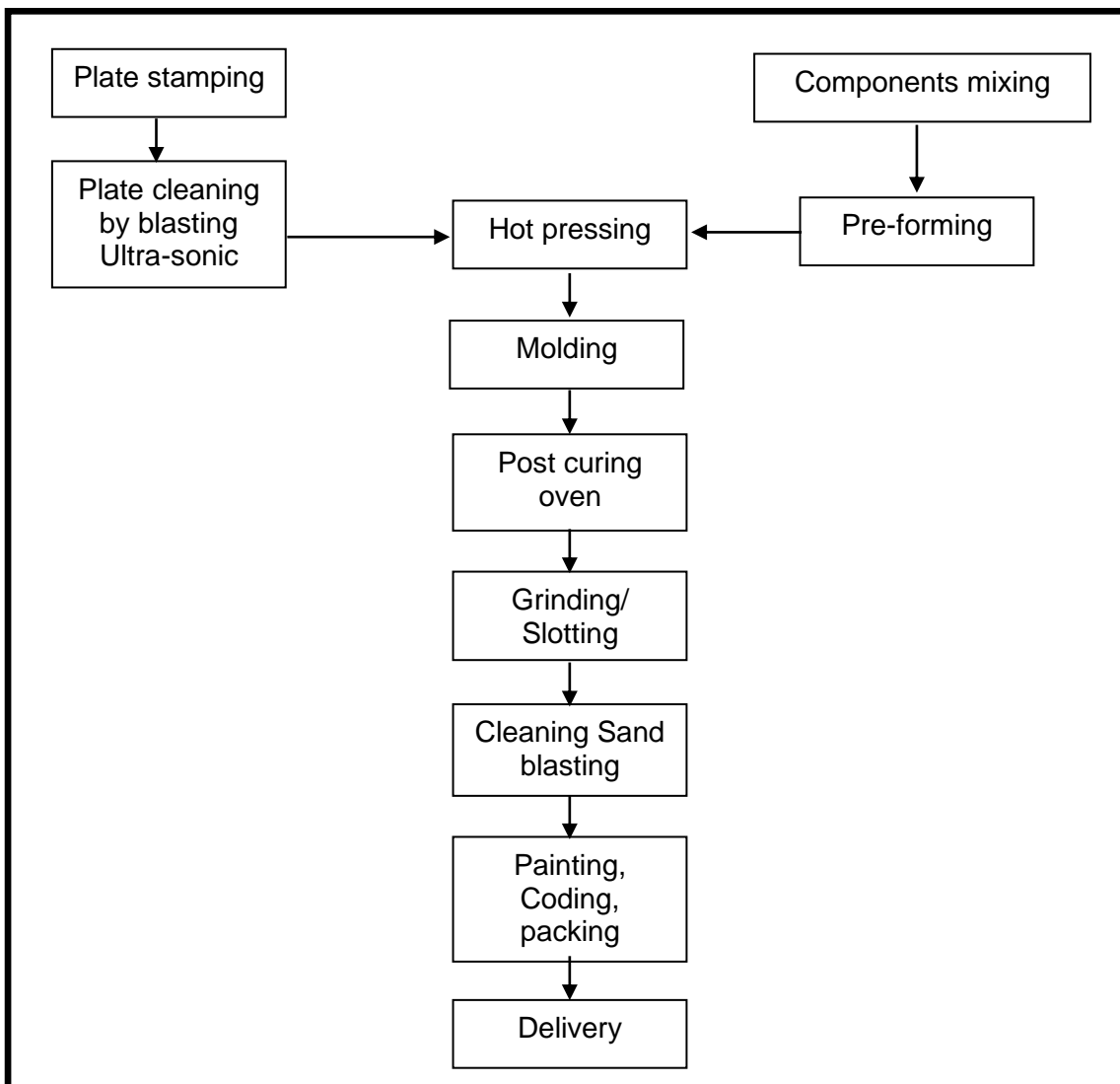


Figure 20 The flowsheet of processing brake and friction lining (35)

## 5 Conclusion

Powdered metal technology to produce new energy and metal-saving products in the world's metal processing industry will be introduced in Mongolia. It also sets the groundwork for improving domestic metal processing and establishing a system of value-added products capable of competing in the global market. Furthermore, the metal powder provides an opportunity to produce high-tech products such as electrical equipment, automotive, computer and mobile phone parts by powder metallurgy and 3D printing, and is the beginning of a new branch of processing industry to benefit from more natural resources. To increase the level of mineral processing through the introduction of advanced technologies and innovations that have less negative impact on the environment, to ensure the growth of the country's economy by developing import-substituting and export-oriented products.

Within this thesis work, we have accomplished particle size distribution by experimental work, the analyzing techniques which are XRD, ICP-MS, ICP-OES and elemental oxygen content analyzer methods have been done in different places by order.s

First of all, an electrolytic powdered copper is more widely used than water atomized powdered copper. Due to its high copper content, low oxygen level, dendritic crystalline structure, and ability to combine with other powdered metals all contribute to its popularity. As a result, it is better suited for electrical and thermal transmission. Moreover, the particle size directly influences the apparent density and fracture toughness as shown in equation 2. It's got finer when apparent density is low which makes better solidification by avoiding fracture at molecule boundaries. Although, hydrogen interacts with oxygen to form water, the oxygen content can cause fracture.

Secondly, water atomization process recycles cathode copper, scrap copper which will make this process environmentally healthy process. In countries like Mongolia, which has a lot of precious metal waste, mining accounts for 93.3 % of its export, there are few precious metals processing plants, and no final products are produced country, this water atomization technology will undoubtedly give impetus to rapid development and the economy. As shown in the table 9 (Industrial products sale) in 2021, the industrial sector sold was a total of MNT 24,825 billion, of which the mining sector alone sold MNT 17,549.2 billion and the processing industry MNT 5,730.2 billion. However, the heavy industry, such as coke, petroleum manufacturing plant, chemicals and chemical products, non-metallic minerals, metal processing, non-

machinery equipment processing plant, and other vehicles equipment manufacturing total sold was 1,291.3 billion MNT which accounts 6.75 % of total industrial sector's 2021 years sale. There are two non-export plants from heavy industry which are chemicals and chemical products and vehicle equipment manufacturing plant. Also, there is a decline occurs by 12.4% from the previous year or 2020 sales from vehicle equipment manufacturing plant.

Therefore, in order to increase the production of car equipment's, create opportunities for export, reduce domestic imports and meet the demand of domestic car equipment parts that it is necessary to establish a production of powdered copper and sintering process, car brake and friction linings. By establishing these manufacturing plants meets the requirement for port revival, industrial revival and urban and rural revival for Mongolia's "New Revival Policy" that will directly influences three of the six purposes.

Long-term economic growth has been achieved through the implementation of the "New Revival Policy" in six ways, the national income per capita has doubled, and the rate of labor force participation will reach 65%. The capacity of the port will be tripled, and the sources of energy will be doubled. "Vision-2050" to create goals and basic conditions for the first stage of Mongolia's long-term development policy. In all of these policies, I believe that these production processes will help to achieve efficient results.

## **5.1 Limitations**

Powder metallurgy is a brand-new technology for our country by this reason analyzing method for my thesis work was limited. There are more some important parameters and properties were missing for example, thermal and electrical conductivity, hardness and reactivity. Since, powder metallurgy plant has been built the metal powder analytical methods should necessary.

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## 7 Appendix

Table 3 Net trade of copper powder in world 2020

Country	Trade Value Export	Trade Value Import	Trade Value Delta
Democratic Republic of the Congo	17	19691	-19674
Egypt	101562	1457947	-1356385
Morocco	88733	841821	-753088
Nigeria	28529	201664	-173135
South Africa	10325814	281712	10044102
Zambia	1267	253	1014
United Arab Emirates	3359424	5800983	-2441559
China	27763631	411307044	-383543413
Cyprus	4	4843	-4839
Hong Kong	64539705	21285904	43253801
Indonesia	677087	9926491	-9249404
India	2268079	25555138	-23287059
Israel	11587750	552676	11035074
Japan	66052618	55468475	10584143
Kazakhstan	1371	93371	-92000
South Korea	16140474	62642445	-46501971
Kuwait	611202	140192	471010
Malaysia	400478087	5658369	394819718
Pakistan	1656275	1447898	208377
Philippines	2389930	7311577	-4921647
Saudi Arabia	572491	5797660	-5225169
Singapore	4988100	4389243	598857
Thailand	12846484	23383631	-10537147
Turkey	4456216	6133536	-1677320
Vietnam	84934	8862767	-8777833
Chinese Taipei	12542902	44109210	-31566308
Austria	4250852	13683872	-9433020
Belgium	6866150	11460733	-4594583
Bulgaria	2012527	4767438	-2754911
Bosnia and Herzegovina	153864	697753	-543889
Belarus	3900	674490	-670590
Switzerland	294864	2113361	-1818497
Czechia	704177	2664209	-1960032

Germany	92287858	52684453	39603405
Denmark	1802	4096937	-4095135
Spain	12700007	11750652	949355
Estonia	14433	1760	12673
Finland	201924	596156	-394232
France	14762474	21563965	-6801491
United Kingdom	34925727	7701331	27224396
Greece	394188	1132466	-738278
Croatia	245845	146001	99844
Hungary	587786	521763	66023
Ireland	153973	77123	76850
Italy	34470148	32766330	1703818
Lithuania	650757	85073	565684
Luxembourg	19224	399257	-380033
Latvia	1915	16563	-14648
North Macedonia	33976	173	33803
Netherlands	1483478	1976266	-492788
Norway	3653	2240516	-2236863
Poland	7582105	4164197	3417908
Portugal	771827	226580	545247
Romania	410447	3705606	-3295159
Russia	30225923	2328486	27897437
Serbia	13771917	696122	13075795
Slovakia	1219698	722839	496859
Slovenia	40900	150620	-109720
Sweden	2347009	9755975	-7408966
Ukraine	744	839242	-838498
Canada	882811	13304032	-12421221
Costa Rica	28698	14970	13728
Mexico	662632	4827245	-4164613
United States	48246861	26508233	21738628
Australia	2039028	2624793	-585765
Brazil	1900751	3618265	-1717514
Chile	484311	276464	207847
Colombia	4642	871310	-866668
Peru	6	112535	-112529

Table 4 Metal content of copper powder

Sample number	Element [%]			Element [mg/kg]							
	Cu	Fe	Al	Mg	Si	Zn	P	Mn	B	Be	Cr
Standard sample	99.54	0.1 5	<0.0 1	37 5	30 9	59 0	50 1	11.6 8	<5. 0	<0.0 5	5.2 2
Analytical methods	Titration	ICP-OES							ICP-MS		

Sample number	Element [mg/kg]									
	Co	Ni	Sr	Mo	Cd	Sn	Sb	W	Pb	Bi
Standard sample	<0.1	17.62	1.04	139	<0.5	346	6.99	<0.5	141	<0.5
Analytical methods	ICP-MS									

Table 5 Determination of physical and chemical properties of copper powder

Sample Number	Color	Average particle size [µm]	Apparent density [g/cm <sup>3</sup> ]	Flow rate [sec/50g]	Oxygen content [mg/kg]
Standard sample	Yellow	47.3	3.76	21.1	918
Analytical methods		LTP-11	LTP-04	LTP-03	LTP-02

Table 6 Copper price on London Metal Exchange (LME) over the last year(3)

Month	LME Copper Cash- Settlement (\$)	LME Copper 3- month (\$)	LME Copper stock
Apr-22	10,308.36	10,325.05	102,834
Mar-22	10,237.59	10,245.65	77,259
Feb-22	9,941.35	9,895.20	76,775
Jan-22	9,775.93	9,748.40	90,478
Dec-21	9,550.31	9,524.67	84,544
Nov-21	9,765.48	9,595.95	100,600
Oct-21	9,778.50	9,635.64	181,564
Sep-21	9,324.07	9,329.70	235,509
Aug-21	9,357.19	9,371.67	242,971
Jul-21	9,433.59	9,464.20	221,994
Jun-21	9,612.43	9,637.98	154,205
May-21	10,183.97	10,196.05	123,245
Apr-21	9,335.55	9,324.13	157,300
Mar-21	9,004.98	8,988.20	102,630
Feb-21	8,460.25	8,439.78	75,339
Jan-21	7,970.50	7,978.38	94,604

Table 7 Production of main products of the mining sector of Mongolia in 2021 (12)

Products	Thousand tons
Coal	30124.3
Copper concentrate	1326.3
Gold	19054.4
Molybdenum concentrate	6326
Iron ore	9171.9
Iron ore concentrate	3676.8
Flourspar	118.3
Flourspar concentrate	60.3
Zinc concentrate	75.2

Table 8 Total production of Industrial sector

Industry	2020	2021	Comparative Change	
	1	2	(2-1)=?	(2/1)=?
<b>Total</b>	<b>16,738.0</b>	<b>18,522.5</b>	<b>1,784.5</b>	<b>10.7</b>
<b>Mining</b>	<b>11,769.5</b>	<b>12,462.3</b>	<b>692.8</b>	<b>5.9</b>
Coal mining	3,741.0	2,554.4	<b>-1,186.6</b>	<b>-31.7</b>
Oil extraction	441.5	753.8	<b>312.3</b>	<b>70.7</b>
Metal ore mining	7,222.9	8,891.5	<b>1,668.6</b>	<b>23.1</b>
Other mineral mining	229.2	213.8	<b>-15.4</b>	<b>-6.7</b>
Mining ancillary activities	134.8	48.8	<b>-86.0</b>	<b>-63.8</b>
<b>Processing plant</b>	<b>3,634.5</b>	<b>4,518.3</b>	<b>883.8</b>	<b>24.3</b>
<b>Heavy industry</b>	<b>1,133.5</b>	<b>1,291.3</b>	<b>157.8</b>	<b>13.9</b>
Coke and crude oil processed product manufacturing	549.1	504.0	<b>-45.1</b>	<b>-8.2</b>
Chemicals and chemicals product manufacturing	91.9	98.9	<b>7.0</b>	<b>7.6</b>
Non-metallic minerals manufacture of articles	251.9	345.9	<b>94.0</b>	<b>37.3</b>
Metal processing production	231.9	331.7	<b>99.8</b>	<b>43.0</b>
From machinery and equipment other metal products production	4.1	6.6	<b>2.5</b>	<b>61.0</b>
Other vehicles equipment manufacturing	4.5	4.2	<b>-0.3</b>	<b>-6.7</b>

(Unit: MNT billion)

Table 9 Industrial sector products sale of Mongolia (1)

Industry	2020	2021		Comparative Change	
	1	2	Export	(2-1) =?	(2/1) =?
<b>Total</b>	<b>19,934.0</b>	<b>24,825.0</b>	<b>15,478.5</b>	<b>4,891.0</b>	<b>24.5</b>
<b>Mining</b>	<b>13,573.2</b>	<b>17,549.2</b>	<b>14,226.4</b>	<b>3,976.0</b>	<b>29.3</b>
Coal mining	3,807.2	3,470.9	3,038.2	-336.3	-8.8
Oil extraction	424.3	701.3	701.3	277.0	65.3
Metal ore mining	8,884.8	13,004.3	10,281.8	4,119.5	46.4
Other mineral mining	271.3	324.8	205.2	53.5	19.7
Mining ancillary activities	185.6	47.9		-137.7	-74.2
<b>Processing plant</b>	<b>5,014.2</b>	<b>5,730.2</b>	<b>1,252.1</b>	<b>716.0</b>	<b>14.3</b>
<b>Heavy industry</b>	<b>1,942.5</b>	<b>1,676.0</b>	<b>858.9</b>	<b>-266.5</b>	<b>-13.7</b>
Coke and crude oil processed product manufacturing	1,056.5	518.0	417.0	-538.5	-51.0
Chemicals and chemicals product manufacturing	108.1	113.7		5.6	5.2
Non-metallic minerals manufacture of articles	311.6	433.8	0.8	122.2	39.2
Metal processing production	457.2	598.8	440.2	141.6	31.0
From machinery and equipment other metal products production	4.2	7.5	0.9	3.3	78.6
Other vehicles equipment manufacturing	4.8	4.2		-0.6	-12.5

(Unit: MNT billion)

Table 10 Results of wet sieving

Aperture, mm	Mass, %	Cum.%Passing	Cum.%Retained
<b>0.09</b>	<b>0</b>	<b>100</b>	<b>0</b>
0.075	9.33	90.67	9.33
0.053	9.42	81.26	18.74
0.038	29.70	51.55	48.45
0.02	34.59	16.96	83.04
-0.02	16.96	0.00	100.00

Table 11 Results of dry sieving

Aperture, mm	Mass, %	Cum.%Passing	Cum.%Retained
<b>0.09</b>	0	100	0
0.075	11.39	88.61	11.39
0.053	13.37	75.25	24.75
0.038	38.48	36.76	63.24
0.02	27.13	9.63	90.37
-0.02	9.63	0.00	100.00

Table 12 Results of XRD analysis

Phase classification	
Name	Copper
Mineral Name	Copper
Formula	Cu
Pearson symbol	cF4
I/lc	8.86
Quality	C (calculated)
Bibliographic data	
<b>Publication</b>	
Reference	, Calculated from ICSD using POWD-12++ 359, 1 (1997)
Crystal structure	
<b>Published crystallographic data</b>	
Space group	Fm-3m (225)
Crystal system	cubic
Cell parameters	a=3.615 Å
Cell volume	47.24 Å <sup>3</sup>
Z	4
Diffraction data	
<b>Published diffraction lines</b>	

	<b>d [Å]</b>	<b>Int.</b>	<b>h</b>	<b>k</b>	<b>l</b>
	2.0871	999	1	1	1
	1.8075	427	2	0	0
	1.2781	171	2	2	0
	1.09	156	3	1	1
<b>Experimental</b>					
<b><i>Physical Properties</i></b>					
<b>Meas. density</b>	8.96 g/cm <sup>3</sup>				
<b>Calc. density</b>	8.933 g/cm <sup>3</sup>				