PRODUCTION OF METAL POWDERS BY GAS ATOMIZATION

A MASTER'S THESIS

in

Mechanical Engineering

University of Gaziantep

By

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June 1996

Approval of the Graduate School of Natural and Applied Sciences

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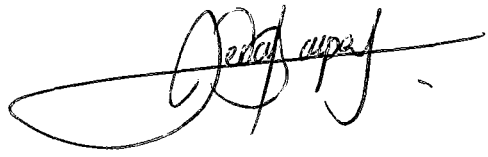

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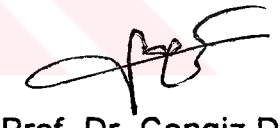

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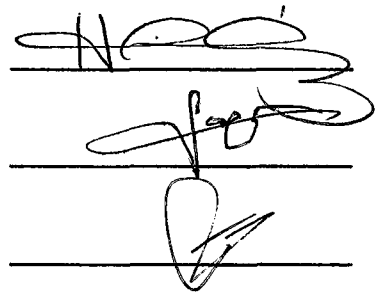

ABSTRACT

PRODUCTION OF METAL POWDERS BY GAS ATOMIZATION

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In this study, a gas atomization unit for metal powder production has been modified. Instead of tundish and melting of metal, a melting unit working with an electric arc has been used. This unit consists of high current, low voltage power source, compressed air, nozzle and electrode feeding mechanism.

In the experimental set-up two different metal wires which are driven by feed drive mechanism, are melted by means of an electric arc developed between the ends of the wires. A nozzle directs the compressed air to the arc and atomise the molten metal. Produced powders are quenched in the water before the solidification to obtain complex shapes. Direct current power source used in the experiment, automatically adjusts the current according to selected voltage.

In the experiments, steel, brass and aluminium wires with different diameters were atomized. Characteristics of the produced metal powders are investigated in terms of size and the microscopic structure. Mean powder sizes for steel, brass and aluminium are 121 μm, 88 μm and 88 μm respectively.

Key Words: Metal arc spraying, atomization

ÖZET

GAZ ATOMİZASYONU İLE METAL TOZU ÜRETİMİ

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Bu çalışmada gaz atomizasyon yöntemiyle metal tozu üreten bir deney düzeneği geliştirilmiştir. Gaz atomizasyonu deney düzeneğinde kullanılan metal ergitme ve pota yerine elektrik arkı ile çalışan bir ergitme ünitesi kullanılmıştır. Bu ünite, yüksek amperli düşük voltajlı doğru akım güç kaynağı, basınçlı hava ve fıskiye ünitesi ile elektrot sürücü mekanizmasından oluşmaktadır.

Deney düzeneğinde sürücü ünitesi tarafından kontrollu bir şekilde sürülen iki ayrı elektrot, ark yaptırılarak ergitilmektedir. Ark sonucu ergiyen metal, fıskiye tarafından püskürtülen basınçlı hava yardımıyla atomize edilmektedir. Üretilen tozların karışık şekil alması için atomizasyon sonucunda katılaşmadan önce suda soğutulmaktadır. Deneyde kullanılan doğru akım güç kaynağı, ark esnasında oluşan akım şiddetini seçilen voltaja göre otomatik olarak ayarlamaktadır.

Deneylerde değişik çaplarda çelik, pirinç ve alüminyun teller toz haline getirilmiştir. Üretilen metal tozları elek ve mikroskopik analizlerden geçirilerek, tozların karakteristik özellikleri incelenmiştir. Tozların ortalama tane büyüklüğü çelik, pirinç ve alüminyum için, 121 μm, 88 μm ve 88 μm olarak bulunmuştur.

Anahtar Kelimeler: Metal tozları, elektrik ark atomizasyonu,

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CHAPTER 1

INTRODUCTION

Powder metallurgy is the process of producing commercial products from metallic powders under pressure. Heat which may or may not be used in the process, must be kept at a temperature below the melting point of the powder.

The application of heat during the process is known as sintering and results in bonding action of fine particles together, thus improving the strength and other properties of the finished product. Products made by powder metallurgy are frequently mixed with different metal powders or contain non-metallic constituents to improve the bonding qualities of the particles and improve certain properties or characteristics of the final product.

During last ten years powder metallurgy and powder technology have made remarkable progress. The powder processing is now recognised and respected as a competitive technology and an alternative to casting and/or conventional forming [1]. Potential has also given way to prove capability in the production of new and unusual materials, parts, and components solely by powder fabrication. The two distinguishing features, pressing powders to shape and sintering below the melting point, have permitted this production method to supply special metallurgical and mechanical properties unobtainable by any other production process involving one or more of the many techniques of casting, forging, stamping, screw-machine operation or machining of cast or wrought metal.

Powder metallurgy has many technical advantages over the other manufacturing technologies which are well publicised in reference [2]

Powder metallurgy encompasses the production of metals in powder form and the manufacture from such powders of useful objects by the process known as sintering. In many cases individual engineering components are produced directly by the process such as components being referred to indiscriminately as sintered components, sintered parts, or P/M parts. However, wrought products can also be produced from powder and recently a huge number of scientifically exciting developments of great industrial potential have taken place. The principle uses of powder metallurgy structural components are shown in Figure 1.1

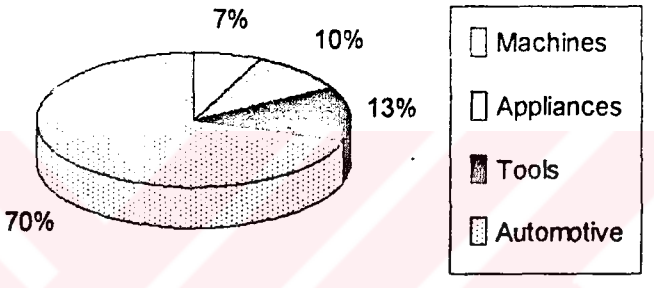


Figure 1.1 Principle Uses of Powder Metallurgy Structural Components [3]

The basic procedure in the manufacture of P/M parts is:

1. Mix the metal powder with a suitable lubricant.

2. Load the mixture into a die or mold and apply pressure. This gives what is called a compactness which requires only to have sufficient cohesion to enable it to be handled safely and transferred to next stage.

3. Heat the compact, usually in a protective atmosphere, at a temperature below the melting point of the main constituent so that the powder particles weld together and confer sufficient strength to the object for the intended use.

The advantage of the powder metallurgy method arises from the diversity of its applications to a number of different products. There are a number of reasons for making engineering components by powder metallurgy and lead to the following groups [3,4,7]

i) Refractory Metals: Certain metals, particularly those with very high melting points, i.e. the refractory metals are very difficult to produce by melting and casting and also are frequently very brittle in the cast state. Tungsten, molybdenum, tantalum and similar metals come into this category.

ii) Composite Materials: These consist of two or more metals. They are insoluble even in the liquid state. They may contain metals with non-metallic substances such as oxides and other refractory materials too. In this class appear:

a) Electrical contact materials such as copper/tungsten, silver/cadmium oxide.

b) Hard metals, i.e. cemented carbides, used for cutting tools, wear resistant parts such as, wire drawing dies, and tools for the hot forging of metals.

c) Friction materials for brake lining and clutch facings in which abrasive and other non metallic materials are embedded in a copper or other metallic matrix.

d) Diamond cutting tools especially grinding wheels in which small diamonds are uniformly dispersed in a metal matrix.

iii) Porous Materials: Most forms of metal are porous to some extents and sintered metals. We are, however, concerned with the production of parts having a significant carefully controlled porosity designed to serve a useful purpose.

iv) Special High-Duty Alloys

An area that is growing very rapidly is the production from powder of high strength materials, high speed steels and so called super alloys based on nickel and to give a product having superior properties to those achieved by casting and forging. The advantage of powder route are higher yield or usable material, and a finer and more uniform micro structure that confers improved mechanical properties, and in the case of cutting tools and wear parts and longer life.

v) Economic Advantages Over Competing Production Methods: Many structures of functional parts are made by powder metallurgy in preference to the machining of cast or wrought metal. The reason for that is mainly economics which may arise from any or all the following considerations [5].

a) Reduction or elimination of secondary operations.
b) The saving of metal, which may run as high as 50 %.
c) A tooling time which is often more favourable.
d) Many design features that can be used are costly to machine by conventional methods.

Tolerances and production rates may be other deciding factors in choosing the powder metallurgy process for making the part under consideration.

Many parts exhibit elements of all three of main advantages described above. The first four are of prime importance in supplying special products, the fifth or economic advantage is the one that must be carefully analysed. Powder metallurgy is chosen as the production method to be used in making a part that might possible be obtained by other means.

Powder metallurgy application is expanding unbelievably (in energy decade). In early days, only sintered products were produced by P/M. In the last ten years, P/M processing techniques have been developed so much that, today, it is possible to produce almost any shape in any density level [6].

Hot forging, cold and isostatic pressing, powder injection molding and spray forming processes in addition to the original compacting and

sintering processes make powder metallurgy a very versatile and competing alternative to cast-wrought processing techniques.

Application of powder metallurgy includes:

1) Cemented Carbides,
2) Self-lubricating Bearings
3) Metallic Filters,
4) Tool Steels,
5) Non-machining Structural Parts,
6) Electrical Contact Materials,
7) Friction Materials,
8) Magnetic Materials, and
9) High-strength Full-density Components.

The demand for metallic powders is continuously increasing. Iron powder has become the single most important powder in the P/M industry. Statistics on iron powder shipment have been used to measure the growth of the P/M industry. Iron powder consumption only in North America in 1986 is 325000 tons which corresponds to 650 billion US dollars market value.

Today in Turkey, there are about ten companies producing powder metallurgy components. These components are generally produced for automotive industry. They are small in size and weak in strength. Full density processing techniques have not been introduced yet. All of these companies are importing the metal powders. We believe that metal powder production technology should be developed in Turkey.

The aim of this study is to produce metal powders by gas atomization using electric arc method. In gas atomization metals are melted in furnace. The principle of this method is different from usual gas atomization technique in respect of melting unit. Instead of using furnace and tundish, two metal wires are melted by means of an electric arc. The molten metal atomized by air jet which is located directly in line with the intersecting wires.

As an experimental set-up an electric arc atomization apparatus constructed by Dogan [7] was modified by controlling the power source

and feed drive mechanism. Characteristics of various metallic powders produced under various atomization conditions have been investigated.

In Chapter 2, the four main categories of production techniques are explained, since the atomization has played an important role in the growth of powder metallurgy, attention is directed to atomization process.

Chapter 3 gives a brief information on the characteristics of metal powders.

Chapter 4 contains the design of experimental set-up and explains the electric arc atomization method. Some properties and general knowledge about power source variables have also been outlined in Chapter 4.

Chapter 5 shows the experimental results and explains the particle size distribution graphically.

Chapter 6 discusses the results obtained from this study and draws conclusions related to the applied atomization technique.

CHAPTER 2

PRODUCTION OF METAL POWDERS

2.1 INTRODUCTION

The required physical and chemical characteristics of the powder may be produced by a variety of methods. These include both mechanical and physico-chemical treatment of either the solid or gaseous metal to convert it in to powder [8].

The method selected for producing a powder depends on specific properties of the material including such physico-chemical characteristic as melting point, reactivity, ductility, or brittleness and reducibility of any oxide content. It is also influenced by economic factors and the relation of the resultant powder characteristics to the desired specification. The degree of control and adaptability of the process and the uniformity and purity of the powder product must also be taken into account, since in certain processes purity to a high degree is essential [9].

The main feature required is the uniformity of powder characteristics.

The four main categories of production techniques are:

- Mechanical
- Chemical
- Electrolytic
- Atomization

In addition to these main approaches, several special techniques are also used, but they will not be discussed here because of their limited use or the narrow class of materials responsive to such approaches.

The four approaches to powder production will be taken up briefly in this chapter. Because atomization has played an important role in the growth of powder metallurgy, considerable attention is directed to atomization processes.

2.2 MECHANICAL METHODS

There are four mechanisms for reducing a material into powder by mechanical comminution; impact, attrition, shear and compression.

Impact involves the rapid, instantaneous delivery of a blow to a material, causing cracks and resulting in size reduction. *Attritioning* applies to the reduction in particle size by rubbing motion. *Shear* is a cleavage type of fracture associated with operations like crushing. Powders formed by shearing are coarse and not often found in powder metallurgy unless the material is extremely hard. Comminution can be by *compressive* forces, if the material is sufficiently brittle it will not deform, but break into a coarse powder.

The formation of metal powders by mechanical techniques generally relies on various combinations of these four basic mechanisms.

2.2.1 Machining

Machining is an easy technique to set up for primary ingot break-up; thus, it is useful scale powder production. A disadvantage is the lack of control in the powder characteristics, including chemical contaminants such as oxidation, oil and other metal scrap. As a basis for consuming scrap from another process, machining is useful. In many instances, the powder is too irregular or coarse for direct use in high performance compacts.

2.2.2 Milling

Milling by mechanical impaction using hard balls is a classic approach for production of powder from brittle materials. A jar mill such as diagrammed in Figure 2.1 uses a ceramic lined cylindrical jar filled with balls and the material to be milled. As the jar rolls on its side, the balls continuously impact on the material, crushing it into powder.

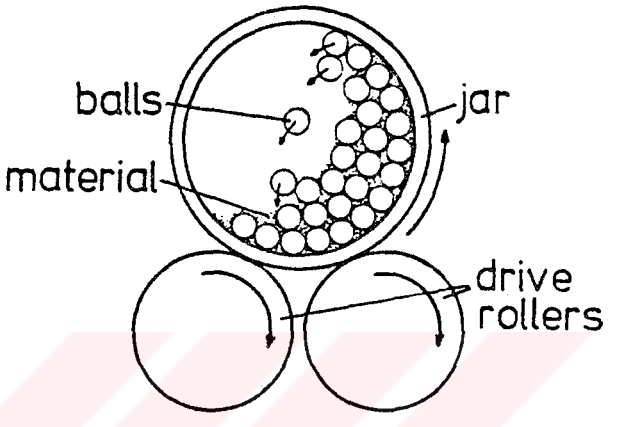


Figure 2.1 A schematic View of Milling

Mechanical comminution is restricted to relatively hard, brittle metals, some reactive metals such as beryllium, metal hydrides and ductile metals used for producing metal flakes. The specific effect that milling has on a powder, depends on the physical and chemical properties of the scrap base metal, the vacuum, gaseous or liquid environment in which the operation is conducted and milling conditions. Selection of the milling process is based on the desired result of the milling operation, the behaviour of the powder under milling conditions, the characteristics of the powder and the physical and mechanical properties of the material.

2.2.3 Other Impacting Techniques

Powder fabrication techniques based on high strain rate impacts are useful for brittle materials. Compressive crushing can be applied to

weak materials to bring the particle size down to 1 mm or so. High velocity impact mills using tungsten carbide blades can further reduce the particle size. The production rate is slow, with the particle size controlled through milling time. Another method, the coldstream technique, uses coarse particles and high velocity gas jets to impact the powder against a stationary target. The input powder is accelerated in the feed gas using pressures of approximately 7 MPa. The coarse powder is shot against a tungsten carbide target at a low temperature. The resulting powder is generally above 10 μm in size with an irregular shape.The low temperature reduces the metal ductility and therby aids impact attritioning. The technique is used in fabricating flame spray powders and stainless steel powders for filters.

2.2.4 Mechanical Alloying

Over the past two decades oxide dispertion strengthened materials have been developed for high temperature creep resistance. Milling techniques have evolved to create a fine dispertion of submicron oxides. The most succesful technique is mechanical alloying. An inherent difficulty in fabricating dispersion strengthened alloy is obtaining a uniform distribution of the dispersoids throughout the material. Mechanical alloying employes the attritioning motion between agitated balls to create microalloyed composite powder. On a microscopic scale the repeated milling, cold welding and fracture of metal powder mixtures with oxide particles produces the desired composite powder. Mechanical alloying uses a stirred mixture of balls and elemental powder to create alloy powder.

2.3 CHEMICAL METHODS

Almost all metals can be changed into powder form by a chemical technique. The particle size and shape can be adjusted over a wide range by control of the reaction variables. The most widely used processes within this category include oxide reduction, precipitation from solution and thermal decomposition [9].

2.3.1 Oxide Reduction

Oxide reduction is achieved by thermochemical reactions involving reducing gases such as carbon monoxide or hydrogen.

The reduction is carried out at a low temperature to ensure minimal sintering of the product (to maintain particle size control). On the one hand, a low temperature is beneficial in producing a fine powder, while on the other a high temperature increases the reduction rate. Consequently, the operating temperature is selected to optimize the reaction kinetics and type of powder formed. Because a large volume change is involved in low temperature oxide reduction, the final product is typically a sponge powder.

Alternatively, high temperature process can result in dense particles with polygonal shapes. The reduced powder is ground to break the inter particle diffusion bands and to ensure the proper particle size. The behaviour during oxide reduction depends on the temperature because of both thermodynamic and kinetic considerations. Thermodynamic concerns arise because of the relative stability of the metal oxide with respect to the reducing gas. The various combination of processing parameters used by powder manufacturers to produce numerous grades of powder are proprietary. The most important process variable is the reduction temperature. Typically, low reduction temperatures result in powder processing fine pores, large specific surface areas, and high green strength. High reduction temperatures produce large inter particle pores and small specific surface area powders that exhibit high compressibility. Extremely low reduction temperatures can readily produce pyrophoric powder.

2.3.2 Precipitation from Solution

It is possible to take up this method into two group;

i) Precipitation from a liquid: A dissolved metal salt such as a nitrate, chloride or sulphate can be treated to produce either a metallic precipitate or a metal containing precipitate. A soluble salt is dissolved in

water and precipitated by a second compound. The resulting precipitate can be reduced if necessary to form a fine metallic powder.

As an alternative, metallic ions can be reacted with hydrogen to form metallic precipitates. Common examples include copper, nickel and cobalt powders. A convenient technique is to go directly into precipitators from ore leaching operations. The mean size can be increased by recycling the powder through the precipitator.

ii) Precipitation from a gas: Gaseous based reactions provide suitable means of producing powders from reactive metals. The powders are formed without melting or contact with a crucible, thereby avoiding a major source if combination. To ensure high final purity, the processing relies on vapour distillation and pre purification of the feed stock material. Composite powders or refractory coatings can be formed by such vapour phase reactions. This is an expensive powder production method. Particle size, purity, shape and agglomeration are all variable with the vapour reaction conditions.

Generally, processing begins with leaching of ores and includes purification and separation stages prior to reduction.

2.3.3 Thermal Deposition

Some powders can be produced by the combination of vapour decomposition and condensation. Both iron and nickel are the most common example of this approach and produced by decomposition of the respective carbonyls. Carbonyls are obtained by passing carbon monoxide over spongy metal at specific temperatures and pressure.

Powder is produced by boiling the carbonyls in heated vessels at atmospheric pressure under conditions that allow the vapours to decompose within the heated space and not on the sides of the container. The powder is collected and sieved and may be milled followed by an anneal in hydrogen. The resulting powders have a small particle size with a purity near 99.5 %.

Like nickel and iron, other metals such as copper, chromium, platinum and cobalt are also processed by carbonyl processing. However, the high energy requirements discourage extensive application to metals beyond nickel and iron.

In this process particle size can be controlled closely. Iron powder is usually spherical in shape and very fine (less than 10 um) while the nickel powder is usually quite irregular in shape, porous and fine.

2.4 ELECTROLYTIC PRODUCTION METHOD

Electrodeposition of metals from aqueous solutions produces a variety of metal powders [10].

A Powder can be precipitated at the cathode of an electrolytic cell under certain operating conditions. Common examples of metals formed into high purity powders by such an approach include titanium, palladium, copper, iron and beryllium. The main attraction of an electrolytic approach is the high product purity. Although electrodeposition produces a high-purity powder with excellent properties for conventional powder metallurgy processing, current usage of electrolytically produced powder is limited because the production involves the control and manipulation of many variables and sometimes is significantly more expensive than other methods.

Although electrolytic methods have been well known as an approach to producing pure powders, there are difficulties with the technique. First, the bath chemistry is very sensitive. Contaminants can hinder the formation and deposition of powders at the cathode. Additionally, only elemental powders are practical by such an approach.

Finally, the product must be handled and cleaned after production, which can be a significant addition to the cost.

2.5 ATOMIZATION

In this process molten metal is broken up into small droplets and rapidly frozen before the drops come into contact with each other or with a solid surface. The principle method is to disintegrate a thin stream of molten metal by subjecting it to the impact of high energy jets of gas or liquid. Air, nitrogen and argon are commonly used gases, and water is the liquid most widely used. A commercial scale plant was set up in Japan to produce iron powder using paraffin as the atomizing liquid the object being to keep the surface oxygen content as low as possible. The process was technically successful, but the advantages did not justify, in commercial terms, the extra cost involved. However, interest has not entirely finished.

By varying the several parameters; design and configuration of the jets, pressure and volume of the atomizing fluid, thickness of the stream of metal etc. it is possible to control the particle size distribution over a wide range. The particle shape is determined largely by the rate of solidification and varies from spherical, if a low heat capacity gas is employed, to highly irregular if water is used. In principle the technique is applicable to all metals that can be melted, and is commercially used for the production of iron, copper, including tool steels, alloy steels, brass, bronze and the low melting point metals, such as aluminium, tin, lead, zinc and cadmium. The readily oxidisable metals, for example chromium-bearing alloys are being atomized on an increasing scale by means of inert gas, specially argon [3].

In this section, since the subject is based on electric arc atomization, besides of other powder production techniques, atomization methods will be put into perspective.

2.5.1 Two-Fluid Atomization

Atomization provides the majority of all powders. Atomization involves the formation of powder from molten metal using a spray of droplets. Both elemental and pre alloyed powders can be formed by such processes. The flexibility of the approach, coupled to its applicability to

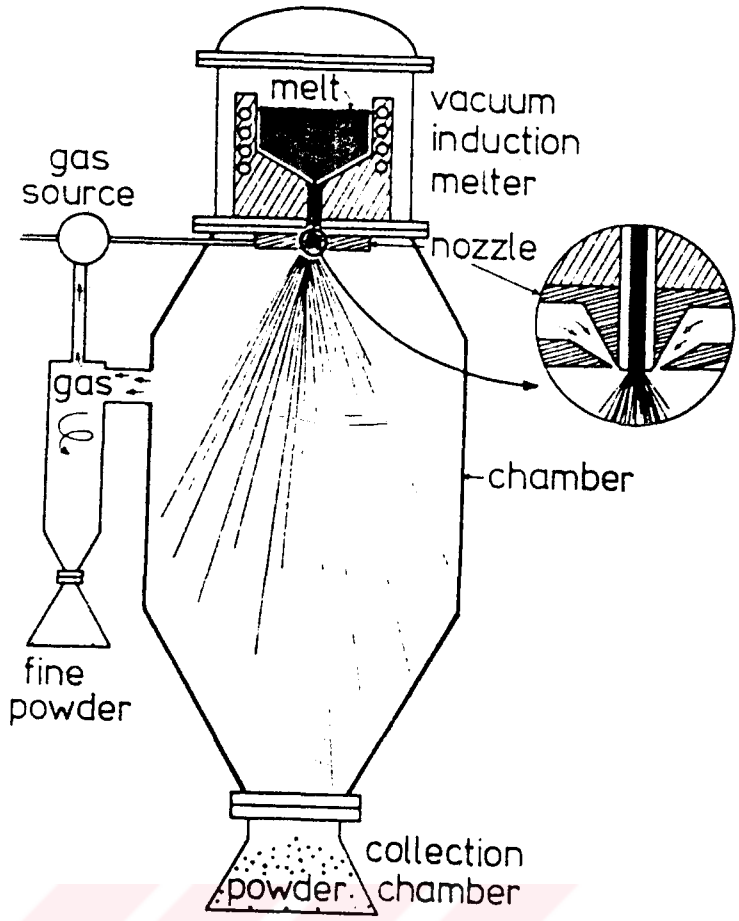
several alloys and easy process control, make it an attractive alternative. A main future of atomization is the general reliance on fusion based technology.

In general, water atomized powders are quite irregular in shape and have relatively high surface oxygen contents. Gas atomized powders are more spherical and rounded in shape and if atomized by an inert gas generally have lower oxygen content [9].

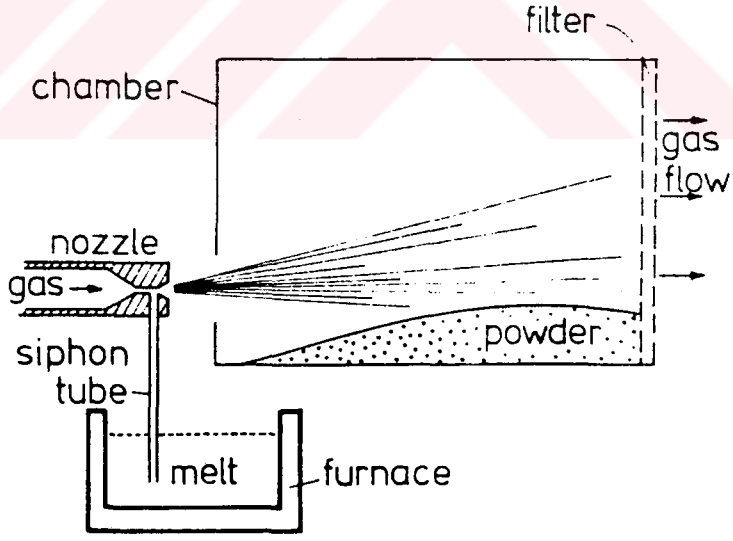
2.5.1.1 Gas Atomization

Figure 2.2.a shows detailed schematics of modified gas atomization process. Melting of metals follows standard procedures. Air inert gas and vacuum induction melting, arc melting and fuel heating are suitable procedures. Tallmadge [11] provides a review of some of the options available using gas atomization. The designs may vary with respect to the metal feed mechanism and the sophistication of the melting and collection chambers. The main idea is to deliver energy to the molten metal stream to form droplets.

Low temperature atomizers are based on a horizontal design of the type sketched in Figure 2.2.b. The high velocity gas emerging from the nozzle creates a siphon, pulling molten metal into the gas expansion zone. a high gas velocity aids break-up of the metal, giving a fine spray of molten droplets. During flight through the collection chamber, the droplets lose heat and solidify. For high temperature metals, a closed, inert gas filled chamber is used to prevent oxidation. The chamber size must be sufficiently large to allow the particles to solidify before striking the walls.



(a)



(b)

Figure 2.2 Types of Gas Atomization Process
a) Vertical Gas Atomizer b)Horizontal Gas Atomization

In the vertical gas atomizer, the molten metal is poured, either directly or by means of a runner, into a tundish, which is essentially a reservoir that supplies a uniform and controlled flow of molten metal to the tundish nozzle. The nozzle, which is located at the base of the tundish, controls the shape and size of the metal stream and directs it through an atomizing nozzle system in which the metal stream is disintegrated into fine droplets by the high velocity atomizing medium.

Liquid metal droplets cool and solidify as they settle to the bottom of the atomizing tank. This tank may be purged with an inert gas to minimize or prevent oxidation of the powder. In gas atomization, the powder may be collected as dry particles or cooled with water at the bottom of the tank. In so called dry collection, the atomizing tank is tall, usually more than 6m. height, to ensure solidification of the powder particles before they reach the bottom of the collection chamber. Horizontal gas atomization using long horizontal tank is also used for the same purpose.

To atomize large amount of powder or for continuous operation, external cooling of the bottom of the atomizing tank may be supplemented by fluidized bed cooling of the powder to prevent sticking and caking of the powder particles. In some gas atomization processes, especially in the production of low melting point metals such as aluminium and tin, molten metal may flow through a horizontal nozzle, or may be aspirated up into a vertical nozzle.

There is obvious interest in linking the mean particle size to the atomization conditions. Droplet formation during atomization is enhanced by a large difference between the gas and melt velocities. This occurs with high gas pressures and high gas flow rates, giving an empirical form as follows [2]:

$$D = \frac{C}{V}\left[\frac{\gamma}{\rho_M}\right]^{0.22}\left[\frac{U_M}{\rho_M}\right]^{0.57}$$

Where:

C : Nozzle geometry constant

U_M : Melt viscosity

ρ_M : Melt density

γ : Surface energy

2.5.1.2 Water Atomization

Water atomization is the most common technique for producing elemental and alloy powders from metals which melt below approximately 1600°C. Water atomization is probably the cheapest method of producing free flowing irregular shaped powders in most materials, and is widely used in the production of iron, stainless steel, and other powders [12,13].

The water can be directed by a single jet, multiple jets or an annular ring. The process is similar to gas atomization, except for the rapid quenching and differing fluid properties. A major disadvantage of water is its readiness to dissociate at high temperatures in the presence of a reducing agent, and therefore water atomized powders tend to have higher levels of surface oxides.

The water atomization process consists of five steps;

a) Melting
b) Atomizing
c) Drying
d) Screening
e) Annealing

Each step has an important bearing on the final product [13].

In Figure 2.3, an example of a water atomizer geometry is shown. High velocity water jets are directed against the melt stream, forcing disintegration and rapid solidification. Consequently, the powder shape is more irregular than with gas as the fluid. Also the powder surface texture is rough, with some oxidation. Because of the rapid heat extraction, shape control requires superheats for above the liquids. The types of

atomizing jets, the angle of jet streams and the velocity of water are three of several factors which control the size and shape of the particles [14].

The pressure is also the main process control variable in water atomization. Higher water pressures result in higher water velocities and finer particle sizes [8].

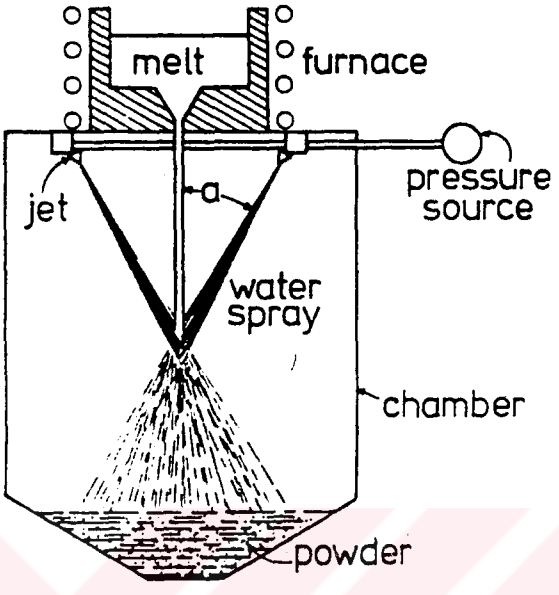


Figure 2.3 The Water Atomization Process

Particle size distribution for water atomization of 4620 steel is given by the following equation [1].

$$d_m = \frac{8700}{P^{0.62}} \quad \text{or} \quad d_m = \frac{5500}{V_w}$$

Where;

d_m : Mean particle diameter, (μm)

P : Water pressure, (MPa)

V_w : Water jet velocity, (m/s)

Table 2.1 shows a contrast between water and gas atomization. The two outstanding differences are the powder shape and the surface contamination.

Table 2.1 Comparison of Water and Gas Atomization

Feature	Water	Gas
Particle size, μm	150	100
Particle shape	irregular	spherical
Agglomeration	little	some
Apparent density, %	35	55
Cooling rate, K/s	10^5	10^4
Segregation	negligible	slight
Oxidation, ppm	3000	120
Fluid pressure, Mpa	14	3
Fluid velocity, m/s	100	100
Efficiency	moderate	low

2.6 CENTRIFUGAL ATOMIZATION

Centrifugal atomization involves molten metal that comes in contact with a rotating disk wheel or cup. The molten metal is mechanically atomized and thrown off the edges of the rotating substrate into a cooling gas and then solidified. The process is divided into two branches;

a) Rotating disc process
b) Rotating electrode process.

2.6.1 Rotating Disk Atomization

In this process, which is shown in Figure 2.4, the liquid metal is directed onto a rotating disk. The liquid metal is mechanically atomized and thrown off the edges of the spinning disk. Solidification occurs in flight and can be enhanced by blasting the emerging particles with a stream of helium [15].

Powders produced by rotating disk atomization tend to have narrow particle size distributions [8]. Particles are generally spherical, with the average particle size decreasing with increasing disc speed.

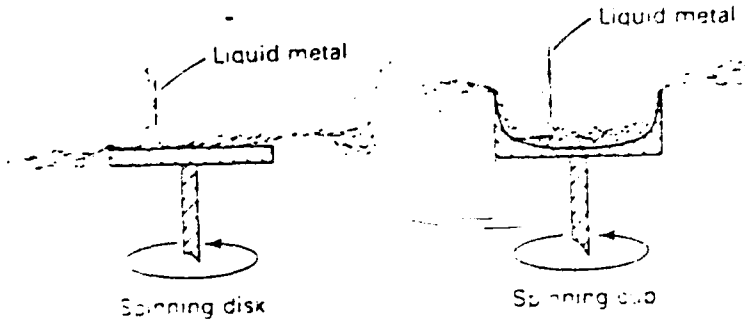


Figure 2.4 Examples of Centrifugal Atomizers

The maximum centrifugal energy is imported to the liquid metal when the liquid acquires the disc peripheral speed prior to discharge. The degree of centrifugal atomization depends upon peripheral speeds, feed rate, liquid properties and atomizer design [13]. The advantage of the disc atomizers is that their output is greater than that from atomizers using other methods of atomization but the droplets are not directed and this can be a distinct drawback in some applications [16].

2.6.2 Rotating Electrode Process (REP)

In this process, the end of metal bar is melted while it is rotated about its longitudinal axis [17]. The centrifugal force throws off the molten metal as a fine spray which solidifies into a powder. Especially, this process is suitable for a variety of high alloy or reactive metals like zirconium, titanium and superalloy metals [18]. Schematic figure of centrifugal atomization is shown in Figure 2.5

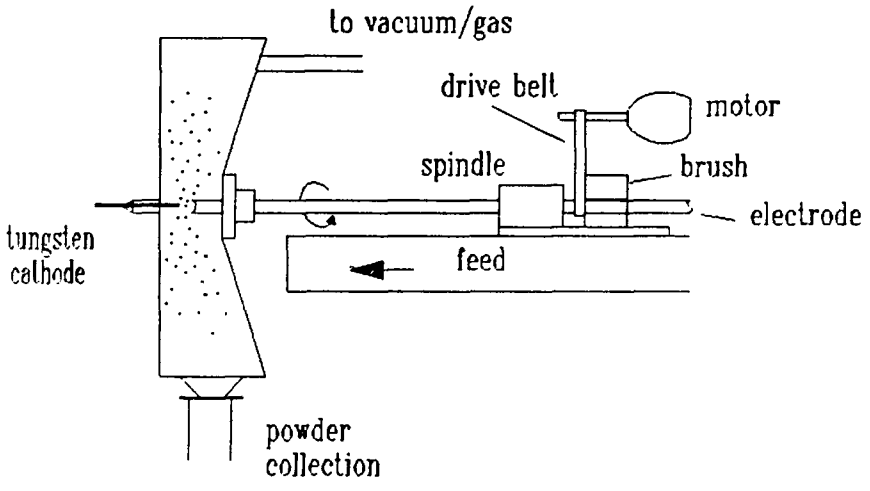


Figure 2.5 Rotating Electrode Process

The apparatus consists of a consumable electrode made from the desired material. The electrode is melted at its end by either a plasma arc or stationary tungsten electrode. The consumable electrode is the anode and rotates at velocities up to 50.000 rpm. The electrode rotation is driven by an external motor. As melting occurs, the electrode is fed into the chamber via an external mechanism. Electrical contact with the electrode is made outside the chamber using a contact brush.

2.7 VACUUM ATOMIZATION

In addition to the major atomization approaches described above, energy can be delivered to a melt by several other mechanisms. One of example for such a process is vacuum atomization. In this method, which shown in figure 2.6, uses a hydrogen saturated liquid metal and rapid desaturation in a vacuum to form a fine powder spray.

The melt is pressurized with 1 to 3 MPa of hydrogen. A siphon tube then exhausts the saturated melt into a large vacuum chamber. Both the high velocity and hydrogen desaturation cause the melt to explode into the vacuum chamber. This method is used for producing powders based on nickel, copper, cobalt, iron and aluminium. Powders are spherical, clean and of a high purity compared to powders produced by other powder-processing methods [19].

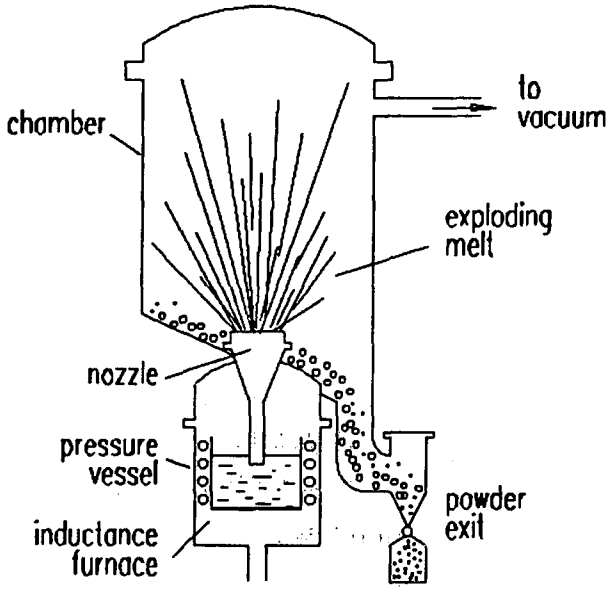


Figure 2.6 Schematic View of Vacuum Atomization

One difficulty with the vacuum atomization approach is the slow cooling rate of the powder because of the low residual pressure in the vacuum chamber. Cooling is predominantly radiant rather than convective. The convective processes, such as experienced in gas atomization, are more effective in extracting heat [8].

2.8. ULTRASONIC ATOMIZATION

Ultrasonic atomization shown in Figure 2.7 is an interesting powder production process because the system operates in essentially a stationary mode, without any high speed motion. This form of atomization has been known to be an effective method in atomizers for water in humidifying system. The application of ultrasonic waves to the production of metallic powder which high velocity gas, up to Mach number 2 at a characteristic frequency of around 100.000 Hz. impinges on the liquid metal stream and disintegrates it into fine particles.

The ultrasonic power required in this method is high, however because there is no contact between the ultrasonic die and the liquid metal of gas shock wave [20].

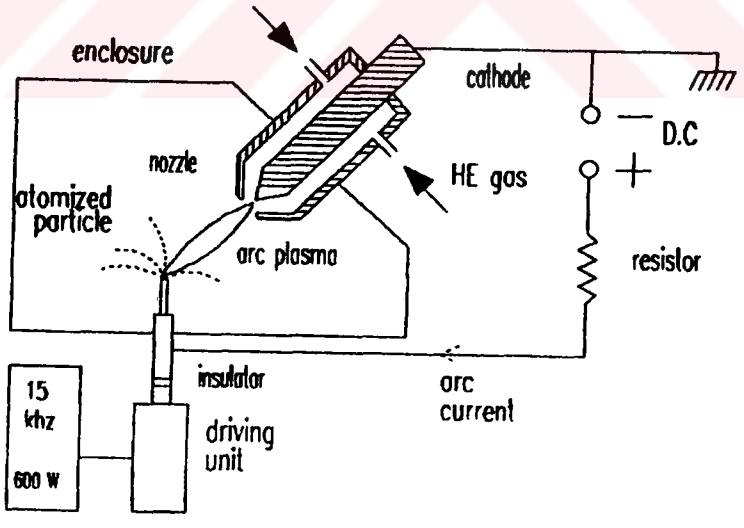


Figure 2.7 Ultrasonic Atomization

Cylindrical metallic bar is attached mechanically to the vibration horn and functions as an arc electrode. The arc plasma is established between the metal bar and internal electrode of the plasma torch through the exit nozzle. A part of the top area of the bar serves as the anode and is melted by the high temperature at the arc root. The anode bar is vibrated through the horn which is connected to the driving unit, energized by the ultrasonic power oscillator. The arc current is supplied from a 1000 Volt D.C. power supply through a stabilising resistor. The magnitude of the current can be varied over the range from 10 to 40 Amperes.

The frequency and the power of the oscillator are 15 kHz. and 600 W, respectively. The amplitude of the oscillation is rated as 20 μm in the direction of the axis of the anode bar. The vibration unit and the horn are electrically isolated with an insulator, so that the arc current does not flow into the vibration unit.

Helium gas is supplied from the plasma torch through the exit nozzle at a flow rate of 100 liter/min., for cooling and solidifying the atomized metal droplets without oxidation.

Main advantages of this process are [13] :

- High relative velocities between gas and metal droplets
- Small powder size
- The device works without any moving components.

2.9. COMPARISON of ATOMIZATION TECHNIQUES

Table 2.2 provides a comparison of several of the atomization techniques available. The techniques are compared with respect to size distributions, typical mean size, particle shape and relative powder production cost. Realistically, this table gives broad knowledge. Because, all of the fabrication approaches have sufficient parameter control to vary size and shape over a moderate range.

Table 2.2 Comparison of Atomization Techniques

Technique	App.mean particle size, μm	Particle shape	Size Distribution	Relative Cost
Gas atomization	100-300	rounded	moderate	moderate
Water atomization	200-800	irregular	wide	low
Rotating disc atomization	100-300	spherical	narrow	moderate
Rotating electrode atomization	200-600	spherical	moderate	high
Ultrasonic atomization	70-200	rounded	moderate	moderate
Vacuum atomization	200-500	spherical	moderate	moderate

2.10 APPROACHES to FORMING SOME METAL POWDERS

Almost all materials found in engineering can be processed into particulate forms. Some materials are listed in table 2.3 along with the types production approaches [21]. These approaches represent the general powder production concepts.

Table 2.3 Typical Approaches to Some Metal Powders

Metal	Common Approaches
Aluminium	Gas atomization, air atomization, milling
Copper	Electrolytic, water atomization, oxide reduction
Iron	Water , gas and centrifugal atomization
Steel	Water atomization, gas atomization
Brass	Water atomization, air atomization
Nickel	electrolytic,oxide reduction,water and atomization, gas

CHAPTER 3

CHARACTERISATION AND TESTING OF POWDERS

3.1 INTRODUCTION

The processing characteristics of a powder such as its behaviour in mixing, filling the die, compaction and sintering, all of which influence the resultant properties of the material are to a great degree influenced by the characteristics of the powder particles making up the mix. Particle size testing is carried out to evaluate the size, distribution, shape and specific surface of the individual particles.

If a powder is examined under the microscope it will be seen to consist of particles of regular or irregular shapes of varying sizes. In order to asses the frequency, by percentage weight or number of the particles of varying sizes, particle size testing is carried out. In some cases the determination of the mean or average size of the particles is required and this often obtained by measuring the surface area of a standard weight of the powder and converting the value to the mean diameter

Three factors have been found to be of value for control purposes namely, size frequency, specific surface and particle shape [9].

Size frequency refers to the frequency of occurrence of particles of every size in a powder. This frequency may be represented in terms of percentage weight or number or by mathematical calculation frequency by weight may be converted to frequency by number and vice versa.

Specific surface refers to the surface area per unit weight of powder measured in cm^2 or m^2 per gr. It is important to distinguish whether a particular method measures the total surface area.

Particle shape cannot be expressed in strict mathematical terms except in the case of perfectly spherical or crystalline particles.

3.2 SAMPLING

When a sampling powders in bulk at any level care is required if a representative sample is to be obtained. The sample thief, the vacuum probe and even the humble scoop need careful use. One approach is to obtain total sampling by applying the cone and quarter technique. The material is poured with great care to produce a symmetrical cone. A thin sheet of metal is used to quarter the heap. One quarter can be used to repeat the process to a smaller sample.

Another total sampling technique, applicable when the quantity of powder concerned has been reduced to laboratory level, is the use of a chute riffler. In this riffler there is an equal change of a particle going into either of two adjacent chutes. The more chutes there are in the riffler the better becomes the randomising mechanism.

3.3 PARTICLE SIZE MEASUREMENT

In the P/M industry, the traditional and most widely used method of particle size measurement is by sieving. Sieves or screen are used not only for particle measurement, but also for separation of powders into different sieve fractions. This twofold use of sieves, in addition to the fact that most P/M powders are -80 mesh (smaller than about 177 μm in diameter, with only minor amounts smaller than 10 μm) has been well suited to industrial application. For powders with larger percentages of 400 mesh (37 μm) particles, sieve distribution data are often complemented with fisher sub-sieve size analysis, microsieve data, or specific surface area data.

Several electronic methods of particle size analysis have been developed during the past two decades. These generally provide higher measurement speed, resolution, and small-size sensitivity than sieves, saving time and labour while yielding more precise data. Sieve Analysis is the most widely used method of determining particle size distribution of powders.

Particle size distribution is controlled and certified by the powder producer and is frequently checked by the end user. Typically, a series of sieves is selected that spans the full range of particle sizes present in a powder. Sieves are stacked in order, with the largest mesh size at the top and a pan at the bottom. An appropriate sample weight of metal powder is spread on the top sieve and covered.

The stack of sieves is agitated in a prescribed manner (shaking, rotating, or tapping) for a specified period of time. The powder fractions remaining on each sieve and contained in the bottom pan are weighed separated and reported as percentages retained or passed by each sieve. The details are given in MPIF specification 5-62.

Table 3.1 Information on Sieves of Use in Powder Metallurgy.

Sieve Designation		US standard sieve opening		Tylor standard
µm	Mesh No	Inches	mm	Mesh No
177	80	0.0070	0.177	80
149	100	0.0059	0.149	100
124	120	0.0049	0.125	115
105	140	0.0041	0.105	150
88	170	0.0035	0.088	170
74	200	0.0029	0.074	200
63	230	0.0024	0.063	250

3.4 PARTICLE SHAPE OF METAL POWDER

Shape and size are probably the two most fundamental characteristics of a particle. Both are interrelated without knowing the shape of a particle it makes little sense to speak of particle size. Schematic diagrams of typical powder particle shapes are given in Figure 3.1

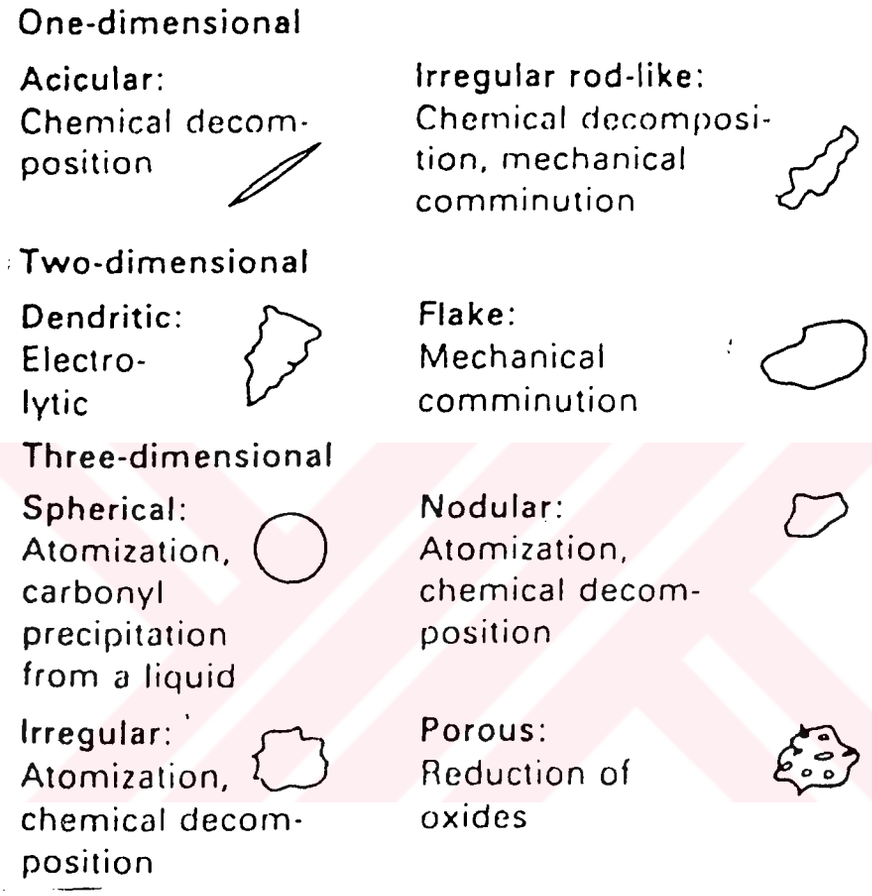


Figure 3.1 Typical Powder Particle Shape and Methods of Manufacture

The shape of particles affects several properties of a powder [2].

Flow: Spherical powders have good flow, flake powders have poor flow and some types of irregularly shaped powders have essentially no flow.

Apparent density: Spherical powders have the highest apparent density. Angular powders have high apparent density while some sponge powders have low apparent density due to internal porosity.

Surface oxidation: The more irregular the particle the higher will be the proportion of surface oxidation.

Compressibility: Some irregular shapes also tend to absorb the powder lubricant, thereby reducing its effectiveness.

Sinterability: As the irregularity of a particle increases, there are more points if contact after pressing, thereby, giving more areas for bonding. An irregular particle has more surface energy which promotes sintering by surface diffusion. Alloy additions are better dispersed if the base powder particles are irregular and total diffusion of the additions is increased.

Despite the basic significance of particle shape on powder properties, there is yet no tests other than the use of fairly simple and qualitative comparisons. However, this problem is currently receiving some attention.

3.5 FLOW RATE OF METAL POWDER

Flow rate is the time required for a powder sample of a standard weight (50 gr.) to flow under atmospheric conditions through a funnel into the cavity of a container or mould. A determination of the flow rate of a powder is important in high-volume manufacturing, which depends on rapid, uniform, consistent filling of the die cavity. Poor flow characteristic cause slow and nonuniform press feeding and difficulty in ensuring even fills of the die cavity.

Before a powder is used in production, its flow characteristics must be known, because some compacting tools require a free-flowing powder, while others can be used relatively poor-flowing powder. Flow of powders is determined by standard methods developed by the American Society

for Testing and Materials (ASTM) and the Material Powder Industries Federation (MPIF).

The device must commonly used for measuring flow rate is the hall flow meter which is shown in Figure 3.2, taken from ASTM b 213 and MPIF 3. The test equipment consists of a funnel with a calibrated hole 2.5 mm in diameter. The funnel, which is made of aluminium alloy 6061-T6, is supplied with a smooth finish to minimise wall friction.

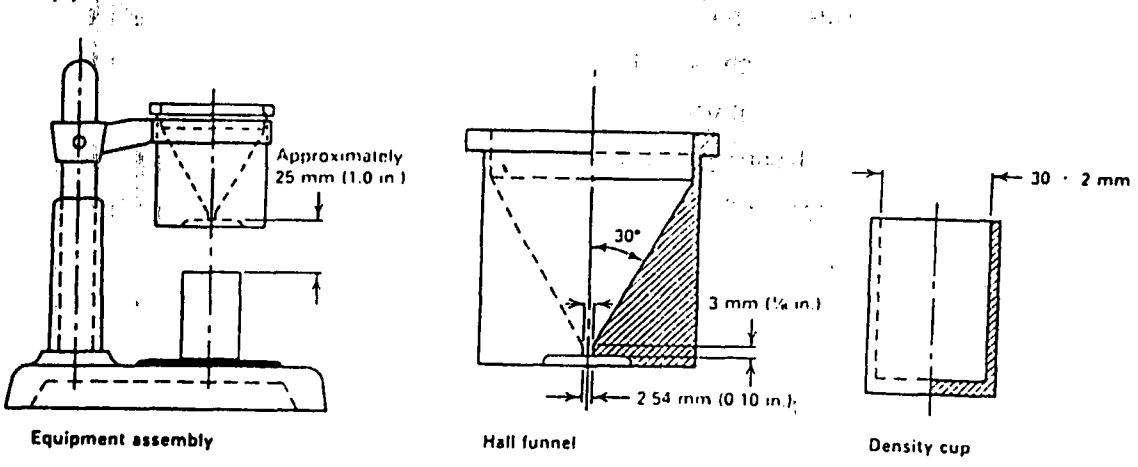


Figure 3.2 Cross-sectional View of Hall Flow meter

3.6 COMPRESSIBILITY OF METAL POWDERS

Compressibility and compactibility are terms used to describe the extend to which a mass of powder can be densified by the application of pressure. Compressibility of a powder is a major attainable, and the size of press needed to press to that density. A related term, compression ratio, is the ratio of the final pressed density of the powder. This ratio determines how deep the part die must be in order to hold all the powder needed to meet the specified part density. Powders of high apparent density are preferred, because tooling can be made shorter and this stronger.

The pressure required to achieve a specified density is a measure of compressibility. Compressibility can also be specified as the density achievable at a given pressure.

CHAPTER 4

GAS ATOMIZATION USING ELECTRIC ARC

4.1 INTRODUCTION

Generally in gas atomization processes, melting of metals follows four standard procedures, namely; air inert gas and vacuum induction melting, arc melting and fuel heating. In the process, molten metal emerges from a nozzle of a tundish and is impinged by high pressure air jet. The molten metal is disintegrated into fine droplets which solidify before making contact with the walls of the atomizer. The droplets contract, under the influence of surface tension and form a spherical powder which is collected and cooled down to room temperature under a protective nitrogen atmosphere which avoids due to oxidation.

The micro structural evolution is influenced by the thermal state of the droplets and their velocities during impingement on the deposition surface. They are controlled by the process variables, to promote efficient atomization [22].

In this study, two wires of either similar or dissimilar materials are melted by means of an electric arc developed between two wires and atomized by compressed air. The atomized powders were solidified in water tank to obtain complex powder shape.

4.2 THE BASIC PRINCIPLES OF ELECTRIC ARC ATOMIZATION

A schematic view of electric arc atomization apparatus is shown in Figure 4.1. Functionally, two consumable wire electrodes, which are

driven individually are fed through the rollers and copper brushes then to the arc zone. The initiated arc between the wire electrodes melts the wire tips.

The electric arc atomization unit consists of three major components. These are:

a) A direct current power source to maintain stable arc condition.
b) A wire feeding and control mechanism.
c) High pressure air compressor and nozzle unit.

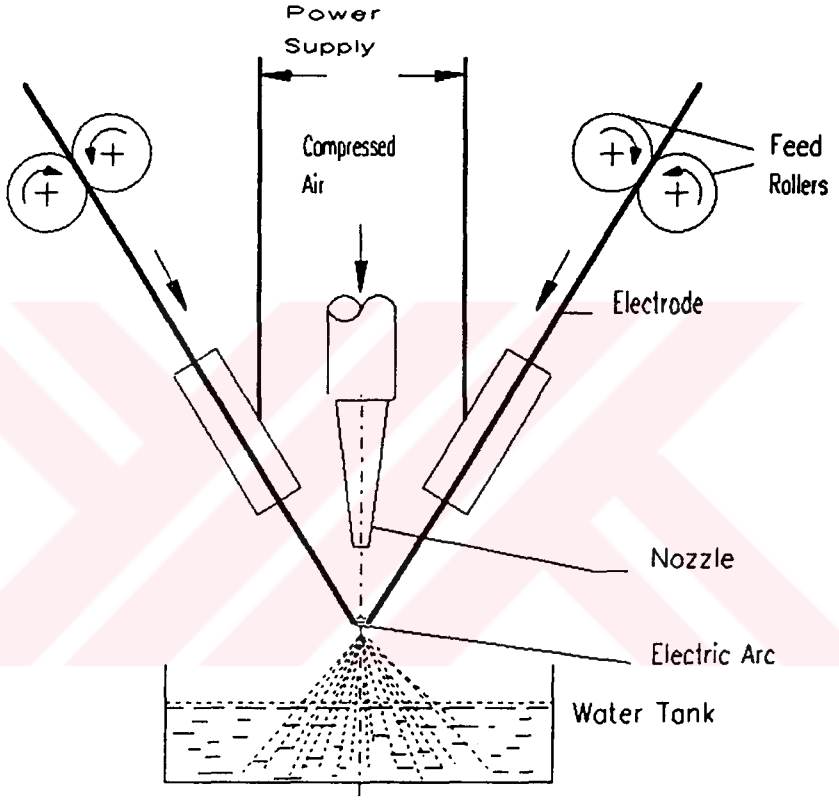


Figure 4.1 A Schematic View of Atomization Apparatus

The main parts of the mechanism are explained briefly as follows.

4.2.1 Power Source Variables

There are several power source adjustments necessary for the production of the best possible welding conditions for a particular application. The continuous control of the arc voltage is critically

important. Some control of the volt - ampere slope characteristic and the inductance is also beneficial.

a) Voltage: Arc voltage is the electrical potential between the electrode and the work piece. The voltage indicated by the power source meter is commonly referred to as the arc voltage and consequently, a direct measure of the arc length. There are many locations in the welding circuit where a drop in voltage occurs other than across the arc. These voltage drops are a function of cable size and length, conduction efficiency of power carrying connections, condition of the current contact tube in the gun, and electrode extension. If they are kept to a minimum, the voltage reading on the power supply can approach closely the true arc voltage [23,24]. It is generally impractical in production work to measure true arc voltage, which has to be measured between the electrode tip and the work.

b) Current: The value of welding current required is set by the single dial or knob current control on the front panel of the used MIG power source used in this experiment. The current is determined by the wire feed speed. The current will increase with increased wire speed and electrode diameter. Less wire speed and smaller electrode diameter will reduce the current.

c) Arc Length: is the distance between the tips of the wires one being the anode and other cathode. Long arc decreases the penetration, gives broader particle and also causes more spatter. The material transition from the wire to the molten pool is caused by larger drops than with a short arc. Long arc welding is characterized by:

a) Constantly burning arc
b) High current and voltage
c) Big molten pool
d) High rating of metal deposited per unit of current and time

In the electric arc if the arc is long, the voltages goes to approximately 35 Volts. Wire diameters of 1.2 mm to 3 mm may be used [29]. Because of the high rating of metal deposited, low spatter losses and due to the big molten pool thinner wires do not give good results.

Short arc between the electrodes transfers the electrode to the molten pool by short-circuiting of the arc. In practise this is done as follows: the moment the wire touches the molten pool, it is loaded with a very high current, because of the resistance grooving too low. The current burns over the wire, and a drop of the wire is slung down into the molten pool. The arc strikes and burns until the wire has reached the molten pool again. correctly adjusted values of wire speed and voltage will give 50 to 200 short-circuits/sec. Figure 4.2 shows schematically the long arc and short arc.

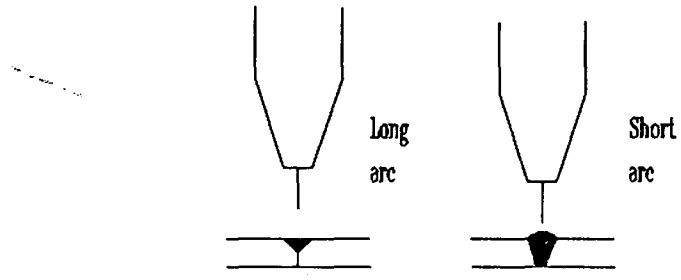


Figure 4.2 Schematic View of Long and Short Arc

Short arc welding is characterized by :

a) Periodic short-circuited arc
b) Low current and voltage
c) Small molten pool
d) Relatively low rating of metal deposited per unit of current and time.

4.2.2 Power Sources

An arc welding power source may deliver:

a) Alternating current (AC)
b) Direct current (DC)
c) Or both

It may also have the characteristic of providing either *constant current* or *constant voltage*.

A constant-current arc welding machine is one which has means for adjusting the arc current and produces a relatively constant output current. The arc voltage, at a given welding current, is responsive to the rate at which a consumable electrode is fed into the arc.

The characteristic of this type of supply are such that if the arc length varies because of the external influences and slight changes in arc voltage result, the welding current remains substantially constant.

A constant voltage arc welding machine is one which has means for adjusting the arc voltage and produces a relatively constant output voltage. The arc current, at a given welding voltage, is responsive to the rate at which a consumable electrode is fed into arc [28].

The arc length and welding current are interrelated to correct for rapid changes in length. For example, arc length variation is fundamentally determined by the differences between melting rate and feed rate, and arc voltage is directly related to arc length. If the arc length (voltage) varies for any reason the current will change quickly to a higher or lower value. The current change will alter the melting rate, thereby returning the arc length to its initial value. Thus a good constant voltage source is capable of providing large current variations while still maintaining nearly constant arc voltage, and a constant speed system for wire feed can be used to good advantage. *The arc current will be approximately proportional to wire feed rate for all wire sizes.*

4.2.3 Static Characteristics of Power Source

All welding power sources have two kinds of operating characteristics, each one effects their performance in different ways. These are; dynamic characteristic and static characteristic.

The effect of the dynamic and static characteristics are detailed in Appendix A.

4.2.4 Wire Feed and Control

The dual wire drive and control assembly provides uniform reliable control of the feeding of the two wire electrodes. In the conventional arc-spraying technique, both wires have the same feed speed, but melting conditions of negative and positive electrodes are quite different [26]. That is why the arc burning point moves out of the centre of the air gun axis, leading to unfavourable atomizing conditions. The burning place of the arc can be influenced by control of the wire feed speed relation between the anode and cathode. One of the important parameter is to stabilize the arc in a fixed position in order to obtain a smaller particle size distribution and a controlled melting of the wires. Therefore the position of the arc must be adjusted by the wire feed speed so that the arc burns exactly in the centre of the spray jet. The driving of the wires is accomplished by two separate drive roll and pressure roll sub-assemblies, both of which are completely insulated from each other. A V-groove type of drive roll is used to avoid disruption of the smooth wire surface. Burred wire surfaces can cause erratic electrical contacting of the wire and also possibly cause wire feeding problems.

4.3 CONDITIONS IN THE ARC

An electric arc is produced by the passage of an electric current through an ionized gas. Initially, in the electric arc metallizing process, the ionized gas is created as the two wires, which are electrically energized, advance to an intersecting point and touch at a low contact pressure and a small point like contact surface. Due to the high density of the electric current, extreme heat is generated at the contact surface, fusing those portions of the metal wires and ionizing the surrounding gas, thereby creating a localised plasma. The plasma now established between the two wires provides a reasonably low resistance path for the flow of an electric current. The high current density flowing path for the flow of an electric current. The high current density flowing through the plasma provides the necessary sustaining power to maintain the ionized state. Within the arc, ionized atoms, which have lost electrons, are left with a positive charge. These positive gas ions flow from the anode to cathode. At the same time, there is an electron flow (100-200 m/s) from

the cathode to the anode and generally contraction occurs at the cathode (Figure 4.3.a). It is evident that arc condition is maintained relatively stable contraction does not occur if high velocity of air is sprayed from one side of the electrodes (Figure 4.3.b) [27]. The power spent in the arc, expressed in electrical units, is the product of the current passing through the arc plasma and the voltage drop across it.

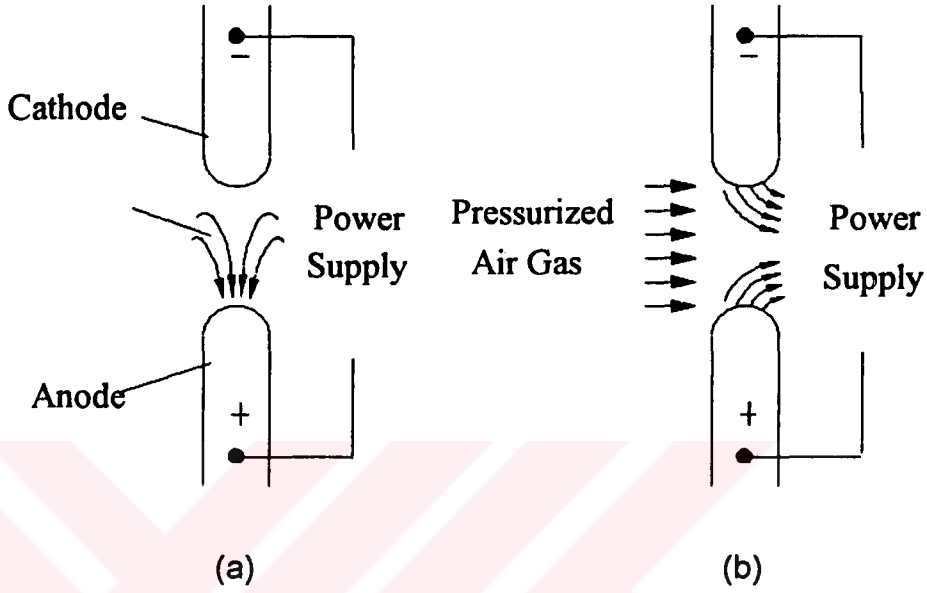


Figure 4.3 Arc Conditions

The cathode is intensely heated by the impacting of the positive gas ions. This intense heating of the cathode causes the releasing of electrically charged particles, i.e. electrons, from its heated surface by thermionic emission. As the electron flow from the cathode surface through the plasma, a considerable part of their energy is given away to the plasma, thereby causing the anode to be cooler than the cathode. In addition, since there is a high velocity flow of atomizing gas blasting on the two electrodes and arc from only one side, as shown in Figure 4.4, a large heat gradient is established such that the electrodes, in the region closest to the flow of atomizing gas are cooler than the regions furthest away. Due to these heat gradients, the melting of the electrodes occurs in a manner shown in Figure 4.4.

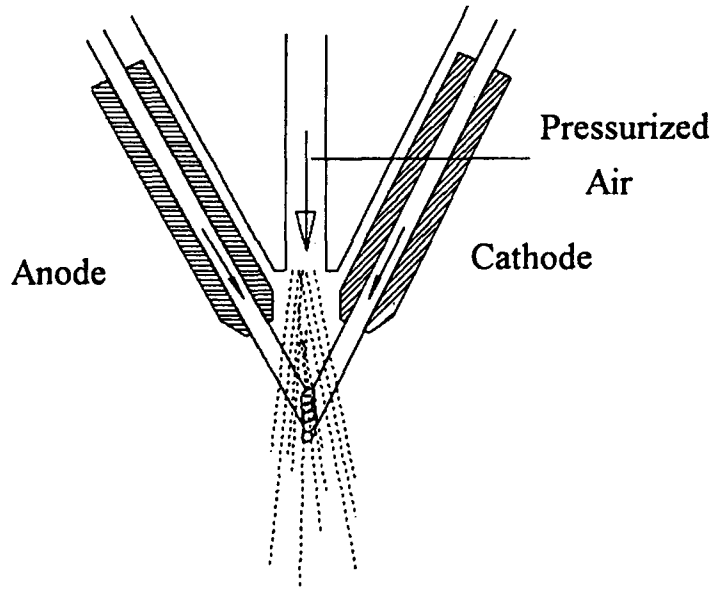


Figure 4.4 Schematic View of Melting Electrodes

Because of the ion flow, anode is cooler than the cathode and thereby it melts at a slower rate. Due to the cooler nature of the anode, the particles formed from the anode are larger than those formed by the cathode. Anode particles are in the form of droplets, while at the cathode there is a finer spray type droplet formation.

It should be noted that the included angle between the two electrodes in the arc zone vastly affects the nature of the fusing of he electrodes. At small angles between electrodes, i.e. less than 35^0, and, at electrode angles between electrodes exceeding 60^0, erratic arc behaviour occurs, due to an increased sensivity to adjustments of relative electrode positions and their relative position to the atomizing gas flow.

Arc stability is dependent upon: wire feed rate, atomizing air pressure, arc voltage, electrode size and material. Therefore, those parameters should be controlled during the experiments.

4.4 EXPERIMENTAL SET-UP

To investigate the effecting factors of powder characteristic, following parameters should be controlled in the experimental set-up. These are:

a) Feed rate of electrodes
b) Wire Diameter
c) The amount of voltage of the power source
d) Electrode angle
e) Air pressure
f) Type of material (wire)

The experimental set-up consists of atomization unit, power source, high pressure air source and nozzle.

4.4.1 The Atomization Unit

In the atomization unit there is a wire feed drive with control mechanism and electrode contact part for each electrode.

In the set-up roller type wire feeding mechanism was used as shown in Figure 4.5 . There is a V-groove on each roller to feed the wire. Both of the rollers were driven by the electric motor of a hand drill by means of pulley, belt and worm gear arrangement.

Two copper brushes were used as the electrical contact part. Electrodes are energized by the direct current power source through the copper brushes by attached cables. At each brush there are two V-grooves to run the different wire diameters and to avoid disruption of the smooth wire surface. Electrodes, placed between the copper brushes, are squeezed by compression springs. Bottom jaw is stationary but, upper jaw is movable and controlled by springs. Wire electrodes coming out of copper brushes contact each other at a distance of 5 or 10 mm. according to wire diameter and angle.

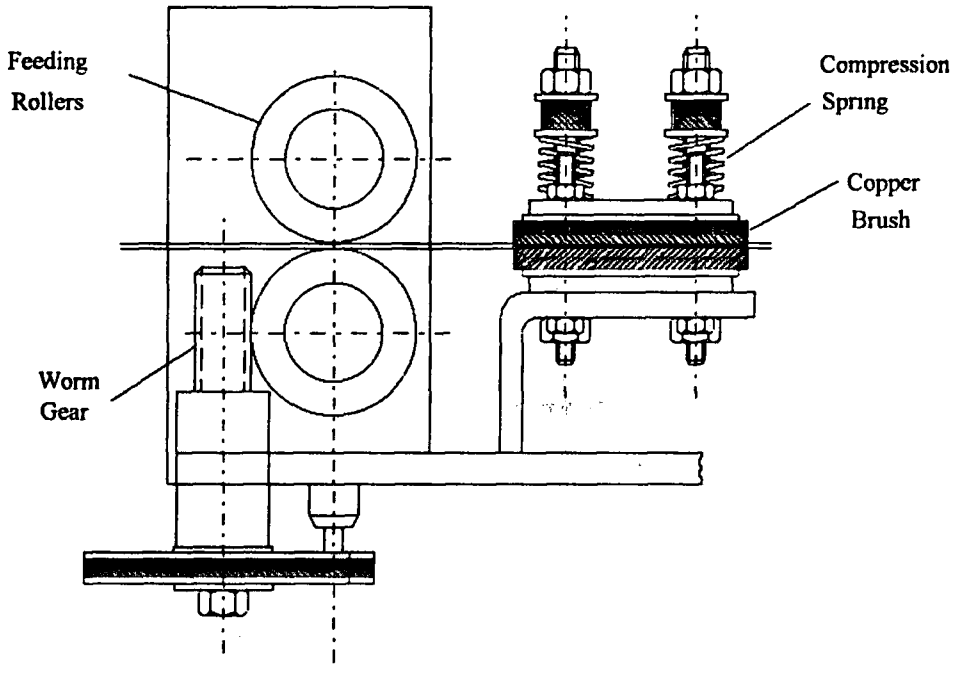


Figure 4.5 Feed Drive Mechanism

Since the hand drill has a series type electric motor, speed of the motor can be controlled by adjusting the input voltage. Therefore, an AC voltage regulator was used to adjust the feed rate of the electrodes. The speed of the electrodes can be adjusted from 50 cm/min. to 500 cm/min.

Since the angle between the wires is required to be available, it is necessary to construct the apparatus enough flexible to change angle. By considering this situation, wire feeding rollers are constructed at the same plane.

In order not to change the position of intersection of wires, feed drive mechanism are mounted to main frame by screw and isolated from each other.

The wires meet at a point directly below the air gun with a certain angle between them. An atomizing air jet is located directly in line with the intersecting wires as shown in Figure 4.6. Continuously drawn wires contact each other and electric arc melts the wires as they are fed into the arc. The jet of air sprayed by a nozzle disintegrate the molten metal. Compressed air supplied to system is at about 8.5 Atm

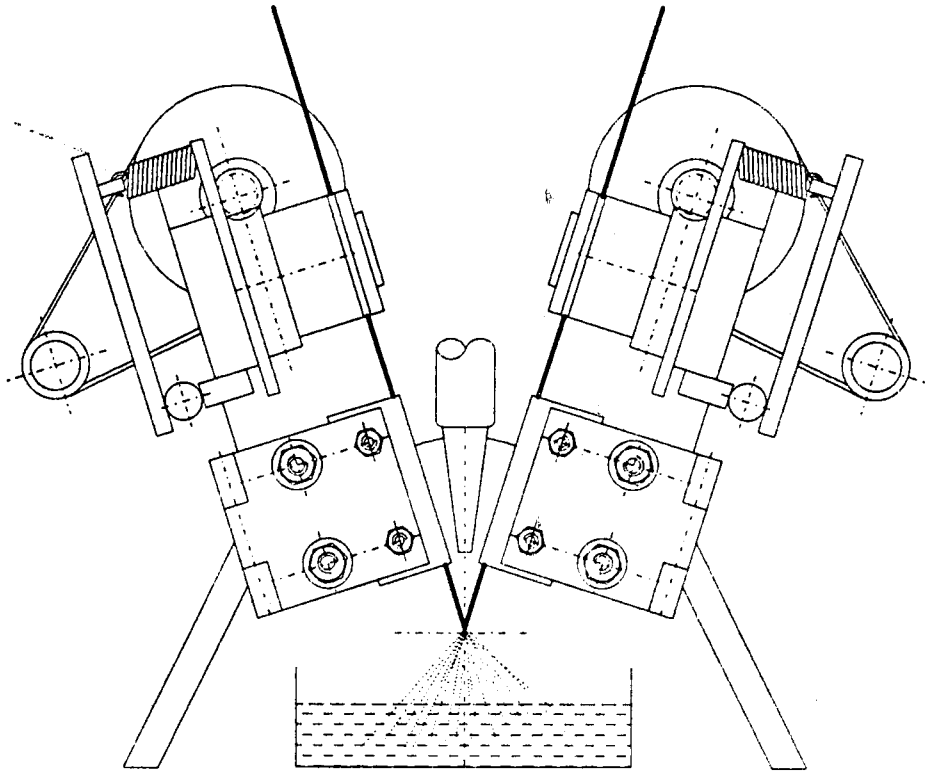


Figure 4.6 General View of Atomization Unit

The photograph of the atomization units is shown below. Figure 4.7 shows the front view of the feeding mechanism. Figure 4.8 shows the front and top views of the atomization unit. Figure 4.9 shows the general view of experimental set-up.

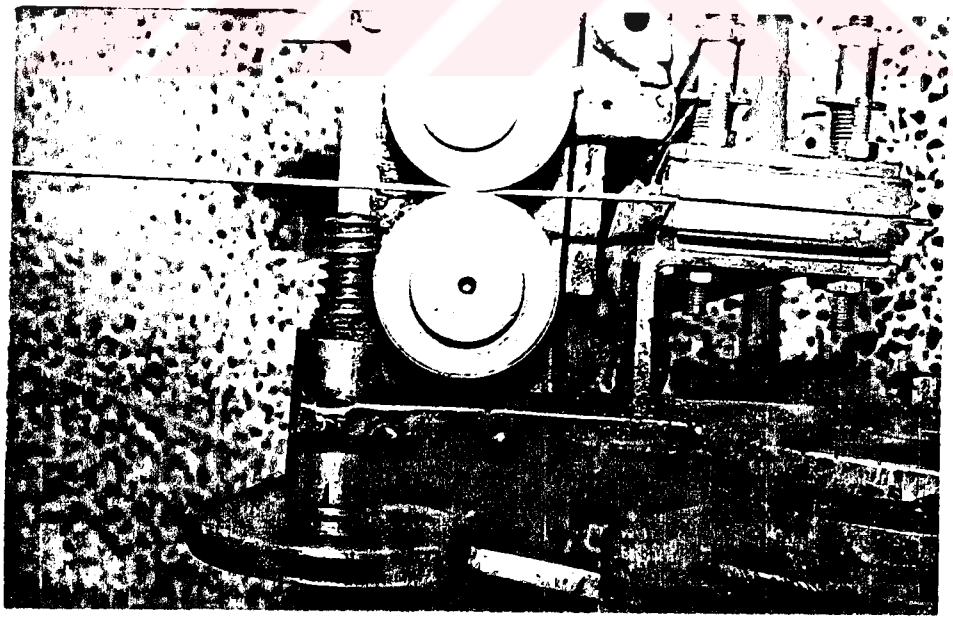


Figure 4.7 Front View of the Feeding Mechanism

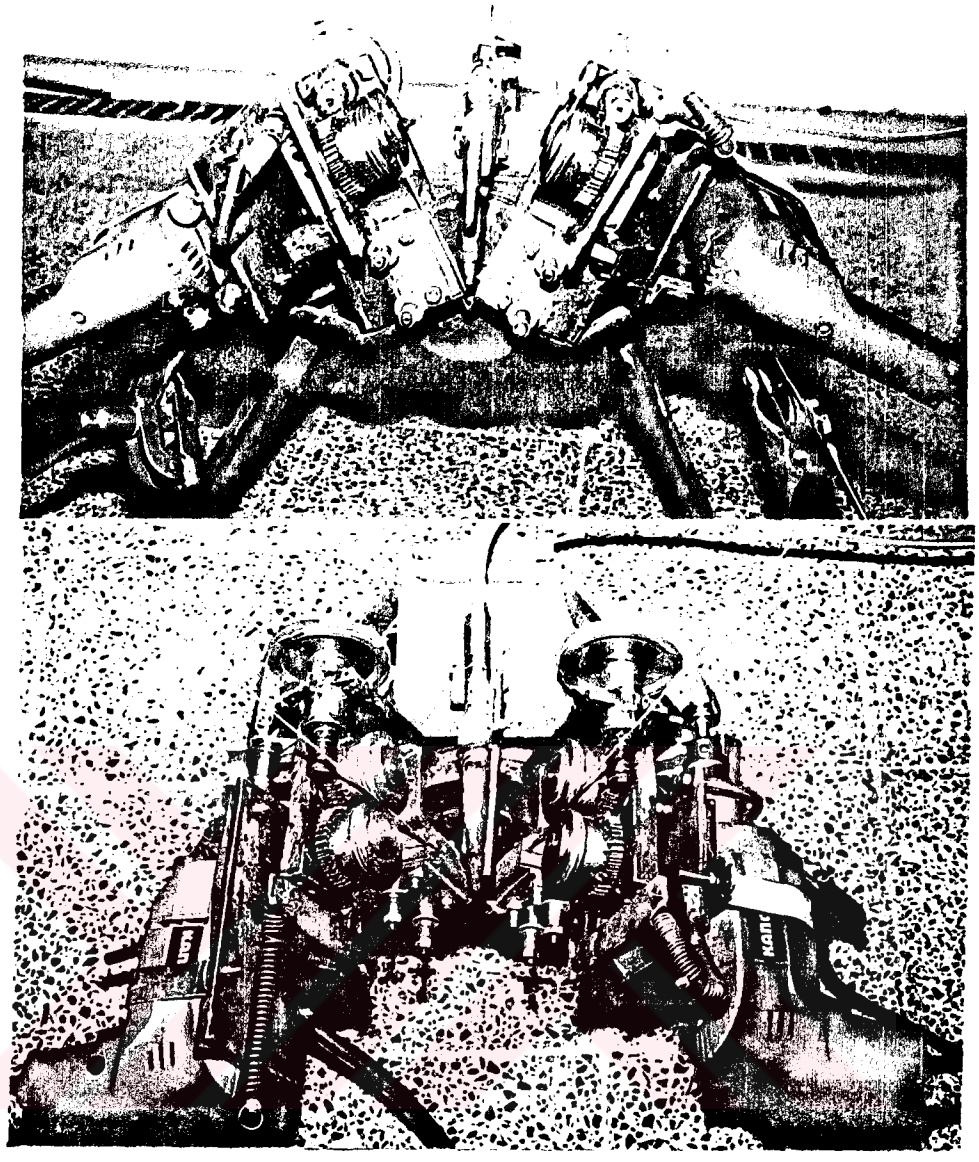


Figure 4.8 Front and Top View of the Atomization Unit.

4.4.2 The Power Source

In the experiment KME 400 type power source, an industrial type power source for MIG welding was used. It has been suggested that a power source of constant voltage type is suitable for standart two wire type electric arc metallizing applications [25]. The KME 400 type power source has a direct current and constant voltage characteristics.

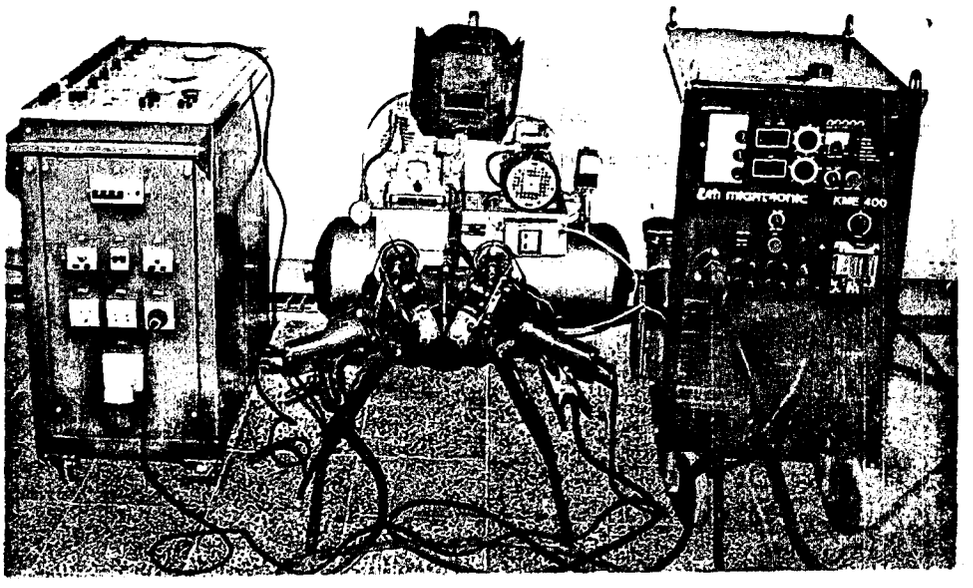


Figure 4.9 General View of Experimental Set-up

The current is automatically adjusted for the selected voltage. The unit maintains an almost constant arc voltage irrespective of the current flowing. The arc to function correctly the rate of wire feed, must be exactly balanced by the burn off rate to keep the arc length constant. Thus a good constant voltage source is capable of providing large current variations while still maintaining nearly constant arc voltage, and a constant speed system for wire feed can be used with advantage.

CHAPTER 5

EXPERIMENTS AND RESULTS

5.1 INTRODUCTION

In the experiments, steel, brass and aluminium powders were produced and the foctors effecting to metal powder had been investigated.

The characteristics of each powder were examined by sieving and microscopic analysis. The photographs of metal powders which are obtained at optimum conditions were taken .

5.2 EXPERIMENTS AND ANALYSIS OF THE POWDERS

In the experiments, lots of trial runs for atomization of steel, brass and aluminium wires were carried out by considering different parameters such as voltage, electrode angle, feed rate and air pressure. But only limited number of results with finer powder were recorded and examined.

A series of experiments were conducted with 2, 2.5 and 3 mm diameter of steel wires, 2 mm and 3 mm brass wires and only 2 mm aluminium wires, atomized at various conditions. During the experiments air pressure supply was adjusted to the maximum value of 8.5 Atm.

The cumulative weight percent distribution of the produced powders was determined by sieving analysis. The sieves used are 63, 75, 90, 125, 212, 250, 300, 425 and 600 μm. mesh size. Approximately, 50 grams of metal powder was sieved. Then the amount of powder in

each sieve was weighted to 0.01 gram accuracy. Percent of powder in each sieve and mean powder sizes were calculated.

A plot of the cumulative particle size distribution a smooth curve has been used to connect the known points and 50 % of the particle size shows the average or mean value of the powder. A cumulative particle size distribution is generated by adding the incremental percentages and plotting the result versus the screen opening size. The optimum value of cumulative weight percent distribution versus particle size and powder size distribution for each material were plotted on semi log and log log papers.

To examine the shape analysis a few grams of powders were taken for each atomization condition, and mixed with polyester. This mixture was cold mounted. Each specimen was grounded and polished by metallographic methods. The shape and microstructural analysis were examined by using a Leitz optical microscope facilities.

5.3 STEEL ATOMIZATION

In this group of experiments the diameters of steel wires were chosen to be 2 mm, 2.5 mm and 3 mm. The angle between the electrodes were adjusted to 45^0 and 60^0. The set-up runs succesfully in voltage range of which are varying from 23 volt to 34 volt. Also feed rate is arranged in order to obtain stable arc.

5.3.1 Atomization of 2 mm Steel Wire

In the atomization of 2 mm steel wire lots of experiment were carried out but only nine of them are presented here.

The percentage of powder size distribution were tabulated in Table 5.1. Figure 5.1 and Figure 5.2 shows the weight percent and cumulative particle size distribution of 2 mm steel wire obtained at optimum conditions which are 60 degree of electrode angle, 28 volt, 95 amper and 340 cm/min feed rate.

Table 5.1 Powder Size Distribution of 2 mm Steel Wire

Angle	Volt	Current	Feed	% Weight Percent Distribution of Powder Size (μm)										
	V	Ampere	cm/min	Pan	63	75	90	125	150	212	250	300	425	600
60	23	90-95	310	7.0	3.5	6.0	16.4	11.5	25.2	10.8	8.4	8.4	2.1	0.7
	26	90	310	6.7	3.6	5.1	11.5	8.7	20.2	10.3	9.9	14.2	7.1	2.7
	28	**95**	**340**	**9.9**	**4.7**	**6.9**	**14.7**	**9.5**	**19.9**	**8.6**	**7.3**	**9.9**	**5.1**	**3.5**
	34	85-100	310	5.2	7.3	5.2	10.5	6.7	16.5	8.9	9.7	15.2	10.4	4.4
45	20	90-100	310	5.7	3.2	4.6	10.6	8.1	19.5	11.2	12.1	16.6	5.3	3.0
	20	95	185	5.0	2.9	4.0	9.5	7.2	19.1	11.1	12.5	16.5	10.1	2.1
	26	80-85	205	6.3	4.3	5.5	13.0	9.1	22.5	11.4	11.4	11.4	3.9	1.2
	26	90	230	4.7	6.3	5.5	12.1	6.3	12.5	11.0	12.2	16.9	9.4	3.1
	32	80-90	230	5.7	3.0	4.5	10.3	7.8	18.9	11.1	11.5	13.3	9.3	4.5

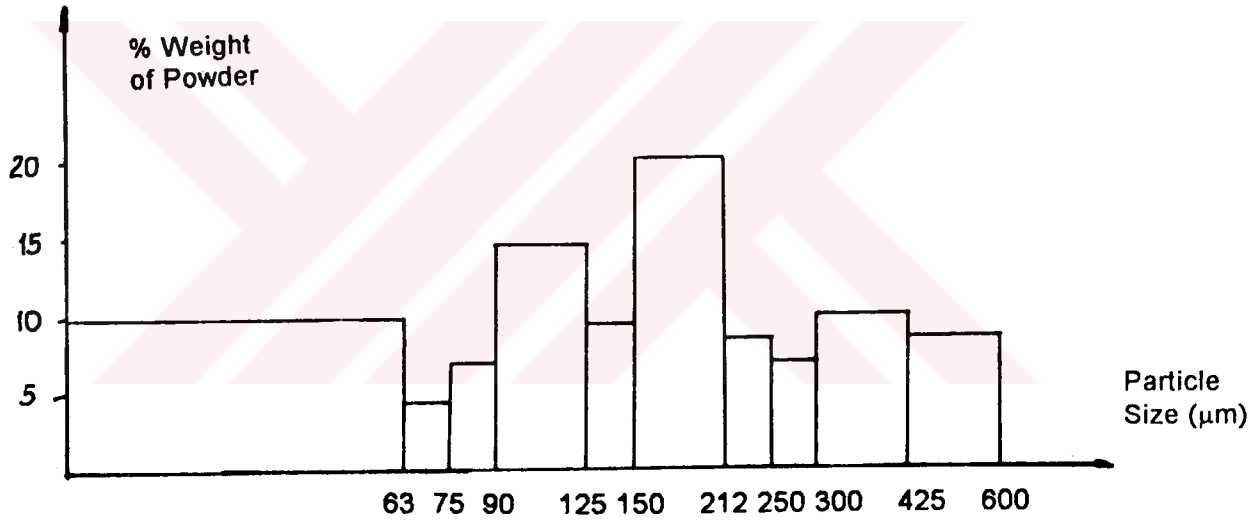


Figure 5.1 Weight Percent Distribution of 2 mm Steel Wire

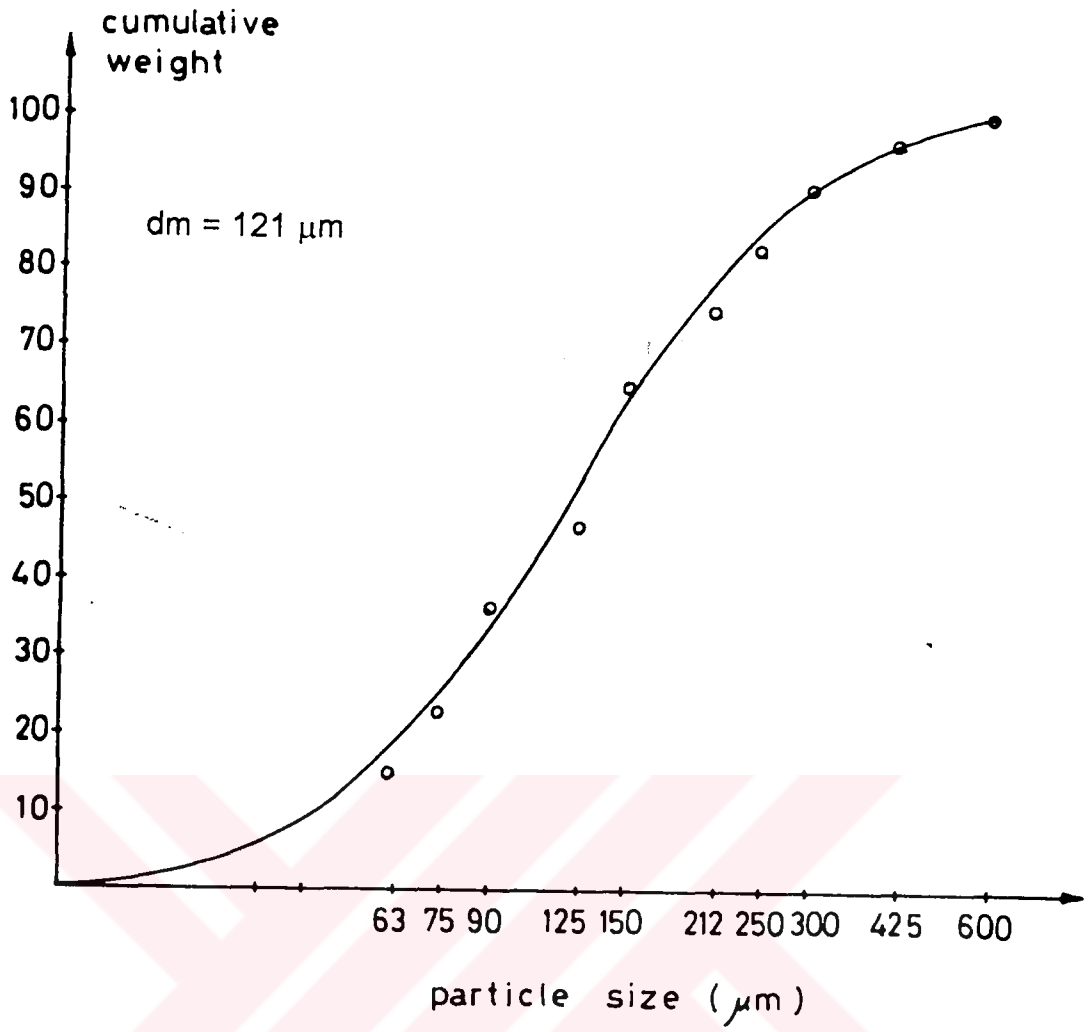


Figure 5.2 Cumulative Particle Size Distribution of 2 mm Steel Wire

5.3.2 Atomization of 2.5 mm Steel Wire

In the atomization of 2.5 mm steel wire lots of experiment were carried out but only four of them are presented.

The percentage of powder size distribution were tabulated in Table 5.2. Figure 5.3 and Figure 5.4 shows the cumulative particle size and weight percent distribution of 2.5 mm steel wire obtained at optimum conditions which are 60 degree of electrode angle, 26 volt, 150-160 amper and 320 cm/min feed rate.

Table 5.2 Powder Size Distribution of 2.5 mm Steel Wire

Angle	Volt	Current	Feed	% Weight Percent Distribution of Powder Size (μm)										
	V	Ampere	cm/min	Pan	63	75	90	125	150	212	250	300	425	600
60	**26**	**150-160**	**320**	**5.3**	**5.9**	**5.9**	**9.0**	**7.4**	**10.5**	**11.3**	**12.2**	**17.6**	**12.4**	**2.5**
	30	135-140	320	4.0	5.0	2.5	5.0	6.5	14.7	8.0	8.8	17.0	17.9	10.5
45	26	160-170	310	6.6	3.2	4.4	10.8	8.2	10.0	10.2	10.4	13.4	19.7	3.1
	30	145-155	310	5.5	2.6	4.1	8.9	7.6	16.1	9.2	12.7	15.6	10.1	7.6

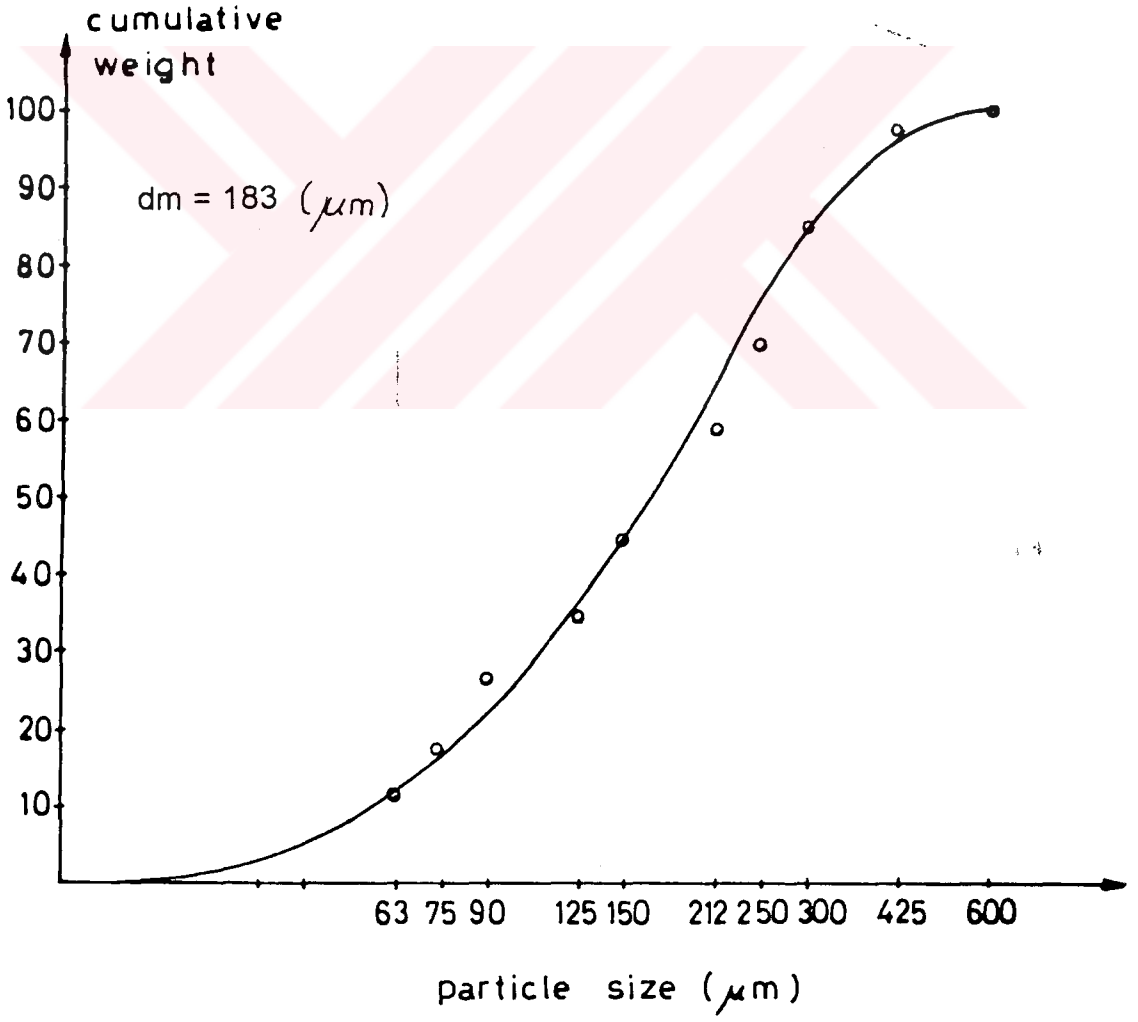


Figure 5.3 Cumulative Particle Size Distribution of 2.5 mm Steel Wire

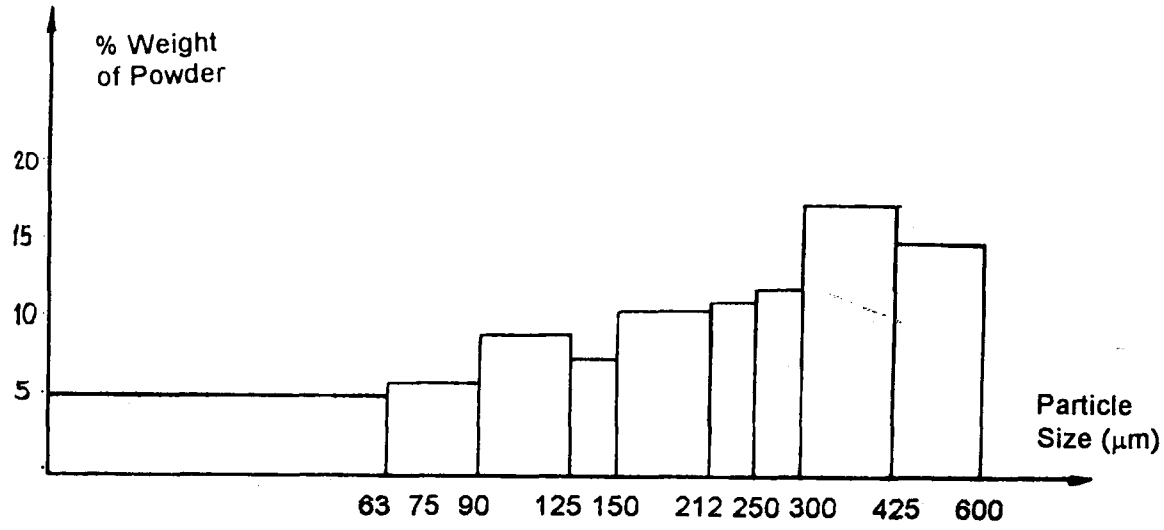


Figure 5.4 Weight Percent Distribution of 2.5 mm Steel Wire

5.3.3 Atomization of 3 mm steel wire

In the atomization of 3 mm steel wire lots of experiment were carried out but only six of them are presented here.

The percentage of powder size distribution were tabulated in Table 5.3. Figure 5.5 and Figure 5.6 shows the cumulative particle size and weight percent distribution of 3 mm steel wire obtained at optimum conditions which are 60 degree of electrode angle, 32 volt, 265-280 amper and 300 cm/min feed rate.

Table 5.3 Powder Size Distribution of 3 mm Steel Wire

Angle	Volt	Current	Feed	% Weight Percent Distribution of Powder Size (μm)										
	V	Ampere	cm/min	Pan	63	75	90	125	150	212	250	300	425	600
60	24	269-278	300	5.0	1.0	2.0	6.4	5.4	11.4	6.7	8.4	19.0	15.7	19.0
	28	260-270	300	4.0	2.1	2.9	6.6	5.3	12.2	7.4	9.0	16.1	18.0	16.4
	32	**265-280**	**300**	**4.3**	**2.2**	**2.8**	**6.8**	**5.3**	**13.0**	**7.7**	**10.1**	**14.9**	**17.4**	**15.5**
45	25	210-230	275	2.6	2.4	2.4	6.2	2.7	9.1	6.5	10.0	18.0	18.9	21.2
	29	205	275	2.1	2.6	2.1	3.4	4.0	6.1	4.7	6.6	17.4	23.2	27.8
	33	190-200	275	2.7	3.0	2.5	6.3	4.4	11.4	4.1	6.3	14.7	19.3	25.3

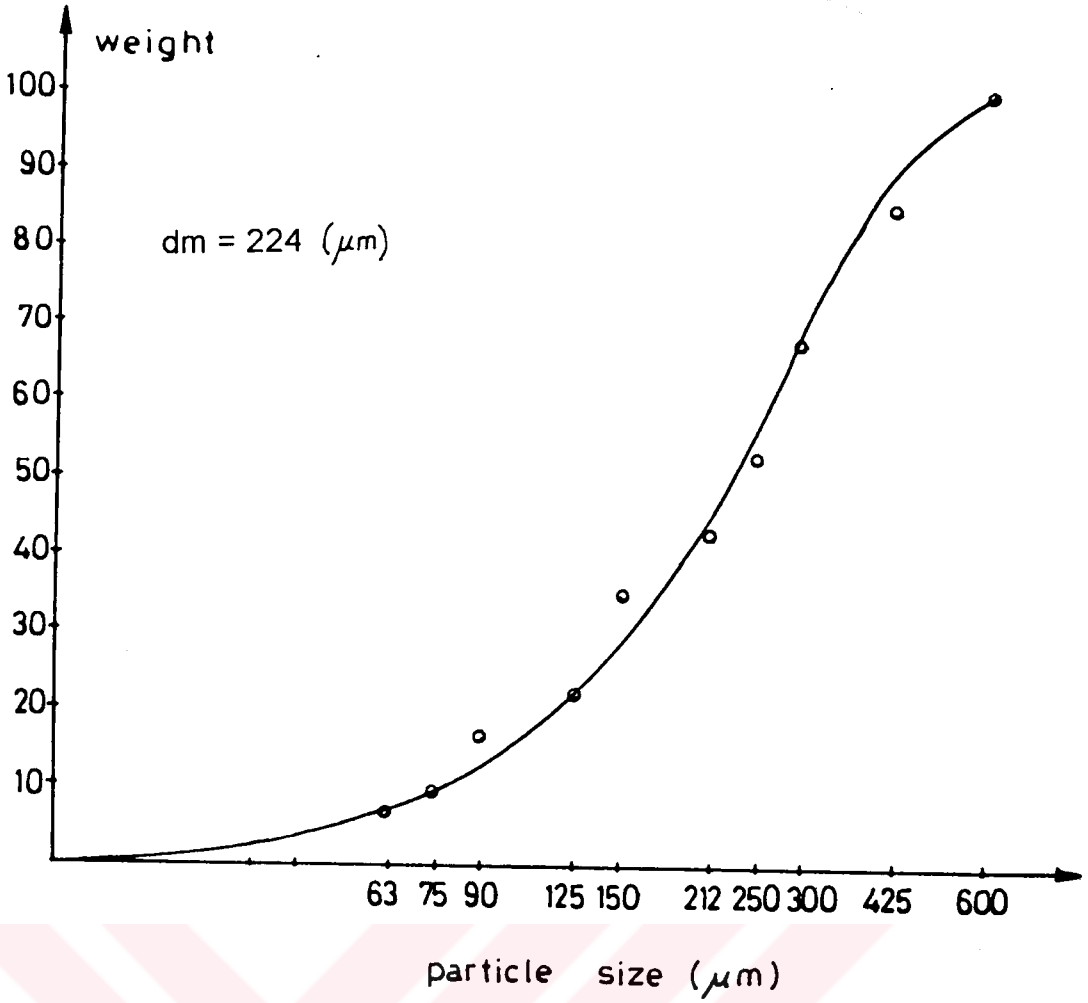


Figure 5.5 Cumulative Particle Size Distribution of 3 mm Steel Wire

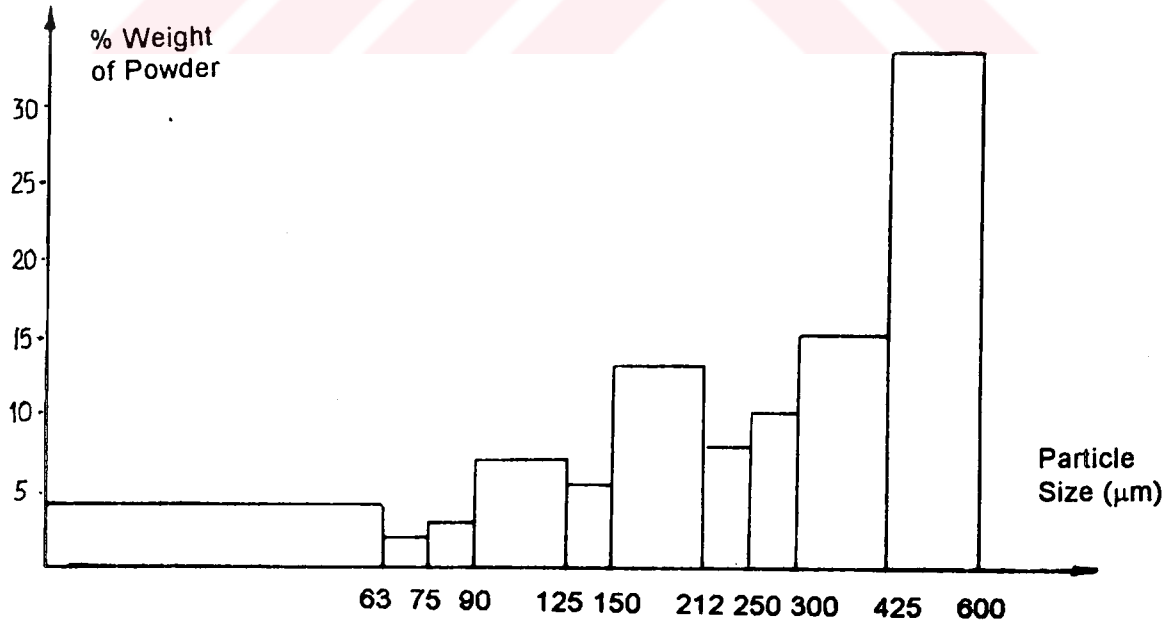


Figure 5.6 Weight Percent Distribution of 3 mm Steel Wire

5.4 BRASS ATOMIZATION

In this group of experiments the diameter of brass wire was chosen as 2 mm and 3 mm. The angle between the electrodes were adjusted to 45^0 and 60^0. The set-up runs succesfully at a voltages which are varying from 23 volt to 34 volt. Also feed rate is arranged in order to obtain stable arc.

5.4.1 Atomization of 2 mm Brass Wire

In the atomization of 2 mm brass wire lots of experiment were carried out but only five of them are presented here.

The percentage of powder size distribution were tabulated in Table 5.4. Figure 5.7 and Figure 5.8 shows the cumulative particle size and weight percent distribution of 2 mm brass wire obtained at optimum conditions which are 60 degree of electrode angle, 34 volt, 190 amper and 475 cm/min feed rate.

Table 5.4 Powder Size Distribution of 2 mm Brass Wire

Angle	Volt	Current	Feed	% Weight Percent Distribution of Powder Size (μm)										
	V	Ampere	cm/min	Pan	63	75	90	125	150	212	250	300	425	600
60	30	184	475	20.4	7.6	8.0	14.9	8.4	14.2	6.2	6.5	6.9	4.0	2.9
	32	72	310	12.3	5.3	6.3	14.3	8.7	17.5	7.7	8.7	11.2	5.9	2.1
	34	190	475	16.5	7.5	7.5	15.1	8.2	14.4	6.8	7.5	9.6	5.5	1.4
45	28	70	310	11.9	5.8	6.6	15.1	9.7	18.2	7.7	8.1	9.6	5.8	1.5
	31	75	310	8.1	3.5	4.6	10.3	8.0	18.0	9.6	11.5	15.3	9.2	1.9

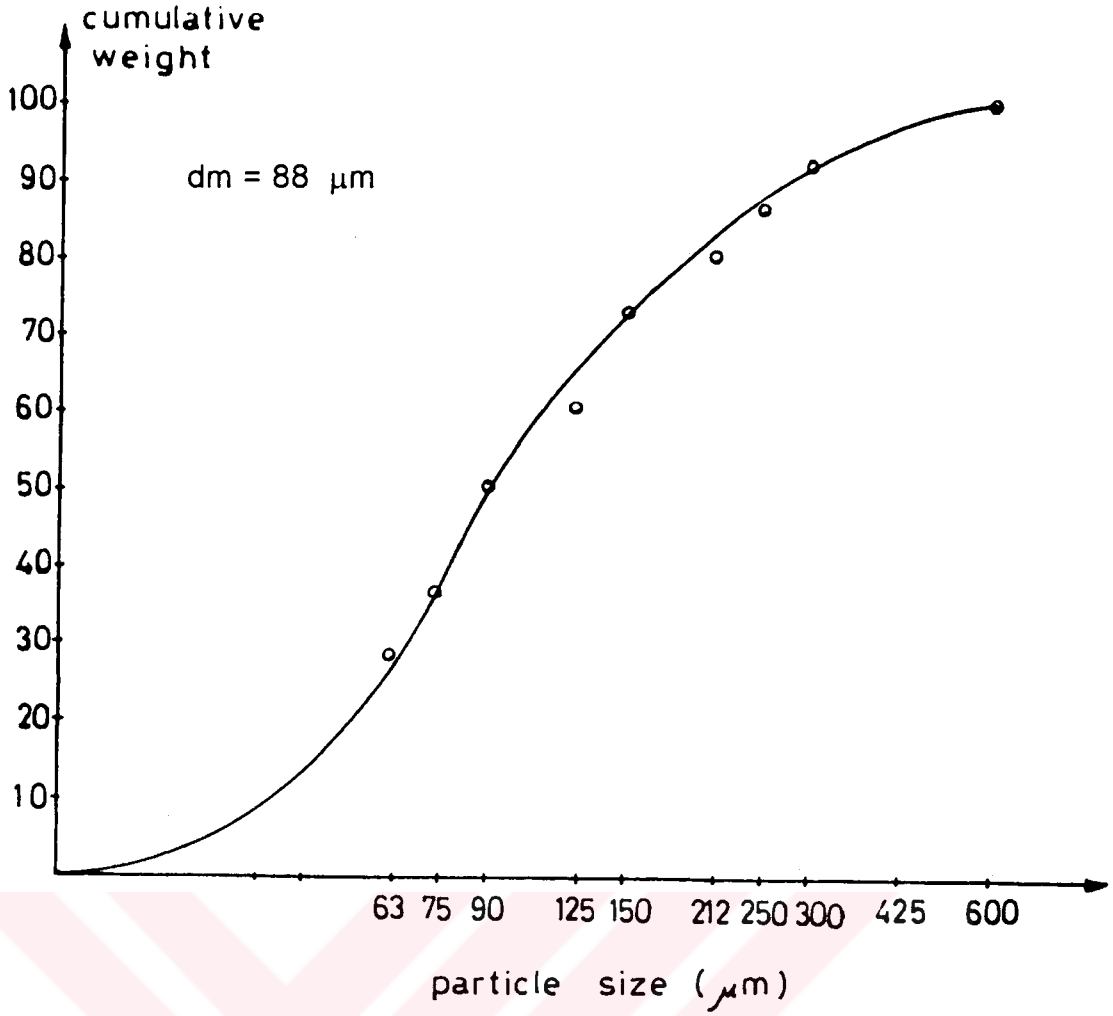


Figure 5.7 Cumulative Particle Size Distribution of 2 mm Brass Wire

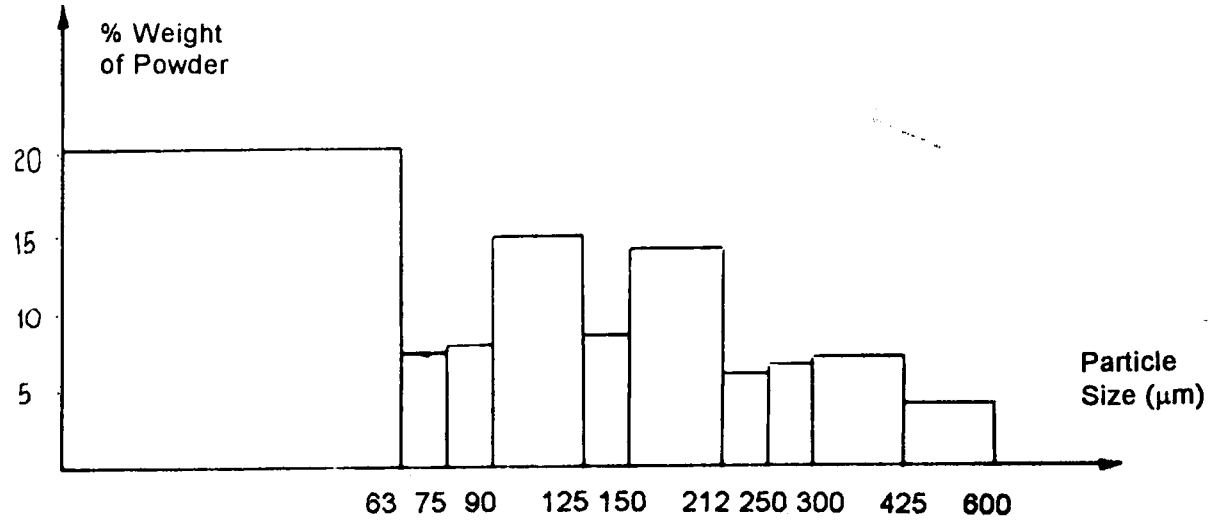


Figure 5.8 Weight Percent Distribution of 2 mm Brass Wire

5.4.2 Atomization of 3 mm Brass Wire

In the atomization of 3 mm brass wire lots of experiment were carried out but only five of them are presented.

The percentage of powder size distribution were tabulated in Table 5.5. Figure 5.9 and Figure 5.10 shows the cumulative particle size and weight percent distribution of 3 mm brass wire obtained at optimum conditions which are 60 degree of electrode angle, 27 volt, 142-147 amper and 310 cm/min feed rate.

For 60 degree of electrodes, one of electrode was changed with 3 mm steel wire and one experiment was carried out by this way. The percentage of powder size distributions are presented at the bottom of the Table 5.5

Table 5.5 Powder Size Distribution of 3 mm Brass Wire

Angle	Volt	Current	Feed	% Weight Percent Distribution of Powder Size(μm)										
	V	Ampere	cm/min	Pan	63	75	90	125	150	212	250	300	425	600
60	23	137-142	310	6.2	2.4	3.3	7.4	5.9	14.7	8.6	10.6	17.4	14.7	8.8
	27	**142-147**	**310**	**5.8**	**4.5**	**4.2**	**6.3**	**5.6**	**13.1**	**9.2**	**11.1**	**15.8**	**13.7**	**10.7**
	30	145-150	350	5.5	4.7	1.2	6.7	5.8	14.5	8.7	11.0	16.6	18.0	7.3
45	25	145-150	300	6.6	2.0	7.2	1.3	5.0	11.3	6.6	9.4	14.2	22.0	14.4
	29	152-157	300	7.2	3.5	8.1	1.2	5.2	12.1	7.2	9.5	14.1	13.2	18.7
BR	30	160-170	310	7.3	2.1	7.1	1.2	4.0	11.8	7.1	9.5	18.6	21.0	10.3
AL	30	160-170	310	8.5	2.7	9.6	3.5	15.3	2.0	6.1	9.3	13.4	23.2	6.4

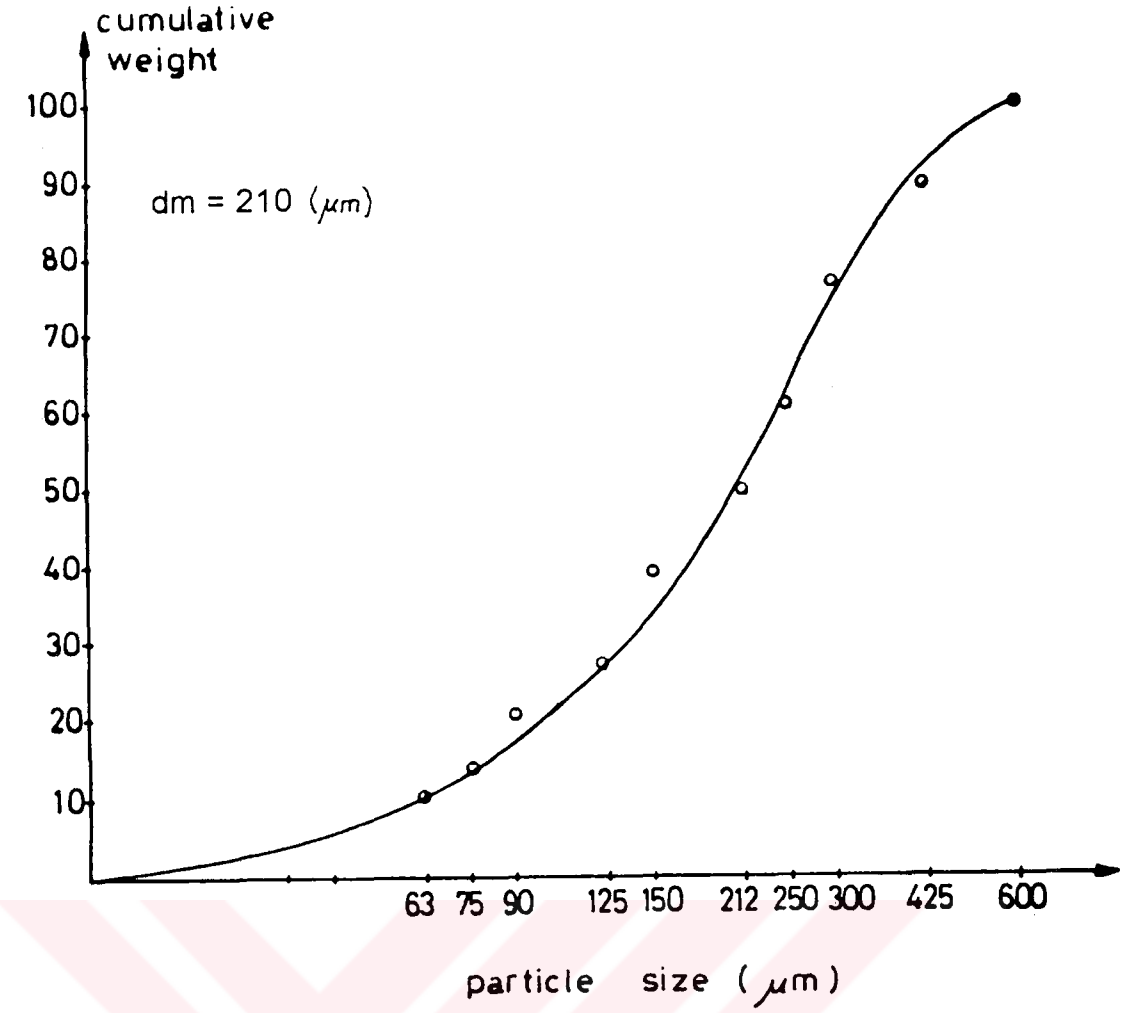


Figure 5.9 Cumulative Particle Size Distribution of 3 mm Brass Wire

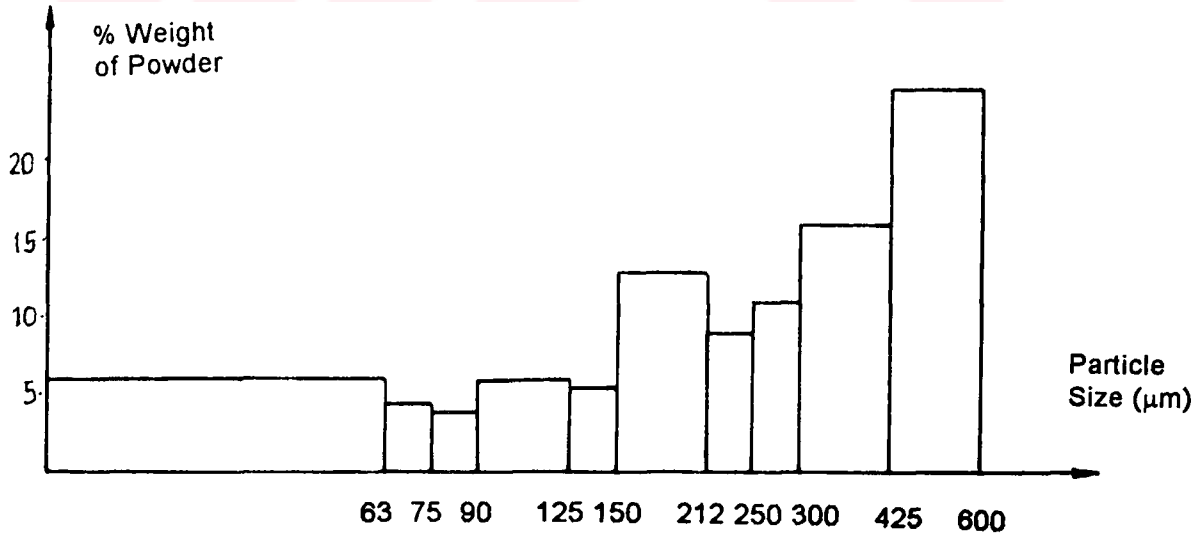


Figure 5.10 Weight Percent Distribution of 3 mm Brass Wire

5.5 ALUMINIUM ATOMIZATION

In this group of experiments the diameter of aluminium wire was chosen as 2 mm. The angle between the electrodes were adjusted to 45^0 and 60^0. The set-up runs succesfully at a voltages which are varying from 25 volt to 30 volt. Also feed rate is arranged in order to obtain stable arc.

In the atomization of 2 mm aluminium wire lots of experiment were carried out but only four of them are presented.

The percentage of powder size distribution were tabulated in Table 5.6. Figure 5.11 and Figure 5.12 shows the cumulative particle size and weight percent distribution of 2 mm aluminium wire obtained at optimum conditions which are 45 degree of electrode angle, 27 volt, 40 amper and 310 cm/min feed rate.

Table 5.6 Powder Size Distribution of 2 mm Aluminium Wire

Angle	Volt	Current	Feed	% Weight Percent Distribution of Powder Size (μm)										
	V	Ampere	cm/min	Pan	63	75	90	125	150	212	250	300	425	600
60	28	135	475	17.8	6.8	6.8	16.5	9.6	15.1	5.5	6.8	6.8	5.5	2.8
	30	135	475	14.3	8.6	8.6	15.7	11.4	11.4	5.7	8.6	5.7	7.1	2.9
45	25	40	310	16.7	8.9	8.9	16.7	11.1	13.3	4.4	6.7	6.7	4.4	2.2
	27	40	310	20.6	8.8	7.8	15.7	8.8	13.7	5.9	5.9	6.9	3.9	2.0

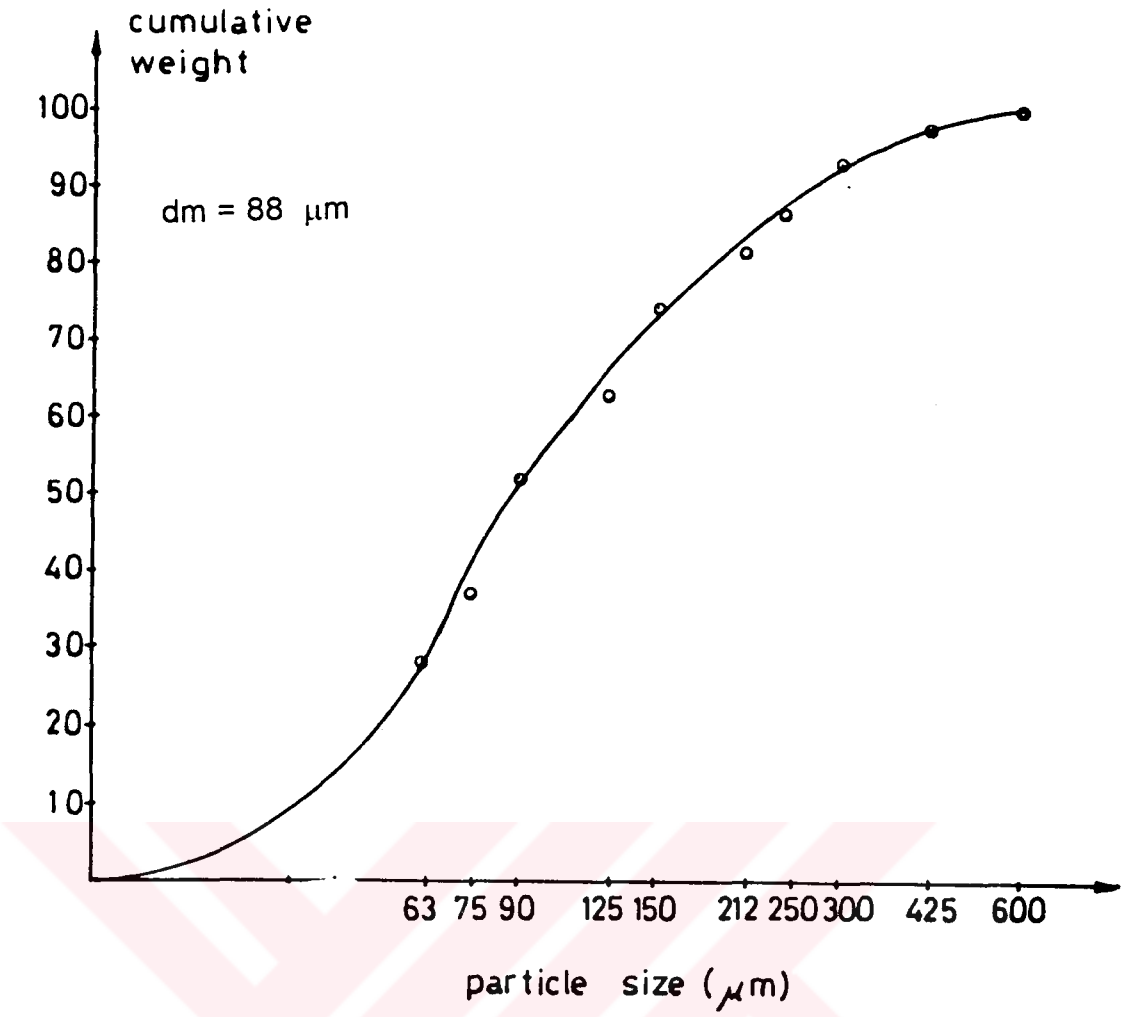


Figure 5.11Cumulative Particle Size Distribution of 2mm Aluminium wire

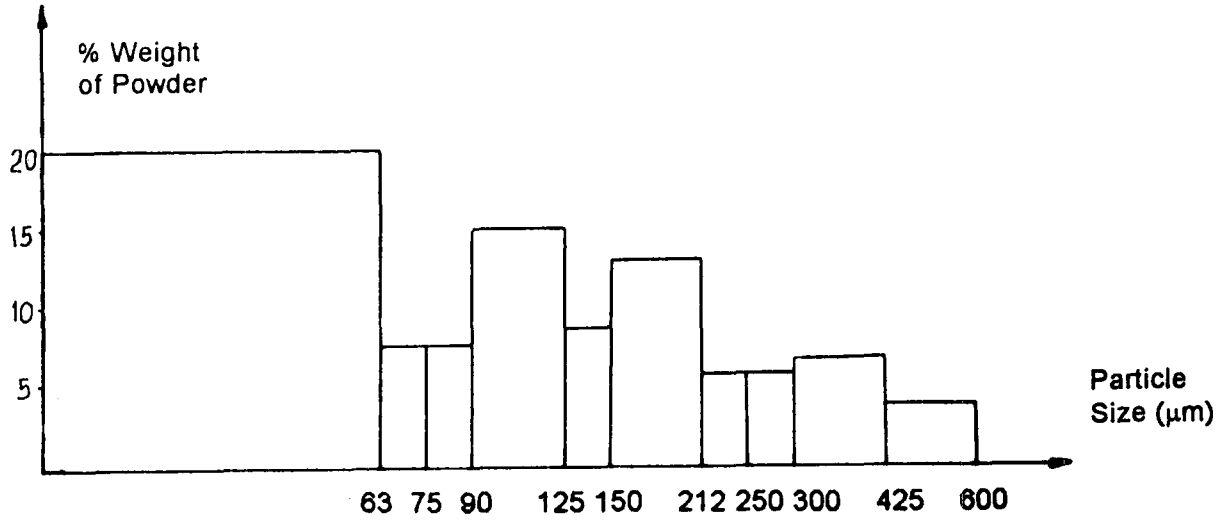


Figure 5.12 Weight Percent Distribution of 2 mm Aluminium Wire

5.6 OPTIMUM PARAMETERS FOR ELECTRODES

Optimum parameters for three materials, i.e. steel, brass and aluminium are summarized in Table 5.7 below:

Table 5.7 Optimum Parameters for Electrodes

Material	Wire Dia. (mm)	electrode angle	Voltage limits	Optimum Voltage	Optimum Current	Feed Rate (cm/min)	Mean Powde Size (μm)
Steel	2	45	20-32	26	80-85	205	138
		60	23-34	28	95	340	121
	2.5	45	26-30	26	160-170	310	198
		60	26-30	26	150-160	320	183
	3	45	25-33	25	210-230	275	276
		60	24-32	32	265-280	300	224
Brass	2	45	28-31	28	70	310	128
		60	30-34	30	184	475	88
	3	45	25-29	29	152-157	300	235
		60	23-30	27	142-147	310	210
Aluminium	2	45	25-27	27	40	310	88
		60	28-30	30	135	475	103

Cumulative weight percent versus particle size of the optimum condition of steel, brass and aluminium were plotted in log log paper as shown in Figure 5.13.

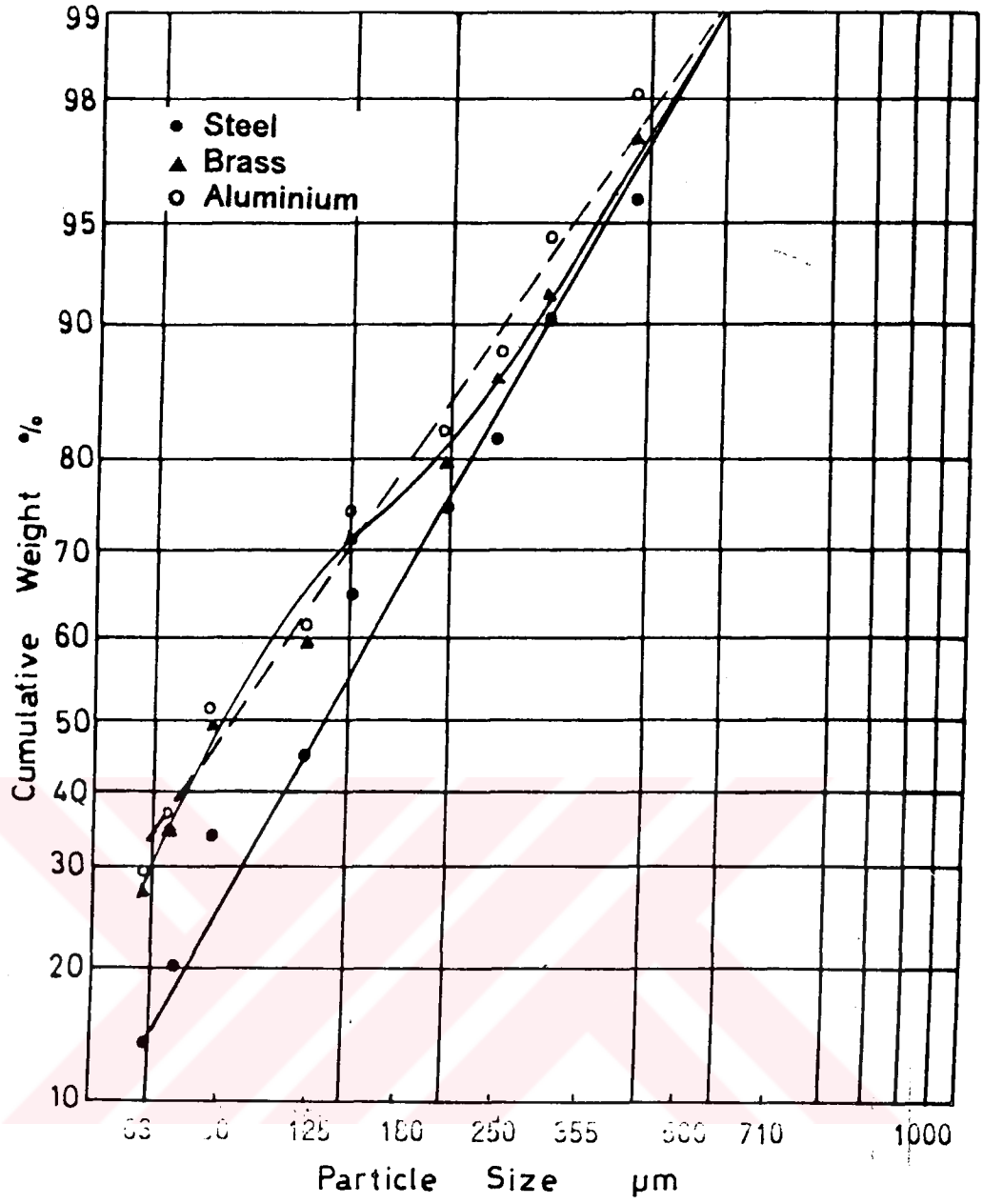


Figure 5.13 Cumulative Weight Percent Distributions of the Steel, Brass and Aluminium Powders

Cumulative particle size distributions of steel and brass were shown in Figure 5.14 and 5.15.

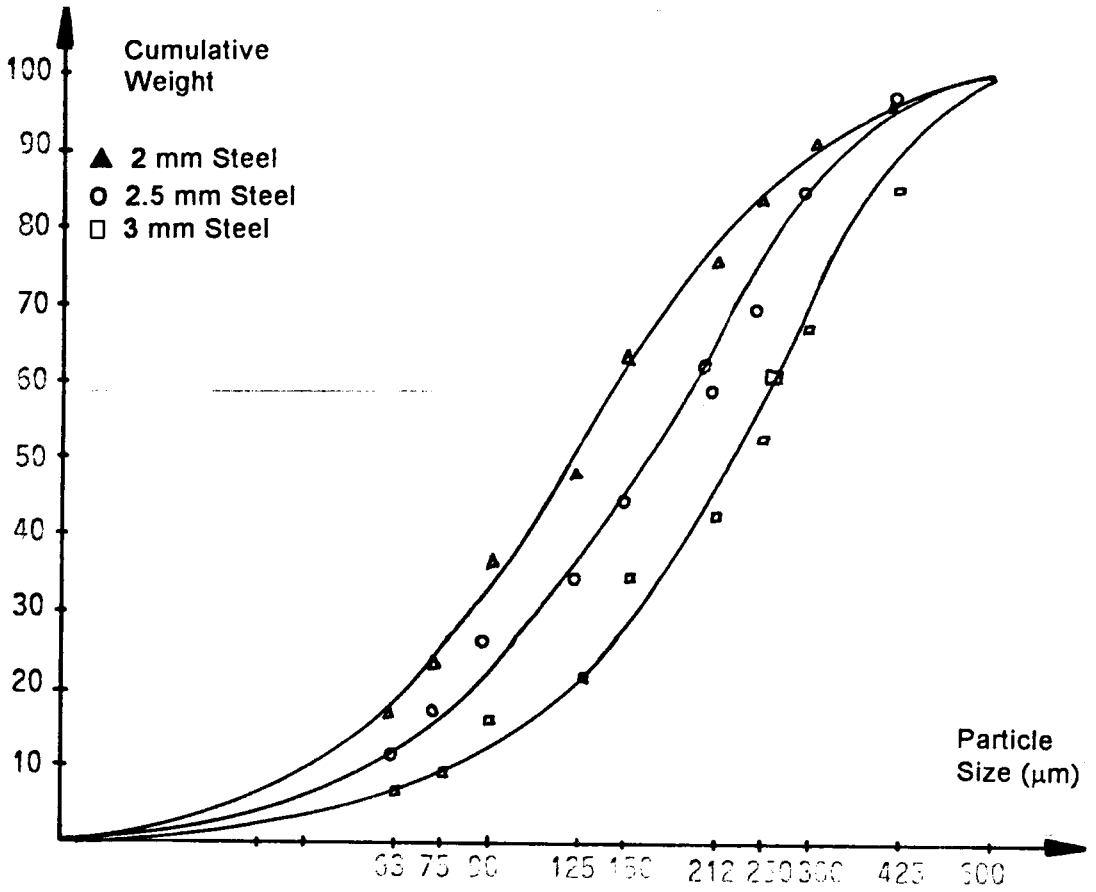


Figure 5.14 Cumulative Particle Size Distribution of Steel Powders

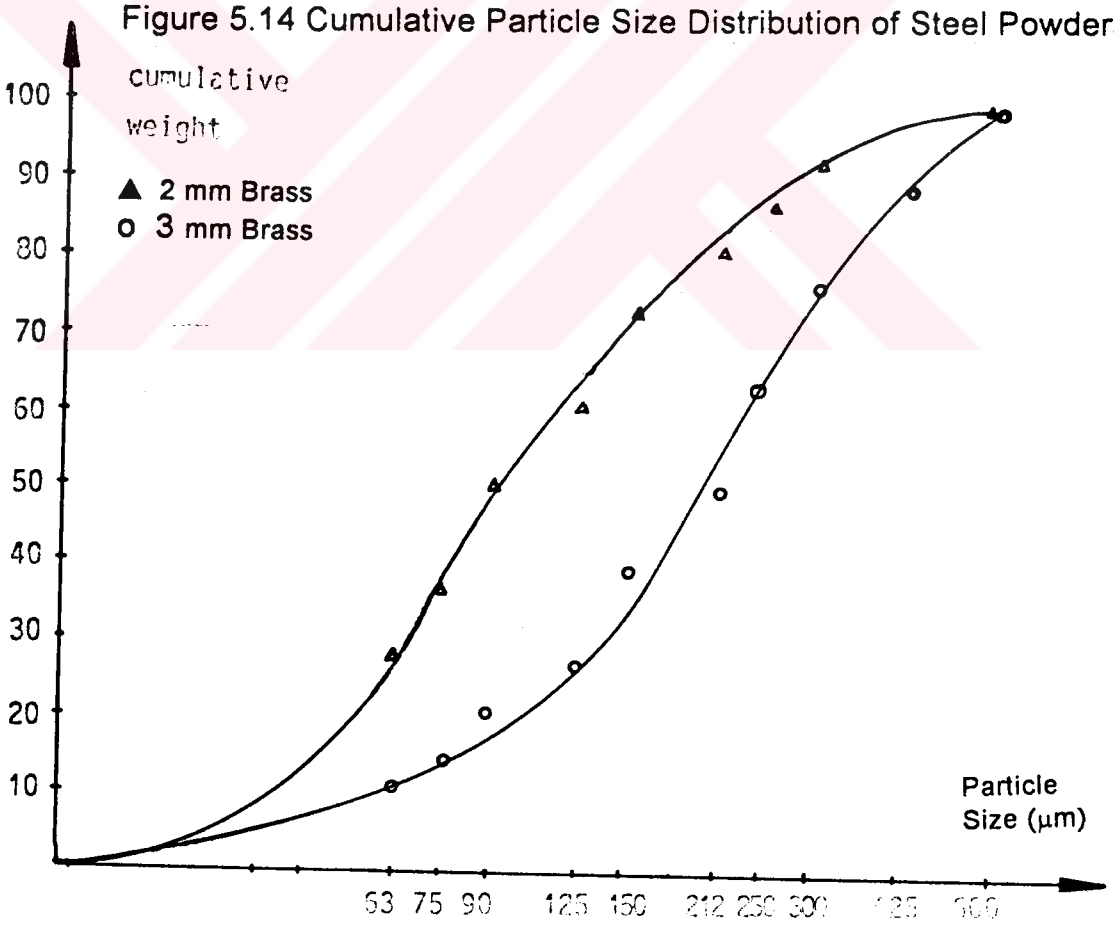


Figure 5.15 Cumulative Particle Size Distribution of Brass Powders

5.7 STATISTICAL DISTRIBUTION OF THE PARTICLE DIAMETER

Once particle size data is collected, concern turns to an analysis of the distribution. The standart deviation is calculated by usual procedures. Collected powder in each sieve is weighted and % weight is calculated by dividing each increament by the total sample weight.

The standart deviation datas are generated in Table 5.8 to 5.13 for optimum values of 2, 2.5, 3mm steel, 2 mm and 3 mm brass and 2 mm aluminium powders.

Table 5.8 Statistical Size Distribution Data of 2 mm Steel wire

sieve opening (μm)	mean part. size(μm) **Xi**	weight (gr)	% weight **Fi**	cumulative weight	$X_i.F_i$	$F_i(X_i - \bar{X})^2$
0-63	31.5	2.3	9.9	9.9	311.9	295612.4
63-75	69.0	1.1	4.7	14.6	324.3	86038.6
75-90	82.5	1.6	6.9	21.5	569.3	10263.2
90-125	107.5	3.4	14.7	36.2	1580.3	137742.5
125-150	137.5	2.2	9.5	45.7	1306.3	42391.3
150-212	181.0	4.6	19.9	65.6	3601.9	10803.5
212-250	231.0	2.0	8.6	74.2	1986.6	6130.9
250-300	275.0	1.7	7.3	81.5	2007.5	36489.0
300-425	362.5	2.3	9.9	91.4	3588.8	247769.7
425-600	512.5	1.2	5.1	96.5	2613.8	484434.9
600-850	725.0	0.8	3.5	100.0	2537.5	948949.7
TOTAL		23.2			20428.2	2398725.7

Standart deviation for the data given above is 154.9

Table 5.9 Statistical Size Distribution Data of 2.5 mm Steel wire

sieve opening (μm)	mean part. size (μm) Xi	weight (gr)	% weight Fi	cumulative weight	$X_i.F_i$	$F_i(X_i - \bar{X})^2$
0-63	31.5	2.5	5.3	5.3	167.0	263800.1
63-75	69.0	2.8	5.9	11.2	407.1	203239.4
75-90	82.5	2.8	5.9	17.1	486.8	174748.6
90-125	107.5	4.3	9.0	26.1	967.5	194745.7
125-150	137.5	3.5	7.4	33.5	1017.5	101471.8
150-212	181.0	5.0	10.5	44.0	1900.5	56878.1
212-250	231.0	5.4	11.3	55.3	2610.3	6293.6
250-300	275.0	5.8	12.2	67.5	3355.0	5077.2
300-425	362.5	8.4	17.6	85.1	6380.0	204906.4
425-600	512.5	5.9	12.4	97.5	6355.0	824753.9
600-850	725.0	1.2	2.5	100.0	1812.5	553190.4
TOTAL		47.6			25459.2	2589105.2

Standart Daviation for the data given above is 160.9

Table 5.10 Statistical Size Distribution Data of 3 mm Steel wire

sieve opening (μm)	mean part. size (μm) Xi	weight (gr)	% weight Fi	cumulative weight	$X_i.F_i$	$F_i(X_i - \bar{X})^2$
0-63	31.5	0.9	4.3	4.3	135.5	420997.6
63-75	69.0	0.5	2.2	6.5	151.8	166859.4
75-90	82.5	0.6	2.8	9.3	231.0	192056.5
90-125	107.5	1.4	6.8	16.1	731.0	381626.9
125-150	137.5	1.1	5.3	21.4	728.8	226880.3
150-212	181.0	2.7	13.0	34.4	2353.0	347094.3
212-250	231.0	1.6	7.7	42.1	1778.7	99018.6
250-300	275.0	2.1	10.1	52.2	2777.5	48645.2
300-425	362.5	3.0	14.9	67.1	5401.3	4881.4
425-600	512.5	3.6	17.4	84.5	8917.5	491682.4
600-850	725.0	3.2	15.5	100.0	11237.5	2245273.6
TOTAL		20.7			34443.6	4625016.2

Standart Daviation for the data given above is 215.1

Table 5.11 Statistical Size Distribution Data of 2 mm Brass wire

sieve opening (μm)	mean part. size(μm) **Xi**	weight (gr)	% weight **Fi**	cumulative weight	$X_i.F_i$	$F_i(X_i - \bar{X})^2$
0-63	31.5	5.6	20.4	20.4	642.6	393014.9
63-75	69.0	2.1	7.6	28.0	524.4	77988.8
75-90	82.5	2.2	8.0	36.0	660.0	61670.7
90-125	107.5	4.1	14.9	50.9	1601.8	58763.2
125-150	137.5	2.3	8.4	59.3	1155.0	9037.1
150-212	181.0	3.9	14.2	73.5	2570.2	1625.8
212-250	231.0	1.7	6.2	79.7	1432.2	22843.8
250-300	275.0	1.8	6.5	86.2	1787.5	71253.6
300-425	362.5	1.9	6.9	93.1	2501.3	254891.8
425-600	512.5	1.1	4.0	97.1	2050.0	468403.4
600-850	725.0	0.8	2.9	100.0	2102.5	892307.1
TOTAL		27.5			17027.5	2311800.2

Standart Daviation for the data given above is 152.1

Table 5.12 Statistical Size Distribution Data of 3 mm Brass wire

sieve opening (μm)	mean part. size(μm) **Xi**	weight (gr)	% weight **Fi**	cumulative weight	$X_i.F_i$	$F_i(X_i - \bar{X})^2$
0-63	31.5	2.6	5.8	5.8	182.7	359894.7
63-75	69.0	2.0	4.5	10.3	310.5	201485.5
75-90	82.5	1.9	4.2	14.5	346.5	164823.2
90-125	107.5	2.8	6.3	20.8	677.3	188770.7
125-150	137.5	2.5	5.6	26.4	770.0	114674.6
150-212	181.0	5.8	13.1	39.5	2371.1	129954.1
212-250	231.0	4.1	9.2	48.7	2125.2	22633.5
250-300	275.0	5.0	11.1	59.8	3052.5	348.1
300-425	362.5	7.0	15.8	75.6	5727.5	105980.2
425-600	512.5	6.1	13.7	89.3	7021.3	736753.3
600-850	725.0	4.8	10.7	100.0	7757.5	2113157.6
TOTAL		44.6			28055.1	4138475.5

Standart Daviation for the data given above is 203.4

Table 5.13 Statistical Size Distribution Data of 2 mm Aluminium Wire

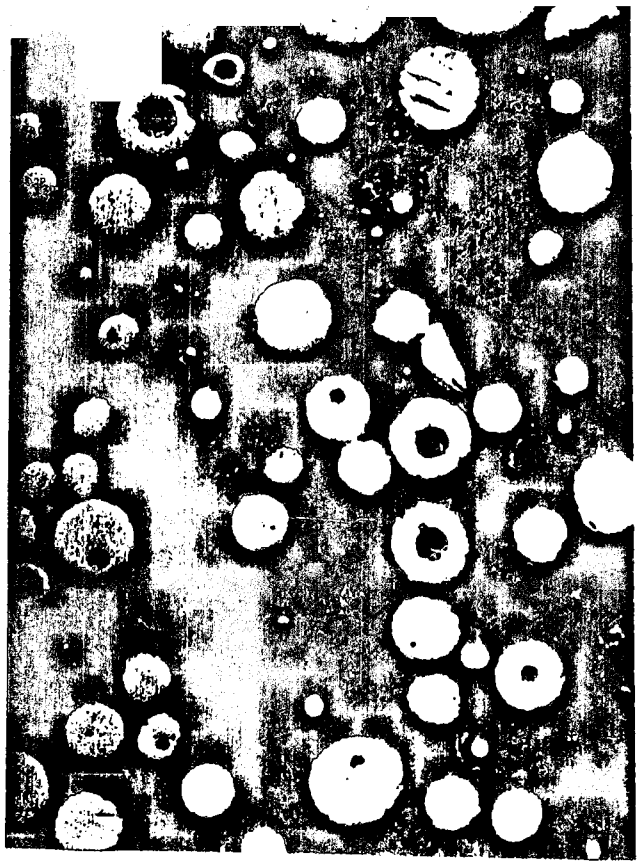
sieve opening (μm)	mean part. size(μm) Xi	weight (gr)	% weight Fi	cumulative weight	$X_i.F_i$	$F_i(X_i - \bar{X})^2$
0-63	31.5	2.1	20.6	20.6	648.9	351361.0
63-75	69.0	0.9	8.8	29.4	607.2	76274.9
75-90	82.5	0.8	7.8	37.2	643.5	49422.1
90-125	107.5	1.6	15.7	52.9	1687.8	46804.2
125-150	137.5	0.9	8.8	61.7	1210.0	5325.4
150-212	181.0	1.4	13.7	75.4	2479.7	4393.8
212-250	231.0	0.6	5.9	81.3	1362.9	28008.5
250-300	275.0	0.6	5.9	87.2	1622.5	75203.8
300-425	362.5	0.7	6.9	94.1	2501.3	277105.1
425-600	512.5	0.4	3.9	98.0	1998.8	478842.6
600-850	725.0	0.2	2.0	100.0	1450.0	633712.8
TOTAL		10.2			16212.6	2026454.2

Standart Daviation for the data given above is 142.4

5.8 SHAPE ANALYSIS OF THE POWDERS

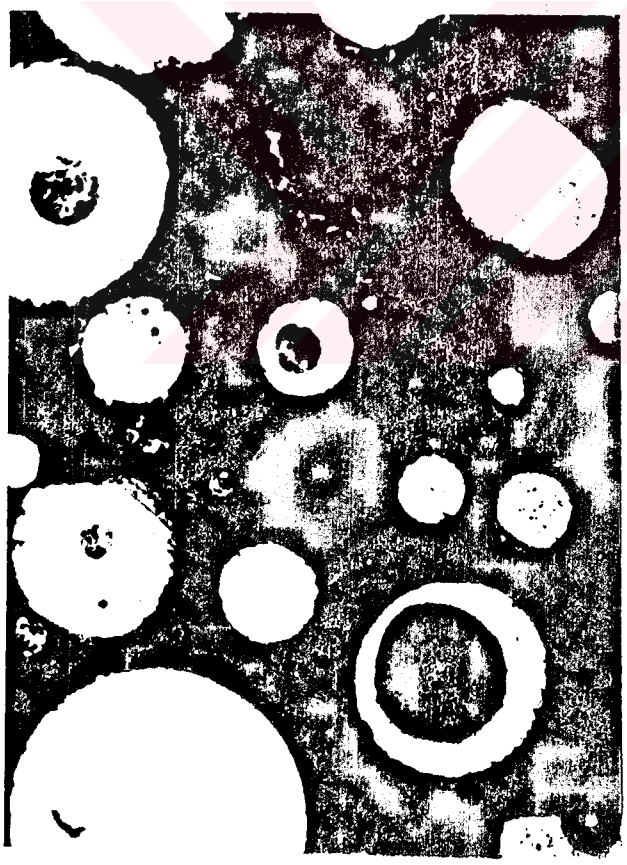
The shape analysis were examined by using a Leitz optical microscope. The microscopic observation show that the shape of the powders are similar to water atomized powders. The complexity of the powder shape is due to the sudden quenching in the water. Both brass and aluminium powders have the complex shape and the steel powders have the spherical shape.

General view of transverse sections of steel, brass and aluminium powders are shown in Figure 5.16 to Figure 5.18.

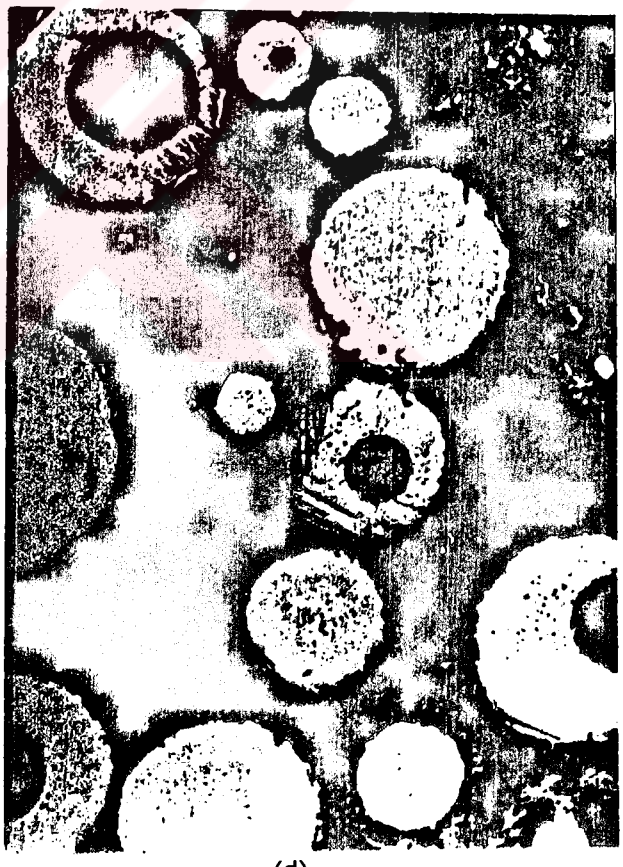


(a)

(b)



(c)



(d)

Figure 5.16 Transverse Sections of Steel Powders

a) x 50 **b)** x 100 **c)** x 100 **d)** x 100

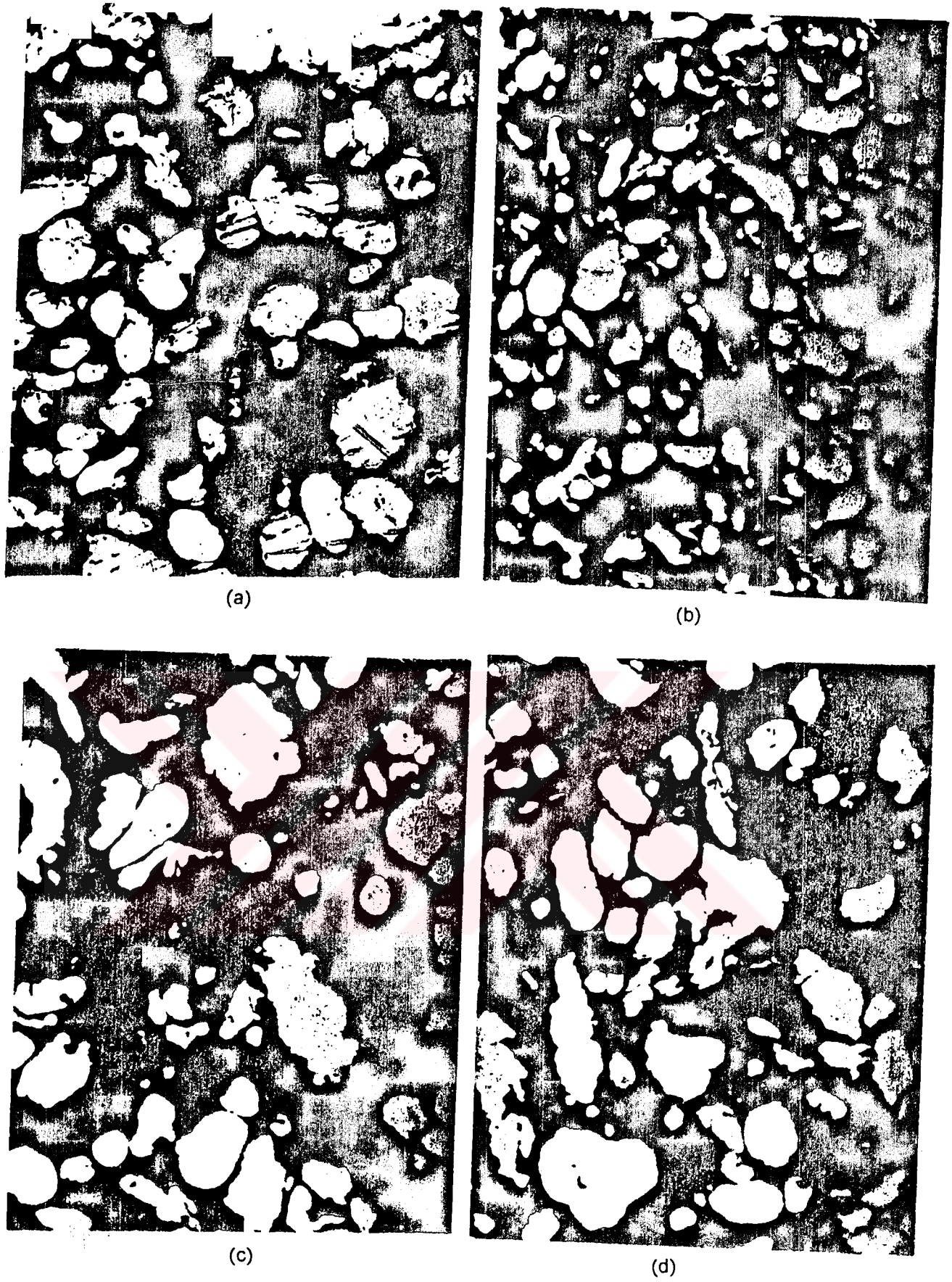


Figure 5.17 Transverse Sections of Brass Powders

a) x 50 **b)** x 50 **c)** x 100 **d)** x 100

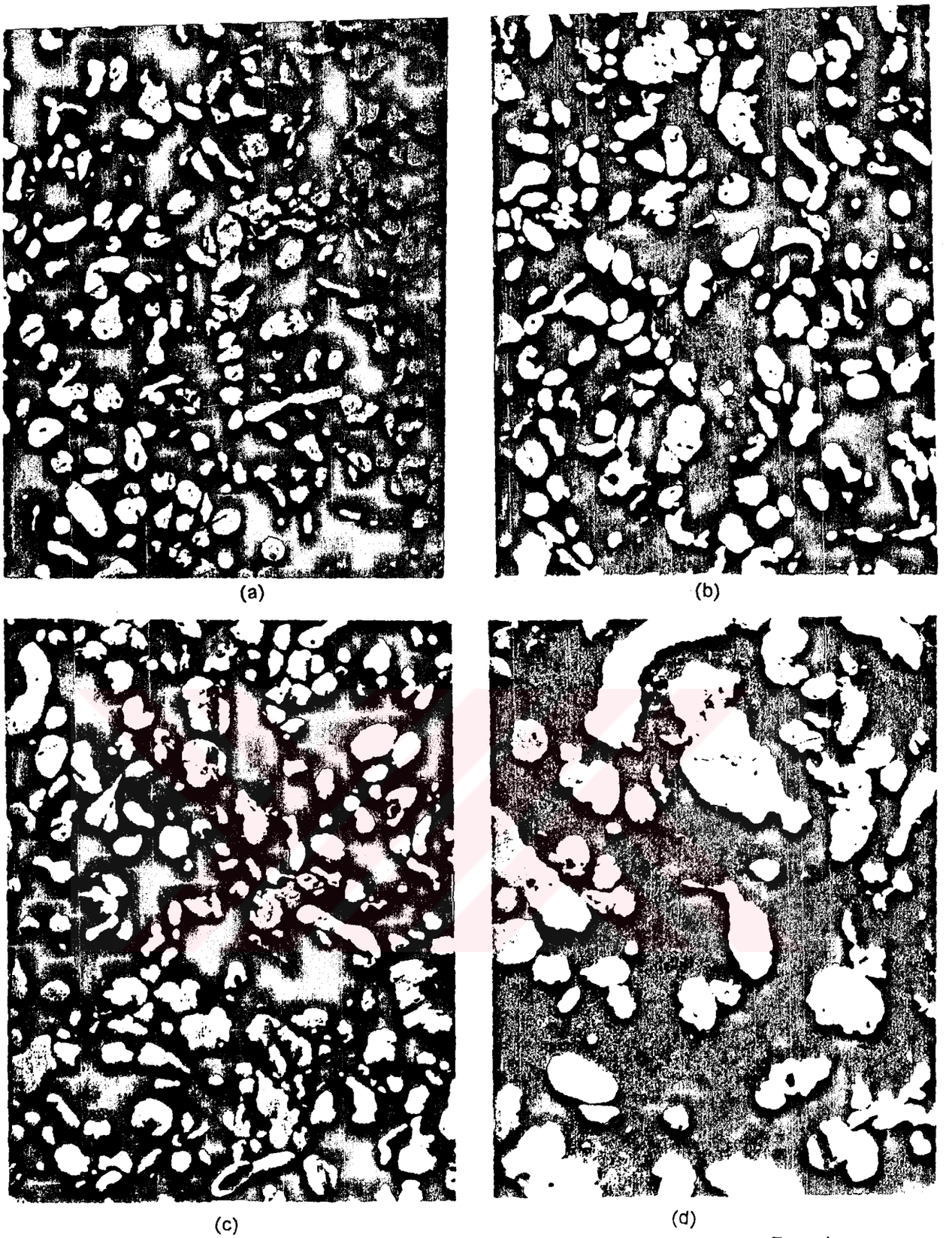


Figure 5.18 Transverse Sections of Aluminium Powders

a) x 50 **b)** x 50 **c)** x 50 **d)** x 100

CHAPTER 6

DISCUSSION AND CONCLUSIONS

6.1 INTRODUCTION

As pointed out in previous chapters, in this work metal powders were produced by gas atomization using the electric arc method. Due to the difficulty in melting of metal in usual gas atomization, research was diverted towards the melting unit. Then, unique design was made by using electric arc.

In literature [25, 39] two wire type electric arc applications are usable for the atomization. The experimental results show that electric arc atomization can produce the metal powders in a good range by size.

In this study, steel, brass and aluminium wires were selected as the main metals for metal powder production.

6.2. DISCUSSION OF PROCESS

In gas atomization metals are melted in furnace. The molten metal emerges from a nozzle of a tundish and is impinged by high pressure gases. Nitrogen, helium or argon gases are used to disintegrate the molten metal. The melting unit and high pressure air supply with nozzle are the main parts of this process.

The most important parameters that effecting the characteristic of metal powder are over heating temperature, nozzle geometry, gas pressure and flow rate. Since the over heating is very effective on the viscosity and surface tension of the molten metal, the liquid metal should

be superheated over the melting temperature to obtain the fine particle size in atomization. Especially, for the metals which have a high melting temperature, it is very difficult to increase the degree of over heating temperature.

In the gas atomization the other factor that should be considered is the gas supply and spraying. Gas supply should provide at least 15 Atm. gas pressure. This gas jets are formed by multiple nozzles arranged circumferentially around the melt stream instead of an annular nozzle. At this point nozzle geometry plays a very important role. Because of the large amount of inert gas used in atomization, it is important to allow for gas recycling.

Therefore, two distinguishing feature come out. One is overheating the liquid metal and the other is geometry of nozzle and gas pressure. These factors increases the investment and the product cost.

In the present work principle of atomization method is different from known usual gas atomization in respect of melting unit. Instead of using furnace and tundish, two metal wires are melted by means of an electric arc and atomized by air jet. Because of this, in this set-up melting unit is omitted. Since the metal wires are melted by an electric arc, the temperature of the molten metal at the burning place reaches to about 5000 ^{0}C [23]. By this way, over heating temperature is reached and molten metal become suitable for atomization. At this point, single type air nozzle which was located directly in line with the intersecting of wires, sprays the air and disintegrates the molten metal.

By considering the experimental results and all above conditions, it is possible to say that an electric arc atomization method has advantages over usual gas atomization process in that points:

a) Economical reasons. Initial set-up cost is very low according to usual gas atomization process.

b) Physical properties. Melting and over heating of these metals are easy and cheap.

c) A simple air nozzle.

d) Relatively low air pressure

In the following sections, performance of steel, brass and aluminium atomization will be discussed by paying special attention to atomization parameters.

6.3 ATOMIZATION CONDITIONS

In the experiments many trial runs were carried out. In order to obtain the optimum conditions, parameters such as voltage, electrode angle, wire diameter and feed rate were changed by observing the results.

During the experiments arc length and arc stability observed carefully. If the arc length is not satisfactory or the arc is unstable, it was seen that the particle size is very coarse. Sometimes, arc did not strike between the electrodes. The reason is the selection of incorrect voltage or feed rate. Since the power source is constant voltage type, only voltage is adjusted and corresponding current was recorded. It was clearly seen that the increment in the current is very closely related to feed rate and electrode diameter. Current increases if the feed rate or electrode diameter increases.

Feed drive and control mechanisms were provided to control the feeding of the two wire electrodes. Since the melting conditions of anode and cathode are different the arc burning point moves out of the centre of the air gun. But this difficulty was eliminated by adjusting the wire feed speed. Also high pressurised air gas aids to keep the arc position in a constant place [33].

In the experiments, it was shown that high air pressure decreases the powder particle size. Therefore air supply was adjusted to practically available maximum value.

6.4 STEEL ATOMIZATION

Experiments were carried out in two different angles 45 and 60 degrees and voltages were changed from 23 volt to 34 volt. The voltages

smaller than 23 and higher than 34 volts didn't give satisfactory results. Also, according to the wire diameter voltage range changes.

In the 2 mm steel wire atomization voltage has a big range of 23 V to 34 V while the current has range between 80 A. to 100 A. Feed rate was arranged to obtain the stable arc. According to the results there is not very close relation between the voltage and current.

In the 2.5 mm steel wire atomization one distinguishing feature from the 2 mm steel wire is the current. The amount of current is almost two times than the 2 mm steel wire because of the wire diameter. The rate of feed rate was not changed in a big amount of range.

As well as 3 mm steel wire is concerned, if the angle is changed from 60 to 45 degree, it is necessary to decrease the feed rate because of the arc stability. On the other hand, current is rather high by comparing the 2 mm and 2.5 mm steel wires. At this point, it is clearly seen that the increment in wire diameter causes the considerable increment in current. During the 3 mm steel wire experiments, voltage is changing in a range from 24 V to 33 V. Voltages which are smaller than 24 volt and higher than 33 volt. do not give satisfactory result for 3 mm steel wire.

6.5 BRASS ATOMIZATION

The experiments were repeated by using the same set-up and have been executed in the same manner. Voltage value was changed between 23 V. to 34 V. and the current was changed between 70-190 Amperes.

In the 2 mm brass wire atomization for 45 degree of electrode angle the voltage value should be at least 28 Volt Arc was not struck between the electrodes for the voltage value which is smaller than 28 volt and applied feed rate. The voltages less than 28 volt. and bigger than 34 volt., only one half of the anode (+) electrode could melted. Thus, voltage limits were defined between 28 and 31 volt for 45 degree of electrode angle. The appropriate feed rate is 310 cm/min. Contrary to 45 degree, 310 cm/min is not enough for 60 degree of electrode angle. It is

necessary to increase the feed rate up to 475 cm/min. At these conditions, it was seen very fine particles and mean powder size was very good with respect to 45 degree. Therefore it is observed that increment in the feed rate causes the increment of current.

During the 3 mm brass wire atomization, current was observed between the values of 137-157 amperes for a feed rate of 310 cm/min. In the same feed rate for steel atomization of 3 mm wire current was observed as 260-280 amperes. It is very clear that one of the parameter that effecting the current is the material type. For 3 mm brass wire atomization experiments were executed from 23 Volt to 30 Volt and different feed rates were also examined. But, only feed rates which are changing from 300 to 350 cm/min gave relatively better results.

6.6 ALUMINIUM ATOMIZATION

All experiments showed that smaller wire diameters give finer powder particle size. Because of this reason only 2 mm aluminium wires were atomized.

For 45 degree of electrode angle satisfied voltage values are recorded between 25 V. to 27 V. Corresponding current is very low according to other experiments. Approximately 40 amperes was enough to melt the wires.

On the other hand for 60 degree of electrode angle, voltage range was recorded between 28 volt to 30 volt. Besides of these, it was necessary to increase the feed rate. But, due to the increment in the feed rate, current was risen about three times.

In the aluminium atomization, metal powders have finer sizes in 45 degree of electrode angle according to 60 degree of electrode angle.

6.7 CONCLUSIONS

An analysis of the effect at which various operating conditions have on particle size provides the following conclusions:

1) An experimental gas atomization apparatus was modified and effecting factors to metal powder have been investigated.

2) Minimum average powder sizes for steel, brass and aluminium are 121 μm, 88 μm and 88 μm respectively.

3) Steel powders have a spherical shape and there are holes in the powders. But brass and aluminium powders have a complex shape. Their shapes and mean particle sizes are very suitable for powder metallurgy applications.

4) Maximum production rates are for steel, brass and aluminium are 19.1 kg/hr., 23.8 kg/hr. and 6kg/hr. respectively.

5) Operating parameters controlled easily.

6) Varying atomising gas pressure over the range of 3-10 Atm. causes the droplets to be smaller with increase in atomising air pressure.

7) By the use of smaller wire size, finer powder particles were produced. This is determined by the use of 2 mm, 2.5 mm and 3 mm electrode wires.

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APPENDIX A

Static Characteristics of Power Source

All welding power sources have two kinds of operating characteristics, each one effects their performance in different ways. These are:

a) Dynamic characteristic
b) Static characteristic

The dynamic characteristic of an arc welding power source is determined by the transient variations in output current and voltage that appear in the arc. Dynamic characteristic describe instantaneous variations or those that occur during very short intervals of time, such as 0.001 second. Static characteristics are measured over longer periods of time under steady state conditions.

The static characteristic outputs can be measured by conventional test procedures. A volt - ampere curves are usually used to describe the static characteristics.

Arc stability is determined by the combination of the static and dynamic characteristics of the arc welding power supply. But the classification of power sources are based on the static characteristics of the power supply, not the dynamic characteristics. Voltage or current which is defining the static characteristic, of the power source are available that will hold output relatively constant. Constant current power sources are also referred to as variable voltage sources, and constant voltage power sources are often called constant potential supplies. Typical sets of V-I curves for constant voltage and for constant current type power sources are shown in Figure A.1. Essentially, the degree of slope is the major difference between constant current and constant

voltage power sources [25]. Slope is the slant of the V-I curve, measured at the output terminals of the power supply under varying load conditions.

Figure A.1.a shows the V-I curve of the constant voltage D.C. supply. The voltage-current characteristic curve which should be flat or level in a true constant voltage supply, is usually designed to have a slight droop.

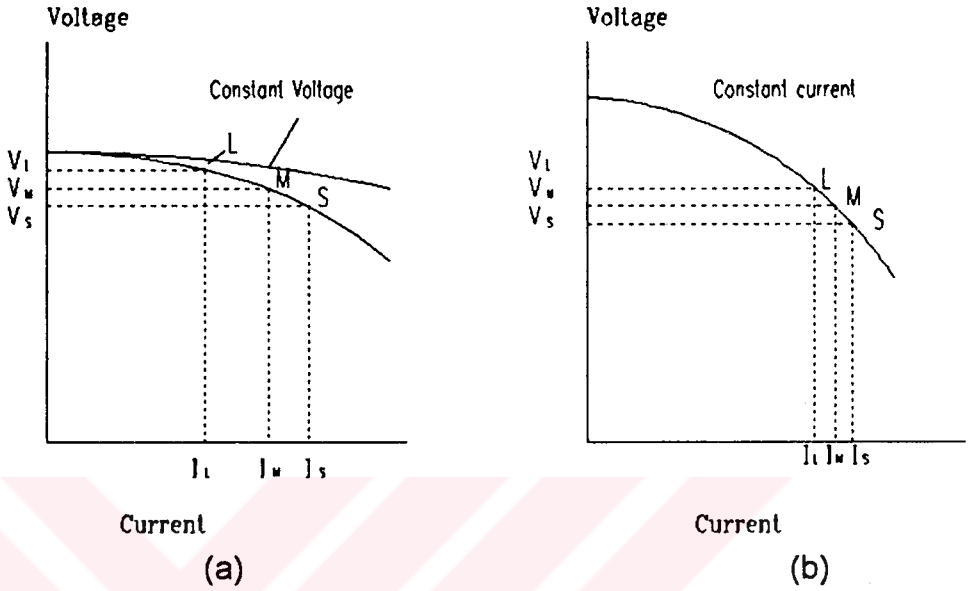

Figure A.1 Static Characteristics of Power Source

This units maintains an almost constant arc voltage irrespective of the current flowing. For the arc to function correctly the rate of wire feed must be exactly balanced by the burn off rate to keep the arc length constant.

In Figure A.1.a, suppose the normal arc length is that with voltage drop V_m indicated at M and the current for this length is I_m amperes. If the arc shortens (manually or due to slight variations in feeding or any other reason) to S the (volts drop is now V_S) the current now increases to I_S, increasing the burn off rate, and the arc is lengthened to M. Similarly if the arc lengthens to L, current decreases to I_L and burn off rate decreases, and the arc shortens to M [26]. The V-I curve of constant current D.C. supply is shown in Figure A.1.b.

With this system the D.C. supply is obtained from a welding generator with a drooping characteristic or more usually from a transformer-rectifier unit. The characteristic curve of this type of supply which was shown in Figure A.1.b shows that the voltage falls considerably as the current increases. If normal arc length M has volts drop V_m and if the arc length increases to L, the volts drop increases substantially to V_L. If the arc is shortened the volts drop falls to V_s while the current does not vary greatly, hence the name constant current which is often given to this type of supply. The variations in voltage due to changing arc length are fed through control gear to the wire feed motor, the speed of which is thus varied so as to keep a constant arc length, the motor speeding up as arc lengthens and slowing down as the arc shortens. With this system , the current must be selected for given welding conditions [26].

It has been suggested that only a power source having a static characteristic of absolutely flat slope (constant voltage) type is usable for standard two wire type electric arc metallizing applications [25]. However, it has been found that in order to utilize a whole range of materials such as molybdenum, steel, nickel, copper, bronzes, aluminium, zinc, etc. over a full range of wire feed rates (starting from the minimum rate consistent with obtaining a constant feed rate up to the maximum load capability of the power source) it is most useful, if not essential in some cases, to have varying degrees of controlled slope. The value for slope characteristic which has been found useful in general is 2-3 volts per 100 amperes. This level is most useful, since during the period of arc ignition, a considerably higher voltage is present across the electrodes in order to assure a more reliable initiation of the arc. As soon as the arc is struck, current is drawn from the power source and the voltage drops to a desired lower level optimally selected for stable arc conditions consistent with the minimum voltage required to produce minimum burn-off or chemical change in the material being sprayed. Specifically, this static slope characteristic has been found most useful in the applications involving materials such as copper, aluminium and in general any material which has a relatively high specific electrical conductivity. Therefore, it should be considered that a power source having a slope characteristic of 2 or 3 volts per 100 amperes possesses the facility for

automatically regulating arc voltages to be consistent with the conditions of spraying, arc ignition or running.

Furthermore, it has been found that in applications of electric-arc metallizing with low melting temperature type electrode materials such as zinc, lead, tin, etc. and where it may be found desirable under certain circumstances to utilize low to medium wire feed rates, difficulty has been encountered in maintaining stable arc conditions. The arc condition which has been noted for this type of application with the use of power supply having minimum slope, is such that there is a continuous making and braking of the arc, yielding a bursting effect. This bursting effect is cyclic at a rate of approximately 2 to 3 burst per second for the minimum wire feed rates. Upon visual and analytical study of the arc under these conditions, it was concluded that due to the high intensity of radiation of thermal energy in the region near the arc and due to the low melting temperature of material and its relatively slow motion at low wire feed rates, the electrodes tend to melt back from the arc, causing the arc length to become extended beyond a point which could be sustained by the arc voltage applied to the electrodes. It would be well to note that arc length is a function of arc voltage [25]. At the point where the arc length extended beyond the stable point, the arc extinguishes and re-ignites itself as the electrodes proceed to contact again.

A power source having steep static slope characteristics of the constant current type was found to completely eliminate this condition. The arc voltage can vary over a relatively broad range with negligible effect on the arc current. Under this condition the power supply voltage was found to cyclically vary to follow the cyclic variations of arc length, thereby sustaining stable arc conditions.

Essentially then it should be considered that a power supply having steep static slope characteristics is suitable for improving the application capability of electric arc metallizing systems in the area of low and medium spray rate of low melting point type electrode materials. Therefore, it is possible to utilize constant current type power supplies for general electric arc metallizing applications as well as specific problem solving such as just described.