Micro Structural and Mechanical Characterization of Spray Formed Al-10 Wt. % Cu Alloy.

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Abstract:- **Aluminium is remarkable for the metals which is having low density for its ability to resisit corrosion due to phenomenon of passivation. The copper has been the most common alloying element almost since the begning of the aliminium industry, and variety of alloys in which copper is major addition were developed. The addition of copper to pure aluminium improves the Mechanical and structural properties. Aluminium copper alloy of copper content 10% is subjected to spray automization and the Micro structural characterstics of spray formed aloy is compared with the die cast alloy.**

Key words: Aluminium, copper, Mechanical properties structural properties, Spray automization.

1. INTRODUCTION:

Aluminum is the second most widely used metal due to its desirable chemical, physical & mechanical properties and it represents an important category of technological materials. Due to its high strength to weight ratio, besides other desirable properties ex. Desirable appearance, non-toxic, non-sparking, non-magnetic, high corrosion resistance, high electrical and thermal conductivities and ease of fabrication. . Copper has greatest impact of all alloying elements on the strength and hardness of aluminum casting alloys, both heat-treated and not heat-treated and at both ambient and elevated service temperatures. Copper also improves the machinability of alloys by increasing matrix hardness, making it easier to generate small cutting chips and fine machined finishes. Addition of copper to pure aluminium transforms the columnar structure to equi-axial grains, also addition of copper to commercially pure aluminium resulted in linear increase of hardness and also mechanical properties.
Al-rich end of the Al-Cu phase diagram is as shown.

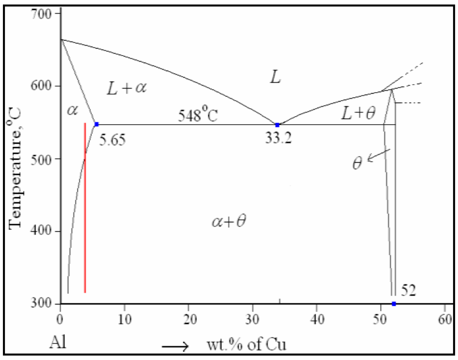


Fig.1: phase Diagram of Al-Cu alloy

The above phase diagram represents only Al rich end of the phase diagram, now let us study the phase diagram of Al-10wt. % Cu alloy.
As it can be observed the melting temperature of Al -10 Cu alloy is about 660oC and that of Al-25 Cu alloy is around 600oC At the point T the molten metal starts to solidify forming two phases α and L as the solidification continues and the temperature reaches T1 the mixture consists of 95% Al and 5% Cu in α and the remaining liquid consists of 31% cu and 68% al as the temperature reaches eutectic phase the tendency of the remaining liquid would be to freeze and produce a finger print like microstructure on al matrix. As solidification continues and reaches temperature T2 below eutectic point mixture of α and θ is obtained where α is Al solid solution and θ is the Cu Al2 precipitates, hence the micro structure below the eutectic temperature is purely Cu Al2 precipitates on Al matrix.

2. CASTING:

Casting is a process of producing metal objects by pouring molten metal into a mould cavity and allows it to solidify. Generally metal casting is produced in sand and metal moulds. Casting or moulding, can be traced in history of 6000 years. As civilization progressed and the use of metals became more advanced, the technology of casting metals advanced as well.

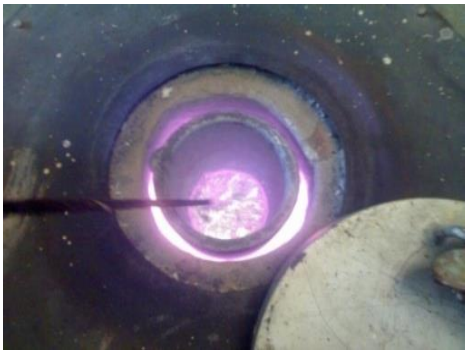


Fig.2.1: Molten metal in furnace.

Fig.2.2: Cast alloy

Spray formimg or spray automization:

Spray forming denotes the fabrication of metallic or ceramic materials in the of form of billets, plates, sheets, or tubes by melt automization and spray deposition onto a substrate. Since spray forming technologies like casting and forging this new tchnologies has to offer several advantages concerning the material properties of its products, such as the absence of macrosegregation, microstructural refinement including fine equiaxed grains, uniformly distrubuted and extremely fine percipitants and modified primary and secondary phases at the grain boundaries, low micro segregations and chemical homogeneity over the entire volume of the pre-product. There also exist some relationships to the metal coating technology of thermal spraying, especially to the high alloying flexibility by adding fine metal powders during the generation of metal coat here the generation of metal matrix composites.

3. EXPERIMENTAL SETUP:

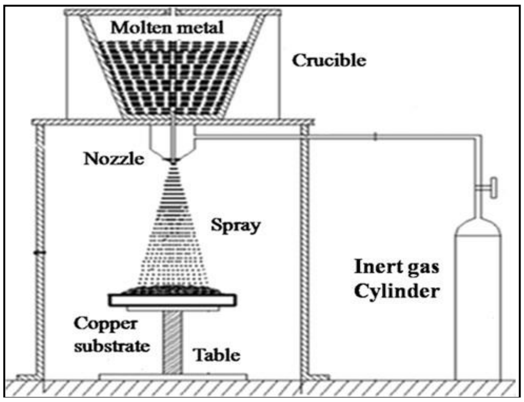


Fig.3: Spray Atomization Experimental set up

4. METHODOLOGY:

The methodology of the whole experiment involves:
1. Fabrication of the Spray forming experimental setup.
2. Casting process.
3. Conducting the experiments.
4. Processing of the obtained preform.
5. Observing the Micro Structure.
6. Finding density of obtained perform.
7. Finding mechanical properties (Hardness and tensile strength).

4.1 Micro structural characterization:

The Micro structure of an alloy refers to the internal structure of the alloy which can be observed from about 50X onwards up to about 1500X. This is different from the observation of crystal structure which needs more than 108 magnifications to study the basic arrangement of atoms.

Micro structure of an alloy would reveal the distribution of phases present in it and which is unique to each alloy.

In this particular experiment Micro structure is observed using:
1. Optical Microscopy.
2. Scanning Electron Microscopy.

4.1.1 Optical Microscopy:

The use of "Optical Microscopes" in "Materials Evaluation" is very popular since it enables the researcher to observe the "internal structure" of materials. This information can then be used to improve material processing and properties which form the foundation of materials science and engineering (MSE).

The microstructure generally ranges from the atomic scale (0.1nm) to 1mm (1000µm) with the most widely used scale of 1-1000 µm. Practically the optical microscopes can be used up to 2000x at which the resolution becomes so poor that objects smaller than 1 µm cannot be distinguished. But since most materials have grain sizes in the range 1-100µm optical microscope is a perfect low cost tool. Typical micro structural features are grains (single crystal), precipitates, inclusions, pores, whiskers, defects, twin boundaries, etc. Most of the manufacturers use OMs for process control and R&D.

There are mainly two types of optical microscopes (OM): Reflected Light (RL) and Transmitted Light (TL). In the former the light is reflected from the surface of the specimen while in the latter the sample is so thin (20-50µm) that light passes through it. A third but less important type may be the stereo microscopes that do not require any sample prep and are generally used to observe fracture surfaces, electronic circuit boards, etc.

4.1.2 Scanning Electron Microscopy:

A scanning electron microscope (SEM) is a type of electron microscope that images a sample by scanning it with a beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition, and other properties such as electrical conductivity

Images in SEM is grabbed in 2 Ways

1. Secondary Electron Mode
2. Back Scattered Electron Mode

In Secondary Electron mode the electrons are produced by interactions between primary electrons and weakly bonded conduction band electrons

In Back Scattered Electron mode the electrons originate from primary electrons after scattered by nuclei of the atom.

4.2 Physical and Mechanical characterization:

4.2.1 Physical Property

1. Density

The density, or more precisely, the volumetric mass density, of a substance is its mass per unit volume. The symbol most often used for density is ρ (the lower case Greek letter rho). Mathematically, density is defined as mass divided by volume.

$$\rho = \frac{m}{v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where ρ is the density, m is the mass, and V is the volume. In some cases (for instance, in the United States oil and gas industry), density is loosely defined as its weight per unit volume, although this is scientifically inaccurate, this quantity is more specifically called specific weight. For a pure substance the density has the same numerical value as its mass concentration. Different materials usually have different densities, and density may be relevant to buoyancy, purity and packaging. Osmium and iridium are the densest known elements at standard conditions for temperature and pressure but certain chemical compounds may be denser.

To simplify comparisons of density across different systems of units, it is sometimes replaced by the dimensionless quantity "relative density" or "specific gravity", i.e. the ratio of the density of the material to that of a standard material, usually water. Thus a relative density less than one means that the substance floats in water. The density of a material varies with temperature and pressure. This variation is typically small for solids and liquids but much greater for gases. Increasing the pressure on an object decreases the volume of the object and thus increases its density. Increasing the temperature of a substance (with a few exceptions) decreases its density by increasing its volume. In most materials, heating the bottom of fluid results in convection of the heat from the bottom to the top, due to the decrease in the density of the heated fluid. This causes it to rise relative to more dense unheated material. The reciprocal of the density of a substance is occasionally called its specific volume, a term sometimes used in thermodynamics. Density is an intensive property in that increasing the amount of a substance does not increase its density; rather it increases its mass.

4.2.2 Mechanical Properties:

1. *Hardness*:

Hardness is a property of material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, abrasion or cutting and scratching.

However is not an intrinsic material property dictated by precise definition in terms of fundamental unit of mass, length and time. Hardness value is result of a defined measurement procedure. Pure metals are very soft and they have very less hardness. By adding some foreign particles the hardness of material increases rapidly. The hardness number of alloys also varies with alloy composition.

Vickers hardness test: it was developed in 1921 by Robert L. smith and George E. sandland at Vickers limited as an alternative to the brinnel method to measure the hardness of material the Vickers test is often easier to use then other hardness test since the require calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is to observe the questioned materials ability to resist plastic deformation from a standard source. The unit of hardness given by test is known as Vickers pyramid number (HV) or diamond pyramid hardness (DPH). The hardness number can be converted into units of Pascal‟s. The hardness number is determined by the load over the surface area of the indentation and not the area normal to force, and is therefore not a pressure

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base with an angle of 136 degrees between opposite faces subjected to a load of 1-100kg force. The full load is normally applied for 10-15secods. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm of indentation.

2. Tensile strength:

In the study of strength of materials, the tensile strength is the capacity of a material or structure to withstand while being stretched or pulled before failing or breaking. It can be measured by plotting applied force against deformation in a testing machine. Some materials will break sharply, without plastic deformation, in what is called a brittle failure. Others, which are more ductile, including most metals, will experience some plastic deformation and possibly necking before fracture.

- *Tensile strength is measured on materials, components and structures*

The Ultimate Tensile Strength (UTS) is usually found by performing a tensile test and recording the engineering stress versus strain. The highest point of the stress-strain curve is the UTS. It is an intensive property; therefore its value does not depend on the size of the test specimen. However, it is dependent on other factors, such as the preparation of the specimen, the presence or otherwise of surface defects, and the temperature of the test environment and material.

5. RESULTS AND DISSUCTIONS:

Microstructure of spray formed and as cast alloys were observed using Optical Microscopy and Scanning Electronic Microscopy.

5.1 Optical micrographs:

100X magnification

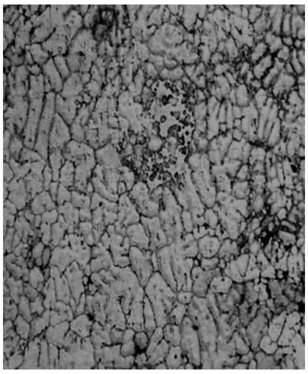


Fig.5.1: As Cast Al-10 wt .% Cu alloy

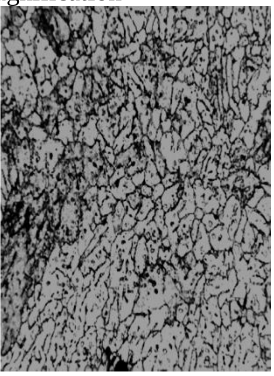


Fig.5.2: Spray Formed Al-10 wt. % Cu alloy

200X Magnification

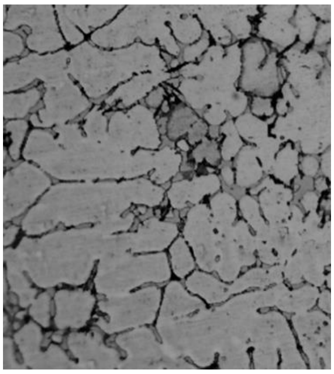


Fig.5.3: As Cast Al-10 wt. %Cu alloy

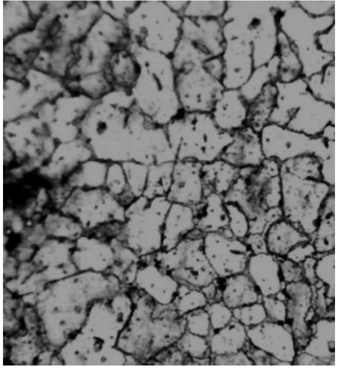


Fig.5.4: Spray Formed Al-10 wt. %Cu alloy

500X Magnification

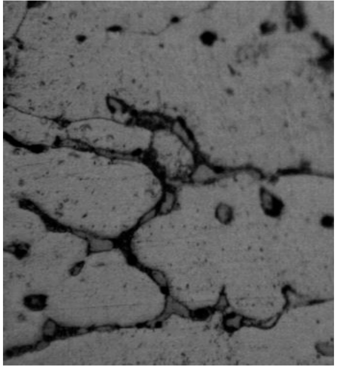


Fig.5.5: As Cast Al-10wt. % Cu alloy

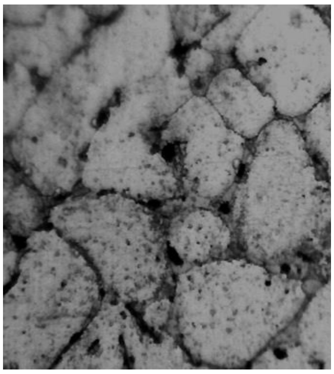


Fig.5.6: Spray Formed Al-10 wt.% Cu alloy

5.2 Scanning Electron Microscopy:

200X Magnification

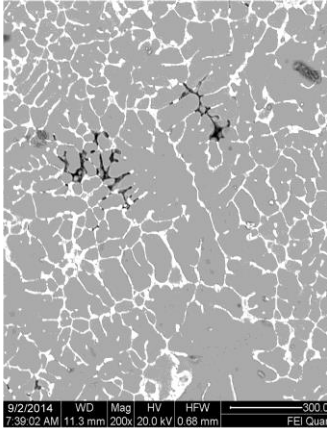


Fig.4.7: As Cast Al-10 wt. %Cu alloy

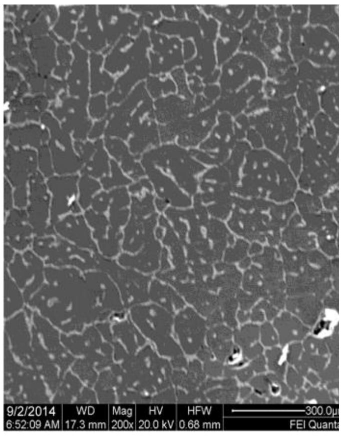


Fig.4.8: Spray Formed Al-10 wt. %Cu alloy.

500X Magnification

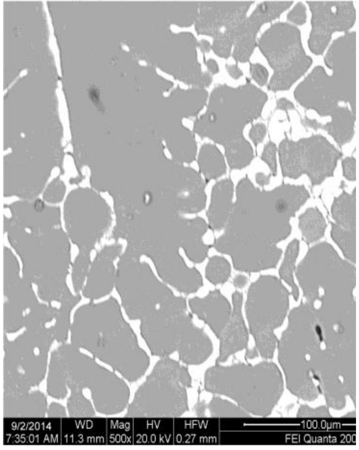


Fig.4.9:As Cast Al-10 wt .%Cu alloy

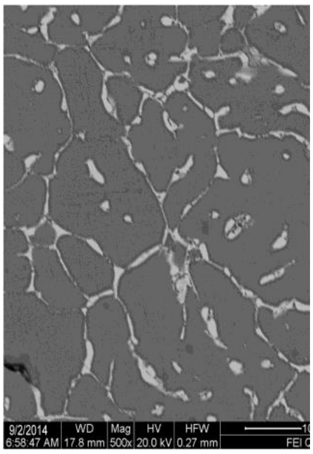


Fig.4.10: Spray Formed Al-10 wt. %Cu alloy

1000X Magnification

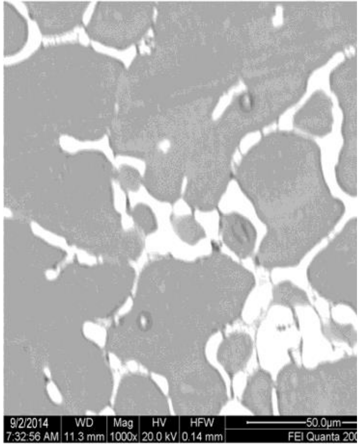


Fig.4.11: As cast Al-10 wt. %Cu alloy

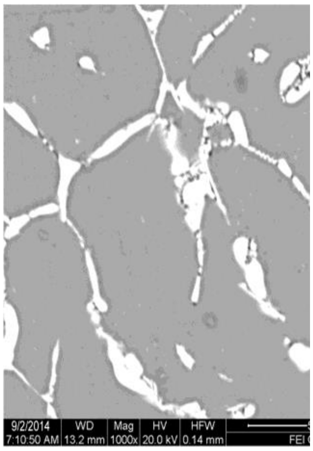
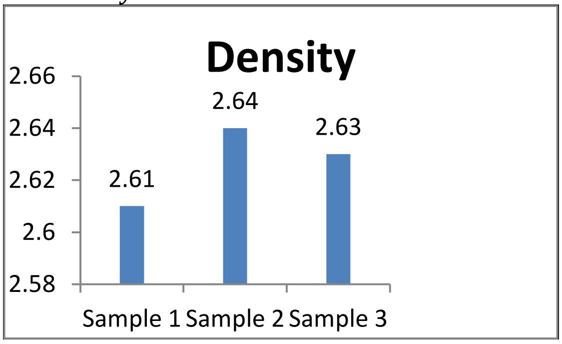
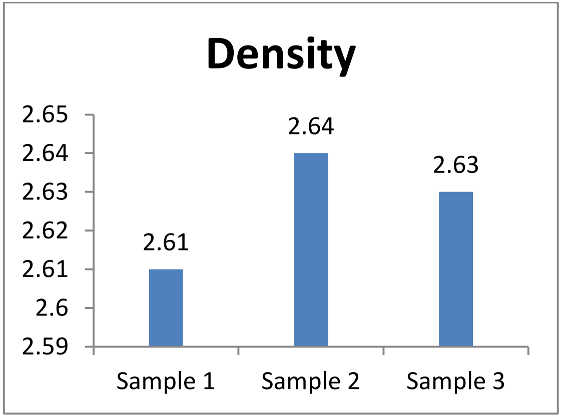


Fig.4.12: Spray Formed Al-10 wt.% Cu alloy

5.3 Density:



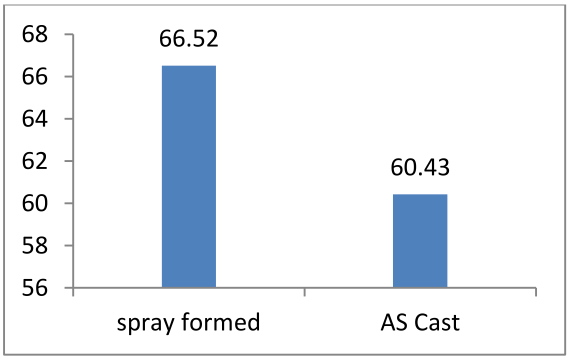
Density of Al-10wt. % Cu alloy of Spray Formed



Density of Al-10wt. % Cu alloy of as cast

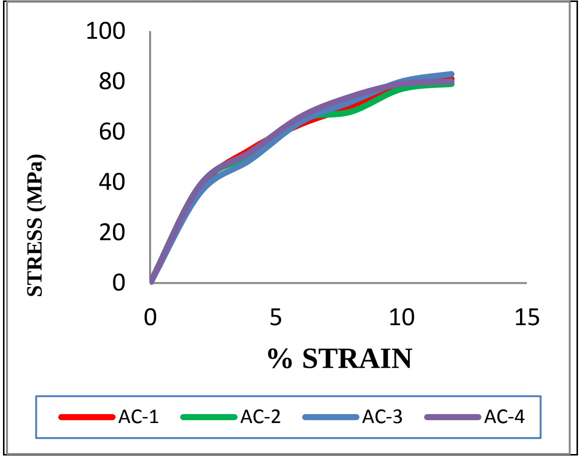
5.4 Mechanical Properties:

1. Hardness:

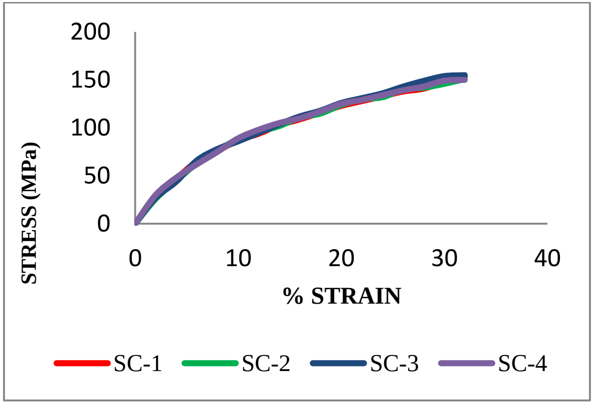


Hardness of AC and SF Al-10 wt. % Cu alloy

2. Tensile strength:



Stress v/s Strain curve of Al-10 wt. % Cu alloy for As Cast



Stress v/s Strain curve of Al-10 wt. % Cu alloy for Spray formed

6. DISCUSSION:

Al-10 wt .% Cu alloy was spray formed by maintaining the process parameters as given below

- Gas pressure 100 bar.
- Melt Temperature (7500C).
- Spray Height (350mm).

Rapid solidification effects inherent in spray deposition process due to high heat exchange rate at the droplet-gas interface and also on the deposition surface ensures considerable chemical and micro structural homogeneity of the spray-deposit. In addition, formation of equiaxed grain morphology and dispersion of ultrafine second phase particles are often the characteristic micro structural features of spray formed alloys. [03]

The evolution of microstructure during spray deposition depends in a complex way on droplet dynamics and their thermal state on the deposition surface. These are controlled by process variables employed to atomize the melt, nozzle-substrate distance and design of spray nozzles [03]. Process modeling based on solidification and heat flow analysis is often used to suggest that the solid fraction in the spray arriving on the deposition surface is critical to control the microstructure and porosity of the spray-deposit. Generally, a too high liquid fraction on the deposition surface results in splashing of the melt from the deposition surface by high-velocity gas jets and formation of large size pores due to gas entrapment. In this case, the microstructure of the spray-deposit resembles with a typical cast structure. Alternatively, an excess solid fraction in the spray generates a large number of porosity due to insufficient liquid phase available to provide bonding of particles during solidification of the spray-deposit. Such a deposit requires secondary processing to reduce porosity and to achieve micro structural homogeneity of the alloy.

The micro structural variation presented above is rationalized in light of the alloy composition and conditions of solidification of droplets during flight as well as the spray-deposit during spray forming process. Subsequent to atomization of the melt, a wide size range of droplets are generated in the spray Rapid solidification effects are induced in small size droplets due to high heat transfer rate at the droplet-gas interface and their large under cooling during solidification. This condition is often desirable to achieve reduced segregation and refinement in grain size. Due to the significant heat sink effect of the spray jet as it entrain large volume of gas at ambient temperature; the spray comprises solid particles and fully or partially liquid droplets during time of deposition. The fraction of solid changes with size of droplets and their fight distance from the atomization zone.

During spray deposition droplets impinge on the deposition surface with high velocities. Consequently, cells and dendrites of semi-solid and semi-liquid droplets are disintegrated into fine debris particles. This effect is more severe as the copper content increases due to increased liquid fraction on the deposition surface arising from large number of droplets in the mushy state. These debris particles either re- melt or coarsen by coalescence depending on the volume fraction of the liquid phase on the deposition surface . The large number of debris particles increases the nucleation frequency of the melt on the deposition surface. At the same time, spherodization of debris particles is also facilitated at high temperature.

In addition, the fluid flow on deposition surface ensures homogenization of temperature and composition of the melt. This condition is not favorable for dendritic growth of the primary -phase due to lack of constitutional super cooling of the melt ahead growing interface. Consequently development of a non-dendritic equiaxed grain microstructure arises during freezing of the melt on the deposition surface.

At the beginning of deposition process, the droplets splat on the substrate and experience a high cooling rate that depends upon the thermal conductivity of the substrate and its temperature. Therefore, the deposit exhibits a fine microstructure in the vicinity of the substrate. The heat transfer by convection at this stage remains insignificant as most of the heat transfer takes place by conduction through the substrate. As the thickness of the deposit increases, the temperature gradient within the growing perform becomes smaller as well as the substrate temperature rises. As a result, heat transfer by conduction becomes slow and a large fraction of heat removal is achieved by convective mode of heat transfer, and a liquid pool builds up in the top layer of the growing preform. The thickness of this pool increases with increase in the deposit thickness until a steady state condition is achieved. This corresponds to a situation when heat transfer through the substrate becomes insignificant compared to heat removal by forced convection. The transient thickness of deposit before the onset of steady state depends mainly on the conductivity of the substrate, conductivity of the deposited material and arrangements employed for the cooling of the substrate. Solidification of liquid pool under steady state condition gives rise to uniform micro structural features in the preform. However, the fine microstructure in the vicinity of the substrate experiences a longer high temperature exposure due to heat flow during further deposition period. As a result, the microstructure becomes slightly coarser but not comparable to that observed in the steady state condition. High momentum transfer from the droplets creates a turbulent fluid flow condition apart from the fragmentation of solid phases existing in the droplets as well as in the solidifying liquid pool. The two processes concurrently lead to refinement and modification of microstructure in the preform. In addition, constrained growth at reduced temperature, inherent in spray deposition process, leads to finer microstructure.

7. CONCLUSION:

The project entitled “Micro structural and mechanical Characterization of Spray formed Al-10wt. % Cu alloy” has been successfully completed by, firstly fabricating the experimental setup , conducting the experiment and comparing the microstructures of spray formed alloy with the as cast alloy.

Al-10 wt .% Cu alloy was sprayed on a copper substrate at a spray height of about 350mm and also these alloys were subjected to casting in a metal mould with a riser and the microstructure of these cast and spray formed alloys were observed and compared , the microstructure of spray formed alloy showed fine equiaxed microstructure as compared to the cast alloy, as the Mechanical properties is a reflection of these microstructures some considerable changes can be observed in the Strength of these spray formed alloys.Mechanical properties such as hardness and tensile strength are incresed in spray forming.

8. SCOPE FOR FUTURE WORK:

In this present work the structural characterization like optical microscopy and scanning electron microscopy tests have been done .Further X-Ray diffraction and Transmission electron microscopy can be done which gives the information about the topographical, morphological, compositional and crystalline structure of the sample. The composition can be varied & the same testing can be conducted.

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