Design and Development of Spray Atomization Process for Atomization of Light Structural Alloys

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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 4.5% is subjected to spray automization and the Micro structural characterstics of spray formed aloy was analysed by optical metallurgical microscope. The mechanical properties were determined by conducting the hardness test and tensile test.

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

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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.

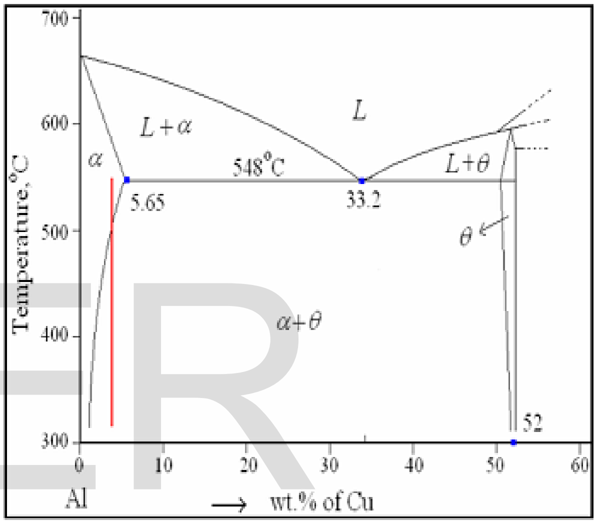


Fig.1: phase Diagram of Al-Cu alloy

The above phase diagram represents only Al rich end of the phase diagram, now let us study the phase diagram of Al4.5wt. % Cu alloy. As it can be observed the melting temperature of Al -4.5% 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.

1.1 DIE CASTING: Now what is this die casting? Why we should go for die casting? Let us see, first of all what is the drawback of sand moulding process? Why we should go, what say live sand moulding, and why we should switch over to die casting. In the case of the sand casting, a separate mould has to be made in each and every case. If we want to make a sand casting, initially we have to make the pattern, then we have to make the mould, then we pour the molten metal. Once we pour the molten metal once the molten metal is solidified we break that sand mould, and the mould is no more permanent. If we want to make another casting, again we have to make another mould and we have to pour, likewise in each and every case we have to make a separate mould. So, this involves lot of labour and also it increases the cost of production and also productivity will be lesser.

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.

1.2 SPRAY FORMING OR SPRAY ATOMIZATION Spray atomization is the transformation of a liquid into a spray of fine particles in a vacuum or a surrounding gas. A spray nozzle is used to generate the atomized spray, which passes through an orifice at high pressure and in a controlled manner.The conversion of bulk liquid into a dispersion of small droplets ranging in size from submicron to several hundred microns (micrometers) in diameter is of importance in many industrial processes such as spray combustion, spray drying, evaporative cooling, spray coating, and drop spraying; and has many other applications in medicine, meteorology, and printing. Numerous spray devices have been developed which are generally designated as atomisers, applicator,sprayer, nozzles. Spray forming involves sequential gas atomisation of melt into a spray of fine droplets deposition on substrate to build up a high density perform. The rapid solidification inherent in spray deposition generates refined, equated and low segregation microstructures.

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.

2. EXPERIMENTAL SETUP

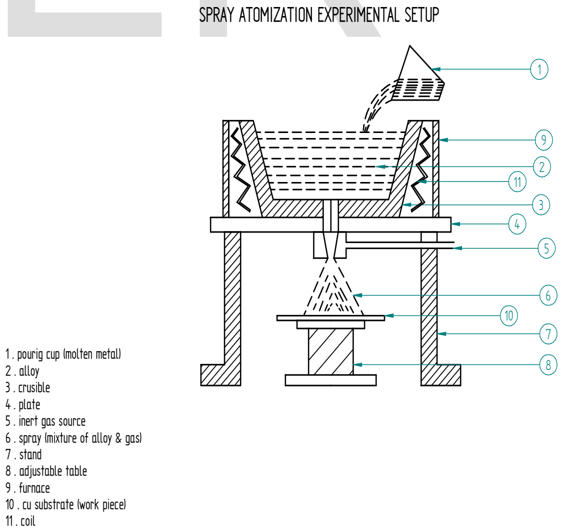
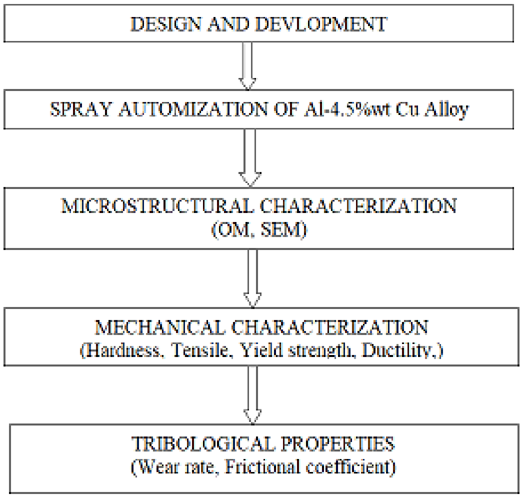


Fig.1 Schematic view of spray atomization experimetal setup.

2.1 METHODOLAGY



2.2 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.

2.3 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.

2.4 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

2.5 Physical and Mechanical characterization:

- Physical Property

➢ **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.

$\rho = m\ v$ ……………………… (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.

2.6 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.

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

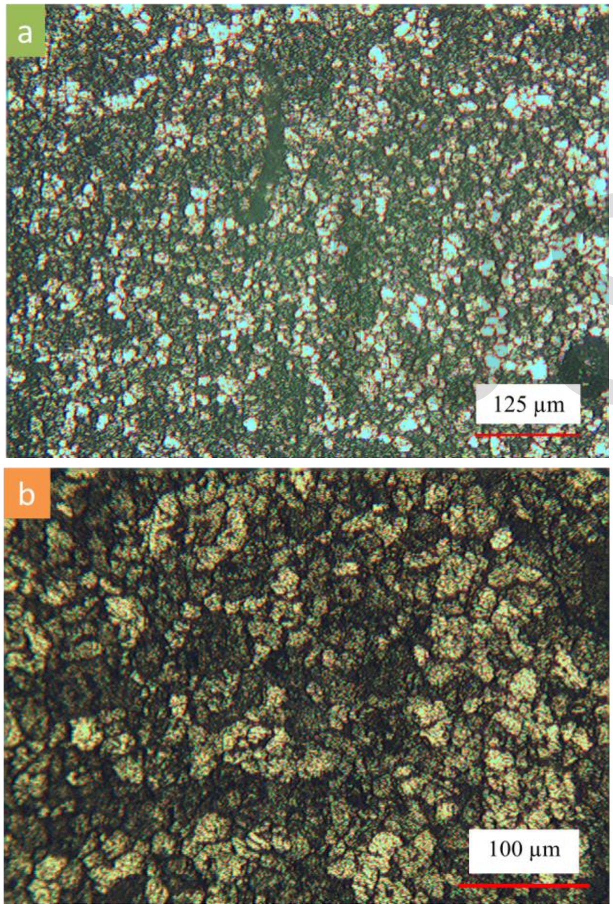
  The Ultimate Tensile Strength (UTS) is usually found by performing a tensile test and recording the engineering stress versus strain. The highest point of the stress-strain curve is the UTS. It is an intensive property; therefore its value does not depend on the size of the test specimen. However, it 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.

3 RESULTS AND DISSUCTIONS:

- Microstructure of spray formed billet is observed in optical microscope and scanning electron microscope. By the observation we get the scanning images from both OM and SEM as follows.And also we find the density, hardness and tensile tests for Al-4.5 wt.% Cu alloy.

- Grain size measured with the help of line intercept method,found to be 35 to 40 microns.
- Compared to as casting process grain size is very less and cooling in a casting is 10^3 degree C/sec. Where in the spray atomization process process the cooling rate 10^6 degree C/sec.
- The provisions for nuclear size is more then compared to as cast process
- Spray atomization is compresses of solid, liquid and semi liquid particles due to this reasons number of nuclear are provided

3.1 Optical micrographs



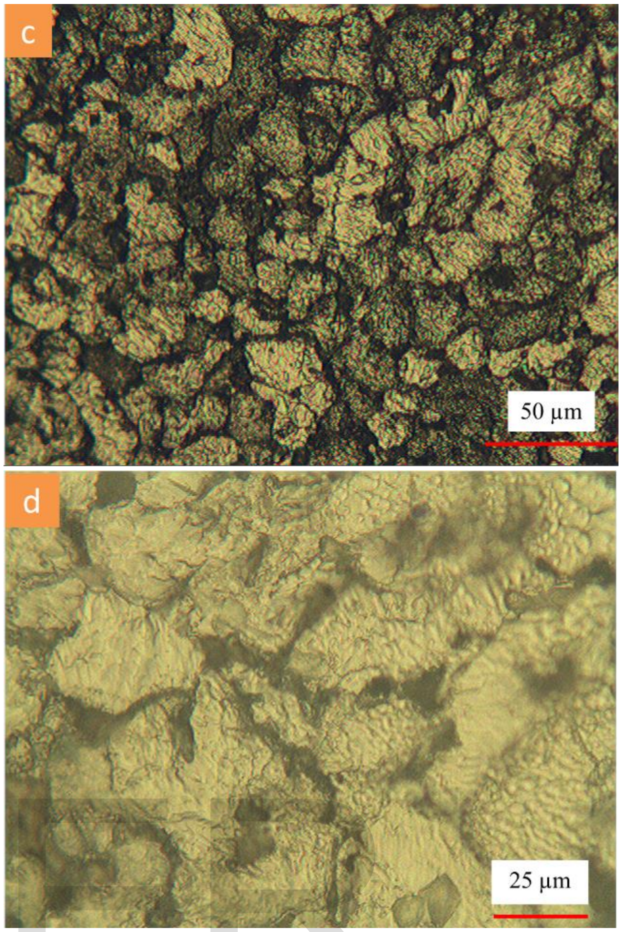
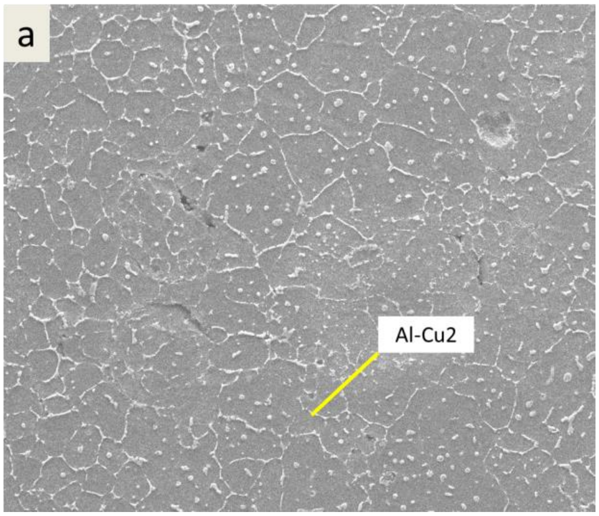


Fig 4.1. Optical micrographs (a-50X, b-100X, c-200X, d-500X magnifications)

3.2 Scanning electron micrographs



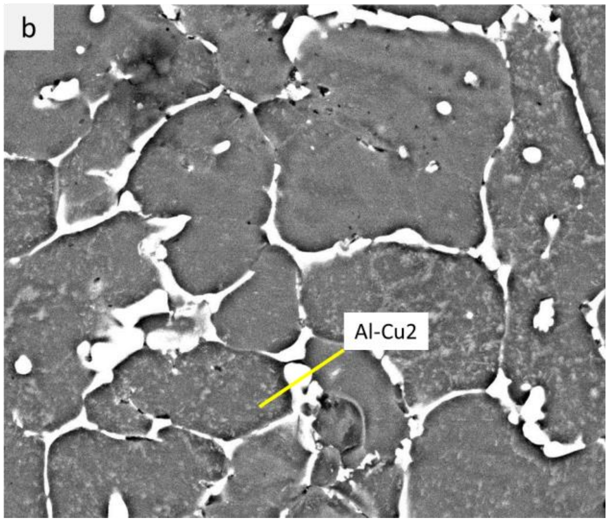


Fig 4.2. Scanning electron micrographs (a-200X, b-800X magnifications)

3.3 Density of spray formig

- After conducting density result we conclude density is decreasing compared to the as cast process because of porosity.
- 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.

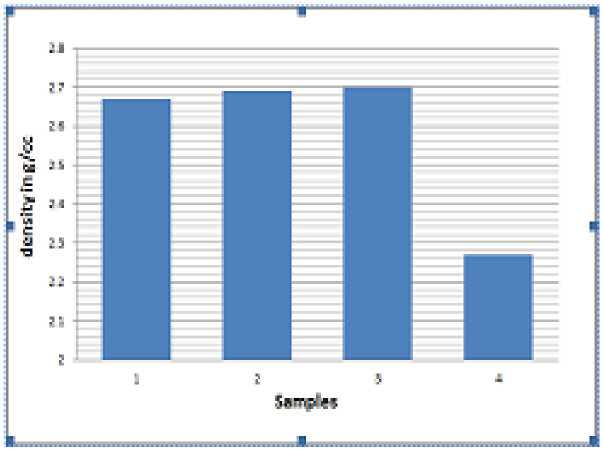


Fig4.3.Density graph of spray formed Al-4.5wt.%Cu alloy.

3.4 Hardness of spray atomization

- Hardness of spray atomization more compared to the die casting because of grain refinement there is a uniform distributions in a particles within a range.
- The secondary phase also distribution along the grain boundary.
- The dislocation are interacting the particles.
- The grain boundary strengthening mechanism place a vary important role. for showing more high yield strength and hardness.
- The particles acts as abstracles for dislocation moment from one place to another place or location.

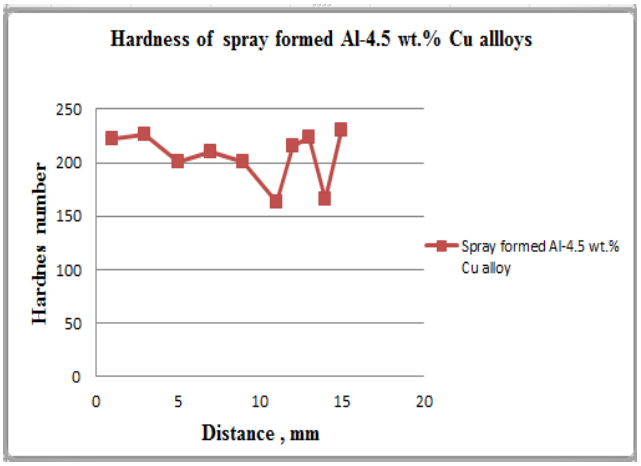


Fig 4.4 Hardness of spray formed Al-4.5wt.% Cu alloy

3.5 Tensile test for spray atomization

- Yield strength of spray atomization alloy is increasing at the cost of ductility that means the ductility will be decreasing by increasing yield strength.
- 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.

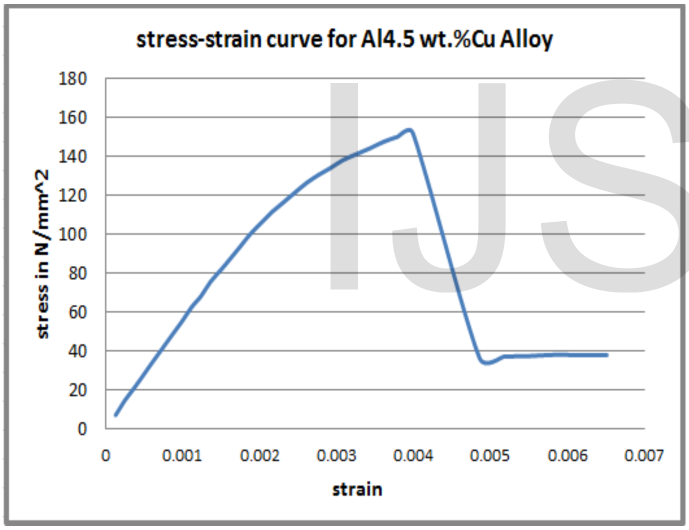


Fig 4.5. Stress-Strain curve of spray formed Al-4.5 wt.% Cu alloy

3.6 DISCUSSION: Al-4.5wt%Cu alloy was spray formed by maintaining the process parameters as given below

☐ Gas pressure 10 bar.
☐ Melt Temperature (950 C).
☐ 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. 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. 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 spraydeposit. 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.

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.

CONCLUSION:

The project entitled “Micro structural and mechanical Characterization of Spray formed Al-4.5wt. % 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.

conducting the experiment. Al-4.5wt .% Cu alloy was sprayed on a copper substrate at a spray height of about 400mm and the microstructure of spray formed alloy were observed, the microstructure of spray formed alloy showed fine equiaxed microstructure. The gas size of the spray atomization alloy found to absorbed as 30 to 40 microns, this is due to increasing cooling rate. The decreasing density compare to the as casting process is because of presence of porosity. The hardness of spray atomization Al-4.5%Cu alloy found to be 60 micro meter to grain refinement because of rapid solidification. 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.

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.

REFERENCES:

1. M.M. Sharma a, M.F. Amateau b , T.J. Eden c, Mesoscopic structure control of spray formed high strength Al–Zn–Mg–Cu alloys, Journal ActaMaterialia, 53, (2005), 2919–2924.
2. P. S Grant, W. T. Kim and B. Cantor, Spray forming of aluminium-copper alloys, Journal on Materials Science and Engineering, A 134, (1991), 124- 132.
3. K.V. Ojha∗, ArunaTomar, Devendra Singh, G.C. Kaushal, Shape, microstructure and wear of spray formed hypoeutectic Al–Si alloys, Journal on Materials Science and Engineering A 487 (2008), 591–596.
4. M.M. Sharma a,M.F. Amateau b, T.J. Eden c, Hardening mechanisms of spray formed Al–Zn–Mg–Cu alloys with scandium and Other element additions. Journal on Alloys and Compounds 416 (2006) 135–142.
5. Gokhanbalik, Danish malik, The use of air atomizing nozzles to produce spray with fine droplets
6. Monika Michalak, AndrzejAmbroziak, Katarzyanzegle, Manufacturing of powders by the method of metal spraying from the liquid phase, Journal of Engineering science-(2016) 156-178.
7. Lawley, Naikel john Atomization in material science and technology-(2015) 201-225.
8. Nikolay A., G. Yefimov Experimental of non ferrous metal powders, Journal on Powders with quasicrystaline structure-(2019) 1125-1132.
9. Oleg D., Neikovsymol Experimental of non ferrous metal powder, Journal on Production of aluminium alloy powders-(2019) 525-534.

10. A.K. Srivastava, S.N. Ojha, S. Ranganatan, Microstructural featured associated with spray atomization and deposition of Al-Mn-Cr-Si alloy, Journal on Material science- January (2001)456-463.
11. Ali Asgarian, Cheng-Tse Wu, Doghui Li, Kinnor Chattopadhyay, Experimental and computational analysis of water spray: Application to molten Metal Atomization- (2016) 224-239.