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STUDIES OF WORKPIECES OF ATOMIZED ALUMINUM POWDER OF 99.5% PURITY

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Abstract- Powder Metallurgy is a process that has been utilized for centuries, dating back to 2500 B.C. It has become one of the most common, most efficient processing techniques. Powder metallurgy components are being used in ever increasing quantities in a wide variety of industries as the technology combines unique technical features with cost effectiveness. Basic experiments were conducted on Copper and Aluminum metal powder performs. Atomized Aluminum powder of purity 99.5% and finer than 100 μm was used throughout the experiments. The results were plotted.

Keywords - powder metallurgy, aluminum powder

I. INTRODUCTION

Powder Metal components are used in the aerospace industry for gears and engine parts. However, they are also found in automobiles, sporting goods, and everyday household items. It is important, then, to understand the process, as it is becoming even more common as time goes by. Among the various metalworking technologies, powder metallurgy (P/M) is the most diverse manufacturing approach. One attraction of P/M is the ability to fabricate high quality, complex parts to close tolerances in an economical manner. In essence, P/M takes a metal powder with specific attributes of size, shape, and packing, and then converts it into a strong, precise, high performance shape. Key steps include the shaping or compaction of the powder and the subsequent thermal bonding of the particles by sintering. The process effectively uses automated operations with low relative energy consumption, high material utilization, and low capital costs. These characteristics make P/M well aligned with current concerns about productivity, energy, and raw materials. Consequently, the field is experiencing growth and replacing traditional metal-forming operations. Further, powder metallurgy is a flexible manufacturing process capable of delivering a wide range of new materials, microstructures, and properties. That creates several unique niche applications for P/M such as wear resistant composites. The applications of P/M are quite extensive. Consider the use of metal powders in the fabrication of tungsten lamp filaments, dental restorations, oil-less bearings, automotive transmission gears, armour piercing projectiles, electrical contacts, nuclear power fuel elements, orthopaedic implants, business machines, high-temperature filters, aircraft brake pads, rechargeable batteries, and jet engine components. Furthermore, metal powders find uses in such products as paint pigments, porous concretes, printed circuit boards, enriched flour, explosives, welding electrodes, rocket fuels, printing inks, brazing compounds, and catalysts. Worldwide market share for P/M parts are given in the following pie chart. Automotive industry is leading with more than 75% of the share. American cars contain more than 16 kg of P/M parts while European cars have 7 kg and Japan cars have 5 kg P/M parts.

II. LITERATURE REVIEW

Some of the basic literature papers have been collected for the study, these are mainly on the basis of aluminium alloys properties and the effect produced on the properties of aluminium alloys on the addition of others metals such as iron, silicon and vanadium.

According to A.S. Khan, B. Farrokh and L. Takacs[1], rapid solidification processing opens new horizons for alloy development. This applies to modification of commercial products and to new compositions which can lead to unusual structures and superior properties. Aluminum alloys have been extensively investigated in terms of the response to rapid solidification. For aviation and space programs, higher specific modulus and strength values without loss of toughness, improved fatigue and improved corrosion resistance are of interest. Among the specific contributions and potentials of rapid solidifications are: increased solid solubility, minimization of segregation, highly refined grain size, modification or elimination of segregation phases, possibility of glass formation and production of new metastable microcrystalline structures.

H.J. Choi, S.W. Lee, J.S. Park and D.H. Bae[2], described that reciprocating machine parts as in the textile industry also possess potential. The desired benefits include increased fatigue resistance and stiffness. In the chemical process industries, there is a potential for tube and piping applications as a result of superior corrosion resistance and elevated temperature stability obtainable with rapidly solidified aluminum alloys.

Currently, only two rapidly solidified Al alloys are beyond the experimental state. The 7090 and 7091 alloy powders are commercially produced by several companies. Alcoa relatively recently announced the first production quantity commercial orders for wrought aluminum powder

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metallurgy parts made from alloy X7090. The parts, a main landing gear support beam and a landing gear door actuator, are being forged for the Boeing 757 aircraft. The alloy contains 2.0-3.0% Mg, 7.3-8.7% Zn, 1.0-1.3% Co, and rest of balance is Al.

T.T. Sasaki, K. Hono, J. Vierke, M. Wollgarten and J. Banhart[3], in their investigation stated that extrusion processes are of two general types. In one type, the powder is mixed with a binder or plasticizer at room temperature; in the other, the powder is extruded at elevated temperatures without fortification. Extrusions with binders are used extensively in the preparation of tungsten-carbide composites. Tubes, complex sections, and spiral drill shapes are manufactured in extended lengths and diameters varying from 0.5-300 mm. hard metal wires of 0.1 mm diameter have been drawn from powder stock. At the opposite extreme, large extrusions on a tonnage basis may be feasible.

S. Scudino, G. Liu, K.G. Prashanth and others[7], described that there appears to be no limitation to the variety of metals and alloys that can be extruded, provided the temperatures and pressures involved are within the capabilities of die materials. Extrusion lengths may range from 3-30 m and diameters from 0.2–1 m. Modern presses are largely automatic and operate at high speeds (on the order of m/s).

T.T. Sasaki, T. Ohkubo and K. Hono[4], used conventional high strength aluminium alloys such as AA 2618, AA 2219 or AA 2024 lose their strength at temperatures above about 200°C, mainly because of a rapid coarsening of their precipitates. For certain applications such as jet engine compressors, automotive gas turbines and combustion engine components, aluminium alloys which retain their strength in the range of 300°C to 450°C could replace steels or titanium alloys. To retain a high strength at elevated temperatures, it is necessary to have a uniform distribution of fine dispersoids which pin the grain boundaries and harden the matrix. A variety of alloy systems have been investigated and are still being explored. In general aluminium alloys with transition metals (Mn, Co, Fe, Ni, Cr) and rare earth metals (Ce, La) show interesting possibilities; alloy-systems such as Al-Fe-Ce, Al-Fe-V-Si, Al-Fe-Mn, Al-Cr-Zr or Al-Cr-Zr-Mn have been studied.

S. Scudino, G. Liu, M. Sakaliyska, K.B. Surreddi and J. Eckert[5], tells iron is the most common impurity element found in aluminium. The solubility of iron in aluminium in the solid state is very low (~0.04%) and therefore, most of the iron present in aluminium over this amount appears as an intermetallic second phase in combination with aluminium and often other elements. Because of its limited solubility, it is used in electrical conductors in which it provides a slight increase in strength and better creep characteristics at moderately elevated temperature. Iron reduces the grain size in wrought product.

Iron is added to reduce the corrosion in steam at elevated temperature. The density increases linearly with addition of iron in Aluminium. The shrinkage in solidification decreases linearly to approximately 3% to 5% Fe alloy. The viscosity of molten alloys increases, but there is no appreciable change in surface tension. The thermal conductivity is reduced. The magnetic properties are not greatly affected by iron additions. Iron increases the hardness and decreases the ductility. Creep strength is greatly increased, on the other hand fatigue strength is reduced. The recrystallization temperature is raised. Iron improves somewhat the machinability of aluminium. Mechanical properties of Al-Fe alloys for both annealed and hardened on changing of iron percentages. When iron content is higher than 4% all mechanical parameters of the alloys deteriorates.

S. Scudino, K.B. Surreddi, S. Sagar, M. Sakaliyska and J.S. Kim[6], described in their study that after iron, silicon is the second most abundant impurity of aluminium, originating from the silica or silicates in the bauxite. Silicon is also intentionally added, which is one of the most common additions to aluminium alloys, to which it imparts fluidity in casting and welding and high mechanical properties through the formation of compounds that make the alloy heat treatable. In wrought alloys, silicon is used with magnesium at level upto 1.5% to produce Mg2Si in the 6xxx series of heat treatable alloys. The system is a simple eutectic one, in which the two phases in equilibrium are Al and Si. Rapid quenching from the liquid raises the solubility up to 16% Si and shifts the eutectic point up to 17% Si.

In order to obtain a homogeneous distribution of fine Si particles in aluminium matrix and thus to improve the adaptability of Al-Si alloy for aerospace and automobile applications, Si particulate reinforced aluminium matrix composites have been processed by using powder metallurgy method. The Si particulates with 20-40 IJm size and AI alloy powders were mixed, degassed and extruded at 350~ or 400"C depending on the composition of the matrix alloy. The micro structural characteristics of the composites such as interracial stability at high temperatures have been investigated by various experimental techniques. Wear properties of the composites were investigated by using a pin-on-disk type wear tester. The results were compared with these obtained from the conventionally cast hypereutectic AI-Si alloys and discussed in terms of the observed micro structural characteristics and physical properties such as hardness and tensile properties. Thermal conductivity is decreased with increase of aluminium. The resistivity increases linearly. The Vickers hardness increases almost linearly. The strength of aluminium-silicon alloys declines very rapidly with increasing temperature. Elongation reaches a maximum approximately at the solidus temperature and then declines rapidly. The increase in the modulus of elasticity is linear. The increase in creep resistance is not substantial. Silicon has no decided grain refining effect on the solidification of aluminium but affects appreciably the hot shortness in casting and welding. Silicon decreases the plasticity of aluminium. Above 700K, the alloys exhibit super plasticity.

Some of the basic literature papers have been collected for the study, these are mainly on the basis of sinter forming process, application of sinter product and some forming process of sintered preforms.

According to E.G. Thomson and S. Kobayashi[8], several approximate methods of obtaining average forming pressures are discussed and their applicability to tube and extrusion problems. They have pointed out that metal- working technology has been focused on the determination of pressure but other areas have obtained less attention. Examples of these area are the plastic flow properties of materials, details of the flow field and the interaction of the process and forming equipment.

A.K. Jha and S. Kumar[9], in their investigation discussed on the variation technological aspects of the high-speed forging of sintered copper powder strips. Experimentally they measured the development of barreling, the strain variations at the free surface and densification during the high speed forging of copper strips at room temperature under dry and lubricated condition. During the high speed forging of sintered materials the decisive factors are the deformation speed, the high speed forging of sintered materials the decisive factors are the deformation speed, the amount of interfaced friction at the die-work piece interface, the initial density of the preform and the pressure distribution from the centre to the edge. They also stated that the density of forged products increases with increase in forging loads, amounts of barreling depends mainly on the degree of densification and friction conditions. The displacement at the interface with the moving dies is more than that at the interface with stationary die during lubricated forging. The inertia forces encountered are functions of the processing parameters and deformation characteristics of the sintered materials.

R. Sagar and B. L. Juneja[10], has used an upper bound solution for finding mean die pressure for the given geometries of disc for the above method of forging. It is found that for certain dimensional ratio of the nut the die pressure is minimum uniform frictional stresses are assumed on top and bottom interface and along the interface on sides. This solution can be extended to close die forging of any polygonal shape.

D. Sherif and E.I. Wakil[11], suggested in his study that the deformation and densification characteristics of sintered sponge iron powder compact subjected to uniaxial comparison are essential in the development of plasticity equation for sintered porous materials, the value of poison's ratio for a sintered compact is a function of its current density, no matter how that density is achieved, the load required to achieve a given density increases with decreasing preform by high percentage of its height. It is recommended to use medium density preform (6.7-6.8g/cm3), when a high final density is required. This has the advantages of relatively low load requirement and of avoiding the cracking of preform during deformation.

G. Sutradhar [12], in their investigation stated that powder preform are sensitive to hydrostatic stress and density, for this reasons the mode of deformation of sintered powder be preforming different to that of wrought materials. The process of the forging of cylindrical aluminium discs under axi-symmetric conditions was constructed for analysis. The problem of the die-load was investigated by applying an appropriate interfacial friction law and plasticity theory for porous materials and found effective for the assessment of die loads during close-die forging of porous materials under cold conditions.

H.N. Tewari and R. Sharan[13], reported that influence of compacting and sintering parameters on forgeability, densification and other properties of iron and iron-nickel preforms. The upset test, coefficient of friction evaluated by ring compression test and amount of barreling were taken as indices for evaluating forgeability. The influence of particle size being investigated, higher compacting pressure and sintering temperature have resulted in the better forgeability for both iron and iron-nickel preforms. Fe-Ni sintered compact have exhibited better forgeability than that of pure-iron preforms. Finer particle size has resulted in more densification and improvement in forgeability.

G. Sutradhar[14], investigated that fine metal powder results in more densification and improvement in the forgeability of the preform, also found that the relative density of the iron powder preform increases with increase in compacting pressure, sintered temperature and forging load. The forgeability is also found to improve with increase in the compacting pressure and the sintering temperature. The amount of barreling depends mainly on the degree of densification and the frictional conditions. Lubricated test pieces show mere surface movement than unlubricated test pieces. During the forging of metal powder preform compaction and compression take place simultaneously. The decisive factors during processing of metal powder preform are the powder particle size, the distribution of the compacting pressure, the forging load and the friction at the tool-work piece interface.

S. Shima and M. Oyane[16], proposed the plasticity theory for porous metals. From the stress-strain curves for sintered copper with various apparent densities, the stress strain curves for pore-free copper is calculated by utilizing the basic equations. In conventional plasticity theory, on which these theories and methods are based, volume constancy is assumed for the materials undergoing deformation, and this assumption applies in effect to pore-free metals very well. In the deformation of porous metals, however, the volumes does not remain constant.

A.K. Jha[11], development a computer simulation techniques to estimate die load and energy during sinter-forging process. In his previous finding A.K. Jha[9], the simulation work is found to be effective for the assessment of the relative density variation, dimensional changes, pressure distribution and power consumption during sinter –forging process, this work will be helpful in the predictive the deformation load and energy during axisymmetric sinter-forging process.

G.L. Baraya and W. Johnson[17] analyzed bar forging with the help of a triangular velocity field. In their solutions, besides the continuity in velocity field, it is also assumed that straight boundaries remain straight after compression. The non-uniformity of flow, which results in barrelling and bulging of the specimen, has not been taken into account. Tomlinson and Stringer[19] made an experimental study of spread and elongation in hot forging with flat tools and compared the results with the tests performed by Tarnowski[20] for rectangular blocks.

III. EXPERIMENTAL STUDY

Basic experiments were conducted on Copper and Aluminium metal powder preforms. Atomized Aluminium powder of purity 99.5% and finer than 100 μm was used throughout the experiments. For compaction firstly the powder material is filled in the die as shown in the image, in which copper powder is filled up in the die. Aluminium and copper both powder was separately compacted in a closed circular die using a hydraulic press at various recoded pressures. The die wall was lubricated with fine graphite powder. After that compaction is done as shown in next figure. Compaction is done by the help of universal testing machine (UTM), on which dies are placed and after then pressure is applied as our requirement.

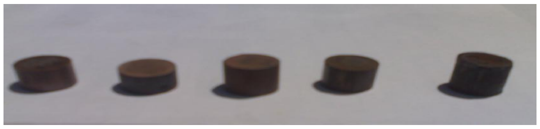


Figure 1: Compacted billets of copper

Figure 2: Compacted billets of aluminium

The basic purpose of sintering is to develop mechanical strength in the metal powder compacts. Sintering of aluminium compacts was carried out at 3000C and 3500C for two hours in an endothermic sand atmosphere and sintering of copper compacts was carried out at 6500C and 7000C for two hours in an endothermic sand atmosphere. All sintering operations were carried out in a muffle type silicon carbide furnace capable of providing sintering temperature of an accuracy of ± 50C. In order to minimize the non-uniformity of density distribution, the sintered compacts were re-pressed at the same compaction pressure in the same die. The specimens were resintered at the same temperature and time.

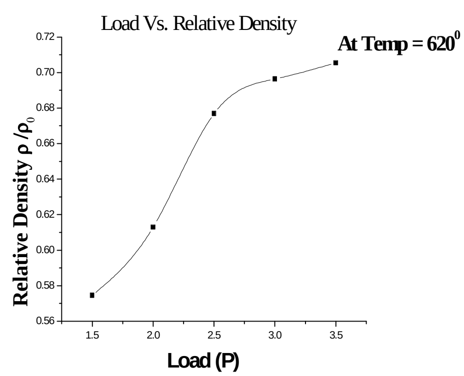
Figure 3: Sintered billets of copper power

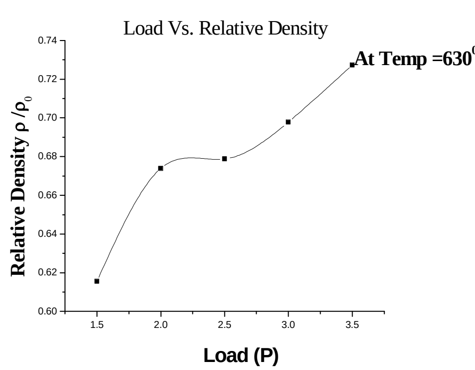
Figure 4: Sintered billets of aluminium powder

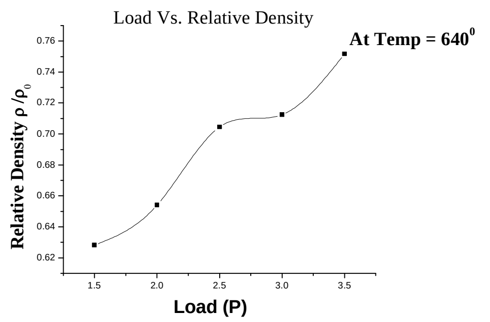
IV. RESULTS AND DISCUSSION

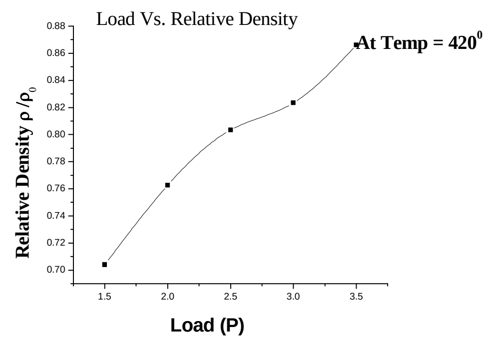
Densification of Aluminium and Copper powder preform before and after deformation is governed by several factors, which interact with each other in a complex manner. Some of the important factors considered here are as follows: Powder particle size has a remarkable effect on the relative density which in turn affects deformation characteristics and fracture mechanisms of the metal powder preforms. Figure 2.2 shows the influence of powder particle size on the relative density of the copper powder preforms compacted at 30 kg/mm2 and sintered at 7500C and the influence of powder particle size on the relative density of the aluminium powder preforms compacted at 10 kg/mm2 and sintered at 3500C and. The decrease in grain size of powder, however, results in more densification and improvement in formability of the powder preforms. Poor flow rate for finer particles are also observed. The relative density variation with increase in compacting pressure. It is seen that the relative density of the Aluminium and Copper powder preform increases gradually with increase in compacting pressure. The formability of Aluminium and Copper powder preforms improves at higher compacting pressure. The basic purpose of sintering is to improve the strength of green compacts. Figure 2.4 shows the variation of relative density with the sintering temperature for preforms compacted at various compacting pressure. It is observed that the relative density of the Aluminium and Copper powder preform increases with both the sintering temperature and compacting pressure. The influence of compression is to increase the relative density of the metal powder preform. The relative density of the preform increases with increase in compressive load as shown in figure 2.5. The relative density of the preform increases very sharply at the beginning of loading and then increases slowly with increase in load. After attaining $\rho \approx 1$ the preform starts yielding significantly. The relative density of the preform is also found to increase with percentage reduction in height. Figure 2.6 shows this variation graphically. It is observed that compressibility of Aluminium and Copper powder preforms improves with increase in initial relative density. For simple compression, the pressure distribution at the die-work piece interface decreases from the center towards the edge. The decrease in adhesion friction results in a further decrease in the pressure distribution which in turn affects the relative density. Therefore, the relative density is a function of pressure and flow stress of the metal powder preform.

V. RESULTS






Load Vs. Relative Density
At Temp = 640^0
Relative Density ρ/ρ_0
Load (P)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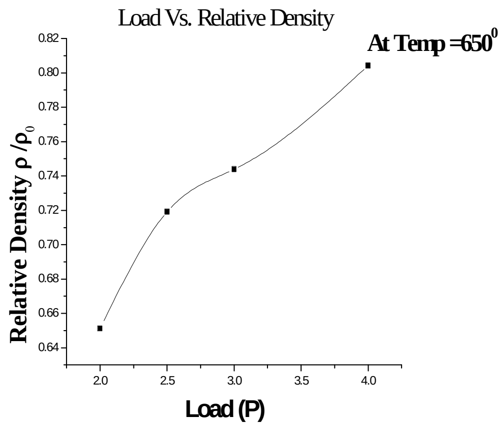
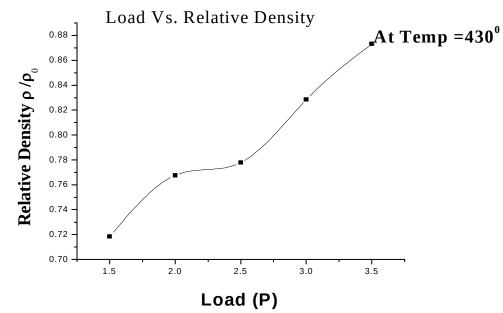
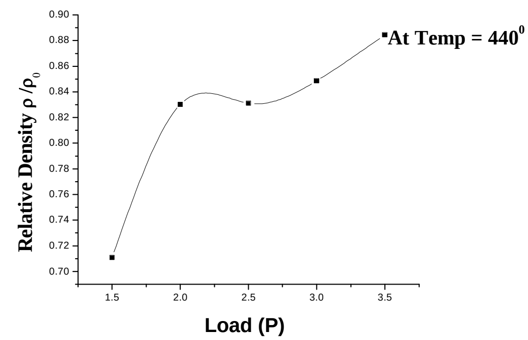
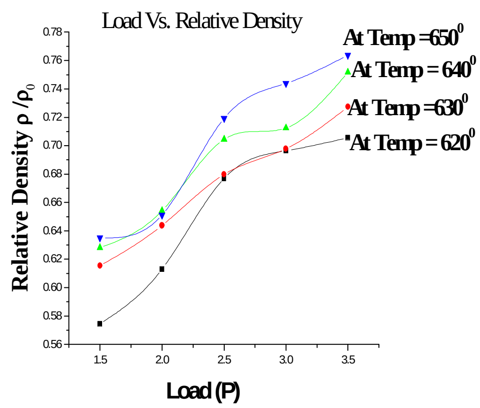
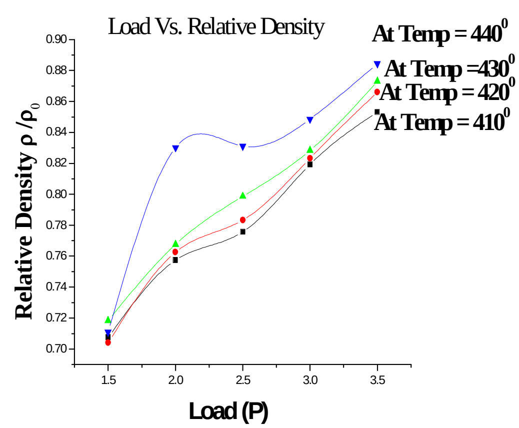
At Temp = 420^0
Relative Density ρ/ρ_0
Load (P)

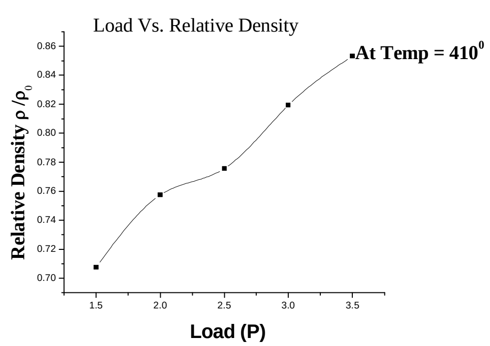

Load Vs. Relative Density
At Temp =650^0
Relative Density ρ/ρ_0
Load (P)

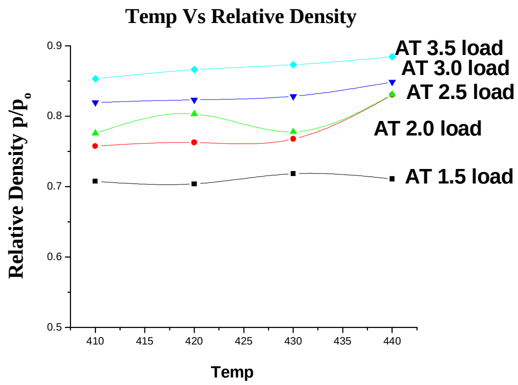

Load Vs. Relative Density
At Temp =430^0
Relative Density ρ/ρ_0
Load (P)

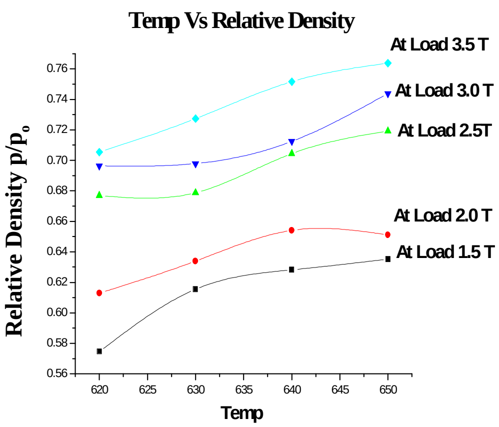

At Temp = 440^0
Relative Density ρ/ρ_0
Load (P)


Load Vs. Relative Density
At Temp =650^0
At Temp = 640^0
At Temp =630^0
At Temp = 620^0
Relative Density ρ/ρ_0
Load (P)


Load Vs. Relative Density
At Temp = 440^0
At Temp =430^0
At Temp = 420^0
At Temp = 410^0
Relative Density ρ/ρ_0
Load (P)


Load Vs. Relative Density
At Temp = 410^0
Relative Density ρ/ρ_0
Load (P)





As shown in the graph relative density increases with the increase in sintering temperature. It is experimentally found that the pieces held at greater sintering temperature have the high density as compared to the pieces held at relatively low sintering temp. This difference in the density occurs due to the bonding formation between the powder particles. At relatively high temperature Crystallization takes place and bonding starts between the particles as a result void reduced in the metal preform hence density increases.

V. FUTURE SCOPE OF WORK

Though the commercial production of a wide range of the powder based components is seen in the market, but acceleration for the higher production of the powder methods based components is yet to be achieved. To gain the acceleration in this field a rich literature is still to be developed and build. A lot of alloys are yet possible and their different tests for mechanical, chemical and other properties are yet to be done. The research work in the field of powder metallurgy with various alloying elements should be carried out suit the market requirements at a cheaper rate.

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