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Preparation of Ss 316l Feedstock for Metal Injection Molding (Mim) Process

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Abstract*— *The purpose of this paper is to make the homogeneous mixing of SS 316L steel powder with a multiple binder system in a custom made mixing machine by varying the process parameters like speed, Temperature and time as the homogeneity impacts on the final product in the MIM process. A homogeneous mix of metal powder and binder is essential in metal injection molding process as it affects the product quality significantly. This paper aims at design of new mixing equipment and characterization of SS 316L feed stock. A mixing machine of 2 kg capacity is designed and fabricated to prepare a homogeneous mix of SS 316l material with a multiple binder system. Mixing time, mixing speed and Temperature of Barrel are considered as process parameters. Taguchi techniques are used to optimize the process parameters .The RPM of the blade is varied from 20 to 40 in steps of 10, the temperature is varied from 200 to 240 in steps of 20 and the mixing time is varied from 20 to 40 minutes in steps of 10. The results of the experimentation reveals that mixing temperature has a profound effect on the homogeneity of the mix.

Key Words*— *Feed stock, Stainless Steel 316L, Homogeneity, Density Measurement, Binder Burnout Test.

I. INTRODUCTION

Industrial production of the process begins from selection and preparation of the raw material to be used for the manufacture of the finished part. This usually includes adoption of the manufacturing techniques and procedures which are usually unique for different product development. Therefore mixing of the constituent elements or components in the production processing of Metal Injection Molding (MIM) products have to achieve efficient and homogeneous mixing. However homogeneous blending of the constituent elements has been the problem . Investigating the particle mixing mechanism has received fundamental attention. In general mixing mechanisms are classified in to three categories. These are convection, diffusion and shearing mechanisms of mixing. Meanwhile mixers combine these three mechanisms to achieve the optimum processing conditions. But their performance is hindered by the design and processing conditions. Hence there is a need for optimizing the process parameters. This is for the fact that preparation of the homogeneous feed stock greatly influences the product quality of the metal injection molding.

Metal Injection Molding is a proved manufacturing technique for the production of small and complex metal parts. It combines the versatility and shape making capacity of plastic injection molding with materials flexibility of powder metallurgy.

Metal Injection Molding involves four stages: mixing of metal powder and binder system injection molding of the feed stock, debinding to remove the binder and sintering. Mixing is the critical stage of the MIM process because the homogeneous dispersion of metal Powder into the plastic binder system which will affects the quality of the final product to be made. The main goal of mixing is to produce a homogeneous feedstock with suitable rheological behavior for subsequent processing steps.

The first step in the MIM manufacturing process is the production of the feedstock that will be used. It begins with extensive characterization of very fine elemental or pre-alloyed metal powders (generally less than 20 µm). In order to achieve the flow characteristics that will be required in the injection molding process, the powder is mixed together with thermoplastic polymers (known as the binder) in a hot state in order to form a mixture in which every metal particle is uniformly coated with the binder. Typically, binders comprise 40% by volume of the feedstock. Once cooled, this mixture is then granulated into pellets to form the feedstock for the injection molding machine.

The next step is the molding of the part in a conventional injection molding machine. The feedstock pellets are gravity fed from a hopper into the machine's barrel where heaters melt the binder, bringing the feedstock to the consistency of toothpaste. A reciprocating screw forces the material into a two-part mold through openings called gates. Once cooled, the part is ejected from the mold with its highly complex geometry fully formed. If necessary, additional design features not feasible during the molding process (undercuts or cross holes, for example) can be easily added at this stage by machining or another secondary operation.

The ejected as-molded part, known as a "green part," is still composed of the same proportion of metal and polymer binder that made up the feedstock, and is approximately 20% larger in all its dimensions than the finished part will be. The next step is to remove most of the binder, leaving behind only enough to serve as a backbone

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holding the size and geometry of the part completely intact. This process, commonly referred to as "debinding," may be performed chemically or thermally, which in some cases may involve a solvent bath as the initial step. The choice of debinding method depends on the material being processed, required physical and metallurgical properties, and chemical composition. After debinding, the part is referred to as a "brown part."

In this process, which is performed in the highly controlled atmosphere of either a batch furnace or a continuous furnace, the brown part is staged on a ceramic setter and is then subjected to a precisely monitored temperature profile that gradually increases to approximately 85% of the metal's melting temperature. The remaining binder is removed in the early part of this cycle, followed by the elimination of pores and the fusing of the metal particles as the part shrinks isotopically to its design dimensions and transforms into a dense solid. The sintered density is approximately 98% of theoretical. The end result is a net-shape or near-net-shape metal component, with properties similar to those of one machined from bar stock. Of course, if necessary, post-sintering operations such as coining, machining, heat treating, coating, and others, may be performed on the part to achieve tighter tolerances or enhanced properties.

The production process of any product begins from the selection of raw material to be used for the manufacturing of the finished product. This usually includes adoption of manufacturing techniques and procedures which are exclusively unique for different product development.

The raw powders used for MIM is are usually quite fine, mostly below 20 microns and thus agglomeration could be very serious. When hard agglomerates, which cannot be broken up during shear kneading are included in the feed stock, final sintered product could then contain in homogeneous microstructures. If the agglomerates are alloying element additions, highly alloyed areas will develop and cause lean alloyed regions, which will affects the mechanical properties, moreover highly alloyed regions may have low density after sintering. Hence the uniformity of the feed stock constituents is always important in mixing process.

II. LITERATURE SURVEY

A.A. Abdullahi et.al. designed a feedstock mixing mechanism based on powder loading, powder size and shape, binder formation, sequence of material addition, mixing time, temperature and shear rate and analyzed with finite element analysis to improve metal molding productivity and improve production cycle time[1].L Liu et.al investigated the suitability of stainless steel SS 316L feedstock for the fabrication of components with Metal Injection Molding with good shape retention, mixing, characterization and feasibility of in-house feedstock is reported[2]. R. Asmawi et.al proposed a new binder system for Metal Injection Molding of stainless steel SS 316L feedstock with waste polystyrene and palm kernel oil and verified whether the powder binder mixture is homogeneous and injectable or not and found good homogeneity and suitability by density measurement test , binder burnout test and SEM morphology observation.

P.J. Vervoot ET. Al studied the technical and economic challenges the Metal Injection Molding have to overcome and they feel that there is a great need to increase the awareness among the designers. K.S. Hwang clearly explained various defects that found in each process of Metal Injection Molding and explained remedies for each defect in every stage of MIM. He explained the importance of homogeneous dispersion of powder in to the binder in the mixing stage.

Faiz Ahmed et. Al investigated the flow behaviour of carbon nanotubes/ copper feed stock for Metal Injection Molding and proved that 10% volume of MWCNT's were successfully injection molded and suitable for further processing of MIM by rheological tests. Z. Y. Liu et. Al investigated the effect of binder system with High Density Poly Ethylene, Paraffin Wax and Vinyl Acetate and found that 316L stainless steel micro parts can be moulded , de-binded and sintered successfully at 20% PW+40%EVA+40%HDPE binder system[2] Yimin Li et. al studied on the effect of powder loading on the Metal Injection Molding of gas atomized spherical shaped 17-4 PH stainless steel powder with binder system of 65%Paraffin Wax, 30%EVA and 5% Stearic Acid and stated that 68% Powder loading is the best for sinter densification and has superior mechanical properties and microstructure.

power

Water atomized stainless steel 316L powder having irregular shape with mean size d50 supplied by 'SomitTexTrade' was used in this study as the metal powder. The powder characteristics of the metal powder are shown in the table.

Table 1 : Composition of SS 316 L

C	Mn	Si	P	S	Cr	Mo	Ni	N
0.03	2.0	0.75	0.045	0.03	18	3	14	0.10

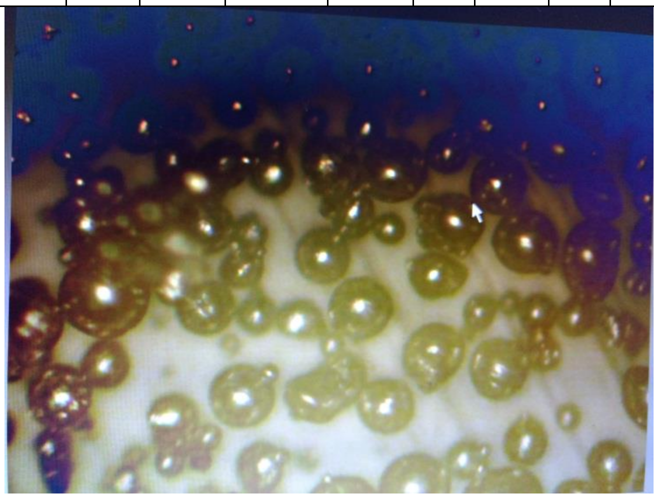

Fig 1 : Microscopic image of steel particles

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Form the morphology of the powder particles it is clear that particles are in spherical shape. The shape is so selected that spherical particle gives high density products than irregular shaped particles.

III. EXPERIMENTAL WORK

Several factors such as mixing time, temperature, powder size and shape, formation of the binder, shear rate and powder loading are the parameters need to be considered to produce homogeneous feed stock. Here in this study only three parameters were selected in order to establish a suitable mixing condition. These are temperature, mixing speed and mixing time. The composite of polymer – wax binder system is mixed with stainless steel 316L powder at a temperature of 190^0 C with a rotational speed of 20rpm by using custom made mixing equipment for 1 hour. The temperature of 190^0 was selected to prevent the degradation of binder constituents.

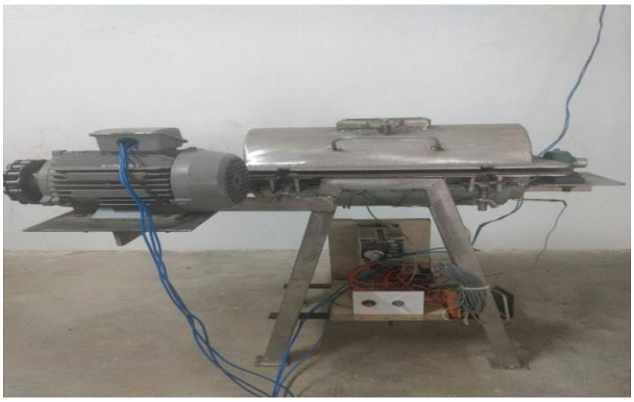

Fig 2: Schematic of mixing equipment

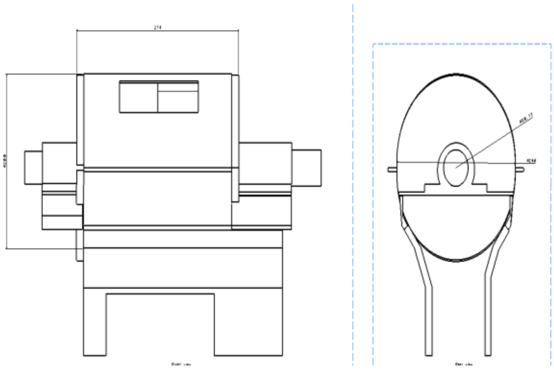

Fig 3 : 2 D view of Mixing equipment

Initially the binder system was taken in to the machine and heater is switched on until the binder melts. Before reaching the melting temperature of the binder the metal powder has been added and rotated for getting feed stock for MIM.

IV. DESIGN OF EXPERIMENTS

The samples were prepared according to DOE (Design of Experiments) and conducted in nine runs by varying the process parameters like Time, Temperature and Speed. The input is the weight of the powder in grms and the output is density of the each sample. The DOE prepared for conducting experiments is tabulated below.

TCN	Mixing Temperature	Mixing Speed	Mixing Time	Weight after Burnout test	SR Ìm	S/N
1	210	30	10	21.094	0.91	0.81
2	210	40	15	21.075	0.85	1.41
3	210	50	20	21.054	0.95	0.44
4	220	40	10	20.974	1.10	-0.82
5	220	50	15	20.882	1.18	-1.43
6	220	30	20	20.958	0.92	0.72
7	230	50	10	20.94	1.59	-4.02
8	230	30	15	20.956	1.32	-2.41
9	230	40	20	21.076	1.30	-0.66

V. HOMOGENEITY TESTS & RESULTS

Homogeneity of the feed stock was analyzed by means of different analysis techniques like density measurement, binder burnout test and scanning electron microscope.

Density measurement test:

In this study, after mixing of the powder with binder system five different samples from the feed stock at different places in the mixing equipment of different weights each have been collected according to the Archimedes' water immersion method the weight of the each sample in the air and also in the water have been collected. Then using the following method the density of the each sample has been calculated in gram/cm3.

Weight of the sample in air = W1

Weight of the sample in water = W2

Density gm/cm^3	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
	3.8995	3.667	3.27	3.600	3.899

Buoyant force = W1-W2

But buoyant force = ρVg

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Volume of the sample V = (W1-W2)/ ρg
Mass of the sample m = W1/g
Then Density of the sample = mass/Volume = m/V

Fig (a) Sample-1

Fig(b) Sample-2

Fig(c) Sample-3

Fig(d) Sample-4

Fig(e) Sample-5

Table 2 : Densities of the samples

Weight of Sample after burning (grams)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
	5.06	5.20	5.65	5.16	5.73

The desities of the five test samples have been tabulated below and de-picted above

From the results of the density measurement test it is proved that all the samples have approximately equal values of densities. Hence the mixture contains homogeneous powder binder combination throughout.

Binder Burn Test

In this test similar to the density measurement test five samples at different places of the mixing equipment but of equal weight (10 grams) have been collected. All the samples have been placed in an oven and heated up to 120 degree so that binder can be removed completely and only steel powder remains. Then the samples have been weighed after binder removal and the test results have been tabulated below.



(a) Sample-1 **(b) Sample-2** **(c) Sample-3**


(d) Sample-4 **(e) Sample-5**

Table: 3 Mass of the samples after burn out

From the above test it is evident that mass of all samples before burning and after burning also have almost same mass values hence the mixture of powder and binder system is homogeneous.

Morphology test

The Electron Microscope of 1000X Magnification image of the test sample is

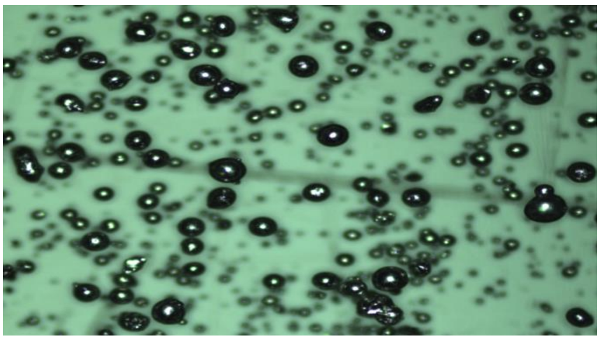

Fig -4

From the Microscopic image of 1000X Magnification it is clear that the powder particles have been dispersed homogeneously in to the binder system. Hence the mixture is homogeneous.

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VI. CONCLUSION

Form the results of different homogeneity analysis techniques it is found that composite binder composed of stainless steel 316L and (HDPE+PW+SA) binder system can produce homogeneous feed stock for MIM process. It is verified by density measurement test of the feed stock where density values for different samples are almost same. Binder burnout test of five samples also revealed feed stock is homogeneous. Moreover Electron Microscope of 1000X Magnification observation also shows powder particulates dispersed homogeneously in to matrix. The mixing temperature has the highest impact where as mixing speed has the least effect on the homogeneity of the feed stock.

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