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Experimental Examination of Process Parameters During Fabrication and Machining of Powder Metallurgy Aluminum Component

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Abstract: ***The present study aims at investigating the effect of process characteristics during fabrication and machining of powder metallurgy (PM) Aluminium cylindrical components. The application of the machining process as an alternate manufacturing process to fabricate the PM Aluminium components for industrial use with desired shape and size is explored. The PM Aluminium cylindrical components were fabricated by compacting the Aluminium metal powder within the compaction dies under various values of compaction load, sintering temperature and sintering time. These PM components were then machined under different standard cutting velocity and tangential cutting velocity, surface roughness data were analyzed. After the investigation it was concluded that, higher values of compaction load, sintering time and sintering temperature leads to higher values of relative density and relative hardness of the sintered Aluminum component. Again from machining results it can be stated that, higher values of fabricating parameters have a higher significance on performance parameters.***

Keywords : Powder Metallurgy (PM), Sintering, Relative Density, Relative Hardness, Cutting Force, Surface Roughness.

I. INTRODUCTION

Powder Metallurgy (PM) is one of the advanced manufacturing technologies by the help of which highly reliable shaped parts of both ferrous and non-ferrous materials can be produced from their respective metal or alloy powders. PM parts are developed by blending alloy and/or elemental powder, compacting the blend in a closed die and then heating (sintering) within a controlled atmospheric furnace to diffuse and bind the particles metallurgically together[1]. PM process is capable of generating parts with good dimensional accuracy, near-net shape and complex geometry[2]. Profound studies have been devoted to chemical and electrochemical methods for preparing fine and ultrafine metal and non-metal powders. Whether it is by optimizing the chemistry or by controlling the porosity to provide improved longevity in wear parts, PM process provide feasible solutions for all intricate manufacturing process route including difficult to handle materials [3].

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Now-a-days, Aluminum has increased demand in the field of domestic and engineering because of its light weight, less fabrication cost, neat shaped component manufacturing and less energy consumption during machining. In addition, Powder Metallurgy Aluminum recommends parts with excellent fatigue and mechanical properties, exceptional machinability, low density, high electrical and thermal conductivity, better response to finishing processes and good corrosion resistance [4]. Moreover, Powder Metallurgy Aluminum components can be easily further processed to minimize porosity and enhance yielding properties as compared to traditional wrought aluminum components. PM parts are becoming increasingly popular in many applications due to their applications and advantages over traditional cast and forged parts and it allows for the production of complex shapes from a wide variety of alloy systems with very little material waste. As a result, PM parts can drastically reduce the amount of secondary processing, such as machining, that is required for definite applications. However, in certain instances, additional machining can be necessary to reach required very high dimensional tolerances or from features that are impossible to create during compaction such as, threads and undercuts.

Gokce and Findik[5] studied the mechanical and physical properties of sintered Aluminum powder and stated that, an increased compaction pressure increases the density of sintered Aluminum part. Morgan and Sands[6] have studied the isostatic metal powder compaction process and investigated the effect of die speed on compacting pressure, green density, green strength and hardness of metal powder compacts. From their study they concluded that, isostatic compaction cannot produce components with high dimensional accuracy. Hwang[7] the powder metal compaction process and concluded that the density variation within the compact depends on compact geometry and frictional condition between compact and dies. Lewis and Khoei [8] have investigated the compression of aluminum powders and formulated the slip-line field and plasticity upper-bound theories for sintered aluminum powder. It was found that yielding of sintered materials is sensitive to hydrostatic stresses component imposed, as yield surface closes on the hydrostatic stress axis. Mamedov and Mamedov [9] presented a new fabrication method for the manufacturing of increased density powder metallurgy components using single press cold sintering technique. Using SEM images they estimated the compact green density of samples and explored the influence of the processing conditions on the density.

They stated that, in order to minimize the negative influence of gases trapped inside the pores, it is required to ensure effective air discharge from the compaction zone. Gokce et al. [10] examined the microstructure and properties of premixed Al-Cu-Mg powder metallurgy alloy and stated that, after sintering the rupture strength of base Aluminum can be increased by 5 times.

II. EXPERIMENTAL PROCEDURE

A. Fabrication of Powder Metallurgy Aluminum Components

Basic experimental work consists of fabrication of PM Alumnium cylindrical components at various recorded values of compaction loads, sintering temperature and sintering time. The specimens were fabricated by compacting the Aluminium metal powder in the powder compaction dies and subsequently sintered in muffle furnace. Figure 1 shows the schematic representation of the compaction process. A 50-ton UTM and muffle furnace used for the fabrication of Aluminium PM components.

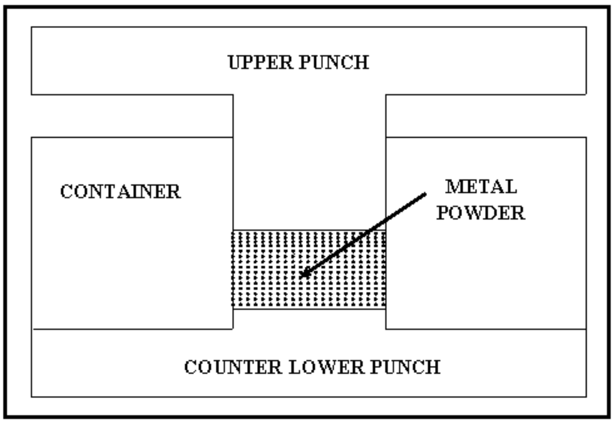

Fig. 1. Schematic representation of compaction process.

The sintering process was carried in endothermic sand environment to prevent the oxidation and loss of the material. Aluminium metal powder having purity more than 99% and particle size from 118 microns to 13.0 microns was used for the fabrication of the specimens. Various specimens as per desired dimensions were fabricated under different compaction loads / pressures, sintering temperatures and sintering times. The recorded process characteristics like compaction pressures, sintering times and sintering times along with the specimen dimensions are presented in table I. All specimens were polished with coarse and fine emery papers to the recorded dimensions.

Table-I: Process Characteristics & Dimensions of PM Components.

Sl. No.	Process / Part Characteristics	Recorded Values
1	Compaction Pressure (Kgf)	3000 & 4000
2	Sintering Temperature (^oC)	400 & 500
3	Sintering Time (hrs)	2 & 4
4	Specimen Length (mm)	60 & 30
5	Specimen Diameter (mm)	25

B. Machining Analysis of Fabricated Components

Post fabrication of the cylindrical PM Aluminium specimens as described in the above section, machining analysis was conducted in the form of turning operations. The machining of PM components was done on CNC lathe (CNC Lathe Colchester Tornado 300UK) at two different cutting speeds and tangential cutting force and surface roughness were measured to investigate the feasibility of the machining processes on PM components. The tangential cutting force data was measured using tool force dynamometer and surface roughness of the machined components was measured using Talysurf surface roughness measurement instrument.

Commercially available multilayer coated $TiCN/Al_2O_3/TiN$ tungsten carbide inserts were used for the machinability experimentation. The inserts were rigidly mounted on right hand style tool holder designated by ISO PCLNR2525M12 and specification of the insert was CNMG120408GS, where 08 specify the nose radius of the tool. The properties and characteristics of the cutting tool are presented in table II.

Table-II: Properties of Carbide Tool.

Sl. No.	Parameters/Operation	Rough Turning	Medium Turning	Finish Turning
1.	Depth of Cut (mm)	Min 10	2-10	Max 0.2
2.	Feed Rate (mm/min)	0.1	0.3-1.0	Max 0.3
3.	Cutting Speed(mm/rev)	40-60	60-100	90-160

III. RESULTS AND DISCUSSION

A. Relative Density and Relative Hardness

The real density of the specimens was calculated by measuring their dimensions and weights. The relative density was obtained as the ratio of real density of the specimen to the standard density of corresponding solid metal. The relative hardness was measured by taking the ratio of the real hardness of the specimens by hardness of the corresponding solid metal. The data for the relative density and relative hardness were recorded for different PM Aluminium specimens fabricated during the basic experimental work and are presented in table III and table IV respectively.

Table-III: Experimental Results for Density.

Process Variables			Response Variable
Compaction Load (kgf)	Sintering Temperature (^oC)	Sintering Time (Hrs)	Relative Density
3000	400	2	0.77
3000	400	4	0.778
3000	500	2	0.789
3000	500	4	0.8
4000	400	2	0.812
4000	400	4	0.861
4000	500	2	0.926
4000	500	4	0.957

Table-IV: Experimental Results for Relative Hardness.

Process Variables			Response Variable
Compaction Load (kgf)	Sintering Temperature (^oC)	Sintering Time (Hrs)	Relative Hardness
3000	400	2	0.6
3000	400	4	0.62
3000	500	2	0.65
3000	500	4	0.67
4000	400	2	0.69
4000	400	4	0.72
4000	500	2	0.75
4000	500	4	0.8

B. Tangential Cutting Force and Surface Roughness

The tangential cutting force was measured by using a Lathe Tool Dynamometer. The results were recorded by repeating the procedure for no. of times. The roughness measurement was carried out by using a portable stylus type Talysurf profilometer (Taylor Hobson, Surtronic 3+, UK). The multiple readings were recorded over the various diameter span of the specimens and average reading was calculated. Table V and VI shows the experimental values of tangential cutting force and surface roughness respectively.

Table-V: Experimental Data for Tangential Cutting Force.

PM Characteristics			Machining Characteristics	
Compaction Load (kgf)	Sintering Temperature (°C)	Sintering Time (hrs)	Tangential Cutting Force (kgf)	
			Vc = 4.24 (mm/min)	*Vc = 18.37 (mm/min)*
3000	400	2	8	10
		4	10	11
	500	2	7	9
		4	8	9
4000	400	2	11	13
		4	11	12
	500	2	11	12
		4	13	13

Table-VI: Experimental Data for Surface Roughness.

PM Characteristics			Machining Characteristics	
Compaction Load (kgf)	Sintering Temperature (°C)	Sintering Time (hrs)	Surface Roughness (microns)	
			Vc = 4.24 (mm/min)	*Vc = 18.37 (mm/min)*
3000	400	2	7.67	6.81
		4	7.37	5.43
	500	2	5.90	4.91
		4	5.46	4.37
4000	400	2	3.66	2.87
		4	4.00	2.87
	500	2	1.97	1.99
		4	4.86	2.8

IV. CONCLUSIONS

This present study investigated the parameters during fabrication and machining of sintered Aluminum component. From the investigation the following statements are concluded.

A. The relative density and relative hardness of the PM Aluminium components increases with increase in compaction load, sintering time and sintering temperature. This is due to decrease in the inter particles pore sizes during high compaction load leading to the better consolidation of powder particles. The higher sintering temperature aids some kind of diffusion process with in the components leading to better bonding of the metal powder particles. The higher sintering time favors the diffusion process for longer time period leading to the growth of the grain size in PM Aluminium components, which also leads to the higher relative density and higher relative hardness of the components.

B. It was also observed that, tangential cutting forces are higher for high density and high strength / hardness components, *i.e.* at higher values of compaction load, sintering time and sintering temperature. Contrary to this, the surface roughness values were found higher for lower values of PM process characteristics, which means that at lower compaction load, sintering temperature and sintering time, the pore sizes are bigger in PM components, as compared to PM components which are fabricated at higher values of PM process characteristics. For better quality PM components, the surface roughness should be lower (surface finish should be higher) and hence, higher values of PM process characteristics are preferred. This means that if objective of the machining process on PM components is high quality products, one must go for higher values of PM process characteristics to fabricate the PM components, which shall also render high performance as discussed above but all in the expense of high power consumption and higher cost of manufacturing (as higher tangential cutting force will lead to high power consumption and high fabrication cost).

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