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Surface Roughness analysis of powder metallurgy components from low and high carbon content ferrous powders

B.B.Pani[1] and S.K.Khuntia[2,*]

Veer Surendra Sai University of Technology, Burla, Odisha.
College of Engineering Bhubaneswar, Bhubaneswar, Odisha.
**Corresponding Author*

Abstract

Water atomization technique was adopted to produce Low carbon content ferrous powders and High carbon content Rapidly Solidified alloyed ferrous powders. Initially the powders were annealed in presence of hydrogen at two different temperatures. Low carbon content ferrous powders were annealed at 700˚C for two hours and high carbon content rapidly solidified alloyed ferrous powders were annealed at 1000˚C for one hour. The powders were mixed at different proportions and then compacted at different pressures ranging from 200MPa to 600MPa. The compacts were sintered at three different temperatures like 900°C, 1000°C and 1100°C.The surface roughness was measured for both green and sintered compacts. It was found that the surface roughness of green compacts as well as sintered compacts decreases with increase in compaction pressure and sintering temperature.

Keywords: atomization, ferrous, powder, annealing, compaction, sintering, density, surface roughness.

INTRODUCTION

The analysis on surface roughness of machine parts and tools is very important in the field of manufacturing processes. A number of investigators have worked on this area. K.Nyembwe et al. (1) studied the surface roughness of castings produced from uncoated rapid ptototyping (RP) sand mould and coated RP sand mould. They observed that mould coating contributed towards surface finish. M.Junaid Mir et al.

(2) carried out the powder mixed electrical discharge machining(EDM) of H11 steel. Again they studied the effect of parameters like pulse time on, discharge current & concentration of aluminum powder on surface roughness and optimized the parameters using Response Surface technique. C.R .Prakash Rao et al. (3) studied the effect of machining parameters like speed, feed and depth of cut on surface roughness of particulate reinforced composites with two types of tools. In both cases they found that with increase in cutting speed, surface roughness decreased and with increase in feed surface roughness increased. P. Shanmughasundaram et al. (4) investigated the effect machining parametes like cutting speed, depth of cut, feed rate along with reinforcements on surface roughness of pure commercial Al and composites like Al-15wt%fly ash & Al-15wt% fly ash/1.5wt% Graphite. They observed that the inclusion of 1.5wt% graphite in Al-fly ash composite reduced the surface roughness remarkably.

S.L.Campanelli et al. (5) revealed the role of Laser Ablation on selective laser molten steel parts in order to improve surface roughness and the effect of removed layers. They found that surface roughness decreased significantly with number of removed layers.. A. Sachdeva et al. (6) investigated the role of process parameters like laser power, scan spacing, bed temperature, hatch length, and scan count on surface roughness for solid models produced by selective laser sintering. Further the parameters were optimized using response surface technique. Again I. Vijay Arasu et al. (7) studied the effect of process parameters like laser power, orientation and scan spacing on surface roughness in selective laser sintering process. They optimized the parameters for improving quality and functionality of metal parts.

In the present manufacturing scenario lot many components are being manufactured in powder metallurgy route. To the authors knowledge , surface roughness studies on powder metallurgy based components are very less. P.K.Bardhan et al. (8) investigated the surface roughness values of sintered powder metallurgy components manufactured from iron powders at different cutting speeds. Again they observed that there was strong influence of compaction pressure, sintering temperature and sintering time on surface roughness. In the present investigation an attempt has been made to study the effect of manufacturing parameters like compaction pressure and sintering temperature on surface roughness of metal matrix composites manufactured from low carbon content ferrous powders (LCFP) and high carbon content rapidly solidified alloyed ferrous powders (HCFP).

EXPERIMENTAL PROCEDURE

Production of LCFP and HCFP and their characteristic studies

Water atomization technique was adopted to produce LCFP and HCFP. Then both the powders were annealed at two different temperatures in a tubular furnace in hydrogen atmosphere. Low carbon content ferrous powders were annealed at 700˚C for two hours and high carbon content rapidly solidified ferrous powders were annealed at 1000˚C for one hour. After annealing, both the powders were characterized. The Chemical characteristics of LCFP are given in Table1 and Physical characteristics of LCFP are given in Table2. The Chemical characteristics and Physical characteristics of HCFP are given in Table 3 and Table 4 respectively. The SEM micrographs taken by JEOL 840 JSM scanning electron microscope for LCFP and HCFP are presented in Figure 1and Figure 2 respectively.

Table 1.-Chemical characteristics of annealed low carbon content ferrous powders in wt.%

C	S	P	Fe
0.04	0.015	0.025	Balance

Table 2.- Physical characteristics of annealed low carbon content ferrous powders

Characteristics	value
Apparent Density, gm/cm^3	2.75
Flow rate, sec/50g	24
True Density, gm/cm^3 (Pycnometric)	7.76
Approximate particle size range(μm)	8-100

Table 3.- Chemical analysis of annealed high carbon content rapidly solidified alloyed ferrous powders in wt.%

C	Al	Cr	Si	S	P	Fe
3.45	2. 1	1.8	1.4	0.013	0.02	Balance

Table 4.- Physical characteristics of annealed high carbon content rapidly solidified alloyed ferrous powders

Characteristics	value
Apparent Density,gm/cm^3	2.62
Flow rate,sec/50g	23
True Density,gm/cm^3 (Pycnometric)	7.3
Approximate particle size range(μm)	8-100

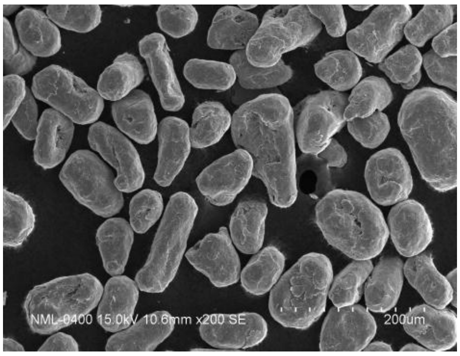

Figure1.- SEM micrograph of annealed low carbon content ferrous powders

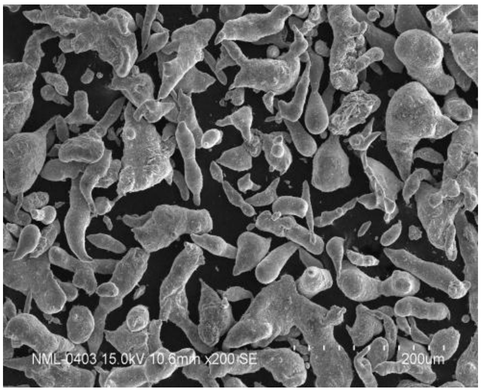

Figure 2.- SEM micrograph of annealed high carbon content rapidly solidified alloyed ferrous powders

Pre-compaction study of mixed powders

High carbon content rapidly solidified alloyed ferrous powders got mixed with low carbon content ferrous powders in various proportions as mentioned below.1% Zinc Stearate (ZS) was added to the various compositions. Each composition was properly blended using a small blender.

1. LCFP(balance)+10% HCFP+1%Zinc Stearate
2. LCFP(balance)+20% HCFP+1%Zinc Stearate
3. LCFP(balance)+30% HCFP+1%Zinc Stearate
4. LCFP(balance)+40% HCFP+1%Zinc Stearate
5. LCFP(balance)+50% HCFP+1%Zinc Stearate

Cold Compaction Studies of mixed powders

Each of the mixed powder samples got cold compacted using double action die sets within the pressure range of 200MPa -600MPa. The green density for each sample was calculated by a microbalance and a micrometer at different pressures .The compaction pressure versus green density data are presented in Table5, Table6 and Table7.

Sintering Studies of mixed powders

The sintering study for all the above samples was carried out in three different temperatures like 900˚C, 1000˚C & 1100˚C. Sintering was done in presence of hydrogen atmosphere in a sintering furnace **(**Make: Therelek Furnaces Private Limited, Range:0-1300°C,Error:±2°C) . The sintered densities were calculated using the same technique as it was discussed for calculation of green densities and the data for the samples are presented in Tables5,Table6 and Table7**.**

Surface Roughness Testing

The surface roughness values for the specimens of various compositions were measured before sintering for different compaction pressures and after sintering for different sintering temperatures. Here Taylor Hobson talysurf roughness tester (Make: Taylor Hobson Ltd.,England, Model: Surtronic-25) was used for the measurements. The data obtained are presented again in Table5-Table7.

Table 5: Surface Roughness value, Ra, in µm of mixed powder compacts before and after sintering at 900°C

Composition in wt%	Compaction pressure, MPa	Green Density,gm/cc	Ra before sintering	Sintered Density,gm/cc	Ra after sintering
LCFP(bal)+ HCFP(50%)+ ZS(1%)	200	5.439	5.92	5.384	5.60
	300	5.69	5.38	5.642	5.21
	400	5.79	5.21	5.748	5. 13
	500	6. 113	4.95	6.074	4.97
	600	6.223	4.83	6. 185	4.83
LCFP(bal)+ HCFP(40%)+ ZS(1%)	200	5.541	5.85	5.505	5.55
	300	5.831	5.52	5.801	5. 14
	400	6. 130	5.20	6. 100	4.80
	500	6.319	4.88	6.299	4.65
	600	6.413	4.80	6.392	4.58
LCFP(bal)+ HCFP(30%)+ ZS(1%)	200	5.580	5.00	5.55	4.88
	300	5.819	4.75	5.793	4.70
	400	6. 137	4.40	6. 111	4.32
	500	6.52	4.21	6.497	4.20
	600	6.582	4.02	6.564	3.95
LCFP(bal)+ HCFP(20%)+ ZS(1%)	200	5.599	4.85	5.578	4.70
	300	5.877	4.41	5.86	4.33
	400	6.3	4.30	6.285	4.20
	500	6.632	4.22	6.619	4. 13
	600	6.647	4. 15	6.635	4.08
LCFP(bal)+ HCFP(10%)+ ZS(1%)	200	5.754	4.75	5.74	4.71
	300	5.984	4.40	5.971	4.33
	400	6.380	4.25	6.368	4. 18
	500	6.697	4. 12	6.687	4.08
	600	6.70	4.05	6.69	3.91

Table 6: Surface Roughness value, Ra, in µm of mixed powder compacts before and after sintering at 1000°C

Composition in wt%	Compaction pressure, MPa	Green Density,gm/cc	Ra before sintering	Sintered Density,gm/cc	Ra after sintering
LCFP(bal)+ HCFP(50%)+ ZS(1%)	200	5.441	5.91	5.384	5.52
	300	5.7	5.40	5.649	5. 18
	400	5.809	5.20	5.764	5. 10
	500	6. 11	4.97	6.068	4.95
	600	6.26	4.82	6.218	4.80
LCFP(bal)+ HCFP(40%)+ ZS(1%)	200	5.539	5.87	5.501	5.60
	300	5.84	5.50	5.806	5.21
	400	6. 1	5.23	6.068	4.92
	500	6.317	4.86	6.293	4.60
	600	6.40	4.78	6.375	4.53
LCFP(bal)+ HCFP(30%)+ ZS(1%)	200	5.583	4.98	5.55	4.88
	300	5.817	4.75	5.788	4.61
	400	6. 13	4.41	6. 1	4.27
	500	6.527	4.23	6.501	4.03
	600	6.581	4.03	6.56	3.95
LCFP(bal)+ 20%HCFP(20%)+ ZS(1%)	200	5.613	4.87	5.589	4.76
	300	5.869	4.40	5.849	4.35
	400	6.29	4.32	6.272	4.22
	500	6.63	4.21	6.614	4. 10
	600	6.66	4. 15	6.645	3.98
LCFP(bal)+ HCFP(10%)+ ZS(1%)	200	5.749	4.77	5.733	4.68
	300	5.979	4.39	5.963	4.30
	400	6.383	4.24	6.367	4. 15
	500	6.696	4. 13	6.683	3.95
	600	6.72	4.06	6.708	3.90

Table7: Surface Roughness value, Ra, in µm of mixed powder compacts before and after sintering at 1100°C

Composition in wt%	Compaction pressure,MPa	Green Density,gm/cc	Ra before sintering	Sintered Density,gm/cc	Ra after sintering
LCFP(bal)+ HCFP(50%)+ ZS(1%)	200	5.446	5.90	5.407	5.48
	300	5.715	5.40	5.673	5.09
	400	5.803	5.22	5.756	5.00
	500	6. 102	4.97	6.045	4.90
	600	6.21	4.80	6. 142	4.72
LCFP(bal)+ HCFP(40%)+ ZS(1%)	200	5.543	5.86	5.519	5.51
	300	5.8	5.50	5.776	5. 12
	400	5.990	5.22	5.956	4.87
	500	6.313	4.88	6.274	4.55
	600	6.43	4.77	6.384	4.49
LCFP(bal)+ HCFP(30%)+ ZS(1%)	200	5.586	5.00	5.566	4.80
	300	5.822	4.76	5.797	4.52
	400	6. 112	4.41	6.0809	4.20
	500	6.523	4.22	6.488	3.96
	600	6.57	4.01	6.528	3.90
LCFP(bal)+ 20%HCFP(20%)+ ZS(1%)	200	5.611	4.86	5.596	4.70
	300	5.872	4.40	5.854	4.31
	400	6.27	4.33	6.249	4. 12
	500	6.628	4.22	6.603	4.00
	600	6.64	4. 14	6.610	3.87
LCFP(bal)+ HCFP(10%)+ ZS(1%)	200	5.751	4.76	5.739	4.60
	300	5.981	4.39	5.967	4.25
	400	6.386	4.25	6.368	4. 13
	500	6.693	4. 12	6.673	3.81
	600	6.75	4.05	6.729	3.80

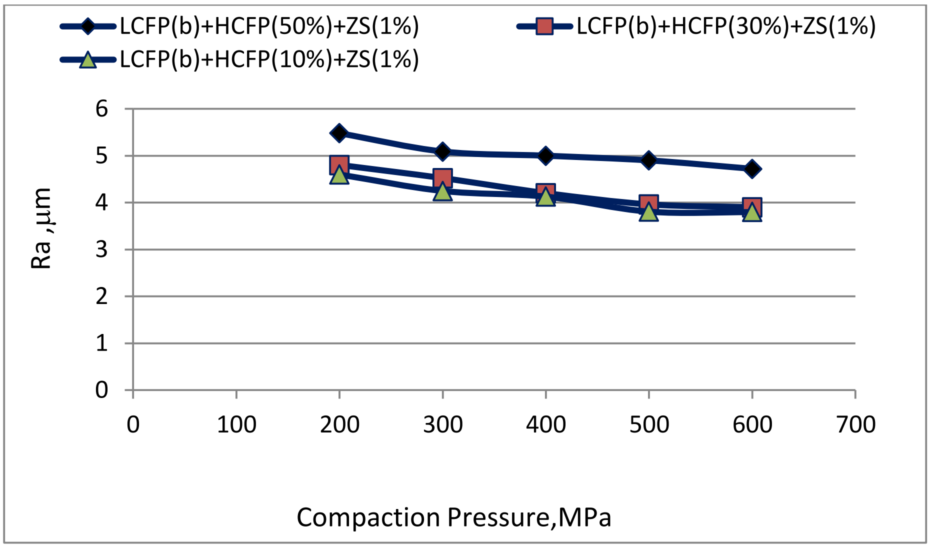

Fig.3: Surface roughness value, Ra, of compacts of different compositions, which were sintered at 1100°C

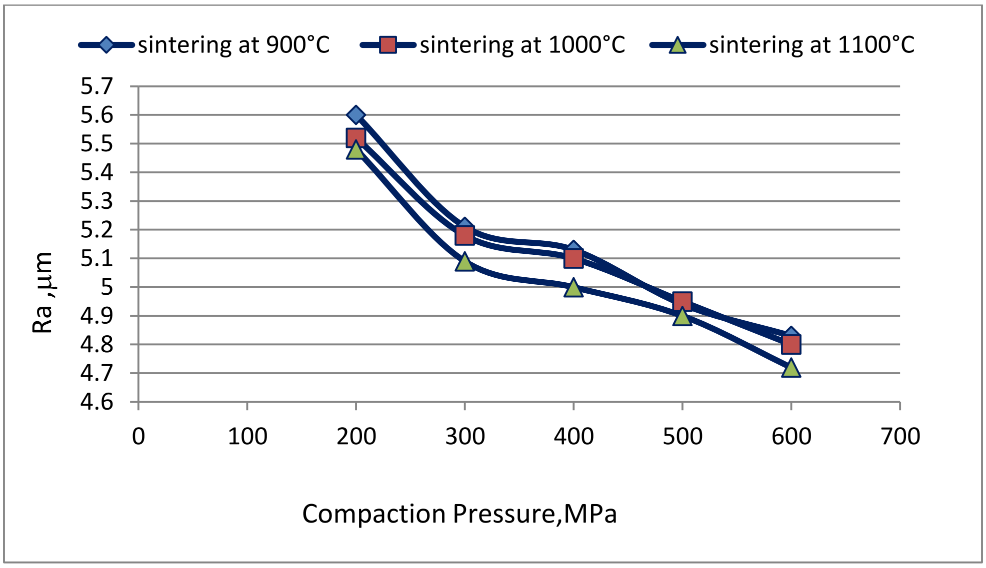

Fig. 4: Surface roughness value, Ra, for compacts of composition LCFP (bal) + HCFP (50%)+ ZS(1%) at different sintering temperatures

RESULTS AND DISCUSSION

Characteristics of LCFP

From Table1, it is found that Sulphur and Phosphorous content in LCFP are 0.015% and 0.025% respectively. These are quite low and cannot affect the manufacturing of

Powder Metallurgy(PM) products. From the Physical analysis,Table2, it is found that the apparent density is 2.75gm/cm^3. This is quite good for manufacturing high density powder metallurgy (PM) parts. Flow rate is 24sec/50gm.This will provide very good flow of powders into die and is good for manufacturing machine parts through PM Process.

Characteristics of HCFP

From table 3, it is observed that 2.1wt% Al, 1.8wt% Cr and 1.4wt% Si are present in the high carbon content rapidly solidified alloyed ferrous powders. Addition of 1.8% of Cr acted as carbide stabiliser, 1.4wt % Si enhanced the A1 transformation temperature upto 1000^{o}C in the powders and Al in 2.1wt% helped in grain refinement. From table4, it is found that flow rate is 23 sec/50gm. This is also quite good. The apparent density is a very useful parameter for designing the die and punch from which the apparent height for a given dimension of a product is calculated. For the above powders, it is found to be 2.62gm/cm^3, which is comparable with any quality powder of such kind.

Microstructural Analysis

The SEM micrographs of LCFP and HCFP are given in Figure1 and Figure2 respectively. In both the cases the powders are observed to be irregular in shape and this helps in interlocking of powders during cold compaction.

Green Density and Sintered Density

The strength of the compacts largely depends upon the densities of the powder metallurgy products. The densities also depend on compaction pressures. So with increase in compaction pressure the green densities as well as sintered densities for the composites go on increasing , which are shown in Table5-table7. The surface roughness values are also found to vary with densities.

Surface Roughness testing

The surface roughness values Ra in μm presented in table5-Table7 reveal that as percentage of LCFP goes on increasing, the surface roughness values for the mixed powder compacts go on decreasing for the corresponding compaction pressures. This is shown in Figure3.This happens because of high ductility of LCFP. During compaction, these low carbon content ferrous powders plastically deform and fill the gaps among themselves leading to smooth surfaces, for which low Ra values are obtained. On the contrary, by increasing the percentage of HCFP, the surfaces of the compacts become more rough leading to higher values of Ra. This is because of presence of high amount of hard particles in the compacts.

From tables5-table7, it is revealed that the sintered samples show lesser value of Ra leading to better surface finish compared to green samples for the corresponding compaction pressures. As the compaction pressure goes on increasing, the surface roughness values also go on decreasing both for sintered as well as green samples leading to better surface finish. It is also revealed from the tables that less values of Ra are obtained when the compacts were sintered at 1000°C compared to that at 900°C and the same tendency continues for samples got sintered at 1100°C. This is because, higher the temperature, better the diffusion among the powder particles leading to better smoothness of surface of the sintered compacts. This is shown in Figure4.

CONCLUSIONS

The following conclusions are derived.

1. As the weight percentage of low carbon content ferrous powders goes on increasing, the surface roughness values Ra for the mixed powder compacts go on decreasing for the corresponding compaction pressures.
2. As the compaction pressure goes on increasing, the surface roughness values Ra go on decreasing both for the sintered and green compacts of mixed powders.
3. As the sintering temperature goes on increasing from 900°C to 1100°C, the surface roughness values Ra go on decreasing for compacts of all compositions and compaction pressures.

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