WARM COMPACTION OF IRON POWDER

H. Erdem Camurlu[1], Lutfulloi Karomatullozoda[1]
Mechanical Engineering Department – Akdeniz University, Antalya, Turkey[1]

erdemcamurlu@mail.com

Abstract: *Iron powder metallurgy is a method that is widely used in production of steel parts that are utilized as machine components or as parts in automotive industry. Milling is extensively used in powder metallurgy of iron, for purposes of mixing. The hardness and yield strength of milled iron powders increase due to work hardening. This leads to low green density of the cold pressed green parts, prior to sintering. In powder metallurgy, warm compaction is utilized for enhancing the green density and green strength.*

In the present study, effect of warm compaction of milled iron powders was investigated. For warm compaction of iron powders, 600 MPa pressure was applied in a steel die at 150 ^oC. The microstructure of the milled samples was examined by scanning electron microscopy. Hardness values of the cold pressed and warm compacted samples were determined by a Brinell hardness tester. Bending strength values of the samples were determined by a universal testing machine. It was found that the hardness of the cold compacted green samples increased considerably, from about 40 Brinell10 to about 140 Brinell10, as a result of warm compaction. Bending strength values increased to over 100 MPa after warm compaction; whereas the bending strength of the cold compacted green samples were in 10-20 MPa range.

Keywords: POWDER METALLURGY, WARM COMPACTION, IRON POWDER

1. Introduction

In the method of powder metallurgy, metals in powder form are mixed, compacted and sintered. In comparison to other manufacturing methods, it has some benefits such as very high utilization rate of starting powders, capability of net shaped production, etc.

Microstructural control is another outcome of powder metallurgy. Due to the fact that the process starts from powdered metal, particle size of which is generally 10 microns or less, the distribution and size of the microstructural constituents such as phases and pores in the final product can be arranged, in a much better manner than the other production techniques.

Mixing and milling is one of the initial steps in powder metallurgy, which is used for blending powders, as well as for powder production and particle size reduction [1]. During milling, especially when the impact of the balls is large, such as in high energy milling, a high amount of plastic deformation of the particles occurs. Ductile metallic particles become flake shaped. In addition, due to cold welding of the flakes, agglomerates form and particle size increases [2]. During milling, the hardness and yield strength of milled metal powders increase due to work hardening. This leads to low green density of the cold pressed green parts, prior to sintering.

In powder metallurgy, warm compaction is utilized for enhancing the green density and green strength. Warm compaction of iron is conducted mostly in 150-180 ^oC temperatures range. During warm compaction, polymer binder and lubricant melts and solidifies, giving the pressed article a higher density and strength [1,3,4]. In addition, it was reported that the properties of the articles that are warm compacted and sintered are superior to those of the articles that are cold compacted and sintered [5].

In the present study, effect of warm compaction of milled iron powders was investigated. After milling, iron powders were warm compacted at 150 ^oC. Mechanical properties and microstructure of the warm compacted specimens were compared with the properties of cold compacted green samples.

2. Experimental Procedure

In the present study, effect of warm compaction of milled iron powders was investigated. Milling of the Fe powder was conducted in a planetary ball mill having a 250 ml capacity stainless steel grinding jar. Process control agent was not used.

In each run, 10 g Fe powder was milled. The grinding jar was equipped with an aeration cover, which made it possible vacuuming and back filling the jar with argon. This provided the milling operation to be conducted in argon atmosphere. Thus, oxidation of the Fe powder during milling was prevented.

The diameter of the milling balls were 6 mm. Ball to powder weight ratio was kept as 10. Milling was conducted for various durations up to 1 hour. Milling was interrupted at definite durations such as 2 minutes, and after 2 minutes of cooling period, milling was continued.

In order to characterize the milled Fe powders, particle size analyses were performed. A scanning electron microscope (SEM) was employed for morphological and dimensional investigations after milling.

For warm compaction of iron powders, 600 MPa pressure was applied in a steel die at 150 ^oC, in a hot press. Milled powders were subjected to scanning electron microscopy examinations and particle size analyses. The microstructure of the compacted samples was examined by optical microscopy (Nikon Eclipse LV 150). Hardness values of the samples were determined by a Brinell hardness tester (Bulut Makine RBOV). Bending strength values of the samples were determined by a universal testing machine (Shimadzu AG-IC, capacity: 50 kN).

3. Results and Discussion

Powders, which were milled for 0, 15, 30 and 60 min were subjected to SEM examinations and particle size measurements.

SEM micrograph of Fe powder which was milled for 15 min is given in Fig. 1. It can be seen that size of the particles are mostly about 10 microns and the particles have sphere-like morphology. There are a few large particles which have flat surfaces. It can be inferred that in 15 minutes milling duration, the effect of milling is quite low.

Average particle size of the Fe powder prior to milling was 10 microns. Particle size distribution plot of the Fe powder which was milled for 15 minutes is given in Fig.2. It can be seen that the size distribution has 3 modes. Most of the particles are about 10 microns, some are about 70 microns and very few are about 300 microns.

During milling flattening of the Fe particles takes place with the squeezing action of the milling balls and vial. The increase in the particle size may be attributed to sticking and cold welding of the flattened Fe particles to each other with the repeated impact of the milling balls.

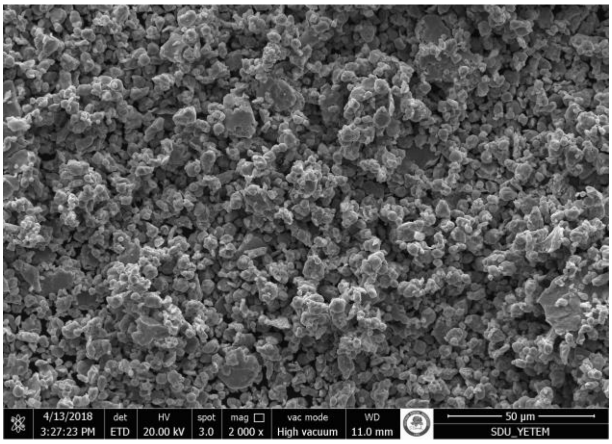

Fig. 1 *Scanning electron micrograph of the Fe powder which was milled for 15 minutes.*

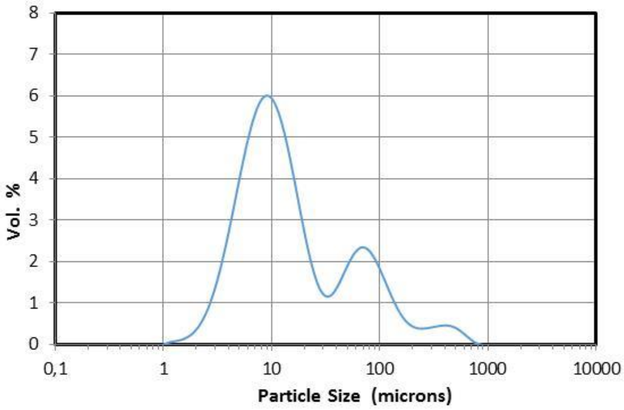

Fig. 2 *Particle size distribution plot of the Fe powder which was milled for 15 minutes*

SEM micrograph of Fe powder which was milled for 60 min is given in Fig. 3. It can be seen that size of the particles are mostly larger than 50 microns and the particles have flake-like morphology. It can be inferred that in 60 minutes milling duration, almost all of the particles are affected from the milling operation.

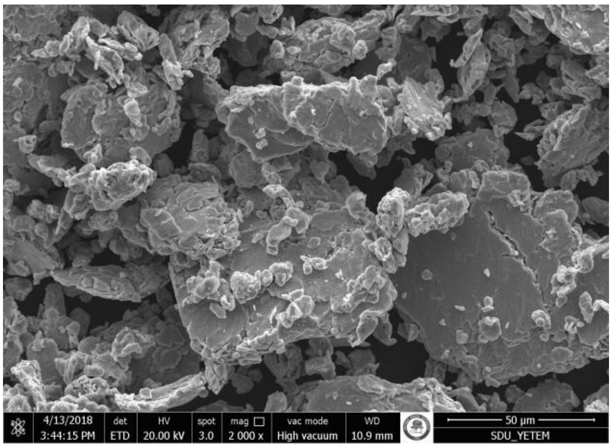

Fig. 3 *Scanning electron micrograph of the Fe powder which was milled for 1 hour.*

Particle size distribution plot of the Fe powder which was milled for 60 minutes is given in Fig.4. It can be seen that the average particle size is about 70 microns. There is a slight second mode at about 10 micron size. It can be inferred when compared with the particle size of Fe powder milled for 15 min that the average particle size increases during milling.

Unalloyed Fe particles are quite ductile and they plastically deform easily. As a result of the cold welding of the flattened Fe particles, formation of large agglomerates takes place. There is a second effect of milling on Fe particles, which are strain hardening due to plastic deformation. There is the possibility that the hardened agglomerates break up upon excessive plastic deformation during milling. The disappearance of the mode at about 300 microns after 1 h milling, that was present after 15 min milling, can be attributed to this effect.

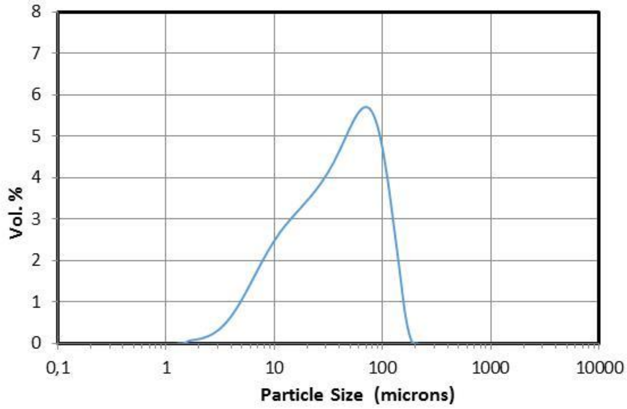

Fig. 4 *Particle size distribution plot of the Fe powder which was milled for 1 hour.*

The unmilled and milled Fe powders were shaped by cold pressing and warm compaction. After that, hardness and bending strength of the green samples were determined. Hardness and bending strength values of the samples are presented in Table 1, Fig. 5 and Fig. 6. Some of the hardness values, that are not present in Table 1, could not be determined since the samples were broken apart during hardness measurements.

Table 1: *Hardness and bending strength values of the samples after cold pressing and after warm compaction.*

Milling Duration (min)	Cold Pressed		Warm Compacted	
	Hardness (HB10)	Bending Strength (MPa)	Hardness (HB10)	Bending Strength (MPa)
0		22,49	134,72	94,87
15		18,91	152,97	117,95
30			159,00	
60	44,00	8,57	152,03	135,00

Hardness values of the cold pressed and warm compacted samples were determined by a Brinell hardness tester. The hardness of the sample that was prepared by cold pressing of the 60 min milled Fe powder, was 44 HB10. It was found that the hardness of the cold compacted green samples increased considerably, to about 150 Brinell10, as a result of warm compaction.

This can be attributed to the increase in the density of the samples when warm compaction is employed. It was reported in literature that the density of the samples are about 3 % higher when warm compaction is applied, as compared to cold pressing [5,6].

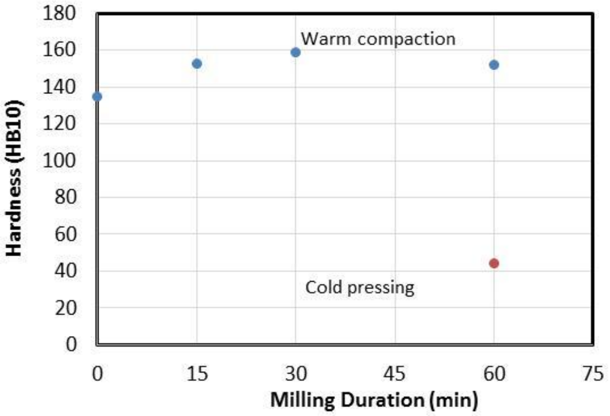

Fig. 5 *Hardness values of the samples after cold pressing and after warm compaction.*

Bending strength values of the samples were determined by a universal testing machine. Bending strength values after cold pressing were about 20 MPa and less. Bending strength increased to over 100 MPa after warm compaction. It can be seen that warm compaction has a significant effect on green strength of Fe articles.

The increase in the bending strength may be attributed to increase in green density after warm compaction. In the present study, warm compaction was applied at 150 ^{o}C. At this temperature, the yield strength of Fe particles is expected to decrease. This leads to higher amount of plastic deformation. Therefore, more void is filled in the article, providing a higher green density and better interlocking of the Fe particles. These effects may be the reasons for the increase in the green strength after warm compaction.

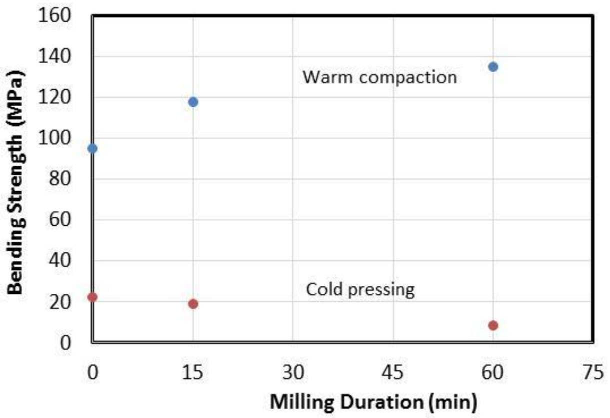

Fig. 6 B*ending strength values of the samples after cold pressing and after warm compaction.*

4. Conclusion

The milled powders are more difficult to compact, due to strain hardening of the particles. Higher pressures are necessary for compacting milled powders, as compared to unmilled powders. Warm compaction is believed to help to reduce the strain hardening effect on milled powders and provide higher density. This leads to higher hardness and higher green strength.

Acknowledgements

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