OPEN ACCESS Freely available online

Global Journal of Engineering, Design & Technology

Review Arice

Advanced Techniques for Improved Properties of P/M Ferrous Soft Magnetic Materials

Deepika Sharma*

Department of physics, Swami Premanand Mahavidyalaya Mukerian, Affiliated to Punjab University Chandigarh, India

ABSTRACT

Powder Metallurgical (P/M) route of manufacturing has its inherent advantages such as the utilization of the material to a greater extent, ability to get the product in net shape without subsequent machining or incorporating any other additional forming operation. At the same time, P/M processing makes it possible to tailor the magnetic properties of a part to suit a specific application by effectively controlling the powder characteristics, material's chemistry and processing parameters. Thus P/M processing offers the material and product designer a wide flexible range and a greater scope for material's development. The desired magnetic properties in P/M soft magnetic materials may be obtained by selecting appropriate alloy chemistry and optimizing the processing parameters. The requirement of high density is a predominant factor for improving the performance of powder metallurgy components employed in soft magnetic applications. Also, new methods are being developed by modifying the existing ones for the production of P/M parts to improve performance, efficiency and life of the components and to make them suitable in a wider range of applications. Most of these methods are of commercial importance and many of them have been patented.

Keywords: Density; Magnetic; Compaction; Tensile; Coating

INTRODUCTION

Traditionally, density is increased by raising compaction pressure, elevating sintering temperature, adding elements for activating sintering process; using Double Press/Double Sinter (DPDS), copper infiltration and powder forging methods. It has been stated that hot forging technique for making heavy duty brake pads offer a better opportunity for pore free material with better bonding between various metallic and non-metallic constituents. The material so produced has been characterized for specific wear, temperature rise during engagement, coefficient of friction, hardness and density. However, there seems to be no attempt in producing soft magnetic materials with relaxed powder characteristics and alternative processing [1].

LITERATURE REVIEW

The techniques summarized below mainly comprise of improving the powder characteristics of magnetic materials in order to support conventional compacting and sintering process to yield high density values and hence soft magnetic properties.

Process of fe-p powder production by coating iron powder with phosphorus

P/M phosphorus irons formulated by admixing high purity water atomized iron powder with ferrophosphorus (containing $Fe2P$ or $Fe3P$) powders are widely used in industry today for magnetic devices. The automotive industry, in particular, is designing magnetic devices using P/M phosphorus irons. A high performance soft magnetic material would permit fuel injectors and sensors to be made smaller or less power intensive, resulting in savings through weight reduction. Performance of other devices, such as relays and solenoids, would also be enhanced. However, the ferrophosphorus powder normally has some degree of carbon, nitrogen and oxygen contamination. These elements are deleterious to structure sensitive magnetic properties. In addition, the oxygen contamination deters sintering because the surface oxide film must be reduced before the phosphorus can diffuse into the base iron. A second potential problem exists

Correspondence to: Deepika Sharma, Department of Physics, Swami Premanand Mahavidyalaya Mukerian, Affiliated to Punjab University, Chandigarh, India Tel: +91123456789; E-mail: deepikasharmabhanot@gmail.com

Received: January 04, 2021; **Accepted:** January 18, 2021; **Published**: January 25, 2021

Citation: Sharma D (2021) Advanced techniques for Improved Properties of P/M Ferrous Soft Magnetic Materials. Glob J Eng Design Technol.10:1.

with admixed powders. Although the Fe3P powders particles are small and fit in the interstices of the larger iron particles, they are not in intimate contact with the iron particles. These smaller Fe3P particles must therefore melt to effectively diffuse into the iron. If Fe3P particle are too large, these travel along grain and particle boundaries to diffuse into the iron matrix. Large amounts of a liquid phase may cause damage to the boundaries as the liquid cascades along these boundaries, resulting in degradation of magnetic structure sensitive properties. Therefore, the size of the Fe3P particles must be tightly regulated to prevent this damage from occurring. It has long been recognized that the best approach to making phosphorus iron is to directly deposit the phosphorus on the surface of the iron particles. Such a powder is a composite powder having compressibility of the order of pure iron powder and sinterability of the order of mixed iron- phosphorous system. Thus producing optimum characteristics for compaction and sintering process [2].

By coating phosphorus on the iron particles, diffusion is more efficient; resulting in improved tensile and magnetic properties, with elimination of large pores and damaged grain boundaries. The method describes the properties that result from coating a water atomized high compressibility iron powder with phosphorus, using fluid bed technology and red phosphorus. The result is an improvement in both magnetic and tensile properties.

The apparatus consists of a large retort that contains the iron powder as shown in (Figure 2). The retort is immersed into a bed of alumina that is heated to a temperature sufficient to heat the fluidized iron powder to the proper temperature to receive the vaporized phosphorus. Prior to introducing the phosphorus, the retort is purged and hydrogenis introduced. The hydrogen reacts with the heated iron powder to reduce surface oxides that are present, thus producing an active iron surface to receive the phosphorus coating. Once the iron surface is prepared, vaporized phosphorus is introduced to the fluidized bed of iron. The phosphorus deposits or reacts with the active iron powder surface, thus providing a uniform coating of phosphorus on the surface of the iron particles [3].

The process is readily controlled by regulating the temperature of the fluidized iron powder, regulating the flow rate of the vaporized phosphorus that is introduced to the fluidized iron powder, and regulating the time that the vaporized phosphorus is in contact with fluidized iron particle. By controlling the flow rate of the phosphorus at a constant temperature, for a specified time, a specified phosphorus coating may be deposited within 50.0 wt.% of the desired phosphorus content. Phosphorus concentrations up to 1.5 wt.% have been deposited on iron powder, employing these controls. The magnetic properties of the specimens sintered at 1120oC and 1260oC for admixed 45P, coated 45P and that for coated 80P containing 0.49, 0.40 and 0.84%P respectively are listed in (Figure 1) [4].

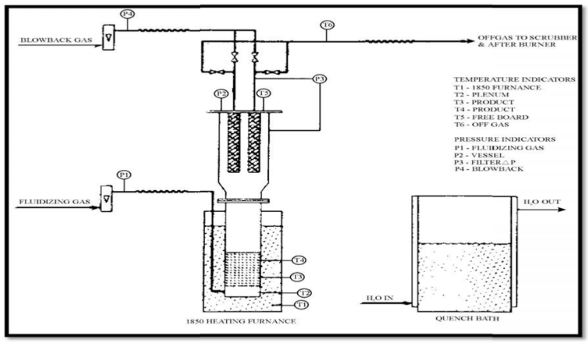

Figure 1: Schematic diagram of fluid bed reactor.

The compaction pressure was 30 and 50 tsi and all these specimens are sintered in hydrogen atmosphere for one hour. The magnetic induction of sintered specimens fabricated from coated 45P powders is slightly higher than that of specimens from admixed 45P. Further, the magnetic induction of the specimens coated with 0.84%P was even higher, owing to the increase amount of liquid phase contributed by increased quantity of phosphorous in the alloy. A significant improvement in the structural sensitive magnetic properties (such as relative maximum permeability, coercive force and remanent) is realized in comparison with the admixed specimens of similar composition [5].

The phosphorous is in direct contact with the iron powder surface in case of coated powders; therefore, sintering may be more uniform, and thereby permitting improved control on dimensions. The tensile strength of the specimens coated with 0.8%P is found higher than that of the specimens prepared from coated 45P powders, owing to increased solid solution hardening provided by higher phosphorous content. However, it is well known that the elongation markedly decreases with this percent of phosphorus in the alloy; still it is above 1%.

Polymer coated iron powders and compacted materials or iron-polymer composites

Iron powder is well known for its use in dust core applications. An electrically insulating layer is applied to the surface of the iron powder prior to compaction. As compacts produced from insulated iron powders are exposed to varying magnetic fields, the eddy currents which are generated in response to these fields are prevented from travelling between particles. This allows the materials to be used with high frequency magnetic fields, as the detrimental effect of eddy currents is restricted. Dust cores, however, have been limited in their application due to the lack of both structural integrity and high density in the final compact [6].

The plastic coated iron powder offers a cost-effective soft magnetic material, which is suitable for moderate to high frequency magnetic applications. A newly developed method for applying a high temperature thermo-plastic coating to the iron particles achieves high-density compacts with high frequency magnetic properties. A uniformly distributed plastic coating is applied to the iron particles by a fluidized bed coating process. The plastic coated iron powder is then compacted at an elevated temperature using a setup similar to that of warm compaction as shown in (Figure 2).

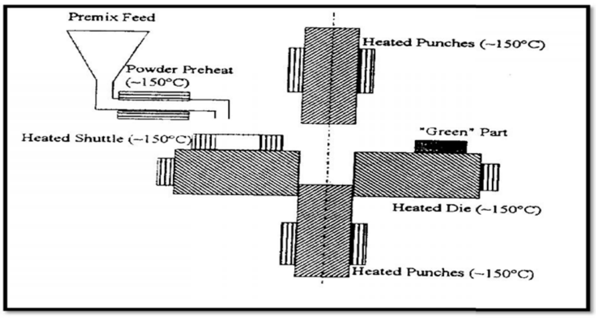

Figure 2: Warm Compaction process diagram.

The temperature of the die and punches is set to a level to achieve compacted densities of up to 7.50 g/cm3 or 98% of the theoretical density of the iron and plastic compaction. A flow diagram is shown in (Figure 3) for the production process of soft magnetic components by using plastic coated insulated iron powders.

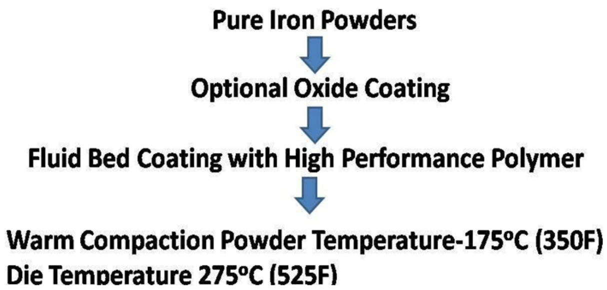

Figure 3: Flow diagram for the production process of the components from plastic coated iron powders.

The uniformity with which the plastic is applied to the iron powder enables a total plastic content of less than 1% by weight to provide high strength compacts with good electrical insulation between particles. The plastic coated iron compact provides green strengths of 125 MPa. A moderate post compaction heating operation (315°C for 1 hour) increases this strength level up to 250 MPa. The high strength enables machining operations to be performed on the compacts when necessary [7].

Iron powder polymer composites are designed to be used in either the as pressed or as pressed and cured condition. Curing dramatically increases the green strength of the component and is done at temperatures less than 315^{0}C (600F). A typical mechanical property of the iron powder polymer composites in the as compacted condition is about 82 MPa (12,000 psi) transverse rupture strength (TRS) i.e. the green strength, while curing increases the TRS to about 240MPa (35,000 psi). Components made from the iron powder polymer composites are brittle and exhibit no elongation during tensile testing. The (Table 1) shows the composition and DC magnetic properties of three distinct coated iron powders, which vary in particle size distribution and coating type viz. Material # 1, # 2 and # 3.

Ancor steel Material	Polymer coating (wt %)	Oxide Coating	Density at 690 MPa (g/cm3)	Initial permeability	Max. permeability	Coercive force (Oe)	Induction at 40 Oe (Gauss)
Material #1 (SC 120)	0.6	No	7.45	120	425	4.7	11200
Material #2 (SC100)	0.75	No	7.4	100	400	4.8	10900
Material #3 (TC 80)	0.75	Yes	7.2	80	210	4.7	7700

Table 1: Magnetic properties of polymer coated iron powder components.

It shows the frequency response of these three experimental plastic coated iron powder components. Ancorsteel SC 120 utilizes a coarser particle size distribution with the lowest polymer contents and yields the highest compacted density. Consequently, it exhibits the best DC magnetic properties and has the highest AC magnetic performance at Low frequencies. Ancorsteel TC 80 utilizes a smaller particle distribution combined with an initial oxide treatment of the powder followed by the polymer coating. This increased level of insulation gives the lowest DC magnetic performance but yields the best high frequency performance, exhibiting constant permeability up to 50,000 Hz (Figure 4).

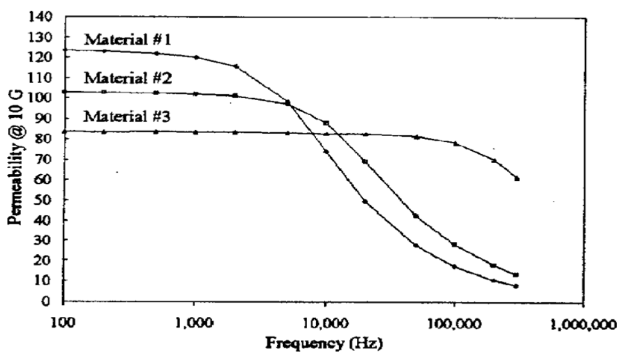

Figure 4: Initial permeability vs Frequency for three experimental plastic coated iron powders.

Magnetic performance can be tailored to meet the need of particular applications by the proper selection of iron and coating. Finer iron particle size distributions yield better high frequency performance while coarser particles optimize low frequency behavior. The total plastic content can also be adjusted with lower plastic contents yielding higher pressed densities and higher plastic contents improving strength and high frequency performance. Plastic coating can be applied to iron powder that has previously been coated by more traditional coating methods employed in the dust core market. This double coating technique provides high frequency performance with the mechanical strength advantage provided by the plastic coating. Plastic coated iron compacts exhibit isotropic high frequency magnetic performance. Traditional lamination stacks used in core assemblies are effective in carrying a varying magnetic flux only in the plane of the laminations while maintaining low eddy current loss. The plastic coated iron eliminates this restriction. Designs that require 3-dimensional flux-carrying capability can now be considered using the plastic coated iron [8].

It shows total core loss versus frequency for a plastic coated iron powder compacts made from material #3 and a commonly used 3%Si-Fe laminated steel assembly. At low frequencies, where total core loss is dominated by hysteresis loss, core loss of the silicon-iron lamination is lower than the core loss of the plastic coated iron. Cold work that is introduced to the plastic coated iron during the compaction process increases hysteresis loss of the material. The plastic coating on the iron powder cannot with stand the annealing temperatures that would be needed to relieve the cold work introduced during compaction. This limits the low frequency performance of plastic coated iron compacts, as hysteresis losses are high relative to laminated steels. The reduced eddy current loss provided by the plastic coated iron out performs laminated steel above certain frequencies as eddy current begin to dominate the total core losses (Figure 5) [9].

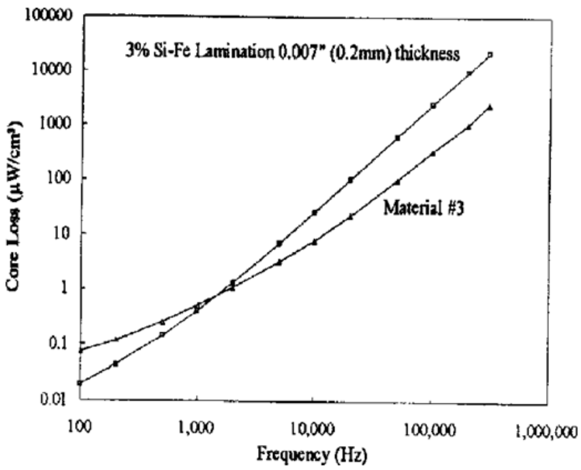

Figure 5: Core loss vs frequency at 10 Gauss induction level.

CONCLUSION

This research investigation is an exploratory work in the area of materials and process development and looking into host of parameters, certain processing parameters, which are optimized for binary Fe-P system. The above two described methods are employed to achieve higher sintered density than the value of density achieved in traditional single compacting and sintering operation The above stated techniques have given a new dimension in the production of P/M ferrous soft magnetic materials with very low core losses.

REFERENCES

1. Sharma D, Chandra K, Misra PS. Design and development of powder processed Fe-P based alloys. Materials and Design. 2011;32(6): 3198-3204.
2. Sharma D. P/M Processed Fe-Ni Alloys for Soft Magnetic Applications. J Chem Pharm Res. 2017;9(4): 264-269.
3. Oliver CG. Advances in powder metallurgy of soft magnetic materials. IEEE Trans Magn.1995;31(6):3982-3984.
4. Sharma D. P/M Processed Fe-Sn Alloys. J chem pharm res 2018;10(6): 152-157.
5. Rutz HG, Hanejko FG, Ellis GW. The manufacture of electromagnetic components by the powder metallurgy process. Adv Powder Metall Part Mater. 1997.
6. Sharma D. Pure Iron and Low Carbon Steels- Soft Magnetic P/M Materials. J chem pharm res. 2017;9(1):225-229.
7. Bhattacharyya D, Shields RJ, Fakirov S. Characterization and novel applications of Fibrillar Polymer Composites. Adv Mat Res. 2008;47(50):1278-1281.
8. Sharma D. Selection and design of soft magnetic materials for transformer core applications. J chem pharm res. 2015;7(7):312-317.
9. Chakraborty S, Mandal K, Sakar D, Cremaschi VJ, Silveyra JM. Dynamic Coercivity of Mo-doped FINEMETs. Physica B. 2011;406(10):1915-1918.