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Review Article

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Pure Iron and Low Carbon Steels - Soft Magnetic P/M Materials

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ABSTRACT

The development of material for improving the performance of devices adds to the comforts of common man which leads to the developments of society. In order to make these devices most energy efficient and economical, one needs to find magnetic materials, which have the highest possible, saturation magnetization and permeability and that too should be at the lowest possible price. So there is a clear chance for improving the properties of the existing magnetic material and developing new ones. Therefore, new materials and technologies provide solutions for emerging out applications.

Keywords: Wrought iron; Pure iron powder; Saturation magnetization

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INTRODUCTION

Now a days the world's leading industries in iron powder production, are specifying the use of water atomized high purity iron powders for high quality soft magnetic applications. The processing cost is substantially high for the production of pure iron; sintered iron with moderate amount of impurities in the form of solid cores is used widely for telephone relays and switches, contactors, electromagnets, plungers, pole pieces, solenoids and in other DC devices [1]. Since pure iron has low resistivity, it is unsuitable for its magnetic application in AC devices. In general, the magnetic properties of pure iron can be further improved as the impurity level is reduced [2]. The residual non-metallic impurity in iron must be less than the solid solubility limit at room temperature. The estimated values for solid solubility limit of carbon, oxygen, sulfur, nitrogen and phosphorous in iron at room temperature are 0.007, 0.01, 0.02, 0.001 and 1.0 percent respectively [3].

Literature review

The term "pure iron" is used to indicate a minimum of 99.8% purity and the absence of other elements by deliberate addition. Iron exhibits attractive magnetic properties such as high permeability, good saturation induction and low hysteresis loss, and it is relatively cheap. Some of the physical and magnetic properties of commercially pure wrought iron are listed in the Table 1.

The variation of magnetic properties of electrolytic iron of high purity (0.012%C, 0.075%H, 0.001%S, 0.003%Si, 0.0004%P) annealed at 800^{o}C are shown in Figure 1. It indicates a characteristics abrupt increase in initial permeability (μ_o) and maximum permeability (μ_m) at about 50^{o}C below the curie point, and continual decrease of coercive force (H_c). hysteresis loss (W_h), and maximum induction (B_m) with increasing temperature.

Iron powder has been used in the communication industry at frequency up to 1 MHz. For this purpose, carbonyl iron powder is often selected to take advantage of the spherical shape, the small size (≈ 5 µm in average diameter) and very hard nature, of the particles, although other grades such as hydrogen-reduced, electrolytic and mechanically disintegrated iron powders are also used [6].

Carbonyl iron powder derives its name from the fact that the powder is produced from the liquid iron pentacarbonyl ($Fe(CO)_5$). Briefly, the preparation procedure involves (1) the reduction of iron oxide to sponge iron in hydrogen, (2) the formation of $Fe(CO)_5$ by reacting the iron with CO and (3) the decomposition of liquid $Fe(CO)_5$ in a heated vessel under pressure through atomization. Iron powder thus prepared has a layer of insulating oxide on the surface of individual particles; thereby cores made of carbonyl iron powder have low eddy current loss, in spite of 0.8%C and ~0.25%N.

Table 1: Physical and magnetic properties of wrought iron [4, 5]

S. No.	Physical properties [4]	Value
1	Density, g/cm^3 at 20^{o}C	7.874
2	Lattice constant, 10^{-8} cm	2.861
3	Resistivity at 20^{o}C, ohm-cm × 10^6	9.7
4	Resistivity for commercial iron, ohm-cm × 10^6	11
5	Temperature coefficient of resistance	0.0065
6	Compressibility, cm^2/kg × 10^6	0.6
7	Modulus of elasticity, dynes/cm^2 × 10^{-11}	21
8	Proportional limit for annealed iron, lb/in.^{2} × 10^{-3}	19
9	Tensile strength, lb/in.^{2} × 10^{-3}	25-100
	Magnetic properties [5]	**Value**
10	Brinell hardness number (annealed)	50-90
11	Curie temperature, θ_c in ^{o}C	770
12	Saturation induction at 20^{o}C, B_s in gauss	21580
13	Bohr magnetons per atom, μ_B	2.218
14	Maximum permeability of commercial product, μ_m	5000
15	Coercive force of commercial product, H_c	0.9

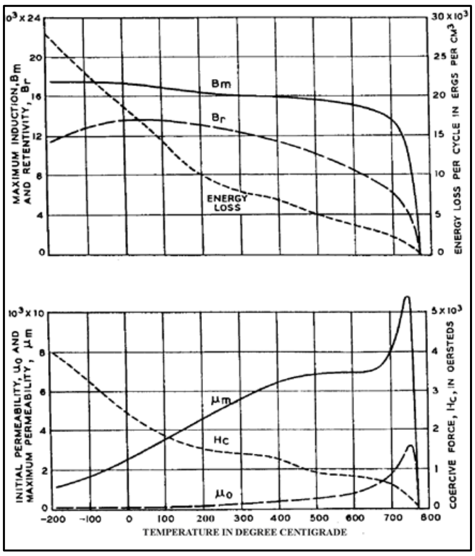

Figure 1: Variation of Magnetic Properties of Iron with Temperature, material is annealed at 800^{0}C [4]

Hydrogen treatment [7] of the iron, also known as hydrogen anneal is effective in removing oxygen, carbon, and nitrogen and, to some extent, sulfur [5] and carbon is removed probably more readily in moist than in dry hydrogen. It involves thorough heating in an atmosphere of wet, pure hydrogen above 1350^{o}C, followed by slow cooling through the $\gamma \rightarrow \alpha$ phase transition. Hydrogen treatment by reducing impurity level in the material lowers the coercive force and improves maximum relative permeability. The effect of temperature of hydrogen treatment on maximum permeability of iron is shown in Figure 2.

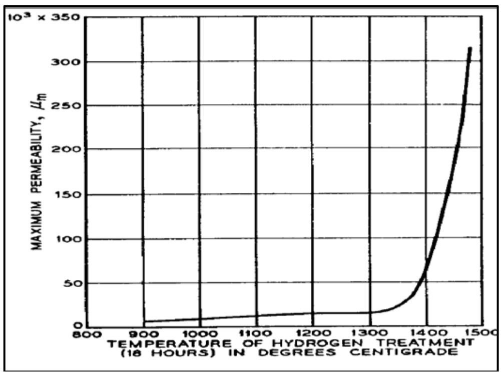

Figure 2: Effect of Temperature of Hydrogen Treatment on Maximum Permeability [7]

Typical magnetic properties for several pure iron materials viz. Ancorsteel 1000, Ancorsteel 1000B, Ancorsteel 1000C produced by M/s Hoeganaes Corporation, USA, compacted at 415, 550, and 690 MPa and sintered at 1120^{o}C and 1260^{o}C for 30 minutes in dissociated ammonia are listed in Table 2 [8]. The chemical analysis of these steel powders is given in Table 3.

Table 2: Typical magnetic properties (15 Oe) of Ancorsteel* 1000, Ancorsteel 1000B and Ancorsteel 1000C [8]

Material	Sintering temperature (^{o}C)	Compaction Pressure MPa (tsi)	Sintered Density (g/cm3)	$H_{c\ (Oe)}$	B_r (kG)	$B_{max\ (kG)}$	$\mu_{\mu\alpha\xi}$
Ancorsteel 1000	1120	415	6.7	2.03	8.3	9.8	1990
		550	7.02	2.08	9.7	11.4	2320
		690	7.21	2.09	10.6	12.4	2650
	1260	415	6.71	2	8	10.2	1920
		550	7.03	1.93	10	11.9	2490
		690	7.25	1.95	10.5	12.7	2790
Ancorsteel 1000B	1120	415	6.79	2.07	9.1	10.4	2150
		550	7.09	2.06	10.7	11.9	2710
		690	7.26	2.03	11.4	12.7	3020
	1260	415	6.8	1.95	9.5	10.9	2460
		550	7.12	1.9	10.8	12.2	2890
		690	7.28	1.9	11.8	13.2	3190
Ancorsteel 1000C	1120	415	6.82	1.84	9.2	10.6	2530
		550	7.14	1.83	10.8	12.1	3070
		690	7.3	1.83	11.6	12.9	3340
	1260	415	6.86	1.76	9.5	11	2730
		550	7.14	1.72	10.9	12.4	3190
		690	7.32	1.68	11.7	13.2	3570

*Ancorsteel is a registered trademark of Hoegnaes Corporation

Table 3: Chemical analysis of Ancorsteel 1000, Ancorsteel 1000B and Ancorsteel 1000C

Ancorsteel	C	O	N	S	P	Si	Mn	Cr	Cu	Ni	Apparent Density (g/cm^3)
1000	< 0.01	0.14	0.002	0.018	0.009	< 0.01	0.2	0.07	0.1	0.08	2.94
1000B	< 0.01	0.09	0.001	0.009	0.005	< 0.01	0.1	0.03	0.05	0.05	2.92
1000C	< 0.01	0.07	0.001	0.007	0.004	< 0.01	0.07	0.02	0.03	0.04	2.92

The data in Table 2 and Table 3 indicate that the magnetic properties improve with increase in purity level of the base iron; it is due to improved powder compressibility. For a given density level, an improved value of maximum permeability of sintered iron is obtained for the base iron powder with improved purity as shown in Fig. 3. Further, permeability increases with an increase in sintered density of the product and as well as with sintering temperature [9].

The coercive force of sintered materials is mainly governed by the grain size of iron matrix and by the size and shapes of the pores; rather than governed by its density [10]. Intense (high temperature and long time) sintering lowers the specific pore surface (total pore surface per unit volume) of the sintered materials by pore rounding and pore coarsening, and thus lowers the coercive force [10].

Pure iron powders are susceptible to nitrogen aging i.e. the coercive force increases with time when the magnetic device is exposed to elevated temperatures for prolonged periods. As a result, the end user can find the magnetic performance of the part deteriorating with time. The key for preventing nitrogen aging is the sintering in atmospheres with low percent of nitrogen (< 25 ppm), thus, minimizing nitrogen pickup in the sintered part [11].

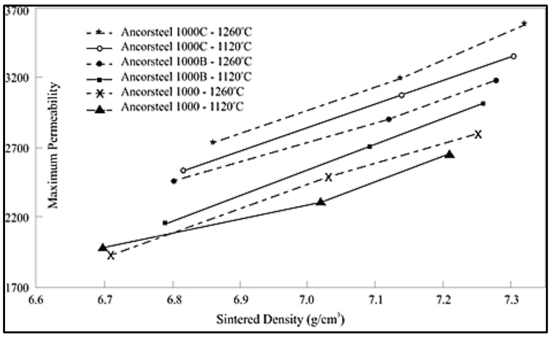

Figure 3: Variation of maximum permeability with density of pure iron [8]

For magnetic applications, two classes of steels are involved. One is low carbon steels and the other the ferritic stainless steels. The composition of low carbon steels is typified by AISI C1010, which contains 0.08-0.13% C, 0.3-0.6% Mn, up to 0.04% P and up to 0.05% S. Despite the presence of these elements in steels, little or no sacrifice of magnetic properties is noticed. Since low carbon steels are inexpensive and yet exhibit far higher yield strengths than pure iron, make the low carbon steels attractive for many low frequency magnetic applications such as laminations for relays, pole pieces and pole supports of motors and other electromechanical equipments [12]. Semi-processed low carbon (Fe-0.04-0.06%C) steels have permeability of about 2000 and watt losses of 5.5 W/kg, the permeability are usually measured at 15 kG (1.5 Tesla) [13]. Further, for low carbon wrought steel with 0.05%C the permeability, coercivity, saturation induction, resistivity and core loss values reported are 5000, 1.0 Oersted, 21.5 kG, 10 micro-ohm- cm and 2.8 W/kg (at 15kG and 60 Hz) respectively [14].

Low carbon steels with appropriate carbon percent for magnetic applications are produced via compacting and sintering route from iron powders admixed with graphite [15]. Sintered irons with carbon and or copper have better dimensional stability during sintering and possess better mechanical properties in comparison to that of low carbon wrought steels. M/S Magnetics International (MI), USA now offers the new iron powders, these MI powders are marketed under the name of Accucore [4]. Different grades of pure iron powders containing C< 0.02% such as NCI 100.24 and ASI 100.29 are also being marketed by M/S Höganäs India limited, Ahmednagar, India. Water atomized admixed or diffusion alloyed low carbon (C< 0.01%), low alloy steel powders for high performance applications (specially for structural purposes), which have high strength, good hardenability and toughness, are developed by M/S Höganäs AB, Sweden and M/S Hoeganaes Corporation, USA with the trade name Ancorsteel [8,16,17,18]. Ancorsteel®2000 (0.61%Mo, 0.46%Ni, 0.25%Mn), Ancorsteel®FD-4600A (1.75%Ni, 0.5%Mo, 1.5%Cu) and Ancorsteel®FD-4800A (4.0%Ni, 0.5%Mo, 1.5%Cu) conform to Metal Powder Industries Federation material standard-35 MPIF FL-4200, FD-02XX and FD-04XX respectively. The use of Ni and Mo as principal alloying elements permits these Ancorsteels to be processed using conventional P/M compacting pressure (620 MPa), sintering temperatures (1120^{o}C), sintering time (30 minutes) and atmospheres (dissociated ammonia). High Mo content in Ancorsteel®85HP (0.86%Mo, 0.12%Mn) and Ancorsteel®150HP (1.5%Mo, 0.12%Mn) allows exceptionally high compressibility and a good response to heat treatment for these low carbon prealloyed Mo steels. M/S Hoeganaes Corporation has indicated that double pressed double sintered alloys have better strength and toughness [19, 20].

CONCLUSIONS

In the summary, the material and its processing technology, both are equally important for the smooth functioning of the device. The characteristics of soft magnetic materials are continuously being improved, and many new applications are possible. In fact, magnetic materials seem to offer an infinite variety of applications, when one application is displaced another arises.

REFERENCES

[1] A Goldman. Handbook of Modern Ferromagnetic materials, Kluwer Academic Publishers, Boston, Dordrecht, London, **1999,** 111-135.

[2] K Sezaki; K Nagai; T Sakauchi. Soft magnetic material composition and molding process therefore, **1989**, United States patent US 4,879055

[3] BD Cullity. Introduction to magnetic materials, Addison-Wesley Publishing Company, Inc.Phillippines, **1972**, 357-368.

[4] RM Bozorth. Ferromagnetism, The Institute of Electrical & Electronics Engineers, Inc., New York, Reissued in cooperation with the IEEE Magnetics Society, **1993**, 48-255.

[5] P Jansson. *Powder Metall*, **1992**, 35, 63-66.

[6] RE Hummel. Electronic properties of materials, Springer-Verlag Berlin Heidelberg, Narosa Publishing House, New Delhi, **1994**, 312-317.

[7] G Janngg; M Drozda; H Danninger; G Eder. *Power Metall Int*, **1984**, 16, 264-267.

[8] PM Hansen. Constitution of binary alloys, McGraw-Hill Book Company, New York, **1958**, 711-720.

[9] D Sharma; K Chandra; PS Misra. *J Mater Des*, **2011**, 32, 3198-3204.

[10] D Sharma. *J Chem Pharma Res*, **2015,** 7, 312-317

[11] DS Lashmore; GL Beane; L Deresh; Z Hua, Ferromagnetic powder for low core loss, well-bonded parts, parts made therefrom and methods for producing same, **2001**, United States patent US 6, 251514.

[12] DS Lashmore; GL Beane; L Deresh; Z Hua, Low core loss, well-bonded soft magnetic, **2000**, United States patent US 6, 129790.
[13] CW Chen. Magnetism and metallurgy of soft magnetic materials, North Holland Publishing Company, Amsterdam, New York, Oxford, **1977**, 239-395.
[14] Atkinson; Simon. *Met Powder Rep*, **1998**, 53, 12-16.
[15] LA Lefebvre; S Pelletier; C Gelinas, Treatment of iron powder compacts, especially for magnetic applications, **1999**, United States patent US, 5993729
[16] A Kordecki; B Weglinski; J Kaezmar. *Powder Metall*, **1982**, 25,201-208.
[17] T Kohno. *J Jap Soc Powder Powder Metall*, **1993**, 40, 579-584
[18] O Fischer; J Schneider. *J Magn Magn Mater*, **2003,** 254-255, 302–306.
[19] K Chandra; PS Misra. Characteristics of sintered Fe-P alloys, Proceeding National Seminar on Advances in Materials & Processing, Department of Metallurgical & Materials Engineering, Indian Institute of Technology Roorkee, India, **2001**, 263-268
[20] KH Moyer. Secondary operations and effects on magnetic and tensile properties, Proceedings of the 1990 Powder Metallurgy Conference and Exhibition, **1990**, 521-528.