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Mini Review

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P/M Processed Fe-Sn Alloys

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ABSTRACT

The present review predominantly deals with the literature on Fe-Sn magnetic materials (having Phosphorous as one of the alloying elements) produced from powders, using compacting and sintering. Influence of the alloy chemistry and processing parameters on the physical, electrical, magnetic and mechanical properties are also highlighted. Structure sensitive properties are sensitive to the metallurgical conditions and the microstructure of the material; in turn these properties are governed by the processing parameters such as use of the binder and or lubricant, compacting pressure, sintering temperature, sintering time and sintering atmosphere, and these are therefore dependent upon processing techniques.

Keywords: Fe-Sn Alloys; Permeability; Processing

INTRODUCTION

Permanent magnetic materials are important for energy applications such as wind turbines and motors for hybrid and electric vehicles. The increasing importance of permanent magnets in modern society has resulted in renewed interest in the design and discovery of new permanent magnet materials [1]. For a good permanent magnet a ferromagnetic compound should have a Curie temperature, Tc, above 400 K, a saturation moment, Ms, in the range of 1 MA/m, anisotropy energy, K1, of about 4 MJ/m^3, and additionally a uniaxial magnetic anisotropy [2-4].

LITERATURE REVIEW

Fe-Sn system has many of the desirable properties for a new permanent magnet phase with a Curie temperature of 725 K, a saturation moment of 1.18 MA/m. and anisotropy energy, K1 of 1.8 MJ/m^3. The phase diagram of Fe-Sn system [5] is shown in Figure 1. Five compounds appear in this system, all of which have hexagonal crystal structures. These are $FeSn_2$, FeSn, Fe_3Sn_2, Fe_5Sn_3 and Fe_3Sn [6]. The γ loop closes at about 2%Sn. Maximum solubility in the α phase is about 17% at 760°C; this is very near the Curie point of iron, which is changed only slightly by the addition of this much tin. At room temperatures the solubility has decreased to 8 or 9%.

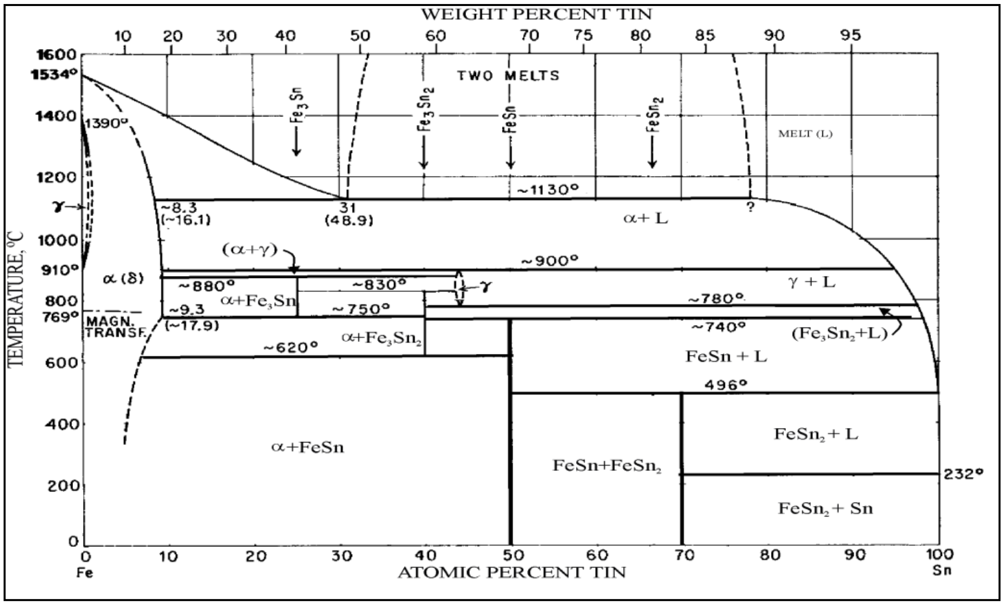

Figure 1: Phase diagram of Iron-Tin alloys [5]

Apparently $FeSn_2$ is magnetic, for the alloy containing 97% tin is weakly ferromagnetic [7]. Curie points and atomic moments of alloys containing 12% and less of tin have been measured. In this range the Curie point drops only to 5°C, and the saturation at room temperature decreases about 8%. Reduction in hysteresis by adding 2% of tin to iron has been reported and a reduction in total losses in sheet, which contained less than this amount of tin, was also observed. In experiments at Bell Laboratories a permeability of 34000 and a coercive force of 0.15 Oersted have been attained by heat treating the Fe-3%Sn alloy in pure hydrogen at 1100°C.

Tin is a ferrite stabilizer, its addition to iron effectively increases the resistivity and at room temperature a solid solution of Sn in α-iron possessing good soft magnetic characteristics exists up to about 8%Sn whose curie temperature is as high as that of pure iron. Further, the addition phosphorous to Fe-Sn system is expected to activate the sintering and enhances both resistivity and magnetic properties. Therefore, it is thought to develop Fe-Sn-P alloys up to 8% of tin for soft magnetic applications and the results are encouraging [8,9]. Further, as per United States Patent [10], it is claimed that the soft magnetic properties of iron based P/M alloys are improved by using powders prepared by mixing SnP powder, or Sn and Fe_3P powders, with iron powder [9,10]. However, due to the microscopically non-uniform distribution of the alloying elements, the concentration of tin should be maintained higher than 4.5 wt % to be effective in improving the sintered density and, consequently, soft magnetic properties. Thus tin content in these alloys may preferably lie in between 4.5-8%. The resistivity of Fe-Sn-P ternary alloy is dominated by the tin content; phosphorous contributes only to a marginal increase (Figure 2). In general the addition of alloying elements reduces the induction however, this ternary alloy has a relatively high induction even with addition of 8% tin.

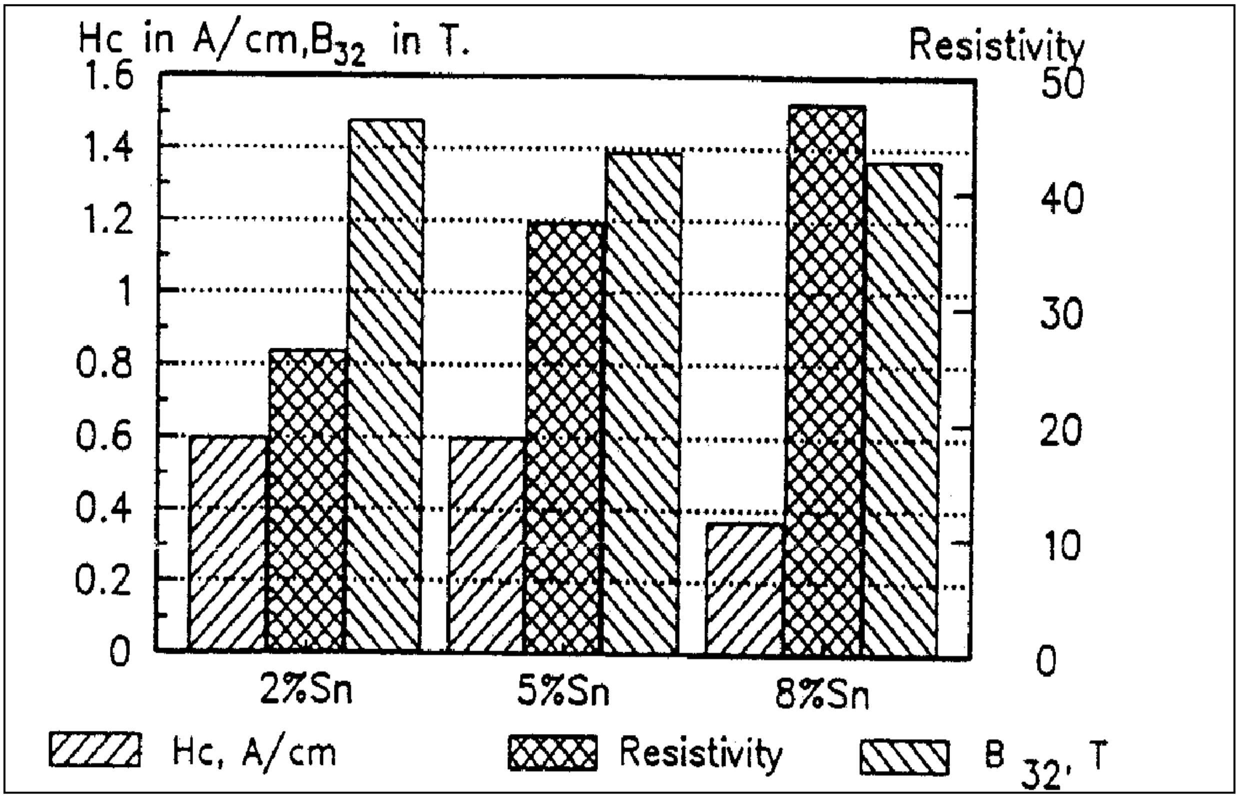

Figure 2: Effect of tin content in Fe-Sn-0.45%P alloys, samples compacted at 589 MPa, sintered for 30 minutes at 1250°C in H_2 atm

The structural sensitive properties are most affected by an increase in phosphorous content (Figure 3). The decrease in coercive force and increase in maximum permeability is approximately one third by an increase in phosphorous content from 0.45% to 0.8%. Induction and resistivity are increased by increase in phosphorous however; the increase in induction is marginal.

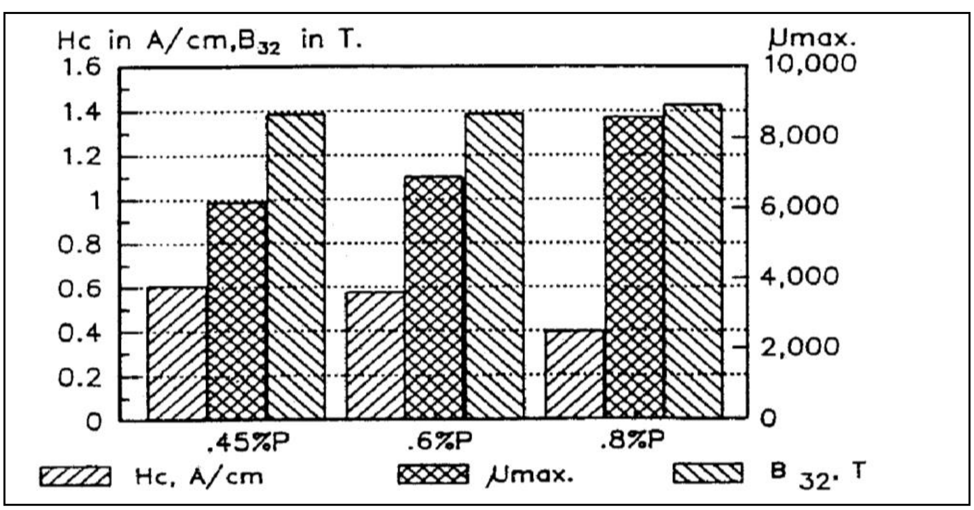

Figure 3: Effect of phosphorus content in Fe-5%Sn-P alloys, samples compacted at 589 MPa, sintered for 30 minutes at 1250°C in H_2 atm

In contrast to other high resistivity alloys, this material is not confined to high temperature sintering i.e. about 1200°C. Sintering at 1120°C resulted in high resistivity and better soft magnetic properties (Figure 4). Increasing the sintering temperature is however amply rewarded, as coercive force is halved and maximum permeability almost doubled.

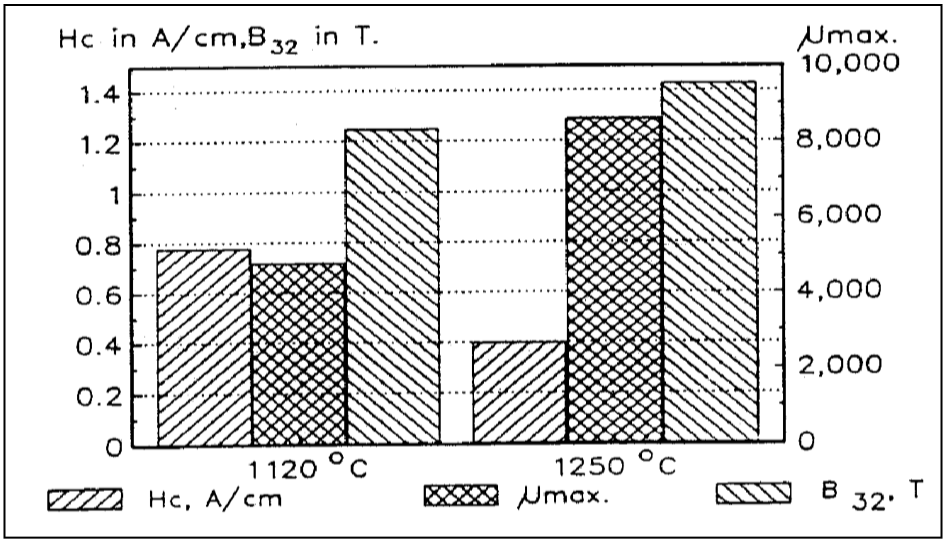

Figure 4: Effect of sintering temperature on Fe-5%Sn-0.8%P alloy, samples compacted at 589 MPa, sintered for 30 minutes at 1250°C in H_2 atm

Table 1 indicates the magnetic characteristics of well-established Fe-3%Si and Fe-50%Ni alloys along with these characteristics for Fe-5%Sn-0.45%P and Fe-8%Sn-0.45%P alloys and alternate materials for established alloys from the point of view of overall economy.

Table 1: Comparison of Fe-5%Sn-0.45%P alloy characteristics with established Fe-3%Si alloy and Fe-8%Sn-45%P alloy characteristics with Fe-50%Ni alloy

Material and Processing Parameters	**Sintered Density (g/cm3)**	**Induction at 32 A/cm, B_{32} at 15 A/cm, B15 (T)**	**Br (T)**	**H_c (A/cm)**	**μ_{max}**	**Resistivity (μ-ohm-cm)**	**Remarks**
Fe-3%Si alloy, compacted at 589 MPa and sintered at 1250°C for 30 min. in hydrogen (dimensional change-1.25%)	7.2	1.3 [B_{32}]	1	0.8	4300	47	Fe-5%Sn-0.45%P alloy with slightly lower resistivity can be accepted as it has equivalent magnetic properties while

Fe-5%Sn-0.45%P alloy, compacted at 589 MPa and sintered at 1120°C for 30 min. in hydrogen (dimensional change 0.21%)	7.2	1.4 [B_{32}]	1.1	0.8	4800	40	reducing dimensional change and sintering temperature.
Fe-50%Ni alloy, compacted at 589 MPa and sintered at 1250°C for 30 min. in hydrogen	7.4	1.1 [B_{15}]	0.8	0.25	13000	50	Fe-50%Ni alloy has excellent magnetic properties, owing to its high cost may be substituted by
Fe-8%Sn-0.45%P alloy, compacted at 589 MPa and sintered at 1250°C for 30 min. in hydrogen	7.4	1.3 [B_{15}]	1	0.37	9700	48	Fe-8% Sn-0.45%P alloy for more extensive use.

CONCLUSION

The review summarizes the material's choice on the basis of selection criteria for some of the components made through P/M route for magnetic applications. The selection of a material for a particular application will depend up on its ability to meet the required performance, and also its availability and cost.

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