Characterization of Amorphous Metal Materials for High-Frequency High-Power-Density Transformer

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***Abstract*-- In many applications such as power electronic devices, it is very desirable to employ high power-density transformers, because the available space and allowed weight are very limited. In general, operating at higher frequency would lead to smaller volume and weight of electromagnetic devices, but the core loss could increase significantly. With very low specific core loss and relatively high saturation magnetic flux density, amorphous metal (AM) materials offer great potential. This scientific research aims to study and model the AM properties for developing high performance transformers such as high efficiency and high power density. The use of Amorphous metals as a core material enables high frequency transformers to attain optimum and higher level of efficiencies. This scientific paper discusses: (i) theoretical understanding of the process of magnetisation and a discussion of AM magnetic properties as are useful for design of electrical devices (ii). Characterize the AM materials and to distinguish them on the basis of their distinctive magnetic properties and their usefulness for High frequency High Power Density (HFHPD) Transformers.**

Keywords: Amorphous Metals AM, High Power Density transformers, High Frequency High Power Density Transformers (HFHPD), Magnetization.

I. Introduction

Transformers are the basic and important components of any power system or electrical circuitry. By far one of the major components in the transformer other than the "transformer windings" that is having the prime importance is the "transformer core". The functionality of the transformer is wholly dependent on this part. Irrespective of the type of transformer used in a certain power system the efficiency largely depends upon, the type of the material i.e. metal used for the core or the choice of core. The better the "magnetic properties of the core material" used the more efficient the operation of transformer will be. "*Magnetization*" is the process that is taking place constantly in the core of a transformer as the electric current is passed through its windings i.e. primary. When the current passes through the primary winding depending upon the "number of turns" in the winding the core starts the process of magnetization as soon as it happens and keep on *Magnetizing* and *De-magnetizing* itself depending upon the magnetizing properties and the saturation time for that particular material of core. Technically, as the current passes through primary winding the metal placed inside this current carrying conductor/coil i.e. "core" faces a magnetic field due to the current and the strength of this magnetic field depends upon the intensity of electric current and hence the magnetic lines of forces due to that current. In particular Iron and some other ferromagnetic materials/metals have small magnetic portions called "*Domains*" that are aligned in an irregular manner as compared with one another these domains in general cancel out each other and hence the material or the specimen as a whole remains un- magnetized. "When an external magnetic field is applied" i.e. in the presence of the magnetic field due to the current carrying coil these domains get themselves "aligned in the direction of applied magnetic field" i.e. in the direction parallel to the magnetic lines of forces as shown in (Fig.1) below.

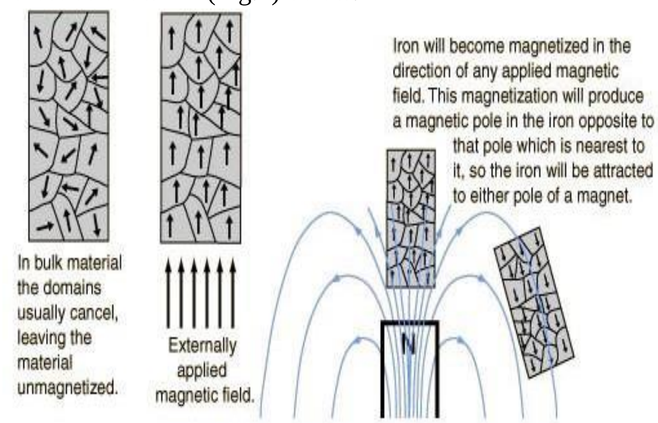

Fig. 1. Representation of Magnetic Domains in a typical Ferromagnetic material

(Fig.2) shows a typical hysteresis loop for the complete cycle of magnetization and demagnetization of a typical ferromagnetic material. The materials with comparatively higher hysteresis loop area are considered to have high hysteresis losses and hence are called "Magnetically Hard materials". They find applications as permanent magnets or magnetic tapes where relatively high "Remanence" or "Coercivity" are needed.

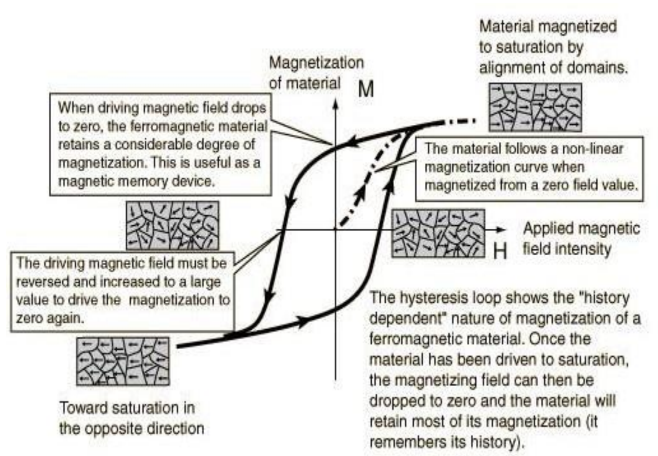

Fig. 2. Representation of Magnetization cycle in a typical Ferromagnetic material

After a “ferromagnetic material” is fully “magnetized in one direction”, the magnetization level does not come back to “zero magnetization” by the removal of the imposed magnetizing field. “The amount of magnetization it retains at zero driving field is called its *Remanence*”. A reverse field must be applied to drive it back to zero. “This amount of reverse driving field required to demagnetize it is called its *Coercivity*”. When current is applied to coil that is looped around a material an alternating magnetic field is applied to the material, it will start magnetizing the specimen this magnetization will trace out a loop called a hysteresis loop. There is a property associated with magnetization of metals called “*Hysteresis*” which is due to the reason that the magnetization do not come back to zero level or the hysteresis loop cannot retrace itself back to zero. This property of ferromagnetic materials is useful as a magnetic "memory". Some of the compositions in ferromagnetic materials retain an imposed magnetization for long periods of time and are useful as "permanent magnets". Hence in case of transformers such materials are preferred for the core as are magnetically soft i.e. have less hysteresis loss, low “*Remanence*” and “*Coercivity*” and as a result have a smaller hysteresis loop area or thinner hysteresis loop.

For this to be achieved the metals are used in the form of alloys i.e. usually in the form of combinations of materials. Most common combination used for transformer cores in high voltage power systems is “Silicon Steel sheets” as it increases the magnetic properties required and makes it magnetically soft with less hysteresis losses. By the addition of a small percentage of silicon it is seen that the magnetic properties of the sheets used for the transformer core increases. These are called electrical steels or “Silicone- Iron” (Si-Fe) sheets the use of such alloys of as a material for core of transformers yields much higher efficiency than the metal used alone. As it increases the magnetic properties and makes material less conductive and can be easily magnetised or demagnetised i.e. makes it much softer than magnetically hard materials. It adds to the permeability of the material, reduces the conductivity and power losses decrease with the increase in the amount of silicone but we cannot add much amount of silicon as it will make the material brittle and difficult to handle.

II. REVIEW OF RELEVENT LITERATURE

According to the theory of electromagnetics, the electromotive force (emf) induced in a transformer winding is proportional to the operating frequency and the magnetic flux linking the winding, smaller magnetic flux is required if the operating frequency is higher. Therefore, increasing switching frequencies of power electronic systems can lead to a dramatic reduction of the volume and weight of transformers used in the systems compared with those operated at low frequencies for a given power rating. But with the increase in the frequencies some other problems originate related with the losses i.e. Eddy-current losses and Magnetic Core losses, “thermal effects on magnetic hysteresis of core materials”, skin effects. The aim of the research is emphasised on finding out the most feasible and applicable soft materials that have the properties of soft magnetic materials i.e. have high permeability, a comparatively high resistance or low conductivity, low losses and used as a core material enables the operation at higher frequencies with significant efficiencies and to characterise the “Amorphous Metal Alloys” to be used as material of core for the “High Frequency High Power Density (HFHPD) transformers” [1].

With the rapid advance of power electronic technology, the operational switching frequencies in power electronic systems, such as the switch mode power supply (SMPS), have been extended to the megahertz region, and the power range associated by converters extends from a few micro-VA to some hundreds of MVA [2-3].

This leads to the smaller size or volume of transformer needing less area and high output efficiency. But the core material used for transformer needs to be compact and highly efficient in order for the transformer to achieve high performance level or to operate at higher frequency and efficiencies respectively. This research work will focus on the soft magnetic materials used in the HFHPD transformers and inductors, including electrical sheets, soft ferrites and amorphous magnetic alloys, in terms of their magnetic properties at high frequency operations. Comparing the various materials reveals that the low power loss soft ferrites seem to be the most suitable for HFHPD applications.

Magnetic materials are traditionally classified as dia-magnets, paramagnets and ferro-magnets according to their bulk susceptibility. Diamagnets have small and negative value of this susceptibility. Their magnetic response opposes the applied magnetic field. Paramagnets are materials having small and positive. Ferro-magnets are most widely recognized magnetic materials for which the value of this susceptibility is positive and much greater than 1 [4].

Ferromagnetic Materials:

The ferromagnets can be further classified as “soft and hard magnetic materials” according to their coercivities. Typically, “soft magnetic materials” have coercivities of below 1 kA/m [4]. They are regarded as magnetically “soft” since they can be easily magnetized or demagnetized. Ferromagnetic materials can also be classified as either grain oriented or non-oriented according to their microstructures. The former has large magnetic domains (recognizable under proper conditions) and the latter has smaller domains, or not easily discernible domain structures [5].

Soft magnetic materials can find their applications as the core materials in power transformers, electronic transformers (those used in power electronic systems), magnetic components in microwave systems, and the stator and rotor cores for rotating electric machines. Soft iron and electrical sheet steels are two typical soft magnetic materials. Although high permeability and low coercivity of magnetic materials are needed for transformer cores, the low conductivity is also very important to reduce the eddy current losses since they operate under AC conditions. The electrical sheet steels are mainly used in AC applications. Silicon iron (Si-Fe) is widely used for the high power applications.

A. Non-oriented electrical steels:

The technology of "Electrical steels" actually began with the publication of the research work of Barrett et al. in about 1900 [6]. The addition of small amount of silicon or aluminium to iron was found to reduce magnetic losses significantly. Thereafter, non-oriented electrical steels have been developed since 1950s along two paths: one is for use in cheap devices towards low cost, and the other one towards high magnetic efficiency. In the special case of larger grains, the loss increases due to the predomination of anomalous eddy current losses. "In general, the higher the resistivity becomes, the lower the permeability will be", because the additions increase the resistivity and reduce the saturation magnetization. At present, wide range non-oriented electrical steels have found applications in different appliances [7-8].

B. Grain-oriented electrical steels:

The "Grain-oriented silicon-iron" is exclusively used as the core materials in power transformers [4] since, the permeability of the material is the highest along the easy axis. The first grain- oriented electrical steel strip was produced in 1939 based on Goss's process, in which a "careful combination of heat treatment and cold rolling is used to produce a texture giving a silicon strip good magnetic properties when magnetized along its rolling direction". In 1965, a revolutionary electrical steel that is a high permeability grain-oriented silicon iron, was reported by Nippon Steel Corporation [8]. "This material contained about 3-4% by weight silicon to reduce the conductivity". Power losses in general decrease with increasing silicon contents but the material will become brittle.

LOW-LOSS AND HIGH-PERMEABILITY SOFTMAGNETIC MATERIALS:

A number of soft magnetic materials, such as soft ferrites, special electrical sheet materials, amorphous materials and nickel-alloys fall into the range of low loss and high permeability, soft magnet materials that can be used as a low power loss "Soft magnetic materials for high frequency high power density (HFHPD) transformers".

A. Soft Ferrites:

Soft ferrites are ceramic magnetic solids that first appeared commercially in 1945 and for many years were thought to be ferromagnets [4]. They have attractive characteristics of high electrical resistivity and high magnetic permeability. The nickel zinc ferrite (NiZn ferrite) and manganese zinc ferrite (MnZn ferrite) are two main types of soft ferrite that have found their use in the applications where low loss and high permeability are required. Soft magnetic ferrites are suitable as a core material for transformers and inductors in power electronic systems operated at high frequencies [9]. The eddy current losses do not influence MnZn ferrites, "if the grain boundaries are enriched by suitable dopants, which can provide a high enough effective resistivity" [10]. Since the chemical composition and the microstructure strongly affect the properties of ferrites, the initial permeability, electrical conductivity and the Curie temperature can be controlled by improvement of raw material quality, a highly sophisticated additive set for chemical composition, and better controlled production process [11]. A new highest permeability ferrite T56 with an initial permeability of i = 20,000 has been developed recently and it is definitely possible to transfer this product into manufacturing scale [10, 12]. Another attractive feature of soft ferrites compared to alloys (Permalloy) is their lower price basis for the raw materials [10]. MnZn ferrites are the common choice for transformer cores in switch mode power supplies.

However, operational temperature do influence magnetic properties of soft ferrites to certain extent [13-17]. The saturation flux density at 100C, for example, can be only about half of the value at 20C depending on the type of soft ferrite. Furthermore, the saturation magnetisation of soft ferrites is typically 0.5 T, which is much lower compared with other types of magnetic materials.

B. Electrical Sheet Materials:

Some efforts have been made to develop electrical sheet steels for high frequency applications. For example, the thin "anisotropy electrical sheets, which are manufactured by cold rolling of low carbon steel containing 3.5% Si", exhibit relatively low magnetic power losses and high permeability which are the beneficial magnetic properties at high frequency or at impulse conditions. The crystalline structure of such a sheet, however, causes an orientation dependence of magnetic parameters. Usually, their best magnetic properties occur in the "rolling direction" while the worst occurs at 55o with reference to the rolling direction. Also the sheet thickness has significant influence on the anisotropy phenomena in such a sheet. The possible reason for this seems to be its strong texture and the domain structure [18]. Nickel-iron alloys (Permalloy) with above 30% nickels are widely used for electromagnetic applications as the most versatile of all soft magnetic materials. They have found their applications in inductors and transformers of different frequency ranges, such as power transformers, audio frequency transformers and high switching frequency transformers in power electronic converters. High quality transformers are often made of this material [4].

C. Amorphous Magnetic Alloys (Metallic Glasses):

Amorphous metal also having some other names like "metallic glass, is a solid metallic material, usually it is an alloy", whose "atomic-scale structure" is disordered, imperfect or unaligned. Metals are mostly "crystalline in their solid state", which means the arrangement of atoms is highly ordered in them. Amorphous metals have a glass like structure and are non-crystalline in nature. But unlike common glasses, amorphous metals do have good electrical conductivity and exhibit marvellous magnetic properties as exhibited by soft magnetic materials. There are various ways for the production of amorphous metals, including physical vapour deposition, extremely rapid cooling etc. [19][20].

Recently small samples of amorphous metals have been produced in the past through a variety of methods involving quick-cooling. The rapid cooling, is fast enough for the material which avoids crystallization and the material is "locked" in a form called "glassy state". More recently, batches of "amorphous steel" have been produced that comprise three times the strength of "conventional steel alloys". The first metallic glass to be reported was an alloy "(Au75Si25) produced at Caltech by W. Klement (Jr.), Willens and Duwez in 1960" [21].

Some characteristics of amorphous or glassy metals are useful for various applications. One of the significant property i.e. low magnetization loss is used in case of some high efficiency transformers that usually operate at line frequency or slightly higher frequencies. It is really hard to use Amorphous steel in applications like motors due to the reason that they are extremely brittle in nature and cannot really be punched into the motor laminations [22].

The amorphous magnetic alloys or metallic glasses are a big invention and a great step forward in the history of soft magnetic materials and ferrites. They are produced by rapid cooling (quenching) of magnetic alloys consisting of iron (Fe), nickel (Ni) and/or cobalt (Co) with one or more of the following elements as additions, boron (B), phosphorus (P), silicon (Si) and sometimes carbon (C). They have very good magnetic properties for soft magnetic material applications [4]. The magnetic importance of amorphous materials was not commonly realized until the first work on them started in 1971 by Allied Signal Inc., Metglas Products [8].

They have found commercial applications in some areas, such as, high frequency devices, transducers, sensors, electronic power supplies and magnetic recording heads. The major advantage of amorphous materials is the low power losses while they have the following disadvantages: (a) The operating temperature is limited to around 120C because of the low Curie and recrystallization temperatures; (b) The saturation magnetisation is low; and (c) Their core losses begin to increase rapidly at higher flux densities. Although metallic glass is the only commercially available magnetic material, which can replace the electrical sheet steels, its full potential is still unclear in power industry [8]. It does not seem to be a real likelihood of largescale adoption of this material as transformer cores [4]. Recently, some researchers investigated the application of metallic glasses in MEMS [23][24].

III. Significance and Innovation

The trend of using high frequency and reducing the size of the power transformer for achieving high power and efficiency is highly likely in the range of power electronics as well as various power systems. This trends of high frequency operation and miniaturization of power electronic systems greatly stimulate the development of low power loss high permeability magnetic materials. With the invention of amorphous metal materials it is now possible as shown by their characteristic properties and with some research in the field of Amorphous Metals that there are possibilities to achieve higher efficiencies and reducing the size of the transformers although less work has been carried out to determine the magnetic properties associated with such materials and hence to characterize them on the behaviour of their magnetic properties. Though some work has been done in the area of discovering them and determining some of the properties but we cannot yet classify among these different amorphous materials regarding their magnetic Properties i.e. magnetization and demagnetization or B/H curve as if which one from the group of these materials can be referred to as more magnetically soft than the other. So some research work needs to be done in this area of amorphous metal materials to find out the ratings and to list them in order to their magnetic properties which can be done by different methods. One way of finding it will be calculating their (B-H) characteristics.

Amorphous Metal Distribution Transformers (AMDT) have been made in the transformer industry and regarded as high efficiency transformers. ABB is among one of the vendors may be the first one to have Amorphous Core Distribution Transformer using the amorphous steel core. The ultra-low loss design solution in (AMDTs) devised by ABB is a perfect example of low loss and highest efficiencies. A unique alloy is used in their design process whose atomic structure has a random or irregular pattern and is used instead of conventional Regular Grain Oriented (RGO) silicon steel. The grain structure in RGO is well organized and aligned which causes much high resistances to the magnetization cycles, and hence the core losses increase. So with a relatively irregular structure or alignment of atoms this amorphous material core allows same high permeability but comparatively low resistance to magnetization cycles and hence less core losses.

Amorphous Metals – A Technological Advantage:

Amorphous metal core based transformers do have a technological advantage. Under no load conditions (AM) based transformer undergo significantly reduce losses as compared with Regular Grain Oriented (RGO) type. One such research /measurement as in the table for representative liquid-filled transformer designs shows the losses to be as low as 70% approximately. Amorphous metal based transformers also exhibit good efficiencies while working optimally in the presence of harmonics or integral multiple of Power frequencies. In the vicinity of non-linear loads such as rotating machines power waveform gets distorted i.e. current and voltage waveforms are disturbed causing harmonics in the circuit which are likely to cause losses in the transformer and power quality gets compromised as well. However in case of Amorphous metal core based transformers (AMDT) these harmonics losses are minimized. This contributes to operating energy savings in a variety of resistive and inductive loads. Lower losses due to Amorphous metal (AM) results in significant savings in energy over the lifespan of transformer. Moreover the non-crystalline structure of (AM) enables easy magnetization, together with low thickness and high resistivity there is a significant reduction in no-load core losses.

IV. Methodology

There is a relationship between the "magnetic field strength (H) and the magnetic flux density"

(B) this is most important characteristic of magnetic materials. When restrained in the same direction, both "magnetic flux density B and field strength H" form a closed loop as plotted on a graph. This loop is called hysteresis or B-H curve or loop. This B-H loop or curve also known as Magnetic Hysteresis loop is of great importance and prime value for determination of magnetic characteristics of a material and softness and hardness of a magnetic material as it tells how much a magnetic material is resistant to its magnetization or demagnetization (Coercive) or how quickly it does so. Clearly the investigation technique or research methodology would involve the study of Magnetic Properties i.e. Magnetization and Demagnetization of Amorphous metal (AM) materials using this characteristics B-H loop or hysteresis curve. The experimental setup would involve a B-H tester i.e. an integrated or a manual circuitry to test the Hysteresis loop of materials. As we all know if a material or a conductor under test when rapped or placed inside the turns of a solenoid or current carrying conductor the flux starts generating and in the vicinity of that flux the metal starts magnetizing itself and magnetic domains in that metal start aligning themselves in the direction of applied magnetic field due to the alternating field of alternating AC current it will demagnetize itself as well but due to the hysteresis the B and H will trace out a curve for every metal specimen under test or under study. That B-H curve will be typical and particularly a characteristic B-H loop of that specific metal. The Area of this B-H loop gives the energy consumed by the hysteresis or the total energy loss due to hysteresis.

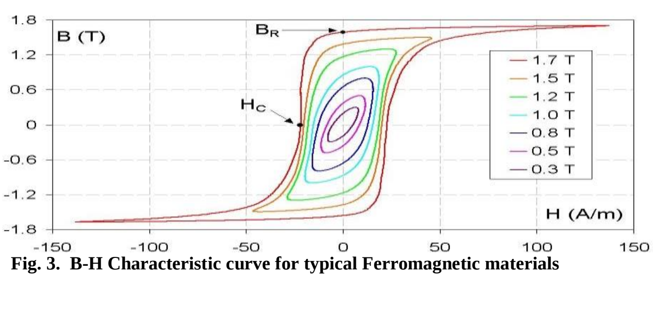

Fig. 3. B-H Characteristic curve for typical Ferromagnetic materials

The investigation technique involved in-depth study of various journal articles and high quality research papers already written in the relevant area, the literature review and the comparison of the research work done so far in this area for the in depth discussion.

Some of the most recent researches carried out in this Area of Amorphous Metals are studied and being compared for a thoughtful insight and in depth study of AM characteristics.

The First publication by "Hasegawa, (2004)" in journal for "Materials Science and Engineering" shows the usability and benefits of using Amorphous metal as core material for use in non- linear loads where harmonics generated by the non-linear loads are largely concerned. The paper explains that in power electronics such as power supplies and other non-linear loads the transformers with AM cores are found to be effective in reducing the losses in transformers due to certain harmonics that build up in the power system in the vicinity of non-linear loads, in the circuit such as modern power electronic devices, variable-speed motors, etc. The magnetization behaviour i.e. the (B-H) curve of Amorphous metal studied and compared in this research to a conventional Si-steels as shown in the (Fig.4) below.

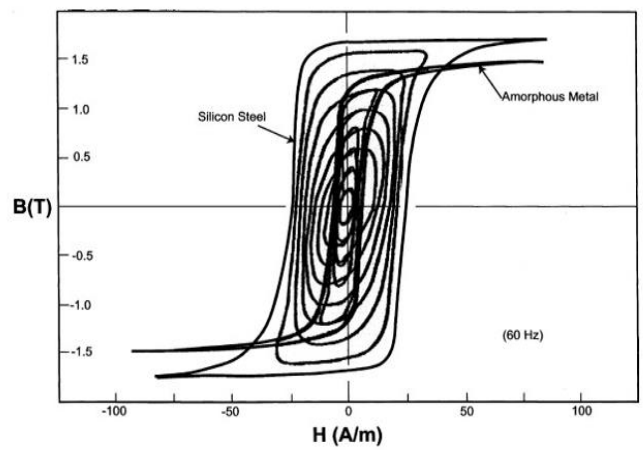

Fig. 4. B-H behaviours for Amorphous Fe-based alloy and a conventional Si-steel

It can be seen clearly that the Hysteresis loop area or (B-H) curve area for an Amorphous metal based material is far less as compared with the conventionally used Silicon-steel. This verifies that the Amorphous metals do exhibit far better magnetic properties as compared to other ferromagnetic materials and Silicon steels as well.

Another research by "Hai Yan Lu, Jian Guo Zhu, and S. Y. Ron Hui, (2007)" deals with the study of "effects of temperature on magnetic hysteresis", this research measures experimentally, the effects of temperature on the "magnetic hysteresis of soft ferrite cores" that are commonly used in high frequency transformers, and also prescribes a method to model these thermal effects. It was found that in the hysteresis loop for a soft ferrite material the saturation magnetization point varies in a non-linear fashion with change in temperature, but "within the normal operating temperature range, typically 20

C–100 C". They further proposed a "method based on approximation for determining the limiting hysteresis loop of a soft ferrite for a given temperature".

V. Results and Discussion:

Now the characterization among these amorphous metal based alloys on the basis of their magnetic properties would involve a comparative study on Amorphous metal alloys with various compositions and different atomic structure. By changing the atomic scale structure or composition by a small ratio these AMs improve their characteristic properties i.e. both magnetic as well as mechanical properties as bending and ductility.

The researches below can be ranked as the potential articles or the most recent researches in the field of "Amorphous metal Materials" or in our expected research area.

One research by "F.L. Kong, C.T. Chang, A. Inoue, E. Shalaan, F. Al-Marzouki, (2014)" shows that they were able to develop "Fe-based amorphous alloys with high saturation magnetization up to 1.7 T" with atomic scale structure in Fe–B–Si– P alloy system. The amorphous alloys exhibited good soft magnetic properties, such as "low coercivities of 3.3–6.2 A/m and high permeability". In additional, these alloys were found to have good mechanical properties like bending ductility, even in an annealed state. The presence of good magnetic and mechanical properties rendered these alloys a promising candidate for the use in magnetic applications like transformers in the future.

Another study "Parthiban Ramasamy, M. Stoica, S. Bera, M. Calin, J. Eckert, (2017)" published in "Journal of Alloys and Compounds" shows the effect of changes in the molecular structure i.e. by the changes in the ratio of ferromagnetic material in the molecular structure of amorphous metals how both the electrical i.e. magnetic properties as well as the mechanical properties like shape and ductility of material changes. Typically they studied the "Effect of replacing Nb with (Mo and Zr) on glass forming ability, magnetic and mechanical properties of FeCoBSiNb bulk metallic glass". By using "Mo" in place of Nb in different ratios in the atomic scale structure of the allow they were able to get different properties like glass forming ability and mechanical strength as well as different saturation magnetization.

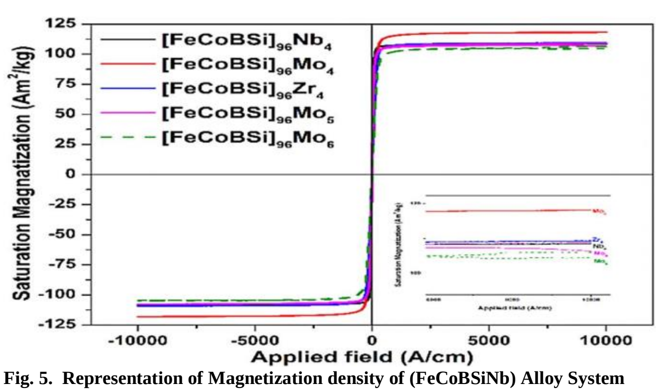

Fig. 5. Representation of Magnetization density of (FeCoBSiNb) Alloy System

One more research in this area namely "FeCo-based soft magnetic alloys with high (Bs) approaching 1.75 T and good bending ductility" is also published in "Journal of Alloys and Compounds" in 2017. This article by "Y. Han, J. Ding, F.L. Kong, A. Inoue, S.L. Zhu, Z. Wang, E. Shalaan, F. Al-Marzouki, (2017)" also discusses the changes in magnetic and mechanical properties of Amorphous metal materials by the changes in their structural composition or changes in the ratio of "Fe" in the molecular structure and their usability and effectiveness for various applications by making them more advanced. In their research they were able to develop "Fe rich Amorphous alloys with FeCo" content ratios above 85 at%. By the partial replacement of (Co) in place of (Fe) in the atomic scale structure of a typical (Fe-Si-B-P) alloy system. The alloy formed as a result was found to have "good soft magnetic properties i.e. high saturation magnetization of 1.75T" as well as good mechanical properties like bending and ductility. Moreover, "the high saturation magnetization shows higher flux density (Bs) of 1.75 T, which is higher than those for previous reported Fe-rich Fe-metalloid alloys. Thus, by the partial substitution of Fe by Co they were able to achieve both Curie temperature (TC) and Bs exceeding those for the Fe-Si-B-P alloys". This improvement of saturation magnetization to a higher value of 1.75T by adding higher total ferromagnetic element content in Fe-metalloid alloy system, showed that a further increase in saturation magnetization can be achieved for Amorphous metal alloys in future.

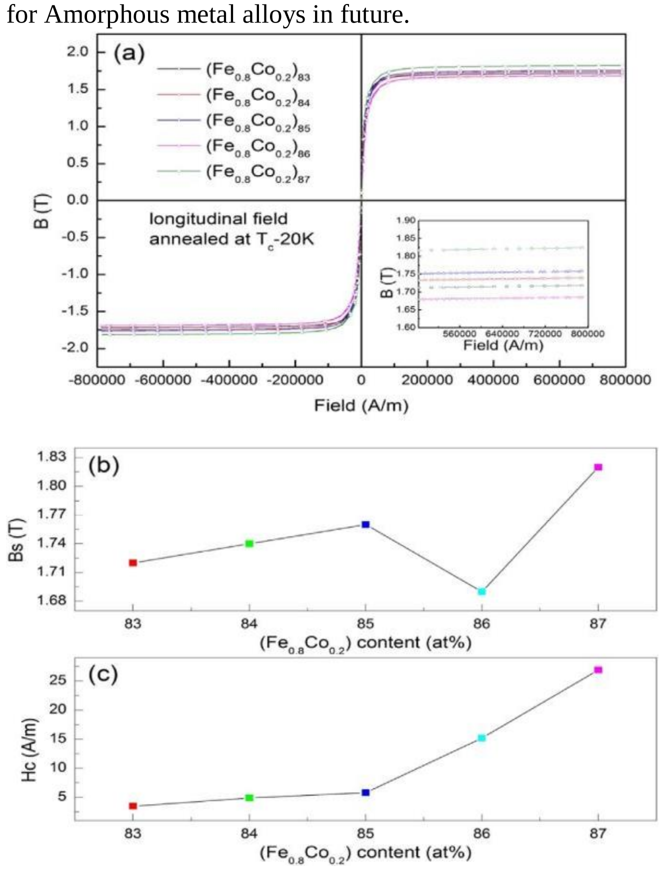

Fig. 6. Representation of Magnetization density of (FeCo-based) Alloy System

One research work by "F. Wang, A. Inoue, Y. Han, S.L. Zhu, F.L. Kong, E. Zanaeva, G.D. Liu, E. Shalaan, F. Al-Marzouki, A. Obaid, (2017)" namely, "Soft magnetic Fe-Co-based amorphous alloys with extremely high saturation magnetization exceeding 1.9 T and low coercivity of 2 A/m" is published in the "Journal of Alloys and Compounds" their research work is clearly in a precise manner and shows a high quality of succinctness. Their research work shows that they were able to develop an Amorphous metal Alloy with atomic scale composition of (Fe0.8Co0.2)85B14Si1 with "extremely high saturation magnetization (Bs) of 1.92T in conjunction with low coercivity (Hc) of 2 A/m". The high saturation magnetization (Bs) with a value of 1.92T is a first time achievement for Amorphous metal alloys up till date. Further they used the methods of "Annealing the as-spun amorphous alloy" in order to get the other soft magnetic properties. It was found that "even in the optimal annealed state the (Fe0.8Co0.2)84B15Si1 and (Fe0.8Co0.2)85B14Si1 amorphous alloys exhibited good bending ductility". The first synthesis of the "Fe-based amorphous alloy having simultaneously high *Saturation Magnetization* (Bs) above 1.9 T, low *Coercivity* (Hc) of about 2 A/m, high effective permeability, high Tc and good bending ductility is promising for future extension of amorphous alloys as engineering soft magnetic materials". The results from their research can be analysed by the graphical representation in the figures below: (1) Magnetization (2) Effect of Annealing on B and Coercivity Hc:

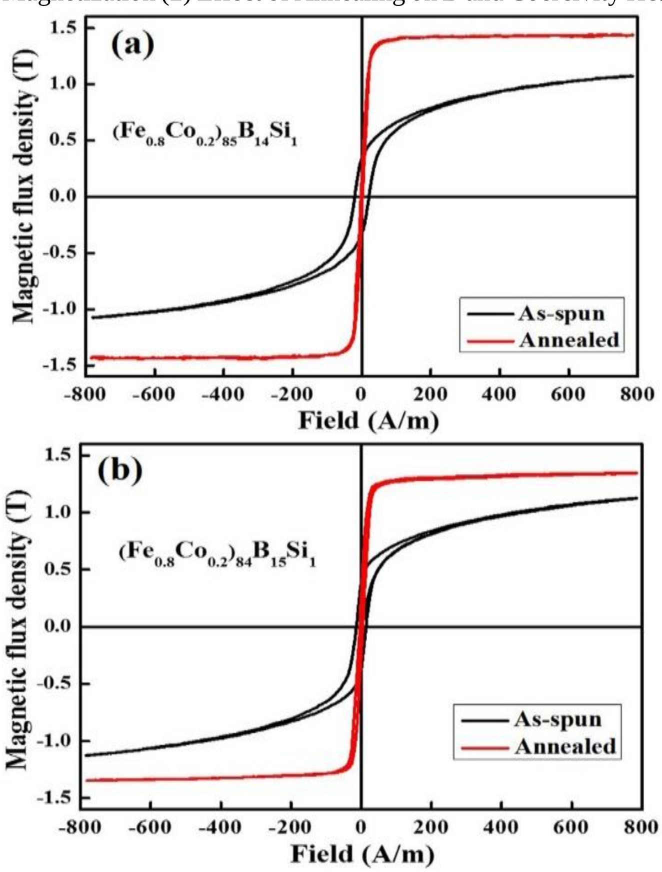

Fig. 7. Representation of Magnetization density of (FeCoBSi-based) Alloy System

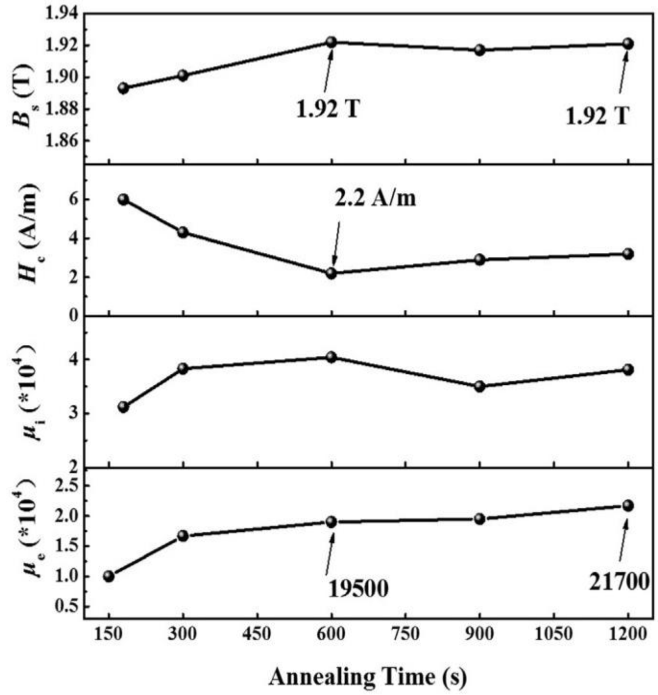

Fig. 8. Representation of Saturation Magnetization (Bs) and Coercivity (Hc) of (FeCoBSi-based) Alloy System

VI. CONCLUSION

It can be seen clearly that with the slight changes in the composition or the Molecular/Atomic structure of ferromagnetic Fe based Amorphous metal Materials their magnetic as well as mechanical properties change. Taking an example from various research works carried out in this area of amorphous metals by various researcher we can analyse that by changing the composition or the atomic scale structure or by adding the ferromagnetic element in different ratios and by the methods of Annealing i.e. temperature changes implementations the researchers were able to get different marvellous and extraordinary changes and enhancements in the properties i.e. Electrical Properties like Magnetization or Saturation magnetization and also the mechanical properties associated with these amorphous metals like bending and ductility or material strength. And with the development of more and more advanced amorphous metal material we would be at a cutting edge of the rising technology as according to the last research by the achievement of "Extremely high saturation magnetization (Bs) of 1.92 T in conjunction with low Coercivity (Hc) of 2 A/m found to be achieved for (Fe0.8Co0.2)85B14Si1 amorphous alloy" there are chances of getting better and better forms of Amorphous alloys in the future to enhance the technology for use in different applications especially the for the use in High frequency transformers. The more effective the core material of transformer is the more efficient will be the transformer itself. The field of research is quiet vast and there is only a little work done by some researchers a lot is needed to be done in order to get better and better form of amorphous metals and better results in this area. Up till date the researches have shown that adding the ferromagnetic element in different ratios in Fe-Co based Amorphous metal system or changing the composition in atomic scale structure has greater effect on both the Magnetic as well as Mechanical properties of these Amorphous Alloys.

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