

**Tutorials (May 13, 2002):**

1). Power Electronics and Motor Drives

A. Emadi, Illinois Institute of Technology, Chicago Illinois, United States

**ABSTRACT**

Power electronics is the technology for conversion and processing of electrical power and its applications. It provides the basis for a variety of new electrical system architectures that allow substantial improvements in performance and flexibility. Power electronic converters are also increasingly used in electric motor drives to control electric machines, which are electro-mechanical power transfer systems. These variable-speed motor drives are replacing conventional mechanical, hydraulic, and pneumatic power transfer systems due to their higher efficiency and superior performances. More than 50% of the total electrical energy produced in the USA is consumed by electric motors.

Power electronic converters and motor drives are used in a broad range of applications from low power telecommunication systems, switching power supplies, Uninterruptible Power Supplies (UPS), and wireless communications; to medium power home appliances such as refrigerators, washing machines, and cordless drives, medical instrumentation, personal computers, and hand power tools; to high power industrial automation systems, machine tools, aerospace systems, automotive applications, and advanced power quality improvement systems in utility grids. Magnetic materials are used to perform many functions in these systems. In this tutorial, we focus on power handling magnetic materials since these are of unique concern in power electronics and motor drives. These primarily include inductors, transformers, and electric machines. Inductors or transformers are present in most of the power electronic systems. Unlike other electric components used in power electronic systems, inductors and transformers are not generally available in their required forms. The large number of parameters that characterized a magnetic component makes it impractical for a manufacturer to produce and stock the vast array of configurations required by the industry. Instead, individually designed magnetic components put copper and magnetic material together in a way that minimizes some combination of cost, volume, weight, and fabrication difficulty.

In addition, current status and future trends in the areas of power electronics and motor drives as the major users of magnetic materials are presented in this tutorial. Different functions of magnetic components such as circuit isolation, voltage transformation, coupling of circuits, and filtering as well as their vital roles are explained. Major issues facing the magnetic component designers in the areas of power electronics and motor drives are also reviewed. Furthermore, new applications of magnetic materials in advanced Adjustable Speed Drives (ASD) such as brush-less DC (BLDC) and Switched Reluctance Motor (SRM) drives are introduced.

**Session I (May 13, 2002):**

**Magnetic Measurement of Electrical Steel**

Session Chairman: Philip Beckley

- 1). Challenges of Non-sinusoidal Flux and Voltage Waveforms  
A. J. Moses, Wolfson Centre, Cardiff University, United Kingdom

**ABSTRACT**

Magnetic devices are being subjected to increasingly greater ranges of non-sinusoidal flux voltage waveforms. Material evaluation or prediction of losses in machines operated under conditions such as PWM voltage excitation require new approaches to measurement and interpretation of data which are reviewed in this presentation.

- 2). Digital Waveform Control for Magnetic Measurement  
S. Siebert, Brockhaus, Germany

**ABSTRACT**

The control of waveforms over the range of industrial testers from the Epstein to advanced on-line devices is moving to digital methods. This gives an extended range of exact control and greater system stability. The status of these developments and their algorithmic strategies is reviewed with examples and future trends are examined.

- 3). Magnetic Measurements on Eleven-Tonne 3-Phase Transformer Cores  
H. J. Stanbury, H. A. Smith, and C. H. Porter, Cogent Power Ltd., Newport, South Wales, United Kingdom

**ABSTRACT**

Testing of electrical steel strip is routine, however it is the performance of the steel once formed into a core that contributes to the overall efficiency of a transformer. The development of an instrument for the making of power loss measurements on complete transformer cores up to eleven tonnes is described.

- 4). Effect of Grain Size on the Static and Dynamic Losses of Non-oriented SiFe  
M. Pasquale, Istituto Elettrotecnico Nazionale Galileo Ferraris, Torino, Italy

**ABSTRACT**

New applications of non-oriented FeSi steel require a better high frequency performance which can be obtained with a proper control of thickness, resistivity, texture, and grain size. While it is widely recognized that lower thickness and higher resistivity always play a positive role in loss reduction, the role of the average grain size  $\langle s \rangle$  must be assessed with more detail. Experimental data obtained on non-oriented FeSi 3% shows that total loss can be broken in three terms,  $P_t = P_h + P_c + P_e$ , respectively hysteresis (static), classical loss, and excess loss. The static contribution,  $P_h$ , results proportional to  $A\sqrt{\langle s \rangle}$  while  $P_e \propto P_0 + B/\sqrt{\langle s \rangle}$ , where A, B, and  $P_0$  are microstructural related parameters, the first connected to the domain structure and the latter two to the precipitated impurities and crystallographic texture.

## Session II (May 14, 2002):

### Developments in Non-oriented Sheet

Session Chairman, Ted Bloom, Ispat-Inland Steel Company

#### 1). Determination of Grain Growth Mechanisms during Secondary Annealing in a CRML Steel

S. Cheong<sup>(a)</sup>, E. J. Hilinski<sup>(b)</sup>, and A. D. Rollett<sup>(a)</sup>

(a) Carnegie-Mellon University, Pittsburgh, Pennsylvania, United States

(b) U. S. Steel Corporation, Monroeville, Pennsylvania, United States

#### ABSTRACT

From a scientific point of view, the grain growth process during lamination annealing of a cold rolled motor lamination (CRML) steel is through strain induced boundary migration (SIBM). In general, the origin of recrystallization or grain growth in metals with low strains derives from strain induced boundary migration (SIBM). In a CRML or a temper rolled non-oriented electrical steel, the primary driving force for grain growth during lamination annealing may result from the variations in stored energy imparted by the temper rolling process. The work presented in this study attempts to determine the mechanisms governing the grain growth process that occurs during lamination annealing in CRML steel. Orientation Imaging Microscopy (OIM) and Monte Carlo (MC) simulation are employed as primary analysis tools. A new method combining OIM and MC simulation is also presented. By virtue of the OIM, it is possible to reproduce the measured microstructure in the MC simulation system that fits in the lattice format of the MC simulation with the one obtained from the OIM by simple data processing steps. In the new analysis technique, the experimental microstructure from the OIM is used as an input microstructure in the MC simulation. By doing so, various grain growth mechanisms during grain growth in CRML steels are examined. Additionally, a misorientation representation for the microtexture deformation during temper rolling is presented.

#### 2). On the Origin of Grain Boundary Embrittlement of Non-oriented Electrical Steel Sheet

M. Predmersky<sup>(a)</sup> and S. Longauer<sup>(b)</sup>

(a) U. S. Steel Kosice, s.r.o., Kosice, Republic of Slovakia

(b) Technical University of Kosice, Kosice, Republic of Slovakia

#### ABSTRACT

The mechanism of embrittlement in fully finished nonoriented silicon steel with 1.5 % Si is described in this paper. The embrittlement is created during continuous decarburization annealing as a consequence of the accumulation of moisture in the furnace atmosphere (dew points above 60°C). After a sheet bending test, completely intergranular fracture occurred on surfaces without second phases at the grain boundaries. After electrolytic polishing, a continuous network of grain boundaries was observed by light and scanning electron microscopy (SEM). Energy dispersive spectroscopy (EDS) analysis showed an increased concentration of silicon on the grain boundaries. Carbon extraction replicas from the fracture surface showed the formation of a continuous amorphous layer or dendritic amorphous particles with a high content of Si and O. From these observations it was concluded that embrittlement was caused by a very thin layer of silicon oxide grown at the grain boundaries near the surface, as a result of changes in the composition of the decarburization atmosphere. This layer has the effect of a very sharp notch at the surface causing intergranular fracture along the full sheet thickness. The segregate enrichment of grain boundaries by fracture surface analysis was observed after decarburization annealing with dew points of 40°C as well. The fraction of intergranular fractures increases with increasing silicon content and decarburization temperature.

#### 3). The Angular Dependence of Magnetic Properties of Electrical Steels

M.A. da Cunha<sup>(a)</sup>, N. C. S. B. Zwirman<sup>(b)</sup>, V. W. Wolgast<sup>(b)</sup>, R. S. Germano<sup>(b)</sup>, F. J. G. Landgraf<sup>(c)</sup>,  
T. Yonamine<sup>(c)</sup>, R. Takanohashi<sup>(c)</sup>, and N. B. Lima<sup>(d)</sup>

(a) Acesita, Tomoteo, Minas Gerais, Brazil

- (b) CSN, Volta Redonda, Rio de Janeiro, Brazil
- (c) Institute for Technological Research (IPT), Sao Paolo, Brazil
- (d) Institute for Nuclear Energy Research (IPEN), Sao Paolo, Brazil

#### ABSTRACT

The angular behavior of the magnetic losses of some electrical steels of different processing is compared. The subdivision of the hysteresis loss in a low- and a high-induction component shows that two different sources of angular dependence can be identified. The high-induction component has a good correlation to the crystallographic texture contribution, while the low-induction may be related to the angular behavior of the mean non-metallic inclusion distance.

#### 4). Non-oriented Electrical Steel for High-Efficiency Motors

A. Fujita, M. Kawano, and M. Komatsubara, Kawasaki Steel Company, Mizushima, Japan

#### ABSTRACT

Non-oriented electrical steels for high efficiency motors have recently been developed for the purpose to meet customers requirements from the viewpoint of energy saving and efficiency enhancement of motors. The steels are characterized by the improvement in their texture. The advantages of the new materials are not only their low iron losses but also appropriate hardness and high magnetic flux densities, which leads to excellent punching ability in assembling and to improvement of motor efficiency in customer use, especially in the use of high-efficiency motors. The developed materials boost the spread of high-efficiency motors and contribute to saving energy consumption.

#### 5). Columnar Grain Growth in Non-oriented Electrical Steels

F. Kovac<sup>(a)</sup>, M. Dzubinsky<sup>(a)</sup>, M. Predmersky<sup>(b)</sup>, and Y. Sidor<sup>(a)</sup>

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#### ABSTRACT

By modifying the thermal profile of the decarburization anneal in the final processing of electrical steels during laboratory and commercial processing, a material of columnar structure has been prepared. The formation process of this structure was controlled by carbon diffusion. From the point of view of magnetic properties, the columnar structure presents a more advantageous texture than the inhomogeneous polyhedral structure, produced by the classical method of decarburization annealing. The results have been presented in the form of microstructural and crystallographic texture analysis via ODF's and by evaluation of electromagnetic properties.

#### 6). Rolling and Recrystallization Textures of Non – Oriented Electrical Steels

M. Cerník<sup>(a)</sup>, A. Leško<sup>(b)</sup>, and L. Hrabčáková<sup>(b)</sup>

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#### ABSTRACT

The present paper deals with the texture evolution in non – oriented electrical steels. The influence of the cold rolling and annealing temperature on the texture component of  $\alpha$  and  $\gamma$  fibres and microstructure has been studied. The optimal annealing temperature range was found for formation of most suitable textures for 1,5 % Si steels. The samples were taken out from production process after hot rolling. Texture have been studied using the x-ray diffraction technique. All texture were examined by measuring the four incomplete pole figures (110), (200), (112) and (103) in back reflection mode. The orientation distribution function (ODF) has to be calculated.

## Messinger Memorial Lecture (May 14, 2002)

Applications of Giant Magnetostrictive Alloys

J. Snodgrass, ETREMA Products Inc., Ames, Iowa, United States

## Session III (May 14, 2002):

### High Alloy Electrical Steel

Session Chairman, Erik Hilinski, U. S. Steel Corporation

#### 1). Effects of Magnetic Annealing on Magnetic Properties of Grain Oriented Si Steel

S. Y. Cha<sup>(a)</sup>, I. B. Chudakov<sup>(b)</sup>, S. K. Chang<sup>(a)</sup>, J. S. Woo<sup>(a)</sup>, and J.-K. Kim<sup>(a)</sup>,

(a) Technical Research Laboratories, POSCO, Pohang, Kyungbuk, Korea

(b) I.P. Bardin State Scientific Center, Moscow, Russia

#### ABSTRACT

It is well known that lower magnetostrictions of silicon steels are needed to lower the noise level in transformers, and electrical machines. In order to reduce the magnetostriction of grain oriented silicon steel, the effects of a magnetic annealing treatment on grain oriented Si steels have been studied in the laboratory. Grain oriented Si steels with different magnetic properties were studied. A magnetic field was applied to the samples during annealing. Magnetic properties and magnetostriction were tested along the rolling direction before and after magnetic annealing. It was found that magnetic annealing is effective for improvement of magnetostriction properties of grain oriented Si steels. The major improvement in magnetostriction was observed in the compressed state of the material. The improvement of magnetostriction under a compressive stress of 2 MPA is 50 percent, which is important from the practical point of view.

#### 2). Advances in the Production of High-Silicon Steel through Hot Dipping and Diffusion Annealing

T. Ros-Yáñez and Y. Houbaert, Ghent University, Gent, Belgium

#### ABSTRACT

High silicon steel with up to 6.5% Si has potential use in electrical appliances as a material for transformers and motor cores because of its enhanced electrical properties: high resistivity and permeability, low losses and low magnetostriction. However, rolling is very difficult because as the Si content increases, the material becomes extremely brittle. The hot dipping and diffusion annealing process, is an alternative production route to obtain high silicon contents while avoiding rolling problems. Additional surface alloying with Si and Al is achieved on a low Si steel substrate by hot dipping in a hypereutectic Al-Si-bath. To obtain a sufficient amount of Al and Si in solid solution over the thickness, a diffusion annealing treatment has to be performed after hot dipping. High silicon steel up to 6.3% Si and 4.5% Al was obtained using a hot dipping/diffusion process. Excellent magnetic properties are obtained after diffusion annealing at 1250°C for 30min; magnetic losses were reduced at 50 Hz to 0.64W/kg (1T) and at 400 Hz to 10W/kg (1T) in sheets with 0.35mm thickness.

#### 3). Workability of High Silicon Steel ( $\geq 4$ wt.%) for Electrical Applications

Y. Houbaert<sup>(a)</sup>, T. Ros-Yáñez<sup>(a)</sup>, D. Ruiz<sup>(a)</sup>, R. Colás<sup>(a,b)</sup> and J. Barros<sup>(a,c)</sup>

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(b) Universidad Autónoma de Nuevo León, Monterrey, Mexico

(c) Valladolid University, Valladolid, Spain

#### ABSTRACT

High silicon steel has a potential use in electrical appliances because of its enhanced electrical properties. However, rolling is very difficult because as the Si content increases, the material becomes extremely brittle. It is generally believed that this is due to an ordering phenomenon. Alloys with different Si content (3.3 up to 5.6% Si) were investigated regarding the effect of

increasing the Si over 4% on processing and properties and to understand the effect of the order-disorder phenomenon on the workability of these alloys. Mössbauer spectroscopy was used to study the effect of thermomechanical cycles on the ordering: the cooling rate between hot and cold rolling was the most important parameter. The results show that the alloys are never random solutions: at lower Si-contents a high Fe<sub>15</sub>Si/ Fe<sub>7</sub>Si ordering is observed, with a slight order decrease after cold rolling. At higher Si-content, all samples present an ordered mixture Fe<sub>15</sub>Si/ DO<sub>3</sub>, except after slow cooling, where very pronounced DO<sub>3</sub>-order is observed (making the material very difficult to cold roll). The thermomechanical treatment modifies the order state. Compression tests (at high strain rate) were carried out at room temperature: samples were tested with strains of 0.50 and 0.75 in two equal steps at a strain rate of 0.5 s<sup>-1</sup>. Improvement in the rolling process can be obtained through adequate hot and cold rolling schemes.

- 4). Development of Semi-Processed Electrical Steels for Compressor Motor and EI Lamination Cores  
Y-S. Hwang and L. Chang, China Steel Corporation, Kaohsiung, Taiwan, Republic of China

**ABSTRACT**

Stress relief annealing after stamping is a common practice in the manufacturing of compressor motor and EI lamination cores regardless of the types of electrical steel used. Therefore, the use of semi-processed electrical steels is attractive because of their relatively low production cost compared to fully processed electrical steels. On this account, China Steel Corporation has tried to develop semi-processed electrical steels to meet the increasing demands on quality improvement and cost savings. In this paper, the effects of processing parameters on the magnetic properties of semi-processed electrical steels are discussed. Results of mill and customer trials are also presented.

- 5). Recent Progress on Electrical Steel Sheet for Eco-Design of Electrical Equipment  
T. Kubota, Nippon Steel Company, Futtsu, Chiba, Japan

**ABSTRACT**

Electrical steel sheet is a soft magnetic material used for the cores of electrical equipment, such as generators, transformers, motors and so on. It is also used for magnetic shielding materials. The progress of not only material properties, but also performance in assembled electrical equipment and magnetic shielding are remarkable. Electrical steel sheet is going to develop as an eco-material for energy savings, noise reduction, and for magnetic shielding.

**Session IV (May 15, 2002):**

**Use of Magnetic Effects in NDE**

Session Chairman, Massimo Pasquale, Istituto Elettrotecnico Nazionale Galileo Ferraris

- 1). Effect of Grain Size and Dislocation Density on Magnetic Properties and Application to NDE  
Monitoring of Tensile Strength and NDE of Welds

M. J. Sablik, Southwest Research Institute, San Antonio, Texas, United States

**ABSTRACT**

This talk will review recent work in which the Jiles-Atherton model was modified to include effects of grain size and dislocation density. The modified model predicts generally that coercive field increases with increasing dislocation density and inverse grain size and that remanent flux density and maximum differential permeability decrease with increasing dislocation density and inverse grain size. Hysteresis loss can increase or decrease depending on the range of dislocation density and grain size. The model is applied to nonlinear harmonics of the magnetic flux density, and it has been found that the third harmonic decreases with increasing dislocation density and inverse grain size.

Application to the following NDE situations will be discussed:

- (1) Since increasing dislocation density and inverse grain size corresponds to increasing tensile strength mechanically, it is seen that the third harmonic can be monotonically correlated with tensile strength and thus be used to nondestructively monitor the tensile strength of steel produced at a steel plant.
- (2) A nondestructive test for determining whether a weld is annealed or not can be deduced from the variations of the magnetic flux density in the vicinity of the weld. A finite element calculation incorporating the effects of the modified Jiles-Atherton model will be discussed to show how such a test for weld anneal can be carried out.

- 2). Use of Magnetoacoustic Emission for NDE of Creep Damage in Power Plant Applications

B. Augustyniak, Technical University of Gdansk, Gdansk, Poland

**ABSTRACT**

This presentation deals with a new magnetic NDE technique of steel quality assessment. The technique uses magnetoacoustic emission (MAE). It is found that MAE is a very sensitive detector of creep damage in an incipient stage that is not accessible to other NDE techniques such as ultrasonics.

The following items will be addressed:

- 1 - the MAE source and its relationship with magnetic hysteresis,
- 2 - MAE signal detection conditions
- 3 - apparatus set with magnetizing core design and MAE signal analysis
- 4 - comparison of MAE levels to micrographs and mechanical measurements
- 5 - examples of MAE application for assessment of power plant pipe creep damage

- 3). Laser Ultrasonic Attenuation NDE in Ferrous Metals

A. Moreau, NRC, S. Bolognini, S. Kruger, G. Lamouche

**ABSTRACT**

One objective of the Ultrasonic Characterization and Sensors group is to build ultrasonic sensors to non-destructively evaluate the microstructure and physical properties of metals. Our research has led us to study how ultrasound is absorbed in steel and other metals, and to study magneto-elastic interactions. Our absorption measurements are based on laser-ultrasonics and the reverberant technique, but laser-ultrasonic velocity and attenuation measurements are also done. A pulsed laser light beam generates a pulse of ultrasound in a small sample which is acoustically insulated from its environment. After some time during which the acoustic pulse scatters and mode-converts into a multitude of vibration components, a laser interferometer measures the surface vibrations decay as a function of time and

frequency, from 1 to 45 MHz; i.e. we measure the sample's absorption spectrum. These measurements can also be done under magnetic field or at high temperatures in a furnace. It is found that, below the Curie temperature, one of the main absorption mechanism is based on micro-eddy currents generated by magnetic domain walls motion induced by stresses. It is also found that temperature and thermal processing greatly affect the strength of this magneto-elastic phenomenon.

An extension of the technique is being developed to obtain absorption spectra in samples of large dimensions, whereby the ultrasound is confined within a small volume by grain scattering. This technique eliminates the drawback of having to cut small samples and is potentially applicable to on-line, industrial applications.

4). A Paradigm Shift in the Magnetic Test Criteria for Motors

K. E. Blazek and T. A. Bloom, Ispat-Inland Steel Company, East Chicago, Illinois, United States

**ABSTRACT**

The value of specifying a minimum permeability for material to be used for motor laminations as a criterion for motor performance is examined. Software developed by Ansoft Corp. to predict motor performance is used to show that the 1.5 Tesla permeability is irrelevant to motor performance. It is shown that the shape of the plot of permeability and core loss curves plotted as a function of the applied field, B, from 0 to 2 Tesla are better indicators of the potential of a material for use as a motor lamination. Examples are shown of these curves for real materials that show a material with a higher 1.5 Tesla permeability will have lower values of permeability at almost all other applied field strengths than a material with a lower permeability at 1.5 Tesla. An example of the B field distribution in a single-phase induction motor is shown that illustrates that most of the motor operates at B fields much lower than 1.5 Tesla. All of the information presented leads to the conclusion that the 1.5 Tesla permeability is superfluous information for predicting the applicability of a material for use as a motor lamination.

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