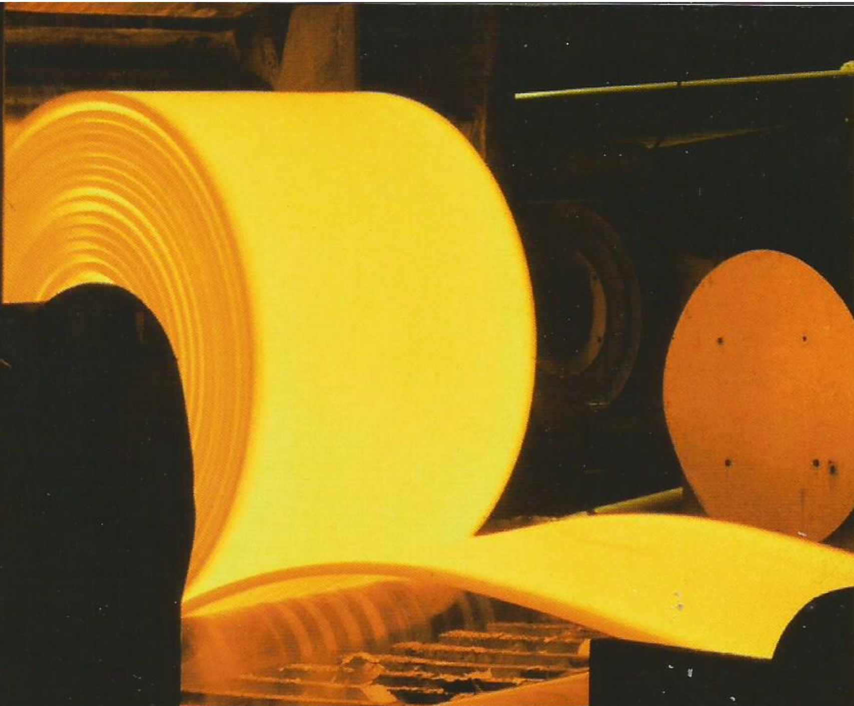

VOL 2

Conference Preprints

THERMOMECHANICAL PROCESSING OF STEELS

24 - 26 May 2000

Church House Conference Centre, London, UK

Recognised by **ESIC**
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Organised by the Steel Division Technical Committee of The Institute of Materials and organised by IOM Communications Ltd

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FOREWORD

On behalf of the Organising Committee and the Steel Division of The Institute of Materials, it is my great pleasure to welcome you to this major International Conference on the Thermomechanical Processing of Steels, the first on this important subject in Europe for over a decade.

The conference has attracted an impressive array of keynote speakers from the Far East, Europe and North America, and authors from all the leading steelmakers, their suppliers, universities and research institutes from around the world.

We have a very full technical programme comprising oral and poster presentations. I am looking forward to some lively discussion sessions, both formally and informally.

This conference is a wonderful opportunity to disseminate recent developments and applications, and to identify the next scientific and technological targets for thermomechanically processed steels, driven by every increasing market demands for better, more consistent and lower cost steels with novel combinations of properties. These will take advantage of advanced steelmaking, casting, rolling and cooling technologies and the latest understanding of structure-property relationships. By tackling and overcoming these challenges, it is intended that the steel industry will retain and improve its competitiveness.

I hope you are stimulated and excited by this conference. Its success depends on the active participation of all the delegates.

I should like to thank, on your behalf, the Organising Committee, the Conference Department at The Institute of Materials, the management and staff at Church House, the Keynote Speakers, Session Chairmen and all the authors for their contribution in making this conference the success it deserves to be.

I also wish to acknowledge the generous sponsorship of the conference by Niobium Products and Corus.

Dr David J Naylor
University Liaison Manager
Corus Research, Development & Technology
Chairman of the Organising Committee

VOLUMEN 2

METALLURGICAL PROCESSING OF HIGH – SILICON (6.4% wt) NON – ORIENTED MAGNETIC STEEL SHEETS DIRECTLY FROM THE MELTED STATE BY RAPID QUENCHING. A STUDY OF THE CONTINUOUS ANNEALING STEP AND ITS INCIDENCE ON TEXTURE GRAIN SIZE AND CORE LOSSES.

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ABSTRACT

This paper presents the studies carried out on high silicon (6.4 % wt) – iron soft magnetic alloys obtained directly from the melted state by rapid quenching.The material thus obtained was then submitted to heat treatment. The influence of the atmosphere type (N_2, H_2, Ar, Vacuum) and temperature range (900 – 1,100 °C) on grain size and texture induced in the material was studied. Likewise, the amount of total core losses (0.8 – 1.0T)in the 10 to 1,000 Hz frequency range was measured and the influence of the above mentioned variables on the losses was analysed. From the analysis of the results it can be deduced that the amount of core losses is, in all cases, lower than that of the highest grade of conventionally processed non - oriented magnetic steel sheet, this being so especially in the range of frequencies above 50/60 Hz. As a consequence, this material is highly adecuate for manufacturing cores of high - performance electrical machines working at high frequencies (≈ 400 Hz.).

Keywords : Non-oriented magnetic steel sheets, High silicon content (6.4% wt Si), Rapid solidification, Continuous annealing, Magnetic characteristics.

1.- INTRODUCTION

Nowadays the siderurgical process for manufacturing non-oriented magnetic steel sheets presents several research and development topic areas, amongst which we must highlight the production of high silicon content alloys (4 – 6.5% wt) by means of the enrichment in silicon by Chemical Vapour Deposition (C.V.D) techniques (1 - 3).

This high silicon level material can be used in a wide variety of industrial applications, the most important of which being the cores production of high – performance electrical machines (4) :

- Electrical A.C. motors (≈ 400 Hz) in on-board equipments.
- Small (< 0.75 Kw) high speed induction motors working at frequencies between 50 – 200 Hz.

- Transformers operating at frequency range in electronic power suply (200 – 10,000 Hz).

Bearing in mind the importance of these applications, several studies have been carried out with the aim of obtaining this material directly from the melted state by means of rapid quenching, as this new siderurgical process is especially interesting from a technical and economic point of view.

Considering the economic importance of the subject in hand, it is evident that the incidence of the siderurgical process – in particular the heat treatment step - on the final magnetic characteristics of the material is worthy of study.

Therefore, the objective of the present research work is the optimization of the heat treatment step, focusing on the study – under conditions simulating the industrial process – of the incidence of the heat treatment parameters, temperature and atmosphere type, on the final core losses (0.8 - 1.0 T, 50 – 1,000 Hz.).

2.- PHYSICAL AND METALLURGICAL BACKGROUND

It is a known fact that the final amount of core losses depends basically on the silicon content (≈ 6.5 % wt). In the case of the material in question, this is due to its extremely low magnetostriction and high resistivity in relation to the conventional (≈ 3 % wt Si) electrical steels (5).

In addition, if after the final heat treatment, we obtain a minimun level of residual tension stresses, along with an adequate grain size (150 – 200 μm) (6), and at the same time induce a non–oriented cube texture { 100 }< 0kl > (7) which eliminates the hard to magnetize <111> directions from the sheet plane, the result is a material especially adequate for the applications previously stated.

These variables, in turn, are a function of the parameters involved in the previous manufacturing process and, particularly, of the heat treatment parameters.

In fact, this treatment (8 - 10) has a decisive influence on grain size and texture, since the type of recrystallization obtained, whether primary or tertiary, is a function of the soaking time, temperature range and the type of atmosphere used (N_2, H_2, Ar, Vacuum) (11).

In the case of vacuum atmospheres, the temperature and vacuum level (amount of oxygen in the furnace atmosphere) play a decisive role in this whole process, since the (6.5 % wt) silicon - iron alloys obtained by rapid quenching develop a { 100 }< 0kl > sharp texture when the atmosphere is free of impurities and sufficient oxygen is present in the furnace atmosphere, and therefore adsorbed on the surface of the material, ensuring the lowest surface energy for the { 100 } planes. However, when there is little or no oxygen present in the atmosphere, the texture { 110 }< hh'1 > develops along with other textures, as reported in our previous research work (12).

3.- SIMULATION OF INDUSTRIAL PROCESS

In accordance with the objective of the present paper microcrystalline ribbons (6.4% wt Si, 25 mm x 38.2 μm) were obtained by rapid solidification, applying the previously described production process parameters (13), and then submitted to the heat treatment processes described in Table I .

Table I. Annealing cycles

Cycle	Atmosphere	Gas flow (m/s)	Annealing			
			Temp (C°)	Time (minutes)		
				Heating	Soaking	Cooling(40C°)
I	N_2, H_2, Ar	0.059	900	19 – 22	180	358 – 369
II	N_2, H_2, Ar	0.059	1,100	26 – 29	180	393 – 405
	Vacuum (1 – 20 Pa)	–	1,050	35 - 39	180	450 - 510

For these materials, the micrographic structure, average grain size (14), and texture induced (15), were determined. These results are shown in Table II.

Table II : Grain size and Texture

Atmosphere (Cycle)	Grain Size (μm)		Texture Area [{ hkl } / {Total } %]				
	D < t	D > t	110	200	210	310	222
N_2, Ar (I)	15.9	93.4	13.1	0.7	4.6	81.6	–
N_2, Ar (II)	–	138.4	9.6	14.1	19.1	57.1	–
H_2 (I)	28.3	174.5	15.6	5.8	3.9	74.6	–
H_2 (II)	–	189.4	11.0	24.1	5.5	59.2	–
Vacuum (1 – 20 Pa)	–	1,100	12.3	76.6	–	11.1	–

D : Average grain size, **t** : thickness of the material

Likewise, the core losses, for each of the heat treated materials described in Table I, were determined at different inductions (0.8 – 1.0 T) in the 50 – 1,000 Hz frequency range using the experimental equipment developed by J. Degauque et al. (16).

Figure 1 shows the results obtained at 1.0 T, indicating also the results corresponding to the non-oriented magnetic materials ; conventional (≈ 3 – 3.5 % wt Si) or siliconized by C.V.D. technique (≈ 6.5 % wt Si) (17).

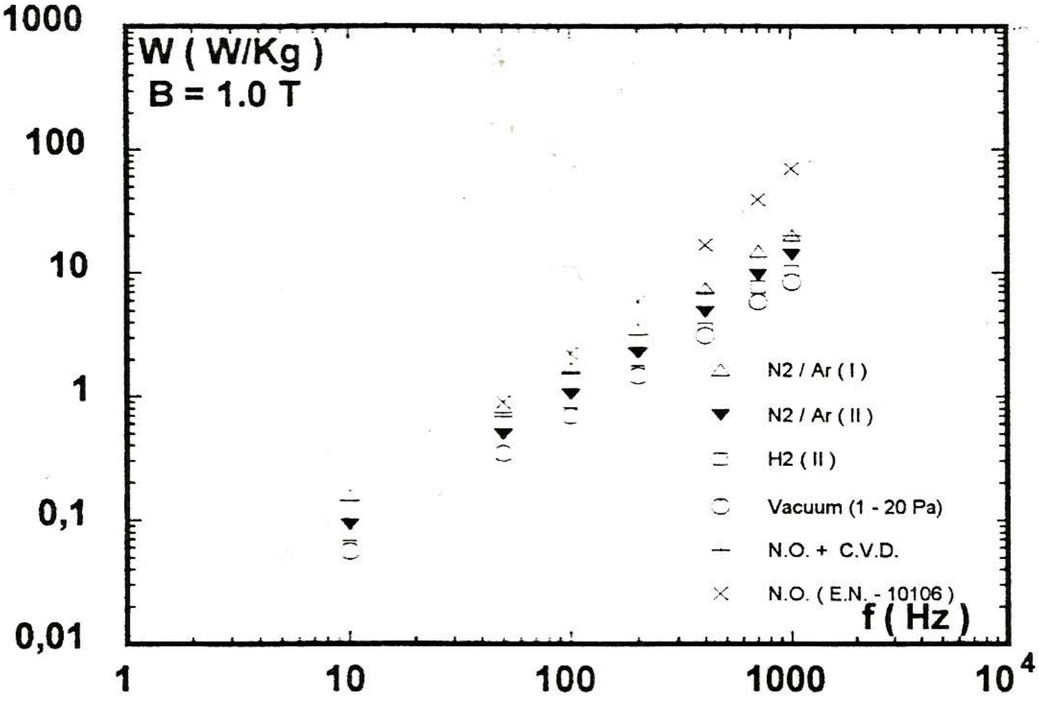

Figure 1. Core losses, as a function of the frequency, for different heat treatments.

4- RESULTS AND THEIR ANALISYS

In view of the results obtained, the influence of the annealing temperature and the type of atmosphere on texture and grain size and, therefore, on the magnetic characteristics of the material was analysed.

4.1 Influence of the heat treatment temperature on texture, grain size and core losses

As regards grain size, it can be deduced from the micrographic observations of the samples (Table II) that the material heat treated under cycle I (900 °C) conditions, regardless of the atmosphere type (N_2, H_2, Ar), presents two clearly differentiated micrographic structures, depending on whether the average grain size (**D**) is smaller (**D** ≈ 15 – 29 μm) or larger

(**D** ≈ 93 – 190 μm) than the thickness of the material (**t** ≈ 38.2 μm). This fact suggests that an unfinished recrystallization process has ocurred under cycle I (900 °C), in the sense that residual stresses remain inside the material.

With respect to the influence of temperature on the texture obtained it can be deduced, from the analysis of the data in Table II, that the annealing temperature has little incidence on the texture of the material, with the { 310 } < hkl > component remaining as predominant in all cases, except for the material annealed under vacuum.

As a consequence and bearing in mind the results from Table II and Figure 1, it can be stated that the 30 to 40 % decrease in the amount of core losses at 1.0 T in heat treated materials under cycle II (1,100 °C), compared with cycle I (900 °C), is basically due more to a process of stress relaxation than to the differences in grain size and texture.

4.2 - Influence of atmosphere type on texture, grain size and core losses

The influence of the type of atmosphere on grain size and texture is considerably lower than that of the temperature in the case of nitrogen, hydrogen and argon atmospheres, but is especially significant in the case of vacuum atmospheres (1,050 °C, 1 – 20 Pa), where the oxygen adsorbed on the surface of the material promotes a tertiary recrystallization process (**D** ≈ 1,100 μm) together with a strong non-oriented { 200 }< 0kl > cube texture.

This allows the obtention of a reduction of 20 – 25 % in core losses with respect to the atmospheres of nitrogen or argon at 1,100 °C.

5.- CONCLUSIONS

The results obtained in the present paper allow us to state that material obtained and treated as explained above presents, in all cases, an amount of core losses inferior to that of the highest grade [FeV – 240 – 35HA, U.N.E – E.N – 10106 : 1996] of conventional non – oriented magnetic steel sheet. This, due to the high silicon content of the material, becomes particularly important at frequencies above 50/60 Hz.

The best results were obtained with material manufactured by rapid quenching and annealed under vacuum atmospheres (1050 °C, 1 - 20 Pa).

Likewise, materials with a high silicon content (6.5 % wt) obtained by C.V.D present magnetic characteristics similar to those obtained by means of cycle I (900 °C) under nitrogen or argon atmospheres.

In view of these results, for reason of economy and ease of handling, the use of nitrogen atmospheres is recommended for the final heat treatment of these materials.

The choice between annealing of type I or II must be based on the comparison between the improvement in the amount of total losses (30 – 40 %), and the higher cost and processing difficulty implied in the annealing temperature increase.

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