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Basic classification and processing of electrical steels

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ABSTRACT
Electrical steels are used across applications such as small relays, solenoids, electric motors, generators, and many other electromagnetic devices. It is used mainly in electrical power distribution systems and in automotive industry. Electrical steel is also referred to as silicon steel, transformer steel, or lamination steel. In this study is described the basic classification of electrical steels. In addition, main properties of electrical steels and the production process of these steels is described.
Keywords – electrical steel, goss texture, grain – oriented electrical steel, non – oriented electrical steel, cutting gap

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I. INTRODUCTION

At the beginning of the 20th century, silicon steel was developed and soon became the preferred core material for large transformers, generators and motors. Nowadays, soft magnetic materials are found in every electronics. Silicon steels as soft magnetic materials used in electrical devices and equipment's are evaluated according to the conditions of the energy loss during magnetization in an alternating electric field. [1]

The most important parameters determining the magnetic properties of steel sheets is texture. For non-oriented silicon steel sheets, the ideal texture would be a cubic grain texture with its (001) or (110) planes parallel to the plane of the sheet and a uniform distribution [100] of the direction, while in grain-oriented silicon steels the grain texture is Goss with (110) [100] crystallographic grain orientation (Figure 1). [1]

Silicon steels are the essence of electrical appliances and they provide the best combination for electricity distribution and transmission. Desired properties of these steels are low magnetic losses, high permeability and induction and low magnetostriction. [2]

Low magnetic losses reduce heat generation and power consumption, a high permeability and induction result in reduced size and mass of the parts, and low magnetostriction decreases the noise (manifested as buzzing) in transformers and large capacity machines. [2]

In recent decades, the basic technology of producing non-oriented, fully processed electric steels has not changed significantly. From the point of view of the main alloying elements, the chemical composition is basically similar, and the processing procedure has not been substantially unchanged. However, compared to previous decades, today the losses in steel with a given Si and Al content are incomparably lower. [3]

Electrical steel producers have made only minor changes to the basic chemical composition used for most commercial standard classes. National and international standards only determine the maximum loss (and many times the minimization of polarization / permeability), but in principle do not show a lower loss. [3]

Electrical steel, which has become a commodity product, determines its market price mostly by its level of quality. This development has brought advantages from the steel user's point of view, but at the same time it has expanded market variability and therefore it is not entirely clear what a standardized grade is. [3]

Reducing production costs and increasing quality requirements are the two initial drivers of research and development activities in industry. Recently, new production techniques have been developed, such as low-heating routes and thin-slab-casting methods. Steel producers are very interested in the magnetic properties of these materials, as these properties can be measured with standardized methods. However, little is known about the texture sharpness of the final sheet produce by either of these process routes. [4]

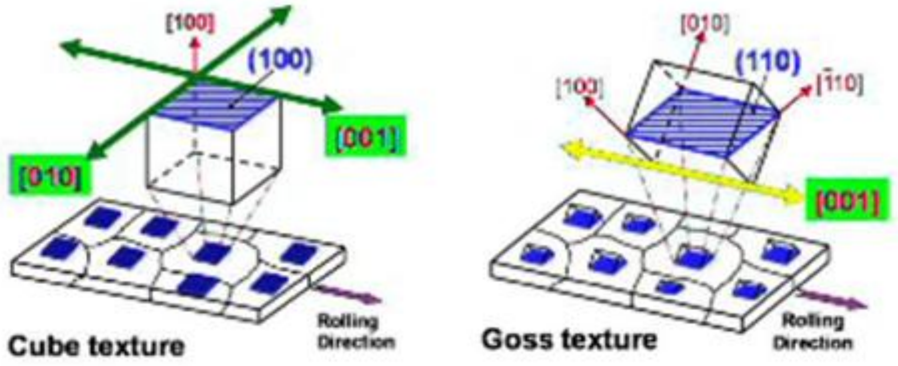

Fig. 1: Cubic and Goss texture with crystallographic grain orientation

II. PROPERTIES OF ELECTRICAL STEEL

Electrical steel is a soft magnetic material with enhanced electrical properties that is widely used across applications such as small relays, solenoids, electric motors, generators, and many other electromagnetic devices. Electrical steel is also referred to as silicon steel, transformer steel, or lamination steel. It is used mainly in electrical power distribution systems and in automotive industries. [5]

Electrical steel is a ferromagnetic material made up of iron that contains varying amounts of silicon (Si) that range from 1% to 6.5%. The development of electrical steels was brought on by electrical devices requiring steels that can decrease the dissipation of heat, an issue that results in energy wastage. Iron was found to be the most economically sound option, but its impurities are not optimal. It was found that the addition of silicon increases resistivity, improves permeability, and decreases hysteresis loss. The most widely used commercially available electrical steel contains about 3.25% Si as higher silicon content tends to make the resulting material too brittle for cold rolling. Electrical steel with 6.5% Si has the most improved magnetic and electrical properties, but additional thermomechanical processes are required in order to overcome its brittleness and limited ductility. [5] [6]

The addition of silicon in iron greatly improves the physical properties of electrical steels. Electrical steels have the following desirable properties for supporting the generation, distribution and consumption of electricity:

- High permeability - increased capacity to support magnetic fields
- Low magnetostriction - low tendency to expand or contract in magnetic fields
- High electrical resistivity - lessens the core loss by reducing the eddy current component
- Decreased hysteresis loss - low hysteresis loss means less wasted energy in the form of heat from alternating magnetizing force [6]

III. TYPES OF ELECTRICAL STEEL

They are made based on the primary magnetic properties of the material. The categorization is based on the method by which the material is produced, or they are based on the grain orientation:

- **Non-oriented fully processed electrical steel:**

Has varying silicon levels that range from 0.5% to 3.25% Si. It has uniform magnetic properties in all directions. This type of electrical steel does not require recrystallisation processes to develop its properties. The low silicon alloy grades provide better magnetic permeability and thermal conductivity. For high alloy grades, better performance is expected in high frequencies, with very low losses. This type is excellent for magnetic circuits in motors, transformers, and electrical system housing. This fully processed type provides difficulty in punchability due to a completed annealing process. Organic coatings are added to improve lubrication in the punching process. [5]

- **Non-oriented semi-processed electrical steel:**

Non-oriented semi-processed electrical steels are largely non-silicon alloyed steel and are annealed at low temperatures after the final cold rolling. The end-user, however, must provide the final stress-relief anneal according to the steel's intended application. The punchability of this electrical steel type is better than the non-oriented fully processed type, so organic coatings are not required. Non-oriented semi-processed grades are good core materials for small rotors, stators, and small power transformers. [7]

- **Grain-oriented electrical steel:**

Grain-oriented electrical steels (Figure 2) are composed of iron with 3% Si content with grains oriented to deliver high permeability and low energy loss. Grain-oriented grades have strong crystallographic properties. This type undergoes a recrystallisation process resulting in an enhanced grain structure that exhibits better magnetic properties in the rolling direction of the sheet. Grain-oriented steels are mostly used for non-rotating applications, such as transformers. [5]

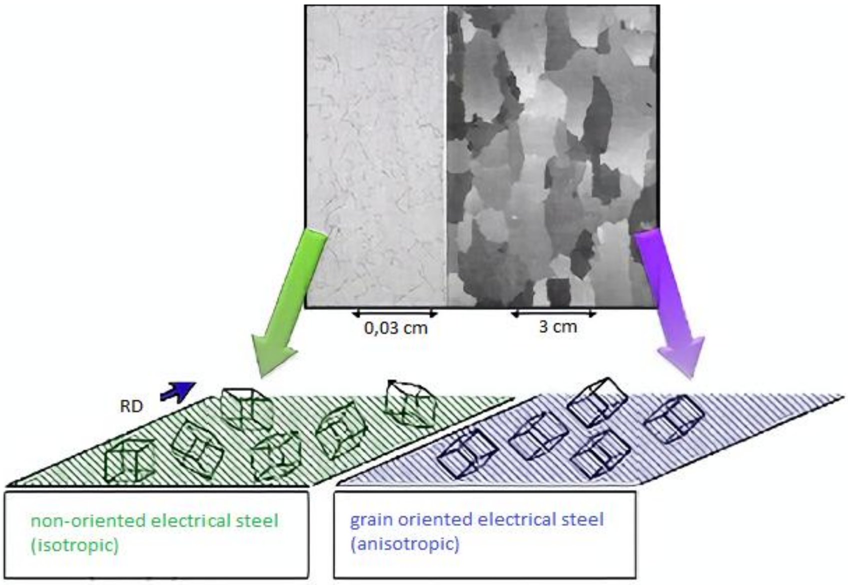

Fig. 2: Goss texture in FeSi steels for electrical applications

IV. TEXTURE OF ELECTRICAL STEEL

Most soft magnetic electrical steels are characterized by a pronounced Goss texture, i.e. a (110) [001] preferred crystal orientation (Figure 3). This sharp texture develops due to a discontinuous or abnormal Goss grain growth during a high-temperature annealing at the end of the production process. Although it is a matter of intensive basic and applied research since more than 50 years, there is no general agreement on the origin of preferred growth of the Goss grains. It is known, however, that the inheritance of Goss orientation from early production stages plays an important role. Therefore, intense research is conducted intending to better understand the evolution of the Goss orientation in industrially processed grain-oriented silicon steels along the various production stages, i.e. hot rolling, cold rolling, primary annealing, and secondary annealing. [8]

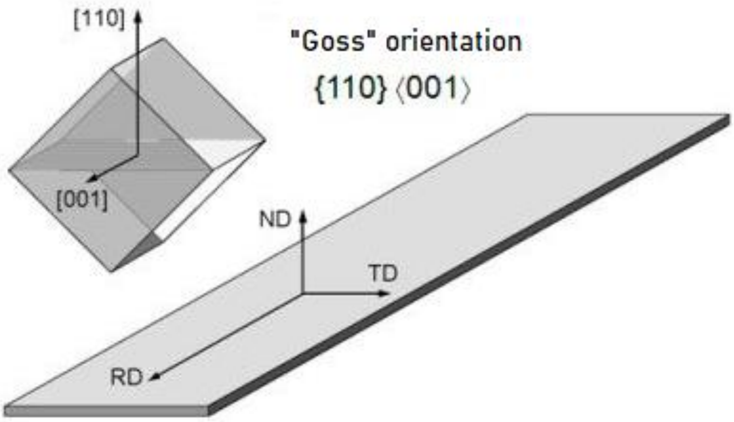

Fig. 3: Goss texture in electrical steel (Goss orientation)

The Goss structure, which is formed by secondary recrystallization, can be very sharp, although it does not dominate the structure of the primary recrystallized steel sheet Si. As primary recrystallization, secondary recrystallization is a nucleation process followed by grain growth. The driving force in this process is the reduction of energy at the grain boundaries. As with primary recrystallization, the formation of a secondary recrystallization texture can be explained by one or both two competing models of oriented nucleation and oriented growth. Secondary recrystallization, or abnormal grain growth versus primary recrystallization, competes with the process of normal grain growth, which also results in a reduction in grain boundary energy.

Abnormal grain growth can only occur if normal grain growth is inhibited. Inhibition is usually achieved by finely dispersing particles such as manganese sulfide or aluminum nitride particles, which are trapped at the grain boundaries. [9]

V. ELECTRICAL STEEL PRODUCTION

Electrical steels are typically cast continuously or melted in oxygen furnaces. They are then hot rolled as they pass through the annealing and descaling process line, where dirt and scale are removed from the surface. Afterwards, they go through cold reduction, where the thickness of the steel is reduced and corrected according to the end-user specifications.

Subsequently, carbon content within the steel is reduced by a decarbonizing anneal, in which the steel roll is heated in a mixture of hydrogen, nitrogen, and water vapour. Additional contaminants, like Sulphur, are removed in this process, as well, resulting in a less brittle material.

For grain-oriented type steel (Figure 4), the coil undergoes a high-temperature coil anneal (HTCA) at about 1100°C in order to achieve the required magnetic properties and grain growth. [10]

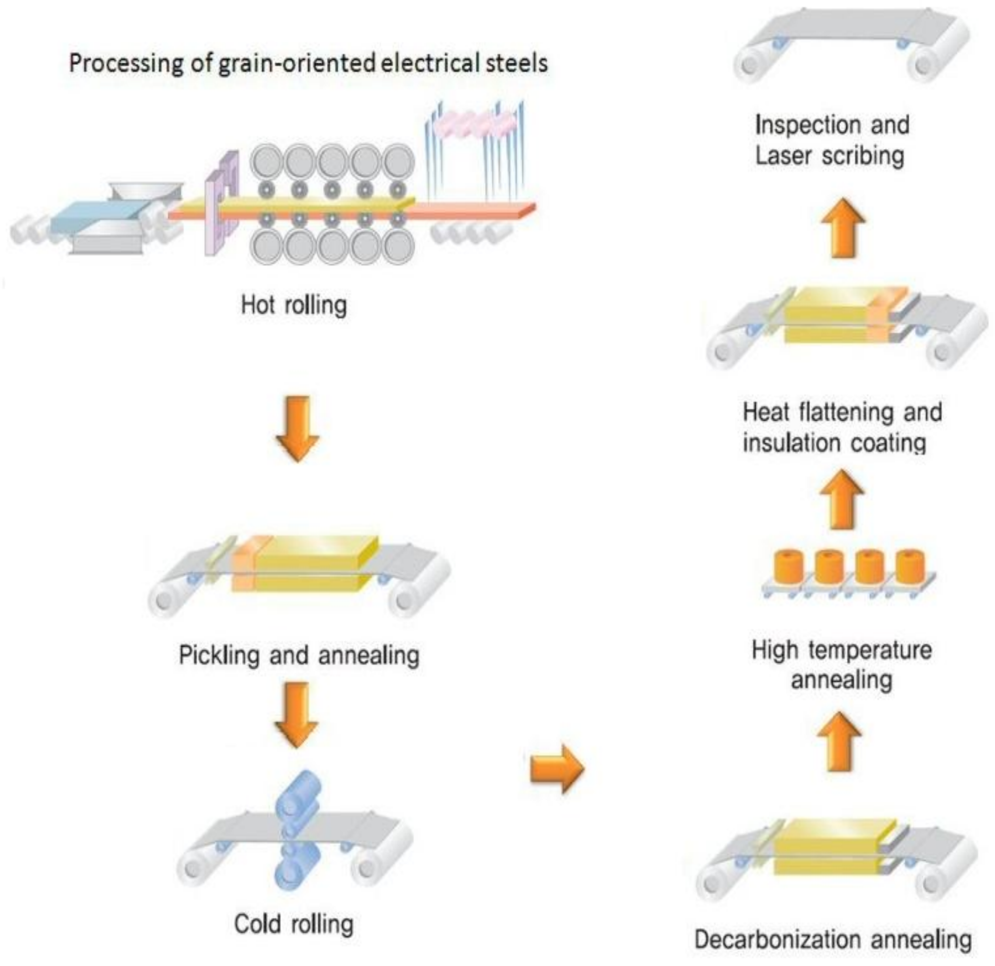

Fig. 4: Processing of grain-oriented electrical steel

In Slovakia electrical steels are produced by U. S. Steel Košice. This company produces isotropic, non-oriented electrical steels. These steels are made with organic and non-organic coatings. The silicon steels are produced in three different gauges, thicknesses. The electrical steels are supplied in form of coils, with maximum weight up to 5 000 kg.

For the experimental research, there was used the material in the form of the thin steel sheets of the nominal thickness 0.5 mm. Two types of the used materials differed in various mechanical properties. We examined the same material after the cold rolling and after the annealing. Evident differences in the record of the tensile test are presented in the Figure 5. From the diagram, it is evident that the material after the annealing had basically higher elongation and lower strength.

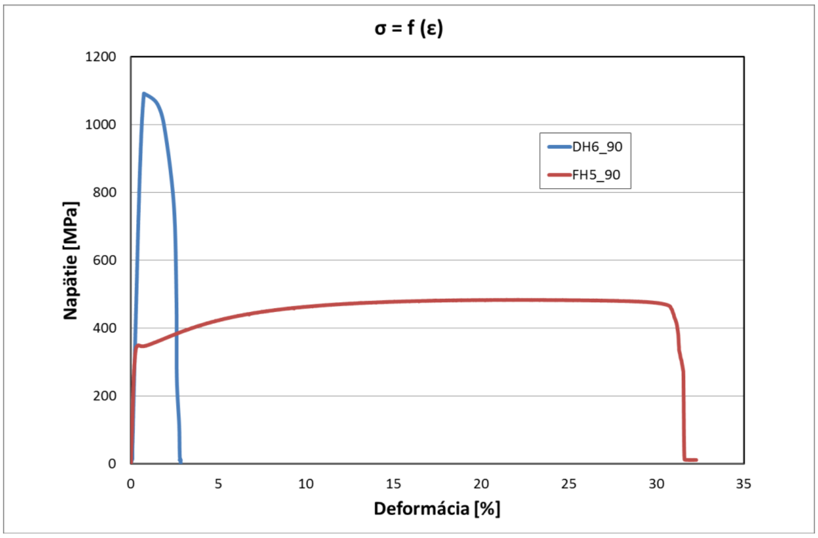

Fig. 5: Diagram of the tensile test of the examined materials

The quality of the cutting surface has been measured by the ratio of the area of the plastic cut to the total thickness of the material. From the results, it can be stated that in the case of the smallest cutting gap, the area of the plastic cut reached almost 100% of the material thickness. With the growing cutting gap, the ratio of the area of the plastic cut to the total thickness of the material was slowly decreasing. Shear stress in the area of the plastic cut caused the extraction of ferritic grains. [11-13] These facts can be seen in the Figure 6-10.


Fig. 6: Material after the rolling

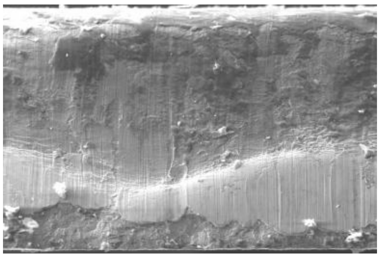
Fig. 7: Cutting gap 0.2mm

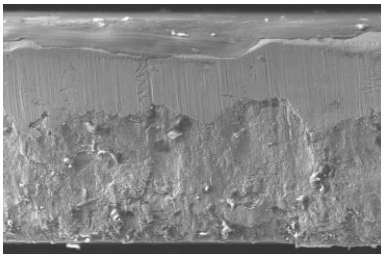
Fig. 8: Cutting gap 0.1 mm

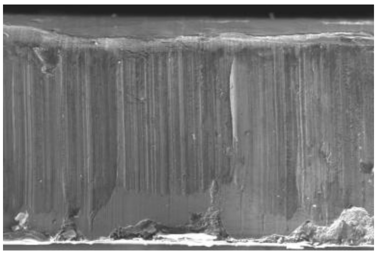
Fig. 9: Cutting gap 0.05mm

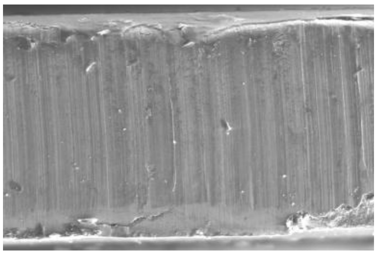
Fig. 10: Cutting gap 0.02mm

VI. CONCLUSION

In this work, basic classification of electrical steel is described. In general, there are three main types of classification of electrical steels. First category defines non-oriented fully processed electrical steel. In the second category, non-oriented semi-processed electrical steel, which is finally processed by the end user. The third category, grain-oriented electrical steel is easier to produce than non-oriented electrical steel, but it has a worse electromagnetic properties and are mostly used for non-rotating applications.

Results show us that with the smallest cutting gap – 0.02 mm, cutting surface is smooth and perpendicular. There are visible extracted grains in the lower part of the cutting surface (Figure 8). Quality of cutting surface during the cutting with the cutting gap of 0.2 mm is not appropriate and it cannot be used during cutting.
From the results, we can understand that it is necessary to observe and control the size of cutting gap and the quality of the cutting edges of a tool during the whole durability of the cutting tool.

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