Tailored electrical steel through silicon diffusion in deep drawing steel

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This study presents a novel diffusion approach for producing high-performance electrical steel from deep drawing steel that enables aligning material characteristics with specific product requirements. In particular, the rotor and stator of electric machines have different requirements concerning electromagnetic and mechanical properties. As a result, it is crucial to work towards locally tailored electromagnetic and mechanical properties of the soft magnetic components. We present a thorough study of silicon diffusion in deep drawing steel, demonstrating potential for creating electrical steels with optimised spatial characteristics, advancing the development of efficient electric motors. Our key results include the continuous scaling of losses with silicon content, as well as a texture anomaly that shows promising electromagnetic characteristics.

Keywords: high silicon steel, diffusion, magnetic texture, electric machines

1. Introduction

Soft magnetic materials play a crucial role in modern energy systems, serving as key components in transformers, electric motors, and generators. Non-oriented (NO) electrical steel sheets are particularly important for applications with rotating electromagnetic fields, such as electric motors, due to their isotropic magnetic anisotropy [1]. Besides electric steels produced by solely hot/cold rolling, high-cost diffusion steels manufactured by further siliconizing e-steel sheets are accessible by CVD processing and show excellent electromagnetic properties at higher Si-content [2,3]. Our research focuses on a diffusion method that overcomes traditional limitations in terms of locally tailored magnetic and mechanical properties by combining these advantages with the excellent properties of high silicon steels [4]. Thereby, the different requirements for rotor and stator [5] can be experimentally addressed.

2. Results and discussion

Precise control over silicon diffusion enables continuous tuning of silicon content, achieving levels up to 5.3 wt%, which surpasses the restrictions imposed by traditional rolling techniques [2]. Even though the texture of deep drawing steels is invers to that preferred for non-oriented electrical steels with suppression of the (110) reflection [6], we show that the classical recrystallisation texture of deep drawing steel can be strongly influenced by the diffusion process as can be seen in Figure 1.

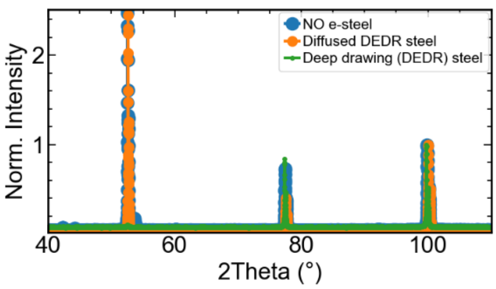

Figure 1: XRD pattern of NO electric steel (using Co Kα), deep drawing steel and diffused deep drawing steel (Fe(211) normed to 1).

Besides this, the continuous tuning of Si content is depicted in Figure 2 and enables us to analyse the experimental losses in dependence of Si (shown up to 5.3 wt% Si in Figure 2a), which allows us to extract parametric scaling behaviours (Figure 2b).

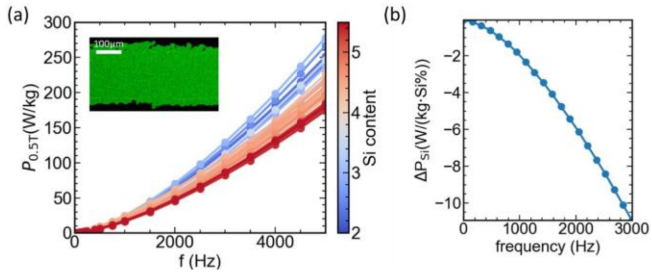

Figure 2: Iron losses as a function of silicon content: a) at B=0.5T, and b) at B=0.5T with extracted loss reduction per silicon. The inset in a) shows an example EDX mapping of the homogeneous distributed Si content of about 4.5 wt% Si.

Our study provides a comprehensive analysis of Si diffusion in deep drawing steel, highlighting its potential for synthesis of electrical steels with customised properties and overcoming limitations of standard rolling production processes.

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