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Characterization and simulation of the effect of punching on the high cycle fatigue strength of thin electric steel sheets

Helmi Dehmani [a,b,c*], Charles Brugger [b], Thierry Palin-Luc [b], Charles Mareau [c], Samuel Koechlin [a]

[a] *Emerson-Leroy Somer, Boulevard Marcellin Leroy, Angoulême, France*
[b] *Arts et Métiers ParisTech, I2M, CNRS, Esplanade des Arts et Métiers, Talence, France*
[c] *Arts et Métiers ParisTech, LAMPA, Boulevard du Ronceray, Angers, France*

Abstract

Rotors of electric machines are built from stacks of thin steel sheets. The fabrication process of these components usually involves punching operations that generate defects on the steel sheet edges. In this study, high cycle fatigue tests are performed on punched and polished edges specimens to investigate the effect of the punching process on the fatigue behaviour of these thin sheets. Results show a significant decrease of the fatigue strength for punched specimens. SEM observations of fracture surfaces reveal that crack initiation always occurs on a punching defect. Residual stresses on punched edges are analysed using X-Ray diffraction techniques. High tensile residual stresses along the loading direction are found. Some specimens edges were scanned using 3D topography prior to the fatigue tests. This allows for identifying the real geometry of the most critical defect. Murakami criterion was then evaluated in order to take into account the effect of defects. The best trend of the experimental results is given when residual stresses are taken into account. Local elastic stresses for 3 defects geometries have been calculated using FEA. Crossland fatigue criterion has been evaluated to try accounting for the local stress state around defects. Results show that the assessed fatigue strength is overestimated using this criterion.

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Keywords: Thin sheet, electrical steel, punching, defects, crack initiation, high cycle fatigue

* Corresponding author. Tel.: +33-556845333; fax: +33556845366.
E-mail address: helmi.dehmani@ensam.eu

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1. Introduction

Electrical steels are increasingly used for building high-speed motors, hybrid and electric traction machines. Because of their better magnetic properties, new generations of Fe-Si thin sheets are used in rotors to improve energy efficiency. The reduction of the iron losses is mainly achieved by decreasing the thickness below 0.5 mm, increasing the grain size, and adjusting the chemical composition (mainly the silicon content). Because it offers an important production rate, punching process is used to obtain electric motor components. However, it generates a specific morphology on the cut edge of components. Four different zones are usually observed: roll-over, shear zone, fracture zone, and burr [1, 2]. Defects with different sizes are observed on the edge. In addition to the geometrical defects, this process also generates hardening and residual stresses locally on the edge [3, 4, 5]. In operation, rotor components are subjected to a cyclic loading. The load cycle is defined as the start and stop of the electric machine. Designers should consider the effect of the punching process on the high cycle fatigue behaviour of these thin sheets to avoid in service failure of components [6]. The main objective of this work is to study the effect of punching process on the high cycle fatigue resistance to crack initiation for thin sheets. The geometrical defects, hardening and residual stresses induced on the edge by this process are investigated.

2. Material and testing conditions

The studied material is a non-oriented fully-processed sheet of iron silicon alloy delivered as rolled sheets with 350 µm nominal thickness. Its chemical composition is given in Table 1.

Table 1 : Chemical composition of the studied Fe-Si alloy

Chemical composition	Si	Mn	Al	Fe
Mass (%)	2-3.5	0.2-0.6	0.4-1.2	95-98

Metallographic observations in Figure 1-a reveal an equiaxed microstructure with a mean grain size of about 100 µm. EBSD analyses show a slight rolling texture induced by the rolling process though the macroscopic mechanical properties are quasi-isotropic. The material has a yield strength σ_y of about 400 MPa and a maximum tensile strength, Rm, of about 500 MPa. The Young's modulus is about 180 GPa and the Poisson's ratio ν is 0.3.

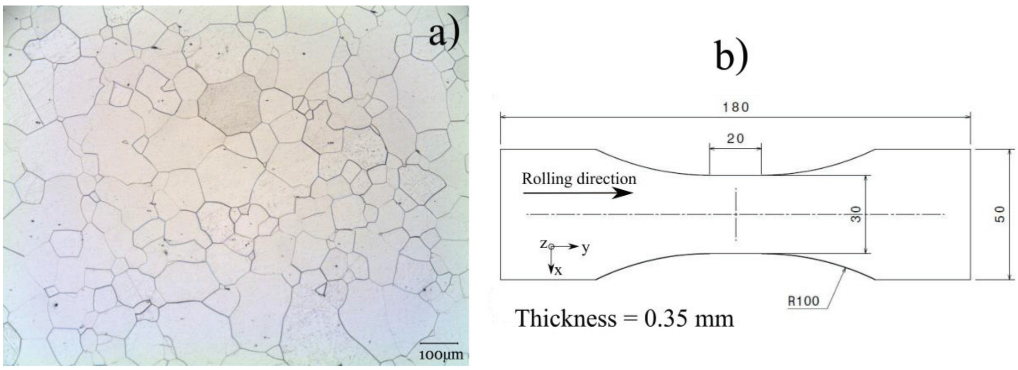

Figure 1 : (a) Microstructure of the studied Fe Si rolled sheets after Nital etching (b) Geometry of the specimens used for fatigue tests

Smooth specimens have been used for the fatigue tests. They were punched out from sheets with the same punching conditions than those used for producing real components, their longitudinal axis being parallel to the rolling direction. The specimen geometry is represented in Figure 1-b.

To evaluate the impact of punching on fatigue properties, some fatigue tests were also performed on specimens with polished edges. Polishing was expected to remove geometrical defects, to reduce the plastically strained region and to attenuate residual stresses due to punching. Polishing operations were carried out using P1200 then P4000 silicon