MATEC Web of Conferences **12**, 04019 (2014)
DOI: 10.1051/matecconf/20141204019

Fatique behaviour of electrical steel

B. Bode, F. Zeismann and A. Brückner-Foit[a]

University of Kassel, Institute for Materials Engineering, 34125 Kassel, Germany

Abstract. Electrical steel comes into focus with the development of electrically powered cars. In contrast to electrical motors used stationarily (e.g. conveyer belt drives in industrial applications), electrical steel in a car engine is subjected to cyclic loading due to vibrations caused by the imbalance of the rotor and start and stop driving events. For a safe and reliable design of an electrical motor the fatigue behaviour of electrical steel needs to be analysed. To minimize eddy current losses, a rotor consists of several hundred electrical steel sheets with a typical thickness of less than 1 mm. Due to optimal electrical and magnetic properties a very coarse microstructure of electrical steel is required. Only one to three grains are distributed along sheet thickness. Regarding the grain size and sheet thickness the material behaviour is governed by the reaction of single grains and grain-grain-interaction to external cyclic loading. Fatigue experiments with a load ratio of $R = 0.005$ and $R = 0.1$ were carried out. They give a very flat S-N-curve where the fatigue limit is close to the yield strength of this electrical steel. Crack initiation is observed at surface roughness and areas of stress concentration resulting from manufacturing processes.

1. Introduction

Electrical steel is used in electrical motors in a wide field of industrial applications. In these cases electrical motors operate in mode of constant rotation and are not subjected to cyclic loading. Electrical steel is also used to build electrical motors for fully electrical or hybrid cars. These mainly operate in areas with high traffic density. Due to start and stop driving events and acceleration processes cyclic loading plays a dominant role. Fatigue behaviour and fatigue mechanisms of electrical steel need to be analysed for the development of a safe and reliable motor design.

Electrical steel is magnetically soft material. It is a Fe-Si-alloy with a Si-content of 2.5%–3.5%. A high Si-content improves electrical and magnetic properties and increases yield strength. On the other hand a high Si-content causes reduction of ductility.

2. Experiments and results

The material in this paper is a fully processed non-orientated electrical steel sheet with 3.15% Si and a thickness of less than 1 mm. Fatigue tests were carried out for load ratios $R = 0.005$ and $R = 0.1$ for unnotched and notched specimens. Results of unnotched specimens are given in Fig. 1.

[a]Corresponding author: a.brueckner-foit@uni-kassel.de

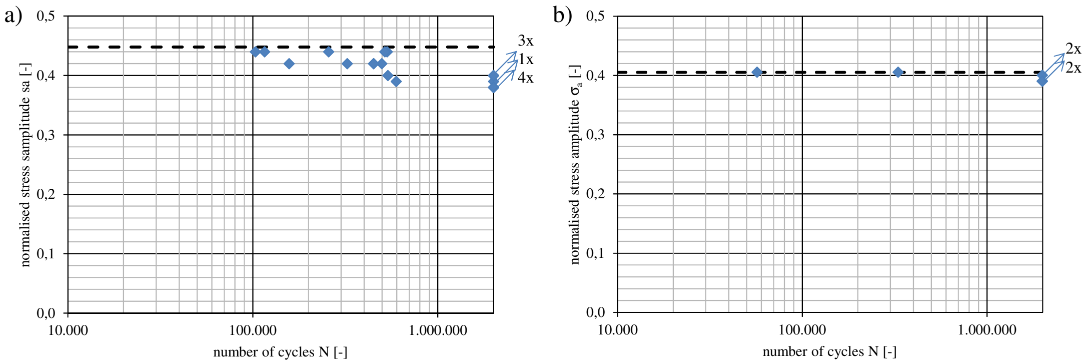

Figure 1. S-N-curve for fatigue test with a) R = 0.005 and b) R = 0.1 (normalised stress amplitude, dashed line indicates material yield strength).

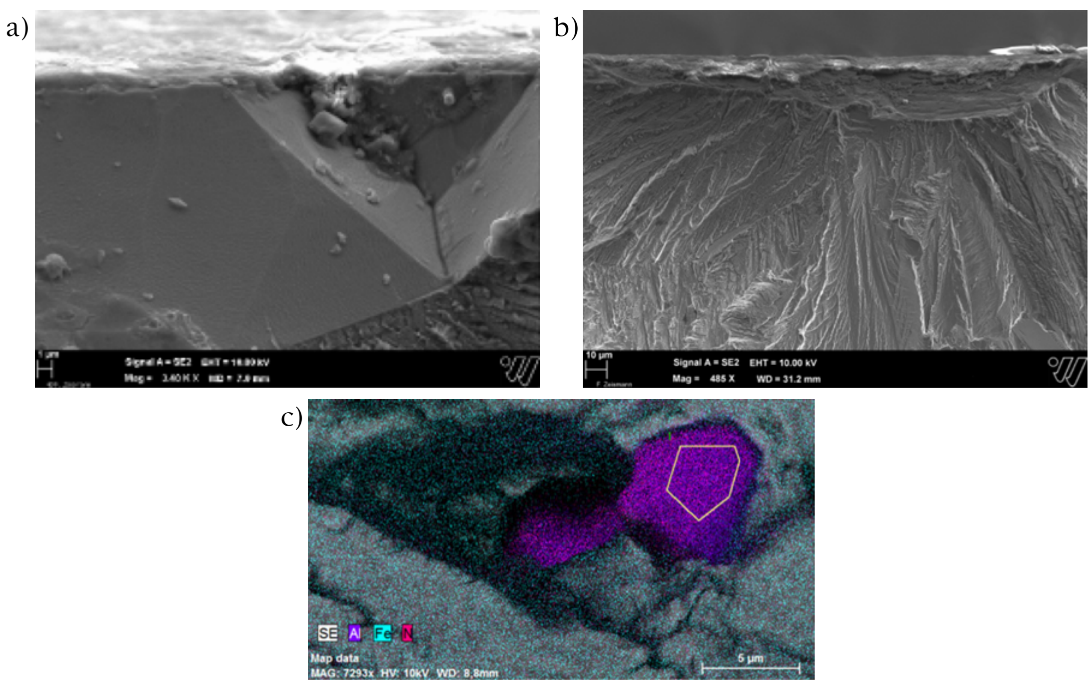

Figure 2. Crack initiation sites of unnotched specimens at a) triple point, b) surface defect, c) AlN particle.

Fatigue tests of electrical steel give a very flat S-N-curve. The critical stress amplitude for crack initiation was found to be 0.42 of yield strength for both R ratios in case of unnotched specimens. Crack origins are grain boundary triple points and surface defects resulting from rolling process as illustrated in Fig. 2. Initiated cracks continue growing transgranularily.

Notched specimens are tested to investigate crack initiation for component-like notch geometries. These are manufactured by a high-precision spark erosion machine. Due to large grain size of this material and notch geometry a cut grain boundary in combination with stress concentration of the notch acts as crack origin. This effect was observed at all notched specimens.

Another effect is observed at specimens manufactured by punching. Cracks initiate at transition zone from smooth cut proportion to fracture surface. In this area punching induced damage is detected as origin of transgranular fatigue cracks.

Additionally, AlN particles are to be found on the fracture surface but showing no effect on crack initiation, see Fig. 2c.