HIGH CYCLE FATIGUE OF AM PRODUCED HOT WORK TOOL STEEL

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Abstract
Additive manufacturing as a mean to produce near net shape components of metal alloys has evolved in many commercial applications during the last decade. Still, development of additive processes and alloy grades requires new research knowledge. In the present study focus is on advanced high strength martensitic steels and fatigue properties. They are used in demanding tooling and high performance applications where high strength and toughness, both static and dynamic, are required. Fatigue strength and failure defect distributions of one AISI H13 AM grade and one corresponding ingot cast and forged grade have been characterized and modelled.

1. Introduction
Fatigue strength in these steels is usually controlled by the steel cleaness, i.e. inclusions and other defects. Plentiful of research has been devoted to this and one main contribution has been made by Murakami and co-workers with a relation by fatigue strength and defect size [1]. One modification was made by Bathias and Paris [2], into a relation between the fatigue strength and the square root defect area size according to Eq. 1.

$$\sigma_N = \frac{\beta(HV+120)}{(\sqrt{area})^{1/6}}\left[\frac{1-R}{2}\right]^{\alpha} \quad ; \beta = 3.09 - 0.12\, ln(N_f) \qquad \alpha = 0.226 + HV * 10^{-4} \qquad \text{Eq. 1}$$

The metallurgy in AM is different to ingot cast or PM and forged steel processing, other kinds of defects may control fatigue strength. In the present work fatigue testing of an AM produced tool steel grade (AM-AISI H13 modified) is compared to a conventional ingot cast and forged AISI H13 grade. The aim is to determine the AM grade fatigue properties and investigate if a similar relation as Eq.1 may be relevant.

2. Results
Fatigue tests were performed, with servohydraulic and ultrasound equipments, combined with microstructural characterization to determine fatigue properties in a large life range, crack initiation mechanisms and defect types and distributions. Properties of the reference AISI H13 are displayed in Figure 1 with S-N curve, initiation defect distribution and fatigue strength model results. Oxide inclusions play a major part in controlling the fatigue strength, and in specimens from the same steel batch smaller inclusions initiates failure at shorter life and larger at longer life. Properties of the AM-AISI H13 mod are displayed in Figure 2 with an initial staircase test, microstructure and a fatigue fracture surface. A fatigue strength at the same level as the conventional AISI H13, a reasonably fine grained martensite with some smaller defects, and fatigue initiation by larger lack-of fusion defects and smaller pores were observed.

3. Conclusions
In the current investigation an AM H13 mod tool steel was examined. It was found that, different to the compared ingot cast and forged steel, initiation was controlled by lack-of-fusion defects and pores. Failure defect distributions were established and fatigue strength models were evaluated.

References
1. Y. Murakami, Metal Fatigue: Effects of small defects and non-metallic inclusions, Amsterdam, Elsevier, 2002.
2. C. Bathias, P.C. Paris, Gigacycle fatigue in mechanical practice, Marcel Dekker, NY 10016, USA, 2005.

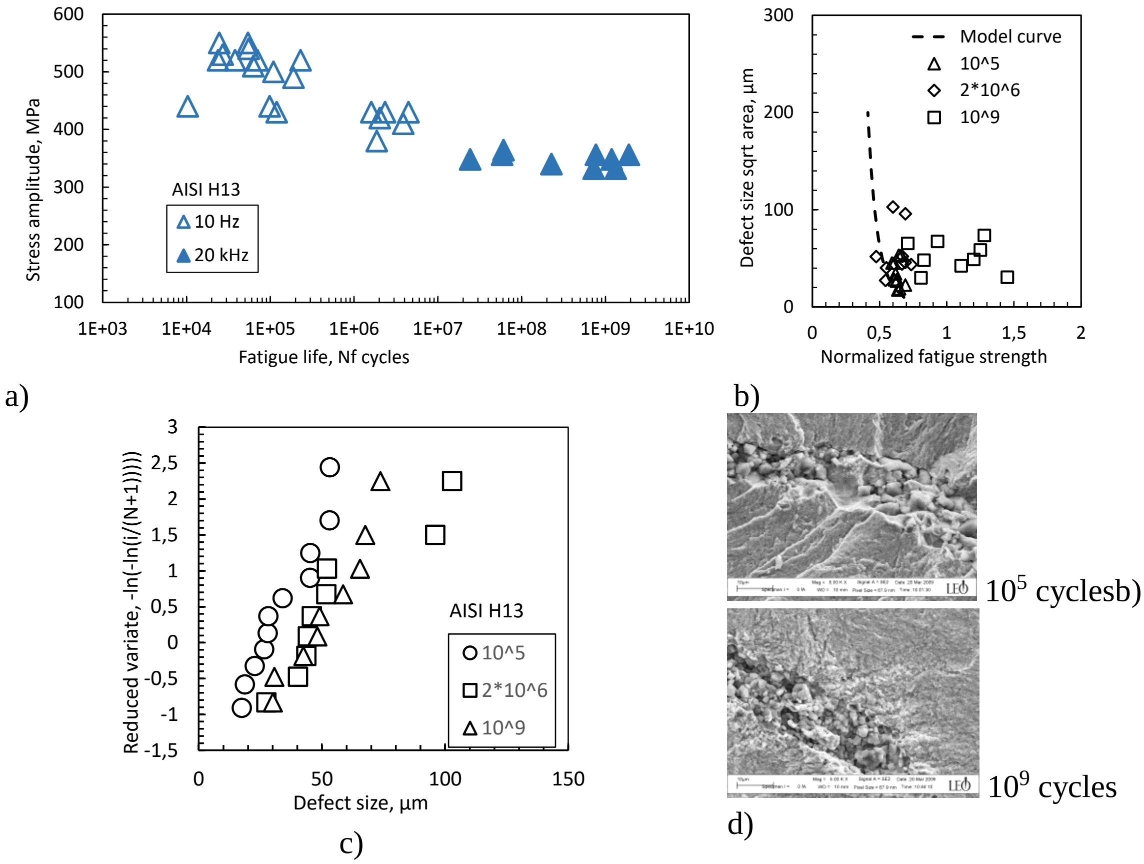

Fig.1 – a) S-N curve, b) fatigue strength model and c-d) failure inclusions of AISI H13 cast&forged tool steel grade at different fatigue life ranges.

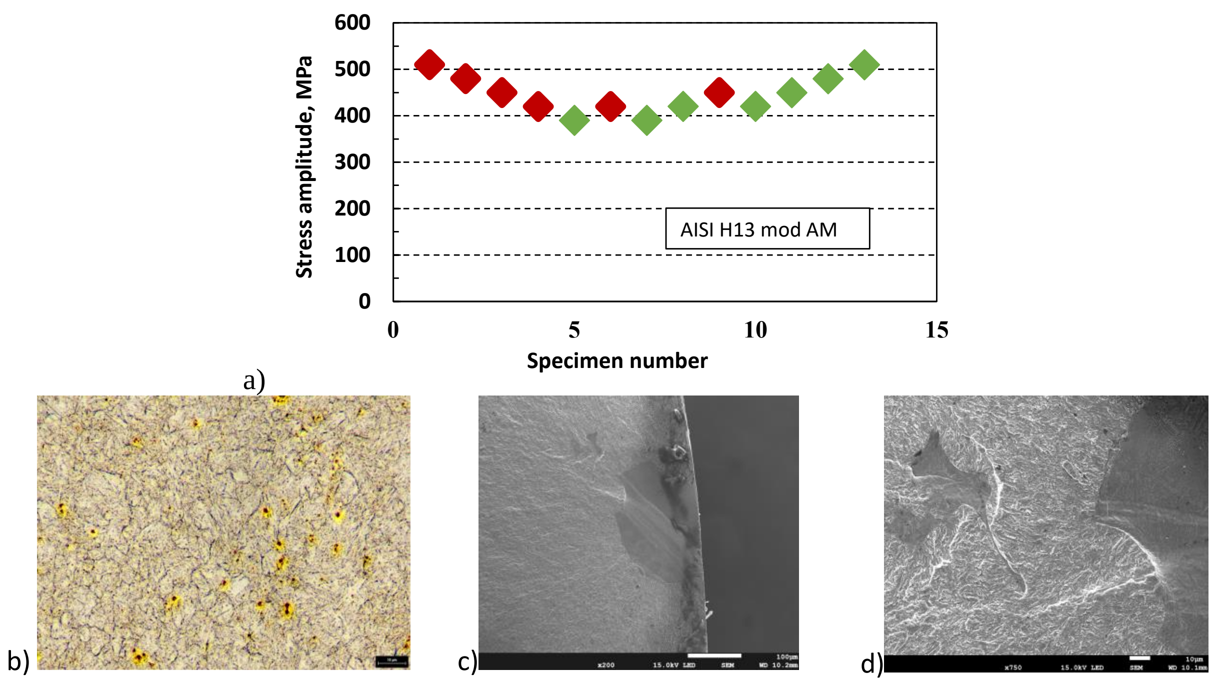

Fig.2 – a) Staircase test, 2.5 10^5 cycles runout, of AISI H13 mod AM produced tool steel grade, b) microstructure of H13 mod AM, and c-d) lack-of-fusion defect initiation.