Crack Initiation and Growth in Shot-Peened and Prestrained Peened High Strength Steel

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ABSTRACT

A low alloy high strength CrMnV-steel of 0.5 % carbon content is quenched and tempered to a tensile strength between 1200 and 1850 MPa.

Flat samples of 100 x 15 x 400 mm are shot-peened without or with a prestrain of 0.75 the yield strength. These two surface conditions are compared in four-point-bending tests to un-peened specimen. The applied load was chosen to give a fatigue life between $10^4$ and $10^6$ cycles. Special consideration is given to the crack initiation which is registered by on-line ultrasonic surface waves. By means of five detectors it is possible to locate individual cracks and follow their extension separately.

These investigations are accompanied by microstructural and fractographic analysis.

KEYWORDS

High Strength Steel, Four-Point-Bending, Shot-PEening, Shot-PEening under Presstress, On-Line Crack Detection

INTRODUCTION

The structure and mechanical properties of low alloy steels with a carbon content of about 0.5 %, quenched and tempered to a tensile strength between 1200 and 1850 MPa were thoroughly investigated in a recent study (Sickmann, 1983). In polished samples without any surface treatment, fatigue starts with glide traces on the surface in the vicinity of nonmetallic inclusions (Fig. 1a). In the bulk of the steel the dislocation pattern is gradually changed and a cell structure formed (Fig. 1b).
Fig. 1: Glide traces (a) and cell structure (b) in polished samples.

The lower the tensile strength the earlier cracks are initiated in the glide traces. Crack extension though is accelerated with growing tensile strength.

The present investigation deals with the influence of surface treatment on the fatigue behaviour of as-rolled, quenched and tempered high strength steels.

EXPERIMENTAL PROCEDURE

The detection of small cracks in as-rolled unmachined parts of a certain surface roughness is not as easy as on polished samples. In order to measure the crack size on-line a number of possible procedures were tested:

- Sprayed films, which change their colour as a crack is started, alter - as a surrounding medium - the fatigue life.

- The change of electric resistance under high direct current of short intervals is not sensitive enough to locate small cracks.

- For the same reason the use of the electric-surface-potential set-up was dropped.

- Ultrasonic surface waves are able to locate small cracks and follow their extension. Therefore this kind of testing was chosen.

Samples of 400 x 100 x 15 mm were subjected to cyclic four-point-bending as is shown in Fig. 2.
Five ultrasonic probes are attached over the width of the sample. By means of a PMMA wedge with an angle of 59°, surface waves are generated. Thereby individual cracks are registered within a surface area of 100 x 100 mm. The crack depth is in accordance with the amplitude of the echo on the oscillograph. The closed loop hydraulic testing machine is controlled by a computer which also processes signals of the ultrasonic detectors. The frequency of the cyclic loading ranges from five to ten Hz.

As mentioned before a low alloy CrMnV-steel with a carbon content of 0.5 % was quenched and tempered to UTS levels of 1200, 1500 and 1850 MPa.

Three different unmachined surface conditions were tested:

a) Prestrained at a level of 1.2 times the yield strength.

b) Shot-peened (Almen intensity: 0.59 A2) and prestrained as above.

c) Shot-peened under a prestrain of 0.75 times the yield strength (Almen intensity: 0.52 A2) and prestrained as above.

The resolution of the ultrasonic testing device depends on the roughness and is found in the vicinity of about 0.2 mm crack depth.

The surface roughness and micro hardness are given in Fig. 3a und 3b.
**Fig. 3:** Surface roughness (a) and micro hardness (b) of a CrMnV-steel

**CRACK INITIATION**

In spite of peening all cracks started at the surface and not within the area of highest residual stresses. Crack initiation is delayed by shot-peening and prestrain peening as is shown in Fig. 4.

**Fig. 4:** Cycles to crack initiation and to fracture in respect to surface condition and max. bending stress.
The ratio of cycles to crack initiation is $N_A$ and cycles to fracture $N_B$ is reduced as the surface stresses by peening are raised (Fig. 5).

![Graph showing cycles to crack initiation and fracture](image)

**Fig. 5:** Cycles to fracture $N_B$ vs. cycles to crack initiation $N_A$ as a function of surface condition and UTS.

**CRACK GROWTH**

Cracks first detected at $N_A$ usually linger for a while or grow slowly until $N_W$ - the number of cycles for a rapid, stable crack growth - is reached (Fig. 6).

![Graph showing fatigue area and stress](image)

**Fig. 6:** Cycles to fracture vs. crack amplitude and relative fatigue area in respect to surface condition, UTS, and maximum bending stress.
The interval from \( N_A \) to \( N_B \) declines as the tensile strength is increased. By shot-peening and prestrained shot-peening the period of crack growth \( (N_B - N_A) \) is prolonged more than the period of crack initiation \( N_A \) (Fig. 4 and 5). The fatigue fracture area at the beginning of instabil crack extension is the higher the lower the UTS and the bending stress.

**SUMMARY**

In order to separate crack initiation and crack growth under cyclic loading in unmachined peened and prestrained peened surfaces of a quenched and tempered high strength steel, ultrasonic surface waves were used for on-line crack detection in a four-point-bending set-up.

By shot-peening stable crack growth is slowed down in the beginning and accelerates as the peened layer is surmounted. At the high strength level of 1850 MPa no delay is observed.

**REFERENCES**