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Evaluation of fatigue of micro-alloyed 23MnB4 steel

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Properties

ABSTRACT

Purpose: Purpose of this article is to extend a complex evaluation of fatigue properties of micro-alloyed 23MnB4 steel in initial state and after heat treatment.
Design/methodology/approach: Testing of micro-alloyed 23MnB4 steel was based on fatigue test completed by metallographic and fracture analyses. The methods of the light microscopy and SEM were used.
Findings: Objective of this work consisted in determination of fatigue characteristics of micro-alloyed 23MnB4 steel, including fracture analyze. Results of fatigue testing at various stress levels for the samples in initial state and after the heat treatment have confirmed that obtained values of cycles to rupture were at least 585 000 cycles. Change of fatigue properties in dependence on heat treatment of the used steel.
Research limitations/implications: The experiment was limited by occurrence a void in cast alloys.
Practical implications: The results may be utilized for application of the investigated material in process of manufacturing.
Originality/value: These results contribute to explanation of fracture mechanism of micro-alloyed 23MnB4 steel.
Keywords: Mechanical properties; Micro-alloyed 23MnB4 steel; Fatigue test; Fracture characteristics

1. Introduction

Micro-alloying enables obtaining of the required plastic properties in materials with simultaneous preservation of strength properties. Micro-alloying is used in steels in the range from very low carbon contents up to eutectoid composition. Suitable required material properties are achieved in low-carbon steels containing 0.2-0.3% C and in alloyed steels with 1-1.5% Mn, which contributes also to grain refinement and decrease of transformation temperature, which has positive influence on solubility of micro-alloying elements. Most important micro-alloying elements are V,Ti, Nb and lately also B. The required properties are obtained by appropriate combination of all these elements together with suitable selection of technological parameters.

Influence of refinement of ferritic grain down from 10 to 5 μm in current micro-alloyed steels is manifested by increased yield strength by 70 MPa and by decrease of transition temperature by 40 °C [1, 2].

2. Used experimental methodology and material

Wire from steel 23MNB4, which belongs to low-carbon steels, is determined for pressing and stamping. Steel wire is suitable for fastening purposes (bolts, nuts, rivets). Surface quality of wire is highly non-uniform. Wires determined for cold drawing are rolled from crude (non-cleaned) bars. That's why quality of wire surface is the critical parameter of these grades. Surface defects are admissible max. into depth of 0.25 mm.

Table 1.
Chemical composition of 23MNB4 steel

Contents of elements	C	S	P	B	Ti	Al	V
[%]	0.24	0.011	0.01	0.003	0.02	0.029	0.003

Mo	N	Mn	Si	Cu	Ni	Cr
0.009	0.008	0.87	0.06	0.04	0.03	0.3

2.1. Heat treatment

Due to possible use of material in condition after heat treatment, part of samples was subjected to heat treatment. Selected types of heat treatment corresponded to normally used types for these steel grades. Part of samples was studied in state after quenching and the other part in state after quenching and tempering. Reheating of samples for quenching and tempering was done in electric laboratory furnace LH09/13 MT600 with automatic temperature regulation under protective argon.

1) quenching parameters: reheating to temperature of 910°C, dwell 35 min followed by cooling in oil heated to temperature of 80°C [10, 12].
2) tempering parameters: reheating to temperature of 425°C and 480°C, dwell 50 min followed by cooling on air [11, 13].

2.2. Execution of tests

Evaluation of fatigue properties of investigated micro-alloyed steels was made with use of samples in initial state and after selected heat treatment.

Fatigue tests were realised by available method of fatigue testing at rotation on quadruple fatigue testing machine UBM 4.

Fatigue tests were made in conformity with requirements of the relevant standards related to fatigue Initial material for evaluation of fatigue properties of investigated micro-alloyed steels was supplied in the form of formed bars with diameter of 11.8 mm. The samples 220 mm long needed for fatigue testing at rotation on quadruple fatigue testing machine UBM 4 were cut from these bars.

Due to the used testing machine, expected use of investigated steel, dimensions of test bars and possibilities at their modification for fixation (diameter of final semi-product was by 0.2 mm smaller than required diameter – i.e. 12 mm – for fixation into sample holder in the fatigue testing machine UBN 4; when a foil was used as a kind of insert, at the point of fixation in the holder there occurred preferential rupture, which influenced results of testing and moreover damaged the holder), that's why there was use a bar with a notch – peripheral groove (see ČSN 42 0363). Notch radius was 1mm. This modification has eliminated the drawbacks mentioned above.

3. Results of testing

3.1. Metallographic evaluation of structure

Selected samples from bars in initial state and after the above mentioned heat treatment were subjected to metallographic evaluation of structure in cross-section. The samples were after usual metallographic preparation if surface etched in nital and structure was evaluated with use of the microscope Neophot 2.

Structure was in initial state formed mostly by fine ferrite with pearlitic net [3, 4, 9], structure of samples after quenching is formed by martensite, or partly by bainite, and samples after tempering are formed by tempered martensite.

Samples after heat treatment showed mild decarburisation right next to the surface of samples.

3.2. Determination of basic mechanical properties

Basic mechanical properties if used steel in initial state and after the heat treatment mentioned above were determined by tensile test on bars with smooth head in accordance with the standard EN. The samples were subjected also to hardness tests according to Vickers HV30 with use of hardness tester HPO 250. The resulting value was determined from 10 values – see the table 2.

Table 2.
Results of mechanical properties

Material	Mechanical properties					
	R_m [MPa]	$R_{p\,0,2}$ [MPa]	A_{30} [%]	Z [%]	HV30	σ_{0C} [MPa]
V- initial state	460	432,0	30,7	74,3	145	160
K- quenched state	1100	1050,6	13,3	55,6	406	115
P- tempered state 480°C	980	924,0	13,3	66,4	307	105

3.3. Evaluation of fatigue tests

Results of fatigue tests at various levels of stress for the samples in initial state and after heat treatment described above are shown in the diagram in Fig. 1. Fatigue properties after annealing were investigated on bars, which were tempered after quenching to the temperature of 480°C.

This diagram shows noticeable change of fatigue properties in dependence on heat treatment of the used steel [5, 6, 7, 8]. Fatigue properties after quenching and tempering were lower than in initial state. After tempering there occurs their improvement in comparison with as quenched state, although fatigue limit was increased only slightly. Values of fatigue limit σ_{0C} are also given in the table 2. Results of fatigue tests had a considerable scatter, particularly in samples in initial state. Afterwards fracture surfaces were investigated on all bars of the used steel. The paper presents some selected examples.

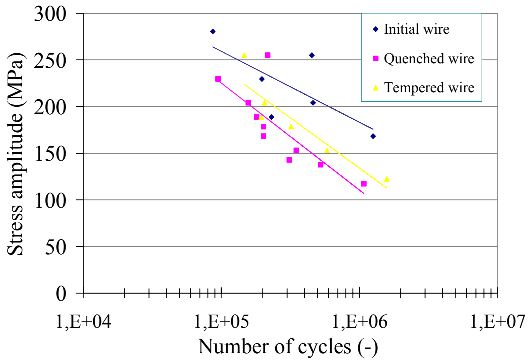

Fig. 1. Results of fatigue tests

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3.4. Evaluation of fracture surfaces

Manifestations of fatigue damage were investigated on fracture surfaces of the above mentioned samples. The samples were marked according to the applied heat treatment by numeric symbol (specification of load in kp according to the scale on the fatigue machine). On all the fracture surfaces there was found presence of radial surface cracks, very fine in case of low stress, medium and very thick in case of stress nearing the fatigue limit. The largest range was in samples K. Macroscopic photos of fracture surfaces (Macro FS) of selected samples and details of fracture surface obtained by SEM on the microscope Jeol 50A are shown in Figures 2-18.

Samples V

In sub-surface areas of fracture there appeared in the samples V indications of grooving near present radial cracks. Size of cracks increased from fine cracks in samples V 32 (see Fig. 2 and 3), V 35, V 40 up to very thick cracks in the sample V 50 (see Fig. 4). This zone was mostly followed by the zone of striae, manifested distinctively e.g. in places V 40 D and V 50 D (see Fig. 5). In the next zone of fatigue crack propagation there were present in large quantities short cracks, often inter-connected, e.g. in places V 32 C, or V 50 D and V 50 E. In vicinity of cracks on the fracture surface grooving was also present.

This zone was directly followed by the zone of static final rupture of tested sample, where the fracture surface was created by mechanism of trans-crystalline permanent damage (TPD), or trans-crystalline splitting (TS). In the samples V 32 and V 50 there occurred final rupture by mechanism TPD (see Fig. 6), in the sample V 40 there was present also large zone of TS (see Fig. 7).

Fig. 2. Macro FS, sample V32

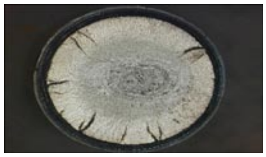

Fig. 4. Macro FS, sample V50

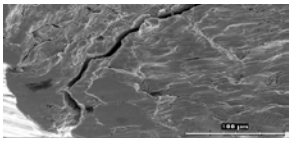

Fig. 3. Detail of fracture surface, sample V32

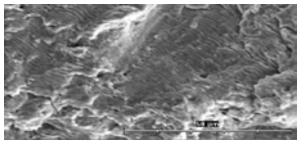

Fig. 5. Detail of fracture surface, sample V50

Samples K – state as quenched

In quenched samples the range of occurrence of radial surface cracks was the greatest. Zones of grooving were more distinct – K 30, K 37 (see Fig. 8, 9) and they occurred at lower stress than in the samples V. The related following zone of occurrence of short cracks – e.g. K 30, K 37 (see Fig. 10a, b) was directly related with the zone of final rupture, which was created mostly by the mechanism TPD – K 23 (see Fig. 11). In the samples K 30 C and K 37 C – there was influence not only of mechanism TPD, but partly also mechanism TS – K 30 C, K 37 (see Fig. 12).

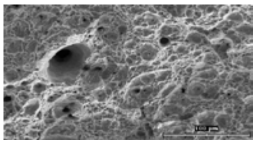

Fig. 6. Detail of of finish fracture, sample V32-TTP

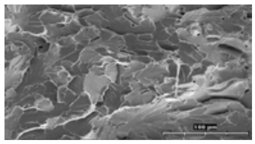

Fig. 7. Detail of finish fracture, sample V40-TS

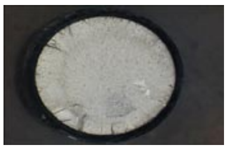

Fig. 8. Macro FS,,sample K30

Fig. 9. Macro FS,,sample K37

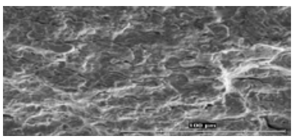

Fig. 10a. Detail of fracture surface, sample K30

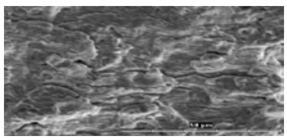

Fig. 10b. Detail of fracture surface, sample K30-zoom

Samples – P – state as quenched and tempered

Range of occurrence of radial cracks was lower than in the previous case (see Fig. 13), with the exception of the samples P 24 and P 40 (see Fig. 14). Mechanism of propagation of fatigue crack was similar as in case of quenched samples. In majority of samples it was possible to observe a distinct zone of grooving - P 22, P 37, P 40 (see Fig. 15, 16) and zone of occurrence of short cracks – P 22 (see Fig. 17) P 37, P 40, linked to the zone of static final rupture – P 22, P 37. Final rupture occurred mostly by mechanism of trans-crystalline plastic deformation with cavity morphology (see Fig. 18)

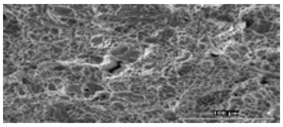

Fig. 11. Detail of finish fracture, sample K23

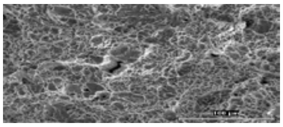

Fig. 12. Detail of finish fracture, sample K30

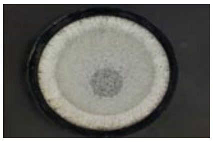

Fig. 13. Macro FS, sample P22

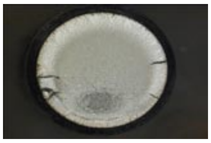

Fig. 14. Macro FS, sample P40

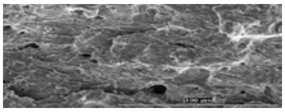

Fig. 15. Detail of fracture surface, sample P22

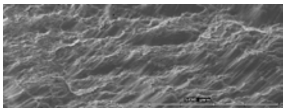

Fig. 16. Detail of fracture surface, sample P37

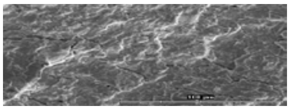

Fig. 17. Detail of fracture surface, sample P37

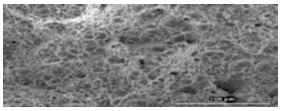

Fig. 18. Detail of finish fracture, sample P37

4. Conclusions

Results of fatigue testing at various stress levels for the samples in initial state and after the heat treatment mentioned above have confirmed that obtained values of cycles to rupture were at least 585 000 cycles. This value fulfils the requirements for production of high-strength fasteners.

It is obvious from described results that there has occurred change of fatigue properties in dependence on heat treatment of the used steel. Fatigue properties after quenching and tempering were lower than in initial state. After tempering, there occurs their improvement in comparison with quenched state, although fatigue limit was increased only slightly. Results of fatigue tests had a considerable scatter, particularly in the samples in initial state.

Manifestations of fatigue damage were investigated on fracture surfaces of the samples. On all fracture surface there was found occurrence of radial surface cracks, very fine in case of low stress, medium and very thick in case of stress nearing the fatigue limit.

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