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COMPARISON OF MICROFRACTOGRAPHIC BEHAVIOUR OF ACICULAR FERRITE AND BAINITE AND HYDROGEN CRACKING RESISTANCE

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ABSTRACT
The formation of acicular ferrite is associated with effective combination of strength and toughness. The behaviour of acicular ferrite is compared with upper bainite properties. Following differences between the microstructural parameters are detected. Acicular ferrite is nucleated on intragranular inclusions. The majority of plates show high-angle arrangement in comparison with upper bainite. Numerous low-angle interfaces are detected within crystallographic upper bainite packets. In acicular ferrite microstructure the unit crack path is defined as a distance between two neighbouring highly misorientated plates. The acicular ferrite microstructure contributes to the achievement of high steels resistance to hydrogen induced cracking due to special arrangement of its plates.
Keywords: acicular ferrite, upper bainite, cleavage fracture, unit crack path, hydrogen induced cracking.

1. INTRODUCTION

The grain refinement resulting in the strength and ductility increase of steel without the toughness deterioration is required. The acicular ferrite (AF) having the microstructure contributing to the fulfilment of this object can be held for a very promising material variant. The AF is formed in the same temperature range as upper bainite (B) by the same displacive mechanism. In case of B, ferrite plates are nucleated on the austenite (A) grain boundaries. The B-packets consisting of parallel plates having the same crystallographic orientation form a very important part of this microstructure. In contradistinction to the B, the AF plates are nucleated on the non-metallic particles being e.g. oxides which fulfil the special conditions concerning their nucleability potency. The single AF plates exhibit the different orientation usually. As it is known, the AF plates are interwoven and it results in the fine grained interlocked morphology of plates [1].

2. BACKGROUND

The beneficial characteristics found in the AF microstructure are related to the higher density of high-angle interfaces detected in this displacive product of the A-decomposition. This type of interface acts as an effective obstacle to cleavage cracks propagation forcing these cracks to change the microscopic plane of propagation in order to accommodate to new load crystallography [2]. Low-angle interfaces are weak obstacles. That is corresponding to the conclusion that the low-angle interfaces on the toughness improvement act very weakly. From point of view of fracture mechanism, it is useful to apply the evaluation concept of a crystallographic packets defined as the continuous set of ferrite plates having microorientation lower than a certain angle (<15°). This evaluation technique makes possible to determine the different size of microstructural unit as a parameter influencing the cleavage crack propagation in compared AF and B microstructures, what is connected with different frequency of high-angle interfaces in the AF (higher frequency) and upper B. Figures 1 and 2 show the characteristic microstructures of compared phases. Figures 3 and 4 demonstrate the fracture surfaces of the AF and B after impact testing at -25 °C. The different feature of presented fracture surfaces confirms the expected different response of the investigated microstructures in dependence on loading. The aim of presented solution is to show how the higher level of achieved physical metallurgy properties in case the AF in comparison with the B can contribute to beneficial influencing of the hydrogen resistance to steel embrittlement, e.g. by susceptibility evaluation to the HIC (hydrogen cracking).

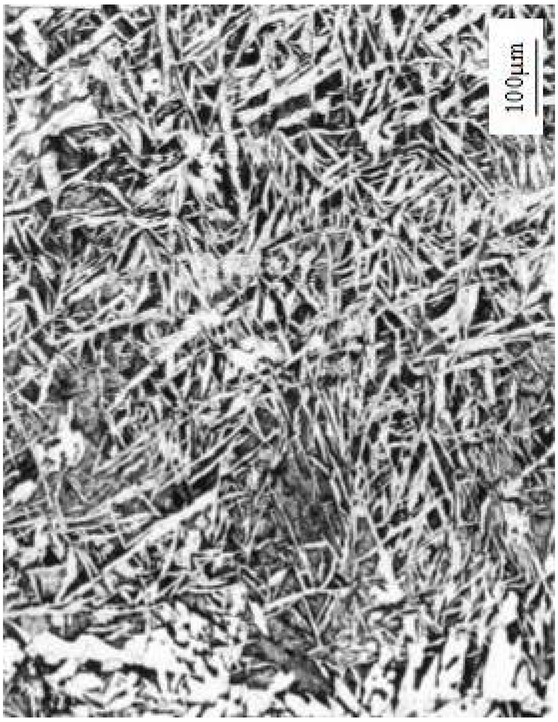

Figure 1. Microstructure of the AF (nital etching)

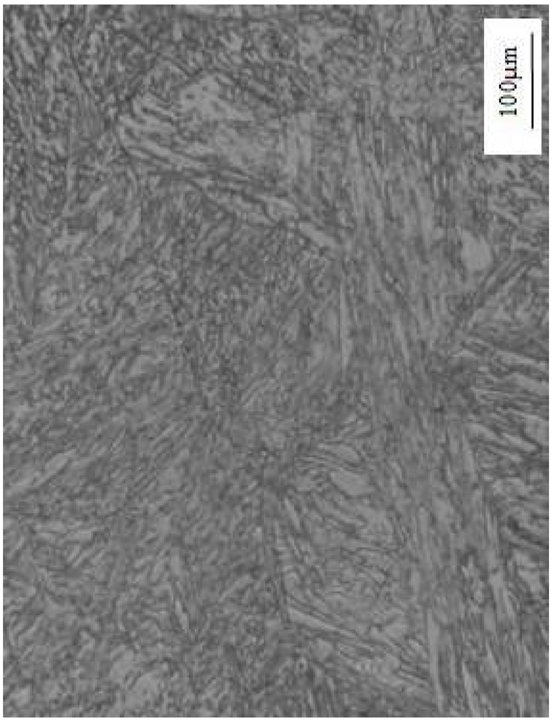

Figure 2. Microstructure of upper B (nital etching)

3. PHYSICAL METALLURGY DIFFERENCES OF THE AF AND UPPER B BEHAVIOUR

Great number of evaluated microstructures shows the AF plates are directly nucleated on inclusions. The detected interfaces having the high-angle misorientations are held for very important characteristics from point of view of achieved higher AF toughness values. The greater misorientations (>45°) are taken for very beneficial. On the contrary, the interfaces forming misorientations lower than 15° are considered as critical non-contributing to the improvement of determined mechanical properties. It was found nearly all interfaces among primary AF plates are of the high-angle type.

In addition to above given main arrangement of high-angle interfaces, the low angle ones are detected within the secondary sympathetic AF plates. In summary, it is possible to conclude, the performed EBSD analysis demonstrates that the AF microstructure is consisting of intricately misorientated plates having internal low-angle plates “filling” the space between neighbouring plates of high angle interfaces [3]. The detected density of highly crystallographically misorientated AF plates corresponds to profuse direct nucleation on potential nucleable particles. For these microstructures it is not possible to establish a relationship between morphology and crystallography. The morphological packets are related to the microstructural unit controlling the cleavage crack propagation in the way realized in upper B-microstructure [2, 3]. In case of upper B, each former A-grain contains several crystallographic packets. The most of packet interfaces are high-angle ones usually having the misorientation angle higher than the high-angle limit of the 45°. Analogously, as it is in the AF-microstructure numerous low-angle interfaces can be found inside the crystallographic packets [4].

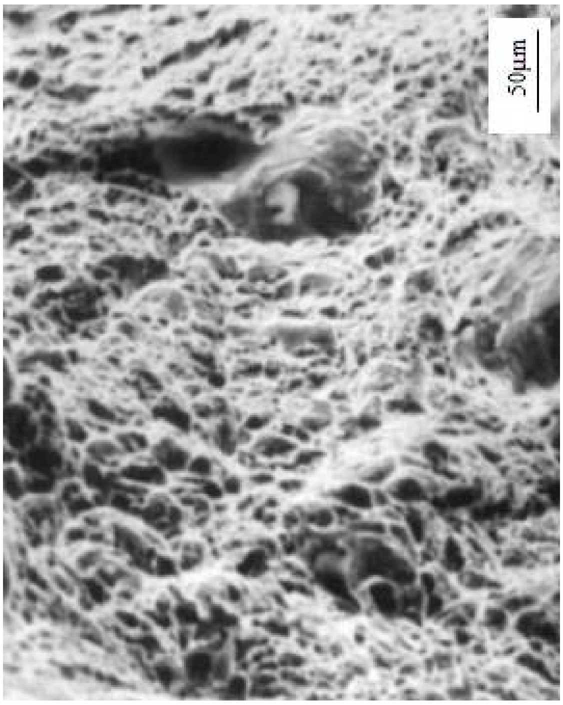

Figure 3 Fracture surface in the AF microstructure

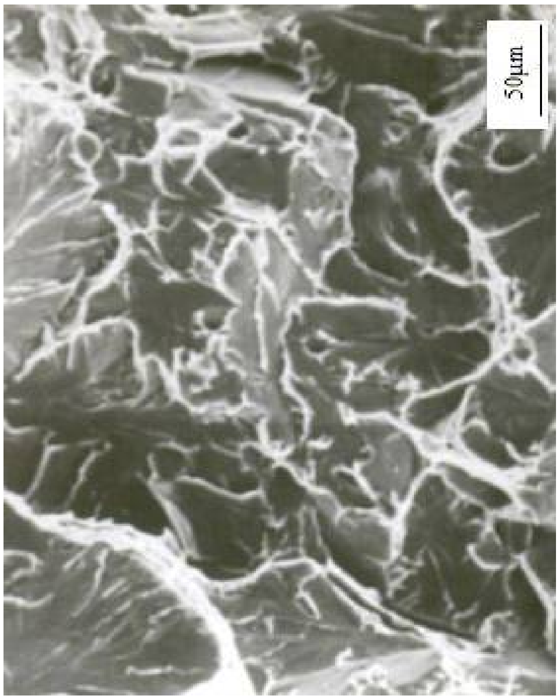

Figure 4 Fracture surface in upper B microstructure

4. FRACTURE CHARACTERISTICS AND SUPERPOSED HYDROGEN EFFECT

The determination of crystallographic grain size is very important because this parameter influences the strength and cleavage fracture resistance of ferritic steels. The results of the grain size evaluation can be used for local estimation of critical cleavage characteristics. The modificated model resulting from this evaluation acts as basic solution technique making possible to account for the AF microstructure higher cleavage fracture resistance in comparison with upper B.

Formerly Pickering [5] pointed out the cleavage unit crack path (UCP) corresponds to the distance between the neighbouring high-angle boundaries. The UCP is defined as the region in which the cleavage crack propagates in a nearly straight line. The high angle interfaces force crack deviations and evidently leave ligament fractured by ductile mechanism finally. The increased crack propagation energy found in the AF microstructure is a result of its fracture behaviour. The density of crystallographically misorientated plates is enhanced in the AF.

The realized analysis show, the AF microstructure is intrinsically tougher than the B one. The compared microstructure variants differentiate in the UCP value. The carbides absences on the AF interfaces play an important role and for reason the facile crack propagation across the grain boundaries (the interfaces) is not observed on the contrary to the B.

The beneficial behaviour of the AF microstructure connected with the increased deviation frequency of cleavage cracks (shorter UCP) as it results from greater density of the high-angle plates interfaces is also kept under the superposed hydrogen effect. The high angle orientation among the AF plates shows that the cleavage crack can be deflected at plate interfaces as it is schematically depicted in the figure 5.

These characteristics are very important from point of view of the increased resistance of this microstructure to the hydrogen embrittlement in comparison with the B microstructure [6]. For this reason, the AF formation by using the nucleability of this phase by some oxide nucleants is preferred, as it follows from the knowledge concerning their nucleability in relation to the presented oxide metallurgy concept [7]. This property of the AF microstructure demonstrates the importance of its deeper physical metallurgy study especially aiming at increase of a durability of exploited steel in the environment containing hydrogen.

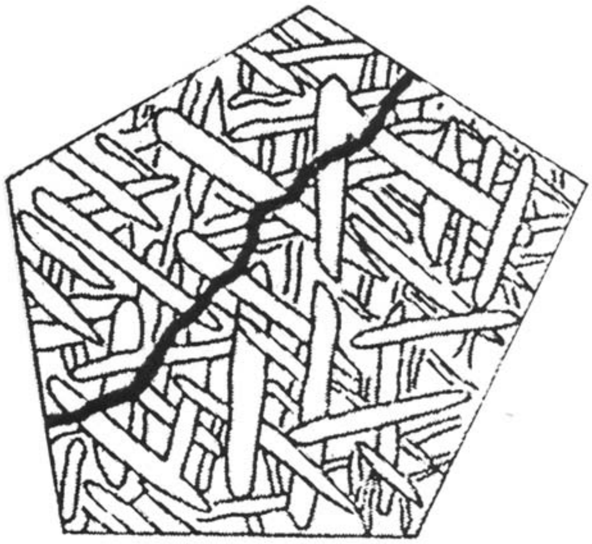

Figure 5 Cleavage crack deflection at boundaries of the AF plates

5. CONCLUSIONS

The AF microstructure represents an excellent combination of mechanical properties and toughness values especially. The microstructure refinement is a necessary constitution to achieve this goal.

The AF consists of highly misorientated fine plates nucleated intragranularly on non-metallic inclusions. In the B the high misorientation is only localized on packet boundary.

Numerous low-angle interfaces are detected within crystallographic B-plates. In compared microstructures the differences of cleavage unit crack path (UCP) are determined.

The UCP in the AF-microstructure is defined as a distance between two neighbouring highly misoriented plates.

The achieved knowledge about the behaviour of adjoining AF-plates and B-packets contribute to definition the microfractographic characteristics with more precision.

The increase of the hydrogen induced cracking (HIC) resistance of the AF-microstructure in comparison with the B is elucidated on the base of different UCP level of compared phases. The higher UCP level of the AF-microstructure can be held for every important parameter contributing to the achievement of its higher HIC resistance.

6. ACKNOWLEDGEMENT

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