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

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ABSTRACT
Acicular ferrite (AF) microstructure represents an excellent contribution of mechanical properties and the toughness level detected in low-alloy steel. Majority of neighbouring plates (laths) have mutual high-angle misoreintation in contradistinction to upper bainite (B) microstructure. High-angle interfaces are only formed between B-packets consisting of low-angle plates (laths) set. The cleavage unit crack path (UCP) has been found to be a distance between two grains of high-angle ferrite regions (corresponding to the two crystallographic B-packets boundaries). In the AF the UCP value is defined as a distance between two neighbouring highly misorientated plates. It shows the UCP values are shorter what results in higher deviation frequency and consequently in limited (retarded) cleavage crack propagation. The nucleation AF conditions in austenite matrix after application of an optimized thermomechanically controlled process consisting of the consecutive straining processes realized in recrystallization and in non recrystallization regions have been determined. The applied nucleation mechanism (base on the nucleation process realized in structural matrix) represents the second variant resulting in the AF formation. The beneficial resistance of the AF particles to hydrogen embrittlement can be held for a very important property of this microstructure what demonstrates the valuable contribution of this microstructure to its engineering application. The AF microstructure is associated with effective combination of strength and toughness. The behaviour of this microstructure is compared with upper bainite properties. Following differences between the microstructural parameters are detected. The AF is nucleated on intragranular inclusions. In majority, plates show high-angle arrangement in comparison with upper bainite. Numerous low-angle interfaces are detected within crystallographic upper bainite packets. In AF microstructure the unit crack path is defined as a distance between two neighbouring highly misorientated plates. The AF 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, high and low angle interface, hydrogen induced cracking.

1. INTRODUCTION

Difference in the AF and B formation consists in their different nucleation sites in steel matrix. The B ferrite grains are nucleated at the austenite (A) grain boundaries. On the contrary, the AF-plates (laths) are usually nucleated at non-metallic particles fulfilling the special nucleability parameters and having the preferential nucleation capacity in comparison with A-grain boundaries [1]. The AF dominated microstructure has been developed after application of the special thermo-mechanical control process (TMCP) composed of two controlled rolling stages, recently. The first one is connected with high temperature A recrystallisation region (at double reduction of 27% approximately), while the second stage is corresponding to non-recrystallisation region (at triple individual reduction of 31-45%). In intercritical temperature region of 800-500 °C a fast cooling process has followed. One hour free air cooling at 500 °C has preceded [2]. The aim of the presented work is to contribute to the physical metallurgy analysis of the AF-influence on the achieved level of the beneficial properties including the resistance to hydrogen degradation effect.

2. BACKGROUND

AF-particles exhibit different orientations in microstructure, what leads to fine grained interlocking morphology, even when the primary A-grain is coarser. That effect chaotically orientated AF-plates (laths) are able to eliminate. The observed positive mechanical properties, toughness level and beneficial hydrogen response of AF-microstructure are related to the high-angle interfaces acting as effective obstacles to cleavage crack propagation. In case of B the high-angle interface (higher than 15 °) only exists between two neighbouring packets consisting of parallelly orientated plates (laths) having the low–angle interface (lower than 15 °) for the most parts. Through the later mentioned interface cleavage crack can be propagated very easy, without important deviations. In this way the B-packet represents the UCP according Pickering [3] being much longer than distances among chaotically interwoven AF-plates (laths), representing the UCP for the AF, demonstrating the high-angle orientation predominantly as the EBSD technique proves [4]. Practically, each AF-plate (lath) represents direction deviation during cleavage crack propagation, being connected with a lost of kinetic energy for a continuing crack propagation what leads to its restriction and/or stopping. Above mentioned facts are connected with positive reached toughness and hydrogen response results.

a) b)

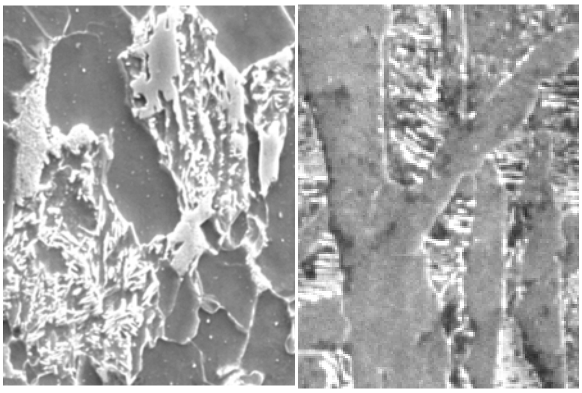

Figure 1a) Microstructure with B (x1900)
b) Microstructure with AF (x2900)

a) b)

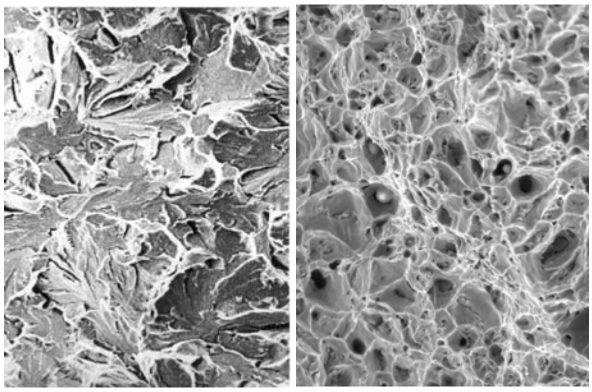

Figure 2a) Fracture surface with B (x500)
b) Fracture surface with AF (x500)

The B and AF microstructure differences show Fig.1a and 1b, while Fig. 2a and 2b represent the B and AF fracture surface features. The AF is related to the regular dimple morphology, in comparison with the B showing a cleavage cracking. Presented figures realized on the same material type (plate of 20 mm in thickness) with following chemical composition (wt %): 0.079C-1.66Mn-0.35Si-0.015P-0.004S-0.052V-0.008Ti-0.035Nb-0.036Al_c. The TCMP of AF-variant is described above and the variant with the B was rolled conventionally with the finishing rolling temperature about 690 °C with final air cooling. Table 1 and 2 summarize reached mechanical properties, toughness and hydrogen embrittlement parameters counted on the base of realized hydrogen induced cracking test (HIC) according NACE TM0284-2003. In steel as being known generally, hydrogen acting is very strong depending on its homogeneous distribution in matrix. The microstructure plays an important role in given case. The rolling conditions and the TMCP control obtained final microstructure type. Moreover, it is supposed the final materials will be used in as rolled state, without successive heat treatments representing higher production costs [5].

Table 1. Final parameters of studied steel variants

	R_e	R_m	A	Z	R_e/R_m	HV30	$KCV_{0°C}$
	[MPa]		[%]		-		$[Jcm^{-2}]$
B	528	644	23,9	56	0,82	212	98
AF	521	628	26,1	62	0,83	204	262

Table 2. HIC parameters for B and AF microstructure (3 x 3 samples) - CLR (in length), CTR (in thickness) and CSR (total parameter) according NACE TM0284-2003

[%]	B			AF		
CLR	17,5-25,3-3,2	46,5-42,4-11,6	40-0-36	0-0-0	0,5-0-0	0-0-0
CTR	4,2-3,4-5,7	4,6-5,6-1	9-0-2,7	0-0-0	1,15-0-0	0-0-0
CSR	0,5-0,6-0,1	0,7-1,8-0,1	1,1-0-0,9	0-0-0	0,01-0-0	0-0-0

3. DISCUSSION

The determination of crystallographic grain size can be held for a very important parameter, because this value immediately influences the strength and the cleavage resistance of ferritic steel as it is well-known. The EBSD technique represents a method making possible to evaluate the grain size in very fine microstructures [4]. The results obtained after application of this technique contribute to the estimation of the fracture behaviour in dependence on the microstructural type. Simultaneously, it makes possible to give account for the physical engineering causes of higher cleavage resistance in comparison with the behaviour of the steel containing B. The unlike detected properties of the AF and the considered B are based on the different UCP values. Fracture features of compared microstructures and their resistance to hydrogen embrittlement are analysed. In paper [3] has been pointed out the cleavage UCP corresponds to the distance between the neighbouring high-angle interfaces. The UCP is defined as the region in which the cleavage crack propagates in a nearly straight line. On the contrary, to the AF (high-angle is localized to single primary plates-laths) in the considered B-microstructure structure the morphological size of the UCP length (indicated as d_B) is corresponding to the distance between individual high-angle packets composed of low-angle plates (laths). The found relation is linear. The d_B knowledge makes possible to estimate the transition temperature (T_t) behaviour in steel as follows [3]:

$$T_t = T_0 – K.d_B^{-1/2}$$

where K represents constant value, T_0 depends on the steel tensile strength. The given dependence shows, T_t is proportional to the square root to the distances among high-angle interfaces. The AF makes the crack propagation difficult due to presence of a great number of high angle plate interfaces (simultaneously also due to shorter distance of this parameter). The high-angle boundaries (interfaces) force the crack deviation and evidently leave ligament fractured finally at development of ductile mechanism. The increased crack propagation energy detected in steel with the AF is a result of fracture behaviour. In this connection, it is interesting to remember the same fracture process takes part in the increased resistance to cleavage crack propagation in case of lower B microstructure. In the AF-microstructure, the density of misorientated plates is enhanced as it is found under increased dislocation density in work hardened A-matrix after application of the consecutive TMCP. This finding leads to the conclusion the uniform relationship between morphology and crystallography is not possible. Instead the cleavage crack propagation found in the B-microstructure the AF can be related to the set of ferrite plates enclosed by the defined high-angle interfaces (and/or grain boundaries).

The realized analysis shows, steel with the AF is intrinsically tougher than one with the B. The compared microstructure variants differentiate in the UCP values. The absence of carbides in the AF-microstructure contributes to the observed beneficial effect of this microstructure. Further, the recent results show the positive effect can be connected with the formation of increased dislocation density in the AF-plates after application of the optimised thermo-mechanical control process composed of a properly arranged sequence of two stage rolling mul-pass deformation in A-recrystallisation region plus non-recrystallisation one [2]. This mechanism is held as a second variant to the usually applied nucleation conception based on the effect of non-metallic inclusions. The increased dislocation density in the AF-plates acts as strong hydrogen trap what results in the improved HIC resistance. This mechanism can be taken for additional process to the basic idea consisting in beneficial UCP level in the AF in comparison with the investigated B-type due to higher number of high-angle orientation among the AF-plates.

This positive AF property is kept under simultaneous hydrogen effect what represents a very important effect from point of view of the beneficial steel application. In described behaviour of the AF-microstructure on a resistance to the HIC and the SSC effect in oil and gas pipe-line steels (X60-X80) confirms the above presented idea [2].

4. CONCLUSIONS

The refined AF-microstructure represents an excellent combination of mechanical properties and achieved toughness level. The majority of plates (laths) have high-angle arrangement in comparison with the B-microstructure. In this one the high-angle interfaces are only formed between the neighbouring packets consisting of the low-angle plates set. The cleavage UCP has been found to be a distance between two grains of high-angle ferrite regions. It corresponds to the two crystallographic packets boundaries. The values of the UCP are defined as a distance between two neighbouring highly misorientated packets.

The conditions for the AF-nucleation in the A-matrix after application of the optimized TMCP consisting of the consecutive deformation processes realized in recrystallization and in non-recrystallization region have been determined. The presented nucleation mechanism can be held for a second nucleation variant leading to the AF-formation. The beneficial AF-microstructure arrangement is kept under the simultaneous hydrogen effect what demonstrates a very important property of the AF-microstructure.

5. ACKNOWLEDGEMENT

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