THE INFLUENCE OF INTERCRITICAL ANNEALING ON STRESS CORROSION CRACKING BEHAVIOR OF A STRENGTH STEEL

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INTRODUCTION

This paper summarizes part of a more general work related to modelling the SCC behavior of High Strength Steels, for where more than forty different heat treatments have been done on AISI 4135 steel, Table 1, (1).

Particularly several samples have been intercritically annealed for three hours at different temperatures after oil quenching. Finally the samples were quenched in water or liquid nitrogen, Table 2.

CONVENTIONAL CHARACTERIZATION

The microstructure obtained at each treatment was characterized by electron microscopy techniques, SEM and TEM, showing in all the cases, except F2, a mixed structure of ferrite and martensite with an important presence of carbides of medium to large size in the ferritic boundaries and also inside the ferrite laths. F2 sample showed a highly dislocated martensitic structure due to its annealing temperature, probably too high, laying on the austenitic zone. Table 3 summarizes the analysis done over the microstructure.

Each sample was mechanically characterized by its Vickers hardness, and the results are shown also in the Table 3.

STRESS CORROSION CRACKING CHARACTERIZATION

The SCC behavior of each treatment was characterized by the corresponding crack propagation rate curves, da/dt versus K_I, obtained with DCB samples, bold loaded and immersed in simulated sea water (2).

TABLE 1 - Chemical composition of 4135 steel (Weigth %)

C	S	P	Si	Mn	Cr	Mo
0,34	0,009	0,015	0,23	0,72	0,99	0,16

TABLE 2 - Intercritical annealing treatments

Sample	Austenizing	Quenching	Annealing	Final Quenching
F0	825°C	Oil	-	-
F1	830°C	Oil	740°C	water
F2	830°C	Oil	770°C	water
F3	830°C	Oil	755°C	water
F4	830°C	Oil	750°C	liquid N_2
F5	830°C	Oil	745°C	water

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TABLE 3.- Microstructural analysis and hardness

Sample	Annealing	Observed microstructure	HV
F0	(Reference)	Dislocated martensite.	622
F2	770°C	100% Dislocated martensite.	631
F3	755°C	20% Ferrite, 80% Dislocated martensite. Carbides.	516
F4	750°C	40% Ferrite, 60% Dislocated martensite. Carbides.	404
F5	745°C	50% Ferrite, 50% Dislocated martensite. Carbides.	330
F1	740°C	60% Ferrite, 40% Dislocated martensite. Carbides.	271

TABLE 4 - SCC characterization

Sample	Annealing	K_{ISCC} (MPa m½)	da/dt (m.s^{-1})	Fracture Type
F0	-	10	1,5 . 10^{-6}	IG
F2	770°C	8	1,8 . 10^{-6}	IG
F3	775°C	17	1,1 . 10^{-6}	IG , TG
F4	750°C	22	0,6 . 10^{-6}	TG
F5	745°C	>200	-	-
F1	740°C	>200	-	-

After that, two parameters have been used to characterize the obtained behavior, the K_{ISCC} value at stage I and da/dt rate at a determinate value of the stress intensity factor K_I (30 MPa m½), when propagation was achieved, stage II.

Also SEM analysis of the fracture surfaces, obtained after the propagation processes, were done. Table 4 summarizes the results obtained including the type of fracture.

The results obtained are correlated in Figures 1 and 2. Figure 1 shows the relation of SCC behavior, characterized by the K_{ISCC}, with the hardness of each microstructure. A conventional situation is observed, where the SCC resistence increases as the strength decreases, but with an important step for hardness under 400 HV, where not SCC propagation was achieved. Figure 2 correlates this situation with the ferrite/martensite contain stablishing the important improvement on SCC resistence when the presence of ferrite is over 50%. The amount of carbides associated to the ferrite should play an important role in such a improvement (2). A similar analysis could be done using the crack propagation rate as a parameter of SCC behavior, offering the same conclusions.

The observed step have been achieved for a mechanical response of the steel lower than a similar one obtained with tempered martensite (3), probably due to the presence of the highly dislocated martensite (1-3).

The improvement on the resistence to SCC is associated to a change in the fracture path: intergranular (IG) at 770°C of annealing temperature, mixed intergranular-transgranular (IG-TG) at 755°C and transgranular (TG) at 750°C. Nevertheless, the last one has the worst SCC behavior obtained with a transgranular type of fracture among all the treatments done on this steel. Its crack propagation rate, 0.6.10^{-6} m.s^{-1}, is very close to the corresponding ones of IG processes, 10^{-6} m.s^{-1}. Again, this situation is related to the presence of martensite and its deleterious effect on SCC.

CONCLUSIONS

An important improvement on SCC behavior, associated to the increasing percentage of ferrite and the presence of carbides, have been observed in the intercritically annealed mixed ferritic-martensitic microstructures of 4135 steel.

The improvement is associated to an important lost on the mechanical properties of the steel, as it was shown previously for tempered martensite microstructures also. Nevertheless, a better SCC resistence-mechanical behavior combination has been obtained for these ones. The deleterious effect on SCC resistence of the dislocated martensite of the annealed microstructures can justifie this difference.

AKNOWLEDGEMENS

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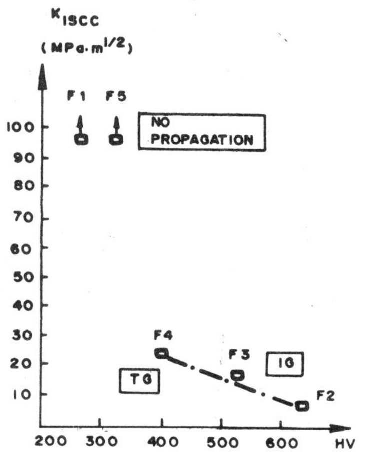

Figure 1 - K_{ISCC}-HV relation.

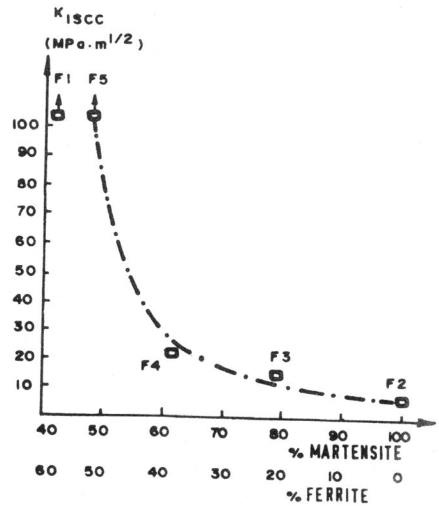

Figure 2 - K_{ISCC} -Ferrite/Martensite relation.