INFLUENCE OF THE MICROSTRUCTURE ON STRAIN AGING OF C-Mn STEELS

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The influence of the microstructure on dynamic strain aging (DSA) was studied on a C-Mn steel in normalized condition or water quenched from various austenizing temperatures.The susceptibility to DSA has been investigated by tensile tests in the 20-300°C temperature range. With respect to hardening, the hardest microstructure appears to be less susceptible to DSA, and this trend is explained by a different dislocation density / free carbon and nitrogen ratio in the various microstructures.

INTRODUCTION

C-Mn steels and associated welds made by submerged arc welding and manual metal arc welding are widely used materials in petrochemical and nuclear industries.

Generally, these materials are susceptible to static (SSA) and dynamic strain aging (DSA), which result in an increase in yield and ultimate stress, and a decrease in ductility. Moreover, as several authors have already shown (Wagner (1), Miglin (2), Srinivas (3)), this phenomenon is responsible for an appreciable loss of fracture toughness in the temperature range where the ultimate tensile strength is maximum.

In the Heat Affected Zones of the welds, different microstructures are present. Until now, the influence of these microstructures on SSA or DSA phenomenon have been scarcely studied (Chakravarity (4),(5)).Yet, these data are necessary for a better structural integrity analysis.

In this study, the susceptibility to DSA of different microstructures of a C-Mn steel (martensite, bainite, and ferrite) was evaluated by tensile tests in the 20-300°C temperature range.

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MATERIALS

Chemical Composition

The C-Mn steel used in the present study was a 40 mm thick plate of AFNOR (French Standard) NFA 36205 grade A 48. The chemical composition is given in Table 1. This steel is semi- killed with silicon and contains very little aluminium (0.004 %) capable of making aluminium nitride (AlN) and trapping nitrogen. Consequently free nitrogen is still present in the structure and may participate to DSA.

TABLE 1- Chemical composition of the A 48 steel (w.% , except for N, O in ppm)

C	S	P	Si	Mn	Ni	Cr	Mo	Cu	Sn	Al	N	O
.198	.012	.010	.207	.769	.135	.095	.025	.273	.023	.004	83	49

Heat treatments

Four blocks of steels (100 mm width, 160 mm long and 40 mm thick) were taken from the original plate, which had been normalized at 870°C and air cooled.

One block (labelled "Reference Condition" in the following) was not retreated.Three other blocks were reaustenized at different temperatures (1250°C, 1050°C and 900°C) and water quenched, in order to produce different microstructures close to those existing in the heat affected zones of welds.

Microstructural observations

For all retreated blocks, a polished section at 40 mm in the longitudinal direction was made and micrographic observations were carried out across the thickness, starting from the center line.

Block 1: Austenized at 1250°C, water quenched. The microstructure consisted of martensite, bainite and ferrite. The observations did not show any differences between the middle and the quarter thickness of the plate.

Block 2: Austenized at 1050°C, water quenched. The microstructure consisted of martensite, bainite and ferrite, but of course grains were finer than in the block 1 microstructure, and the distribution of ferrite was different. Indeed, at 1250°C the chemical composition was rehomogenized inside the austenite grains, and the proeutectoid ferrite was more acicular. For this 1050°C austenizing temperature, the microstructure in the quarter-thickness appeared slightly more quenched and finer than the mid-thickness microstructure.

Block 3: Austenized at 900°C, water quenched. A banded microstructure was obtained consisting of bainite, ferrite and degenerated pearlite.

Block 4 : Normalized at 870°C, air cooled. For this Reference Condition, the standard microstructure consisted of banded ferrite and pearlite.

TENSILE TESTS

Tensile tests were carried out from room temperature up to 300°C on cylindrical specimens (ø 4 mm, located at quarter- thickness) using a strain rate $\dot{\varepsilon}$ =2.4 $10^{-4}s^{-1}$. For the reference condition, the conventional tensile curves (nominal stress σ versus elongation $\Delta L/Lo$) showed a Lüders strain at all temperatures. At 100°C and 200°C, the Portevin Le Chatelier (PLC) phenomenon was present. While a typical serrated yielding was observed at 200°C, the phenomenon was less pronounced at 100°C leading to more irregular curves. For all retreated conditions, there was no Lüders strain whatever the temperature, and the PLC phenomenon appeared only in its irregular form at 100°C.
The yield strenght σ_{YS}, the ultimate tensile strenght σ_{TS}, the total elongation and the reduction of area are reported versus temperature on Fig. 1 to 4. For increasing temperatures, all the microstructures display the DSA phenomenon, with an increase of σ_{YS} and σ_{TS}, and a decrease of both elongation and reduction of area. For the reference condition, σ_{TS} is maximum at 200°C, whereas for the retreated conditions this maximum is observed at 250°C. The maximum in σ_{TS} corresponds to a minimum in reduction of area observed at the same temperature (200°C for the reference condition, 250°C for the retreated conditions). On the other hand, the total elongation (and homogeneous elongation) is minimum in the temperature range 100°C to 200°C whatever the conditions, that is to say for lower temperatures than the maxima in σ_{TS}.

DISCUSSION

Dynamic strain aging and ductility

During the DSA phenomenon, the σ_{TS} maximum versus temperature is associated with a minimum in ductility. This trend may be explained by the strain rate sensitivity index m = d(ln σ)/d(ln $\dot{\varepsilon}$) - Hong (6), Kubin (7). In the absence of DSA, the strain rate sensitivity is high and once a neck is formed the increase in local strain rate increases the resistance to flow, sufficiently so that the deformation tends to continue outside the neck, thus delaying the strain localization and resulting in a high ductility. When DSA is present, the strain rate sensitivity index is low, and in the necked region the deformation concentrates very early thus resulting in a low ductility.

Susceptibility to dynamic strain aging

To determine the susceptibility to dynamic strain aging of the various microstructures, several relationships were plotted (Fig. 5) .

. σ_{TS}^{max} - σ_{TS}^{min} versus $\sigma_{TS}^{20°C}$

. $(\Delta L/L_o)^{20°C}$ - $(\Delta L/L_o)^{min}$ versus $\sigma_{TS}^{20°C}$

. $Z^{20°C}$ - Z^{min} versus $\sigma_{TS}^{20°C}$

(where $\sigma_{TS}^{20°C}$, $(\Delta L/Lo)^{20°C}$, $Z^{20°C}$ are the values of σ_{TS}, elongation and reduction of area measured at 20°C ; σ_{TS}^{max} is the maximum of σ_{TS}; σ_{TS}^{min},

$(\Delta L/L_o)^{min}$, and Z^{min} are the minimum of σ_{TS}, elongation and reduction of area).

The harder the microstructure, the lower the tensile strength increases with temperature. With respect to hardening, the 1250°C austenized temperature condition appears to give a microstructure which is less susceptible to DSA. The microstructures which are less susceptible to aging are also those which present the lower loss in elongation, but the more intense decrease in reduction of area. The total elongation and the reduction of area vary in opposite directions.

The studied steel is semi-killed with silicon and contains a very small aluminium quantity (0.004%) capable of forming aluminium nitride (Al N) and trapping nitrogen. Thus, the increase of the austenizing temperature does not allow the formation of further solute nitrogen. On the other hand, the water quench (retreated conditions) produces slightly higher solute nitrogen and carbon contents than air cooling (reference condition). Furthermore, it is well established that the density of dislocations is considerably higher in martensitic than in normalized structures. Nevertheless, in martensitic structures these dislocations are essentially pinned by the interstitial atoms (C,N) and most of the interstitial atoms are trapped in the vicinity of these pinned dislocations. Consequently, only few free C and N atoms can be involved in the DSA process in agreement with tensile test results.

CONCLUSION

The influence of microstructures on the susceptibility to dynamic strain aging (DSA) was studied on a C-Mn steel. Four microstructures were studied after different austenizing temperatures and water quenching. The hardest microstructures, constituted of martensite, bainite and ferrite appear to be less susceptible to DSA. This trend has been interpreted by the highest dislocations density with respect to the lattice free carbon and nitrogen contents. Consequently, in the hardest microstructure, relatively less carbon and nitrogen atoms can be involved in the interaction with mobile dislocations. However, these microstructures lead to the most important decrease in reduction of area. Thus, the susceptibility to the loss of fracture toughness associated with dynamic strain aging is difficult to predict, and tests on the different microstructures are still necessary.

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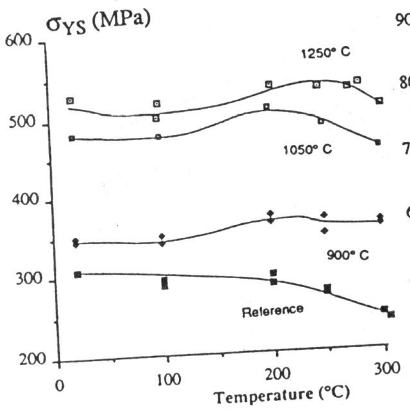
ILLUSTRATIONS



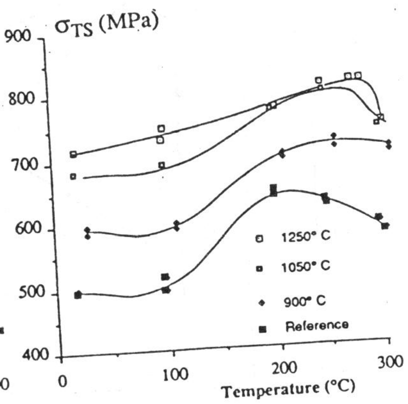


Fig.1 : σ_{YS} evolution versus temperature Fig. 2 : σ_{TS} evolution versus temperature

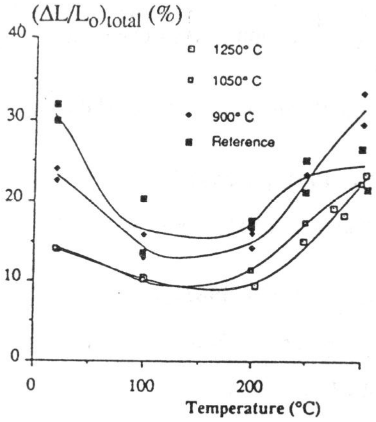


Fig.3 : Elongation evolution versus temperature

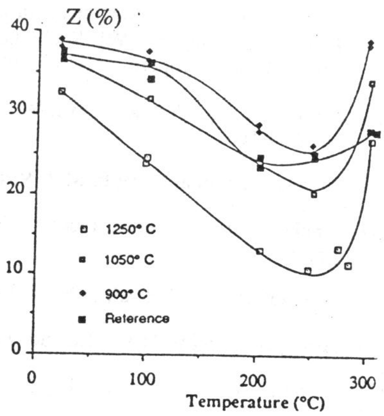


Fig.4: Reduction of area evolution versus temperature

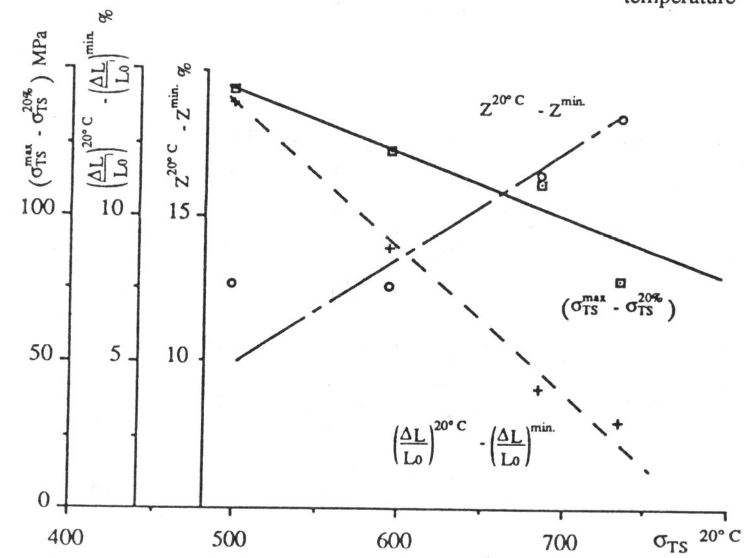


Fig.5: Susceptibility of DSA parameters versus $\sigma_{TS}^{20°C}$