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D. Wagner, J. Moreno, C. Prioul. Influence of Post Weld Heat Treatment on the Dynamic Strain Aging of C-Mn Steels. Journal de Physique IV Colloque, 1996, 06 (C8), pp.C8-159-C8-162. <10.1051/jp4:1996833>. <jpa-00254641>

HAL Id: jpa-00254641

<https://hal.archives-ouvertes.fr/jpa-00254641>

Submitted on 1 Jan 1996

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Influence of Post Weld Heat Treatment on the Dynamic Strain Aging of C-Mn Steels

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Abstract : Welded C-Mn steel structures are generally subjected to a post weld heat treatment (PWHT), consisting in a 100 minute isothermal holding at 600°C, whose major role is to reduce the residual stresses in the heat affected zone. Nevertheless, an associated decrease of the material sensitivity to Dynamic Strain Aging (DSA) seems to be observed. Since this DSA phenomenon, generally induces a large increase in the ultimate tensile strength and a ductility loss in the 100-300°C temperature range, with a view to practical design, it is important to accurately characterize the beneficial effect of PWHT on DSA. In order to study this influence of PWHT on the DSA in welded joints, tensile tests as well as internal friction tests were performed on C-Mn steels and manual metal arc welded joints, in the as-welded state or after PWHT. After PWHT, the decrease of both the Snoek and the Cold Work Peak heights, which are observed on the internal friction spectrum, can be clearly associated to the lowering of the sensitivity to DSA measured by tensile tests.

1- INTRODUCTION

C-Mn steels and associated welds made by Manual Metal Arc Welding are widely used materials in industrial components. Generally, these materials are susceptible to Static (SSA) and Dynamic Strain Aging (DSA). This DSA phenomenon, which induces an increase in the Ultimate Tensile Strength associated to a ductility loss in the 100 - 300 °C temperature range, has a detrimental effect on the fracture toughness of the welded joints in the same temperature range [1, 2]. These phenomena (SSA and DSA) are commonly observed in alloys containing solute atoms interacting with dislocations. In C-Mn steels, it is well established that the diffusing species are interstitial carbon and nitrogen atoms [1].

Welded C-Mn steel structures are generally subjected to a post weld heat treatment (PWHT) consisting in a 100 minute isothermal holding at 600 °C, whose major role is to reduce the residual stresses in the weld. Nevertheless, in most cases, it is observed that this PWHT also decreases the sensitivity of the material to DSA, but this effect and its mechanisms are not well characterized.

In order to study this influence of PWHT on the DSA of welded joints, tensile tests as well as internal friction experiments were performed on C-Mn steels and manual metal arc welded joints in the as-welded state or after PWHT. Since the internal friction technique allows to evaluate the balance between free carbon and nitrogen atoms in the lattice and carbon and nitrogen atoms interacting with mobile dislocations, this technique has been used, despite the complex chemical composition of these industrial materials.

2- MATERIALS and EXPERIMENTAL PROCEDURE

For this study, a C-Mn base metal and a weld were used. The base metal was a 40 mm thick plate of AFNOR (French Standard) NFA 36205 grade A48 in the normalized condition, whose chemical composition is given in Table 1. This steel was semi-killed by silicon, with a very small content of aluminum capable of forming aluminum nitride (AlN) and trapping nitrogen. Consequently free nitrogen was still present in the lattice and might participate to DSA. Its microstructure was a classical banded ferrite-pearlite one. The weld metal was a material deposited by multipass manual metal arc welding (MMAW), made with a basic coated electrode SAFER MF 48 NUC, whose chemical composition is given in Table 1.

Table 1 : Chemical composition of base and weld metals.

	C	S	P	Si	Mn	Ni	Cr	Mo	V	Cu	Sn	Al	N	O
A 48	0.198	0.012	0.0104	0.207	0.769	0.135	0.095	0.025	-	0.273	0.023	0.004	0.0083	0.0049
MMAW	0.042	0.012	0.017	0.357	0.735	0.021	0.029	0.004	0.022	0.056	0.006	0.004	0.0093	0.0465

In a multi-pass weld, each successive pass induces a reheating of the sub-layer affected zone. At the optical microscope scale, the recrystallized affected zone consisted of both fine grained and coarse grained ferrite. In each layer, a non recrystallized zone was remaining which contained proeutectoid ferrite, lamellar bainite and acicular ferrite. The base metal and associated weld were representative of real components ones, especially from the DSA sensitivity point of view.

The tensile tests were performed in the 20 - 300 °C temperature range, with a strain rate of $2.4 \cdot 10^{-4} \text{ s}^{-1}$. The tests were carried out on specimens in the normalized state (base metal A48), in the as-welded state (MMA weld), and on stress relieved specimens. Stress relieving was achieved by a PWHT consisting in a 100 minute holding at 600°C.

The internal friction tests were realized in the -20 to 600 °C temperature range, at 1 Hz frequency, on an inverted torsion pendulum [3] with a heating rate of 130 °C per hour. Two types of tests were performed : either continuous heating up to 600°C, followed by a 100 minute isothermal holding and cooling back to room temperature (Fig 1a), or successive interrupted tests in the 20 to 600°C temperature range (Fig 1b and 1c). In any case, for comparison purpose, a final reheating up to 600°C and cooling down to 20°C was made.

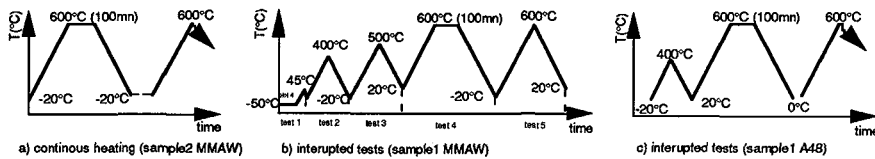


Figure 1: Internal friction thermal cycles.

3- EXPERIMENTAL RESULTS

3-1 Tensile tests

The evolutions of the ultimate tensile strength (UTS) and of the total elongation versus temperature are plotted in Figure 2 for the two materials before and after stress relieving, respectively in the normalized state (A48 base metal) and in the as-welded state (MMA deposited weld).

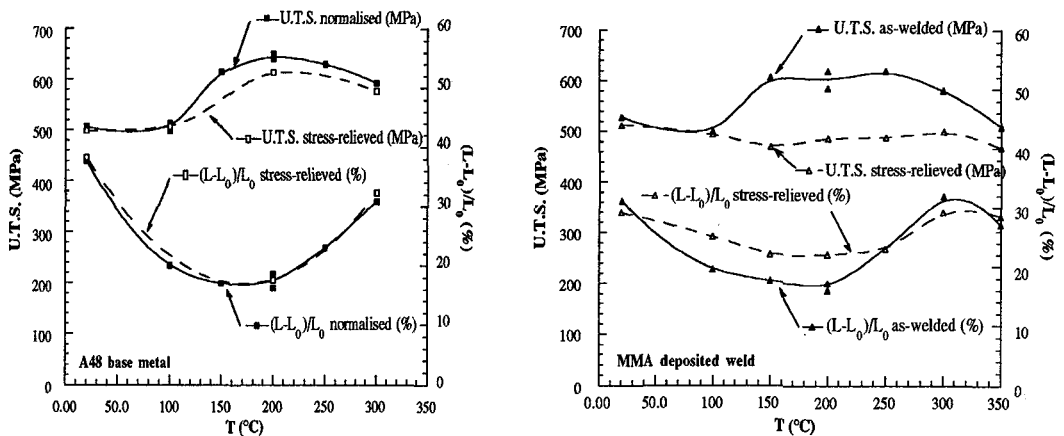


Figure 2: U.T.S. and total elongation vs. temperature for A48 base metal and MMA deposited weld.

In the temperature range tested, the two materials display ultimate tensile stress maximum associated to elongation minimum which are characteristic of the DSA phenomenon. The sensitivity to DSA of the normalized A48 steel can be attributed to its very low aluminum content (0,004%) and consequently low

capability of making aluminum nitride (AlN) and trapping nitrogen. The sensitivity to DSA of the deposited materials can be attributed to the combination of aluminum with oxygen in the early solidification process. Consequently, aluminum cannot be effective in trapping free nitrogen in this deposited metal. After PWHT, the sensitivity to DSA is reduced (as evidenced by the UTS decrease and the total elongation increase). This reduction of DSA sensitivity is more pronounced in the deposited material.

3-2 Internal friction tests

As shown in figure 3 these two industrial alloys exhibit both a Snoek peak (SP) and a cold work peak (CWP), as well as a large internal friction increase in the 400 to 600°C temperature range.

During the first heating (normalized or as-welded state) well defined asymmetric Snoek peaks are observed, whereas the corresponding CWPs maintain to a very low level (Fig 3).

Interrupted tests performed in the 20 to 600°C temperature range (curves not reported) showed that for the two materials, the SP is very stable and totally reversible in the 20 to 400°C temperature range. For higher temperatures a decrease of the SP and CWP can be observed.

The internal friction plots obtained during the final reheating (i.e. after simulated PWHT by isothermal holding for 100 minutes at 600°C) are also reported in Figure 3. These figures show that the simulated PWHT induces a decrease of both the SP and CWP height. Nevertheless, in agreement with the tensile tests results, this decrease is more pronounced in the MMA weld than in the A 48 steel.

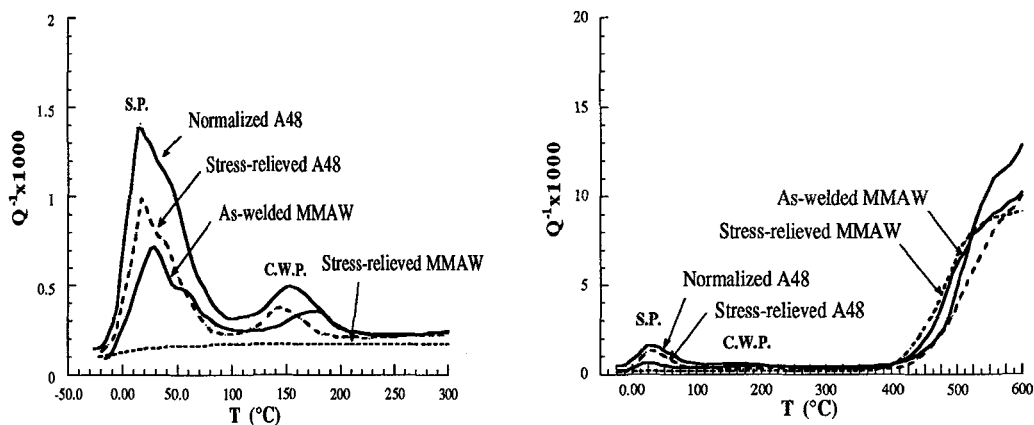


Figure 3: Internal friction Q^{-1} vs. temperature for A48 base metal and MMA deposited weld.

4- DISCUSSION

Room temperature aging and tempering (between 20°C and 450°C) of Fe-C, Fe-N and Fe-C-N have been studied by many authors in various microstructures [4-8], including supersaturated water-quenched ferrite and martensites. From these studies it appears that, after room temperature aging the interstitial atoms are distributed among various sites :

- most of the nitrogen and carbon atoms are clustered in local enriched zones which, after a sufficient time lead to α'' $Fe_{16}N_2$ or $Fe_{16}(C,N)_2$ (carbo)nitrides precipitation.
- a noticeable part of interstitial atoms are trapped in the vicinity of lattice defects such as dislocations.
- the remaining part of the interstitial atoms are randomly distributed between the octahedral sites of the solid solution.

During tempering, the local enriched zones lead at first to α'' ($Fe_{16}N_2$) or $Fe_{16}(C,N)_2$ (carbo)nitrides and ϵ carbides precipitation, then to γ Fe_4N nitride and cementite Fe_3C .

As shown in Figure 3, the SP due to free carbon and nitrogen redistribution between equivalent octahedral sites in the lattice, which appears at 20°C, reveals a more complex shape than in pure iron. As discussed by Koiwa [9], the SP asymmetry in these industrial steels comes from the overlapping of the C peak and the N peak, and especially from substitutional atoms (Mn...) interacting with N (possibly C) which broaden the

peak. Our own (unpublished) results on MMA welds with different Mn contents have confirmed the important effect of this substitutional element on the peak shape.

The CWP, observed between 150 and 200°C, which is due to interstitial atoms mobility in the dislocations stress field, presents a very low level which can be related to the low density of dislocations in the materials tested, but also to the high stability of free interstitial C and N atoms in the lattice for temperatures lower than 400°C, as mentioned above. Carbon and nitrogen redistribution from the lattice to more stable sites requires higher temperatures (close to 600°C), for which dislocation redistribution also occurs.

This study confirms our previous results [10] which showed a linear correlation between the SP height and the ductility loss measured by tensile tests. Furthermore the internal friction results demonstrate that to reduce the sensitivity to DSA in C-Mn steels, it is necessary to perform a thermal treatment at temperatures close to 600°C that is corresponding to the "stress relieving" treatment.

During the PWHT, recovery associated with various microstructural modifications occurs. Recovery induces both interstitial and dislocation contents decrease [11]. Under heating, vacancies and interstitial atoms annihilate, as well as dislocations which either annihilate each other or induce trapping of interstitial atoms. Evans [12] has investigated the effect of stress relieving (at 580°C for 2 hours) on multi run MMA deposits (whose chemical composition and as-welded microstructure were similar to those of this study) by examining replicas by transmission electron microscopy. His study confirmed that the stress relieving thermal treatment has a pronounced effect on the microstructure, causing precipitation and spheroidization of second phase particles (carbides).

The large internal friction increase for temperatures higher than 400°C seems to be correlated to the recovery process and associated microstructural modifications. Unpublished results on various materials (base metals and MMA welds) have shown that the internal friction level, measured at 600°C, increases with dislocation density or manganese content. Nevertheless its interpretation is difficult considering the complex microstructure of the materials studied and the absence of an internal friction peak (even for temperatures as high as 700°C). These results suggest that the redistribution of the interstitial atoms leading to a DSA decrease is closely connected to the microstructure evolutions developing during PWHT, involving dislocation and probably manganese redistribution at 600°C.

5-CONCLUSIONS

The PWHT applied to welded C-Mn steel structures in order to induce stress relieving, also decreases the material sensitivity to DSA. The reduction of this sensitivity can be measured by internal friction tests. Indeed, the decrease of both the Snoek and the Cold Work Peak heights, which is observed on the internal friction spectrum, can be clearly associated to the lowering of the sensitivity to DSA, as measured by the tensile tests. Interrupted internal friction tests show that the Snoek peak is fully reversible even after thermal treatment up to 400°C. These results suggest that nitrogen (and carbon) atoms, which are responsible for the DSA in these C-Mn steels, are very stable in the lattice. Their redistribution appears to be connected to the complex microstructure evolutions developing during tempering at 600°C.

Acknowledgments.

This work was carried out under the financial support of FRAMATOME. Thanks are due to B. Houssin, F. Faure and Y. Meyzaud for fruitful discussions.

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