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Journal of Nuclear Materials 271&272 (1999) 455–458
journal of nuclear materials

Influence of thermal aging on tensile and impact bending properties of the steel grades OPTIFER and F82H mod.

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Abstract

The low activation martensitic chromium steels OPTIFER Ia, Ib, II, III and IV and F82H mod. were subjected to aging by annealing between 550°C and 650°C for up to 10,000 h. In general, this caused a decrease in tensile strength by up to 10%. The decrease in total elongation depended on the thermal treatment of the material. Impact bending strength was hardly affected by aging. With one exception, all tested steels turned out to be sufficiently resistant to aging. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Higher alloyed steels, such as the low activation martensitic chromium steels presented here, are multicomponent systems with several thermally activated and time-dependent transformation and precipitation possibilities. However, conventional technical production processes, e.g. hot forming, take place rather rapidly so that the time-dependent diffusion processes are frozen more or less away from the equilibrium. These non-equilibrium states are often characterized by an increased strength, which is desired but not thermally stable. By means of a short-term thermal treatment, it is possible to anticipate in advance some of the modifications which would take place at the expected operating temperature of the material. For financial reasons, the time of thermal treatment must be much shorter than the operating time. Hence, conversion kinetics is accelerated by an increased temperature. Eventually, the temperature increase also results in a change of the thermodynamic equilibrium. Under accelerated conditions, the ‘equilibrium state’ is never precisely reached for the operating temperature. Often, this state is not even anticipated at thermal treatments, as the advantageous mechanical properties of the non-equilibrium state are exploited. In any case, a certain aging potential always exists and leads to changes in the mechanical properties after a long operation time. This problem shall be studied for the steels OPTIFER and F82H mod. by means of tensile and impact bending tests following artificial aging.

2. Test material and test methods

The test material consists of five low activation martensitic chromium steels OPTIFER Ia, Ib, II, III and IV of our own production [1–3] and the Japanese steel F82H mod. [4] of a similar type. Chemical composition of the steels is given in Table 1. The initial states were: 1075°C 0.5 h +750°C 2 h for the steels OPTIFER Ia, Ib, II and III and 950°C 0.5 h +750°C 2 h for the steels OPTIFER Ia, IV and F82H mod. and 1040°C 38 min. +750°C 1 h for F82H mod. The thermal aging temperature was chosen between 550°C and 650°C.

Strength and ductility of the steels were measured in a tensile test using an electromechanical universal testing machine. Hardness testing was performed using a Vickers hardness testing device (model Diatestor by Wolpert). The toughness of the steels was measured in an impact bending test using a pendulum ram impact testing machine. Impact energy and its temperature dependence yield the transition temperature from ductile to brittle fracture (DBTT), which may be used as a parameter indicating the embrittlement.

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Table 1
Chemical composition of the low activation martensitic chromium steels OPTIFER-Ia, Ib, II, III and IV and F82H mod. in wt% [1–4]

OPTIFER Heat	Ia 664	Ib 667	II 668	III 666	IV 986 489	F82H mod. 9741
Cr	9.3	9.5	9.5	9.32	8.5	7.6–8.4
C	0.10	0.12	0.125	0.12	0.11	0.09–0.11
Mn	0.50	0.49	0.49	0.49	0.57	0.16
P	0.0046	0.004	0.0043	0.004	0.004	0.002
S	0.005	0.001	0.002	0.002	0.004	0.001–0.015
V	0.26	0.234	0.28	0.248	0.23	0.14–0.16
B	0.0061	0.0063	0.0059	0.0064	0.004	–
N_2	0.0155	0.0062	0.0159	0.0173	0.06	0.008
W	0.96	0.98	0.006	0.0235	1.16	1.95–2.1
Ta	0.066	0.163	0.018	1.60	0.15	0.005–0.02
Ge	–	–	1.2	–	–	–
Cer	<0.001	0.041	<0.001	–	–	–

3. Test results

3.1. Tensile properties

The OPTIFER Ia, Ib, II (and III) steels with the initial state of 1075°C 0.5 h +750°C 2 h were subjected to aging under three different conditions and then tested in a tensile test at 250°C. The results measured are shown in Fig. 1. The influence of aging on the strength is very strong for the steel OPTIFER III. However, it is only of academic interest in this case. After a few thousand hours of annealing at 600°C, strength decreases rapidly, similar to the hardness. This is due to premature recrystallization or grain coarsening. The steel OPTIFER Ib only loses about 10% of its strength by aging. The steels OPTIFER Ia and II remain nearly unchanged. Due to aging, total elongation of all OPTIFER steels drops markedly. Uniform elongation decreases slightly in all steels (except for OPTIFER Ib).

Tensile properties of the steels OPTIFER-Ia, IV and F82H mod. with the initial state of 950°C 30 min +750°C 2 h had been altered by aging at most as shown in Table 2. Tensile strength and 0.2% yield strength of the steel OPTIFER-IV decreases by about 15 and 20 MPa, respectively, whereas total and uniform elongation remains roughly unchanged. Tensile strength and 0.2% yield strength of the steel F82H mod. decreases by about 50 and 60 MPa, respectively, whereas total and uniform elongation remains roughly unchanged. Tensile properties of the steel OPTIFER-Ia are shown in Fig. 2 in dependence of aging conditions. Tensile strength and 0.2% yield strength decreases at most by about 10 and 20 MPa, respectively, and total elongation decreases by 6% whereas uniform elongation remains unchanged.

The tensile properties of the steel F82H mod. with the initial state of 1040°C 38 min +750°C 1 h were not changed after aging at 550°C 5000 h and 600°C 5000 h, respectively. The steel grades OPTIFER-Ia and F82H mod. austenitized at 950°C show in comparison to austenitizing at higher temperature (1040°C or 1075°C) a lower loss of ductility and a higher loss of strength due to aging (Table 2).

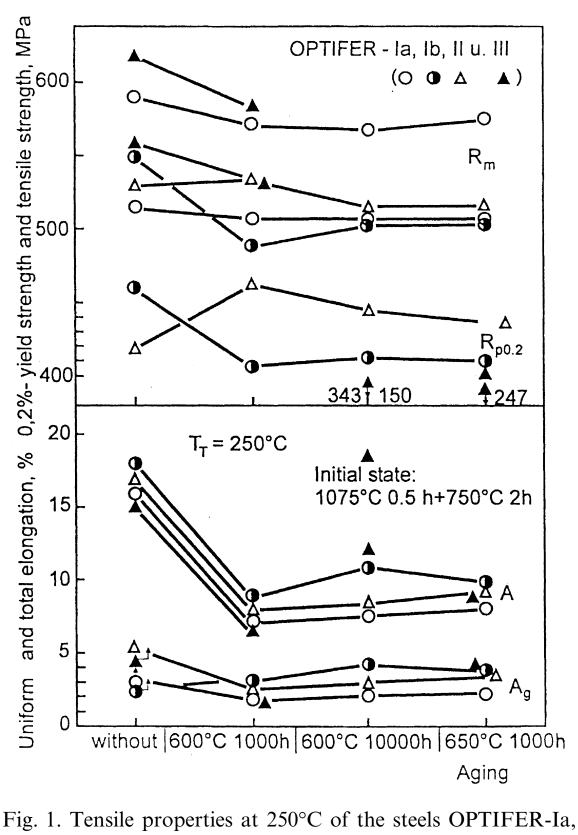

Fig. 1. Tensile properties at 250°C of the steels OPTIFER-Ia, Ib, II and III after aging show small effects on strength (exception: OPT.-III) and larger effects on total elongation.

Table 2
Maximum effects obtained due to aging

Steel	T_{AU} (°C)	$\Delta R_{p0,2}$ (MPa)	ΔR_m (MPa)	ΔA_g (%)	ΔA (%)	ΔDBTT (K)
OPT.-Ia	1075	−5	−15	−1	−8	–
OPT.-Ia	950	−20	−10	0	−6	+15
OPT.-Ib	1075	−55	−55	+1	−8	–
OPT.-II	1075	(+20)	−10	−3	−8	–
OPT.-III	1075	(−400)	(−280)	−3	−7	–
OPT.-IV	950	−20	−15	+0,5	0	+10
F82H mod.	950	−60	−50	+1	0	+68
F82H mod.	1040	0	0	0	−3	+27

Remarks: Δ = Change; $R_{p0,2}$ = 0.2% yield strength; R_m = tensile strength; A_g = uniform elongation; A = total elongation, DBTT = ductile to brittle transition temperature.

3.2. Impact bending properties

The results of the impact bending tests of the steel grades OPTIFER-IV and F82H mod. are represented in Figs. 3 and 4, and they are summarized together with results from steel OPTIFER-Ia in Table 2. Steel OPTIFER-IV shows a very small increase in DBTT of +10 K due to aging (Fig. 3). Steel F82H mod. shows a remarkable increase in DBTT due to aging (Fig. 4). There is ΔDBTT = 9 K at 550°C 5000 h and ΔDBTT = +27 K at 600°C 5000 h and ΔDBTT = +68 K at 600°C 10000 h (and ΔDBTT = +20 K at 650°C 1000 h without figure), respectively. These effects exist at the austenitizing temperature T_{AU} = 950°C and T_{AU} = 1075°C. Steel

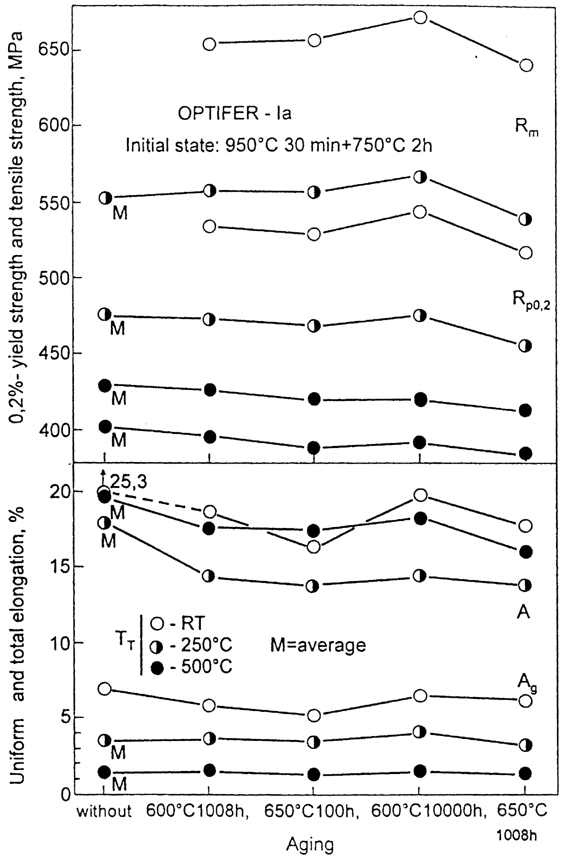

Fig. 2. Tensile properties at different test temperatures of the steel OPTIFER-Ia in the initial state 950°C 0.5 h + 750°C 2 h show small effects after aging.

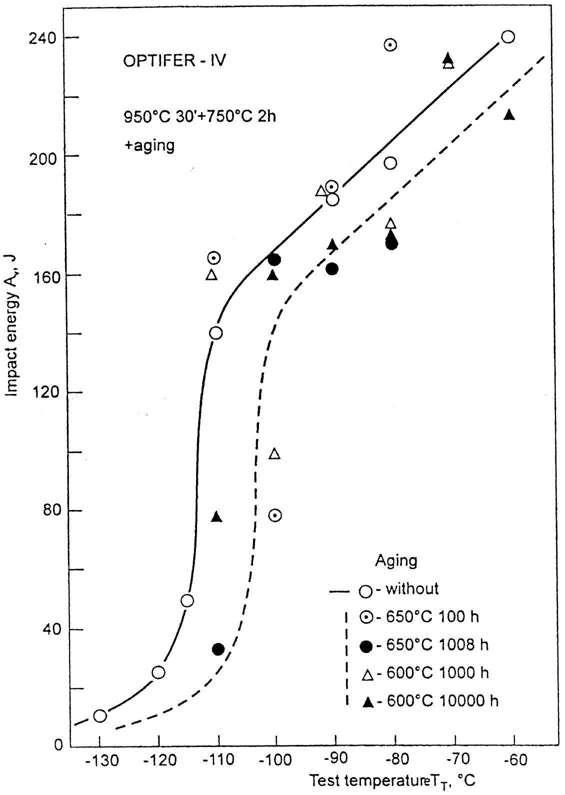

Fig. 3. Impact energy of the steel OPTIFER-IV as a function of the test temperature shows only a small increase in DBTT (≈10 K) after aging.

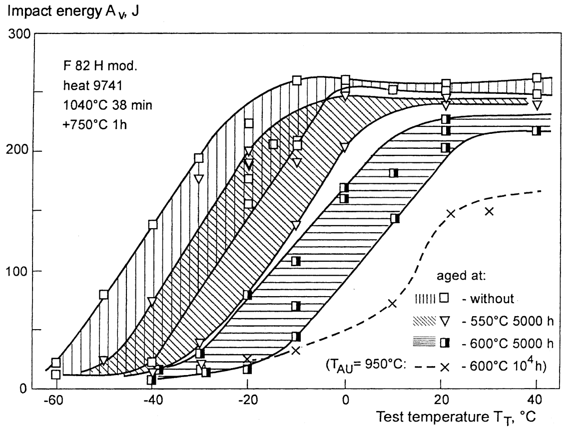

Fig. 4. Impact energy of the steel F82H mod. as a function of the test temperature shows an increase in DBTT (up to +68 K) after aging.

OPTIFER-Ia shows an increase of the DBTT of +15 K due to aging at 650°C 1000 h.

3.3. Hardness

The results of hardness tests show no significant changes as a function of the Jaffe–Hollomon-parameter up to $P = T_K(18+\log t) \times 10^{-3} = 19$. Above the hardness of the steel OPTIFER-III decreases from HV30 = 220 to 120 due to recrystallization and coarse-grain formation.

3.4. Comparison of the steels

In Table 2, a survey is given on the changes of the mechanical properties of the steels due to aging. The most significant alterations measured are indicated. In general, they correspond to aging at 650°C 1000 h or 600°C 10 000 h. It must be noted that steels with an austenitizing temperature of $T_{AU} = 950$°C lose more strength and less ductility during aging than steels of $T_{AU} = 1075$°C. In contrast to this, steels with an austenitizing temperature of $T_{AU} = 1075$°C lose about half their total elongation and sometimes much of their uniform elongation too. It may be assumed that this is accompanied by a considerable increase in DBTT. When comparing the steels, the steel OPTIFER IV turns out to be least susceptible to aging. Strength only decreases slightly, and, which is even more important, ductility, and the associated impact bending strength are not or only slightly affected. Taking into account that aging at 650°C 1000 h already represents a certain overtesting, all tested steels (except for OPTIFER III) may be considered to be sufficiently resistant to aging.

4. Conclusion

The low-activation martensitic chromium steels OPTIFER Ia, Ib, II, III and IV and F82H mod. were subjected to aging by annealing between 550°C and 650°C for a period of up to 10 000 h. In general, this caused the measured tensile strength to decrease by about 10%. Depending on the thermal treatment, total elongation drops slightly or considerably. Impact bending toughness was only slightly affected. With one exception only, all tested steels have a sufficient resistance to aging. Very positive results were obtained for the steel OPTIFER IV. The test results indicate that aging is dependent on the prior thermal treatment of the materials. This remains to be studied in detail using a final reference material.

Acknowledgements

This work has been performed in the framework of the Nuclear Fusion Project of the Forschungszentrum Karlsruhe and is supported by the European Communities within the European Fusion Technology Program.

References

[1] L. Schäfer, H. Kempe, Metallkundliche und mechanische Untersuchungen an dem schwach aktivierbaren martensitischen Chromstahl OPTIFER-IV. Kernforschungszentrum Karlsruhe, Wissenschaftliche Berichte Nr. KfK 5353, August 1994.

[2] M. Schirra et al., OPTIFER, ein weiterer Schritt zur Entwicklung niedrigaktivierender martensitischer Stähle. Forschungszentrum Karlsruhe, T. u. U., Wissenschaftliche Berichte Nr. FZKA 5624, November 1995.

[3] L. Schäfer, OPTIFER-IV, ein martensitischer Chromstahl mit hoher Kerbschlagzähigkeit, Jahrestagung Kerntechnik '96, Mannheim, KTG und Deutsches Atomforum eV. Tagungsbericht, Bonn: INFORUM-Verl. S. 597–600.

[4] L. Schäfer, M. Schirra, R. Lindau, Mechanical properties of the low activation martensitic chromium steel F82H mod., Proceedings of 19th Symposium on Fusion Technology. SOFT-19 (1996), 16–20 September 1996, Lisbon, Portugal, PG 21.