ELSEVIER

Journal of Nuclear Materials 258–263 (1998) 1336–1339

journal of nuclear materials

Influence of delta ferrite and dendritic carbides on the impact and tensile properties of a martensitic chromium steel

L. Schäfer *

Forschungszentrum Karlsruhe, Inst. für Materialforschung II, (IMF-II) Postfach 3640,76021 Karlsruhe, Germany

Abstract

Martensitic chrome steels with a high content of chromium incline to form delta ferrite frequently accompanied by massive dendritic carbide precipitations. Both phases mostly influence the mechanical properties of this steel in countercurrent manner. The relatively soft delta ferrite causes an increase of ductility and toughness, whilst the brittle dendritic carbides decreases both. Both phases mostly decrease the strength of the steel. One or the other influence will be dominant in dependence of the quantitative relation of the two phases. This is the cause for very different statements in the literature. The dendritic carbides should be avoided using a cooling rate of more than 10^3 K/min after the austenitization, because this phase mostly impairs the mechanical properties of the steel. However, the delta ferrite without dendritic carbides can be tolerated mostly. © 1998 Elsevier Science B.V. All rights reserved.

1. Introduction

Within the framework of the blanket project under the European fusion technology program (EBP), structural materials based on martensitic chromium steels are being developed for the first wall and the blanket structures of ITER test modules. According to the Schaeffler diagram, however, martensitic chromium steels with a high chromium equivalent and a low nickel equivalent tend to form delta ferrite. Moreover, delta ferrite may occur in the one-phase field of the martensite following unconventional mechanical and thermal treatments of the material. The influence of delta ferrite on the mechanical properties is not described consistently and completely in the literature [1–7]. Many contradictions arise from the fact that a frequent companion of the delta ferrite, which also has a decisive influence on the mechanical properties, has often been ignored up to now. The sometimes massive dendritic carbide precipitates of the type $M_{23}C_6$ (with M≈65% Cr + 30% Fe+⋯) more or less encapsulate the delta ferrite [8–10]. The present work is aimed at studying the conditions (tempering) of carbide dendrite generation and how it can be avoided. Furthermore, the influence of delta ferrite, carbide dendrites and both phases together on the mechanical properties of the steel shall be determined.

2. Test material

Six melts of martensitic steel with a variable chromium content of 9–14% were used as the test material. The resulting proportion of delta ferrite ranges between 0% and 25%. Except for the chromium content, the six melts are very similar. Their mean chemical composition is: 0.13% C; 0.34% Si; 0.63% Mn; 9–14% Cr; 0.65% Ni; 0.60% Mo; 0.27% V; 0.18% Nb; 0.006% P; 0.004% S. Delta ferrite represents the first solid phase that separates from steel melts during cooling. Subsequently, delta ferrite is converted into γ-iron. This conversion is sometimes incomplete for kinetic reasons (mainly due to the alloying elements of the chromium equivalent) such that fractions of delta ferrite remain in the γ-iron and in the martensite during further cooling. According to microstructural analyses using the scanning electron microscope, occupation of the phase boundaries between the martensite matrix and the delta ferrite by a chromium-rich carbide of the type $M_{23}C_6$ increases with

* Tel.: +49 7247 823577; fax.: +49 7247 824566.

0022-3115/98/$19.00 © 1998 Elsevier Science B.V. All rights reserved.
PII: S0022-3115(98)00200-1

Fig. 1. Dendritic structure of the $M_{23}C_6$-seam carbide of the delta ferrite [10].

increasing delta ferrite content of the test melts (see Fig. 1). At a certain cooling rate (~15 K/min), these carbides grow from the chromium-enriched delta ferrite and are possibly bound to it in a semi-coherent manner. Due to the high oversaturation and the unfavorable nucleation conditions, the carbides often have a dendritic form [8–10].

3. Results of the notched bar impact bending tests

To determine the influence of delta ferrite (alone) on the impact properties, the specimens were austenitised at 1075°C for 0.5 h, quenched in water and tempered at 520°C for 2 h. This ensures that no relevant amounts of massive dendritic carbides or other carbides are formed. In Fig. 2 impact properties of these specimens are represented as a function of their pure delta ferrite content (without carbide dendrites). Increasing delta ferrite content causes the maximum force F_m to decrease, while the ductility S_u and the impact energy A_v increase. This is the direct influence of the softer delta ferrite phase (see also [9]).

When selecting a slower cooling rate, e.g. 15 K/min, massive dendritic carbides are precipitated around the delta ferrite during cooling [8]. They cause together with the delta ferrite the impact properties represented in Fig. 3. With an increasing fraction of delta ferrite and, hence, an increasing proportion of carbide dendrites (at a small cooling rate), all impact properties measured (maximum force, ductility S_u and impact energy) decrease. This means that the dendritic carbides have a dominant influence on impact properties, as a result of which the positive influence of delta ferrite on ductility S_u and impact energy is turned to the negative.

From Figs. 2 and 3, the influence of the dendritic carbides alone without delta ferrite is calculated supposing the property P of steel containing delta ferrite F and dendritic carbides C together, $P(F+C)$, related to the property without F and C, $P(\text{-})$, is equal to the product of F and C alone: $P(F+C){:}\ P(\text{-}) = P(F){:}\ P(\text{-}) \cdot P(C){:}\ P(\text{-})$ [11]. $P\ (C)$ is shown in Fig. 4. It can be noticed that small amounts of dendritic carbides originating from a delta ferrite content of about 5% do not influence maximum force, but strongly affect impact energy. At higher delta ferrite contents (e.g. 25%) and high contents of dendritic carbides, ductility and impact work are hardly influenced, while the effect on the material strength increases.

A lot of tensile tests at room temperature were carried out likewise. Toughness was obtained as the product of tensile strength and uniform elongation. The results are given in [11] and presented qualitatively in Table 1.

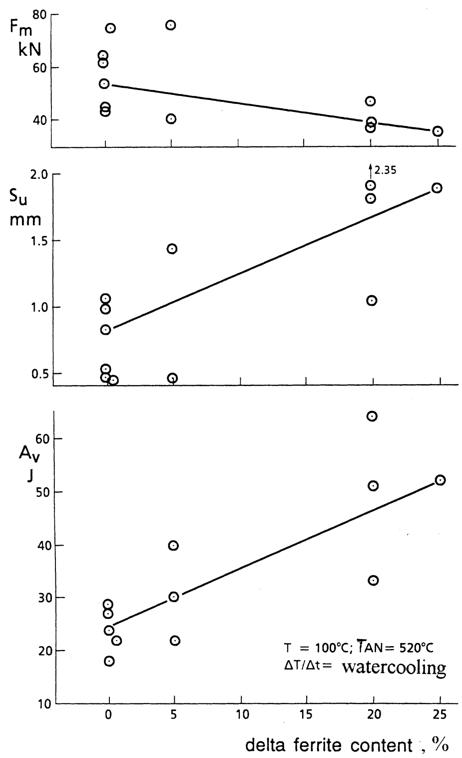

Fig. 2. Maximum force F_m, deformation up to cleavage fracture S_u and impact energy A_v from impact bending tests for steels watercooled in order to avoid dendritic carbides in dependence of the delta ferrite content.

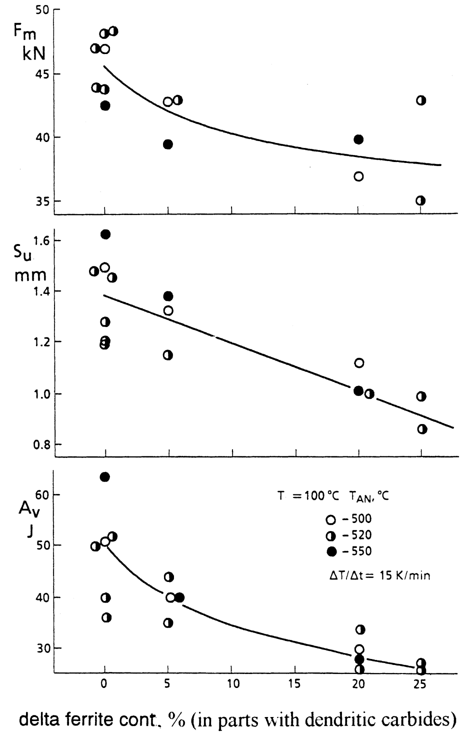

Fig. 3. Maximum force F_m, deformation up to cleavage fracture S_u und impact energy A_v from impact bending tests for steels cooled in a furnace with 15 K/min in order to get dendritic carbides in dependence of the delta ferrite content.

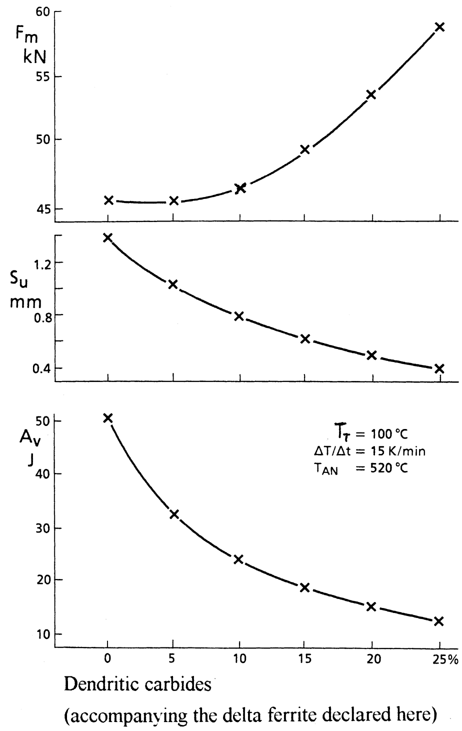

Fig. 4. Calculated maximum force F_m, deformation up to cleavage fracture S_u und impact energy A_v for impact bending tests for steels with amounts of dendritic carbides accopanying the delta ferrite declared here.

4. Discussion

According to Table 1, delta ferrite is a relatively soft phase in the martensite. It reduces the strength of the steel, increases its ductility and, hence, (due to the dominant increased ductility) its toughness, but not always its fracture toughness (AR_m). As the brittle phase in the martensite, the dendritic carbides reduce both the ductility at fracture and the toughness of the steel. Strength is decreased in the tensile test and increased in the impact bending test, which is due to various fracture mechanisms. The combined effect of delta ferrite and dendritic carbides on the strength is always negative. This also applies to the notch bar impact bending test, because the strength-reducing effect of delta ferrite predominates. In addition, influence on the ductility and toughness is negative when considering the fracture (S_u, A, A_v and R_mA). As regards the deformation state well before fracture (A_g and R_mA_g), however, the combined influence of delta ferrite and dendritic carbides improves both the ductility and the toughness. This combined influence was measured following cooling at a rate leading to the maximum possible amount of dendritic carbide. Of course, other mixing ratios of dendritic

Table 1
Influence of delta ferrite and massive dendritic carbides, separately and in combination, on the mechanical properties of a martensitic chromium steel (+ = increase; - = decrease)

	Strength			Ductility			Toughness		
	F_m	R_m	$R_{p0.2}$	S_u	A	A_g	A_v	AR_m	A_gR_m
Delta ferrite, DF	–	–	––	+	+	++	+(+)	–	+(+)
Carbide dendrites	+	–	–	––	–(–)	+	––	–	0(–)
DF + CD	–	–(–)	––	–	–	++	–(–)	––	+

Tensile test: $R_{p0.2}$ = 0.2% yield strength; R_m = ultimate tensile strength; A_g = uniform elongation; A = total elongation. Charpy impact test: F_m = maximum force; S_u = bending at brittle fracture; A_v = impact energy.

carbides and delta ferrite are possible. The model assumption comprises a matrix of martensite and two included phases, one of which (delta ferrite) is softer, more ductile, tougher and less strong than the martensite, while the other phase (dendritic carbides) is harder, less ductile, less tough and stronger than the martensite. Both phases have an opposite influence on the mechanical properties of the steel. Pure delta ferrite increases the ductility and toughness of the steel, while dendritic carbides decrease them. Strength is negatively affected by both phases. When used together, either phase may predominate depending on the mixing ratio of dendritic carbides and delta ferrite and the test method or type of load. This also explains the contradictory results in literature [1–7]. As the mechanical properties of the steel are nearly always adversely affected by the dendritic carbides, they should be avoided largely by selecting a cooling rate of at least 10^3 K/min. In contrast to this, delta ferrite alone may often be tolerated.

Acknowledgements

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

References

[1] E.A. Loria, Trans. ASM 54 (1961) 31.
[2] M. Schirra, S. Heger, Der Einfluß des δ-Ferrit-Gehaltes auf die Vergütungseigenschaften und das Zugfestigkeits- und Zeitstandsverhalten eines Cr–Ni–Mo–V–Nb-Stahles mit 9-14% Chrom, Kernforschungszentrum Karlsruhe, KfK-Bericht 5080, 1994.
[3] E. Krainer, H. Scheidl, Radex-Rundschau 3 (1977) 246.
[4] E.A. Little, D.R. Harries, F.B. Pickering, in: Proc. Int. Conf. on Ferritic Steels for Fast Reactor Steam Generators, BNES, London, 1978, 136.
[5] E.A. Little, D.R. Arkell, D.R. Harries, G.R. Lewthwaite, T.M. Williams, Proc. Int. Conf. on Irradiation Behaviour of Metallic Materials for Fast Reactor Core Components, CEA, Ajaccio, France, 1979, p. 31.
[6] R.L. Klueh, P.I. Maziasz, J. Nucl. Mater. 155–157 (1987) 602.
[7] W. Wessling, Siegen 17 (1976) 4.
[8] E. Materna-Morris, Scanning Microscopy 4 (2) (1990) 287.
[9] K. Anderko, L. Schäfer, E. Materna-Morris, J. Nucl. Mater. 179–181 (1991) 292.
[10] E. Materna-Morris, L. Schäfer, K. Anderko, Der Einfluß der Deltaferritphase auf das Bruchverhalten von 9-14% Chromstählen im instrumentierten Kerbschlagversuch. Sonderbände der Praktischen Metallographie, Bd. 20, Dr. Riederer-Verl., 1989, p. 283.
[11] L. Schäfer: Einfluß von Deltaferrit und Karbiddendriten auf die Zug- und Kerbschlag-eigenschaften martensitischer Chromstähle, Forschungszentrum Karlsruhe T. u. U., Wissenschaftliche Berichte FZKA 5727, 1996.