INFLUENCE OF LOADING RATE ON THE TRANSITION BEHAVIOUR OF STRUCTURAL STEELS

J. Falk, W. Dahl

► To cite this version:

J. Falk, W. Dahl. INFLUENCE OF LOADING RATE ON THE TRANSITION BEHAVIOUR OF STRUCTURAL STEELS. Journal de Physique IV Proceedings, 1991, 01 (C3), pp.C3-613-C3-621. 10.1051/jp4:1991386 . jpa-00250531

HAL Id: jpa-00250531

<https://hal.science/jpa-00250531>

Submitted on 1 Jan 1991

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

INFLUENCE OF LOADING RATE ON THE TRANSITION BEHAVIOUR OF STRUCTURAL STEELS

J. FALK and W. DAHL

Institut für Eisenhüttenkunde, RWTH Aachen, Intzestr. 1, 5100 Aachen, Germany

Abstract

The influence of loading rate on the transition temperature T_i of different steels with yield strength between 170 MPa and 600 MPa were investigated. The effect of loading rate on T_i was discussed and a model for determining the transition temperature T_i by the results of tension tests was presented.

Introduction

In earlier publication /1/ it was shown that the temperature shift of a transition temperature T_{70} with higher loading rates could be described with the relative strain rate sensitivity of a yield strength. T_{70} is the temperature, where the quasistatic K_{IC} -T-curve reaches the K_{IC} -value of 70 MPa $\sqrt{m}$. In the present work further investigations of the description of the temperature shift of T_i will be presented.

Testmaterials

The chemical compositions and heat treatments of the steels investigated are shown in table 1.

The Fe 510 (CaSi) steel has a lower sulfur content and a more globular type of inclusions. The C10 steel has a coarse grained microstructure ($d = 50\mu m$) due to annealing at 1200°C for a period of 5 hours.

Experimental techniques

The tension tests and fracture mechanics tests were performed on a servohydraulic testing machine at ram speeds between 0,02 mm/s and 3500 mm/s. In the fracture mechanics tests at maximum ram speed of 3500 mm/s the force was measured by strain gauges fixed on the outer faces of the CT-specimens opposite the crack tip. The load line displacement was measured using a non-contact measuring device working system on the principle of eddy current losses. The experimental set-up is described detailly in earlier publications /2,3/.

Material	Process	Content (wt%)											
		C	Si	Mn	P	S	Al	Ni	Cu	V	Mo	Cr	Nb
20MnMoNi55	I	0.20	0.24	1.38	0.011	0.005	0.068	0.52	-	-	0.30	0.06	0.032
15NiCuMoNb	I	0.17	0.28	0.92	0.009	0.001	0.022	1.22	0.64	0.001	0.53	0.27	-
Fe510(CaSi)	II	0.20	0.46	1.43	0.017	0.001	0.037	0.03	0.06	0.002	0.01	0.05	-
C10	III	0.09	0.19	0.37	0.027	0.025	0.003	0.03	0.03	0.010	-	0.05	-

I - quenched and tempered; II - normalized; III - annealed at 1200°C (5h) normalized

Table 1: Chemical compositions and heat treatments of the steels investigated

Experiments:

The fracture mechanics tests were performed at the four ram speeds 0,02 mm/s, 2 mm/s, 500 mm/s and 3500 mm/s. The test temperatures were in the transition region of cleavage to ductile fracture. J-Integral was calculated according to EGF P1-90 /4/.

The transition temperature T_i was determined as the temperature, where the J-T-curve reached J_i .

Results:

Figure 1: J-T-curve of the 20 MnMoNi 5.5 with determined T_i

Figure 1 presents the J-T-curves of the 20 MnMoNi 5.5 for four different ram speeds. The transition temperature T_i is shifted from 145 K to 212 K by the increasing ram speed from 0,02 mm/s to 3500 mm/s.

Figure 2: J-T-curves of the 15 NiCuMoNb 5 with determined T_i .

Figure 3: J-T-curves of the Fe 510 (CaSi) with determined T_i

Figure 4: J-T-curves of the C10 with determined T_i

In the Figures 2-4 the determined J-T-curves for the steels 15 NiCuMoNb 5, Fe 510 (CaSi) und C10 are plotted.

The temperature shift of T_i from the ram speed of 0,02 mm/s to the ram speed of 3500 mm/s is for the 15 NiCuMoNb 5 74 K, for the Fe 510 (CaSi) 89 K and for the C10 104 K.

It is obvious that the value of the temperature shift depends on the strength of the material.

Description of the temperature shift with the results of tension tests

In earlier publication /1/ a correlation was proposed between the temperature shift ΔT and the relative strain rate sensitivity of the yield strength m_r , which is defined as:

$$m_r = \frac{\partial \sigma_0}{\sigma_0 \ln \dot{\epsilon}} = \frac{\partial \ln \sigma_0}{\partial \ln \dot{\epsilon}} = \frac{m \cdot \sigma_0^* \cdot k \cdot T}{\Delta G_0 \cdot \sigma_0} \cdot \left[1 - \frac{k \cdot T \cdot \ln \dot{\epsilon}_0 / \dot{\epsilon}}{\Delta G_0} \right]^{m-1} \quad (1)$$

σ_0 is the yield stress at the beginning of strain hardening for example $R_{p2,0}$. m , σ_0^* , $\dot{\epsilon}_0$ and σ_i are shown in table 2.

material	$\dot{\epsilon}_0$ [s ⁻¹]	σ_i [MPa]	σ_0^* [MPa]	m
20MnMoNi55	10 ⁸	534	744	2.65
15NiCuMoNb5	10 ¹⁰	571	790	2.87
Fe510 (CaSi)	10 ⁸	382	761	2.84
C10	10 ⁸	166	967	2.71

Table 2: Constants σ_0^* , $\dot{\epsilon}_0$ and σ_i and m for the description of the temperature and strain rate dependence of the lower yield strength R_{eL}

Figure 5: m_r -T-curve for the lower yield strength of the 20 MnMoNi 55

In Figure 5 the relative strain rate sensitivity of the lower yield strength for the four loading rates of the 20 MnMoNi 55 is plotted versus temperature. Furthermore the determined transition temperatures T_i for the different loading rates are marked.

It was found, that the temperatures T_i at the different loading rates are parallel to a straight line at the beginning of the m_r -T-curve.

Determining the transition temperature T_i for any loading rate in the investigated strain rate range by the results of tension tests the knowledge of the following points is necessary:

- 1) the strain rate and temperature dependence of a yield strength of the steel.
- 2) the transition temperature T_i for one loading rate.

Then a parallel to the straight line in the beginning of the m_r -T-curve must be drawn through the temperature T_i at one loading rate and the intersection points of this parallel with the m_r -T-curve for an other loading rate give the temperature T_i for this loading rate.

Figure 6: m_r -T-curve for the lower yield strength of the 15 NiCuMoNb 5

Figure 7: m_T -T-curve for the lower yield strength of the Fe 510 (CaSi)

Figure 8: m_T -T-curve for the lower yield strength of the C10

Figures 6-8 present the m_T -T-curves for the lower yield strength with the determined T_i of the other investigated steels. It becomes clear that also for this steels the transition temperature T_i from the experiments can be determined by this method.

Figure 9: Calculated T_i -values versus determined T_i -values by fracture mechanics tests.

In Figure 9 the T_i -values determined with the method mentioned before are plotted versus the T_i -values from fracture mechanics tests at different loading rates.

For the three steels 20 MnMoNi 5 5, 15 NiCuMoNb 5 and Fe 510 (CaSi) the prediction of T_i with the proposed method is quite good.

Only for the C10 the prediction of the transition temperature T_i is not so good as for the other steels. This is probably caused by the temperature T_i at quasistatic loading, which seems not to be correct, because the other 3 transition temperature are nearly on a straight line.

Summary

Fracture mechanics tests were performed at four different loading rates for the steels 20 MnMoNi 5 5, 15 NiCuMoNb 5, Fe 510 (CaSi) and C10 in the transition areas temperature from cleavage to ductile fracture. The transition temperature T_i was determined.

With higher loading rates the transition temperature was shifted up to higher temperatures. The transition temperature T_i at higher loading rates could be predicted by knowledge of the strain rate and temperature dependence of a yield strength at the beginning of strain hardening based on the model of thermally activated yielding and a transition temperature T_i at one loading rate.

It seems to be important that the constants σ_1, σ_0^* , m and $\dot{\epsilon}_0$ are determined with a high statistic certainty because mistakes at the determination of this constants propagate in the precision of the prediction of T_i . Further investigations should be done especially with steels with a larger range of strength levels.

References

- /1/ Brüninghaus, K.; Hesse, W.; Twickler, M. u. Dahl W.:
Impact 87, DGM-Informationsgesellschaft, pp. 121-128
- /2/ Brüninghaus, K.; Twickler, M.; Twickler, R. u. Dahl W.:
Dymat 88, Ajaccio 1988, Journal de Physique, Colloque C 3,
Supplément au n^o 9, 49(1988), pp. C3-301-306
- /3/ Brüninghaus, K.; Falk, J.; Twickler, M. u. Dahl W.:
to be published in Nucl. Eng. and Design
- /4/ EGF Recommendations P1-90 for Determining the Fracture Resistance
of Ductile Materials, December 1989