EVALUATION OF THE BEHAVIOUR OF HEAT TREATED LOW ALLOY V - N STEEL

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The influence of heat treatment parameters on the dynamic characteristics of ferrite-perlite low-alloy V - N steel was studied. Dynamic yield strength and fracture toughness values were measured by Charpy V specimens. Mechanical properties dependence on test conditions and structural factors have been investigated. Fracture appearance transition temperature (FATT) values have been obtained by using the changes of absorbed energy of the fracture surface. Based on the results obtained, the change of the fracture toughness and the critical length of the crack values were analyzed.

INTRODUCTION

The wide application of low-carbon low-alloy steels is determined both by economical and technological considerations, necessitating a thoroughly study of their behaviour under different loading rates and temperatures. The sensitivity of their mechanical properties to load rate and temperature in the ductile-brittle transition range also determines their application.

The increassed demandes on structural steels require better ductility and toughness as well as higher strength. In order to meet such applications not only the standard mechanical propertiess are needed but also parameters describing material resistance to defect initiation and growth.

Recent investigations have shown in many methods of testing under various load conditions the influence of test specimen geometrics [1, 2] on the relationships between

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microstructural characteristics, inclusions content, and their material properties and fracture toughness [3, 4]. However such information on nitrogen structural steels under various load rate-temperature conditions is not common, with only a few documented results.

The purpose of the present work is to determine the relationship between test conditions (loading rate and test temperature), microstructure and the deformation and fracture characteristics of V-N (nitrogen-vanadium) structural steels.

MATERIALS AND PROCEDURES

The chemical compositions of the steels investigated are given in Table 1.

TABLE 1 - Chemical compositions of investigated steels

Steel	Chemical composition in %						
	C	Mn	Si	V	N	S	P
A 10G2SAF	0.10	1.44	0.60	0.10	0.016	0.022	0.024
B 17G2SAF	0.16	1.41	0.50	0.12	0.017	0.018	0.024
C 23G2SAF	0.21	1.60	0.56	0.12	0.015	0.017	0.025

The different steels were prepared by the following heat treatment. After normalization at 900°C both 17G2SAF steel and 23G2SAF steel were oil quenching from 900°C and then were air tempering at 180 °C. The former was produced and by martempering (air tempering at 650 °C) and the latter was quenching from 920 °C and subsequently air tempering at 550 °C.

Metallographic analysis has shown that the initial microstructure comprises ferrite and fine lamellar pearlit (Fig. 1a). Heat treatment (low and high temperature tempering) of studied steels changes their structures to fine acicular martensite (Fig. 1b) and sorbite (Fig. 1c).

Experimental results have been obtained in accordance with the requirements of ISO-6892 and ISO-148. Fracture toughness tests conformed with ASTM E 399 (static conditions) and ASTM E 24.03.03 (dynamic conditions). The Charpy V-notch fracture energy was also determined in conformity with ASTM E 24.

RESULTS AND DISCUSSION

The effect of test temperature and heat treatment on the basic mechanical characteristics of the steels under quasi-static load is shown in Table 2.

TABLE 2 - Mechanical characteristics of studied steels

Steels	Mech. charact.		Temperature, C -80	-40	-20	0	+20
10G2SAF	σ_y	[MPa]	500	470	440	425	412
norm.	CVN	[J]	20.9	30.8	44.8	67.2	80.0
17G2SAF	σ_y	[MPa]	580	560	540	530	502
norm.	CVN	[J]	24.2	35.8	58.7	84.4	95.0
23G2SAF	σ_y	[MPa]	660	640	630	621	616
norm.	CVN	[J]	44.4	48.6	93.2	124.0	128.4
17G2SAF	σ_y	[MPa]	710	690	660	645	635
qchd.	CVN	[J]	24.0	29.5	42.0	45.2	66.0
17G2SAF	σ_y	[MPa]	820	780	745	730	720
mart.	CVN	[J]	36.0	43.2	48.0	54.7	78.0
23G2SAF	σ_y	[MPa]	875	840	825	814	809
qchd.	CVN	[J]	28.7	36.3	47.6	49.0	58.0
23G2SAF	σ_y	[MPa]	980	950	815	900	884
mart.	CVN	[J]	38.0	47.4	61.7	89.1	113.0

Tensile strength increases after low temperature tempering mainly due to the presence of cubic martensite. Good combinations of high strength and ductility are observed after high temperature tempering.

The results of the tests for determing the effect of load rate on yield strength σ_y are shown in Fig. 2. The data allow to establish that the load rate sensitivity decrease with increasing the values of mechanical properties of studied steels. Load rate increase has led to reduction of the temperature range in which specimen deformation comprises plastic component. The load rate sensitivity of the yield strength is also temperature dependent.

One basic characteristic which defines the tendency of materials to brittle fracture is the ductile-brittle transition temperature. This may vary over a wide range depending on the criteria used for determination. In the present study the transition temperature is determined from the absorbed energy values obtained during Charpy V-notched test and the fracture appearance as a function of test temperature (Fig. 3). For this purpose the surface appearance at 100% plasticity Tp, 100% crystallinity Ti and 50% crystallinity, FATT and absorbed energy 35 J/cm^2 were used. (Table 3)

TABLE 3 - Transition temperatures of the studied steels determined by various criteria

Materials			10G2SAF	17G2SAF			23G2SAF	
			norm.	norm	mart	qchd	qchd	mart
Specimen	crit.	changes in	T°C	T°C	T°C	T°C	T°C	T°C
Charpy specimen V-notch	FATT	fracture appear.	-7	-18	-20	-28	-30	+20
	T	Energy 35 J/cm^2	-38	-42	-38	-57	-40	-60
	T_p	Energy	8	2	20	40	18	35
	T_i	Energy	-60	-58	-50	-40	-35	-35

The heat treatment and especially the high tempering temperature strongly influence of the character of fracture. The results show that at a test temperature of -70 °C 17G2SAF and 23G2SAF steels have a high percentage of plastic component of the fracture surface (from 9 to 20%) while the normalized steels - only 1 to 3%. The dynamic test shows that the heat treated steels at Tt = 200 °C have lower energy values than those of normalized and high tempered steels.

In term of microstructure, the changes during tempering proceed from successive transformations of the initial phases - stable tetragonal martensite, refined austenite, decomposition products. During low temperature tempering the changes occur mainly inside the martensite lamelle. The high internal stresses obtained in quenching result on low martensite stability. Low CVN-values observed after low-temperature tempering are associated with retained austenite. A change in the austenite - martensite relation is observed in the steels when heated up to 180 C. An initial precipitation of lamellar carbide phase is observed within this range. There are reasons for assuming that the decrease of absorbed energy during the fracture is the result of the combined effects of the retained austenite decomposition and carbide precipitation initiation processes.

The advantages of static and dynamic fracture toughness (K_{IC} K_{Id}) parameters to standard mechanical characteristics is the possibility to relate the nominal stress, defect shape and dimensions and material resistance to unstable development of these defects. Figure4 shows the variation of K_{IC} and K_{Id} as a function of temperature. For test under quasi-static loading ($\dot{K}$~2 MPa$\sqrt{m}$/s) the validity range is the temperature interval below -140°C, while under dynamic loading ($\dot{K}$~2.5x10 MPa$\sqrt{m}$/s) this is below -40°C. Due to the globular sorbite structure which increases toughness and strength characteristics the load rate and temperature sensitivity is not strongly manifested for high tempering steels. Low temperature tempering increases fracture toughness but as a whole the cubic martensite structure contributes to the propagation of initiated cracks. A suitable parameter for more precise evaluation of steel's behaviour is the critical crack length (a_{cr}) when brittle fracture of specimens occur. Figure5 shows the temperature dependence of a_{cr} on yield strength. It is clear that a_{cr} reduces strongly with increasing yield strength and it is possible to establish combinations of heat treatment which give the same value of critical crack length.

CONCLUSIONS

The more important results of the present study are as follows:

1. The heat treated low alloy V-N steels show temperature and load rate dependence of the mechanical characteristics.

2. By changing the tempering temperature the fracture toughness of the steels studied increases and good combination between ductility and strength is achived after high temperature tempering (at 550°C).

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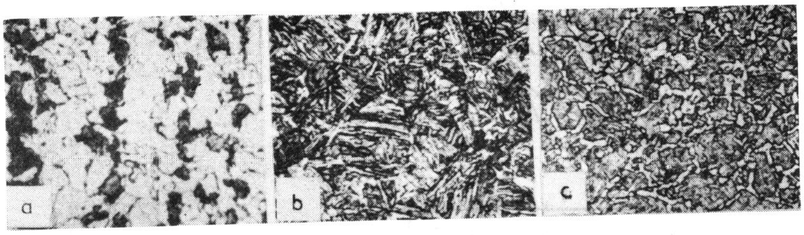

Figure 1. Microstructures of studied steels after various heat treatment (x500)

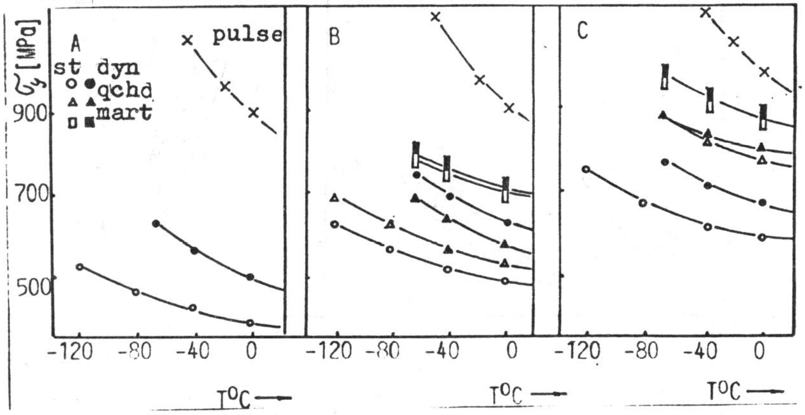

Figure 2. The effect of load rate on
- static loading
- dynamic loading

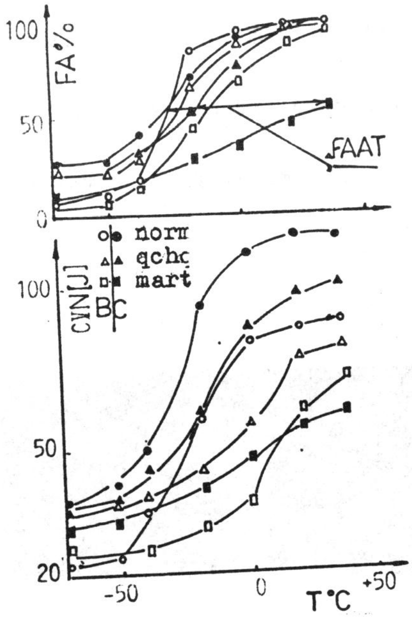

Figure 3. Values of Charpy V-notch test as function of the temperature.

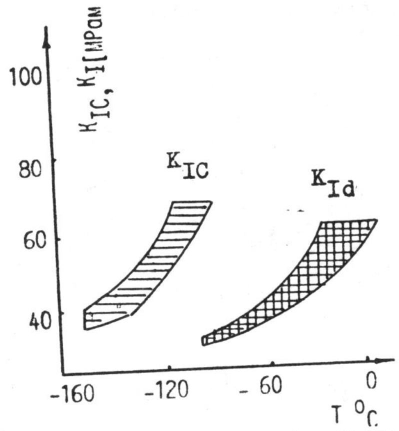

Figure 4. Fracture toughness dependence on test rate and temperature.

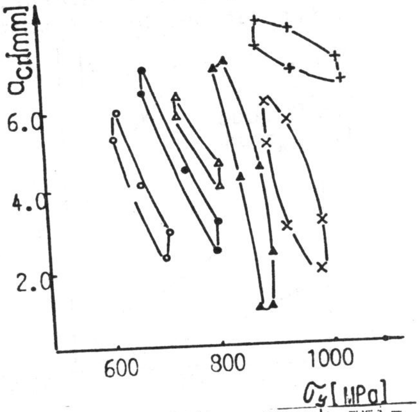

Figure 5. Microcrack critical dimensions as a function of the yield strength. (as Fig.3)