INFLUENCE OF MICRO STRUCTURAL PARAMETERS ON FATIGUE RESISTANCE OF DUAL-PHASE STEEL

J.P.Messias*, C.A.R.P.Baptista**, H.J.C.Voorwald* and V.A.Pastukhov**

The aim of the present research is to investigate the resistance to fatigue crack propagation of dual-phase steel in different microstructural conditions obtained through intercritical heat treatment. Samples were intercritically treated in order to obtain two different dual-phase condition: martensite-ferrite and ferrite-martensite. For each material condition, constant amplitude loading tests were performed for stress ratio igual to: 0,2; 0,33 and 0,5. The results are analysed using generalized Paris-Erdogan kinetic equation of crack growth.

INTRODUCTION

Interesting work done by Roos et al (1) showed that the microstructure of dual-phase steels is composed basically of a ductile phase (ferrite) and products resulting from austenite transformation (martensite). On such materials, mechanical behavior can be significantly affected by microscopical properties which demonstrate sensitivity to technological parameters.

It may be considered that mechanical behavior of these steels depends upon morphology and upon the properties of their phases according to Ramage (2) and Suzuki and Mc Evily (3). Another important parameter to be considered to obtain the desired volume fraction of the phases is the intercritical heat treatment temperature. For a intercritical treatment temperature, Shang et al (4) proposed that steels with higher carbon content will result in higher martensite volume fraction. Higher martensite volume fraction values are related to low carbon content and hardness. Research done by Chen and Cheng (5) showed that dual-phase steel mechanical properties like yield strength and ultimate tensile strength

* Department of Materials and Technology - UNESP/FEG
** Department of Materials - DEMAR/FAENQUIL

increase with martensite volume fraction. Some factors like volume fraction, carbon content, plasticity, martensite distribution, ferrite carbon content are correlated with dual-phase steel ductility. One importante aspect of mechanical properties of structural material to be considered is a resistance to fatigue crack propagation. Some studies associated to fatigue crack nucleation in dual-phase steel showed that cracks occur on interfaces matrix ferrite-martensite particles due to deformation incompatibility between phases (3). Experimental results in low cycle fatigue tests with five different dual-phase microstructures showed that better fatigue behavior was associated with an increase in martensite content untill 50%. For higher martensite volume fraction, a decrease in the fatigue strength was observed according to Li et al (6).

Research by Padkin (7) with some low carbon steels showed that the increase in carbon content resulted in lower values of ΔKth and an increase in da/dN for the same ΔK level. In this work, the resistance to fatigue crack propagation of dual-phase steel in different microstructural conditions obtained through intercritical heat treatment is investigated. The results are analysed using generalized Paris-Erdogan kinetic equation of crack growth.

EXPERIMENTAL PROCEDURE

In this work, it was used a 7,0mm thick hot rolled low carbon steel SAE 1010 of following chemical composition (%ωt): C 0,08; Mn 0,85; P 0,019; S 0,006; Si 0,02; Al 0,01. Mechanical properties of this steel are: Vickers hardness 148; yield strength 250 Mpa and ultimate tensile strength 367 Mpa. The material was intercritically treated, according to two heat treatments, in order to study the influence of microstructural parameters on the fatigue strength. The heat treatments inclued the following steps:

1.

. annealing 90 minutes at 950°C, in controlled atmosphere furnace (nitrogen + 0,15 carbon), air cooled;

. pre heating during 30 minutes at 480°C in air furnace;

. heating during 40 minutes in a neutral salt bath furnace, in the intercritical temperatures studied (750°C, 800°C and 850°C);

. quenching in cold water (3°C).

2.

. annealing 90 minutes at 950°C, in controlled atmosphere furnace (nitrogen + 0,15 carbon), air cooled;

. heating during 15 minutes at 950°C in controlled atmosphere furnace and treated at one of the intercritical temperatures (750°C, 800°C and 850°C), in a neutral salt bath furnace (40 minutes);

. quenching in cold water (3°C).

Center notched specimens for fatigue crack growth tests were manufactured of all material conditions. Specimens dimensions are 290 x 72 mm. Fatigue crack growth tests were carried out in an Amsler vibrophone, 10 ton capacity. The frequency of cyclic loading was 155 Hz. Crack length was measured by optical means. For each material condition constant amplitude loading tests were performed adopting three different stress ratios: 0,20; 0,33 and 0,50.

RESULTS AND ANALYSIS

It may be observed that for the intercritical heat treatment 1, microstructural was composed by martensite resulted from the transformation of austenite nucleated at ferrite grain contours. For the intercritical heat treatment step quenching, 2, microstructure was composed by a ferritic matrix involving martensite. Microstructural characteristics of dual-phase steel include the properties and volume fraction of its phases. The temperature of heat treatment, martensite/ferrite volume fraction, micro hardness and mechanical properties for all material conditions are given in table 1.

TABLE 1 - Microstructural Characteristics and Mechanical Properties

		MARTENSITE		FERRITE	σe	σt	ξ	φ
		% V	MICRO HV	MICRO HV	[MPa]	[MPa]	[%]	[%]
	ANN.	-	-	92	30,7	39,9	44,5	73,2
1	750	23	551	178	387	593	15,0	57,6
	800	30	454	163	400	615	14,7	61,4
M-F	850	51	331	172	364	547	15,6	68,4
2	750	20,4	245	125	284	551	27,9	58,9
	800	28,9	219	125	290	559	26,2	63,3
F-M	850	48,3	198	155	403	637	19,5	62,9

A comparison with the annealing condition indicate that an increase in strength occured without a significant reduction in ductility. It is also possible to observe from table 1 that, for both heat treatments an increase in the intercritical treatment temperature results in higher values of the martensite volume fraction and a decrease in micro hardness. For condition 1, results show that the yield strength and ultimate tensile strength are higher when compared with 2, for temperatures of 750°C and 800°C and lower for 850°C.

The comparison of ultimate tensile strength and martensite micro hardness with intercritical heat treatment temperature indicate that the higher strength value is associated with the lower hardness.

One important aspect of mechanical properties to be considered is a resistance to fatigue crack propagation. The optimal heat treatment of material used for fabrication of such components can improve the lifetime of some engineering components. Considering all experimental data, independent from loading and heat treatment conditions resulting in one value for the constant "b", the fatigue crack growth behavior was analysed using the variation in "C_1" parameter, function of intercritical heat treatment temperature and load ratio. From equation 1 it is possible to observe that higher values of constant C_1 result in higher fatigue crack growth ratio.

$$\left(\frac{da}{dN}\right) = C_1 . K_{max.}^{b} \qquad (1)$$

$$\left(\frac{da}{dN}\right) = C_1 . K_{max.}^{b} (1-R)^{\beta} \qquad (2)$$

The same method can be applied for equation 2 where "β" and "b" are constants for all materials; C_1 depends only on heat treatment temperature and independs on "R".

Using equation 2, it is possible to compare the two microstructures, ferrite-martensite and martensite-ferrite considering, simultaneously, data from both morphologies, as is represented in figure 1.

In table 2, values of constant C_1 are indicated. It is possible to observe that morphology ferrite-martensite is responsible for higher fatigue crack growth resistance.

TABLE 2 - Values of Constant C_1.

b = 1,50		β = 1,90
T(°C)	C_1	
	F-M	M-F
750	5,18 E-11	6,94 E-11
800	5,12 E-11	7,37 E-11
850	5,76 E-11	6,73 E-11

CONCLUSIONS

1. For both heat treatments, an increase in the intercritical treatment temperature results in higher values of the martensite volume fraction and a decrease in micro hardness.

2. The comparison of ultimate tensile strength and martensite micro hardness with intercritical heat treatment temperature indicate that the higher strength value is associated with the lower hardness.

3. The microstructure ferrite-martensite showed better fatigue crack propagation resistance when compared with the microstructure martensite-ferrite.

4. Independent of the microstructure, the higher mechanical strength is not directily related to the higher fatigue resistance.

SYMBOLS USED

$\left(\frac{da}{dN}\right)$ = fatigue crack growth rate
C_1, β, b = materials constant
R = load ratio
$K_{max.}$ = maximum stress intensity factor

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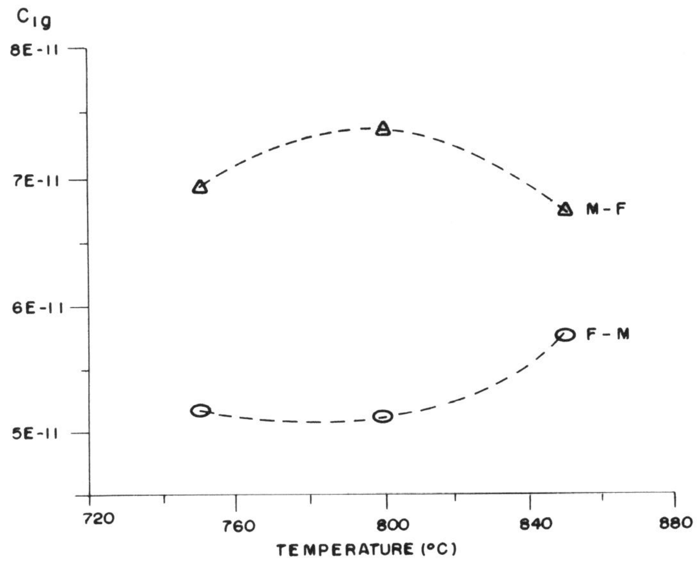

Figure 1 C_1 as a function of heat treatment temperature.