FATIGUE CRACK PATH IN MEDIUM-HIGH CARBON FERRITE-PEARLITE STRUCTURES

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ABSTRACT

The stage II fatigue crack path in a 0,5%C ferrite-pearlite carbon steel with wide quantitative differences in microstructure has been metallographically characterized. Results show that stage II fatigue cracks do not follow systematically any preferred path across one of the two phases present, independently of ΔK level, R value, ferrite volume fraction (ranging from 7 to 32%) or other attained microstructural variations.

KEYWORDS

Fatigue crack path; ferrite-pearlite steels; two-phase structures; fatigue crack growth.

INTRODUCTION

The most familiar coarse two-phase metallographic microstructures are doubtless the ferrite-pearlite mixtures of hypoeutectoid carbon steels. Despite its humbleness the fatigue behaviour of such common materials conceals some debatable points. The fatigue crack path through such microstructures is one of them, a question linked to possible differences of fatigue crack growth rates in ferrite or pearlite.

Several opinions can be found in the literature: for Cooke and Beevers (1974) the crack appears to favour the crossing of pearlite, but for most authors (Aita and Weertman, 1979; Barsom, 1971; Fowler and Tetelman, 1978; Karlsson and Hamberg, 1981) proeutectoid ferrite is the preferred fatigue crack path. The problem is not a trivial one: ferrite-pearlite relative proportions and microstructural sizes being susceptible of modification by composition changes or by heat treatment for a given composition, some improvements of fatigue crack propagation resistance could be attempted through microstructure control (volume fractions, continuity-contiguity circumstances, etc.; for instance, see Barsom and Imhof, 1978; Fletcher, 1978 and Fowler and Tetelman, 1978, for some suggestions and discussion in that direction). For other two-phase mixtures (e.g., ferrite-martensite) microstructure variations can produce significant changes in fatigue crack growth rates (Ishihara, 1983; Suzuki and McEvily,1979).

Only Karlsson and Hamberg (1981) seem to have performed some quantitative measurements on area fractions of crack paths in ferrite-pearlite structures; they found that 75-77% of fracture surface area corresponded to ferrite in a Fe-C alloy with 57% ferrite volume fraction. In the present paper, some measurements of fracture surface area fraction of stage II fatigue cracks in a medium-high (0,5%C) carbon steel are presented.

MATERIALS AND EXPERIMENTAL PROCEDURE

The material used throughout this work was a 0,5%C carbon steel from a UICR7 grade railway wheel (a hot forged and rolled, rim-quenched wheel). Standard CT specimens (B=3 mm) with axial-circumferential orientation were extracted from the rim of the wheel; depending on their radial level their microstructure varied because of the gradient imposed by rim-quenching. Some specimens were specially heat treated in order to widen the microstructural spectrum. Composition of the steel and microstructural parameters are given in Table 1[1]. Last column of this table, $(fv)_i$, represents the minimum ideal ferrite volume fraction necessary to maintain continuity of proeutectoid ferrite around pearlite aggregates (assuming circular aggregates of diameter D surrounded by a ferrite layer of thickness d),

$$(fv)_i \cong \frac{(D+2d)^2-D^2}{(D+2d)^2+D^2} \qquad |1|$$

The values obtained are consistent with continuity of ferrite for all the microstructures tested.

TABLE 1 Material Properties

Composition (w.t%)

C	Mn	Si	Al	Sn	Cu	Cr	Ni	Ti	As	P	S
0,49	0,78	0,24	0,005	0,023	0,26	0,07	0,10	0,011	0,036	0,019	0,020

Microstructural parameters

Specimen	Ferrite(%)	Ferrite grain size (μm)	Pearlite aggregate size (μm)	Pearlite spacing (μm)	$(fv)_i$ (%)	Austenite grain size (μm)
ACND2	21±1,9	5,7±0,2	21±0,8	0,25±0,024	23	-
ACND3	20±1,8	5,6±0,2	22,5±0,8	0,19±0,015	22	-
ACND5	15±1,8	3,8±0,2	20,6±0,8	0,19±0,017	17	-
ACND8	13±1,7	4,9±0,2	31±1	0,25±0,010	14,5	-
T08A1	24±1	3,2±0,1	11,2±0,4	0,25±0,014	24	12±0,6
T08H2	32±2	5,7±0,2	13,2±0,4	0,27±0,019	34	12±0,6
T10A2	7±1	1,2±0,04	17±0,4	0,29±0,013	7	48,5±0,4

Details of the fatigue experiments (conform to ASTM E647-81) and of fatigue crack growth rates in stages I and II have been published elsewhere (Rodríguez Ibabe, Fuentes Pérez and Gil Sevillano, 1983a and b).

[1] In this work, upper and lower limits on tables or error bands in figures correspond to 95% confidence levels.

Fracture surfaces of broken specimens were Ni-plated and longitudinal (//) and transverse (⊥) sections (relative to the crack growth direction) normal to the crack plane - corresponding to three different ΔK levels, 10,20 and 30 $MNm^{-3/2}$ - were prepared for metallographic observation.

Fracture surface area fractions were measured by linear intersection counting using grids of parallel lines inclined different angles relative to the crack plane (Underwood, 1970). Due to the - in general - small angles of inclination of the segments of the crack profile, the use of small inclination angles for the grids was very tedious and 30º was the lowest angle attempted.

RESULTS AND DISCUSSION

An example of crack profile is given in fig. 1. It has been chosen because it displays examples of the crack cutting pearlite across (A) or along (B) the lamellae, cutting indistinctly ferrite and pearlite (C), branching along the layer of proeutectoid ferrite (D) or along the ferrite-pearlite interface (E). It illustrates very well the dangers of local, qualitative observations.

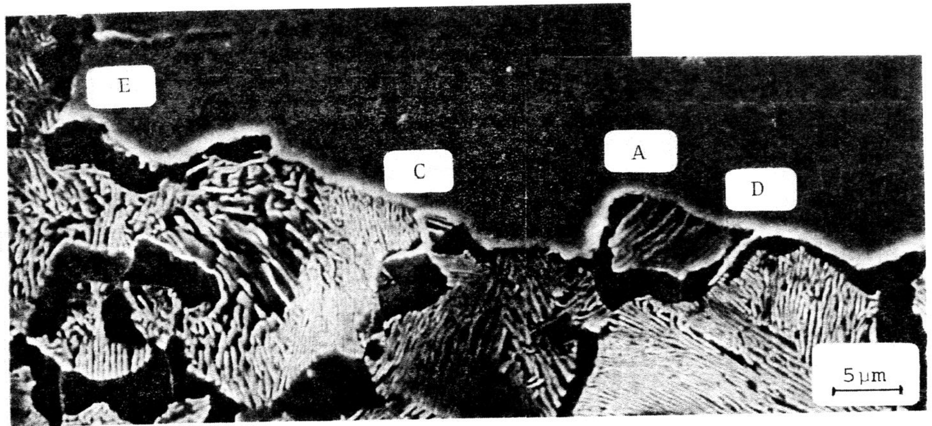

Fig. 1 Section normal to the crack plane and parallel to the crack growth direction of specimen T08H corresponding to ΔK = 30 $MN/m^{3/2}$.

The results of the crack path measurements are detailed in Table 2. They correspond to a variation of ferrite volume fraction from 7 to 32%. Global average measures of ferrite area fraction of fracture surface vs. ferrite volume fraction are given in figs. 2 and 3. The main conclusions are,

- stage II fatigue cracks propagate indiscriminately through ferrite or pearlite for ferrite volume fractions ranging from 7 to 32% in a 0,5%C carbon steel. There is no preferred crack path, independently of R value or ΔK level.
- under the same conditions, there is no significant preference for ferrite or pearlite to occupy specific locations or to adopt special inclinations on the crack profile.

The conclusions may seem rather surprising in view of the big difference in mechanical properties of ferrite and pearlite (e.g., whose flow stresses may differ by a factor of 6). They are much more plausible if the rates of fati-

TABLE 2 Ferrite Area Fraction (%) on Fracture Surface

SPECI-MEN	ΔK ($\frac{MN}{m^{3/2}}$)	ANGLE BETWEEN GRID AND CRACK PLANE: section parallel to crack propagation direction 30º	60º	90º	120º	section normal to crack propagation direction 30º	60º	90º	FERRITE VOLUME FRACTION fv(%)
ACND2 (R=0)	10 20 30	25,5±6,2 26,5±5,6 31,5±4,4	22,5±5,2 23,5±6,4 28 ±5,4	24,5± 5 20,5±4,2 24,5±4,2	24 ±5,6 20 ±4,8 24,5± 5	18,5±5,6 20,5±5,4 28,5± 6	22,5±4,6 20,4± 4 30,5±4,8	21,5±4,8 21,5±5,2 25 ± 5	21±1,9
ACND3 (R=0,3)	10 20 30	23 ±6,6 16 ±4,8 14 ±3,4	21,5±7,4 19 ±4,8 14 ±3,2	21 ±7,2 18,5±5,4 14 ±3,6	22,5±6,6 18,5±4,8 12,3±3,4	17 ±8,6 24,5±6,4 11,5±2,8	20 ± 5 24 ±3,8 11,5±1,8	19,5± 4 25,5±4,4 12,5±2,6	20±1,8
ACND5 (R=0,5)	10 20 30	14,5±4,6 22,5±5,6 19 ±3,4	14 ±4,4 22,5±5,4 16 ±3,4	15 ±5,6 20 ±5,2 18 ± 5	15,5± 5 15 ± 4 13 ±2,8	16,5± 6 20 ±6,4 22,5±5,8	18,5±3,6 17,5±3,8 24,5±3,6	15,5±5,6 15 ±3,8 17 ± 6	15±1,8
ACND8 (R=0,7)	10 20	14,5±5,8 12,5±5,8	14 ±5,8 12 ±5,4	9,5±3,6 13 ±4,4	10,5± 3 11 ±5,6	9 ±5,2 12 ±4,8	9,5± 3 12 ±2,6	9,5± 3 12 ±3,8	13±1,7
T08A1	10 20 30	29 ±4,6 25,5±5,8 22 ±4,6	24,5± 4 25 ±5,4 20,5±4,4	26,5±4,4 22 ±4,8 22,5±4,2	23,5± 4 21 ±5,4 21,5±5,4	22,5± 7 22,5±5,6 25,5±5,6	21 ±3,8 21 ±2,6 22,5±3,6	19 ±4,8 21,5±3,6 20,5± 4	24± 1
T08H2	10 20 30	30,5±4,2 34 ±6,2 38,5±4,4	36 ± 5 29,5±6,2 32,5± 4	34 ±4,2 29 ±4,4 29,5± 4	36,5±5,8 25 ±5,2 30,5± 4	32,5± 6 25,5±5,2 33,5±5,6	29,5±3,6 26 ±3,8 32 ±3,4	30,5±5,4 24,5±4,8 30 ± 4	32± 2
T10A2	10 20 30	7 ±3,4 7,5±3,4 8 ±4,4	7 ±3,2 5,5± 3 7,5±3,4	7,5±2,4 6 ±2,2 7,5±2,6	7 ±2,8 7 ±2,6 6 ±2,2	9,9±4,2 6,5±2,4 7,5±5,2	9 ± 3 6,5±1,8 9,5± 3	9 ±3,6 5,5±2,2 9 ±3,4	7 ± 1

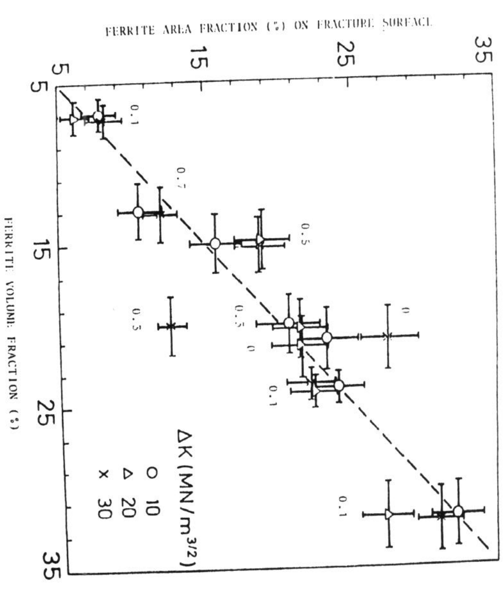

Fig.2 Area fraction of ferrite on fracture surface vs.ferrite volume fraction for different ΔK level and load ratio R (R values indicated in the figure).

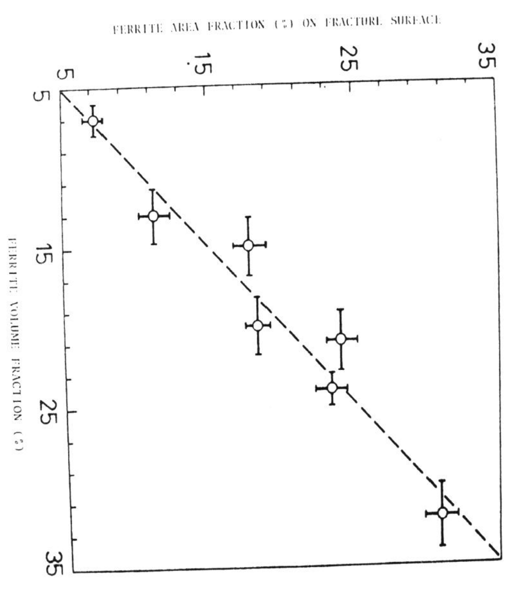

Fig.3 Area fraction of ferrite on fracture surface vs.ferrite volume fraction.Average values.

gue crack growth of ferrite and pearlite are compared (figs. 4,5 and 6): the bands of collected results for fully pearlitic eutectoid steels or for mild steels match quite well taking into account the observed interlaboratory variability of such measurements (a 3 to 1 variability is estimated as typical from an extensive statistical survey by Clark and Hudak, 1975). Oddly enough, the propagation rates of ferrite-pearlite structures, appear to be slightly lower than the corresponding rates of their isolated constituents tested in bulk (Rodríguez Ibabe, Fuentes Pérez and Gil Sevillano, 1983b).

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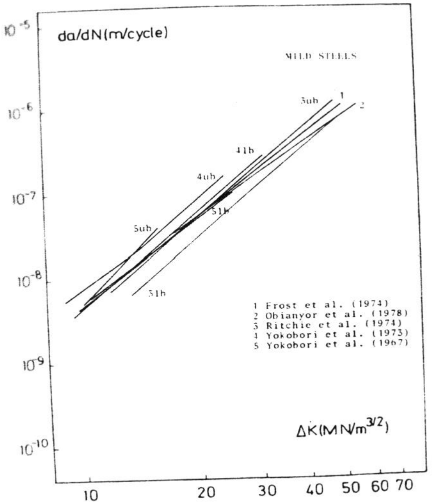

Fig.4 Fatigue crack growth curves of ferrite (mild steels). When indicated, only upper (ub) or lower bounds (lb) to the reported results have been plotted.

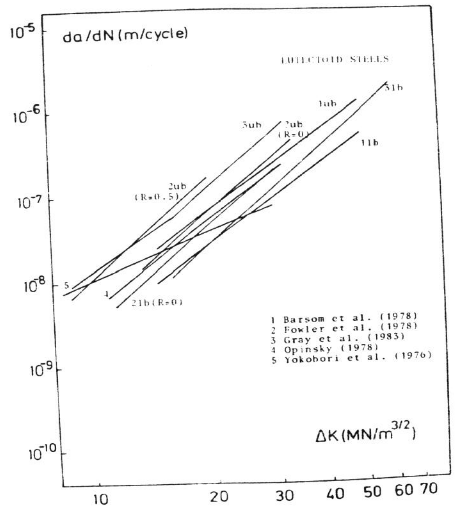

Fig.5 Id.fig.4,for pearlite (eutectoid carbon or carbon-manganese steels).

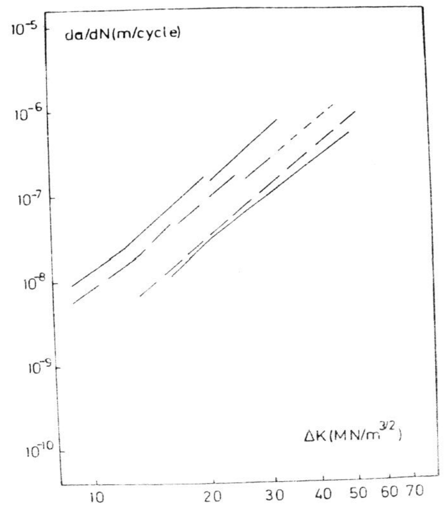

Fig.6 Scatter bands of fatigue crack growth rate curves for pearlite (continuos line) and ferrite (dotted line).