FATIGUE CRACK GROWTH RATE AND FRACTURE TOUGHNESS OF DIFFERENT GRADES OF RAIL STEELS

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ABSTRACT

This paper presents the investigation on fatigue crack growth rate (FCGR) and fracture toughness (FT) behaviour of standard carbon rail steel (UIC-860-standard), wear resistant rail steel (UIC-860-90A), high strength rail steel (Cr-Mo) and high strength rail steel (Cr-V). The FT and FCGR have been determined using (12.5 to 20)x50x200mm, three point bend(TPB) specimens. Wear resistant rail processed through LD-CC route exhibited superior fracture toughness. Cr-V grade showed inferior fracture toughness. Similar FCGR behaviour was observed for standard carbon, wear resistant and Cr-Mo grade rail steels. Cr-V grade exhibited faster FCGR compared to the other three grades.

KEYWORDS

Rail steel, fracture toughness, fatigue crack growth rate,

INTRODUCTION

In the development of a rail steel, its wear and fatigue require simultaneous attention. In addition, the projected future needs for the use of heavier freight cars and for higher operating speeds, require rails with still higher wear resistance. Higher wear resistance usually achieved at higher hardness of a steel, can produce lower FT and higher FCGR. Thus, the development of rail steel with higher resistance to fatigue is an important problem.

The generation of FT and FCGR data of rail steel has been recently undertaken in other countries (Fowler 1976; Nisidas et al 1979; Cheylyshev et al 1980; Gray (III) et al, Kalousek et al and Sunwoo et al 1982; Parsons et al 1983; Glinka et al and Scutti et al 1984) and it has two purposes:

i) to reliably predict the life of a rail and retire it in time to avoid accident or traffic dislocation

ii) to develop newer rail steels and rails with longer life.

Keeping the above purposes in view, an alloy development programme was conducted on a pilot scale at one of the steel plants of the Steel Authority of India Limited with the objective of achieving high strength, high wear resistance and good combination of FT and FCGR. This steel was selected for further study of its FT and FCGR characteristics, which is the subject of the present work.

TEST MATERIAL AND EXPERIMENTAL PROCEDURE

Materials and Specimens. Test specimens for FT and FCGR were prepared from three different grades of rail steel and one grade of high strength (Cr-Mo) rail steel plate rolled in laboratory rolling mill. Chemical composition and mechanical properties of rail steels investigated are given in Tables 1 and 2.

Table 1. Chemical composition of rail steels

Steel	C	Mn	Si	P	S	Cr	Mo	V(%)
Standard	0.58	1.26	0.06	0.052	0.039	-	-	-
90-A	0.68	1.07	0.26	0.022	0.014	-	-	-
Cr-Mo	0.76	0.72	0.25	0.040	0.020	0.75	0.21	-
Cr-V	0.65	1.09	0.34	0.035	0.016	0.90	-	0.20

Table 2: Tensile properties of rail steels

Steel	0.2%YS,MPa	UTS,MPa	Elong.%	R.A.%
Standard	446	822	16	31
90-A	579	907	13	28
Cr-Mo	992	1204	10	30
Cr-V	642	1032	16	42

All rail steel specimens for FT and FCGR were machined from the head region of as-rolled rails according to the location and orientation of the specimens shown in Fig.1.

UIC-860-standard and UIC-860-90A are the standard rail grades used in the Railway network in India, whereas (Cr-V) grade was produced on pilot scale for evaluation of the feasibility of its production and use in India. High strength rail steel

(Cr-Mo) grade was experimental heat made and rolled in laboratory into plate for assessing its suitability for pilot scale production and investigation.

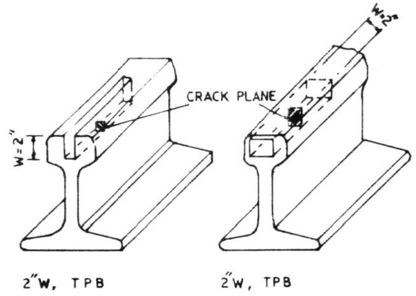

Fig.1: Location and orientation of test specimen

Average values of interlamellar spacing, S, as determined in different fields of transmission electron micrographs for each rail steel is given in Table 3.

Table 3: Average values of interlamellar spacing

Steel	Standard	90-A	Cr-Mo	Cr-V
Interlamellar spacing (μm), S	0.45	0.20	0.08	0.12
Hardness (BHN)	248	266	360	330

The TPB specimen have LT orientation and were prepared and machined according to the procedure recommended in ASTM E399 (1976).

Testing Procedure. For fracture toughness testing, the procedure involves measurement of load, clip gauge displacement, and crack extension. From these measurements, K_Q and K_{max} values were calculated using the standard ASTM E399 procedure.

For FCGR testing, the procedure involves measurement of load and crack length at various elapsed cycles. The raw data is analysed to obtain da/dN and ΔK.

The FCGR data were obtained from at least two identical specimens, and in most cases, from four or more identical specimens. The K_{max} values for FCGR data in all points were uniformly dispersed in the da/dN vs. ΔK plot.

RESULTS

Chemical composition and mechanical properties of rail steels investigated are given in Tables 1 and 2. Table 3 gives the values of interlamellar spacings of these experimental steels. Fig.2 depicts the microstructural features of all the four rail steels investigasted.

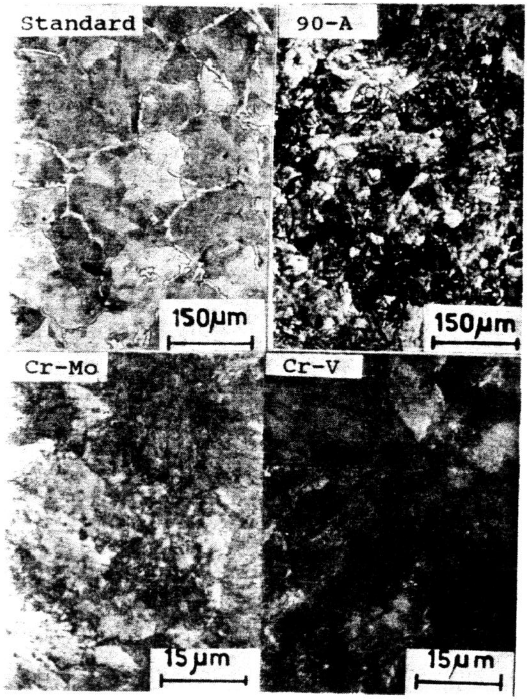

Fig.2: Photomicrographs of rail steels investigated

Table 4 summarizes the K_Q and K_{max} values for different specimens tested. A typical load displacement test records of TPB specimens for rail steels tested is shown in Fig.3.

The FCGR behaviour of steels investigated is shown in Fig.4. The straight lines were drawn by using least square method for straight line fitting.

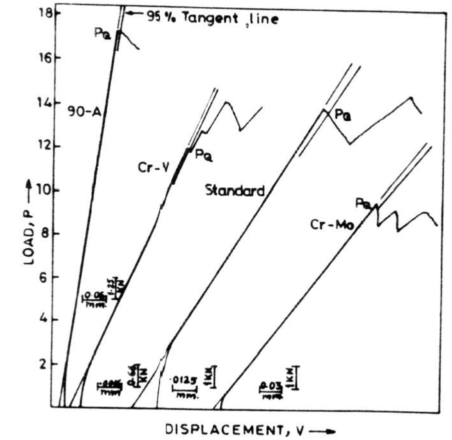

Fig.3: Typical load displacement test records of rail steels tested.

Table 4: Room Temperature Fracture Toughness of Rail Steels

Rail Steel	Specimen Number	Specimen Thickness, mm		K_Q $MPa.m^{1/2}$	K_{max} $MPa.m^{1/2}$
Standard	1	12.5		42.9	54.7
	2	12.5		43.3	62.6
	3	12.5		46.7	61.3
	4	14.1		44.0	45.9
	5	13.8		41.6	47.7
			Avg.:	43.7*	54.4
90-A	1	20.1		47.5	50.0
	2	20.1		46.2	46.2
	3	20.6		42.7	42.7
	4	20.1		48.6	48.6
	5	20.1		50.5	50.5
			Avg.:	47.1	47.2
Cr-Mo	1	16.9		42.1	46.0
	2	16.9		41.9	41.9
	3	16.9		41.2	44.8
			Avg.:	41.7	44.2
Cr-V	1	14.5		31.5	37.6
	2	14.5		31.2	35.8
	3	14.5		31.9	31.9
	4	14.5		32.2	32.2
			Avg.:	31.7	34.3

* Invalid because $P_{max}/P_Q > 1.1$

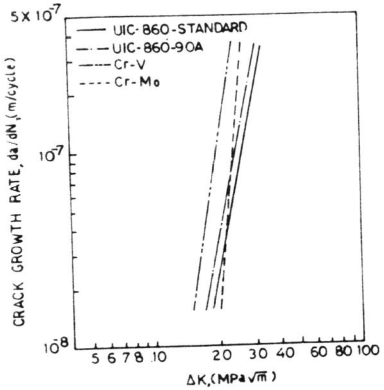

Fig.4: Fatigue crack growth rates in different grades of rail steels (f=5Hz, R=0.1, TPB specimens)

DISCUSSION

Fracture Toughness. Most of the specimens tested for all the four grades exhibited Type II load-displacement curves (E399,1976) (Fig.3). This behaviour is attributed to pop-in crack extension and has been observed in other grades of rail steels (Fowler 1976; Singh et al 1991; Fletcher et al 1977; Parsons 1980) Pop-in is a small amount (0.2-1.0mm) of abrupt crack extension and produces a corresponding discontinuity in the load-displacement test record obtained during the loading of a precracked specimen. It abruptly increases crack length as depicted in Fig.3.

Microstructure of standard rail contains ferrite at the prior austenite grain boundaries, whereas the other three grades of rail steels are fully pearlitic (Fig.2). It is evident from Table 3 that interlamellar spacing of pearlite for standard rail is wider compared to other three grades. Cr-Mo grade has the smallest interlamellar spacing. Coarser pearlite in the standard rail could deflect a crack and the presence of ferrite could prevent crack extension both producing a higher K_{pop} value.

In the other way, a lower yield strength and hardness values in the standard rail, produces a larger crack tip plastic zone (Irwin). This, in turn, could increase plastic energy dissipated at the crack tip at a given K_I value and correspondingly increases the K_{pop}.

The reported K_Q values have shown scatter. The different K_Q values in the identical specimen, are obtained due to the possible error in locating the exact origin of the load-displacement test record and due to non-linearity observed at the start of the test record as shown in Fig.3. The variation in the observed yield strength of the material from one location to another could also contribute to the observed scatter in the K_Q values.

Fracture toughness test results show that 90-A rail and Cr-Mo rail steel exhibit similar fracturre toughness. This result agrees with the finding of other investigations (Parsons 1980; Fletcher). However, Cr-V rail showed lower fracture toughness. The vanadium containing rail steels often contain the precipitates of vanadium carbide (Marich et al 1978; Rantanen et al 1979). The steel is strengthened by precipitates but at the sametime it may deteriorate the fracture toughness of the steel.

It is evident from Table 4 that the carbon and the Cr-Mo rails have better fracture toughness than the Cr-V rail.

Fatigue Crack Growth Rate: FCGR data were determined as per ASTM E647 procedure (E647-78T 1981). It is obvious from Fig.4 that the FCGR of standard rail is lower in comparison with other three grades. In the standard rail, the presence of pro-eutectoid ferrite along the grain boundaries of the prior austenite grains (Fig.2) could produce the lower FCGR. This observation is in agreement with the results reported elsewhere (Fowler 1976). The effect of a ferrite layer along the prior austenite grain boundary causes discontinuous crack growth from one grain to an adjacent one. The continuous ferrite layer surrounded by hard pearlite is responsible for the retardation of the crack growth.

The Cr-V rail has the highest crack growth rates among all the four grades investigated. The reason for the higher FCGR may be associated with the fact that the vanadium-containing rail steel often contain vanadium carbide-precipitates (Marich et al 1978). The FCGR values of 90-A and Cr-Mo rail steels lie between standard and Cr-V grades.

CONCLUSIONS

Wear resistant rail precessed through LD-CC route exhibited superior fracture toughness. Cr-V grade showed inferior fracture toughness probably due to the presence of vanadium carbide precipitates. Similar FCGR behaviour was observed for standard carbon, wear resistant and Cr-Mo grade rail steels.

Cr-V grade exhibited faster FCGR compared to the other three grades. Cr-Mo high strength rail can be used in situations where fatigue and wear are considered important.

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