IMPORTANCE OF KNOWING FRACTURE TOUGHNESS AND FATIGUE STRENGTH OF RAILWAY RAILS

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The basic requirements of UIC 860 V Codex of International Railway Union of railway rails quality and results obtained by determination of used materials fracture toughness and fatigue strength of rail steel grade 700, 900 A and 900 B from regular output of Zenica Iron and Steel Works are treated in the paper. The obtained results are compared with reference data and correlations between some properties as well as calculation of critical flaw sizes at rails are established making a contribution to traffic safety enhancement.

INTRODUCTION

Railway rails are in every day continuous use exposed to very severe demands permanently striving towards higher speeds and axle load increase in addition to safe vehicle guidance and carriage as well as longer operation life. For the purpose of providing these contradictory demands, manufactures are obliged by reaching world standards and UIC 860 V Codex to produce rails having properties as good as possible, especially with respect to: residual stress, non-metallic inclusion content and plane-strain fracture toughness (1). Two main values by which the increasing railway track load can be prevented are rail mass per metre (attained world increase is from about 45 to 77 kg/m) and tensile strength (increase from about 700 to 1200 N/mm^2). The increase in rail mass per metre provides higher moment of resistance and the increase in tensile strength mainly along with the change of chemical composition enables considerable increase of high yield point and so endurance of higher loads on

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railway tracks in addition to decreased material wear (2). The permissible increase in tensile as well as fatigue strength of rail steel could be achieved only by establishing the safety against fracture and corresponding material toughness expressed in terms of determination characteristics and a new important material charateristic - plain-strain fracture toughness (K_{Ic}). Knowing of K_{Ic} enables the establishing of dependence between critical flaw size in material and permissible stress. By timely periodic inspection of railway track condition using up-to-date ultrasonic detector car, the replacement of damaged rails can be done and fracture can be avoided preserving material property and human lives (3).

1. UIC 860 V Codex requirements

Technical delivery requirements of railway rails UIC 860 V - 1986/87 are in conformity with world trends in modern production of railway rails made of naturally hard steels (4 to 9).
The survey of specified values of chemical composition and tensile properties for four grades of naturally hard rail steels is given in Table 1.
According to Table 1 follows that increase in tensile streangth on rail steels is obtained by increasing the carbon, manganese, silicon and chrome content while required steel cleanness is obtained by decreasing the permissible content of phosphorus (P) and sulphur (S). A very adverse influence of phosphorus content in rail steels upon plain-strain fracture toughness values is shown in Figure 1 (5).

2. Results

Summary results of investigations of tensile property, plain-strain fracture toughness and fatigue strength of rail steels grade 700, 900 A and 900 B carried out on rail head specimens of 49 kg/m (Fig.2) is given in Table 2 (1o).
According to Table 2 and references (8 to 11) follows briefly that:

- tensile properties were completely in conformity with regulation of UIC 860 V Codex at all grade having been tested and specimens were made of 10 mm diameter out of sample from standard place (0 point in Fig.2).
The chemical composition of all heats tested (4 per grade 700 and 900 A and 1 per grade 900 B) has also given satisfactory results in conformity with those specified in Table 1;
- plain-strain fracture toughness was tested on limited number of three-point bend specimens of dimensions

TABLE 1 - Chemical composition, tensile strength and elongation of rail steel according to UIC 860 V 1986/87

Grade	Chemical composition of elements in %						Tensile strength $\sigma_{TS} = R_m$ /N/mm²/	Elongation, min. A_5/%/
	C	Mn	Si	Cr	P_{max}	S_{max}		
700	0,40-0,60	0,80-1,25	0,05-0,35	-	0,05	0,05	680-830	14
900 A	0,60-0,80	0,80-1,30	0,10-0,50	-	0,04	0,04	880-1030	10
900 B	0,55-0,75	1,30-1,70	0,10-0,50	-	0,04	0,04	880-1030	10
1100 *	0,60-0,82	0,80-1,30	0,30-0,90	0,80-1,30	(0,03)	0,03	≥ 1080	9

* The other alloying elements such as V and/or Mo,Nb can be used according to agreement between manufacture and buyer

TABLE 2 - Tensile properties, plain-strain fracture toughness and bending fatigue strength of rail steel tested

Mark: rail steel	Mark: values	Yield stress $\sigma_{YS} = R_{eH}$ /N/mm²/	Tensile strength $\sigma_{TS} = R_m$	Elongation A_5 /%/	Plain-strain fracture toughness K_{1c}/N/mm$^{3/2}$/	Bending fatigue strength R_{sd}/N/mm²/	Ratio R_{sd}/R_m
700	range	410-484	733-802	18-21,2	1261-(1860)	252-294	0,34-0,37
	mean	463	758	19,9	1526	273	0,36
900 A	range	534-570	963-980	10-12,4	1093-1478	294-326	0,31-0,33
	mean	549	972	11,0	1303	312	0,32
900 B	range	594	935	13,2	912-916	315-325	0,33-0,35
	mean	-	-	-	914	320	0,34

given in Fig. 3 in conformity with ASTM E 399-83 standard. In addition the valid values of steel grades 700 and 900 A were obtained with usual scattering of individual values while there were no enough samples of steel grade 900 B for more reliable estimate. The exception were two heats grade 700 with strength values lower than average values where specimen thickness condition was not satisfied. The obtained values of rail steel plainstrain fracture toughness are in good agreement with references (7 et al) quoted usual value range from 880 to 2050 $N/mm^{3/2}$. For the time being the determination of this very important material characteristic is required obligatory only by standard of People`s Republic of China (10);

- bending fatigue strength was tested quite extensive on standard rotating bar bending specimens of 10 mm diameter and 105 mm length with weight load and operating frequency of 50 Hz (base was 10 millions cycles). As follows from Table 2 there are correlations between bending fatigue strength and tensile strength which are also in good agreement with references (8 at al) and mostly meet complex requirements of general public transport in service. Just because of the fact that railway rails are the most important and the most loaded element of railway track equipment recently the permissible rail stress is determined according to Smith diagram of fatigue strength (11).

3. Calculation of critical flaw size

The application of "damage tolerant philosophy" according to Jones (12) implies that initial cracks in materials should not propagate under operating condition above critical size during expecting operation life. Therefore, the knowing of critical flaw size in rails is of great importance and its calculation is carried out in this paper by simplified formula for critical crack size a_c given in Fig. 4 for two usual values of permissible stresses $\sigma_{3\ doz}$ and $\sigma_{4\ doz}$. In the similar way the evaluation of rail resistance to transversal crack propagation in rail heads supposing to be the most dangerous damages for traffic safety is carried out in the world.

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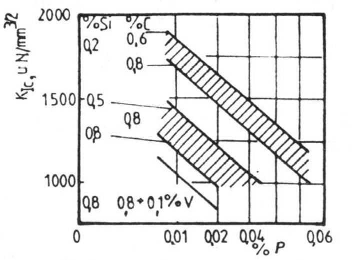


Figure 1 Phosphorus content (apscise) influence on K_{1c} (ordinate)

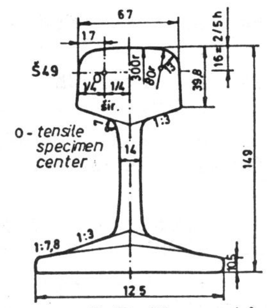


Figure 2 Rail section 49 kg/m

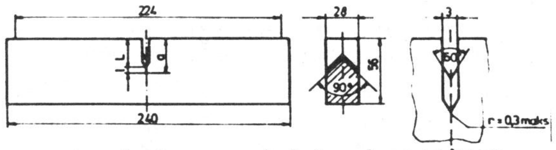
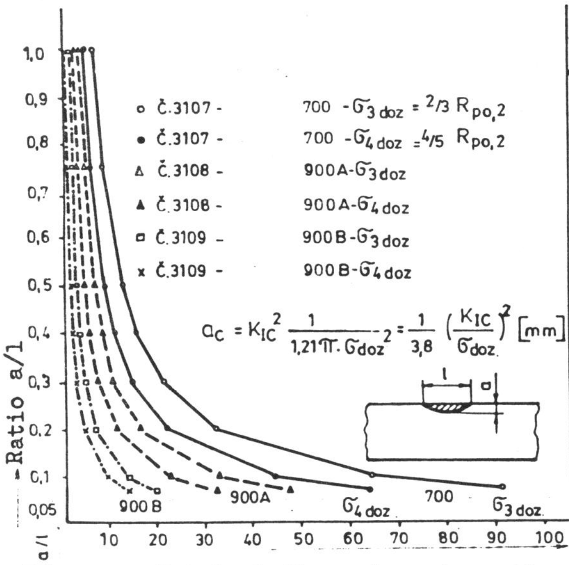


Figure 3 Three-point bend specimen



Average	Steel 700	900A	900B
K_{IC}	1526	1303	914
$R_{po,2}$	463	549	594
R_m	758	972	935
$\sigma_{3doz.}$	309	366	396
$\sigma_{4doz.}$	371	439	475

K_{IC} [N/mm$^{3/2}$]

$R_{po,2}$, R_m

σ_{doz} [N/mm^2]

Figure 4 Critical flow sizes in rails a_c, l_c and a/l for permissible stresses $\sigma_{3\ doz}$ and $\sigma_{4\ doz}$