DESIGN INDEX, U-FUNCTION AND ITS COEFFICIENTS IN LIFE-TIME (PRE)DETERMINATION OF MACHINE ELEMENTS AND MACHINERIES FOR DYNAMIC LOADING

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Abstract: Topical problem described in presented paper is the guarantee and reliability of life-time prediction of structures made from dynamically loaded weldable steels. Author explains the principles of ”the new method” of classification of steels with acceptation of non-dimensional design index R_e / R_m in (pre)determination of machines elements for dynamic loading. Calculations for one, two and three parametric influence of carbon content, yield strength R_e , tensile strength R_m and design index R_e / R_m on load ratio critical value R_{crit} using linear and non-linear statistic and statistical reliability fields are presented.

Key words: design index R_e / R_m ; crack tip closure ; low-strength and medium-strength weldable steels ; reliability of life-time prediction

1. Introduction

Choice of group of materials suitable for production of specific machines elements cannot be realized separately without relationship to others machines elements and final product as the structural unit. It must be successively applied at all levels of engineering design [1].

Application of methods of design of structure from structural materials in relationship to their properties in this way determines with monitored process the predicted life-time of machines elements, minimizes the risk of limited state formation and has significant role during its optimal choice [1,2].

The author with his research group acquired during many years research work a huge number of original results for Slovakian weldable structural 11373, 11503 and 11523 steels (used for static and dynamic loaded machines elements such as shafts, axle pins, flanges etc., for building of means of transport’s weldable structures, for bridge girder systems, parts of machines, heat devices and pressure vessels, for devices working in temperatures below normal etc). In paper presented method of using of non-dimensional design index R_e / R_m is original and allows the new view over previously obtained results.

Method of mechanical properties screening allows as well to estimate mechanical properties combinations. It can also become clue for systematic development of new progressive structural materials types [3,4,5,6,15,16,17,18].

Application of the non-dimensional design index R_e / R_m for classification of steels (with more objective and more significant statistical accuracy in stadium of design machines elements for dynamic loading) is presented in this paper.

2. Essence of the new approach for classification of steels for dynamic loaded machines elements and machineries using design index R_e / R_m

Tab. 1 gives comparison of low-strength and medium-strength Slovakian weldable 11373, 11503 a 11523 steels and similar foreign weldable steels, where influence of load frequency f, test specimens thickness B, carbon content, values of R_e and R_m , range of applied load ratios R, mean values of coefficients resp. validity ranges of Paris equation coefficients C and m, forms of U-function and so-called critical values of load ratio R_{crit} (if U-function equals to 1) and non-dimensional design index R_e / R_m is concerned. Air temperature was 20 ± 3 °C.

Structure of these steels after normalizing contains ferrite + pearlite.

Tab. 1
Comparison of chosen data for Slovakian weldable structural 11373, 11523 and 11503 steels and similar foreign structural weldable steels

material	Lit	C wt. %	R_e MPa	R_m MPa	f Hz	B mm	C m/cycle	m	form of U – function	R_{crit}
11373	[7]	0.15	235	372	5 ; 10	3	$3.95 \cdot 10^{-12}$	3.411	$U_1 = 0.65 + 0.561 \cdot R + 0.427 \cdot R^2$	0.460
11523	[8]	0.172	355	580	10	3	$5.346 \cdot 10^{-13}$	4.012	$U_2 = 0.709 + 0.411 \cdot R + 0.106 \cdot R^2$	0.612
11503	[9]	0.18	465	596	10	3	$6.335 \cdot 10^{-13}$	3.879	$U_3 = 0.702 + 0.413 \cdot R + 0.074 \cdot R^2$	0.650
AISI304	[10]	0.08	298	583	20	6	$8.52 \cdot 10^{-11}$	2.48	$U_4 = 1 / (1.5 - R)$	0.50
SM-50	[11]	0.13	360	530	140	2.7		3.55	$U_5 = 0.65 + 0.561 \cdot R + 0.427 \cdot R^2$	0.46
AISI1018	[12]	0.14	380	550	5		$8.5 \cdot 10^{-11}$	2.5	$U_5 = 0.65 + 0.561 \cdot R + 0.427 \cdot R^2$	0.46
Fe510	[13]	0.187	460	630	10	3	$7.24 \cdot 10^{-13}$	3.96	$U_6 = 0.69 + 0.45 \cdot R$	0.68
Fe510	[14]	0.187	460	630	20	6	$6 \cdot 10^{-13}$	4.0	$U_7 = 0.75 + 0.35 \cdot R + 0.05 \cdot R^2$	0.675

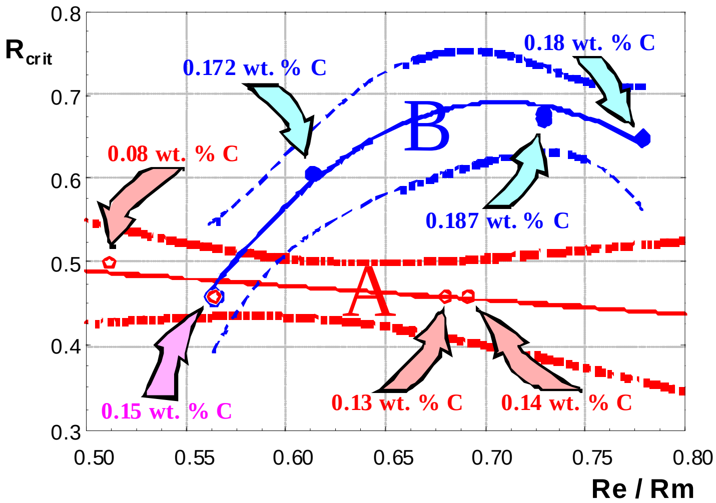

Fig. 1 Classification of steels (see tab. 1) using design index R_e / R_m versus R_{crit} dependence with presentation of 95 % confidence interval for the specific statistics :

group of steels – region A ... selected steels with < 0.08 ; 0.15 > wt. % C

group of steels – region B ... selected steels with < 0.15 ; 0.187 > wt. % C

3. Interpretation of 1-parametric (C , R_e , R_m , R_e / R_m) influence on load ratio critical value R_{crit}

Labelling " region **C** " used in next part of the paper means that statistic calculation with presentation of 95 % confidence interval for the specific statistics was realised in the case of all selected steels with < 0.08 ; 0.187 > wt. % C .

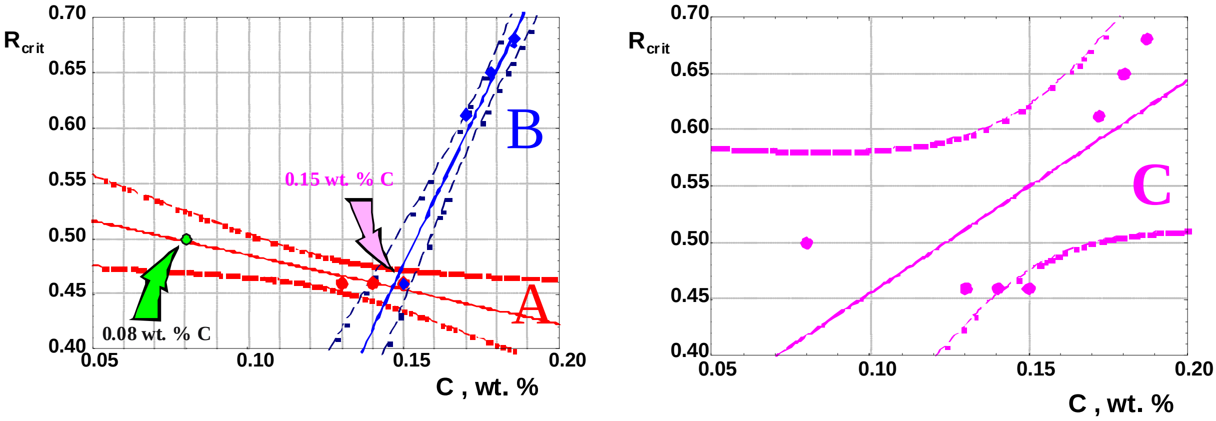

Fig. 2 Influence of carbon content [wt. %] on load ratio critical value R_{crit} of Slovakian weldable 11373, 11503 and 11523 steels and similar foreign steels with 95 % confidence interval for the specific statistics :

left : region A ... selected steels with < 0.15 wt. % C

region B ... selected steels with < 0.15 ; 0.187 > wt. % C

right : region C ... all steels without carbon content consideration

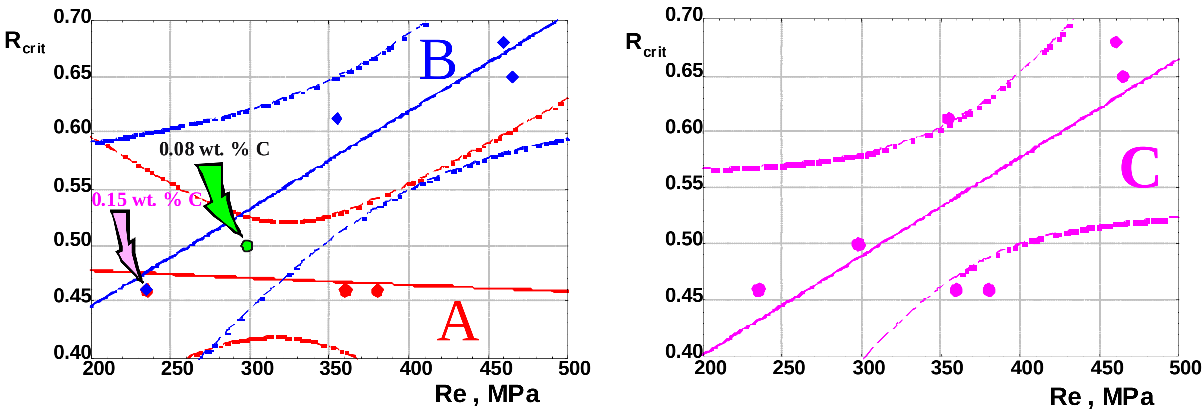

Fig. 3 Influence of yield strength R_e on load ratio critical value R_{crit} of Slovakian weldable 11373, 11503 and 11523 steels and similar foreign steels with 95 % confidence interval for the specific statistics :

left : region A ... selected steels with < 0.15 wt. % C

region B ... selected steels with < 0.15 ; 0.187 > wt. % C

right : region C ... all steels without carbon content consideration

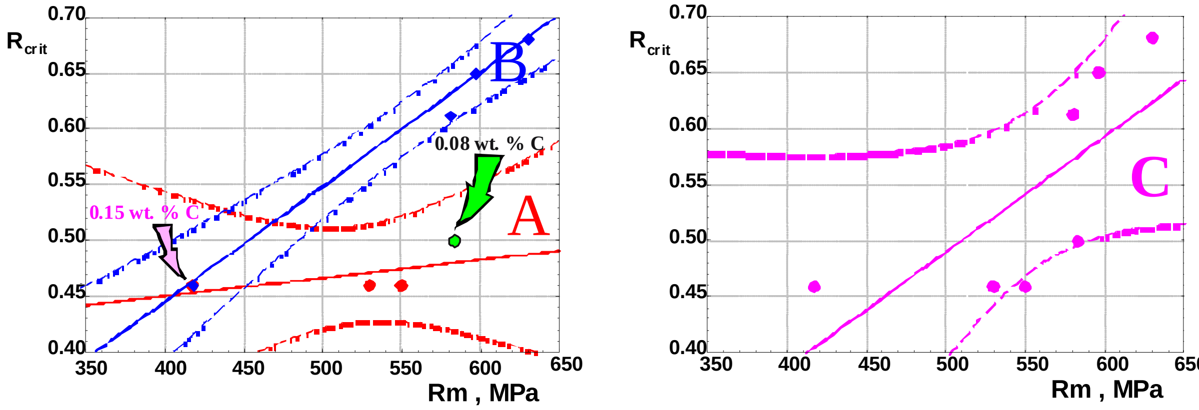

Fig. 4 Influence of tensile strength R_m on load ratio critical value R_{crit} of Slovakian weldable 11373, 11503 and 11523 steels and similar foreign steels with 95 % confidence interval for the specific statistics :

above: region A ... selected steels with < 0.15 wt. % C
region B ... selected steels with < 0.15 ; 0.187 > wt. % C
bellow:region C ... all steels without carbon content consideration

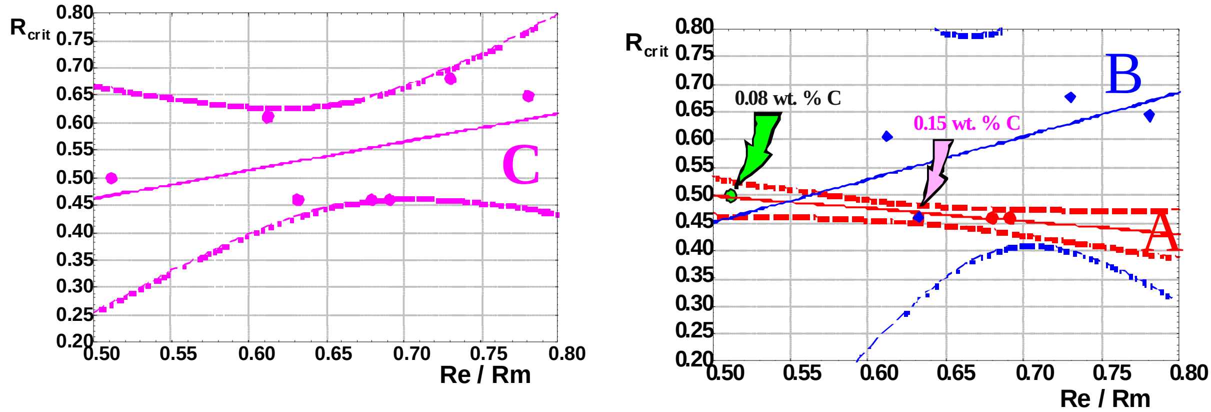

Fig. 5 Influence of design index R_e/R_m on load ratio critical value R_{crit} of selected Slovakian weldable steels and similar foreign steels with 95 % confidence interval for the specific statistics :

left : region A ... selected steels with < 0.15 wt. % C
region B ... selected steels with < 0.15 ; 0.187 > wt. % C
right : region C ... all steels without carbon content consideration

4. Interpretation of 2-parametric (C + R_e , C + R_m , R_e + R_m) influence on load ratio critical value R_{crit}

Results of predetermination using 2-parametric (C + R_e , C + R_m , R_e + R_m) influence on load ratio critical value R_{crit} are given in table data bellow for 95 % statistic reliability.

regression form: $R_{crit} = a_0 + a_1 \cdot (C , wt. \%) + a_2 \cdot (R_e , MPa)$	confidence region **C**	confidence region **B**
coefficient a_0 – point estimation	-0.1506	-0.3819
coefficient a_0 – interval estimation	-0.3082 ; 0.007035	-1.4456 ; 0.6819
coefficient a_1 – point estimation	3.6387	5.5941
coefficient a_1 – interval estimation	2.3905 ; 4.8869	-3.4724 ; 14.6606
coefficient a_2 – point estimation	0.0003246	0.00004346
coefficient a_2 – interval estimation	$-2.7 \cdot 10^{-5}$; $6.76 \cdot 10^{-4}$	-0.00134 ; 0.001429
correlation index I_{yx}	0.988	0.993
coefficient of determination D , %	97.69	98.65

regression form: **$R_{crit} = a_0 + a_1 \cdot (C , wt. \%) + a_2 \cdot (R_m, MPa)$**	confidence region **C**	confidence region **B**
coefficient **a_0** – point estimation	-0.2326	-0.1574
coefficient **a_0** – interval estimation	-0.3805 ; -0.08474	-0.5676 ; 0.2528
coefficient **a_1** – point estimation	3.4583	2.4366
coefficient **a_1** – interval estimation	2.3678 ; 4.5488	-2.7119 ; 7.5851
coefficient **a_2** – point estimation	0.0004226	0.0006062
coefficient **a_2** – interval estimation	$7.7 \cdot 10^{-5}$; 0.000768	-0.00029 ; 0.0015
correlation index I_{yx}	0.992	0.998
coefficient of determination D , %	98.43	99.74

regression form: **$R_{crit} = a_0 + a_1 \cdot (R_e , MPa) + a_2 \cdot (R_m , MPa)$**	confidence region **C**	confidence region **B**
coefficient **a_0** – point estimation	-0.1063	0.08339
coefficient **a_0** – interval estimation	-1.0099 ; 0.7973	0.02265 ; 0.1441
coefficient **a_1** – point estimation	-0.00006509	0.0002366
coefficient **a_1** – interval estimation	-0.00313 ; 0.002996	$3.8 \cdot 10^{-5}$; 0.000435
coefficient **a_2** – point estimation	0.001250	0.0007686
coefficient **a_2** – interval estimation	-0.00219 ; 0.004694	0.000543 ; 0.000994
correlation index I_{yx}	0.825	0.999
coefficient of determination D , %	67.99	99.94

5. Interpretation of 3-parametric (C + R_e + R_m) influence on load ratio critical value R_{crit}

Results of predetermination using 3-parametric (C + R_e + R_m) influence on load ratio critical value R_{crit} given in table data bellow are specified for 95 % statistic reliability.

regression form: **$R_{crit}=a_0+a_1 \cdot (C,wt.\%)+a_2 \cdot (R_e,MPa)+a_3 \cdot (R_m , MPa)$**	confidence region **C**	confidence region **B**
coefficient **a_0** – point estimation	-0.2283	0.02148
coefficient **a_0** – interval estimation	-0.4979 ; 0.04133	-1.1246 ; 1.1676
coefficient **a_1** – point estimation	3.4596	0.6793
coefficient **a_1** – interval estimation	2.0165 ; 4.9028	-11.6896 ; 13.0483
coefficient **a_2** – point estimation	0.00002088	0.0001946
coefficient **a_2** – interval estimation	-0.00088 ; 0.000919	-0.00083 ; 0.001218
coefficient **a_3** – point estimation	0.0004001	0.0006976
coefficient **a_3** – interval estimation	-0.00067 ; 0.00147	-0.00081 ; 0.002204
correlation index I_{yx}	0.992	0.999
coefficient of determination D , %	98.43	99.96

6. Conclusion

Application of non-dimensional design index R_e/R_m support made available the more objective and at the same time more statistic accurate classification of same previously obtained results predicted fatigue life-time.

Specifically, the boundary between steels with carbon content from the range <0.08; 0.15>wt. % C (when load ratio critical value R_{crit} equals nearly constant) and steels with carbon content from the range < 0.15 ; 0.187 > wt. % C (if load ratio critical value R_{crit} depends on design index R_e/R_m value) was defined using non-dimensional design index R_e/R_m.

Designer can use presented obtained results of estimation in this way:

- presented obtained results of the point and interval estimation obtained from 2-parametric ($C + R_e$, $C + R_m$, $R_e + R_m$) influence on load ratio critical value R_{crit} , that are more accurate than results of prediction using 1-parametrical influence (higher values of correlation index I_{yx} and coefficient of determination D) ,
- presented obtained results of the point and interval estimation obtained from 3-parametric ($C + R_e + R_m$) influence on load ratio critical value R_{crit} are the most accurate - more accurate than results of prediction using 1-parametrical and 2- parametrical influence (higher values of correlation index I_{yx} and coefficient of determination D) .

Literature

1. ASHBY, M.F.: Multiobjective optimalization in material design and selection. Acta Materialia, 48, 2000/2, 359-369.
2. STRNADEL, B.: Design struktury a vlastností konstrukčních materiálů při jejich optimalizovaném výběru. Zborník z konferencie Nové Město na Moravě. 2001.
3. SCHIJVE, S.: Fatigue crack closure, observation and technical significance, ASTM STP 982, Philadelphia, 1988, 214-221.
4. ZHANG, G. et all.: Crack propagation studies on AL 7475 on the basis of constant amplitude and selective variable loading histories.
5. VÁRKOLY, L. - VÁRKOLYOVÁ, B. et al.: Fatigue failure of material - theory and solved examples. ES ŽU Žilina, 1998, 235 s.
6. VÁRKOLY, L. - VÁRKOLYOVÁ, B. et al.: Únavová odolnosť materiálov používaných pri konštrukcii dopravných prostriedkov. In Materials and technologies. Žilina, 1999, 56-80.
7. VÁRKOLY, L. – POČAROVSKÝ, M.: Štúdium uzatvárania čela únavových trhlín v oceliach strednej pevnosti – časť I. Materiálové inžinierstvo č. 2, roč. 7, 2000, 59-72.
8. VÁRKOLY, L. – ČINČALA, M.: Štúdium uzatvárania čela únavových trhlín v oceliach strednej pevnosti - časť II. Materiálové inžinierstvo, č. 4, roč. 7, 2000, 65-72.
9. VÁRKOLY, L.: Uzatváranie čela únavových trhlín v oceliach nízkej a strednej pevnosti. Materiálové inžinierstvo, č. 1, roč. 8, 2001, 49-54.
10. KURIHARA, J. M. - KATO, P. J.: Analysis of Fatigue Crack Closure Caused by Asperities Using the Modified Dugdale Model. Metallurgical Transactions A – Phys. Metal. & Mat. Science, 1996, p. 459-474.
11. YOKOBORI, T. – SATO, K.: The effect of frequency on fatigue crack propagation rate and striation spacing in Al2024-T3 aluminium alloy and SM-50 steel. Engineering Fracture Mechanics, 1996, 81-88.
12. LIAW, P.K.: Long fatigue cracks – microstructural effects and crack closure. MRS bulletin, 1989, 25-35.
13. DILLING, J.: Report 6-78-2. Stevin Laboratory, TU Delft, 1999.
14. VEER, F. A. - DRIJVER, F. P.: Fatigue Crack Growth Along a Flash Welded Joint Between a High Strenght and a Low Strenght Steel, Varna, 1992.
15. McEVILY, A.: On crack closure in fatigue crack growth. ASTM STP 1982, Philadelphia, 1988, 35-41.
16. SIKLIENKA, M. - ČERNECKÝ, J.: Zariadenie na meranie napätia. Proc. of XXXVIth conference of the Departments of Machine parts, Brno, 1995, pp. 117-119.
17. DVOŘÁK, I.: Degradační procesy a mezní stavy. VA Brno, 1995.
18. VÁRKOLY, L. – VÁRKOLYOVÁ, B.: Spoľahlivosť predikcie únavovej životnosti konštrukcií z nízko a stredne-pevných zvariteľných ocelí. Zborník z medzinárodnej vedeckej konferencie TRANSFER 2003, Trenčín, 2003.