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LIMIT STATE CAUSES IN ELEMENTS WITH CRACK

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Abstract: *This paper shows the problem is that fatigue doesn't submit under up to date criterion of limit states, taking into consideration that allowed fatigue strength in the area of engineering construction submitted to variable strains, is lower from limit state. At high cyclic fatigue is far lower. And at low cyclic slightly lower, but in the domain of plastic deformation. At endurance prognosis for problem solution it is necessary to analyze changes in elements with damage which causes limit states.*

Key words: *fracture design, crack development, endurance, railway vehicles*

1. INTRODUCTION

Changes in elements with crack that because limit states in theirs first approximation are defined by: stress state in crack growth zone and growth law, material strength – sensitiveness to cracks, material crystal lattice characteristics, corrosive stress and corrosive fatigue. [1]

2. STRESS STATE IN CRACK GROWTH ZONE

General condition of material destruction (1) with existing damage with limited size, for the general load case in conditions of flat deformation, defines values for allowed stress concentration strength round the crack tip, i.e. the elliptic surface of limited crack fracture toughness (fig. 1). Strength measures for stress singularity for the all deformation shapes (according to Grifit: an energy to crack surface unit, necessary for formation of the new fracture surface behind the crack tip), are limited by the surface of limit fracture toughness of a crack. Evaluation for resistance to fracture at the condition of non destruction is directly defined from the general destruction condition (1): for quasi-clean tearing in the conditions of flat deformation KI≤KIc, or KI ≤ Kc, in conditions of stress flat state; and analogously; for quasi-clean sliding in a plain, KII≤ KIIc; and for quasi-clean share, KIII≤ KIIIc.

$$\left(\frac{K_I}{K_{Ic}}\right)^2+\left(\frac{K_{II}}{K_{IIc}}\right)^2+\left(\frac{K_{III}}{K_{IIIc}}\right)^2=1 \quad (1)$$

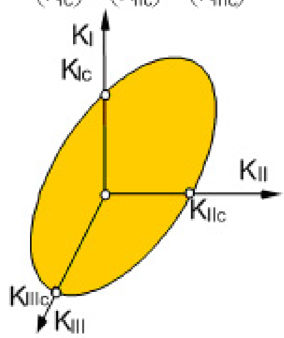

Fig.1. Material deterioration elliptic surface

Direction of possible destruction from the condition (1) can be determined with previous definition about basic laws for influence of main causes to crack growth and they are:

- In plastic zone stress trajectory and it's expected maximum for the condition that the crack growth direction is normal to the direction of maximum normal stresses action.

- Shape of plastic zone by application of plastic criteria: -maximum tangential stresses or limit energy criterion for shape change.

It is emphasized that with larger element thickness, under the state conditions when plastic and stress zones have flat deformation, stress concentration rapidly grows in plastic zone (round circle opening σ_y =3 σ_T, and plastic zone diameter is even 9. times smaller).

Material sensitiveness to cracks can be easily defined through factors that control fracture due to fatigue: level of acting stress σd, critical crack length lcr, fracture toughness at flat deformation KIc, and influence of local residual stresses, temperature, parameter values as a function of material fracture toughness with the flat deformation etc.

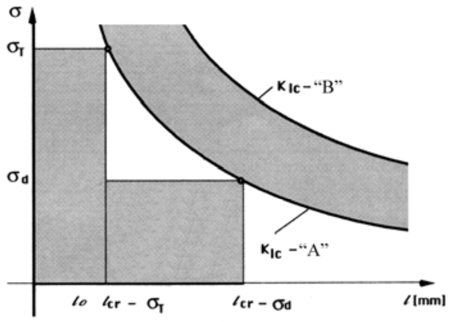

Fig.2. Material quality effect to fracture

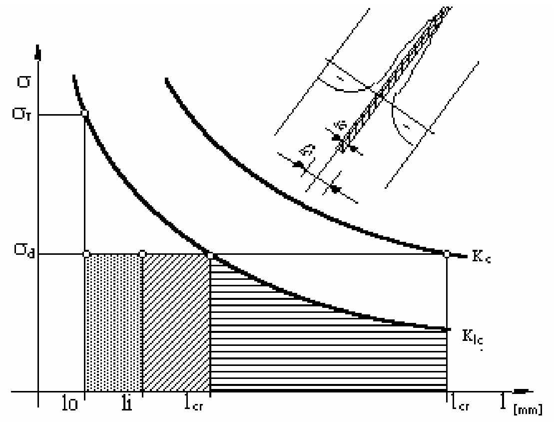

Fig. 3. Influence of local residual stresses near weld
On horizontal axes:
$l_0 \div l_i$ (residual stress σ_d,) $l_i \div l_{cr}$(KIc) for σ_d;
l_{cr} (KIc) $\div l_{cr}$ (Kc) changing from KIc to Kc

Figure 2. shows an effect when applying material with higher strength values against fracture "B". Actual stress can be equalized with achieved stress on small range, in ranges of high residual stresses, so lcr should be defined for σ_T instead for σ_d, (l_0 =lcr). When the both, basic metal and welded metal, are strong enough (for instance material "B" fig. 2), lcr is also satisfactory for totally achieved load. At loading with material fatigue, taking into consideration that the crack can grow outside a zone of residual stress, lcr should be defined on the level of σ_d, because it is not material constant, but σ_d, function. This doesn't apply to state structures with initial load – (monocle wheels), i.e. crack dullness caused by high residual stresses. Materials with low values of KIc can be applied in cases with decrease of σ_d during strain; action of preventing crack initiation; stress rearrangement that causes initiation, growth and the crack is directed to reduction stress area, or it is not oriented towards critical plain of unstable spread cause (case of "scaling" on rails).

Figure 3. shows an influence effect from local residual stresses on to fatigue crack increase and also shows an effect of conditions caused by flat deformation and flat stress state crack "loss" due to local weakening of material strength in residual tension ranges. Never the less that in period of following stresses, regions close to weld can hardly show elastic behaviour as a response to stress, there shouldn't be early damage, because plastic behaviour relies on redistribution of local stress concentration.

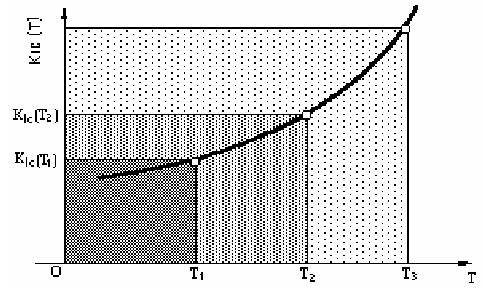

Fig. 4. Diagram of temperature influence on fracture toughness

Definition *lcr* for σ_d and material thickness analysis is required here. For high *l*cr values, sub critical growth of fatigue crack is a cause for stress weakening, which results in stress in plane or elastic-plastic behaviour. *l*cr is determined by accomplished stress at elements where appearance of cracks is expected, and than *l*cr is compared to maximum possible value from the basis of possible technology of manufacture and inspection. For high strength materials any crack that appears should be hold rapidly, so it doesn't leave high residual stress range (l_0 fig. 3.). The effect is small at crack fatigue growth.

Figure 4. shows temperature influence on strength in conditions of flat deformation KIc (Ti). Figure 5. shows the effect of *l*cr decrease for the same level of σ_d with decrease of KIc at

the temperature decrease. Figure 6 shows the change of parameter n in equation Paris-Erdogan $d\ell/dN = \alpha(\Delta K)^n$ for different values KIc for material steel with mean and high strength.

From the diagram: $n > 3$ for $KIc < 60\,MN^{-3/2}$ and $n = 2 \div 4$ for elastic-plastic behaviour.

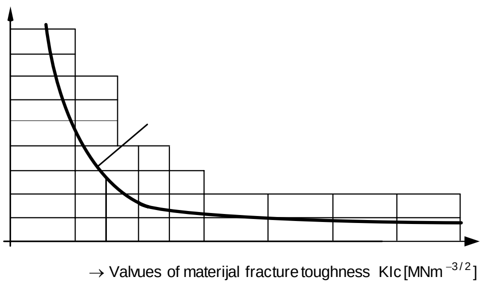

Fig. 6. Curve for exponent values n = f (KIc)

3. MATERIAL CRYSTAL LATTICE – CAUSE OF LIMIT CONDITIONS

Material crystal lattice is characterized on the basis of influence to strength and metallurgical influence – when non-metal inclusions act as deformation centre and reduce the initiation period of cracks due to fatigue, location in not homogeneity structural is a crack start.

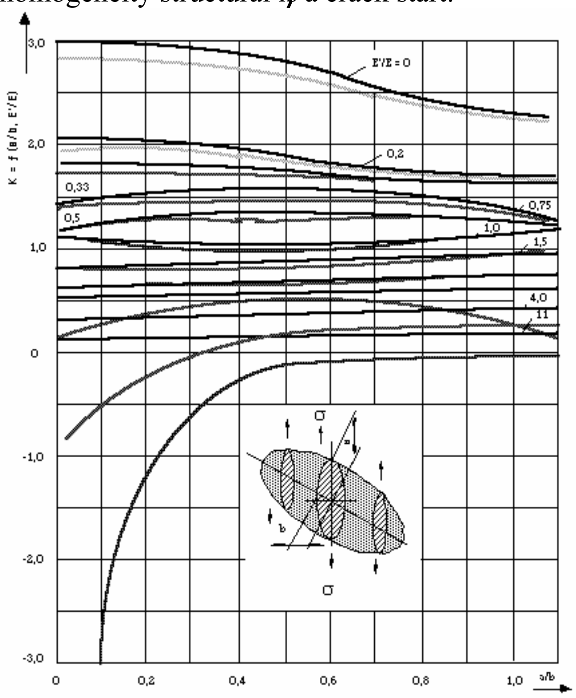

Fig. 7. Values of coefficient which shows ellipsoidal inclusion influence
K = f (E'/E and a/b)

That can cause fatigue or brittle fracture in the latest stadium.

Figure 7. shows importance of inclusion expressed by coefficient K= f (a/b, E'/E), where a/b is relation of half axes of inclusion with ellipsoidal shape and modules of elasticity E', and E is modules of elasticity for the element's basic material.

Coefficient is maximal ($K = 3 \div 2,8$) for all half axes relations of ellipsoidal inclusions a/b=0÷1 and for E'/E=0 (modules of elasticity of inclusion is extremely small), and for E'/E = 1 and $a/b = 0,1 \div 0,75$ value K ≈ 1.

Presence of impurities in the shape of rough bubbles brings to creation of closed "islands", disturbs integrity, reduces carbon contents, which causes ferrite structure and strength reduction

Hydrogen "flakes" are consequence of cracking of closed hydrogen islands in steel during cooling, which reduces creation period of fatigue cracks. Smaller longitudinal hydrogen flakes (on tracks) are more common during slower cooling, but during fast cooling, piles of longitudinal and transversal hydrogen flakes are created.

Nitrogen, during aging of unstable steels, partly changes carbon in carbides and increases influence of intrude metal phases (sigma and Laves), which bring to fracture.

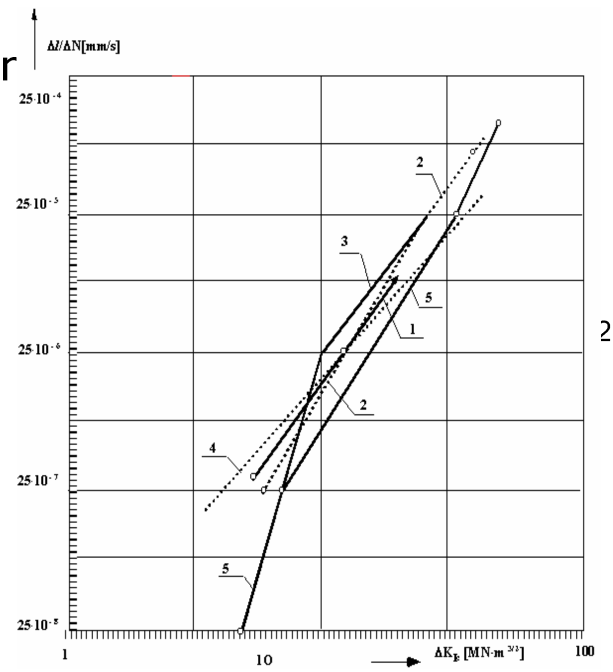

Fig. 8. Change of crack speed growth with a change of ΔK. 1 - soft steel, 2-marten sit released to 100°C, 3 - marten sit released to 200°C, 4 - marten sit released to 500°C,
5 - Bain at

Piles of carbon atoms round dislocations and presence of nitrogen and water cabinetries lead to steel hardening and brittle incensement.

Inimical in contents of P, S, C, O, H oxides, accumulated sulphides, nitrides, carbonizes etc.

in the shape of parallel surfaces arranged by high, bring to appearance of woody crack. Annealing only covers with marten sit structure. On working temperature $200^{\circ}C$ and higher, marten sit decomposes, plastic state increases and woody appears again due to temperature decrease. At welded ferrite steels, from fracture mechanics viewpoint, dependence of crack growth speed as tearing is significant - $d\ell/dN$ with change of range ΔK (fig. 8.). Despite the difference in chemical composition, microstructure and mechanical characteristics, tested steels $\sigma_T = 400 \div 1300$ Mpa have almost same strength $400 d\ell/dN = 10^{-1} \div 10^{-3}$ to crack spreading – described by relation $d\ell/dN = 5 \cdot 108 \Delta K^{-2,7}$.

6. CONCLUSION

All performed analysis of limit condition causes in purpose for duration definition accuracy and fracture control interval (manufacture design) it is suggested:

a) For ultra hard steels with $K_{Ic} > 0,5 \cdot \sigma_{02}$, as the main cause of limit state take corrosive area condition on crack length - relation: $\ell = 0,2 \cdot (K_{Ic}/\sigma_{02})^2$.

b) For practical, apply experimental equation as a function of cyclic characteristics of fracture toughness: $d\ell/dN = \begin{Bmatrix} (0, & za\ 0 \le K \le Kth) \\ \alpha \cdot \Delta K^n, & za Kth \le K \le Kfc \\ \infty, & za\ K \succ Kfc \end{Bmatrix}$ and apply empiric dependence between cyclic K_{fc} and static fracture toughness $K_c\ (K_{Ic})$: $K_{fc} = (0,5 \div 0,6) K_c$, (instead of K_{fc} to crack growth speed $3 \div 4 \cdot 10^{-3}$ mm/cycle and K_{th} to crack growth speed $3 \div 4 \cdot 10^{-7}$ mm/cycle).

Parameters of cyclic material strength to fatigue cracks α and n and cyclic toughness of the beginning of crack controlled growth K_{th} determine according to correlative empiric equations connected to σ_{02} and σ_v $[N/m^2]$: $\log \alpha = 0,056\sigma_v - 13,72$ and $n = 4,52 - 0,0026 \cdot \sigma_{02}$, $K_{th} = 12,7 - 0,006 \cdot \sigma_{02} [N/m^{3/2}]$.

Function of asymmetry cycle $R = 0 \div 0,9$:

$K_{th,R} = K_{th,0} - (11,37 - 0,0065 \cdot \sigma_{02})\ [N/m^{3/2}]$.

For martens and nickels steels values are satisfactory for $K_c = 230\ N/m^{3/2}$ and $K_{Ic} = 95\ N/m^{3/2}$; for carbon steels $K_c = 64\ N/m^{3/2}$ and $K_{Ic} = 32\ N/m^{3/2}$.

In relation $d\ell/dN = \alpha \cdot \Delta K^n$ for elastic-plastic material behaviour, values are satisfactory for $n = 2 \div 4$. For thermal cracks created during braking $\alpha \approx 0,5$, and $n \approx 2,45$. For welded ferrite steels apply relation $d\ell/dN = 5 \cdot 108 \Delta K^{-2,7}$.

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ПРИЧИНИ ЗА ГРАНИЧНОТО СЪСТОЯНИЕ В ЕЛЕМЕНТИ С ПУКНАТИНА

Надежда ШУБАРА

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Резюме: *Докладът разглежда проблема, че умората не се подчинява на съвременните критерии за гранични състояния, като се вземе пред вид, че разрешената сила на умората в областта на инженерните конструкции, подложени на променливо напрежение, е по-ниска от граничното състояние. Умората при висока цикличност е доста по-ниска. А при ниска цикличност е малко по-ниска, но в областта на пластичните деформации. При прогноза за издръжливостта, за да се реши проблемът, е необходимо да се анализират промените в елементите с повреди, което причинява граничното състояние*

Ключови думи: *проектиране на счупването, развитие на пукнатината, издръжливост, железопътно возило.*