GENERAL CRITERIA FOR INCREASING SAFETY FROM FATIGUE FRACTURE

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Summary

The primary factors which characterize susceptibility to fracture because of fatigue are: work level stress, level of given strain, size of fissure, abruptness of discontinuity, strength of materials at a particular temperature and thickness. They define three general suggestions for minimizing fatigue fracture:

1. The reduction of work strain level;
2. Reduction of the minimal discontinuity, improvement of manufacturing technology and control for the same level of work strain;
3. Use of materials with improved strength resistant to appearance and development of fractures.

The application of principles for prevention of fractures and increased structure inspect ability, use of highly fracture resistant materials, control of fractures caused by growth of fatigue fissures and stress transfer are possible methods for increasing structure effectiveness.

1. INTRODUCTION

The chosen method for increasing safety from fatigue fracture can build upon major past experiences under minimum strength criteria, and does not always have to be for the purpose of maintaining limiting material strength. Adjustments in order to establish adequate security factors may be performed based on work condition facts, with material quality, which maintains required safety, and without life cycle costs.

Prognosis of total useful endurance of components of railway vehicle structure in relation to growth of fatigue material crack is a function of necessary time for initializing and a time to critical crack development. Region of initialization is limited to a very narrow discontinuity or to a crack growth, which becomes measurable and outspreads due to material fatigue. Sub critical crack growth can be described with one of the existing growth "lows", and then crack enters in aria of sudden growth which brings to the failure, or creep, which results lost of a part or a structure. According to previous, component durability can be prolonged with increase of endurance until initialization or until critical crack growth in designing process.

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2. GENERAL DESIGNING CRITERIA

General designing criteria for increasing fracture safety are already applied; however fracture mechanics postulates characterize process more quantitative. Here in essence, having in mind that size of stress intensity limit component K_{Ic} that describes stress state round crack top can be expressed by relation e.g.

$$K_{Ic} \equiv C \cdot \sigma \sqrt{\pi \cdot l_{cr}}$$

Where: C – Factor in function of crack geometry and structural element shape;
σ - Known work load;
l_{cr} - Critical crack length which results fractures.

Critical crack length l_{cr} is expected that increase of K_{Ic} (fracture toughness at flat deformation) or decrease of σ has larger effect to crack resistance than decrease of initial crack size l_0. At the same time, control of σ and K_{Ic} is easier than of initial crack size l_0. General condition of material destruction 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. Strength measures for stress singularity for the all deformation shapes are limited by the surface of limit fracture toughness of a crack [1] and [4]. When, e.g., primary parameter, which influences speed of sub critical crack growth, i.e. component K_I (for quasi-clean tearing in the conditions of flat deformation [1] and [4]) (or ΔK - see Paris-Erdogan $dl/dN = \alpha(\Delta K)^n$, dependence of crack growth speed as tearing is significant - *dl/dN* with change of ranges of fluctuation of stress intensity ΔK [1] and [4]) increases on a level larger than two, then the decrease of σ (or $\Delta\sigma$) will bring to significant increase of useful endurance K_{Ic} at the majority of construction elements. It can be established that:

I – Decrease of structural stress, or stress fluctuation, for same production quality and control, as well as for the same limiting material strength K_{Ic} – at straight strain or, K_c - at straight stress state, results new larger safety margin. It is larger in relation to fatigue fracture, or expanded durability to fatigue appearance, taking into consideration the possibility of larger sub critical crack growth before discontinuity damage (Fig.1).

II – Improvement of production quality and control at usage of the same level of structural material stress has for the goal minimizing of initial discontinuity (Fig.1.).

III – Appliance of structural material with improved crack strength K_{Ic} for same structural stress results new discontinuity safety margins (Fig.1.).

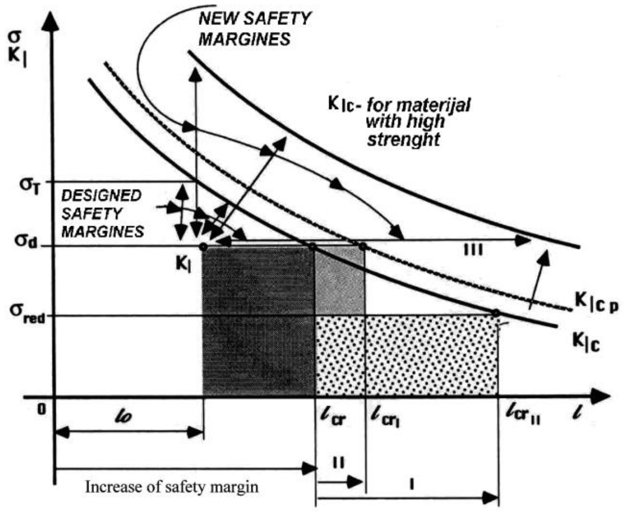

Fig.1. Illustration of appliance of general criteria for increase of safety of fatigue fracture [1] and [3]

Specific approach of fracture control of structural elements like railway vehicle depends on working condition characters and following general parameters:

- for known working structural load, changes of structural stress can be noted at primary basic fracture control, in consideration that reduced level of structural stress significantly reduces crack growth;
- for insufficiently correct defined working load of element, use of constructive materials with good strain on crack appliance and propagation – K_{Ic} is desirable;
- for complex welded structure like railway vehicle, where production quality and control techniques are not so precisely defined like at other types of structures (e.g. aircraft) recommendation are materials with some determinate minimum of strain level on appearance and spread of crack;
- relatively low level of strain can be tolerated only for elements of known working load and control level that is capable to control fracture due to fatigue;
- For elements where damage effects cannot be tolerated (designing safety criterion – e.g. railway vehicle wheel set) all factors that influence fatigue fracture have to be controlled.

Effect of three integral primary factors of control of structural sensitivity on damages: dilatation stress levelσ, crack size l and material strain on cracks K_{Ic}, for completely endurable structures exposed to load till material fatigue appearance, can be analyzed with appliance of illustrative diagram on Fig.2.

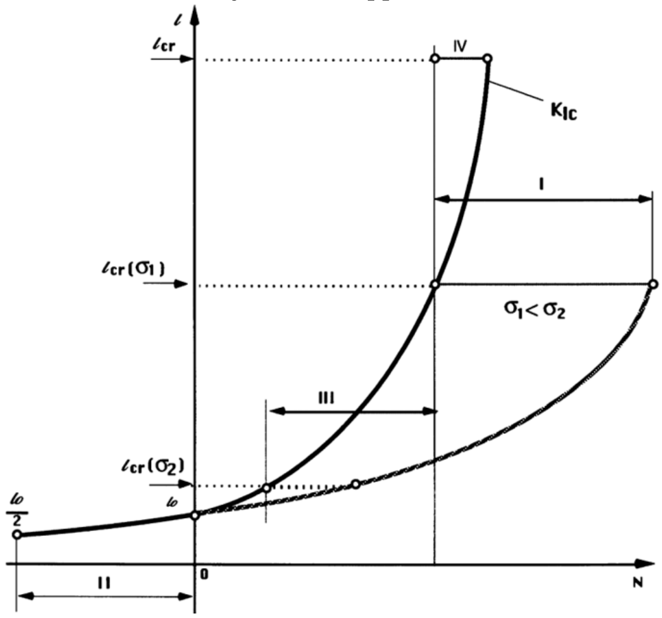

Fig.2. Illustration of primary factors for fatigue fracture control [1] and [3]

In area I (Fig.2.) can be seen that great effect on improvement of endurance has significant decrease of fatigue crack growth speed as a result of stress scope decrease ($\sigma_1 < \sigma_2$). Primary factor to fracture influence is here the scope of structural stress ($\sigma_{\max} - \sigma_{\min}$).

In area II (Fig.2.) can be seen that great effect on improvement of endurance is consequence of very low growth speed at inherent small fatigue cracks. Here the primary factor for crack safety is quality of production and control.

In area III (Fig.2.) great improvement of endurance is consequence of transition of material behavior from straight-elastic dilatation into elastic-plastic state. This level of behavior is secured by the demands for increased strength at average load speeds.

For low effect on endurance in area IV (Fig.2.) on transmission from elastic-plastic to plastic behavior, cause is the great crack growth speed that stays big without consideration of doubled or tripled critical size of crack length l_{cr}. Here the effect on endurance is insignificant, but has a positive influence on change of way of damage.

Beside general criteria for increase of fracture safety an appliance of less known is also recommended:

- method of appliance of highly resistant materials which doesn't fracture due to fatigue even at the most severe working conditions for the structure, which is in essence an extreme case of already prominent method of appliance of material with improved strength on appearance and growth of crack;
- Method of fracture control on the basis of crack growth due to fatigue that is based on a fact that initialization, crack growth and fracture occurrence are functions of fluctuation of stress intensity ΔK and K_{Ic}. At the same time, they are in a function of projected stress (fluctuation of working stress). Method is reviewed on (Fig.2.);
- Method for fracture prevention due to fragility is not insoluble. For low to average load speeds strength K_{Ic} is satisfactory, disregarding that K_{Id} is small at load speeds with contact. Possibility of fracture here is significantly reduced, which means that load speed control is an effective method for fracture control.

3. CONCLUSION

General nature of designing of all types of big complex structures accepts existence of damage, especially for naturally expected overloads. Aim of engineering project is optimized structural behavior consistent with economics speculations, so that the probability of structural damage is minimized. All factors that refer to strength criterion have to be considered and economic decision in function of technical data for given levels of specified behavior has to be defined. Established level of behavior (plain stress, elastoplastic or plastic behavior) for working load and conditions has to be the basis for specifying of materials and determinate strengths. For the majority of structural changes due to fatigue, criterion of satisfactory behavior presents certain moderate level of elastic-plastic behavior in working temperature conditions and a speed of operating loads.

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