SLOVENSKI STANDARD
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Železniške naprave - Ocenjevanje odpornosti konstrukcije železniških vozil - 3. del: Ocena odpornosti proti utrujenosti na podlagi kumulativne škode

Railway applications - Strength assessment of railway vehicle structures - Part 3: Fatigue strength assessment based on cumulative damage

Bahnanwendungen - Festigkeitsnachweis von Schienenfahrzeugstrukturen - Teil 3: Betriebsfestigkeitsnachweis

Applications ferroviaires - Évaluation de la résistance des structures de véhicule ferroviaire - Partie 3 : Évaluation de la résistance à la fatigue basée sur la méthode des dommages cumulés

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Railway applications - Strength assessment of railway vehicle structures - Part 3: Fatigue strength assessment based on cumulative damage

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European foreword

This document (prEN 17149-3:2021) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This document is currently submitted to the CEN Enquiry.

This document is part of the series EN 17149 *Railway applications — Strength assessment of railway vehicle structures*, which consists of the following parts:

— Part 1: General

— Part 3: Fatigue strength assessment based on cumulative damage

The following part is under preparation:

— Part 2: Static strength assessment

Introduction

If a fatigue strength assessment is necessary for railway vehicle structures, this assessment may be made with an endurance limit approach or a cumulative damage approach.

An endurance limit approach is based on the assessment of the stress amplitudes (e.g. derived from the design load cases or from measurements) against the applicable endurance limit. Such an approach is established in combination with the normative loads such as those defined in EN 12663 series or EN 13749.

A fatigue strength assessment based on cumulative damage takes into consideration stress spectra with varying amplitudes and numbers of cycles or stress time histories. This document provides the basic procedure and criteria for a pragmatic method to be applied for fatigue strength assessments based on the cumulative damage approach.

The main body of the document is based on the nominal stress approach, but the consideration of variable amplitudes and cycles counts according to methods described in this standard may equally be applied with the structural stress and the notch stress approach (additional information is included as informative annexes).

Within this document the term fatigue strength assessment is always related to the cumulative damage approach unless otherwise noted.

1 Scope

This document specifies a procedure for fatigue strength assessment of rail vehicle structures based on cumulative damage.

It is part of a series of standards that specifies procedures for strength assessments of structures of rail vehicles that are manufactured, operated and maintained according to standards valid for railway applications.

This document is applicable for variable amplitude load data with total number of cycles higher than 10 000 cycles.

An endurance limit approach is outside the scope of this document.

The assessment procedure of the series is restricted to ferrous materials and aluminium.

This document series does not define design load cases.

This document series is not applicable for corrosive conditions or elevated temperature operation in the creep range.

This series of standards is applicable to all kinds of rail vehicles; however it does not define in which cases a fatigue strength assessment using cumulative damage is to be applied.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 15085-3:2007[1)], *Railway applications — Welding of railway vehicles and components — Part 3: Design requirements*

prEN 17149-1:202X[2)], *Railway applications — Strength assessment of railway vehicle structures — Part 1: General*

ISO/TR 25901-1:2016, *Welding and allied processes — Vocabulary — Part 1: General terms*

3 Terms and definitions

For the purposes of this document, the terms and definitions, symbols and abbreviations given in ISO/TR 25901-1:2016 and prEN 17149-1:202X apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

[1)] document impacted by AC:2009.

[2)] under development.

4 Stress determination

4.1 General

The stress spectrum used to perform the fatigue strength assessment based on cumulative damage approach shall be expressed in terms of stress amplitudes, mean stresses and number of cycles to represent the design life.

The design stress spectrum shall incorporate any necessary allowance to account for uncertainties in their values. If relevant, this may be achieved by application of a partial factor γ_L on the representative stress spectrum as specified in the application code. In 6.2 recommendations and requirements for the partial factor γL are given.

NOTE EN 12663 series, EN 15827 and EN 13749 contain information on how to determine design loads for cumulative damage assessment of railway vehicles.

The combination of the individual stress components direct and shear is considered in 7.5.

4.2 Parent material

The stresses for the parent material shall be determined by the nominal stress approach as described in prEN 17149-1:202X.

4.3 Welded joints

4.3.1 Modified nominal stresses

The modified nominal stresses for welded joints shall be determined according to prEN 17149-1:202X, 5.3.

4.3.2 Structural stresses and notch stresses

For the fatigue strength assessment of welded joints, the structural stress approaches and the notch stress approach may be applied. For the application of these approaches, the requirements for the calculation of the relevant stresses and fatigue strength is described in the following informative annexes:

— Annex H for the structural stress approach and

— Annex I for the notch stress approach.

5 Fatigue strength

5.1 Parent material

5.1.1 General

This clause describes the method for a derivation of the fatigue strength of parent material under the following conditions:

— materials used such as construction steel, weldable cast steel, cast iron (GJS and ADI), wrought steel, cast aluminium, and wrought aluminium;

— application temperature up to 100 °C for aluminium and up to 200 °C for steel;

— plane stress tensor on the components surface (no significant stress component perpendicular to the surface, e.g. press fit connection).

The restrictions defined above are met with most applications of parent material for railway vehicles, in which case a simplified assessment method is appropriate. If the scope of the application is exceeded, an assessment method shall be chosen which accounts for the specific application (e.g. high temperatures and 3-dimensional stress states).

Annex C gives an overview over the applicable material factors.

5.1.2 Component fatigue strength $\Delta\sigma_{\mathrm{R}}$ and $\Delta\tau_{\mathrm{R}}$

The fatigue strength is specified by S-N curves, which define the values of the component fatigue strength $\Delta\sigma_{\mathrm{R}}$ and $\Delta\tau_{\mathrm{R}}$ (in N/mm^2, unless stated otherwise) related to:

— $N_C = 10^6$,

— stress ratio $R_\sigma = R_\tau = -1$,

— survival probability of $P_s = 97{,}5\ \%$,

— membrane stresses.

The values of the component fatigue strength are determined with the following formulae:

$$\Delta\sigma_{\mathrm{R}}(N_C = 10^6, R_\sigma = -1) = R_{\mathrm{m}} \cdot f_{\mathrm{R},\sigma} \cdot f_{\mathrm{SR},\sigma} \cdot f_{\mathrm{R,C}} \quad (1)$$

$$\Delta\tau_{\mathrm{R}}(N_C = 10^6, R_\tau = -1) = R_{\mathrm{m}} \cdot f_{\mathrm{R},\tau} \cdot f_{\mathrm{R},\sigma} \cdot f_{\mathrm{SR},\tau} \cdot f_{\mathrm{R,C}} \quad (2)$$

5.1.3 Material properties

5.1.3.1 Tensile strength according to material standards $R_{\mathrm{m,N}}$

$R_{\mathrm{m,N}}$ is the nominal tensile strength according to the material standards considering the actual sheet thickness. For milled components, the thickness before milling (semi-finished product) shall be considered.

For rolled sheets and extrusions an anisotropy factor f_{A} shall be considered in the direction transverse to the main direction of rolling in accordance with Table 1, unless this is already considered or explicitly excluded in the material standard or component specification. For other material applications $f_A = 1{,}0$.

$$R_m = f_A \cdot R_{m,N} \quad (3)$$

Table 1 — Anisotropy factor f_A for steel and aluminium

Material	$R_{m,N}$ [N/mm²]	f_A
Rolled Steel	≤ 600	0,9
	> 600 ≤ 900	0,86
Rolled sheets and extrusions of aluminium	≤ 200	1,0
	> 200 ≤ 400	0,95
	> 400 ≤ 600	0,9
All other material applications		1,0

For heat-affected zones in the vicinity of welded joints the nominal tensile strength for the heat-affected zone $R_{m,HAZ}$ shall be used instead of R_m. The value for $R_{m,HAZ}$ shall be derived from technical literature (e.g. [2], [5]).

5.1.3.2 Tensile strength specified by drawing or specification $R_{m,S}$

Alternative to a material standard, the mechanical properties may be specified by the drawing or specification.

$R_{m,S}$ is the tensile strength according to a drawing or component specification. If higher values than those defined in the material standards are specified for $R_{m,S}$ and the values are checked only by random testing, then the specified values are not sufficient reliable and therefore would be non-conservative to use for the purposes of a fatigue strength assessment. To perform a fatigue strength assessment with a survival probability of P_S = 97,5 % the tensile strength $R_{m,S}$ defined by the drawing or component specification shall be reduced according to the following:

$$R_m = 0{,}94 \times R_{m,S} \qquad (4)$$

The value of 0,94 is applicable if the strength value is checked by three random tests (e.g. hardness test or tensile test). For other numbers of tests, this value shall be adjusted according to technical literature (e.g. [2]).

If a validated P_S = 97,5 % value within the component is available, this value may be used without further reduction.

The $R_{m,N}$ values defined in material standards for a given wall thickness may be used for the purposes of fatigue strength assessment with a survival probability of P_S = 97,5 %.

5.1.3.3 Influence of technological size

The assessment method described in this standard does not make any adjustment for the wall thickness of the component. The strength properties used shall consider the appropriate wall thickness.

For components made from semi-finished products the strength properties shall consider the wall thickness of the original semi-finished product.

5.1.3.4 Influence of application temperature

If the component operating temperature remains within the scope of applicability defined by this standard, no further adjustment to account for the application temperature is required for the fatigue strength assessment.

5.1.4 Design Parameters

5.1.4.1 Surface roughness factor f_{SR}

The surface roughness factor f_{SR} is dependent on the nominal tensile strength R_m, the surface roughness R_Z and the manufacturing process and is defined by Formula (5) and Formula (6).

$$f_{SR,\sigma} = 1 - a_{R,\sigma} \cdot \log\frac{R_Z}{[\mu m]} \cdot \log\frac{2 \times R_m}{b_R} \quad (5)$$

$$f_{SR,\tau} = 1 - f_{R,\tau} \cdot a_{R,\sigma} \cdot \log\frac{R_Z}{[\mu m]} \cdot \log\frac{2 \times R_m}{b_R} \quad (6)$$

$a_{R,\sigma}$ und b_R are given in Table 2. $f_{R,\tau}$ is given in Table 4.

Table 2 — Factors $a_{R\sigma}$ and b_R for steel and aluminium

Material	$a_{R,\sigma}$	b_R [N/mm²]
Steel (rolled or forged)	0,22	400
Steel castings	0,20	400
Spheroidal graphite cast iron (GJS)	0,16	400
Ausferritic spheroidal graphite cast iron (ADI)	0,16	400
Aluminium	0,22	133
Cast aluminium	0,20	133

Typical values of the surface roughness R_Z are given in Table 3.

Table 3 — Typical values for R_Z

R_Z [µm]	Example
20	Machined surface
25	Plasma or laser cut plate edges of steel, before shot blasting
50	Oxyfuel flame cutting of steel
80	Roughly machined surface; Shot blasted rolled sheet surface; Rolled sheet and extrusions of aluminium
200	Rolled sheet surface of steel, not shot blasted; Forging steel; Casting surface; Plasma or laser cut plate edges of aluminium

If explicit values for surface roughness are defined in the drawing or component specification those values shall be used for the fatigue strength assessment. When applied to castings the benefit of machined surfaces is only applicable if the machined surface is free from surface breaking defects.

For plate edges of rolled sheets the following requirements shall be applied:

— Sharp corners and surface rolling flaws shall be removed by longitudinal grinding;

— cracks or visible gouges are not permitted;

— weld repairs are not permitted (should be treated as welded joint);

— notch effects due to shape of edges shall be considered;

— minimum corner radius or chamfer 1 mm;

— all burrs shall be removed.

For plate edges of steel manufactured by plasma and laser cut the surface roughness factor $f_{S,R}$ shall be reduced by the factor 0,94 and for thermal cut by the factor 0,81.

For plate edges of aluminium, manufactured by plasma or laser cut a surface roughness of R_z = 200 µm shall be applied independent of the actual surface roughness to account for the local metallurgical effects. An improvement in the surface roughness factor is only applicable if the affected material (typically 2 mm) is completely removed by machining after cutting.

The values are valid for nominal stress without the consideration of any stress gradients perpendicular to the surface. In case of a stress gradient perpendicular to the surface (e.g. stress concentration) the influence of the surface roughness may be reduced according to technical literature, e.g. [2].

5.1.4.2 Influence of stress gradient

In the assessment method described in this standard the benefit for the fatigue strength associated with the stress gradient perpendicular to the surface at the assessment location is not included in the fatigue strength values.

The beneficial effects of stress gradients may be considered according to technical literature, e.g. [2].

5.1.4.3 Influence of surface treatment

As a conservative approach in this simplified assessment method the benefit for the fatigue strength associated with the surface treatment (e.g. peening) is not included.

The beneficial effects of the surface treatment may be considered according to technical literature, e.g. [2].

5.1.5 Fatigue strength factors for normal and shear stresses $f_{R,\sigma}$ and $f_{R,\tau}$

For the determination of the component fatigue strength (stress range) for parent material the fatigue strength factors given in Table 4 shall be used. These fatigue strength factors are related to $N_C = 10^6$ cycles and a stress ratio of R = -1 and correspond to a survival probability of P_S = 97,5 %.

Table 4 — Fatigue strength factors for normal and shear stresses related to $N_C = 10^6$ cycles

Material	$f_{R,\sigma}$	$f_{R,\tau}$ [a]
Steel (rolled or forged)	0,75	0,577
Steel castings	0,57	0,577
Spheroidal graphite cast iron (GJS)	$0{,}42 + \frac{117\ \text{N/mm}^2}{R_m}$	0,65
Ausferritic spheroidal graphite cast iron (ADI)	$\frac{295\ \text{N/mm}^2}{R_m}$	0,7
Aluminium	0,6	0,577
Cast aluminium	0,6	0,75
[a] Ratio between the fatigue strength of shear stress and the one of direct stress.		

NOTE For steel castings and spheroidal graphite cast iron, the fatigue strength factors fR,σ given in Table 4 are derived according to [2] (fatigue strength factor for alternating direct stresses fw,σ). The fatigue strength factors represent the fatigue strength ratio with respect to stress range, these factors include a margin of 1,2 as given in [2] to cover uncertainties. For aluminium, the fatigue strength factors given in Table 4 are determined according to test results.

5.1.6 Fatigue strength factor for castings $f_{R,C}$

The NDT-level and the corresponding cast quality level applied for castings have an influence on the fatigue strength values for the local assessment point within the cast component. The fatigue strength factor for castings $f_{R,C}$ accounts for the effects of any remaining defects on the fatigue strength within the casting component. For all non-casting components $f_{R,C}$ = 1,0.

In the case of structural castings, it is necessary to specify the quality requirements with respect to the permitted volumetric and surface defect levels to guarantee the mechanical properties to be achieved in regions subjected to high stresses. The relevant mechanical properties and quality requirements shall be verified according to the component specification.

The fatigue strength factor for castings $f_{R,C}$ shall be chosen in accordance with the cast quality achieved in the cast component. If no specific data is available, Table 5 shows values which may be used for local assessment points of the casting depending on the NDT-level during production and the verified quality level according to Annex B.