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Harmonization and improvement of fracture mechanical design codes for steel constructions

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ABSTRACT

The fracture mechanics based methodology used to develop the Charpy-V transition temperature criteria in the Eurocode 3 standards EN1993-1-10 and EN1993-1-12, combined with an extension of the original method to higher yield strengths, is used to estimate impact toughness influence factors q_i in line with the crane standard EN 13001-3-1. The inherent conservatism in the present Eurocode 3 methodology is quantified and new transition temperature requirements accounting for the built in conservatism in EN 1993-1-10 and EN 1993-1-12 are obtained in the form of a simple table based on the sum of the influence factors $\sum q_i$. The new requirements are universal, i.e. they do not correspond to a specific material standard or sub-grade. The requirements are only a function of the sum of the influence factors $\sum q_i$. The results can be extended to lower transition temperature requirements, if for the applied steels such transition temperatures can be fulfilled.

1. Introduction

The Eurocode 3 sections EN 1993-1-10 [1] and EN 1993-1-12 [2] contain tables for the maximum permissible values of element thickness as a function of steel grade, quality and reference design temperature. The tables cover steel strengths from S235 to S700 and section thicknesses above 10 mm. The tables have been constructed based on a fracture mechanical brittle fracture analysis using a Charpy-V impact energy criterion as reference.

Ultra high strength steels above 700 MPa with strengths up to 1300 MPa are not covered by the tables in EN 1993-1-10 and EN 1993-1-12. Such steels are generally used in thinner sections than 10 mm, when the tables are limited to section thicknesses above 10 mm. Recently an extension of the procedure [3], used to generate the tables in EN 1993-1-10 and EN 1993-1-12, to higher strength steels, has been developed [4]. The extension is based on recent work looking at the fracture toughness temperature dependence and Charpy-V correlation [5–7] for ultra high strength steels.

Presently there are some standardised Charpy-V impact energy criteria covering also ultra high strength steels. One example of such criteria is given in the crane general design standard EN 13001-3-1 [8]. It is applicable to yield strengths up to 1300 MPa. It makes use of so called impact toughness influence factors q_i that are a function of operation temperature, strength level, thickness, stress, and fatigue class. For each property influence a specific q_i value is determined and the sum of the individual q_i values determines the Charpy-V impact criterion. The table in EN 13001-3-1 specifying the individual q_i

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Nomenclature

$K_{appl,d}$	applied stress intensity factor corresponding to a reference stress of 100 MPa
Mk	stress intensity correction factor
T	temperature
T_{ed}	design temperature
N	number of fatigue cycles
Y	stress intensity factor
a_0	initial flaw size in EN 1993-1-10
a_d	design flaw size
b	square bar long side dimension
c_0	initial flaw length in EN 1993-1-10 = $2.5 \cdot a_0$
d	round bar diameter
$f_{Rd}\sigma$	limit deign stress = fy/1.1
f_y	nominal yield strength
h	square bar thickness dimension
q_i	fracture mechanical influence factor
t	section thickness
t_0	normalization thickness = 1 mm
$\Delta\sigma_c$	stress range = Fatigue class
ΔT	built in conservatism in EN 1993-1-10 expressed in the form of a temperature shift
$\Delta T\sigma$	adjustment for stress and yield strength of material, crack imperfection and member shape and dimensions"
σ_0	reference stress = 100 MPa
σ_{Ed}	design stress in EN 1993-1-10
σ_{Sd}	design stress in EN 13001-3-1
σ_y	yield stress
$\sum q_i$	sum of influence factors q_i
J0	steel quality definition according to EN 10025-2
J2	steel quality definition according to EN 10025-2
JR	steel quality definition according to EN 10025-2
M	steel quality definition according to EN 10025-4
MC	steel quality definition according to EN 10149-2
N	steel quality definition according to EN 10025-3
NC	steel quality definition according to EN 10149-3
Q	steel quality definition according to EN 10025-6
QL	steel quality definition according to EN 10025-6

values is reproduced in Table 1 [8]. The Impact toughness requirement and corresponding steel quality for $\sum q_i$ is then identified in another table reproduced here as Table 2 [8].

The use of influence factors q_i, is a simple and elegant method of evaluating the effect of different factors on the brittle fracture propensity, provided that the weight parameters have the correct impact. In a previous study [9], the EN 13001-3-1 criteria were compared to EN 1993-1-10 for the steel strength 355 MPa. It was found that there are large discrepancies between EN 13001-3-1 and EN 1993-1-10. In [9] this was attributed to different basis of the criteria. The EN 1993-1-10 criteria are based on fracture mechanics and experiments with wide plates. The background for the criteria in EN 13001-3-1, are mainly based on operation experience end empirical extrapolation.

The tables in EN 1993-1-10 and EN 1993-1-12, based on reference design temperature, are somewhat difficult to use for structural optimisation, since they only give values for a specific case. The effect of changing yield strength or thickness is not clearly evident from the tables. The procedure with influence factors is much more flexible in this respect. Therefore, here the fracture mechanics based EN 1993-1-10 and EN 1993-1-12 tables, including the extension to higher yield strengths [4], are transformed into influence factors in line with EN 13001-3-1. Further, there is a considerable inherent conservatism built into the procedure [3] behind EN 1993-1-10 and EN 1993-1-12. This conservatism is quantified and a new table, based on the influence factors, is developed for impact toughness requirement and corresponding steel quality. The results of this work can be used to harmonize different European brittle fracture toughness requirements.

2. Influence factors

The table in EN 1993-1-10 is given in terms of a reference design temperature T_{ed}. The standard table is reproduced in Table 3 [1] and the extension to higher yield strengths in Table 4 [4].

Table 1 contains influence factors for separate parameters covering: operation temperature, material yield stress, material thickness, stress range and utilization of static strength. The physical significance of the influence factors in Table 1 is not

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