Low-Temperature Fracture Toughness Estimates for Very High Strength Steels

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The lack of design rules limits the application of Very High Strength Steels (VHSS). One critical point limiting their use lies in their poorly documented low-temperature fracture properties in relation to more conventional steels. The two major concepts governing the assessment of steel construction codes are the Master Curve (MC) methodology and the $T_0$-TC$_{V28J}$ transition temperature correlation. Focusing on novel, directly quenched, high-performance steels, we investigated the applicability of the Master Curve methodology with special emphasis on the low-temperature region and checked the validity of the standard $T_0$-TC$_{V28J}$ transition temperature correlation. Improvements to the criteria are proposed for further consideration.

INTRODUCTION

Although Very High Strength Steels (VHSS) with nominal strengths up to 1200 MPa have been available on the market for many years, the use of these steels in the civil engineering industry is still rather uncommon due to the lack of design rules and manufacturing experience, scarcity of special sections, and undue conservatism in the design limit of the current structural application of VHSS. The introduction of EN 1993-1-12 (CEN, 2007) permits the use of steels up to S700, but steels with higher yield strength are not yet covered in any code. One critical point limiting the use of VHSS steels lies in their rather poorly documented low-temperature fracture properties in relation to more conventional steels covered by the codes.

There are two major concepts governing the assessment of steels in EN 1993-1-12 (CEN, 2007). They are the Master Curve (MC) methodology (Wallin, 1999) and the $T_0$-TC$_{V28J}$ transition temperature correlation (Wallin, 1989). The Master Curve methodology provides a description of the fracture toughness scatter, size effect, and temperature dependence for both the transition region and the lower shelf. It enables a complete characterization of a material’s brittle fracture toughness on the basis of only a few small-sized specimens. The method combines a theoretical description of the scatter, a statistical size effect, and an empirically found temperature dependence of the fracture toughness. The fracture toughness in the brittle fracture regime is thus described by only one parameter, the transition temperature $T_0$ (see Fig. 1). At this temperature, the mean fracture toughness for a 25.4-mm-thick specimen is 100 MPa$\sqrt{m}$.

The Master Curve method is applicable to ferritic structural steels and has been standardized by the American Society for Testing and Materials in ASTM E1921-16, Standard Test Method for Determination of Reference Temperature, $T_0$, for Ferritic Steels in the Transition Range (ASTM, 2016). The standard defines ferritic steels as “typically carbon, low-alloy, and higher alloy grades. Typical microstructures are bainite, tempered bainite, tempered martensite, and ferrite and pearlite. All ferritic steels have body-centered cubic crystal structures that display ductile-to-cleavage transition temperature fracture toughness characteristics” (ASTM, 2016). It is the first fracture toughness testing standard that gives advice on the use of the test result. Presently the standard is limited to steels with yield strengths ranging from 275 to 825 MPa.

The fact that a single parameter ($T_0$) fully describes the fracture toughness in the brittle fracture regime has enabled the correlation between $T_0$ and the 28 J Charpy-V transition temperature TC$_{V28J}$. The first correlation between TC$_{V28J}$ and the transition temperature corresponding to 100 MPa$\sqrt{m}$ fracture toughness was presented by Marandet and Sanz (1977). However, they did not consider the effect of thickness on the fracture toughness transi-