Correlation between Fracture Toughness and Charpy-V Impact Data of Duplex Stainless Steels

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ABSTRACT

Duplex stainless steels are ideal for steel structures exposed to low temperatures and fatigue loading. However, it has to be guaranteed that brittle fracture is avoided in low temperature applications due to the fact that duplex stainless steel shows a toughness-temperature transition behaviour as known from carbon steel.

The objective of this contribution is to present the development and validation of the Master Curve concept and to show the applicability of the transition temperature correlation for duplex stainless steels based on experimental fracture toughness and Charpy-V impact tests.

KEY WORDS: Duplex stainless steel; Fracture toughness; Weldment; fracture toughness tests; Charpy-V impact tests, Master Curve.

INTRODUCTION

Due to their high mechanical strength, excellent corrosion resistance in highly corrosive environments, and low maintenance costs, duplex stainless steels are ideal for steel structures exposed to low temperatures and fatigue loading. The use of duplex stainless steel has increased significantly over the last twenty years in steel bridge constructions, (Mameng et al., 2018). However, it has to be guaranteed that brittle fracture is avoided in low temperature applications.

In European standards, the choice of material to avoid brittle fracture for carbon steel is covered in EN 1993-1-10 based on a fracture mechanics based concept. The European design standard for stainless steel structures, EN 993-1-4, refers to different types of stainless steel including duplex stainless steels to be used only down to -40 °C service temperature because the knowledge about the low temperature toughness behaviour of duplex stainless steels was insufficient. For this reason, design rules had to be developed covering the specific low temperature toughness behaviour of duplex stainless steels. These rules have recently been developed on the basis of EN 1993-10 and have been implemented in the revised version of the draft (prEN 1993-1-4, 2022) in such a way that maximum permissible element thicknesses depending on the steel strength, its toughness, the applied stress level and the reference temperature are given in accordance to the procedure used for EN 1993-1-10. The fracture behaviour of steel material is influenced by various parameters like plate thickness, degree of cold forming and weldments and its sub parameters like the welding process and type of filler material. The experimental determination of the fracture toughness according to (ASTM E1820-20b, 2020) covering all these different parameters is very time consuming but necessary as simpler and less expensive Charpy-V impact tests according to (ISO 148-1, 2016) do not provide any information about how the material resists a crack from growing and can only be used as qualitative tests to have a comparison between different base materials. However, a correlation between fracture toughness and Charpy-V impact data is a possible tool to assess the fracture toughness of duplex stainless steel as already shown for carbon steel, see (Stranghöner, 2006), (Sedlacek et al., 2008). For this reason, in the frame of the German national FOSTA research project “P 1390”, a comprehensive investigation was started to develop a fracture mechanics based concept for various duplex stainless steels for the choice of duplex stainless steel material to avoid brittle fracture. One of the objectives of this project is to validate the Master Curve concept and the applicability of the transition temperature correlation for duplex stainless steels based on experimental fracture toughness and Charpy-V impact tests. This contribution presents the results of these investigations.

TRANSITION TEMPERATURE CORRELATION AND MASTER CURVE CONCEPT

Based on EN 1993-1-10, the fracture mechanics concept relies on a transition temperature correlation combined with a Master Curve approach for temperature dependent fracture toughness (Stranghöner, 2006), (Sedlacek et al., 2008).

The transition temperature correlation between the temperature at a Charpy-V impact toughness of 27 J (T27J) and the temperature at a fracture toughness of 100 MPa\(\cdot\)m (T100), is described by the so-called modified Sanz-Correlation, see Eq. 1, (Wallin, 1989) (Sedlacek et al., 1993, 2008).

\[
T_{100} = T_{27J} - 18 \pm 2 \cdot \sigma
\]

where \(\sigma\) is the standard deviation (\(\sigma = 13 ^\circ C\)).

The Master Curve is given by Eq. 2 according to (Wallin, 1990, 1994, 2011) to describe the fracture toughness of materials and weldments. where \(b_{eff} = 5 \cdot a_0\) for plates with a semieliptical surface crack, \(a_0\) is the design crack depth at which brittle fracture occurs and \(P\) describes the