Assessment methods to avoid brittle failure of old steel structures

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Summary

Although many structures made of mild steel erected during the period between 1890 and 1940 are still in service after decades, there is usually no need to replace them. When assessing these existing steel structures to be able to decide on necessary rehabilitation and reinforcement measures engineers require information about the mechanical as well as the technological properties of the material. Additionally, it is essential to quantify the level of reliability against brittle failure. In contrast to conventional tests such as the impact test, fracture mechanics is suitable for appropriate assessment against brittle fracture of riveted or bolted structures made of old mild steel.

Keywords: mild steel; Thomas steel; brittle fracture; embrittlement due to ageing; transmission towers; weldability; notch impact test; tensile test; fracture mechanics; J-integral

1. Introduction

Many iron and steel structures were built during the fast development of new materials, methods of calculation and construction in the end of the 19th Century and at the turn of the 20th Century. These structures are partly still in use today. A profound knowledge about old metallic materials and their specific properties as well as about suitable assessment and analyzing methods is a basic requirement for a precise approach to the repair and maintenance of old steel structures.

2. Brittle fracture of members made of mild steel

In addition to determining the level of the structural safety, the proof of sufficient material toughness (safety against brittle failure) is essential in the assessment of existing steel buildings and steel bridge structures and for the decision on necessary rehabilitation and reinforcement measures. This particularly applies in connection with construction or manufacturing notch effects, the question of the weldability of the material as well as deterioration caused by existing fatigue cracks.

The present assessment methods in Europe to avoid brittle failure are normatively regulated in the standard EN 1993-1-10. The methods are based on fracture mechanics and were developed for welded structures made of current steel grades with high toughness. Assuming a bad construction detail (welded transverse and longitudinal stiffener) and an associated initial crack length, the required material toughness is determined by the R6-routine according to BS 7910. The fracture toughness of the current steel grades is determined based on the Master-Curve-Procedure by *Wallin* and described by a correlation equation to the notch impact energy by *Sanz*, which was also calibrated for these modern steels. Bypassing complex fracture mechanic tests, in this approach the safety analysis is connected with the guaranteed minima of notch impact toughness in technical delivery requirements which are common for steel construction [1].

These methods are not suitable for old mild steel structures with riveted or bolted connections. On the one hand, notch effects and residual stress states differ in welded and riveted structures. On the other hand, the material properties of old mild steels (*Bessemer*-, *Thomas*- or *Siemens-Martin* steel) are characterized by considerably larger scatter, particularly due to the inhomogeneous distribution of tramp elements and higher contents of non-metallic inclusions. The often much lower impact

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toughness of mild steel lies in the lower shelf even at room temperature. Therefore, structures are often rejected by engineers with insufficient experience with old steels because they assume "material embrittlement due to ageing".

3. Fracture mechanics safety analysis

Fracture mechanics is suitable for an appropriate assessment of brittle failure in riveted or bolted mild steel structures because it considers design-related toughness requirements including possible defects as well as the available toughness properties of the material. Basic fracture mechanics studies in Europe definitely indicate that mild steels have sufficient toughness to withstand brittle failure even at low temperatures (down to –30 °C for external components [2]). The preferred fracture mechanics parameter for characterizing the existing toughness of mild steel is the J-Integral (J_{Ic}). This value should be either directly measured or determined by reference values in literature.

An early attempt to describe the fracture toughness of mild steel as a function of temperature is given in [3]. However, this pragmatic model represents an oversimplification of the real material properties and needs to be revised in the authors' opinion. The methods of fracture mechanics safety analysis of crack sensitive components have been significantly developed since the '90s (see [1]). Current internationally accepted methods, such as SINTAP, use the Master Curve approach to statistically describe the fracture toughness of steels as a function of temperature.

Up to now, the partially very complex assessment methods based on fracture mechanics were only applied to selected structures, e.g., old bridges and components made of steel casting. Therefore, a practical method for assessing the safety against brittle fracture of riveted mild steel structures is being developed in a current research project at the Institute of Steel and Timber Structures at the TU Dresden. The developed method bases on fracture mechanic assessment methods, experimentally determined material parameters described with the above-mentioned material model and toughness requirements of typical types of structures determined by finite element calculations. Additionally the specifics of crack initiation at riveted members in statically loaded steel structures are analyzed.

Mild steel produced in the converter (*Thomas*- and *Bessemer*-steel) has a relatively high content of nitrogen due to the refining by air. The high diffusivity of nitrogen causes embrittlement over time, which is termed ageing. This process is particularly marked in the range of plastic deformation, for instance caused by the fabrication of the holes of riveted joints by punching. Punching was a typical way of making holes in former times. Figure 1 (left) illustrates the fracture surface of such a component with a high content of nitrogen and a hardening of the material as a result of punching. The brittle crack initiation at the highly stressed edges of the holes is clearly visible. Figure 1 (right) shows this hardening effect detected as a deformation of the grain structure in the micro-section.

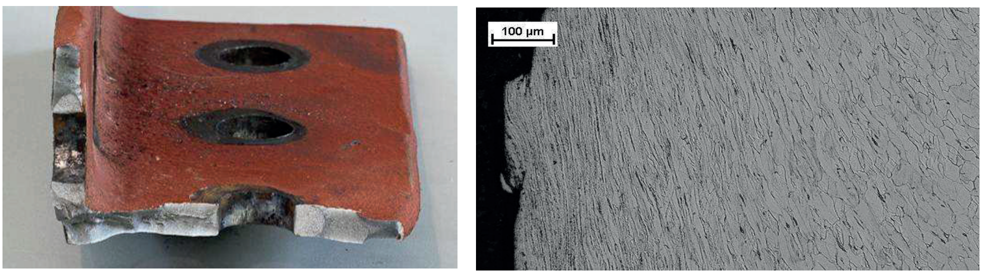

Figure 1: Fracture surface of angle profile (left) and micro-section at the edge of hole (right)

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