# Influence of weld volumetric flaws on fracture toughness tests


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## MOTIVATION

Welding is one of the main processes used to join metals. Even though welding technologies have evolved immensely in the past decades, the generation of imperfections during welding (e.g. lack of fusion, crack, porosity) is an issue that cannot be entirely resolved. When a weld imperfection exceeds workmanship acceptance limits it is considered a defect. Defects can compromise the structural integrity of welded structures/components leading to failure.

To evaluate whether a defect is safe or rather poses a risk of failure, a more comprehensive engineering analysis called Engineering Critical Assessment (ECA) is deemed necessary. For certain ECA's, a resistance curve (R-curve) representing material resistance to crack extension, is required. This curve can be obtained by fracture toughness tests on so-called Single Edge Notched Tension (SENT) specimens (Fig. 1). SENT testing has been widely used to characterize the fracture behavior in low crack tip constraint conditions.

Research has shown that volumetric discontinuities (e.g. porosity) can influence the outcome of fracture toughness tests of weld metal. Laboratory test specimens are reduced in size and even small internal flaws can lead to a significant impact on the test results. Current fracture toughness standards do not provide clear and direct guidance regarding the validity of tests performed on specimens containing weld volumetric flaws.

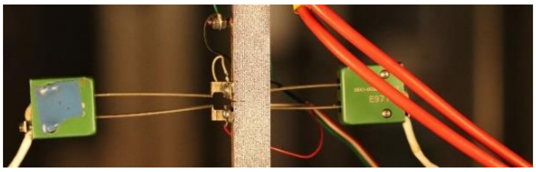

*Fig. 1 SENT test*

## OBJECTIVES

The main goal of this research is to understand the impact of volumetric discontinuities on fracture toughness test results. To achieve that, the following objectives have been defined.

1. Evaluate the influence of volumetric discontinuities on two crack sizing techniques, Unloading Compliance (UC) and Direct Current Potential Drop (DCPD). These are the most applied techniques to measure crack growth in single specimen fracture toughness testing.
2. Experimentally investigate how and to what extent volumetric discontinuities influence the ductile fracture behavior of welded SENT specimens.
3. Apply a micro-mechanical damage model to finite element simulations to numerically assess the influence of discontinuities on SENT resistance curves (R-curves).

## APPROACH

To achieve the objectives listed previously, this research combines experimental and numerical analyses

**Experimental:**

SENT specimens manufactured from welded plates and containing volumetric flaws were tested. These flaws were characterized by micro-Computed Tomography (CT) scans (Fig. 2).

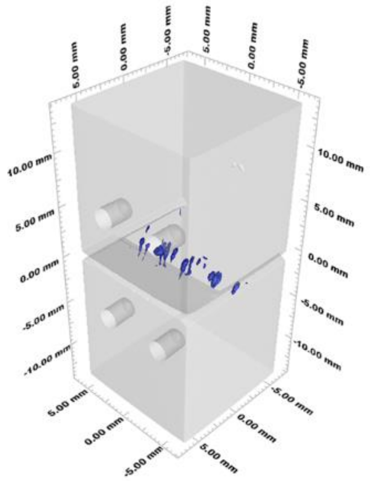

*Fig 2 Three-dimensional micro-CT reconstruction of a welded SENT specimen. Volumetric flaws are represented in blue.*

Steel S255MC plates were welded by Metal Inert Gas (MIG) using a G3Si wire electrode. To strive for repeatability, a welding robot was utilized. Different welding parameters (e.g., wire stick-out and gas flow rate) were applied in order to induce the generation of volumetric discontinuities of diverse sizes and densities. From these plates, SENT specimens were machined and the discontinuities were characterized by micro-CT scans (Fig. 2)

SENT tests were performed in a hydraulic universal testing machine. To measure crack growth, the Unloading Compliance (UC) and the Direct Current Potential Drop (DCPD) techniques were conjunctly applied during the tests. In addition, a double clip gauge setup was used to measure crack opening displacement (Fig. 1). To monitor the deformation field, a stereoscopic (3D) Digital Image Correlation (DIC) system was used. Test data allow the construction of resistance curves from which it is possible to evaluate the impact of volumetric discontinuities on the fracture behavior of the specimens.

**Numerical:**

To investigate the possible influence of volumetric discontinuities on UC and DCPD crack growth measurements, an extensive Finite Element (FE) parametric study was performed where single pores and random porosity distributions were generated by element deletion into a SENT model (Fig. 3). The UC analyses were performed using a mechanical FE model whereas, for DCPD, an electrical FE model was used. The position and size of the pores were linked to DCPD and UC crack growth measurement errors.

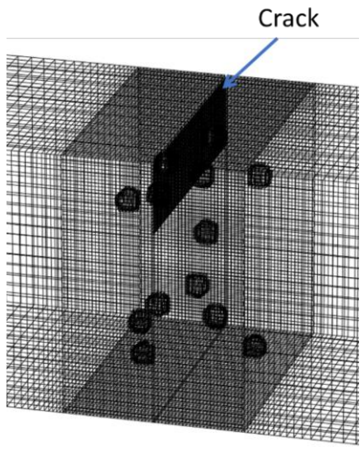


*Fig. 3 Transparent view of the center of an FE SENT model where pores were introduced by element deletion*

The last stage of this study is to incorporate a damage model into the FE SENT model in order to simulate ductile crack growth. This will allow improving the understanding of the influence of discontinuities on the R-curve. The micromechanical Complete Gurson Model (CGM) has been adopted as a damage model. The calibration of the model has been conducted utilizing tensile test results of notched round bars. Discontinuities characterized by micro-CT scans are modeled into the FE SENT model (Fig. 4) and numerical R-curves are compared with experimental curves for validation purposes. A comprehensive parametric study will be performed where discontinuities of different sizes at different positions will be generated into the model. Then, the impact of these discontinuities on R-curves will be evaluated.

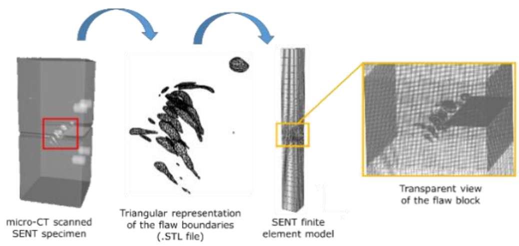


*Fig. 4 Framework used to plug discontinuities characterized by micro-CT scan into the FE SENT model*

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