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Test method for determination of the essential work of fracture of thin ductile metallic sheets

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European Foreword

This CEN Workshop Agreement (CWA 17793:2021) has been developed in accordance with the CEN-CENELEC Guide 29 "CEN/CENELEC Workshop Agreements – A rapid prototyping to standardization" and with the relevant provisions of CEN/CENELEC Internal Regulations – Part 2. It was approved by a Workshop of representatives of interested parties on 2021-05-31, the constitution of which was supported by CEN following the public call for participation made on 2020-10-26. However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

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Introduction

Fracture toughness has shown to be a useful material property to predict formability and impact performance of metal sheets. For this reason, it has become a relevant property for sheet metal producers and stampers. However, the measurement of the fracture toughness of metallic sheets is not widely extended in the industrial sector, especially by the complexity of the Elastic Plastic Fracture Mechanics (EPFM) standardized methods (J-integral, CTOD, CTOA). Such techniques are complex and involve exhaustive specimen preparation, rigorous data treatment and the measurement of the crack advance during the tests, which is one of the main difficulties in fracture toughness measurement. Additionally, specimen geometry constraints described in some EPFM standards such as ASTM E-1820 are too restrictive and its application to thin sheets is often difficult.

In the present document, an alternative test method based on fracture mechanics to characterize the plane stress fracture toughness of thin metallic sheets is proposed, the Essential Work of Fracture (EWF) methodology. The technique has shown to be suitable to readily characterize the fracture toughness of thin advanced high strength steels (AHSS) and aluminium alloy sheets. The main advantage of the EWF methodology is the relative easiness of the tests compared to the standard methods. Currently, there is no standard test method available for the evaluation of the EWF of thin metallic sheets but a testing protocol developed by the TC4 committee (TC04- Polymers, Polymer composites and adhesives) of the European Structural Integrity Society (ESIS). However, this protocol is focused on the fracture testing of polymers and composites. Therefore, the development of a reference document for measuring the EWF of thin metallic sheets is necessary to spread the application of the method.

Other of the limiting factors that hampers the industrial implementation of fracture mechanics testing procedures is the specimen preparation. In order to obtain reliable fracture toughness values, the EWF method requires the nucleation of fatigue pre-cracks in multiple specimens, which is time consuming and makes the process more expensive. In this sense, EURECAT has developed a tool (patent Nº EP 3567364A1) to avoid fatigue pre-cracking of specimens. The tool permits to easily introduce sharp notches (notch radius similar to fatigue pre-crack) in metallic sheets with a simple shearing process. In the FormPlanet project, this new notching procedure for thin sheet specimens notching has been optimized and validated for different metallic materials. The present document describes the experimental procedure and the limitations of the proposed approach.

1 Scope

This CWA describes the procedure for the evaluation of the plane stress fracture toughness of thin ductile metallic sheets by means of the EWF methodology. The document provides the guidelines for specimen preparation, testing and data post-processing as well as the limitations of the method.

NOTE 1 The test method proposed in this document is intended to relatively thin metallic sheet materials presenting plane stress conditions, which do not fulfil the thickness requirements described in ISO 12135:2016. It is important noting that toughness values obtained by the present method are thickness-dependent. Therefore, they cannot be considered as an intrinsic material property but a geometry-independent constant for a specific sheet thickness.

NOTE 2 The recommended specimen is the Double Edge Notched Tension (DENT) because of its symmetry and minimal specimen rotation and buckling during the test. The specimens are notched, fatigue pre-cracked and tested up to fracture at a constant displacement rate. Alternatively, a mechanical notching process is described for obtaining sharp-notched DENT specimens. Investigations have shown that EWF results obtained with specimens prepared by means of this mechanical notching process are equivalent to those obtained with fatigue pre-cracked specimens for a range of AHSS. Further analysis is required to confirm the reliability of this procedure for specimen preparation in other materials of lower strength.

NOTE 3 The method requires testing multiple specimens with the same geometry but different crack lengths. From the test, two characteristic parameters are obtained; the specific essential work of fracture, w_e, and the non-essential plastic work, w_p, multiplied by a shape geometry factor β. w_e is independent of in-plane dimensions and represents the plane stress fracture toughness of thin ductile sheet materials. Since it is obtained from an average of energy values for the complete fracture, it is considered an overall resistance value to stable crack extension, i.e. it contains energetics contributions from crack initiation and propagation resistance. It is also possible determining a single initiation toughness value, w_e^i, which represents the material resistance to crack growth initiation. The parameter βw_p depends upon specimen dimensions and, therefore, it is not a material constant.

NOTE 4 Resistance to stable crack extension can be also expressed in terms of a critical crack opening displacement (δ_c). An empirical relationship between w_e, δ_c and flow properties is established.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ASTM E1820, *Standard Test Method for Measurement of Fracture Toughness*

ASTM E399, *Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials*

ISO 12135:2016, *Metallic materials — Unified method of test for the determination of quasistatic fracture toughness*

ISO 22889, *Metallic materials — Method of test for the determination of resistance to stable crack extension using specimens of low constraint*