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Studying the Rate Dependence and Adiabatic Heating of Essential Work of Fracture in Press Hardening Steels

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Abstract

The automotive industry is currently in a paradigm shift transferring the fleet over from internal combustion vehicles to battery electric vehicles (BEV). This introduces new challenges when designing the Body-In-White (BIW) since it is essential to protect the heavy and energy-dense battery in a crash scenario. Press hardening steels (PHS) have emerged as an excellent choice when designing crash safety parts due to their high-strength and forming flexibility. It is however crucial to evaluate the crash performance of the selected materials before producing parts. Component testing is cumbersome, and it is difficult to separate material behaviour from other influences such as spot welds. Fracture toughness measured in the frame of fracture mechanics using the Essential Work of Fracture (EWF) has emerged as an interesting tool to rationalise crash performance of steel sheet designs. The EWF has previously been shown to increase, sometimes substantially, with increasing strain rate, but the cause of this is still largely unknown. For high strain rates, adiabatic heating can have a significant effect on the mechanical and fracture properties, especially for steel grades with metastable austenite. However, the rate dependence is still evident for press hardened martensitic steel grades. In this work, quasi-static and high-speed EWF experiments are performed on two PHS grades designed for anti-intrusion and energy absorption, respectively. The thermals are monitored using infrared thermography to study the adiabatic heating and thus the thermal environment in the FPZ during EWF at high-loading rates. The results are compared and discussed.

Keywords: Rate dependence; Essential Work of Fracture; Adiabatic heating.

1 Introduction

Progressively more stringent safety standards aimed at the automotive industry as well as new design challenges introduced by the transition to electric vehicles have put an increasing demand on ultra-high strength steels. Press hardening steels (PHS) have become increasingly popular due to their ability to form high-strength parts with complex shapes without significant springback, further improving crash safety performance and potentially reducing the weight of components.

The essential work of fracture (EWF) [1] is a technique for measuring fracture toughness of thin sheets and is based on the concept that the region in front of a crack tip can be divided into an *essential* fracture process zone (FPZ) where the actual fracture takes place (and which is a material property for a specific thickness) and an outer region screening the large strains created in the FPZ with *non-essential* plastic work. Although geometry-independent in nature [2], the deep edge notched tensile (DENT) specimen is often used due to the contained plastic zone and absence of buckling. By testing a series of DENT specimens with different ligament lengths fulfilling the same plane stress state, the essential work of fracture for the material is obtained, which is a material property for the specific thickness of the sheet. EWF has emerged as an interesting and viable parameter to rationalise the crack behaviour of advanced high strength steels (AHSS) components in the automotive industry, both in forming [3] and crash applications [4].

An interesting phenomenon using EWF is that it has been shown to increase with strain rate for AHSS grades [5]. However, the cause of this effect is still largely unknown, and the data available for the strain rate dependency of fracture toughness for modern AHSS and PHS grades is still limited. Further investigation of more steel grades is thus necessary to see if this effect is indeed universal, and if so, what could be the causing parameters of this effect. It is well known that strain rate and adiabatic heating both affect the phase transformation rate and the mechanical behaviour for certain steel grades [6]. Since the local strain