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Dynamic Fracture of Ductile Materials

Design of an experimental program to assess the dynamic fracture properties of a dual phase automotive steel

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Abstract

The dynamic behavior of materials must be considered when determining the crashworthiness of a vehicle and the safe design of the vehicle components. Series of mechanical tests at wide ranges of stress and strain rates are essential to identify the material's damage and fracture behavior identical to realistic conditions. In the present contribution, an extensive experimental program has been developed to assess the dynamic fracture properties of dual phase steel (DP-K 1000). Various tensile specimen geometries covering wide range of stress states are employed for testing at quasi static conditions. The limitations imposed on the sample geometries by clamping technique and requirements of high strain rate test based on split Hopkinson bar test principle restrict the use of static geometries for the dynamic range. An optimization approach based on finite element simulations has been adopted to determine the most suitable dimensions for various tensile specimen geometries quantified by stress triaxiality. The possibility of introducing a standard for dynamic sample geometries has also been investigated. Moreover, the influence of transition zone on the deformation of the specimen has been analyzed and incorporated into the optimization strategy. The optimized specimen geometries are finally adopted for dynamic material testing so as to derive enough inputs for constitutive material modeling and to facilitate fundamental material research.

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Keywords: Dynamic, geometry, optimization, stress triaxiality, material modelling.

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1. Introduction

Steels are the one of the most important structural materials, enabling technological breakthroughs in various fields, such as energy, transportation, safety and infrastructure. Profound progress in these fields have been achieved through the development of advanced high strength steels (AHSS) fueled by the conflicting demands on the automotive industry to simultaneously improve crash safety and fuel economy. AHSS offer excellent strength and formability properties. Indeed, a high strength is desirable, for weight reduction through down-gauging, while a large deformation capacity is important for good formability. One of the most important grade of advanced high strength steel is the dual phase steel which offers superior formability and energy absorption properties as compared to other steel grades. Dynamic behavior of the material must be considered in determining the crashworthiness of the vehicle and for the effective design of vehicle components. For automotive applications, crash worthiness and consequently, preservation of strength and ductility at high strain rates, is of major importance. Conformance of the product with the applicable standards (as in the case of a crash box) are ensured by performing a series of material and mechanical tests covering the entire range from small scale tensile tests to full scale crash tests under realistic conditions of use.

Mechanical tests at wide ranges of stress states and strain rates are essential to identify the material damage and fracture behavior congruent to real case scenarios. In the present contribution, an experimental program is developed to study the dynamic damage and fracture properties of a CR700Y-980T DP-K 1000 steel with average grain size below 2 µm. The initial yield strength is 765 MPa, the tensile strength 1000 MPa and the uniform tensile elongation 13%. The material was delivered as steel sheets of thickness 1.5 mm.

In order to obtain the strain rate dependent plasticity, damage and fracture properties of the material, an extensive experimental program has been designed. The program involves various tensile sample geometries to cover a wide range of stress states. Regular dog bone, central hole and notch dog bone specimen with different notch radii are adopted for the same purpose. The tests are performed under quasi-static and high strain rate conditions. For the high strain rate tests, a Split Hopkinson Bar (SHB) tensile setup is used. Predefined standards such as ASTM exists for sample geometries to be tested at quasi-static conditions and for basic dog bone geometry at high strain rates. However, the use of the SHB test technique imposes certain limitations on the sample geometry and sample clamping technique. As a consequence, similar geometries cannot be implemented for dynamic tests. Despite the applications of dynamic characterization of materials using SHB, plasticity and fracture tensile test specimens have not been standardized yet. The dimensions of the specimen was found to have direct influence on the force equilibrium as required for split Hopkinson bar testing and final stress-strain behavior [1]. The obtained stress strain curve at a particular strain rate is generally assumed to represent the material behavior. However, it is observed that the changes in specimen geometry -shape and dimensions- give rise to distinct differences in the established mechanical behavior. Size effects and the emergence of non-axial stresses and non-homogenous specimen deformation are to a large extent dependent on the specimen geometry. Hence, the observed behavior is a combination of structural and material response [2, 3]. Structural effects might also result in a delay between established and the actual onset of yielding.

The choice of the most appropriate specimen geometries for dynamic experiments is closely associated with the requirements arising from both fundamental and practical considerations. Herein, an approach using numerical analysis has been discussed which can help in identifying the most suitable specimen geometries which can ensure well controlled stress state and practically eliminate strain inhomogeneity in the specimen arising due to geometrical effects.

2. Methodology

The sample geometries displayed in Figs.1, are proposed for tensile tests on DP steel in static conditions: (a) regular dog bone, (b) specimen with a central hole, (c) Notched Dog Bone (NDB) with notch radius r of 6mm, (d) NDB R20 with r of 20mm and (e) NDB R50 with r of 50mm.