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Characterization of 7-mm-Thick Hot-Rolled Ultrahigh-Strength Steel Used in Warm Forming

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Abstract

This article describes the mechanical material characterization of a novel 7 mm thick Ultra High Strength Steel grade, WARM-LIGHT-980 (UTS 980 MPa), intended for warm forming processes in the temperature range of 430 to 580°C. The aim is to produce lighter parts with high stiffness and good fatigue properties targeted for the Heavy-Duty Vehicle sector. The elastoplastic properties as well as the ductile failure properties were therefore determined at the enhanced temperatures for future use in numerical simulations of e.g. warm forming operations. The failure strains at various stress triaxialities were extracted from digital image correlation of different specimen geometries. Due to the thickness (7 mm), impractically large specimens would be needed, therefore downsized 1.2 mm specimens were produced. The use of smaller and thinner specimens has been confirmed by comparing the work hardening up to necking obtained in uniaxial tensile tests (1.2- and 7-mm thickness). The enhanced temperatures were obtained by inductive heating and the homogeneous temperature distribution was validated by thermal photography.

1 Introduction

Lightweighting in the Heavy-Duty Vehicle (HDV) sector comes with a focus on stiffness and fatigue properties. Therefore, a movement from hot-rolled cold formed high strength steels with yield stresses around 500 MPa and UTSs in the range of 550 to 700 MPa, towards hot-rolled warm formed ultra-high strength steels with UTSs around 1000 MPa with similar or better fatigue properties, might be viable options. Parareda et al. [1] investigated a warm formed UHSS in terms of fatigue resistance and compared it with hot formed 22MnB5, showing promising results.

The material suggested in this study is a prototype hot-rolled martensitic ultra-high strength steel from voestalpine Stahl GmbH, WARMLIGHT-980 (WL980). With a specifically designed thermal history, an intended UTS of at least 980 MPa could be obtained after the warm forming operation.

To predict important properties such as forming forces, potential cracks, etc., in warm forming operations using CAE, the elastoplastic and failure behaviours must be determined at operating temperatures. This work focuses on adapting well established characterization methods for thin steel sheets and applying them on in this case 7 mm thick steel sheets under warm forming conditions. In an industrial setting, the design of the warm forming process in terms of tooling and final part geometry would be supported by forming simulations utilizing shell elements. Due to practical limitations to test the 7 mm material under plane-stress conditions, causing rather large specimens, the sheet thickness can advantageously be reduced. However, the consequence of thickness reduction and the reliability of the obtained mechanical properties must be investigated and established.

Studies to obtain mechanical properties have been performed by, e.g. Bao and Wierzbicki [2] who investigated 2024-T351 aluminium alloy and conducted numeral tests representing a wide range of triaxialities and they were able to recreate the tests with numerical simulation. Jonsson and Kajberg [4] characterized 1.4 mm and 1.55 mm steel sheets at room temperature using DIC and utilized a plane-stress fracture criterion to describe the failure of the material. Sjöberg et al. [3] characterized 1.6 mm thick Alloy 718 for different stress triaxialities at elevated temperatures. This was done utilizing Digital Image Correlation (DIC) to evaluate the strain at fracture. These successfully proven characterization methods will be utilized to support CAE of a warm forming process assuming a plane-stress condition. The elastoplastic properties as well as failure behaviour of a novel UHSS intended for warm forming are in this study investigated at three different temperatures, 430 °C, 505 °C and 580 °C using specimens with reduced thicknesses.