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Increasing the energy absorption capacity of structural components made of low alloy steel by combining strain hardening and local heat treatment

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Abstract

Modern high and ultra-high strength steels often require extensive alloy concepts and complex processing routes. To tailor the properties of low alloy steel accordingly, strain hardening combined with a subsequent local heat treatment presents a promising alternative. As a result, the final annealing step of the whole steel strip after cold rolling can be omitted. This process combination can be used to locally increase the formability of semi-finished parts as well as to improve the functionality of final parts. In this work, local heat treatment strategies are applied to increase the energy absorption capacity of a structural component. A high strength low alloy steel is strain hardened by cold rolling and heat-treated locally via laser irradiation. To identify suitable parameters for the laser heat treatment, the material is subjected to a short time heat treatment followed by a tensile test in a dilatometer. The determined mechanical properties are used for an FE study of a crash test. The FE model is used to develop potential local heat treatment strategies and to evaluate their crashworthiness. To validate the model, the developed heat treatment strategies are applied on real crash boxes. In dynamic impact tests, it is shown that the combination of strain hardening and local heat treatment can be used to improve the energy absorption capacity compared to a globally heat-treated crash box and to control the crash behaviour of structural components.

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Keywords: crashworthiness; dynamic crash test; lightweight; local laser heat treatment; tailor heat-treated blanks

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1. Introduction

Current lightweight design strives for high and ultra-high strength steels. However, high strength often involves a limited formability, which causes difficulties in production or final application [1]. To maintain the advantages of a high strength, the approach of 'Tailor Heat-Treated Blanks' (THTB) is to restore the formability locally prior to forming operations [2]. The critical areas of the blank are heat-treated, while the rest remains at high strength. In contrast to temperature assisted forming processes, the subsequent forming is typically performed at room temperature. This concept can either be used to increase the formability of semi-finished parts or to improve the functionality of the final part. As a result, THTB show a property distribution that is adjusted at best to the function of the final part. In preliminary work, a tailored heat treatment was successfully applied to improve the crash behaviour of a structural component made of strain hardened high manganese TWIP steel [3]. Such advanced high strength steels often require extensive alloy concepts combined with complex processing routes [4].

In this work, the THTB approach in combination with strain hardening is applied on a structural component made of low alloy steel to present an economic alternative to advanced high strength steels. While the local heat treatment pattern of the previous work [3] was determined based on the experimental results, this research uses an FE study to investigate numerically potential local heat treatment strategies. The goal is to develop an FE model that allows for the evaluation of the energy absorption in a crash test and to validate both methodology and model via experiments.

The investigated material is a micro-alloyed high strength low alloy (HSLA) steel. It is especially used for lightweight design applications, such as structural components in cars, due to its high yield stress. Increasing the yield stress further by strain hardening via cold rolling, enhances the energy absorptivity in areas of the structural component which are subjected to relatively low strains. Areas in which high strains occur might suffer from a lack of formability and hence are prone to cracks. Accordingly, these critical areas shall be locally softened by a laser heat treatment. To identify the influence of the heat treatment parameters on the material properties, the strain hardened material is subjected to a short time heat treatment using a dilatometer. The influence of the heat treatments is evaluated via tensile tests and microstructural investigations. The material data determined for different temperatures is used for an FE simulation of a crash test. This FE model allows for evaluating the crashworthiness by means of the energy absorption capacity and is used to develop potential local heat treatment strategies. The numerically designed heat treatment strategies are applied on crash boxes via laser irradiation followed by a high-speed impact test to validate the crashworthiness. Finally, the FE model is used to derive further options for an improvement of the crash behaviour of structural components.

2. Experimental and numerical investigations

2.1. Material and identification of heat treatment parameters

The HSLA steel 1.0986 was cold rolled as strip from 4.0 mm to 1.6 mm. No final heat treatment was applied. The height reduction of 60 % leads to a significant strain hardening and hence increases the potential of a local heat treatment. To determine an appropriate temperature range for the laser heat treatment, heat treatments with different maximum temperatures ranging from 650 °C to 1200 °C were applied using a dilatometer (DIL 805A/D, co. TA Instruments). Similar to the characteristics of a laser heat treatment, each heat treatment consists of a linear heating and exponential cooling rate. The samples are heated inductively under high vacuum with 50 °C/s up to the respective maximum temperature, where the temperature is kept for 2 s. Using an inert gas, the temperature is reduced exponentially within two minutes down to 40 °C. The resulting mechanical properties were tested under quasi-static loading using the tensile test device of the dilatometer. The microstructure was analysed by light optical microscopy.

2.2. Dynamic impact tests

Crash tests of structural components are used to evaluate their deformation behaviour under dynamic loading. In this case, a crash box, which is often used to compare different materials used for structural components, is chosen.