Rate-dependent hardening behavior and TRIP effect in Quenching and Partitioning steels for application in crash energy-absorbing structures

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Abstract

Belonging to the 3rd generation advanced high strength steels (AHSS), Quenching and Partitioning (Q&P)-steels exhibit an excellent combination of high strength and good ductility while having a similar alloying concept as the already existing 1st and 2nd generation AHSS, such as DP- and TRIP-steels. While the mechanical properties are generally well understood, Q&P-steels are still subject to current research and can not be widely found in industrial applications. Driven by the need to decrease vehicles' weight while maintaining high safety standards, the predictability of material behavior under dynamic load cases in simulations is a deciding factor for successful industrial usage. To widen the understanding of mechanical response to high-speed loading, a wide range of strain rates from $0.001 s^{-1}$ up to $1000 s^{-1}$ are conducted on two grades of Q&P-steels, namely QP980 and QP1180. Special attention is given to the hardening behavior, which is influenced by a rate-dependent TRIP effect. The effect of strain rate on the microstructure evolution is also investigated to enable the theoretical connection of the rate-dependent TRIP effect with the respective mechanical response. The influence of increased strength and ductility compared to classical AHSS, such as dual-phase steel DP1000, is finally validated on a generic axial crash structure commonly found in vehicle crash management systems [1].

Introduction

Under the pressure of global warming, the automotive industry is subject to a plethora of increasingly strict requirements regarding their fleet's greenhouse gas emissions, culminating in the full transition to battery electric vehicles (BEV). Current BEVs still lack the range of traditional internal combustion engine (ICE) vehicles, making them a particular target for light weighting efforts. Apart from substituting large parts of the vehicle's structure with lightweight materials such as aluminum- and magnesium alloys which can be cost-prohibitive, the development of advanced high-strength steels (AHSS) is an ongoing effort to create new steel grades with an improved combination of strength and ductility while keeping the cost down. The category of AHSS is currently loosely divided into three generations. The 1st generation AHSS including grades such as dual phase (DP) and complex phase (CP) steels, as well as transformation-induced plasticity steels (TRIP), are currently used in industrial applications and pose an improved behavior compared to conventional high-strength steels. To further increase their strength, the 2nd generation of AHSS was developed. This includes grades such as full austenitic stainless steels and twinning-induced plasticity steels (TWIP). These alloys offer excellent mechanical properties but, unfortunately, achieve this by high amounts of expensive alloying elements such as manganese. Therefore, the 3rd generation of AHSS was developed and made commercially available in recent years. Strength and ductility-wise, they fall between the 1st and 2nd generations. The three most mature grades are Carbide-free bainitic steels (CFB), Medium-Mn steels, and Quenching and Partitioning steels (QP). Most of these 3rd generation steel grades depend on the TRIP effect, which is based upon the phase transformation mechanism of austenite to martensite. This mechanism is induced by the deformation of the material such that a given amount of retained austenite is transformed, thus providing an additional hardening mechanism to the material's mechanical response. Based on this description, it is easy to recognize that the resulting hardening behavior strongly depends on the amount and properties of the retained austenite phase as shown by \cite[doi:10/grnffb]. They report an improved mechanical response of QP980 until necking compared to DP980. Afterward, due to their similar microstructure, they behave comparably until fracture.

References

1. **Prediction of crack formation in the progressive folding of square tubes during dynamic axial crushing**
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