The Effect of Microstructure on the Mechanical Behaviour of Dual-Phase Steels

Hossein Seyedrezai (rezaei@me.queensu.ca)
Department of Mechanical and Materials Engineering, Queen’s University, Kingston, Ontario, Canada
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Introduction

There is a continuing trend in the automotive industry to move towards lighter, more fuel-efficient vehicles. To ensure competitiveness of ferrous alloys, new grades of Advanced High Strength Steels (AHSS) are being developed with a combination of superior strength and good formability. Dual-Phase (DP) steel is the most commonly used AHSS and it comprises martensite particles distributed in a ferrite matrix. This grade of steel is characterized by its distinct mechanical behaviour of continuous yielding at low stresses, very high initial work hardening rate and large uniform elongation. These phenomena are attributed to the inhomogeneous plastic flow arising from the strain incompatibility between the hard, non-deforming martensite and the soft, ductile ferrite. Furthermore, the mechanical behaviour of DP steel is highly dependent upon the size, spatial distribution and volume fraction of martensite particles as well as the ferrite grain size. The present research seeks to investigate these effects by designing various dual-phase microstructures through heat treatments prior to the inter-critical annealing step.

Methods and Results

A DP780 steel sheet (supplied by US Steel Canada) was subjected to a series of pre-treatments followed by inter-critical (IC) annealing in the dual-phase region. Two sets of pre-treatments were employed: Quenching and Tempering (QT) and Austempering (AT). For the QT treatment, 100mm×20mm samples were heated to the single phase austenitic region at various temperatures for 30 minutes, quenched to 0°C (i.e. in an ice and water mixture), tempered for one hour at 600°C (QT6) and finally quenched to 0°C. For the austempering pre-treatment, the samples were heated to the austenitic region at 920°C for 30 minutes, air-cooled to 500°C, held for 20 minutes and finally quenched to 0°C (AT5). The pre-treated specimens, along with the samples of the as-received cold-rolled material (CR), were then given an inter-critical (IC) annealing treatment of 2 minutes at various temperatures followed by quenching to 0°C. Total of 22 different microstructures were produced and then examined via SEM and TEM. Figures 1 to 3 show three examples of such microstructures. In addition to the martensite and ferrite, carbide particles were also detected in virtually all microstructures regardless of the IC annealing temperature. Only long IC annealing treatments (30 minutes) produced complete carbide dissolution. Finally, it was found that the kinetics of the transformation during IC annealing depends upon the starting microstructure as follows:

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\text{QT+IC < CR+IC < AT+IC.}
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In the next step, uniaxial tensile tests were performed and the work hardening exponent, \( n = \frac{d\sigma}{d\epsilon} \), as well as the instantaneous hardening exponent, \( n_{\text{inst}} = \frac{d \log \sigma}{d \log \epsilon} \), were calculated. It was found that the microstructure has a significant effect on the tensile behaviour of DP steels. The work hardening exponent has a direct correlation with the martensite volume fraction, \( f \), while it has an inverse relationship with the martensite particle size, \( r \). This can be observed in Figure 4 where the work hardening exponent (at 2% true strain) is plotted against \( \sqrt{f/r} \). Additionally, the size and spatial distribution of martensite also affects the tensile behaviour. Figure 5 shows the engineering stress-strain plots for selected microstructures with similar volume fractions of martensite (~14.2%). Figure 6 presents the evolution of \( n_{\text{inst}} \) with engineering strain for the microstructures of Figure 5. It can be seen that the CR+IC microstructure, with the most uniform size distribution of martensite particles, produces the most desirable tensile behaviour in terms of high strength, large uniform elongation and high work hardening exponent while the QT+IC (with the least uniform size and spatial distribution of martensite particles) has the most inferior tensile properties.