

SUMMARY

Over the last two decades a significant research effort has been put in the development of Advanced High Strength Steel grades (AHSS). This research was mainly driven by the automotive industry aiming at reducing weight in order to increase gas mileage, improving passive safety and competing with light-weight materials such as Al and Mg alloys. The primary goal in the development of the grades has always been an increase in strength without significant loss in ductility. A variety of steel grades have since been developed such as Dual Phase (DP), Transformation Induced Plasticity (TRIP), Twinning Induced Plasticity (TWIP), Complex Phase (CP),...

The AHSS can be divided into two groups. The so-called first generation AHSS have multiphase microstructures consisting of mixtures of ferrite and martensite (DP), ferrite and bainite containing retained austenite (TRIP),... Lean alloying is used resulting in cost-effective grades.

The second generation AHSS mainly has an austenitic microstructure. Highly alloyed compositions are used resulting in significant cost. The optimum combinations of strength and ductility are by far exhibited by the second generation grades. An important gap exists in the tensile strength *versus* total elongation diagram between the properties exhibited by the first and second generation grades. Novel developments in AHSS research may hence focus on obtaining these properties at a desired lower alloying cost than needed for the second generation grades. It was shown that mixtures of martensite and austenite may exhibit the required properties of the so-called third generation.

Quenching and Partitioning (Q&P) has recently been proposed as a fundamentally new approach of producing AHSS microstructures consisting of martensite and carbon stabilized retained austenite. The heat treatment consists of a two-step process. After soaking in the intercritical region or above the A3 temperature, the steel is quenched, avoiding bainite formation, to a pre-determined temperature QT in the Ms-Mf region. A partially martensitic, partially austenitic microstructure is present at this stage. In a second, so-called partitioning step, the steel is either maintained at the QT or brought to a higher temperature PT. The aim of the latter step is to carbon stabilize the austenite present at the QT by carbon depletion of the martensite and transport to the austenite. After final quenching to room temperature, a martensitic microstructure containing significant volume fractions of carbon stabilized retained austenite is obtained. Vital for the Q&P process is the retardation of carbide formation. Alloying with Si, Al and/or P is hence required making lean TRIP compositions suited for Q&P processing.

A variety of compositions was tested in present work with alloying modifications mainly involving Si, Al, and Mo. The effect of these alloying elements on the retained austenite fractions obtained following Q&P was assessed. The highest volume fractions were obtained in a MoCMnSi grade. The Mo alloying also reduced the sensitivity of the fractions to increased holding at the partitioning temperature. Decreasing fractions with partitioning time are observed in CMnSi grades. (Partial) replacement of Si by Al results in lower retained austenite fractions. In order to investigate and understand these alloying effects differential scanning calorimetry (DSC) and dilatometry was conducted.

The DSC study enabled determination of the activation energies associated with austenite decomposition. The results were in agreement with the observed retained austenite volume fraction trends. The highest activation energy for decomposition was obtained for a MoCMnSi Q&P sample, followed by the CMnSi grade. (Partial) replacement of Si by Al resulted in significantly lower activation energies. The DSC run of a Q&P sample also revealed an additional peak which is believed to be associated with carbon partitioning from martensite into the austenite. A carbon increase of the retained austenite was measured beyond the peak whereas similar volume fractions were measured indicating that decomposition of austenite did not occur at this stage. A kinetic analysis showed that this peak is controlled by carbon diffusion in martensite. A thermodynamic calculation of the enthalpy change associated with carbon transfer from supersaturated ferrite into austenite was in fairly good agreement with the measured heat release.

The dilatometric study showed that decomposition occurs during partitioning. A composition dependent volume expansion was observed at the quenching temperature, during the heating section from the QT to the PT and during partitioning. This austenite decomposition is strongly retarded by Mo alloying in the MoCMnSi grade. Significantly more austenite decomposition was observed in the CMnSi and CMnAlSi grades. These observations agree with the activation energies obtained by the DSC study and help understand the obtained retained austenite volume fractions.

Tensile mechanical properties were assessed for a variety of steel compositions and compared with conventional AHSS processing routes and microstructures such as (tempered) Dual Phase, TRIP, bainite and tempered martensite. Q&P has shown to be an effective way of producing third generation AHSS properties. The strain hardening exhibited by Q&P steels shows a significant dependence on the partitioning conditions temperature and time, and is intermediate between the strain hardening behaviour of quenched & tempered (Q&T) and austempered (TRIP) steels for the same (aus)tempering/partitioning conditions applied. Longer partitioning times and/or higher partitioning temperatures result in increased ductility and in some cases to an upward

slope of the instantaneous strain hardening as a function of true strain plot. It was shown that strain-induced transformation of retained austenite to martensite occurs, contributing to strain hardening. The MoCMnSi grade, containing the highest retained austenite volume fractions at longer partitioning times and higher partitioning temperatures, has shown to exhibit the best total elongation and tensile strength combinations going up to 1300MPa tensile strength with 15% total elongation.

Hole expansion tests were also conducted and a comparison was again made with other advanced high strength microstructures. In general, lower HER is obtained for microstructures containing intercritical ferrite than for fully austenitized samples at similar tensile strength levels. The optimum balance in hole expansion and tensile strength is obtained for fully austenitized Q&P microstructures. The strain-induced transformation of the retained austenite is believed to trigger void nucleation. The austenite morphology difference observed for austempered and Q&P microstructures is believed to play a key role governing void nucleation and growth.