Virtual Process Chain for Recycled Steel: Effect of Chemical Composition on Forming, Joining, and Crash Performance

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Abstract

The increasing use of recycled electric-arc-furnace (EAF) steels in automotive body structures introduces variability in chemical composition, particularly in elements such as Mn, Si, Cr, Cu, and Sn. These compositional fluctuations directly affect phase transformations during hot stamping, weld quality during resistance spot welding (RSW), and ultimately crashworthiness. Within the EU-funded CiSMA project, Aerobase Innovations AB has developed an integrated virtual process chain using LS-Dyna to evaluate the effect of chemical composition variability on the complete manufacturing and performance sequence of press-hardened steel components: hot forming with tailored properties (soft-zones), resistance spot welding, and axial crushing.

The demonstrator component is a hat profile in 22MnB5 joined with a cover plate in DP780 by RSW. The PHASES model, a composition-dependent phase evolution model developed by Aerobase, predicts microstructure evolution and resulting mechanical properties throughout the process chain (www.copilot.aerobase.se). Coupled thermo-mechanical forming simulations capture the effect of chemistry on phase fractions and soft-zone properties, while electro-thermo-mechanical-metallurgical RSW simulations predict weld nugget and heat-affected zone (HAZ) characteristics. The complete material state is then transferred to the axial crush model. This work presents simulation results for multiple chemical compositions, comparing forming outcomes, weld characteristics, and force-displacement responses in axial crush, thereby quantifying the sensitivity of crash performance to material variability in recycled steels.

1 Material- and process model

The virtual process chain consists of three sequential simulation stages. In the first stage, coupled thermo-mechanical hot stamping simulations predict the shape, temperature history, and phase composition of the 22MnB5 hat profile after forming and die quenching. Tailored properties are introduced through soft-zones with controlled cooling rates, producing regions with different phase compositions ranging from fully martensitic to mixed bainite-ferrite microstructures. The PHASES model incorporates Koistinen–Marburger martensite kinetics and diffusional transformation models dependent on grain size, chemistry, and deformation history, predicting local phase fractions and resulting mechanical properties as a function of chemical composition. To represent the variability introduced by recycled EAF steel production, chemical compositions are generated spanning different fractions of recycled scrap content, capturing realistic ranges of residual elements (Mn, Si, Cr, Cu, Sn) within the 22MnB5 specification window. In the second stage, an electric-thermal-mechanical RSW simulation (www.copilot.aerobase.se) using an axisymmetric model predicts weld-nugget formation, HAZ extent, and associated phase transformations when joining the hat profile to the DP780 cover plate. The PHASES model tracks microstructure evolution during the rapid thermal cycles of welding, capturing re-austenitization, martensite formation, and tempering effects in the HAZ. Models for the A_{e3}-temperature, activation energy, initial yield stress, and failure strain as functions of chemical composition are used to capture the chemical dependence. The resulting phase compositions and mechanical properties from the weld simulation are mapped to the crash model. In the third stage, the hat profile assembly is subjected to an axial compression test. The component-level crash simulation incorporates the full history of material state from forming and welding, including residual stresses, thickness variations, phase distributions, and soft-zone properties. Force-displacement responses are computed for the range of chemical compositions to evaluate the scatter in energy absorption, peak force, and folding behaviour.

2 Results

The simulation results demonstrate the sensitivity of crash performance to variability in chemical composition in recycled steels. Variations in residual element content within the 22MnB5 specification range lead to measurable differences in phase fractions after hot stamping, which propagate through the welding stage and manifest as scatter in the axial crush response. The soft-zone regions show sensitivity to chemistry, as the diffusional transformations governing bainite and ferrite formation are strongly composition dependent. The RSW simulations reveal that compositional variations also affect nugget growth kinetics & HAZ microstructure, influencing the local mechanical properties at the joint. The integrated virtual process chain provides a tool to assess whether compositional variations across different recycled scrap fractions result in acceptable crashworthiness, thereby aiding the wider use of sustainable materials in safety-critical automotive structures.

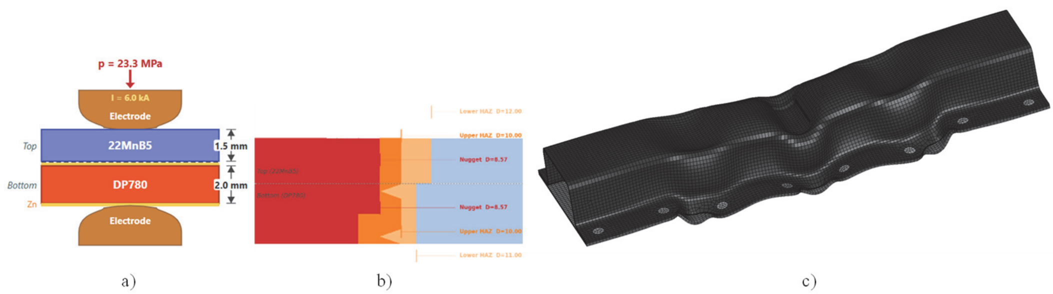

Figure 1: a) Axi-symmetric spot-welding model. b) Predicted nugget- and HAZ for the weld between the 22MnB5 profile and the cover plate. c) Deformation during the initial stage of axial compression test.

References

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