D6.2 Virtual stamping and crash testing using a fracture energy-based modelling approach of automotive prototype components

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Executive summary

Sup3rForm is a European Research Fund for Coal and Steel project investigating third-generation advanced high-strength steels for lightweight structural applications in future mobility. It focuses on quenching and partitioning steels and medium-manganese steels, which offer opportunities to combine high strength with improved formability. Their industrial application requires reliable predictions of manufacturing behaviour and structural performance during impact. Understanding when cracks initiate and how they affect energy absorption is essential to assessing whether thinner components can meet manufacturing and performance requirements.

Deliverable D6.2, “Virtual stamping and crash testing using a fracture energy-based modelling approach of automotive prototype components”, contributes to Work Package 6, “Multiscale modelling and simulation”, led by Luleå University of Technology (LTU). Within this framework, it addresses the development of a component-scale fracture mechanics-based model, material calibration, forming feasibility and structural crash assessment. It connects experimental characterisation from previous work packages with numerical evaluations supporting material selection, prototype development and subsequent industrial trials.

The work used mechanical and fracture information from D4.1 and D5.1, impact experiments from D5.2, and local formability information from D3.1. Material data supplied by ArcelorMittal and voestalpine and experimental forming limit curves determined by CRF supported the stamping assessments. The deliverable contributes to Milestone MS8 on virtual stamping and crash assessment and provides a technical basis for semi-industrial stamping trials in Task 7.1. Its findings establish promising applications and remaining validation needs rather than demonstrating production readiness or vehicle-level crash compliance.
Two forming case studies were investigated: material substitution in an existing reinforcement beam while retaining the tooling, and manufacture of a newly designed door crash-beam demonstrator. Simulations examined material flow, strain concentrations, forming forces and, for the new demonstrator, springback—the dimensional change after tool release. The fracture energy-based model was assessed separately against axial crushing and three-point bending experiments, including notched specimens designed to promote cracking.

For the existing reinforcement beam, currently manufactured from 2.0 mm DP800 steel, the results demonstrated that material strength alone was insufficient to determine substitution feasibility. Q&P1400 at 1.60 mm exceeded the forming limits approximately 60 mm before complete die closure, indicating that the existing deep drawing configuration was unsuitable under the investigated conditions. Including kinematic hardening did not prevent these exceedances. HF980-Q&P GI AM at 1.50 mm showed favourable feasibility, although local thinning required verification. HF1180-Q&P GI AM at 1.66 mm remained a candidate for process or geometry refinement, while the medium-manganese grade at 1.40 mm exhibited critical edge behaviour requiring further investigation. These findings helped prioritise material–process combinations for physical trials.

For the new door crash beam, simulations indicated preliminary forming feasibility for HF980-Q&P GI AM and Q&P1200 EG VAS, both at 1.50 mm. Q&P1200 required a maximum press-slide force of approximately 240 tonnes-force, compared with 120 tonnes-force for HF980, and exhibited greater predicted springback: approximately 5.5 mm compared with 4.5 mm. Increasing the blank-holder force for HF980 to approximately 100 tonnes-force reduced maximum springback to approximately 2.5 mm. Controlled restraint of material entering the die therefore offered a means of improving dimensional accuracy, provided that forming limits and equipment loads remained acceptable. Experimental strain measurements and three-dimensional scanning were identified as necessary to confirm these predictions.

The developed material model was implemented in LS-DYNA as a user-defined subroutine for computationally efficient shell-element simulations. It combined strain-rate-dependent plastic deformation, a stress-state-dependent fracture initiation criterion and an energy requirement governing subsequent failure. This separated the onset of critical damage from the energy needed to produce material separation. Calibration incorporated experimental tensile and fracture information and regularisation to address the influence of spatial resolution. Tensile simulations demonstrated the intended increase in post-initiation resistance with increasing fracture toughness. However, the plasticity description did not fully reproduce the hardening saturation identified for several steels, introducing uncertainty at large strains.

Comparisons with axial impact and standard bending experiments were generally encouraging. The models reproduced the principal deformation modes, overall force responses and absorbed energy, although differences remained in initial force peaks and individual folding events. These results supported application within the investigated conditions where plastic deformation dominated the structural response. They also showed that agreement in total absorbed energy did not necessarily imply equally accurate prediction of local cracking.

Notched bending tests exposed more substantial limitations. The model reproduced the limited cracking observed for MMn1000 UC VAS but missed the central cracks and associated loss of load-carrying capacity for Q&P1200 EG VAS and HF980-Q&P GI AM. For HF1180-Q&P GI AM, cracking occurred later than experimentally observed and followed two approximately symmetrical paths rather than a single central path. Continued numerical load-carrying capacity consequently caused substantial overpredictions of absorbed energy. Possible contributors included fracture calibration, boundary-condition differences and the requirement that all 20 integration points within an element reach failure before deletion. Further assessment was needed to distinguish their effects.

Prototype forming comparisons likewise demonstrated that the fracture treatment strongly influenced the predictions. The energy-based criterion substantially reduced predicted failure compared with the modified Mohr–Coulomb criterion and linear damage accumulation, while identifying similar critical regions. Local integration-point failure did not always trigger element deletion, emphasising that the absence of deleted elements did not imply an undamaged component. Experimental observations of cracking, strain and thickness were needed to determine which approach best represented the forming process.

Development experienced delays associated with parallel implementation, material-data processing and access to validation inputs, as recorded in the earlier draft. The present report progressed beyond coupon-level development to structural crash comparisons and prototype forming assessments. Remaining priorities were sensitivity studies of element deletion and boundary conditions, targeted calibration improvements and experimental verification of the forming predictions. These activities provide the basis for consolidating the assessments and supporting industrial trials.

D6.2 delivered a component-scale modelling framework and manufacturing assessments aligned with the relevant WP6 objectives. It identified promising material–process combinations and demonstrated encouraging predictions for deformation-dominated loading. It also established limitations in fracture timing, crack paths and the resulting loss of structural resistance. The work therefore supported prototype and process development while defining the validation required for broader industrial use. Subsequent updates should incorporate the planned validation results and their implications for model reliability and manufacturing feasibility.