# Simulating the Complete Forming Sequence for a Roll Formed Automotive Bumper Beam

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## ABSTRACT:

As part of the development of a new automotive bumper beam, a complete simulation of the entire forming process was carried out using LS-DYNA. The material for the beam was an ultra high strength steel presenting many challenges for the forming process. The sequence of forming operations was roll-forming (including forming a sweep in the initially straight roll-formed section), local annealing, forming of an initiator in the wall of the section and then crushing the end of the previously rolled section. The forming results (geometry, thinning and work hardening) were all transferred to the simulation of the bumper performance under various impact conditions.

The paper describes the development of certain novel simulation techniques, particularly for the roll-forming for which the implicit analysis options of LS-DYNA were used, representation of the annealing process, as well as the method in which data was transferred between the various simulations. Above all, we describe how the simulations were used to guide the design of the bumper beam system up to the point of prototype manufacture and test.

Keywords:

Roll forming simulation, implicit analysis, automotive bumper beam design, Ultra High Strength Steel

# INTRODUCTION

Wagon Automotive's Closure Systems Business Group has for some time specialised in the design and manufacture of roll formed products, notably bumper beams for automotive applications. Roll forming offers a cost-effective method for manufacture of bumper beams in Ultra High Strength steel. Careful design of the roll forming process can be used to overcome the limited formability of such materials; roll forming also allows single piece closed profiles to be created that cannot be easily formed by conventional stamping methods. The resulting structure is highly efficient, in terms of both cost and weight, under impact loads (especially high speed crash).

However, one limitation that is normally encountered with a roll formed design is that the profile is, by the very nature of the forming process, constant along the length. While it is possible to easily create a sweep radius along the beam length, it is not immediately obvious how variation in the profile depth along the length can be achieved. In some cases, for reasons of packaging for example, it is desirable to have a change in section geometry in different regions of the beam. With the design solution presented in this paper, a proposal was made to collapse the ends of the rolled beam by a stamping process in order to increase package space.

A reduction in profile depth at both ends of the beam in turn offers increased package space for the design of the crush cans. These components are particularly important for lower speed insurance tests (R Car, Thatcham, and AZT). More package space here allows increased efficiency of energy management in the design of the crush cans. Reducing the beam profile depth can also be useful to generate an increased volume in front of the bumper beam to package pedestrian impact solutions.

Dutton Simulation was asked to assist Wagon Automotive in evaluating options for reducing the section depth (x-axis of the vehicle) in front of the crush cans in order to create the bumper beam design as shown in Figure 1.

After some initial studies in which the crushing process was simulated with 2D models it became clear that simulation of the full forming process including the roll forming operation was going to be necessary

Figure 1: Bumper Beam Design

in order to correctly predict the behaviour in the ensuing crush process. This paper describes the forming sequence for the beam and the approach taken to simulating the entire process.

## PROPOSED MANUFACTURING PROCESS

The first stage in the manufacture of the bumper beam is the roll forming operation. The initial coil (delivered cut to the required width) is continuously fed into the roll forming equipment comprising, in the case of the present design, twenty-two sets of rollers. These rollers progressively form the closed "B" profile. At the exit of the last set of rolls, the profile is completed by spot-weld pairs along either side of the centreline before a final set of offset rolls bend the profile to the required sweep radius in plan. The beam is then cut to length.

In most cases, this would be the end of the manufacturing process. However, for the present design concept further operations are introduced to reduce the profile depth over the crush cans (at both ends of the beam). In order to ensure a repeatable and controllable process, a collapse initiator needs to be formed into the wall of the profile. However, before the material in this part of the wall can be re-formed, an annealing operation is required to modify the material properties locally for increased formability. The initiator is then formed by clamping one end of the beam and forming the initiator geometry from either side (with central support as required). Finally, the end of the beam is collapsed using a conventional stamping process.

## MATERIAL

The material selected for the bumper (chiefly from impact load considerations) was Docol 1200DP. Docol is a range of cold rolled high to ultra high strength steels supplied by SSAB [1], who also provided the mechanical properties and formability parameters for the project. Gauge was 1.4mm. This material has limited formability; for example, the FLD0 for 1.5mm gauge is given as 0.16 true strain.

## INITIAL FORMING SIMULATION – INITIATOR DESIGN

The unusual nature of the proposed manufacturing process, as well as the nature of the proposed material, led to the decision to use simulation to assist in the development of the manufacturing process. It was hoped that simulation would assist in identifying the process parameters (especially the size, shape and position of the initiator bead) in order to ensure a repeatable, controllable collapse avoiding excessive strains in the radii of the crushed ends. It was also important to predict the quality of the finished product (flatness of mating faces, distortion due to springback, etc.).

Initially, a series of studies were carried out on short lengths of beam in plane strain to examine the way the "B" profile would collapse under a crush load. A range of geometries with varying initiator shapes, sizes and positions were evaluated (see Figure 2) before a preferred concept was established. Some geometry options included an initiator indent on the inner walls of the section; options to include this in the process were considered but in the end a good solution was established, providing a stable inward collapse, that relied only on an indent in the outer walls – which could easily be introduced with a forming operation after roll forming.

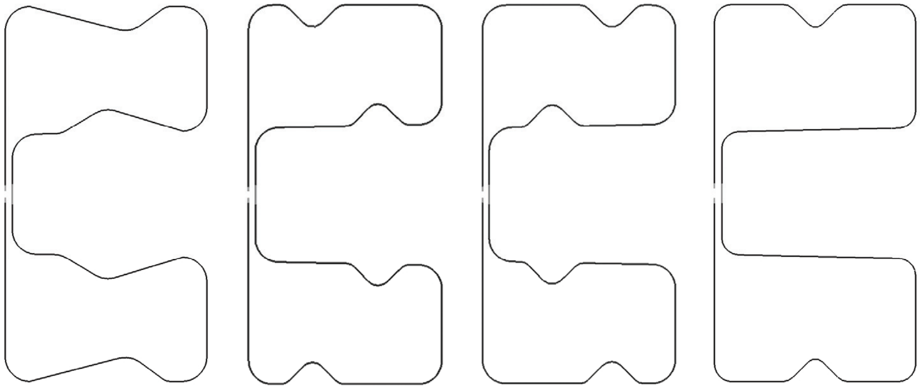


**Figure 2: Examples of initiator geometries considered**

It was realised that the behaviour of the rolled profile under a crush load would certainly depend on the prior roll forming process, especially from the work hardening of the radii. For this initial work a simple bending model was used to simulate the effects of previous rolling operation. This process was similar to a flange forming operation – one side of the blank was clamped to the punch while a bending die was wiped down the protruding face to create a right-angle bend of the required radius. Work hardening and thinning were mapped (using eta/DYNAFORM, [2]) onto each radius of the "B" profile geometry before simulating the crush operation (and then the ensuing impact load cases); the principles for mapping the effects of forming onto latter simulation models were as established in previous work [3].

## SIMULATION OF THE FULL FORMING PROCESS

The initial predictions of the collapse of the beam with estimated effects of forming introduced by mapping from a simple bend model were thought to be acceptable for early exploration. However, it is generally understood that the roll forming process leads to a different distribution of strain in the bend radii of the profile due to the progressive nature of the forming process. Therefore, in order to have greater confidence in the predictions, it was felt it would be necessary to simulate the entire forming process, from initial coil through to beam with crushed ends.

## ROLL FORMING SIMULATION

Roll forming simulation to date has generally been limited to flower pattern strain predictions that generally use empirical bending strain calculations in 2D to assess the feasibility of the proposed roll stand design. Full finite element simulation of the process is hampered by the continuous nature and physical scale of the relatively slow rolling process. Explicit methods have been felt impractical without use of excessive mass scaling to make the duration of the problem manageable. Given the advances in the implicit formulation in LS-DYNA (3) it was decided to attempt the roll forming simulation using this approach.

A number of experiments were carried out to explore how the problem could be handled practically. The following are some of the key learning points from the study:

- The implicit method proved more reliable and ultimately more efficient than the explicit formulation; although initial convergence took a little time as contact occurred with the first set of rolls, once underway the analysis proved very stable and converged readily as each new set of rolls came into contact;

- The blank was held stationary (fully fixed along the centreline which stays on the same plane throughout the process) and the tools moved past it; this reduces the physical size of the problem and perhaps avoids problems of rounding errors (single precision was used);

- Shell elements were used for both the strip and rolls; aspect ratio of these elements was about four to one, and the short edge was roughly equal to the material thickness;

- Only a limited length strip of blank was used with constraints to simulate the continuous material; sufficient length for full contact with at least two stands was maintained throughout. There is evidence of difference in the strains in the first few rows of elements but the majority of the blank length shows uniform properties (the ends were discarded for further processes). Further runs are planned with a longer blank to confirm these effects;

- The tools were not rotating (as they do in reality) but friction was reduced to zero to simulate the effect of the rotation; also, the tools were closed vertically as they approached the leading edge of the strip (which also helped with contact convergence);

- Attention to detail in the contact definition was vital to a successful run; in particular normal direction, penalty stiffness and contact gap cf. shell thickness.

At the outset, the goal was only to simulate the first bend in the profile (the initial design had four similar bend angles and radii although in fact this changed during the development) with the intention of mapping the results from one bend to the others. However, as the project progressed a practical approach to simulating the roll forming process was developed that allowed simulation of the full sequence of twenty-two rolls. The roll forming tooling is shown in Figure 3.

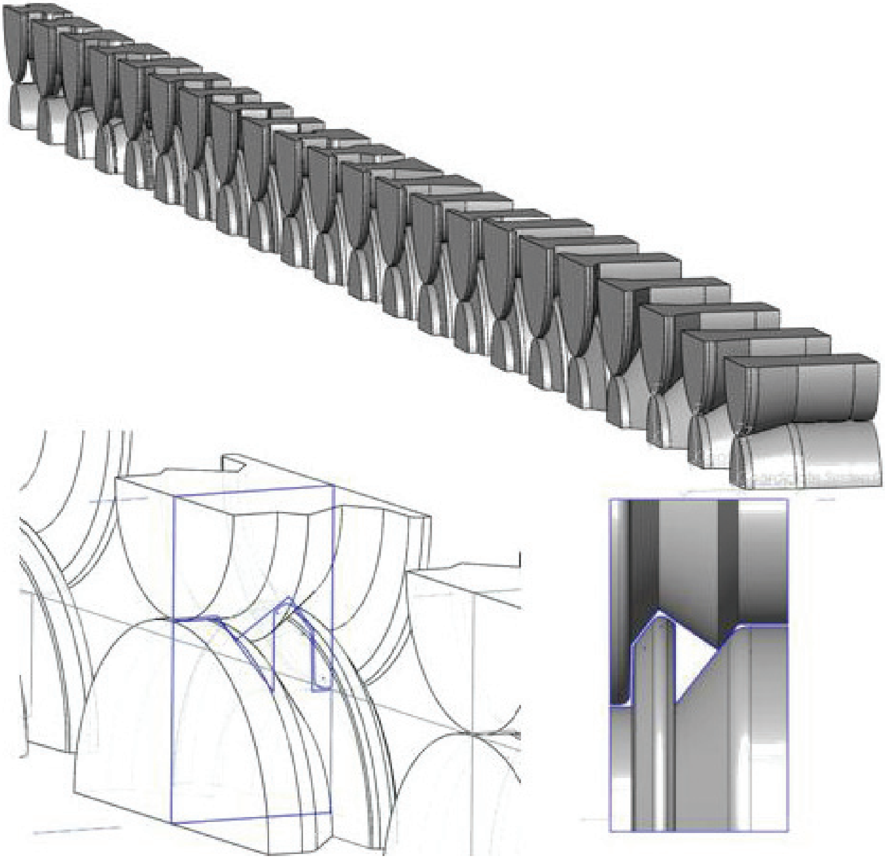


**Figure 3: Roll form tooling with detail for one stand**

A selection of views of the strip undergoing deformation is shown in Figure 4.

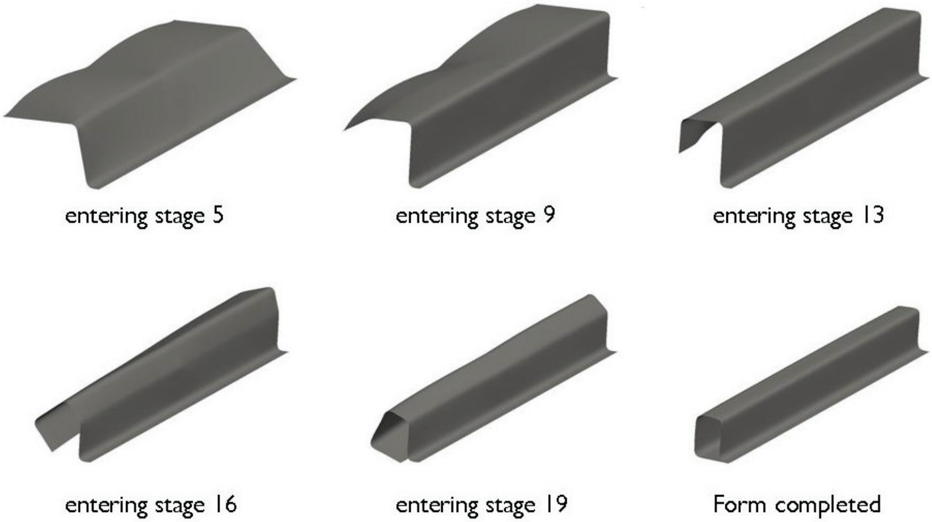


**Figure 4: Roll forming simulation**

In the final runs, the spot weld operation was added after the final roll stand (using tied contacts with pre-determined birth time); this was important to control the final shape – the strip is effectively undergoing a continuous springback between each roll stand and the profile tends to open up if the spot welds are omitted. Finally, a simplified simulation of the sweep bend was added to the end of the run.

The completed analysis allowed not only confirmation of the strains in the bends to provide input to the latter stages of the process but also revealed a number of issues with the forming process itself. Figure 5 shows examples including (A) skew of the entire section, (B) reverse curvature on the top face and (C) radii pinching. Hence, not only does the simulation of the roll forming process provide input to the ensuing forming models (and to also provide input for crash models allowing inclusion of the effects of forming), it can also now be used as an aid to tool design.

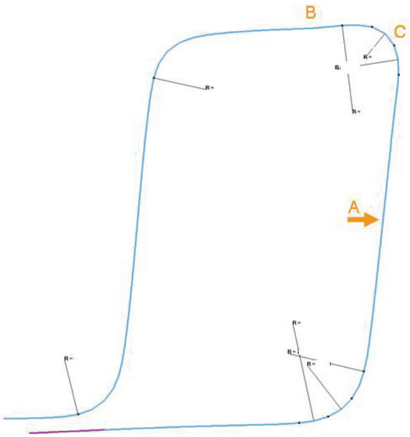


**Figure 5: Profile Distortion**

## ANNEALING SIMULATION

Although it would have been possible to carry out a thermal analysis of the annealing process (to predict the temperature vs. time profile element by element) instead a number of physical tests were carried out with instrumented samples, supported by detailed data from the material supplier (SSAB). So for the current project, the properties of the elements in the annealed area were modified by mapping data applicable to the measured annealing profile in that location. However, the simulation model was used in a later investigation of the effect of modifying the length of the annealed region and further work to simulate this part of the process remains under consideration.

## INITIATOR FORMING SIMULATION

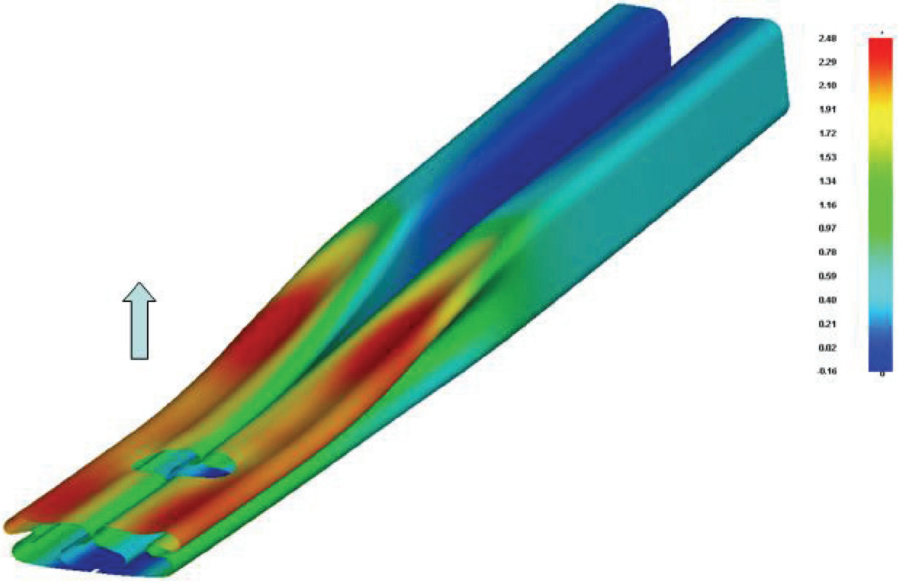
The initial 2D work had already established the most likely candidates for initiator geometry; furthermore, it had been determined that only the outer walls would be modified to introduce an initiator bead. Therefore, three different locations on the outer wall were examined to position the preferred initiator geometry.

The objective was to determine which location would give the most stable collapse and maintain strains to an acceptable level. The simulation model was used to examine the strain distribution across the crushed profile and through the transition into the full roll formed profile. The preferred solution needed to give equal collapsed height on the front and rear of the beam while limiting the maximum overall vertical dimension of the collapsed ends. The flatness of the rear face also needed to be maintained within a close tolerance for assembly of the crush cans.

## END CRUSHING SIMULATION

The final stage of the simulation was a relatively straightforward crush forming with a two piece tool in order to collapse the end of the beam. The section depth was reduced by more than 50%.

As explained above, a key concern was the level of major strain in the outer fibres of the collapsed material – too high a strain would lead to cracking. Strain levels on the outer fibres of each bend were examined; the peak strains in fact occurred in the transition between the crushed end and the uncrushed central part of the beam. Dimensional stability of the collapsed profile was also confirmed. Finally, a springback simulation was carried out; the crush process was adjusted to ensure that the depth after springback was as per the design requirement, and also to check flatness of the crushed face the following assembly operations. Figure 6 shows the shape of the beam end after crushing and springback.



# FURTHER SIMULATION – CRASH PERFORMANCE

The models were re-visited a number of times during the design process to assist in defining details such as the optimum length of the annealed region, the effect of changing the tow-eye location and development of a pierced shape in the strip for the tow-eye mounting.

In most cases, the model of the formed bumper beam was provided to Wagon Automotive's analysis team and the results (thinning, work hardening) were mapped onto a model used to predict the impact performance of the beam under various load cases (including Thatcham, high speed, static durability, etc.) as the final stage in the product design process.

# SUMMARY AND CONCLUSIONS

Roll forming is an important manufacturing process and has particular advantages in forming Ultra High Strength steels. Such steels offer many benefits in vehicle design but cannot easily be formed by traditional stamping.

During the course of this project the ability to successfully simulate the roll forming process using LS-DYNA (using the implicit formulation) has been demonstrated. This proved to be an important part of the development of the design and manufacturing process for this particular component; and it can now also be usefully applied to the development of further products in the future.

# ACKNOWLEDGEMENTS

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Please note that the design concept shown in this paper is the intellectual property of Wagon Automotive plc and is the subject of a pending patent application.

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