Numerical Analysis of the Hydro Forming Process Involving an Automobile Rear Subframe by Finite Element Methods

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Abstract: Background: The hydroforming process has been extended and applied widely among automotive companies over the last 20 years. It has many advantages such astubular parts offering improved structural integrity, fewer vehicle frame components, mass savingsin material usage and weight reduction as well aslessspringback, higher stiffness, and better design freedom. Aim: In the present study, a process for generatingrear subframe components has been developed usingthe tube hydroforming process.Carbonated steel tube material,havingultimate tension strength over 440 MPa,wasadapted for improved performance. At the initial design step, a feasibility investigation, aided by the finite element method,was employed to meet detailed hydro-formability. Variables like an inner pressure, axial direction feed, and designpatternwere investigated in the rear subframe for vehicle chassis systemthrough hydro-forming. Overall, hydroformablesubframe parts were established by cross-sectional investigation.

Results: All expansion rates were designed to be capable of forming.Detailed simulations showed that the final thickness, due to hydroforming, exceeded the standards for component development. Application: It is necessary to verifythat the workability of the pipe material at each stepevery forming process, like as prebending, preforming, and hydro-forming, is defined accurately. To dothis, more efficient section design criterion wasoptimized through an analysis of both the shape and the thickness of the hydroformed components.

Keywords: Hydroforming; Subframe; Computer-Aided Engineering; Formability

I. INTRODUCTION

Applications ofhydroforming technologies have been growing rapidly in the automotive industry throughout the last decade. The initial deformation and shape evolution of hydroforming component models were mostly made of simple polygonal shapes that were used to manufacture sanitary goods and musical instrument[1-3]. Hydroforming technology has also become more competitive in recent years, allowing for the development of highpressurized hydraulic system and the expansion of pressdevices. Compared with conventional press forming methods, this technology hasmore advantages, such as reduced part numbers, integrated molding, reduced assembly costs(due to a reduction in parts and mold), the omission of punching and welding processes, high-shape accuracy, and animproved component rigidity and durability [4-7]. Using hydroforming technology, it is possible to produce various automobile parts,particularly those used for exhaust systems, back and forthsubframes, side members,and cam shafts. Typically, the tube material employed for hydroforming is expanded and shaped through a high-pressure fluid in a special mold made of durable metal. The tubes, cut to the appropriate length, are bent, preformed, and hydroformedinto the final shape. In general, the preforming process is applied to the hydroforming mold to be seated. In most cases, the preforming shape ultimately decides the success or failure of the hydro-forming step. Here, the pre-formed pipe is loadedonto a hydro-forming mold or formed at a certain internal fluid pressure (usually12,000 PSI or less) [8-10]. The strength of the tube material used to attain areduction in vehicle weight also increases. Currently, materials with a tensile strength between 300 and 400MPa are widely used;however, the application of steel sheets having tension strength over 400MPa is stillthe preferred choice, especially for chassis parts [1,2].

In presenter search, the step for developing hydroforming rear sub-frame components using 440MPa grade steel was investigated. Here the application of numerical methods to the design criterion is presented by analyzingthe shape and thickness of the hydroformed parts.

II. MATERIALS AND METHODS

2.1. Calculation of the hydroforming pressure

To verify the forming possibility, an accurate hydroforming pressure or device capacity wasconsidered first. Figure 1 shows the thin tube that was forced using inner pressure. The resulting yield stress of the tube could then be estimated with Equation 1:

$$\sigma_y = P_i R_i / t \quad (1)$$

Where P_i, σ_y, R_i, and t are the inner hydro-forming pressure, tube yield strength, and equivalent inner radius of the pipe and pipe wall thickness.

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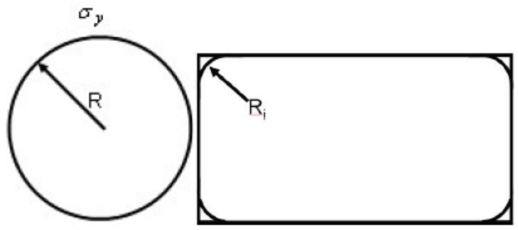


(a) (b)

Figure 1. Relationship between the internal pressure and the pipewall thickness

The press device power can then be calculated by knowing the total componentarea. In Eq. 2, the press device power (i.e., the hydro-forming die closeness load), F_{clamp}, is directly proportional to the inner hydro-forming pressure, pipe size and so on.

$$F_{\text{clamp}} = P_i \cdot d_i \cdot l \qquad (2)$$

Here, d_i and l are tube outer diameter and pipe length, respectively. Should the axial direction feed process include the axial force, of which, has the ability to act as a pressure intensifier within the internal tube, the sealing and formability operations can be determined using Eq. 3:

$$F = F_s + F_a + F_f, \qquad (3)$$

Where F_s is the maximum load to closethe pipe tips and described in Eq. 4 as

$$F_s = P_i \pi \left(\frac{d_0 - 2t}{2}\right)^2, \qquad (4)$$

where d_0 is the pipe inner diameter.

In Eq. 3, F_a is the load needed to shift material from different pipe tips through plastic deflection as described in Eq. 5 by

$$F\_a = \text{Tube\_Section\_Area} \times \sigma_z = (d_0 - t)\,\pi \cdot t \cdot 1.2 \cdot \sigma_{\text{ult}} \qquad (5)$$

where, σ_{ult} is the ultimate tensile stress of the pipe. In Eq. 3, F_f is the loadowing to friction as describing in Eq. 6 by

$$F_f = \mu \cdot P_i \cdot A_f \qquad (6)$$

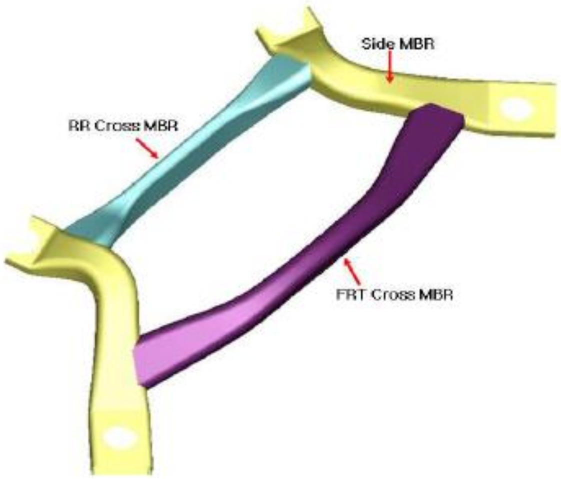
where μ and A_f are the friction coefficients and the friction areas where material is moving relatively. A friction coefficient of 0.06 was used in the present analysis. Table 1 shows the calculated results for press device power when the axial direction load for feed and calibration pressure is given. The axial force for feeding was found to be 205.1 ton.

Table 1.Calculated results of the press capacity

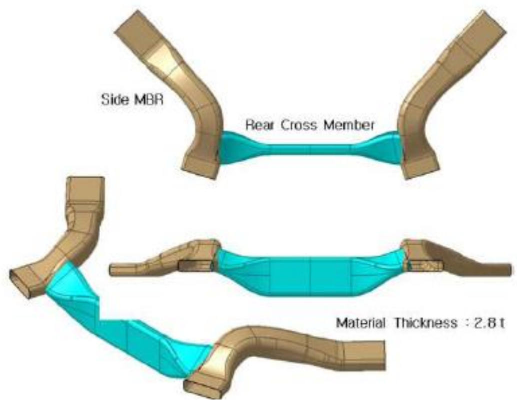
Expansion ratio, minimum	–0.4%
Expansion ratio, maximum	10.9%
Corner radius, minimum	10 mm
Pipedimension (determined)	84.0 mm
Tube was thickness	2.8 mm
Loadby the friction	78.8 ton
Max.load to seal tube tips	85.8 ton
Load to move materials at pipe tips	40.5 ton
Calibration pressure, min.	1,778.2 bar
Axial direction load for feed	205.1 ton

2.2.Parts Design for Side Members

In an automobile, the rear subframe is the main part of the chassis component. It is typically located at the bottom rear of a passenger car and serves not only as an axle but also as aconnection between the body and the wheel of a vehicle [1,2]. The rear wheel is connected to this particular part through several links to ensure anenjoyable ride. The rear subframeconsists of two side members and two cross-members. In this study, only the two side membersare designed by pipe hydro-forming. Figure 2 shows thegeometry of the rear sub-framehaving the symmetryside MBRs (members).



(a)



(b)

Figure2. The simulated geometry of (a) a rear sub-frame and (b) symmetry side MBRs and a rear cross-member

III. RESULTS AND DISCUSSION

To confirm the formability of parts through the hydro-forming process, one part is first examined longitudinally. Figure 3 shows the design changes made for the two side member parts. In order to increase the possibility of hydroformation, the thickness was lowered due to any expansion that may occur during the forming process. Compared with the existing model, the design was changed to lower the side member height by 10.6 mm, as shown in Figure 3a. In Figure 3b, the bending curvature is shown to increase by 12.0 mm to facilitate bending. The shape was also changed by reducing the width by 5 mm in order to lower the end-portion expansion ratio (Fig. 3c).

Figure 4 shows the simulated cross-sectional analyses of the two side members. Each number presented is the circumferential length of each section. Since the outer diameter of the initial tube is 84 mm, the circumference of the tube is equal to 263.76 mm.

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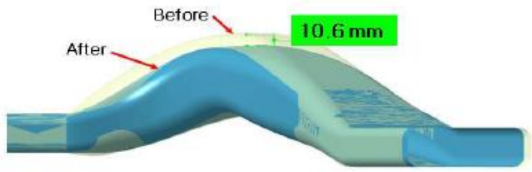
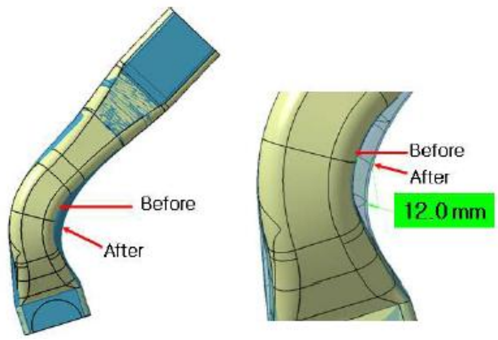
The maximum and minimum cross-sectional circumferential length and minimized corner radius of the component can be obtained by the cross-sectional results. Here, the required tube length, press load, and maximum pressing force can be calculated. For these parts, the minimum and maximum circumferential lengths are 262.7 and 292.4 mm, respectively, with expansion rates between · 0.4% and 10.9%. Therefore, the proper pipe size would need a tube outer diameter of 84.0 mm, a circumferential length of 263.76 mm. If circumferential length of the designed product is greater than or equal to the circumferential length of the tube, the hydroforming process could then be used to produce a satisfactory moldthrough tube expansion. In this case, parts can maintain structural integrity as the maximum expansion point is close to both ends of the part. It can also increase the expansion rate up to 30% at both ends through axial feeding, which is often used in hydroforming processes[3]. The tube material chosen for the hydroforming process was subject to tensile testing and the resulting properties shown in Table 2[1,2].



(a)



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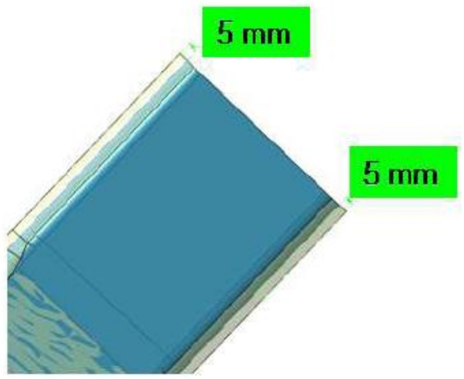

(c)

Figure 3. Changes to the design shape through (a) reduced height, (b) increased curvature, and (c) decreased end width for the side members

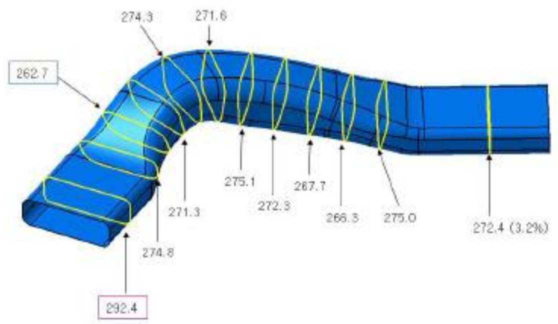

Figure 4. The circumferential analysis of member parts (units: mm)

Table 2. Mechanical properties of pipe material

Elastic Modulus, GPa	Uniform Elongation, %	Tensile Elongation, %	Yield Strength, MPa	Tensile Strength, MPa	n
210	16.3	31.4	365	473	0.15

Figure 5 shows the shape of the parts to be simulated by the hydroforming process. Since the side member is made up of two parts (left-hand and right-hand symmetry parts), it was designed to be formed througha one-step mechanism and used to cut the middle part. This reduces the forming process by one step.

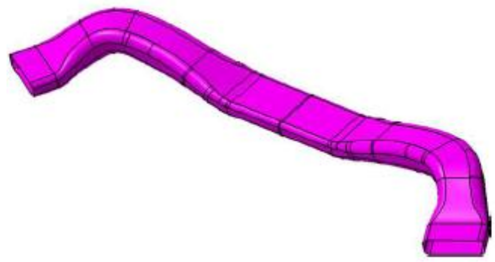

Figure 5. The side member shape for the one-step hydroforming process

Figure 6 shows the shape metal bending process for the preformed parts before hydroforming. In order to make the hydroforming die cavity fit easily into the parts, the simulation model was designed with free-bendingusing 6 degrees of freedom. The bending curvature was set at 155 mm. The resultingsimulations of tube bending into the hydroforming mold is shown in Figure 7.This confirmed that hydroforming is possible without any preforming steps.

Figure 6. The six-bending tube shape used for hydroforming

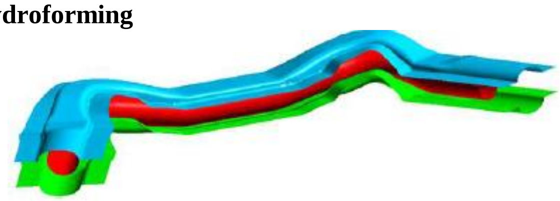

Figure 7. The upper and lower die cavity used for hydroforming

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Figures 7 and 8 show the upper and lower die cavities, as well as the outer line of the die cavity, which allows for the easy insertion of the bending tube.

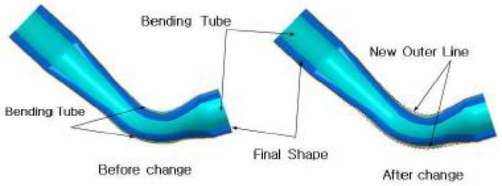

Figure 8. Outer line changes for the die cavity seating

For the hydroforming analysis, the calculationwas performed by using LSDyna, a commercially well knownprogram. Figure 9 shows the shape and thickness reduction rate after the hydroforming process was completed. The maximum forming pressure required was predicted at 1,500 bar and the maximum thinning at 13%. The maximum allowable reduction in thickness for the material used was found within 25% range, which was less than the expected thickness.

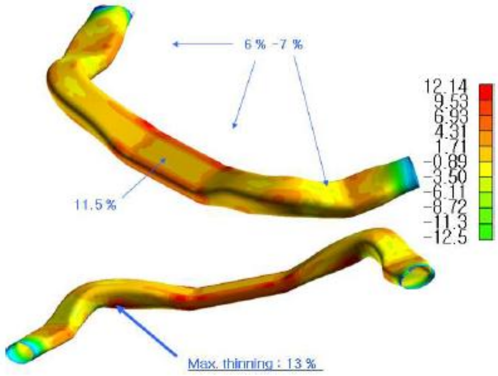

Figure 9. Calculated shape and thickness distribution after the hydro-formingstep

IV. CONCLUSION

We have successfully developed a hydroforming side member for the sub-frame of an automobile having a high strength steel, tension stress over 440 MPa. For the component design step, an exploratory analysis of the part shape was performed, and the entiresteps were constructed. All expansion rates were designed to be capable of forming. Detailed simulation results showed that the final reduction in thickness was due to the hydroforming process. The latter exceeds the standards for component development.

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