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HYDROFORMING ANALYSIS OF STRUCTURAL STEEL PLATES

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ABSTRACT

In this study hydroforming analysis of low carbon cold formed structural steel sheets (St12, SAE 1006) are studied experimentally and numerically. The effects of hydrostatic pressure, plate thickness, mould curvatures were investigated. The failure zones, stress and deformations were compared with finite element model. It was found that the metal elongation and strength, plate thickness, mould design were effective tools for hydforming performance of sheet metals. The Bilinear isotropic hardening nonlinear material modelling with shell elements are used in Ansys 16.0 Lsdyna explicit module. The effects of element size on stress results and thinning of sheet metals at plastically deformed place are also discussed in model. The results are found in good agreement with the results of experimental works.

INTRODUCTION

Hydroforming is used hydraulic fluids at high pressures to form metal which is at room temperature into a die cavity.

It is a way of shaping materials structurally stiff in a cost effective way. Hydroforming is generally used in tube forming process recently which is a relatively new technology as compared to other conventional stamping processes with high mass production.

It is generally preferred for light weight vehicles design. The technology of hydroforming has achieved today a status that permits the economic volume manufacturing of high-quality lightweight components for the automotive industry [1]. Attainable weight reductions of around 30%, reduction of components and improved part properties are only some of the advantages in comparison to the manufacturing of such components by conventional sheet metal forming [2]. Sheet hydroforming is typical method used hydrodynamic deep drawing. The liquid can be used as a punch, a draw die or an assisting way to improve sheet formability. In the light of the different functions of the liquid, hydroforming may be defined as active sheet hydroforming and passive sheet hydroforming [3]. Almost many materials used in classical stamping may be used in sheet hydroforming. Sheet hydroforming has increasing interest in the automotive and aerospace industries because of its many advantages such as higher forming limitation, good quality for complicated and multilayer structures [4].

Finite element analysis especially Ls-Dyna is increasing importance for hydroforming process design [5], [2]. It is usually preferred for optimum design and reliability of process.

Simulation integrated design results (thinning partions stress strain values) are valuable for design of curved parts hydroforming with additional preforming operations [2].

EXPOSITION

In the study at first stage hydroforming performance of low carbon structural steels are studied by using set up seen in figure 1. Conventional low carbon steels are used in studies where mechanical are given in table 1. At the second stage explicit finite element model is developed according to working conditions of hydroforming process. The developed finite element model and boundary conditions are given at figure 2-3.

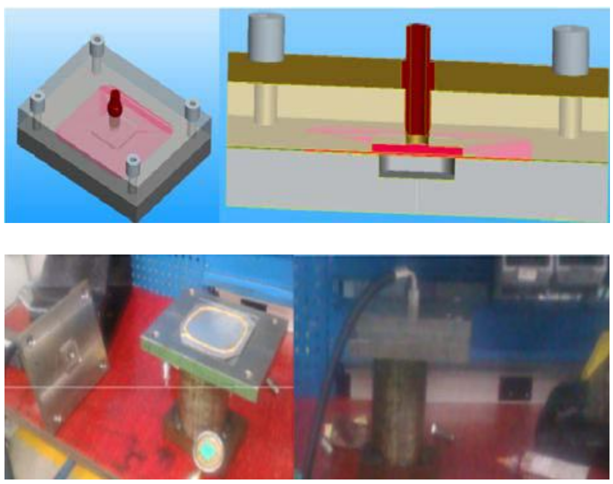

Fig. 1. Hydroforming Process in Experiments

The material properties are taken from manufacturers in experiments.

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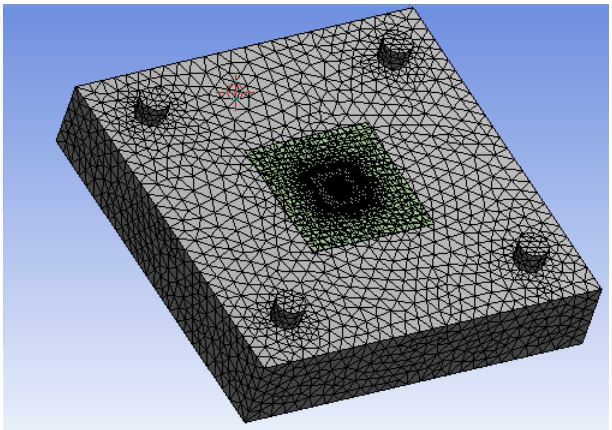

Fig. 2. Finite element model of explicit analysis

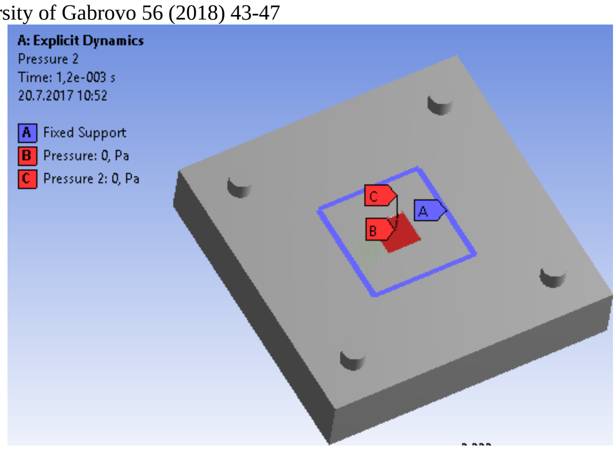

Fig. 3. Boundary conditions applied at explicit model

Table 1. Material properties used in experiments

Materials	Elastic Modulus (MPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Tangent Modulus (MPa)	Elongation (%)	Thickness (mm)
ST 12 (DIN EN 10130)	205000	230	320	321	28	0.75
AISI SAE1006	205000	240	355	550	21	0.9

Hydrostatic pressure variation is defined at figure 4. Where critical time is determined 1e-3s for Ls-Dyna analysis.

Convergence study is performed according to element size seen in figure 5.

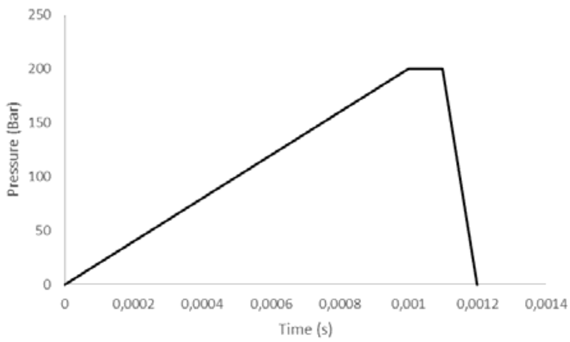

Fig. 4. Hydrostatic pressure applied on sheet metals

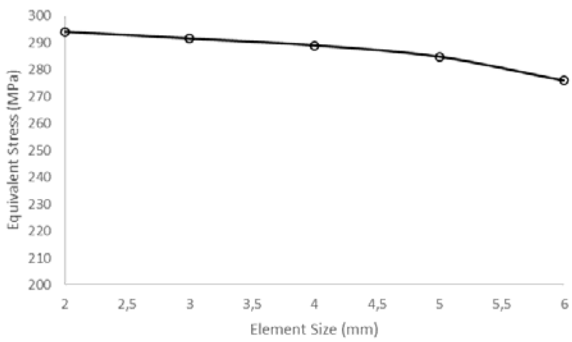

Fig. 5. The effect of element size on equivalent stress results (St12)

Optimum element size is determined according to element size results, optimum results are obtained for 3mm element size.

In the experiments at the first stage St12 materials with 100bar hydraulic pressure is applied for forming process. First mould is used for this aim seen in figure 6. The catastrophic failure zones (figure 7) are determined without using full potential of material because of the mould design seen in figure 6. The sharp corners of moulds are machined and final mould is obtained seen in figure 6 second design.

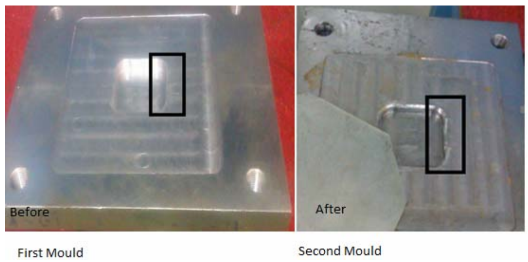

Fig. 6. Mould design change

Fig. 7. Failed St12 specimen under 100bar pressure for first mould design

The finite element model maximum equivalent stress and plastic strain results are given at following figures 8-9 for first and second mould design.

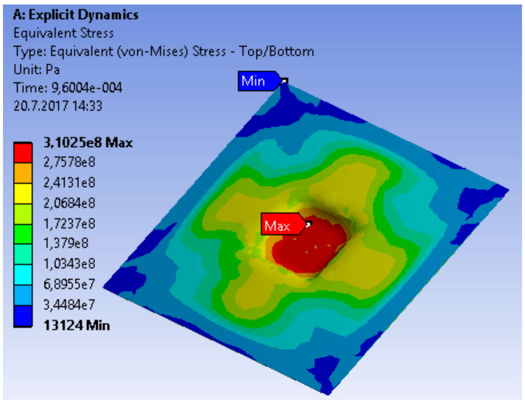

Fig. 8. Maximum equivalent stress results of St12 plate for first mould design

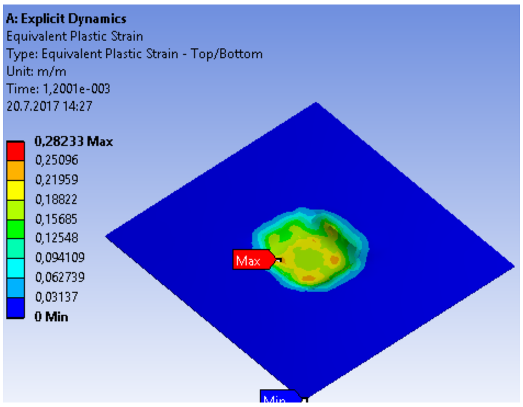

Fig. 9. Equivalent plastic strain results of St12 plate for first mould design

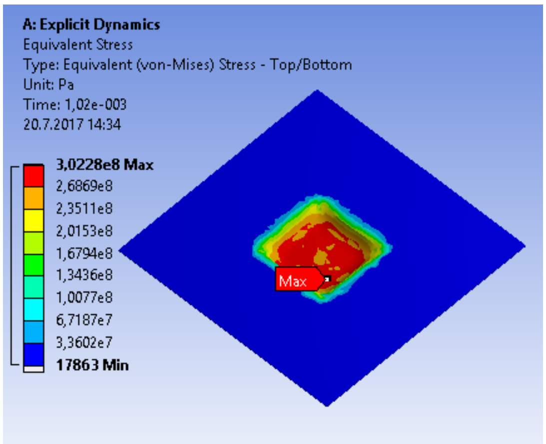

Fig. 10. Maximum equivalent stress of St12 plate for second mould design

The results show that equivalent maximum stress is declined 310MPa to 302MPa and the plastic strain results show that thinning of sheet metal for first mould is more than second mold design. When thinning and failure zones of plates are investigated it is found that the plastic strain, the residual stress results seen in figure 11-12 are in good agreement with experimental results.

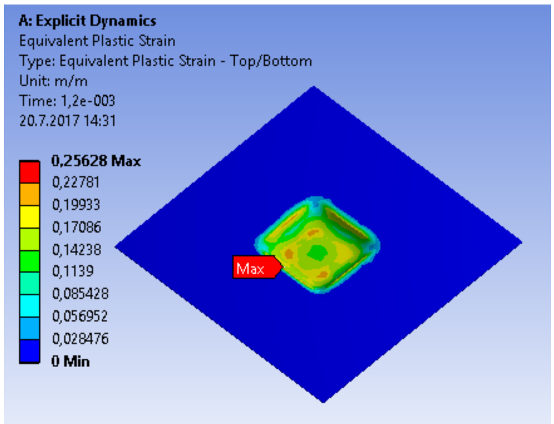

Fig. 11. Equivalent plastic strain results of St12 plate for second mould design

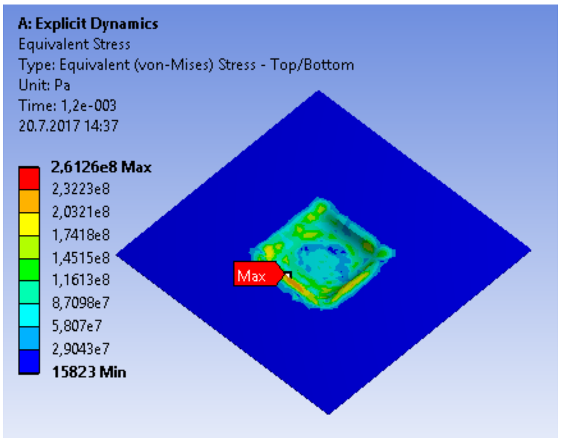

Fig. 12. Residual stress results of St12 plate for second mould design

In the following part two different steels (St12 and Sae 1006) hydroforming performance is compared for new mould design in figure 13-17.

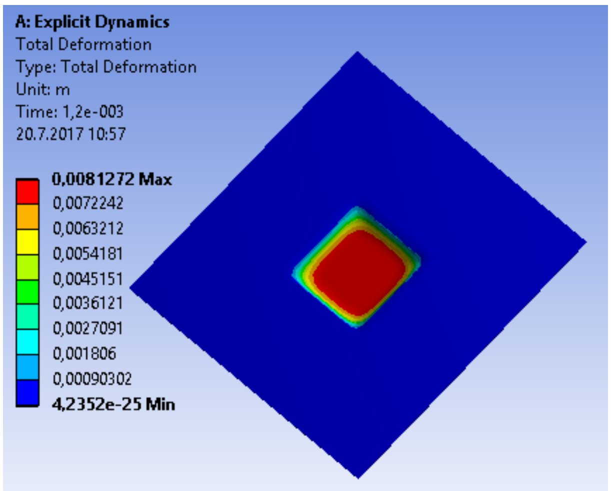

Fig. 13. Total Deformation results of St12 plate for second mould design

Fig. 14. Formed St12 specimen under 200bar pressure for second mould design

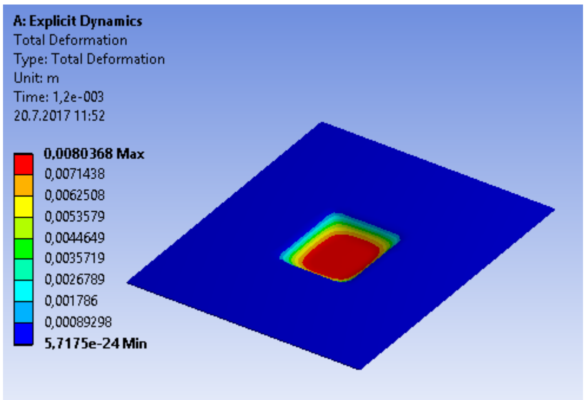

Fig. 16. Total Deformation results of Sae 1006 plate for second mould design

Fig. 17. Formed Sae 1006 specimen under 200bar pressure for second mould design

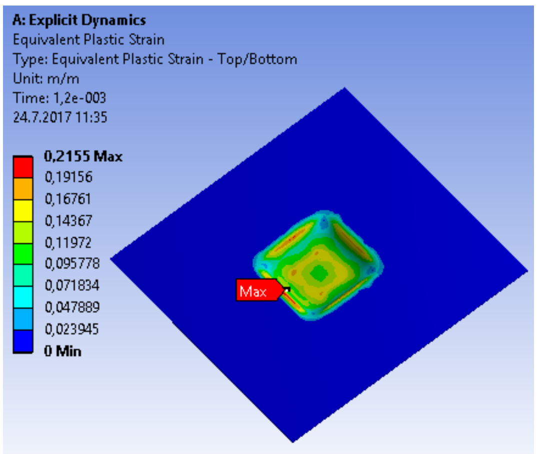

Fig. 18. Equivalent plastic strain results of Sae 1006 plate for second mould design

The residual stress and plastic strain results show that the most thinning zone in our parts is transition part where the plastic equivalent strains and equivalent stresses are taken maximum values seen in figure 11-12, 18-19.

Table 2 is summarized the scene in our study.

The results show that AISI 1006 material plastic deformation values are lower than St12 material because of the strength and ductility values. Thinning of deformed part of the plate is focused at following stage. Equivalent plastic strain results of formed section of plate are used for determination of thinning.

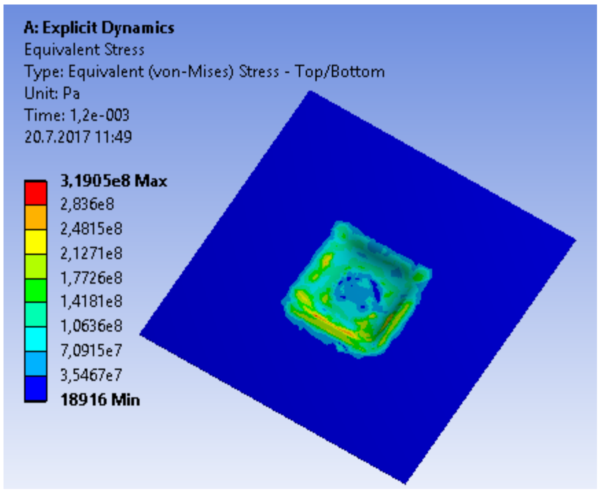

Fig. 19. Residual stress results of Sae 1006 plate for second mould design

Equivalent plastic strain calculations are calculeted by Prandtl-Reuss (Levy-Mises) flow rule. Effective plastic strains may be defined as follows [6].

$$\begin{aligned}
d\varepsilon_{xx}^{p} &= \frac{2}{3}d\lambda\left[\sigma_{xx}-\frac{1}{2}\left(\sigma_{yy}+\sigma_{zz}\right)\right]\\
d\varepsilon_{yy}^{p} &= \frac{2}{3}d\lambda\left[\sigma_{yy}-\frac{1}{2}\left(\sigma_{zz}+\sigma_{xx}\right)\right]\\
d\varepsilon_{zz}^{p} &= \frac{2}{3}d\lambda\left[\sigma_{zz}-\frac{1}{2}\left(\sigma_{xx}+\sigma_{yy}\right)\right]\\
d\varepsilon_{xy}^{p} &= d\lambda\sigma_{xy}\\
d\varepsilon_{yz}^{p} &= d\lambda\sigma_{yz}\\
d\varepsilon_{zx}^{p} &= d\lambda\sigma_{zx}
\end{aligned} \tag{1}$$

Where plastic multiplier is defined as follow:

$$d\lambda = \frac{3}{2}\frac{d\hat{\varepsilon}^{p}}{\hat{\sigma}} \tag{2}$$

Table 2. *Finite element modelling results for two different materials*

Material	Equivalent Maximum Stress (MPa)	Residual Stress (MPa)	Equivalent Plastic Strain (m/m)	Total Deformation (mm)	Safety Factor for Tensile Strength
ST 12	300	261	0.256	8.12	1.0586
AISI 1006	337.5	319	0.2155	8.103	1.0517

$$\begin{aligned} d\varepsilon^p_{xx} &= \left(d\hat{\varepsilon}^p/\hat{\sigma}\right)\left[\sigma_{xx} - \frac{1}{2}\left(\sigma_{yy}+\sigma_{zz}\right)\right] \\ d\varepsilon^p_{yy} &= \left(d\hat{\varepsilon}^p/\hat{\sigma}\right)\left[\sigma_{yy} - \frac{1}{2}\left(\sigma_{zz}+\sigma_{xx}\right)\right] \\ d\varepsilon^p_{zz} &= \left(d\hat{\varepsilon}^p/\hat{\sigma}\right)\left[\sigma_{zz} - \frac{1}{2}\left(\sigma_{xx}+\sigma_{yy}\right)\right] \\ d\varepsilon^p_{xy} &= \frac{3}{2}\left(d\hat{\varepsilon}^p/\hat{\sigma}\right)\sigma_{xy} \\ d\varepsilon^p_{yz} &= \frac{3}{2}\left(d\hat{\varepsilon}^p/\hat{\sigma}\right)\sigma_{yz} \\ d\varepsilon^p_{zx} &= \frac{3}{2}\left(d\hat{\varepsilon}^p/\hat{\sigma}\right)\sigma_{zx} \end{aligned} \tag{3}$$

Here;

$d\hat{\varepsilon}^p$ is equivalent plastic strain increment, $\hat{\sigma}$ is equivalent stress, σ_{xx}, σ_{yy}, σ_{zz} are normal stresses, σ_{xy}, σ_{xz}, σ_{yz} are shear stresses, $d\varepsilon^p_{xx}$, $d\varepsilon^p_{yy}$, $d\varepsilon^p_{zz}$ are plastic strain increments in normal direction, $d\varepsilon^p_{xy}$, $d\varepsilon^p_{yz}$, $d\varepsilon^p_{xz}$ are plastic shear strain increments.

Thickness variation is found by using z direction plastic strain increment. Plastic stain in z direction may be defined as follows: [7]

$$\varepsilon_z = ln\frac{t_1}{t_0} \tag{4}$$

Here t_0 is initial thickness, t_1 is last thickness after forming.

Equivalent plastic strain, equivalent stress and normal stress results obtained at Finite element analysis are used in the equation.

In maximum thinning values of plates for two materials are given at the table 3 below.

It is seen that thinning percentage of steels are near where plastic strain values are supported this results.

CONCLUSION

In our study sheet low carbon structural steels hydroforming performance is investigated. Ls dyna explicit module is preferred because of the large deformations occurred in hydroforming process. The bilinear isotropic hardening nonlinear material modelling is used in our analysis. The boundary conditions are determined according to experimental forming process. Experimental and numerical analysis results show that mould design is effective tool for plastic deformation of steels. Residual stress and plastic strain results are found in good correlation with experimental results when the sheets failure, thinning zone are focused. This study may be enlarged with strain hardening effects of cold formed steels with different carbon concentration values.

Table 3. *Thinning of plates for two steel materials*

Materials	Equivalent Plastic Strain (mm/mm)	Initial thickness t_0 (mm)	Last Thickness t_1 (mm)	Thinning percentage (%)	Strain Hardening Exponent n [8],[9].
ST 12	0.256	0.75	0,711	5.18	0.217
AISI 1006	0.2155	0.9	0,842	6.4	0.227

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