OPTIMIZATION OF HYDROFORMING DIE GEOMETRY FOR MANUFACTURING OF SOLAR ABSORBERS

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Abstract

In a development of a new type of solar absorbers is required to modify an absorption area to the system of pyramidal cavities. It is necessary for higher absorption effect and less dependence on incidence angle of solar radiation. Due to complicated final surface, the hydroforming was chosen as a production technology. This paper deals with numerical simulations of forming operations and an identification of critical areas. Furthermore, the die shape and a weldment - sheet blank optimization are performed. A theoretical simulation of the hydroforming process was carried out by using ANSYS software.

Keywords: solar absorber, hydroforming, ANSYS, numeric simulation, optimization

1. INTRODUCTION

Currently the design of flat-plate solar collectors for water heating consists of flat aluminum sheet with an absorbent layer and a pipe meander which is connected to the reverse side of the aluminum sheet. In this case, the technologies of laser or ultrasonic welding eventually crimping are used. This construction has two principal drawbacks. The first drawback is the transfer of heat from the absorber sheet to the pipe, where only linear contact is between them. However, this is also related to the problem of joints between the aluminum sheet and the copper tube. The second drawback presents perpendicular incidence of solar radiation on the absorber plate, which is required for maximum thermal efficiency. This demand is met only during a small period of a day and the total daily (annual) thermal efficiency is low. Therefore, the solar collector should be oriented to the south with a slope of 45° for optimum thermal efficiency. This solution is very problematic, from both an architectural and a technical point of view.

Therefore, a new type of flat plate solar absorber was designed for elimination of above-mentioned drawbacks. It is based on the so-called plate design solar absorber with meandering structure providing controlled heat transfer medium circulation over entire surface of the absorber. In addition, an absorption area comprises set of pyramidal cavities, which absorbing solar radiation through multiple reflections. This idea reduces the dependence on impact angle of solar radiation and increases the heat transfer surface. But this solution creates difficulties of technological disposition [1].

2. MANFACTURING OF ABSORBERS

Technology of laser welding and technology of hydroforming were proposed for the production. The manufacturing process comprising these steps: the first step is welding of two sheets together using a laser deep penetration welding; this weld creates the required meandering structure. Due to requirements for utility properties, weldability and formability of the absorber material, sheets of austenitic chromium – nickel stainless steel X5CrNi18-10 (ČSN 41 7240, DIN 1.4301) was chosen for the production [2].

Thereafter, this weldment is inserted into the hydroforming device, whose internal surface consists of desired structure (set of pyramids). Then forming liquid under high pressure starts to be pumped into a space between plates, see Fig.1. Outlet and inlet holes G1/4" in the sheet are formed by flowdrill technology where a friction tool forms the collar of hole from the excess material in the plate. In this collar, thread is created for screwing flanges for inlet and outlet of forming fluid. Actual realization of the hydroforming device for the absorber sample size 150x150 mm is shown in Fig. 2. A hand pressure two-stage pump with maximum work pressure of 700 bars is connected to the hydroforming device through quick screw connectors. For optimal reflective properties, the die with an apex angle 60° is used for experiments [3], [4], [5].

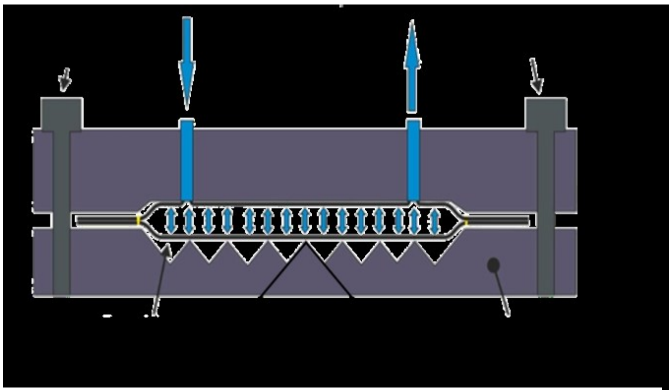
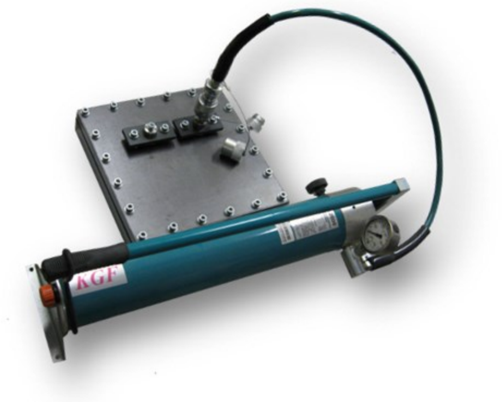


Fig. 1 Principle of hydroforming device



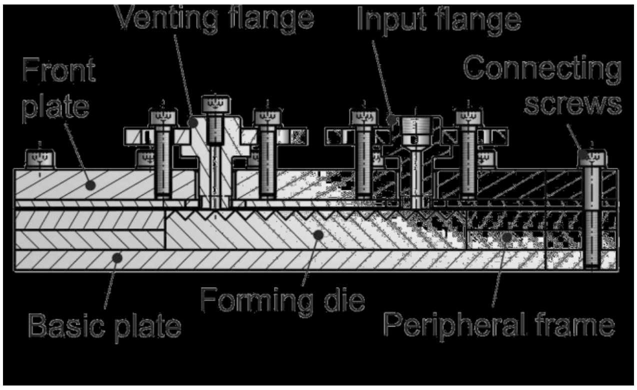


Fig. 2 Hydroforming device (on the left – realization including hydraulic pump, on the right – cross section)

3. OPTIMIZATION BY USING FEM

A primary problem of required structured (pyramidal) surface production lies in finding of optimal die shape properties with a prediction of sheet thickness in the area with the greatest deformation of indents, i.e. identification of critical points with maximum thinning of the wall, which of course must not exceed the permissible limit. Another problematic point is the transition weld – stamped material in area of meandering structure, where the stress peaks may cause a tearing of weld. Besides analytical calculation described, the problems in complexity can be solved by numerical simulations using Finite Element Method (FEM). It also allows the user to easily change the conditions of simulating and therefore helps to easier and faster optimization of stamping process [6]. **Material Model**

It is noteworthy that the main point of pre-processing, i.e. preparing data before the actual numerical calculation, is correct description of material behavior. To simplify of the simulation, the die material is considered as a perfectly rigid. Therefore, the material description is primarily focused on the material of the sheet metal blank. As it was previously stated, austenitic chromium – nickel stainless steel X5CrNi18-10 was chosen for the production of absorbers. The main experimentally obtained characteristic of this material are tensile test data (Fig. 3).

For correct description of the material, it is necessary to convert engineering stress – strain data according to classical equations (1) and (2) to obtain dependence between true stress and true (logarithmic) strain, which is primarily used as material input for the numerical simulation.

$$\sigma_{TRUE} = \sigma_{ENG} \cdot (1+\varepsilon) \qquad (1)$$

$$\varphi = \ln(1+\varepsilon) \qquad (2)$$

where σ_{TRUE} [MPa] is true stress, σ_{ENG} [MPa] is engineering tensile stress, ε [-] is engineering strain, φ [-] is true (logarithmic) strain.

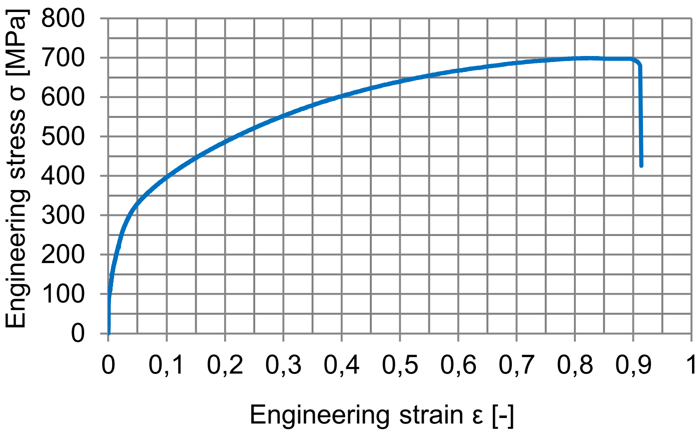


Fig. 3 Tensile test record for X5CrNi18-10 steel

With this assumption, material properties could be approximately entered to the ANSYS Workbench 14 software e.g. by using bilinear material model, which is characterized by values in Table 1.

Table 1 Material properties of X5CrNi18-10 steel

Yield strength	$R_{p0,2}$	[MPa]	282.85
Tensile modulus	E	[MPa]	$1.99 \cdot 10^5$
Plastic hardening modulus	E_{pl}	[MPa]	1 727.50
Poisson ratio	μ	[-]	0,30
Density at 20 °C	ρ	[kg · m³]	7.90 10^3

3.2 Geometrical Model

It is important to note that the simplified geometric model was used in order to simplify and speed up the computation of the forming process. It is based on partial symmetry and neglect possibility of those parts that do not have direct involvement in the stamping process. Further, it is necessary to make a full continuum discretization of stamped material and tools using finite element mesh. A detail of the simulation model (assembly of the stamping die and a stamped material – the sheet with the indicated weld line) used symmetry is presented in Fig. 4.

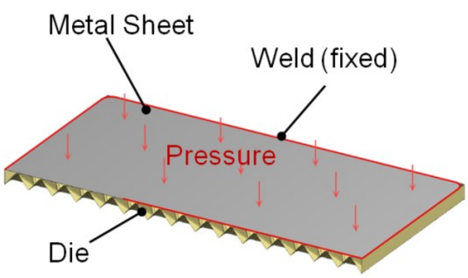
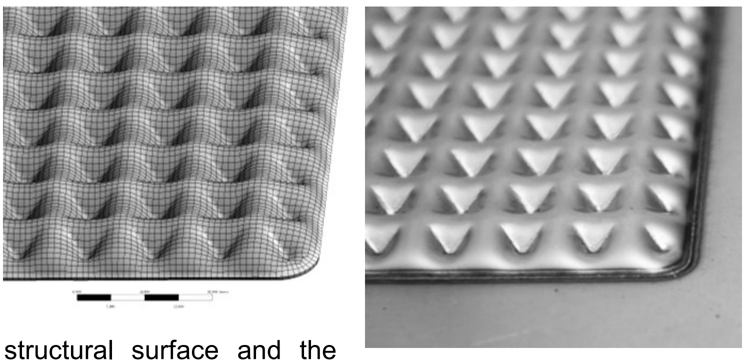


Fig. 4 Geometry model of FEM



structural surface and the

Fig. 5 Comparison between numerical model and real formed structural surface

A fully defined computational model, which is ready to calculate, was obtained after discretization of individual macro elements and applying boundary conditions, i.e. stamping pressure, contacts, symmetry options and other boundary conditions. Now it is possible to focus on the evaluation after the simulation by using FEM. Fig. 5 shows a simple comparison between formed prediction of shape by simulation using 600 bars forming pressure.

3.3 Solution of Optimization

The simulation by finite element method gives a required pressing force or sheet deformation parameters as a primary results. But it also allows to perform deeper analysis such as design exploration or shape optimization of critical areas. First problem of hydroforming process are the cracks that may occur on the tops of pyramidal structure after hydroforming. These are caused by too small rounding of die edges or by using of too thin metal sheet. By using statistical tools in ANSYS, it is possible to determine the dependence between radius of die edges, sheet thickness and maximum value of plastic strain, which was chosen as the criterion of fracture. The critical value of the plastic strain was defined at 0.63. Fig. 6 shows a response surface of mentioned dependence with safety area (hatched region). The conducted analysis shows on use of sheets with thickness 0.8 mm and the die pyramid edges with radius of 2 mm as a minimum safety combination.

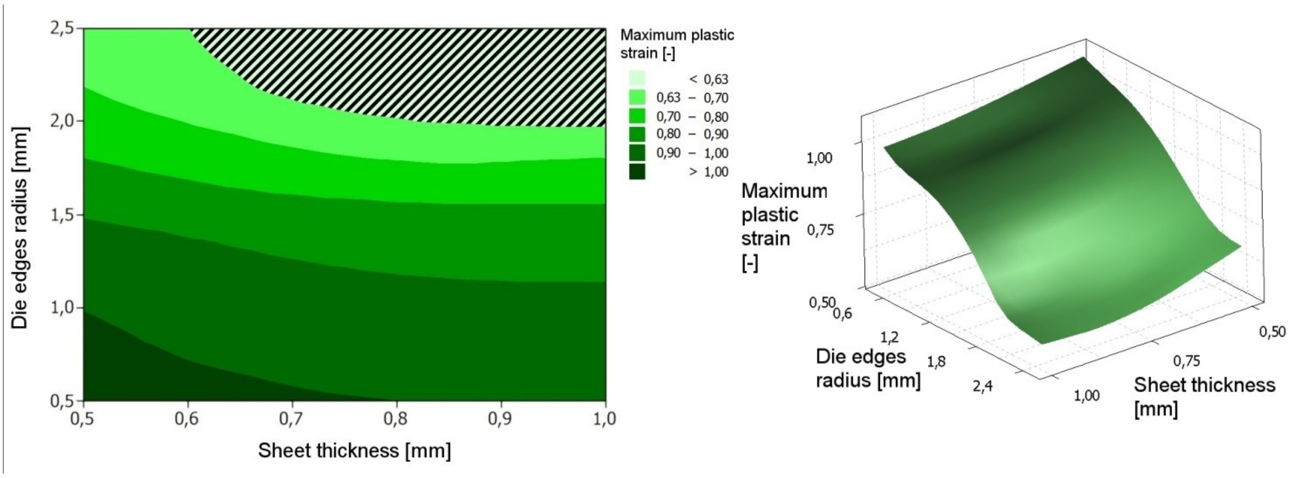


Fig. 6 Optimization response surface (on the left – contour plot, on the right – 3D plot)

It is equally impossible to proceed in case of problems with welds. As stated above, a supercritical load may cause the tearing of the weld in the transition weld – formed material, especially in the weld area, which forms the meandering structure (see Fig. 7). Based on simulation and statistical analysis, dependence between the radius of the welding path and the maximum plastic deformation was compiled. From the linear dependence clearly implies the necessity of use of at least 4.5 mm curvature. The chart is shown in Fig. 7.

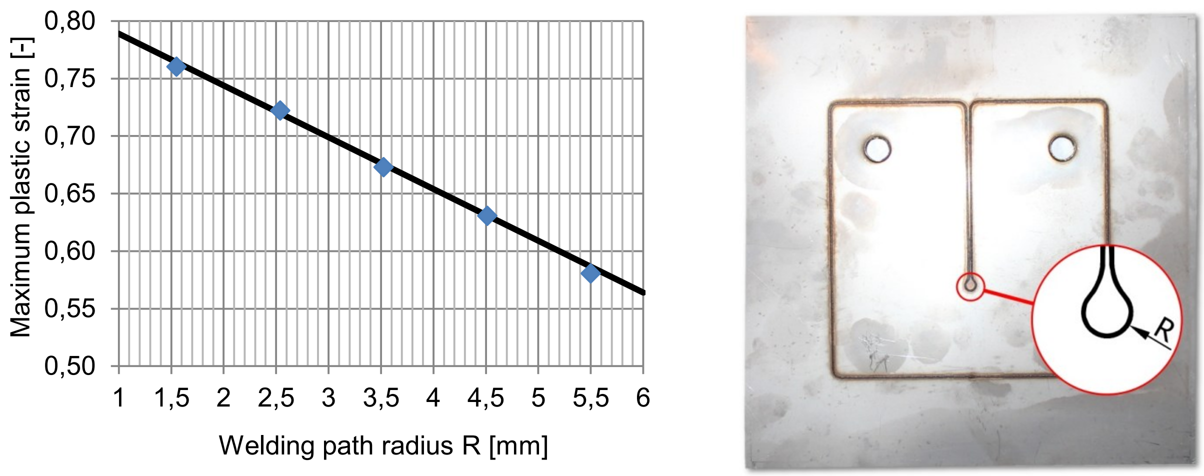


Fig. 7 Welding path optimization (on the left – optimization graph, on the right – optimized area)

Comparison between results of weld load numerical simulation and experiment, which was made without previous optimization of the weld path represents Fig. 8. Rather, it is a macro-detail of the crack that is appeared as a result of supercritical stress loading of the weld. The figure shows the case of welding path radius of 3 mm, when according to the simulation the stress peaks reach approximately 1 600 MPa, at the transition weld –molded material, i.e. above the ultimate tensile strength of the material.

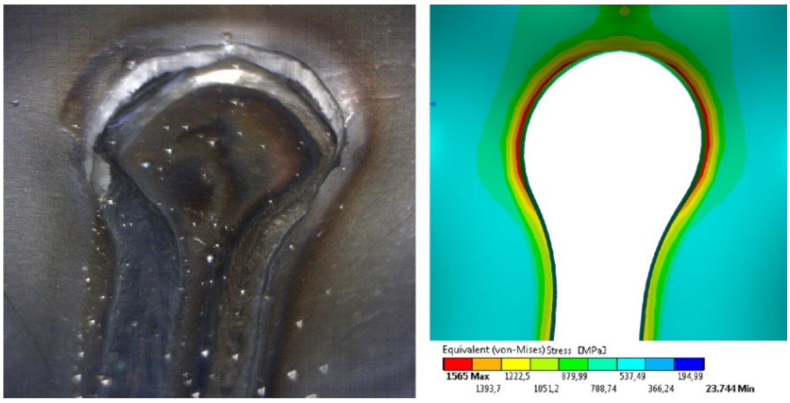


Fig. 8 Comparison between numerical model and real weld crack

4 EXPERIMENTAL HYDROFORMING

The simulation shows required parameters of the die and the welding path geometries. Further, it shows that the required forming pressure for the sheet thickness 0.8 mm is approximately 650 bars. It follows that the forming pressure causes force size of about 1125 kN on the both sides of the device. Due to possible deformation of the hydroforming device during the forming process, it is necessary to increase its rigidity. Otherwise, the resulting force of hydraulic oil inside the hydroforming device causes die swelling over 10 mm. Therefore, the entire hydroforming device is compressed by using the hydraulic press (Fig. 9) applicating a counterforce to the forming pressure. Fig. 10 shows the shape of the indents after hydroforming.

Fig. 9 Hydroforming device inside hydraulic press

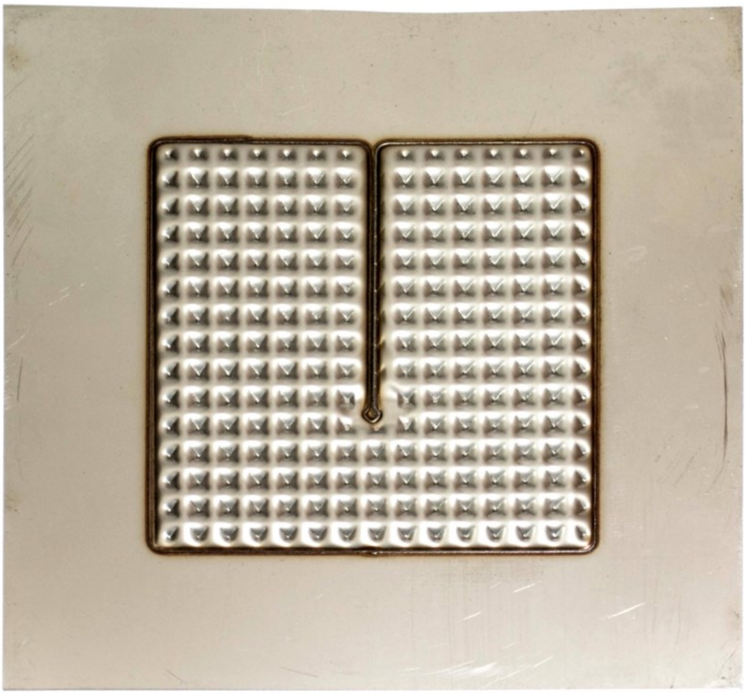


Fig. 10 Hydroformed structure surface

CONCLUSION

In this paper, the hydroforming device for manufacturing of solar absorber sample with structured surface was designed and tested based on the shape optimization. Practical hydroforming tests were conducted with samples, which were made of austenitic stainless steel X5CrNi18-10 with thickness of 0.8 mm. Hydroforming process was also simulated and optimized by ANSYS software. Experiments showed that the manufactured hydroforming device with optimized die design can create a structured surface of the solar absorber for dies with an apex angle 60° without any defects. The comparison between the theoretical simulation and experimental forming shows a very good agreement.

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