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INVESTIGATION ON SHEET HYDROFORMING OF TAILOR-WELDED BLANKS AND COMPARISON WITH CONVENTIONAL DEEP DRAWING

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Abstract

In this investigation, finite element simulations were carried out using commercial explicit finite element program to determine the formability characteristics of laser welded sheets during hydroforming process. Steel blank sheets (St14) with different thickness were combined together to form three different tailor-welded models ((0.8-1), (0.8-1.2) and (1-1.2) mm). During the sheet hydroforming process of these models, thickness strain distribution and biaxial in plane strain are investigated and in order to prediction of local thinning compared with maximum allowable biaxial strain of the sheet material defined by FLD diagrams. The simulation results indicate that even with difference in thicknesses, steel tailor-welded blanks can produce superior deep drawn parts with hydroforming process. Simulation results have been compared with results of conventional deep drawing process.

Key words: tailor welded blanks; hydroforming; laser welding; deep drawing; strain distribution

1. INTRODUCTION

In recent years, the automotive and aerospace industry has paid a great deal of attention to weight reduction and fuel economy. The need of reducing fuel consumption, as well as more strength crash requirement, lead to stiff and lightweight and design of part. For the purpose of achieving the objectives, tailored methods using various welding processes, such as laser-welding and the mash seam-welding processes, were developed. This type of blanks have several advantages in the manufacture of automobiles, namely a low cost, reduction of car weight, and flexibility in mass production [1]. Material flow and formability of blanks are highly affected by the orientation of the weld line. For tool and process design, the orientation of the weld line has to be taken into consideration [2]. Among various welding processes, laser welding process receives more attention for fabricating such blanks since creates a narrow weld and heat-affected zone (HAZ) at the junction of the sheets [3]. Choi et al [1] investigated the differences of weld-line movement and thickness strain distribution of two kinds of blank shape, namely square and circular, with the three different initial weld-line locations, during the deep drawing process, through experimental and numerical analysis. Qiu et al, [4] simulated the stamping process of the tailor welded blank (TWB) using DYNAFORM software. Ahmetoglu et al, [2] carried out deep drawing of round cups from tailor-welded blanks.

Another process that recently attracts most attention is sheet hydroforming process. This process is used for manufacturing of some components for automotive, aerospace, and electrical applications [5]. Sheet Hydroforming (SHF) is press forming

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technology in which the hydraulic pressure is used instead of a female die. SHF gives many advantages especially in deep drawing, such as saving tooling cost, improving dimensional accuracy, structural strength and stiffness, fewer secondary operations and increasing drawing ratio and better surface quality, less springback, and reduced scrap [6]. Hama et al., [6] simulated the elliptical cup deep drawing process by sheet hydroforming. Kang et al, [7] made comparison between the forming processes of sheet hydroforming and conventional stamping for production of an automobile fuel tank using a commercial explicit FEM code. It was concluded that the hydroforming process could produce a sound fuel tank with a more uniform thickness distribution than the stamping operation.

In this study, forming of tailor welded blanks with hydroforming process is investigated. The purpose of using hydroforming process is to benefit of hydroforming advantages. Simulation of hydroforming of tailor welded blanks made by the laser welding of three different sheet metal thickness were carried out first. This study is focused on finding drawing depth available in the hydrofoming process. To establish this goal, an analysis by the commercial explicit program for the investigation of the characteristics of TWBs in the hydrofoming process has been carried out and simulation results have been compared with results of conventional deep drawing process.

2. SIMULATION

2.1. Hydroforming process

Numerical simulation of hydroforming processes, using finite element method is an important predictive tool. Finite element models that accurately predict the deformation behaviour of steel TWBs can be used at the design stage to design tooling for manufacturing complex parts. In this investigation, three different thickness steel sheets, (0.8, 1 and 1.2 mm) were combined together to represent steel TWBs. Figure 1 shows the stress–strain curve of material. The material properties are listed in table 1.

Figure 2 shows the fininte element mesh of circular tailor-weldad blank. An average element size of 3 mm with five layers of elements through thickness was used in the numerical simulations. Steel sheets was discretized using shell element and tools such as punch, die, and blankholder were considered to be rigid. Due to the symmetry, only the half of the parts was modeled. Since laser welding process create a narrow weld and heat-affected zone (HAZ) at the junction of the dissimilar sheets [8], therfore the effect of HAZ in simulation was neglected. The geometries of tools, such as punch, blankholder and die cavity, are shown in figure 3.

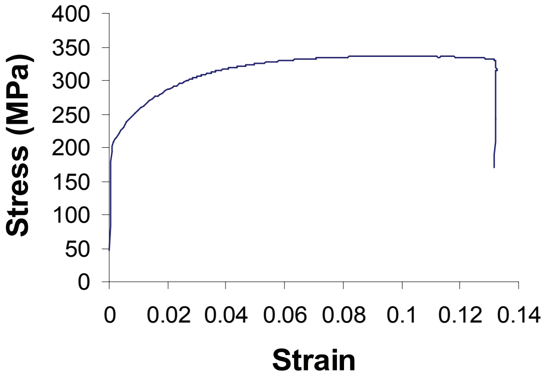

Fig. 1. Stress-strain curve for St14 material.

Table 1. Material properties of blank sheets.

Modules of Elasticity E (GPa)	200
Poisson ration ν	0.3
Yield stress σ_y (MPa)	180
Density ρ (Kg/m^3)	7800

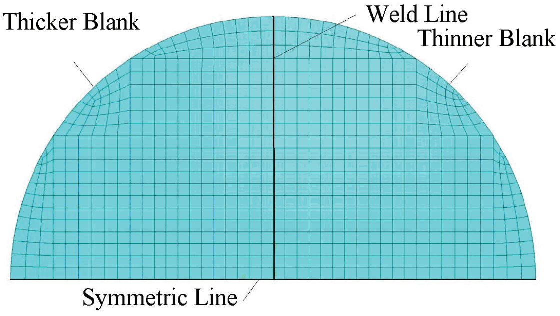

Fig. 2. Finite element mesh of TWB.

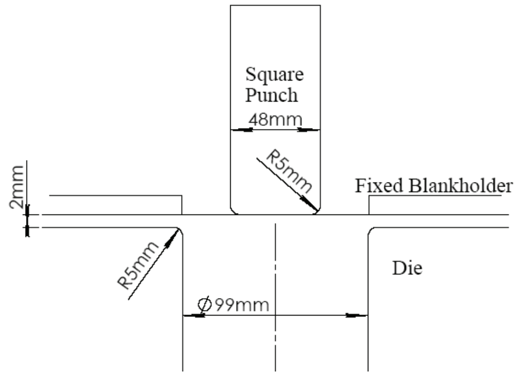

Fig. 3. Geometries of tools.

In sheet metal forming process, the boundary conditions are dictated by the contact established between the blank and tools. Penalty's friction law is employed between the contact sheet nodes and rigid bodies (tools). The friction conditions between the deforming tailor-welded blank and tool entities differ from the sheet hydroforming and deep drawing process. Hence care should be taken to closely reproduce the frictional conditions between different entities. The friction at the interface between different tool entities and the tailor-welded blanks was modeled by using penalty law with a different constant friction coefficient for each contact zone; the values are listed in table 2. During simulations it was assumed that fluid pressure exerted in the die cavity forces sheet metal toward punch surface. For attaining optimized fluid pressure, extensive simulations have been carried out and optimized fluid pressure was found based on the suppressing of necking at the punch profile.

Deep drawing of TWBs needs careful determination of process parameters. This definition of parameters become more critical by increasing in thickness differences of used sheets. The tendency of thinner sheet in splitting is high. Hence care should be taken to minimize strength to the thicker sheet. In conventional deep drawing process, it is possible to split blankholder into two halves to apply different forces on two segments, but in SHF of TWBs, this can be accomplished using fluid pressure. One of the issues that arise in the SHF of TWBs is concerned with the fluid pressure that allows a smooth flow of metal into the cup. Hence, an optimal fluid pressure is essential for successful SHF in order to attain suitable deformation behavior, increasing deformability of sheet, controlling wrinkling and springback. In the present study, optimum fluid pressure has been determined through extensive simulations and based on the suppressing of necking at punch profile. In this process, the optimum fluid pressure has been defined to be equal to 7 MPa.

Table 2. *Friction coefficients at the interface of tool entities and the blank material in hydroforming process.*

Friction coefficient		
Blank holder	Die	Punch
0.01	0.01	0.1

2.2. Deep drawing process

In order to investigate the difference between hydroforming and deep drawing processes of TWBs, another simulation has been carried out for deep drawing process. For simulation square die with dimension of 54×54 mm with 10 mm fillet radius has been considered. A force of 24.2 KN applied on blank by blank holder. The friction at the interface between different tool entities and the tailor-welded blanks is different from hydroforming process, and the values are listed in table 3.

Table 3. *Friction coefficients at the interface of tool entities and the blank material in deep drawing process.*

Friction coefficient		
Blank holder	Die	Punch
0.05	0.05	0.1

3. RESULTS AND DISCUSSION

3.1. Hydroforming process

Figure 4 shows deformed shapes of different thickness combinations of the final step of simulation in the case of 155 mm blank diameter and 40 mm depth of drawing. Significant difference in the draw-in between the different combinations can be observed from the figure. An overall shift in the blank periphery is observed towards thinner side at the flange. Excess deformation is observed at the flange midsections very close to the weld line as a consequence of the thickness mismatch and differential material flow characteristics. In all combinations of TWBs, thinner sheet is subjected to greater plastic deformation and hence the weld line shifts towards thicker side.

Thickness strain distribution, has been measured in central (direction 1) and diagonal (direction 2) as shown in figure 5.

Figure 6 shows the thickness strain distribution in the central direction. The thickness strain has the largest negative value at the wall of the square cup and displayed positive value at the flanges. The largest negative thickness strain is greater in (0.8-1 mm) combination and lesser in (1-1.2 mm). The distance of largest negative thickness strain from weld line is longer in (1-1.2 mm) combination. Therefore it can be seen that, combinations with thicker sheets has better condition rather than thinner combinations.

Figure 7 indicates the thickness strain distribution of the square TWB with different thickness combination in the diagonal direction. In comparison

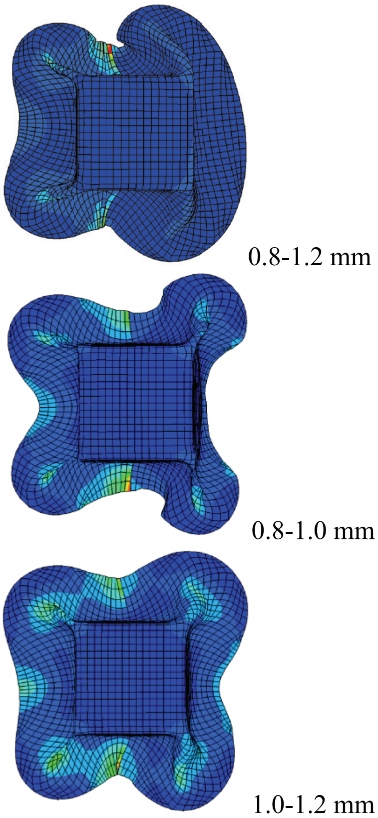

Fig. 4. *Deformed shapes of different thickness combinations.*

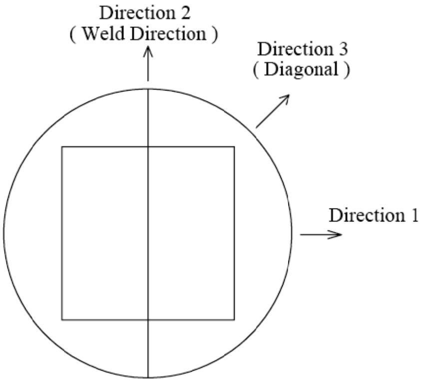

Fig. 5. *Different directions illustration.*

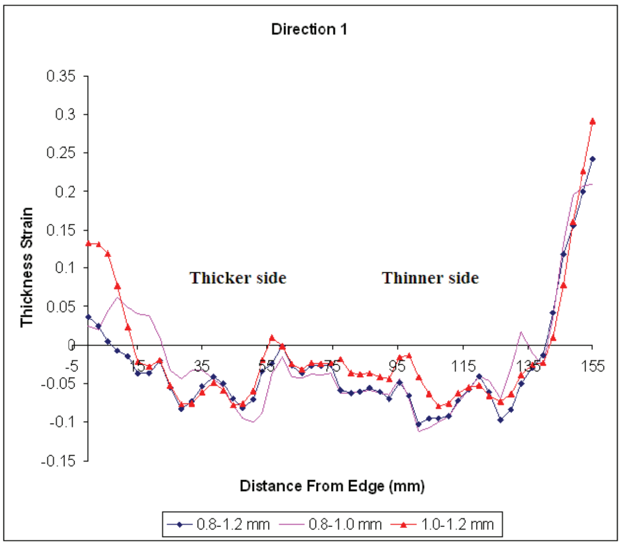

Fig. 6. *Thickness strain distribution (central direction).*

with figure 6, the largest negative thickness strain is larger in the diagonal direction (-0.16), than that at the central direction (-0.11).

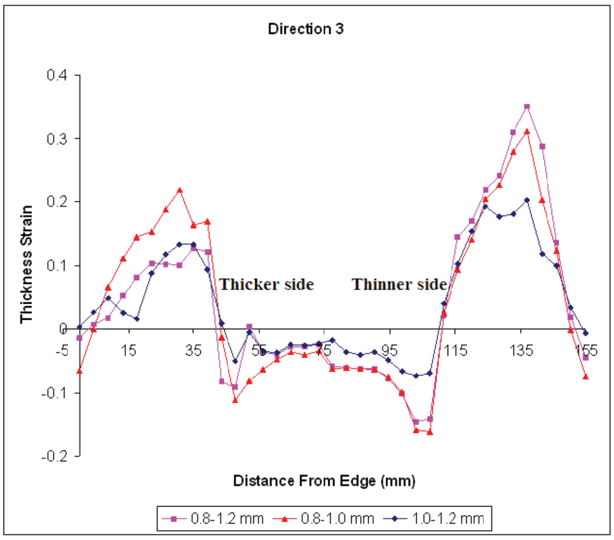

Fig. 7. *Thickness strain distribution (diagonal direction).*

With reference to the results for central direction (figure 6) and diagonal direction (figure 7), the thickness strain distribution in the central direction has less variation relative to the diagonal direction.

In order to predict the local thinning, in plane strains are compared with FLD diagram of (St14) [9]. As shown in figure 8 there is no local thinning in each combination and all of parts seem to be safe. The fracture resistance in 1.0-1.2 mm combination is higher than other combination.

3.2. Deep Drawing process

In order to study the difference between hydroforming and deep drawing process of TWBs, hydroforming and deep drawing process have been simulated for blanks with diameter of 130 mm and 15 mm drawing depth. Figure 9 indicates the biaxial strain distribution of three combinations, in deep drawing process. In two cases (0.8-1) and (0.8-1.2) mm, local thinning is seen in diagonal direction, but in hydroforming process all parts are safe and there is no sign of local thinning even to 25 mm depth.

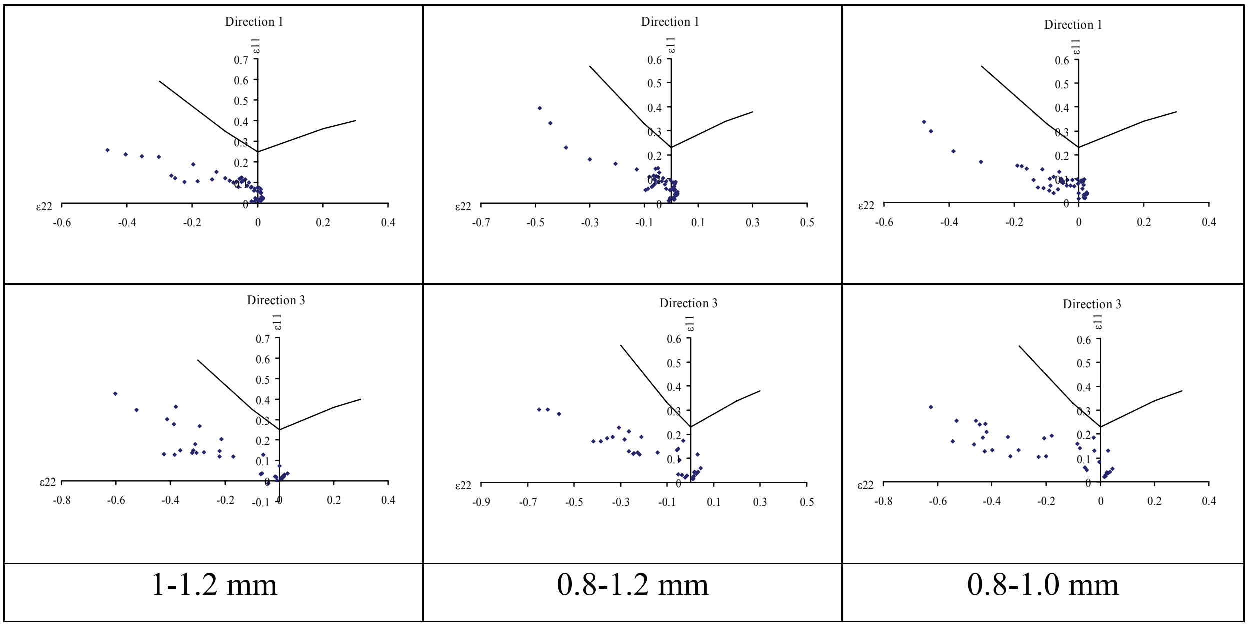

Fig. 8. Biaxial in plane strain of different combinations in hydroforming process (D=155 mm, H=40 mm).

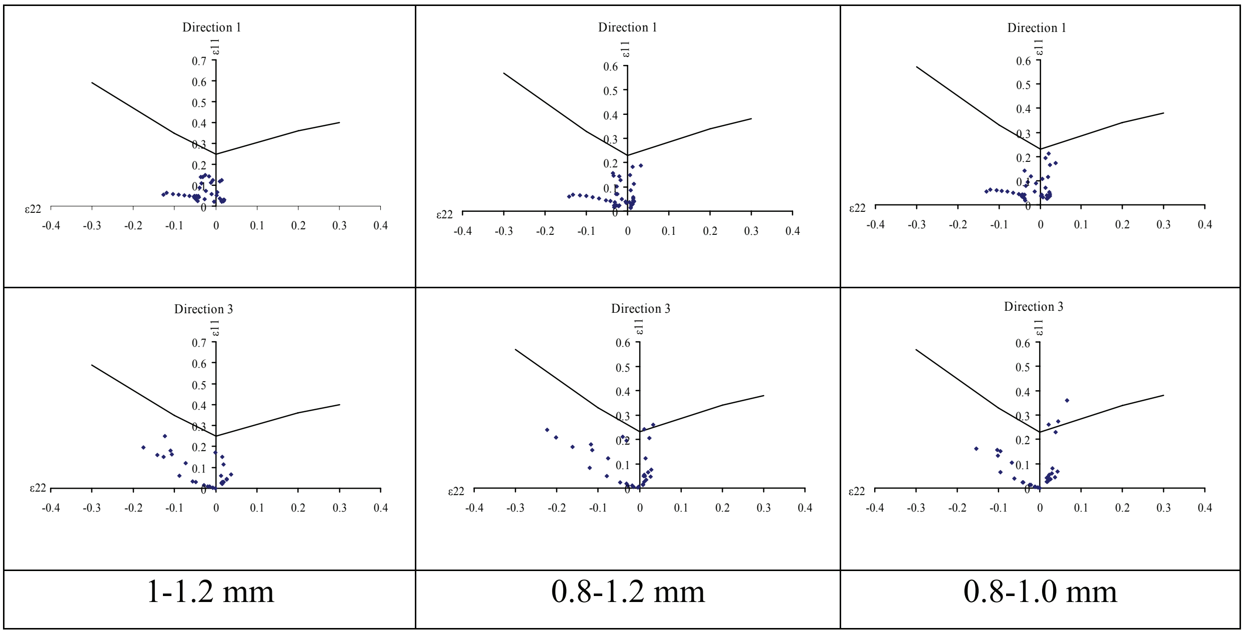

Fig. 9. Biaxial in plane strain of different combinations in deep drawing process (D=130 mm, H=15 mm).

Figure 10 (a, b and c) shows the comparison of thickness strain distribution in the diagonal direction in two processes (hydroforming and deep drawing), for initial blank with diameter of 130 mm and 15 mm drawing depth. In deep drawing process, because of blankholder force presence, positive thickness strain in flange is lower than that in hydroforming process. Also in hydroforming process, thickness strain distribution is more uniform than that in deep drawing process. Likewise in hydroforming process, distance of position that largest negative thickness strain occurs, is so far than position with equal thickness strain in deep drawing process.

CONCLUSIONS

In this study, computer simulation analysis has been carried out for sheet hydroforming and deep drawing of tailor welded blanks. The following conclusions are the outcome of the present study.

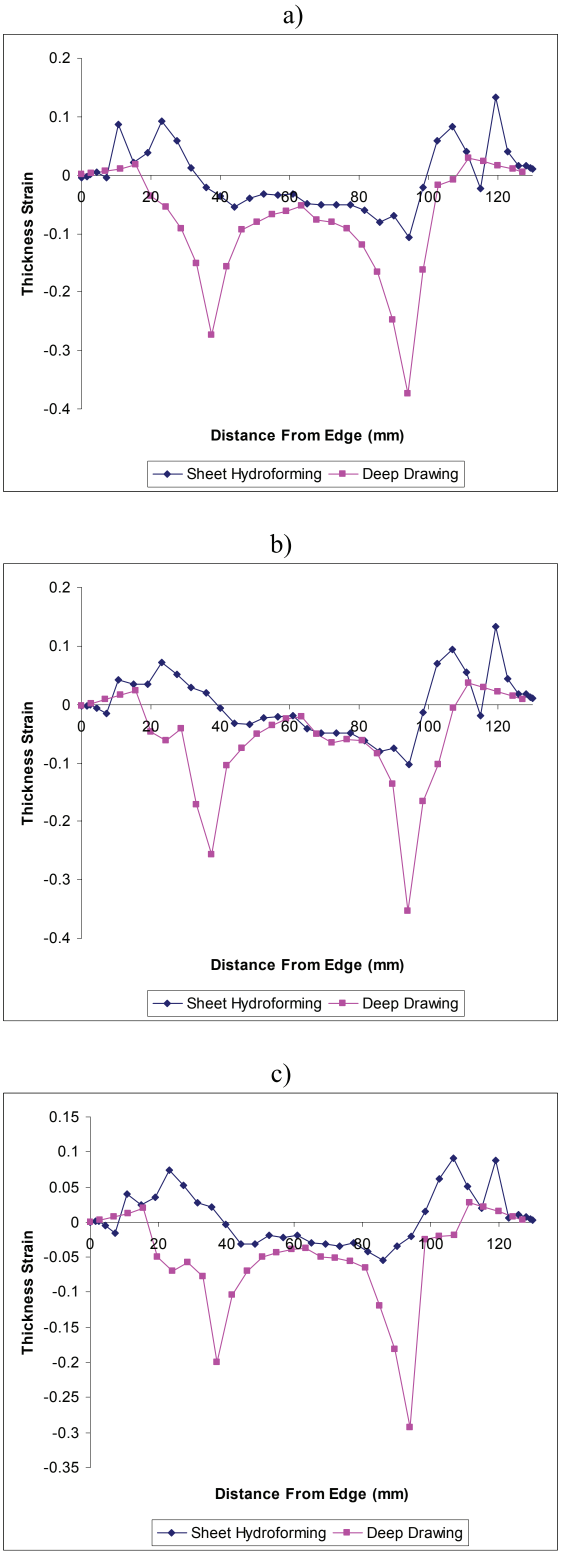

Fig. 10. *Comparison of thickness strain distribution in diagonal direction, a) 0.8-1 b) 0.8-1.2 c) 1-1.2 combination.*

- According to simulation results, advantage of hydroforming of TWB to the deep drawing process is observed. In hydroforming, the friction between blank and die is lower than deep drawing, thus formability of TWB could be improved.
- The value of the largest negative thickness strain in hydroforming process is lower than that in deep drawing process; therefore the achievable drawing depth for TWB in hydroforming process is higher than that in deep drawing process.
- In both processes, diagonal direction is critical than central direction, therefore when designing TWBs, the positions of the weld lines should be considered for a successful operation.
- In hydroforming process, local thinning is mostly affected with thinner sheet. In combinations where both sheets are thin, local thinning possibility is higher than combinations with thick sheets.

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ANALIZA PROCESU HYDROFORMINGU BLACH CIENKICH Z WSADÓW SPAWANYCH LASEROWO W PORÓWNANIU Z KONWENCJONALNYM PROCESEM GŁĘBOKIEGO TŁOCZENIA

Streszczenie

W pracy przedstawiono symulacje wykonane metodą elementów skończonych w schemacie jawnym przy użyciu komercyjnego oprogramowania w celu wyznaczenia charakterystyk odkształcalności laserowo spawanych blach w procesie hydroformowania. Arkusze blach (St14) z różną grubością zostały złączone ze sobą tak, aby otrzymać trzy różne złożenia ((0.8-1), (0.8-1.2) oraz (1-1.2) mm). Podczas hydroformowania wymienionych blach łączonych przeanalizowane zostały rozkład odkształcenia na grubości blachy oraz w dwuosiowym stan odkształcenia w blasze. Badania te miały na celu przewidywanie powstawania lokalnych przewężeń obliczanych w porównaniu do maksymalnego dopuszczalnego odkształcenia zdefiniowanego za pomocą diagramów FLD dla wybranego materiału. Wyniki symulacji pokazały, iż nawet w przypadku łączenia blach o różnej grubości, możliwe jest wytwarzanie metodą hydroformowania wyrobów głęboko tłoczonych o wysokiej jakości. Otrzymane rezultaty zostały porównane z wynikami dla konwencjonalnego procesu głębokiego tłoczenia.

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