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NUMERICAL ANALYSIS OF FORMING SHEET PANELS WITH STIFFENING RIBS

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Abstract. The transport industry, especially aviation, pays special attention to vehicle weight because lower weight means lower fuel consumption and in turn lower environmental pollution. Not only light metals like aluminium and magnesium alloys or titanium and its alloys are of interest in the transport industry but also new production technologies are taken into consideration as factors decreasing structure weight. Sheet metal forming offers light and strong components, therefore monolithic e.g. casting components are often replaced by drawn parts made of sheet metals. Forming large panels of thin sheets, especially hard-to-deform sheets with a high susceptibility to spring back, is a huge challenge. Forming both aluminium and titanium alloy sheets as well as nickel based steel sheets, which are the main structural materials in aviation, is difficult. Titanium, particularly titanium alloys, in comparison to steel and aluminium has a much more beneficial specific strength (strength-to-weight ratio) therefore it is used where high mechanical strength and low weight of the construction are especially essential. However, there are many technological problems, such as: poor drawability, high spring back and low tribological properties that have to be overcome in cold sheet-titanium forming. In the paper, numerical analysis of forming a part of a large sheet panel will be presented. The numerical simulation will be performed using the PamStamp program specially dedicated to sheet-metal forming. The program is based on the finite element method (FEM). The stress and strain distributions in the analysed part will be presented. The effect of the blank-holder force and frictional coefficient on the forming process will be studied. The quality of the obtained drawn part will be assessed based on the correctness of its shape and dimensions with reference ones, as well as on the thinning of the drawn part material.

1 INTRODUCTION

The transport industry, especially aviation needs strong and light materials for their construction because lighter aircraft means lower fuel consumption, and consequently lower levels of exhaust emissions and environmental pollution [1-4]. When selecting materials for aircraft structural parts, specific gravity in particular is taken into account, and in this respect magnesium and aluminium alloys as well as titanium materials are the most favourable. However, considering material strength, both aluminium and magnesium alloys are inferior to titanium alloys, which have the highest specific strength among all structural materials, i.e.

the highest strength-to-density ratio up to 600°C. Above this temperature only steel-nickel alloys can work, unfortunately their specific weight is nearly two times higher than titanium alloys. Therefore, in order to reduce construction weight there is a tendency to replace massive cast parts with lighter ones made of sheet-metals. Among many producing technologies, such as casting, machining, metal forming or powder metallurgy, sheet-metal forming seems to be the most appropriate concerning the strength and lightness of thin-wall products [5-7]. Sheet-metal forming processes give the possibility to manufacture drawn parts in different sizes - from small to huge components, with different geometry - from simple to complex geometry, and very often near-net-shape parts, which do not need extra machining. A further decrease in construction weight is possible using tailor welded blank (TWB) technology [8-12] as well as honeycomb structures [13,14] but the development of these technologies would not be possible if not for the progress in welding technologies, including electron and laser beam welding [15-20] as well as friction stir welding [21,22]. Modern welding technologies allow not only for the creation of new aviation designs but also the modification of existing ones. Because the design criteria, especially in aviation are complicated and require expertise and experience, all improvements require computational support in modelling and simulation of both material and process design [23-26].

Apart from theoretical problems, the implementation of new advanced technologies as well as high strength materials requires solving numerous technological problems. Sheets made of such materials, e.g. titanium alloy, are characterised by low drawability at ambient temperature and high spring back. In order to improve their drawability and eliminate spring back phenomena, forming at a higher temperature is usually applied [27,28]. However, it involves, especially during titanium forming, the use of protective atmosphere or vacuum to avoid gas absorption and hence material embrittlement.

Titanium in addition to favourable specific strength has good corrosion resistance to many technological environments and because of its high melting point (1,668°C), it is considered as a fireproof material suitable for firewalls. Even though sheet-metal forming has been known for many years, forming titanium sheets still poses many problems [29-32]. Titanium, especially titanium alloy sheets have poor drawability [7,29], a tendency to fracture [33], high springback [34,35] and unfavourable tribological properties, particularly an inclination to galling [29,36].

Forming large panels like enclosures or firewalls from thin sheets is a real challenge. Generally, all panels made of sheets tend to buckle and vibrate. In order to stiffen huge panels and reduce sheet flex, it is necessary to emboss some ribs (stiffeners), which can also be used to create decorative elements in a product that would otherwise be cost prohibitive. Embossed stiffeners allow constructors to reduce sheet-metal thickness, which is essential concerning structure weight reduction without decreasing its strength or rigidity. Although these embossed stiffeners are usually shallow, it is very difficult to avoid the deformation of flat panel areas, especially if it is made of hard-to-deform materials like titanium and in addition to a very thin sheet. Even slight panel deformation poses problems during component assembly. Therefore, in the work springback phenomenon during forming a part of a titanium sheet panel with embossed stiffeners is studied.

2 GOAL AND SCOPE OF WORK

The work aims at elaborating some guidelines on how to form large thin titanium sheet-panels having enough stiffness to avoid bending or twisting and losing the original shape during exploitation.

In order to increase the titanium panel stiffness, some embossed stiffeners, which are shown in Figure 1, were designed on the panel surface. Embossing is usually used to form a pattern or design on ductile metals because of aesthetic or functional reasons. In the work the functional application is considered. Generally, such stiffeners should be formed by stretching, however, some part of the deformed material can be drawn from the sides of the sheet panel into a shallow depression. The clue to this process is how to ensure pure stretch forming, in which the metal sheet is completely clamped round its circumstance and the shape is achieved at the expense of sheet thickness. Stretching the metal causes it to become thinner.

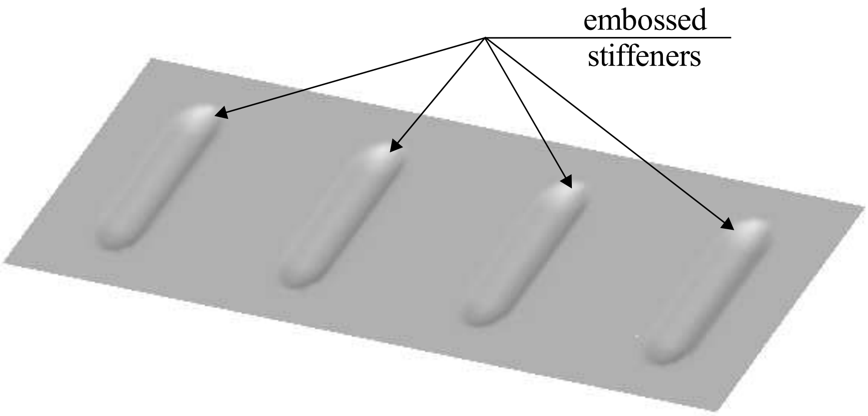

Figure 1: Geometry and position of embossed stiffeners

To optimise the process parameters, such as blank-holder force and frictional conditions, a virtual embossing process was designed using PamStamp 2G v. 2011 [37], which provides solutions for sheet-metal forming processes especially in the automotive and aerospace industry. The system is based on the finite element method (FEM).

In the work, a part of a large panel with embossed stiffeners is analysed. The panel is made of a commercially pure Gr 2 titanium sheet with a thickness of 0.4 mm, which poses a basic difficulty due to the low ductility and high spring-back of such a thin Gr 2 titanium sheet. The effect of the blank-holder force and frictional conditions on the stress and strain distribution in the analysed part are studied.

3 NUMERICAL CALCULATIONS

3.1 Numerical model

The surface model of the tool was prepared using Catia v. 5, and then the model was put into PamStamp 2G. 4-node shell elements were used for generation mashes on both the blank and the stamping tool, which consists of a die, punch and blank-holder. Boundary conditions were assigned to each part of the tool to specify their position in the coordinate system. All degrees of freedom were moved away from the die while the punch and the blank-holder have the possibility to move on the Z axis. It was possible thanks to the applied velocity vector to the punch as well as force to the blank-holder. The blank had all degrees of freedom. The numerical model of the tool is shown in Figure 2 while the material data for the Gr 2 sheet, which were assumed in the calculations are given in Table 1.

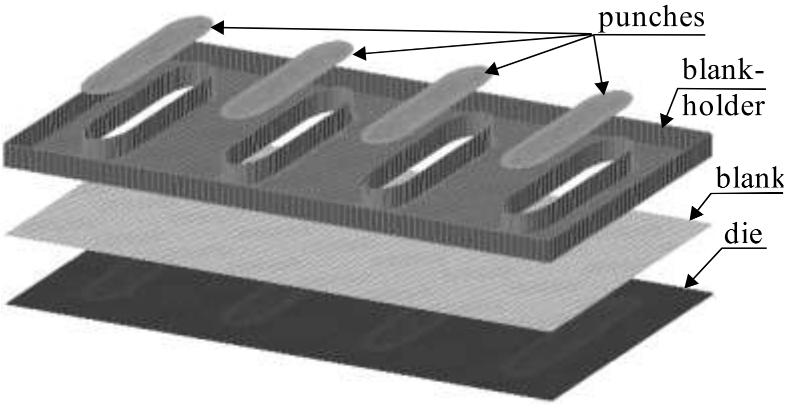

Figure 2: Numerical model of tool

Table 1: Material properties assumed in numerical calculations

Material	Young's modulus E [GPa]	Offset yield point $R_{p0.2}$ [GPa]	Poisson's ratio ν [-]	Density ρ [kg/m^3]	Strength coefficient K [GPa]	Strain hardening exp. n [-]
Gr 2	105	0.236	0.37	4,500	0.465	0.125

The material anisotropy was described using Hill'48 yield criterion. The strain-stress curve, which is presented in Figure 3, is defined based on Hollomon's law:

$$\sigma = K \cdot \varepsilon^n \tag{1}$$

where: K - strength coefficient, n - strain hardening exponent.

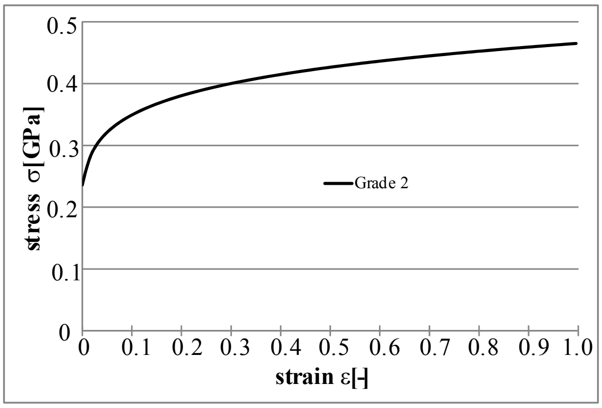

Figure 3: Stress-strain curve for Gr 2 sheet

In the calculations, different variants of frictional conditions and load were analysed, i.e. six values of blank-holder force were assumed: 200, 400, 600, 800, 1000 and 1200 kN, and two values of friction coefficients were assumed: $\mu=0.1$ and $\mu= 0.4$.

3.2 Numerical calculation results

Some calculation results for the analysed process parameters are compiled in Table 2.

Table 2: Basic process parameters and some calculation results

Friction coefficient μ [-]	Holding-down force F_{h-d} [kN]	Plastic strain ε [-]	Difference in initial and final panel width [mm]	Max. difference between position nominal and drawn-part after spring-back [mm]
0.1	200	0.055	1.99	3.65
	400	0.059	1.69	2.54
	600	0.061	1.55	1.91
	800	0.064	1.44	1.28
	1000	0.061	1.23	1.95
	1200	0.068	0.96	1.99
0.4	200	0.078	1.00	2.18
	400	0.079	0.78	1.31
	600	0.080	0.15	0.85
	800	0.081	0.11	0.87
	1000	0.082	0.11	0.84
	1200	0.083	0.10	0.79

The plastic strain distribution is presented in Fig~~ure~~s 4 and 5, respectively for the friction coefficient $\mu=0.1$ and $\mu=0.4$. The results are presented for three values of blank-holder forces, i.e.: $F_{h-d}=200$kN, $F_{h-d}=600$kN and $F_{h-d}=1200$kN are shown.

Analysing the data given in Table 1 and the plastic strain distribution presented in Figures 4 and 5, it can be seen that for the smaller value of friction coefficient $\mu=0.1$ and the smallest blank-holder force $F_{h-d}= 200$kN, the ribs are created by drawing the sheet material into the die cavities. As a result, the panel width decreases by nearly 2 mm. It means that in the case of larger parts with several stiffening ribs, large sheet deformation arises therefore the sheet panel will bend, warp and change shape. The subsequent numerical simulations showed that the greater the frictional coefficient and the greater the blank-holder force, the less sheet that is drawn into the die cavity.

For the higher friction coefficient $\mu=0.4$ and the greatest blank-holder force $F_{h-d}= 1200$kN, the ribs are formed only by material stretching and the plastic strains are distributed symmetrically (Fig. 5 c). It suggests that the whole part will not undergo a large degree of springback.

Thickness distributions are presented in Figures 6 and 7, respectively for the friction coefficient $\mu=0.1$ and $\mu=0.4$. The results are presented for three values of blank-holder forces, i.e.: $F_{h-d}=200$kN, $F_{h-d}=600$kN and $F_{h-d}=1200$kN are shown.

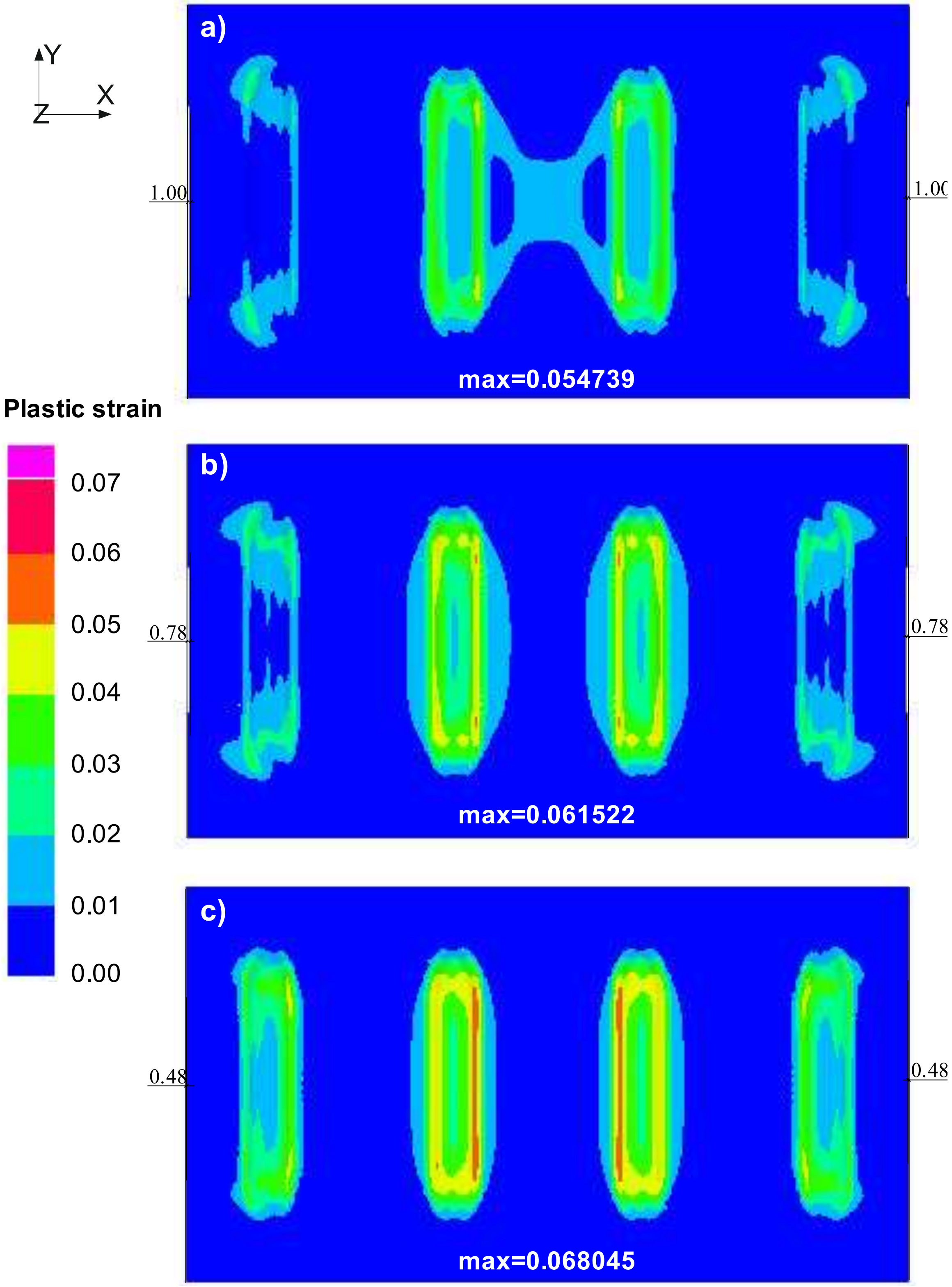

Figure 4: Plastic strain distribution ε [–] for frictional coefficient μ=0.1 and blank-holder force: a) 200 kN, b) 600 kN, c) 1200 kN

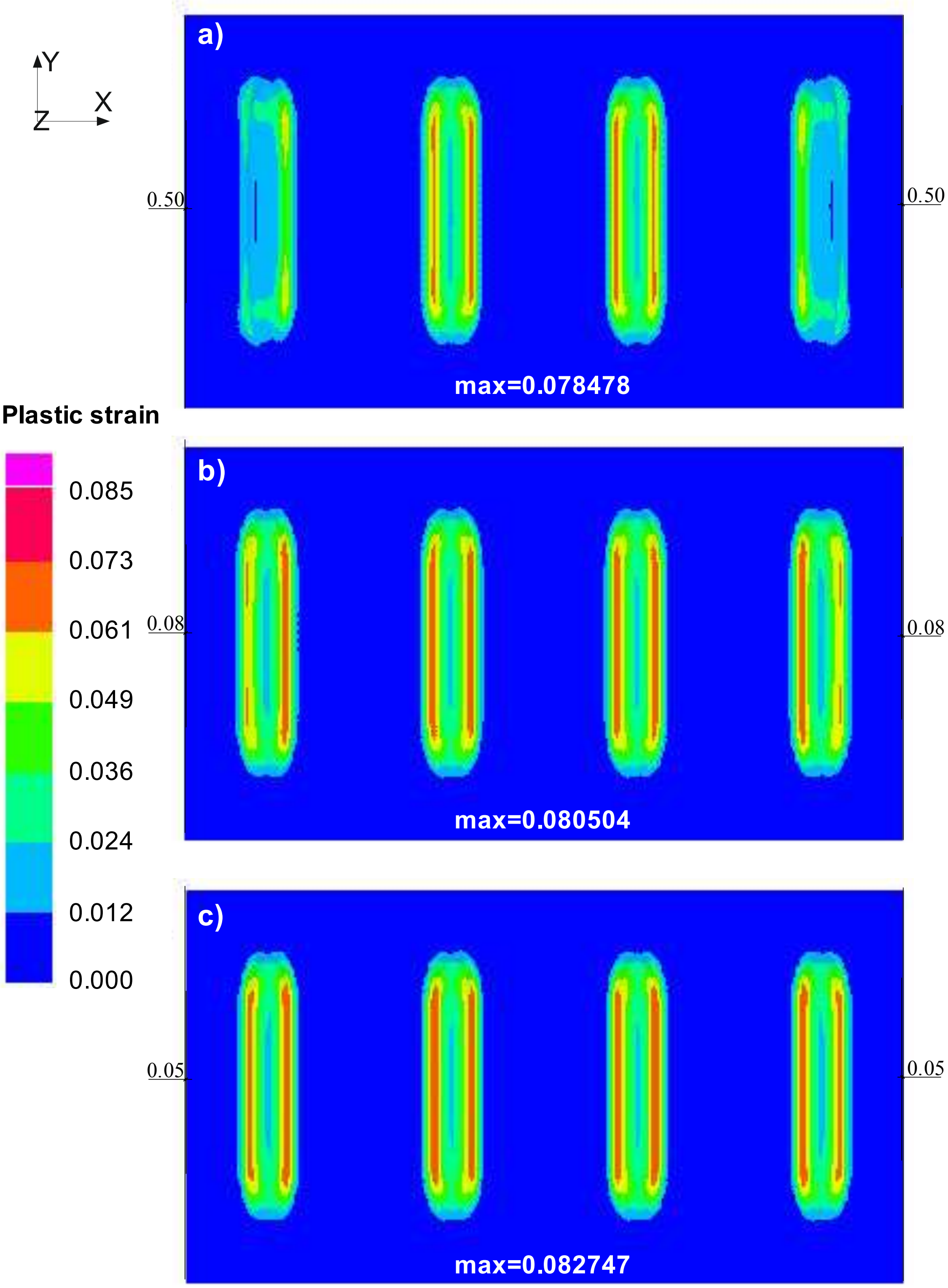

Figure 4: Plastic strain distribution ε [–] for frictional coefficient μ=0.4 and blank-holder force: a) 200 kN b) 600 kN, c) 1200 kN

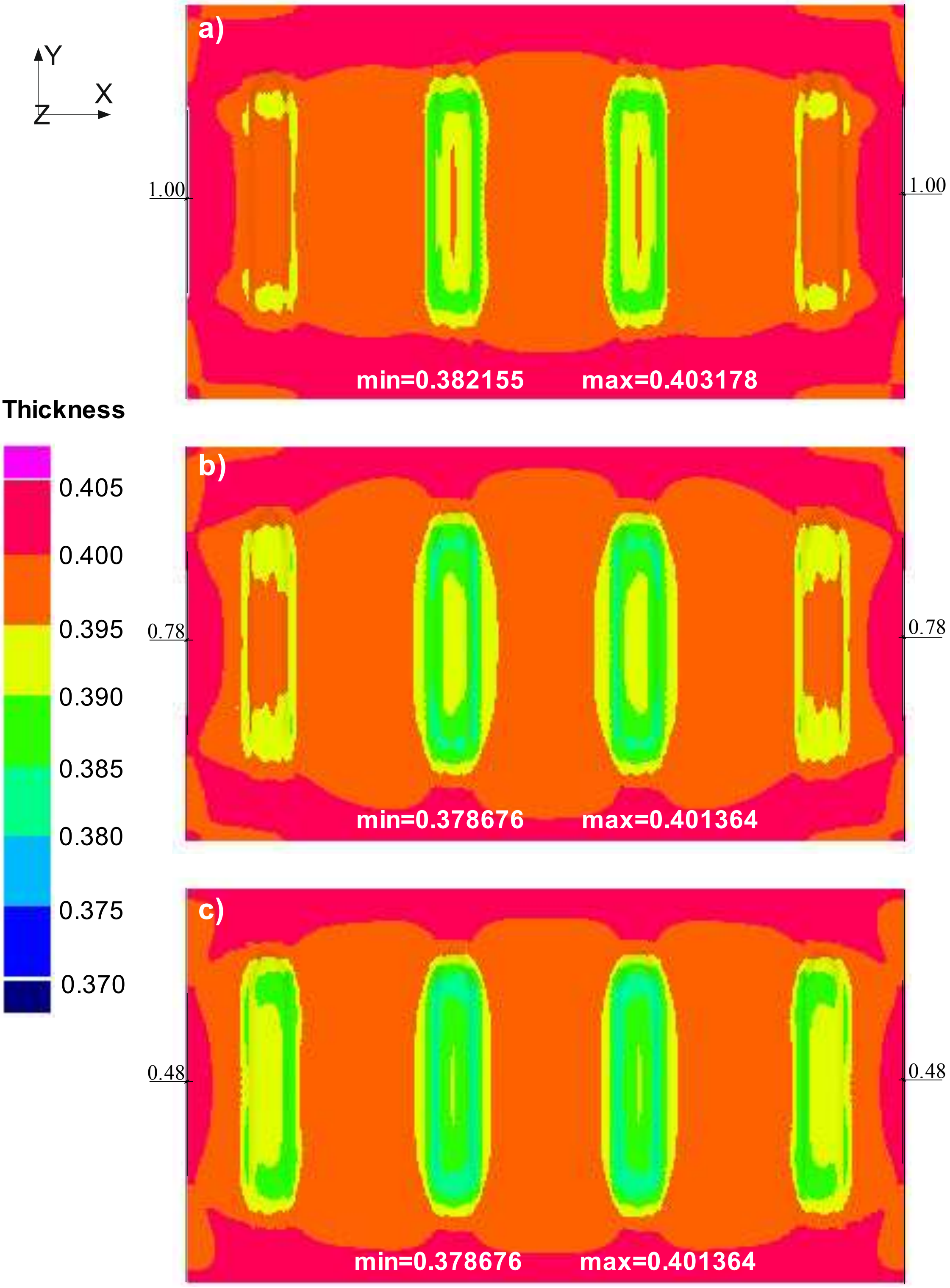

Figure 6: Thickness distribution [mm] for frictional coefficient μ=0.1 and blank-holder force: a) 200 kN, b) 600 kN, c) 1200 kN

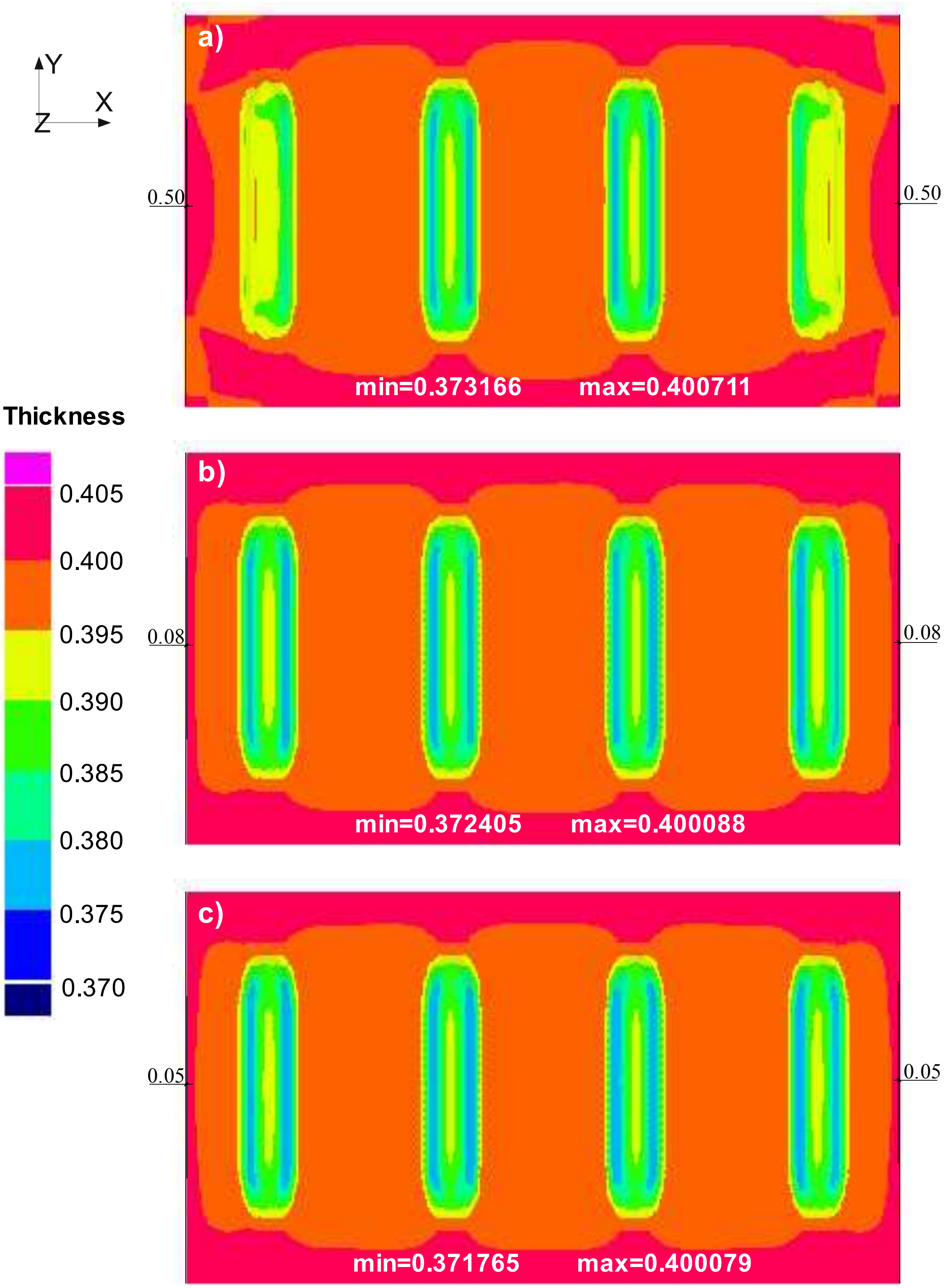

Figure 7: Thickness distribution [mm] for frictional coefficient μ=0.4 and blank-holder force:
a) 200 kN, b) 600 kN, c) 1200 kN

By analysing the thickness distributions, it can be seen that the greater the frictional coefficient and the greater the blank-holder force, the fewer changes in the thickness of the flat part of the sheet. It also suggests that the whole part will not undergo a large degree of springback. Thus, if we want to avoid bending or twisting and losing the original part shape, it is necessary to create such forming conditions that the stiffening ribs are shaped only by material stretching. It is necessary to avoid drawing the material from the flat part of the sheet into the die cavity.

4 CONCLUSIONS

According to the numerical calculation results it can be stated that both holding down force and friction coefficient value, which are assumed on the contact surfaces, are very important for the forming process. These process parameters affect plastic strain distribution as well as thinning of the deformed sheet essentially. It is observed that the greater the frictional coefficient and the greater the blank-holder force, the fewer changes in thickness of the flat part of the sheet. Therefore, it is advised to increase surface roughness by e.g. sand blasting to increase the friction coefficient. The higher the frictional coefficient, the lower the blank holder force needed, hence a smaller stamping press is required.

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