11th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

ANALYSIS OF TOOL RADIUS ON VESSEL HEAD QUALITY MADE BY INCREMENTAL PLASTIC DEFORMATION

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ABSTRACT
A experiences show that on vessel head quality the most effect make pressure force, radius of tool and number and order of operations. This paper present results of tool radius effect on pressure vessel heads quality made by numerical and experimental researches. Numerical analysis is performed by calculating critical buckling force. Presumption is, that wrinkling of circular plate after first deformation make the greatest effect on number of operations, and it directly instance on residual stress magnitude and distribution in finally product.
Keywords: Incremental Forming, Buckling Force, Sheet Metal, Tool Parameters.

1. INTRODUCTION
When incremental forming is used to manufacture large products, such as spherical tank ends, wrinkling phenomena has significant influence onto quality of final products. The tool diameter is 2 to 5 times smaller than the forming part diameter, the edge of forming part is free, and the thickness of sheet metal is small. All these facts are prerequisites for occurrence of wrinkling.

A number of researches were performed recently in order to minimise errors in incremental sheet metal forming. Mackerle presented exhaustive bibliography in [1] about application of Finite element method in sheet metal forming simulation. The bibliography deals with material properties (texture, anisotropy, and formability), springback, fracture mechanics and calculation strategies, as well as with specific forming processes: bending, extrusion, deep drawing, pressing, hydroforming etc.Cao and Boyce in [2] used forming limit diagrams as a criterion for disproportional tool load regimes. Their research showed that clamping force can be used to control and influence wrinkling. The forming press does not use clamping, therefore other methods should be taken in account to prevent wrinkling.

Kim and Yang in [5] investigated buckling phenomena in deep drawing process using energy principle. They introduced "buckling factor" which is used to predict shape and location of wrinkles in sheet metal. Wrinkling occurs in areas which are not in contact with tool [3]. The only contact occurs between the plate and the edge of concave tool, and between plate and upper, convex tool. The contact surface is relatively small.

The following analysis assumes that tangential stresses before buckling are neglectable and plate thickness is uniform.

2. NUMERICAL ANALYSIS
Fig. 1. shows the simplified model used for FEM analysis. The plate support is circle with radius r, and the force F acts downwards on the surface with radius f. The plate's outer radius is R and the thickness is d.

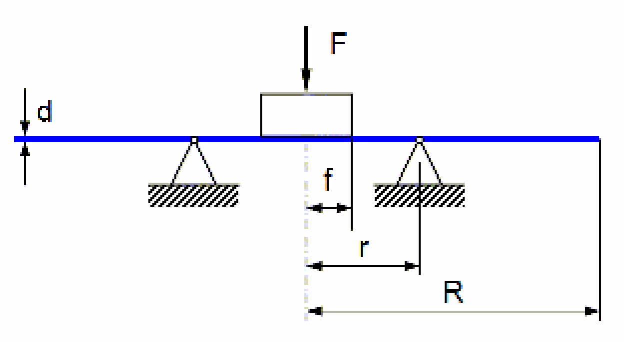

Figure 1. Simplified model used for FEM analysis.

The analysis is performed by calculating critical buckling force for a range of parameters: thickness, outer plate radius and support radius.

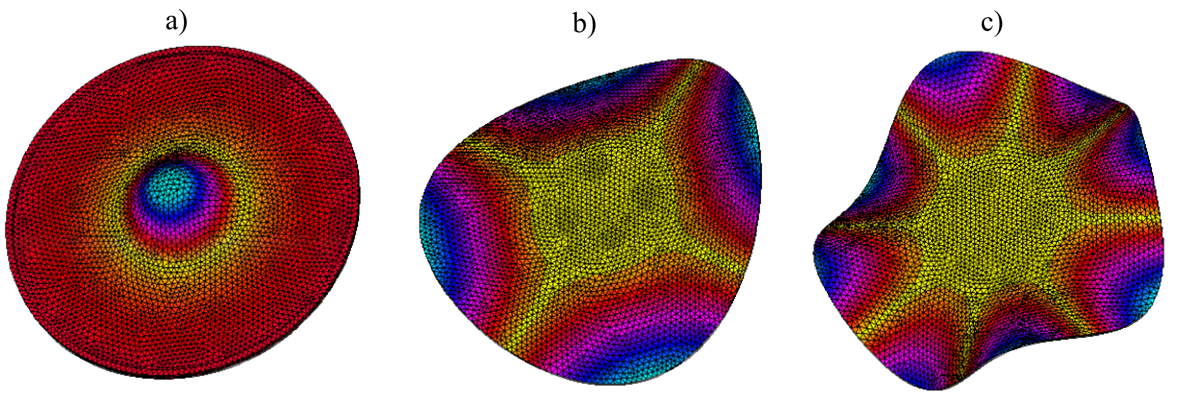

Figure 2. Buckling mode shapes: (a - without transversal waves, b - with 4 waves, c - with 8 waves).

The results are sorted out according to the number of wrinkles (waves), in order to predict the most affordable set of parameters: it is the case when there are only one circular wave and no transversal waves.

Fig. 2. shows three typical cases of buckling. Since numerical analysis results are sorted by buckling force intensity, it is important to determine the shape to be able to relate the number of waves with quality of final product.

This major assumption of this research is that the first, elastic buckling plays key role in further quality of product manufactured by means of incremental forming. The lower the number of wrinkles in the first forming operation, the less incremental operations is required to obtain the final shape.

The parameter examined was the lower tool radius (the radius of circular support). The calculation was performed for lower tools with radius between 210 and 390 mm. The results are shown in Fig. 3.

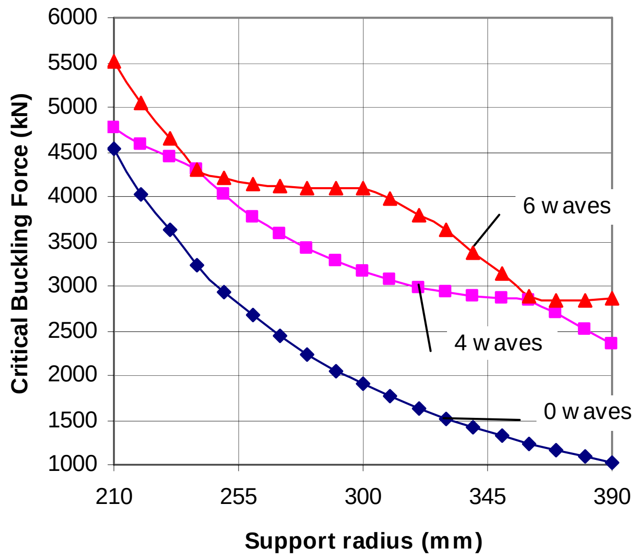

Figure 3. Critical buckling force for different support radius.

3. EXPERIMENTAL ANALYSIS

Measurement of residual stresses was made by the blind hole drilling method[6].

Experimental conditions for definition of residual stress in buckled plate[4]:

- Buckled plate «K4» was made with lower tool radius of ∅1700 mm, and upper tool radius of ∅1700mm. Press force was 1.045 MN and forming operations start from centre of plate. Number of forming operations was 264. Buckled plate had radius of 2526 mm and depth of 203 mm.
- Buckled plate «K2» was made with lower tool radius of ∅500 mm, and upper tool radius of ∅1700mm. Press force was 1.045 MN and forming operations start from centre of plate. Number of forming operations was 725. Buckled plate had radius of 2520 mm and depth of 260 mm.

Table 1. Results of measured residual stress in buckled plate.

Buckled plate	Measured point	Tool radius	Position of gauge	Principal stress		Equivalent stress
				σ_1 [MPa]	σ_2 [MPa]	σ_{ef} [MPa]
K4	MM1	Ø 1700	Out	-62,2	-166,4	145,6
	MM2	Ø 1700	Out	220,7	140,9	193,5
	MM3	Ø 1700	Out	159,7	118,4	143,5
K2	MM1	Ø 500	Out	-10,9	-197,2	192
	MM2	Ø 500	Out	-120,8	-317,5	277,6
	MM3	Ø 500	Out	-61,5	-189,3	167,3

In order to confirm the analysis results, the influence of parameters was tested by varying the press force and measuring geometry of buckled plate. The measurement results confirmed FEM analysis results; the lower the press force, the less wrinkles occur after first forming operation.

Figure 5 shows measurement results projected on cylindrical surface. The figure represents the case that corresponds to buckling mode shape with 4 wrinkles. The x-axis is given in degrees, and the y-axis represents the measured amplitude for different measurement radii (0, 185, 555 and 930 mm).

Figure 4. Measurement of buckled plate geometry.

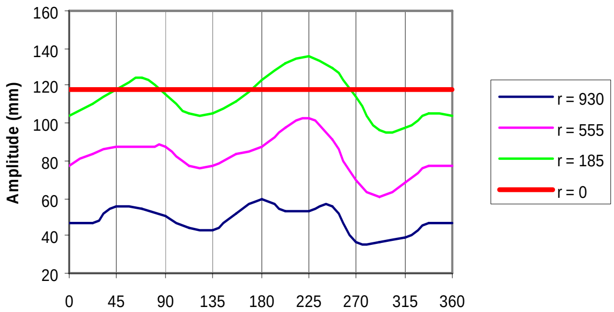

Figure 5. Example of buckling mode shape with 4 wrinkles

5. CONCLUSIONS

According to analysis performed, the following conclusions can be drawn:

- It is desirable to have lower press force for the first forming operation, since it will produce the buckling mode shape without wrinkles.
- The lower tool radius should be as large as possible. If radius of lower tool is too small, it is harder to control press force in order to obtain less wrinkles.

The lower tool radius produced larger residual stress in buckled plate.

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