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NUMERICAL AND EXPERIMENTAL INVESTIGATION OF HOLE FLANGING PROCESS

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ABSTRACT

The paper aims to present the experimental and numerical work in the field of hole flanging process, having as particularity a process where the blank is held by a pressure plate which is acted by a rubber disk. The hole flanging is used across many different industries. A drilled or punched hole is expanded in a flange, by the surrounding metal deformation of the hole. In the experimental work drilled holes were used. The process of the hole flanging was studied by varying two process parameters, namely punch geometry and initial diameter of the hole. Flat and spherical punches were used. Three diameters of the initial holes which result in three flanging coefficients were considered. The hole flanging profiles were experimentally determined using reverse engineering. The numerical study comes to validate the experimental one and also it gives the possibilities to analyse the stresses induced in material for different deformation conditions. Finally, the comparison between the numerical and experimental results highlighted the importance of flanging coefficient in the process quality.

Keywords: hole flanging, sheet metal, finite element

1. INTRODUCTION

The hole flanging is used in many different industries. It has many advantages: it confers a greater resistance to edge flanged, a better aspect to the part, allows the mechanical assembly between different parts [1]. The hole flanging is a process in which a sheet blank, with a hole in its center, is rigidly clamped around its periphery by a blank holder, and then a punch is used to force he blank into a die to form a hollow flanged component. During the process, the sheet is bent twice, once around the punch radius and again around the die radius [2].

The workpiece is pre-holed and the punch is used to force the pre-holed into the die as shown in figure 1 thus, there is a deformation of the edge and an expansion of the diameter [3]. The punch has a constant speed during the process. In hole-flanging conditions, thinning occurs in the flange, caused by edge stretching [4].

The value of stress is not the same in the whole deformation zone. The material in the flanged zone is in biaxial tensile stresses state [5]. The hole edge is in the state of uniaxial stress in tangential direction and the stress value is maximum [6].

A flanging coefficient (m) could be defined, as the ratio between the initial (d) and the final hole diameter (D), m=d/D.

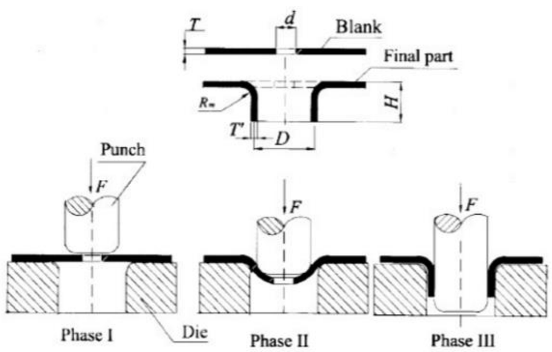

Fig. 1. *The hole flanging process [1]*

The process is influenced by the material plasticity, relative thickness (t/d), state of edge, shape of flanging punch, shape of hole, clearance between the punch and the die. The better the plasticity of material, the smaller would be the flanging coefficient [7]. The larger the relative thickness of the material, the smaller will be the flanging coefficient. The higher the surface quality of the hole, without burr and work hardening, before flanging, the smaller will be the flanging coefficient [8]. The larger the roundness of the punch, the more beneficial would be the flanging deformation. The clearance can be selected as large as possible if there is no demand on perpendicularity for the hole edge of the workpiece. If there is a perpendicularity demand the value of clearance is usually determined as: Z=0.85t.

The flanging die is similar to that of deep drawing. As in deep drawing, there are different methods to hold the blank on the die: to apply a pressure on the sheet or to use drawbeads.

In the paper there are presented the numerical and experimental researches of the hole flanging process, having as particularity a process where the blank is held by a pressure plate which is acted by a rubber disk. It is investigated the influence of punch geometry: cylindrical (flat-bottomed) and hemispherical, as well as the influence of the initial hole diameter on the value of hole expanding limit.

2. EXPERIMENTAL RESEARCH

As material, sheet metal blanks from DC01 having a thickness of 0.8 mm were used. The material is produced by ARCELOR Mittal. The mechanical properties are presented in table 1.

Table 1.

R_m (N/mm²)	R_c (N/mm²)	A (%)
296	147	42

The samples were cut in disks, 64 mm diameter each, with a tool, figure 2, especially designed to cut the sheet metal.

Fig. 2. *Tool used to cut the sheet metal*

After this stage, it is necessary to make holes. Using drilling three series of drilled disks with three different diameters: 6, 9 and 12 mm, were obtained.

The drilled samples were deformed using the die presented in figure 3. This tool is set on a hydraulic press of 20 tons. The tool used as blank holder is a disk from rubber. Because the properties of the rubber are not uniform, there were problems with the material deformation in the hole as it will be presented later in the paper.

The diameter of the die was constant and was equal to 16.3 mm. Two punches with the same diameter, equal to 14 mm and having different shapes: one flat (F) and the other one spherical (S) were used.

Fig. 3. *Tool used for hole flanging*

Figure 4 presents the images of the deformed samples. This picture reveals that some parts are not symmetrical. We double check if all the elements were the same axis, if the punch was vertical and there is no reason to get this result for some of these pieces. However, we can see on one of this part, a characteristic flaw: a small crack appears on the bended edge as you can see in the figure 5.

Fig. 4. *Deformed samples with hole flanged zone*

Fig. 5. *Typical defect: a crack on the edge*

We can also see that some parts didn't have a rotational symmetry in particular for the biggest inner diameter. This is probably due to the little material portion which is deformed during the process and the small non concentricity of the different parts of the tool.

After the deformation, and cutting the samples along the diameters, thickness of the material was measured. Profiles in deformed area for four samples were obtained, using a profile projector, figure 6.

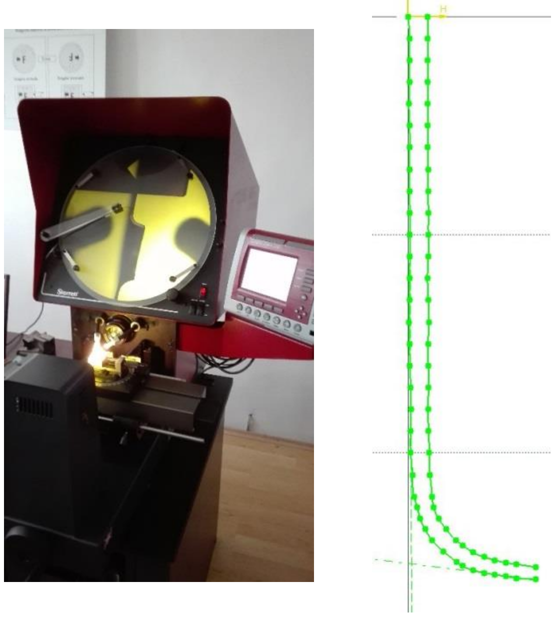

Fig. 6. *The profile of the hole flanged*

The thickness variation along the profile of the one of the measured part is presented in figure 7.

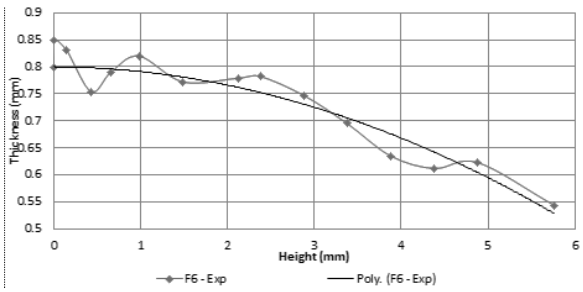

Fig. 7. *Thickness variation along the edge, 6 mm inner diameter and a flat punch*

Figure 7 shows that for a hole of 6 mm and a flat punch, the variation of thickness is important and could lead to crack appearance at the free end of the flanged portion, see figure 5.

3. NUMERICAL RESEARCH

To avoid the experiment work, which means waste time and money, we can use a software tool to predict the results. A lot of combinations with different geometries, different properties of the material, friction conditions and so on could be tried. This involves that you know the process and the parameters which influence the results [9-11]. We modeled the elements of the experimental part numerically. During this study, we used the software DYNAFORM package [12]. On DYNAFORM, we must define FOUR tools: a die, a punch, a blank and a binder. For the punch, we define the velocity and the stroke. We estimated it at 50 mm/s and 15 mm. We defined the force applied on the binder at 10 kN. Also, we defined the friction coefficient at 0.1.

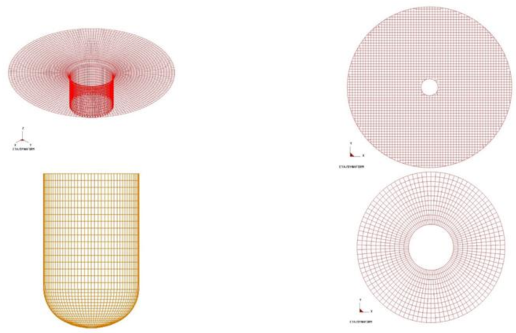

Fig. 8. *Elements of hole flanging numerical model*

For the blank, we defined the mechanical properties, based on the data obtained from Arcelor Mittal, figure 9. The elements chosen for the mesh were the Belytschko-Tsay, because, they have the best ratio results/time.

Caracteristics Used	Values
Mass Density	7 830 kg/m^3
Young Modulus	207 GPa
Poisson's ratio	0,28
Yield Stress	151 MPa
Hardening Modulus	415 MPa
Anisotropic R	2,16
Speed Punch	50 mm/s
Stroke Punch	15 mm
Binder Force	10 kN

Fig. 9. *Values of the model parameters*

4. COMPARISON BETWEEN THE EXPERIMENTAL AND NUMERICAL RESULTS

4.1. Geometry Comparison

To validate the numerical model, first, we compared the numerical results for the height with the theoretical formula (1). This formula comes from the law of the volume conservation and the main hypotheses are: only the material thinning is considered, the tension is spatial, the deformation is planar, and so the circumferential stresses are active

σ_θ including deformations ε_θ and ε_g. These conditions require $\varepsilon_\rho = 0$.

$$h_1 = \frac{d_1 - d_0}{2} + 0.43r + 0.72g \qquad (1)$$

where: h1 is the height of the flanged edge; d1 – diameter of the flanged hole; d0 – diameter of the pre-hole; r – die radius; g – blank thickness, figure 10.

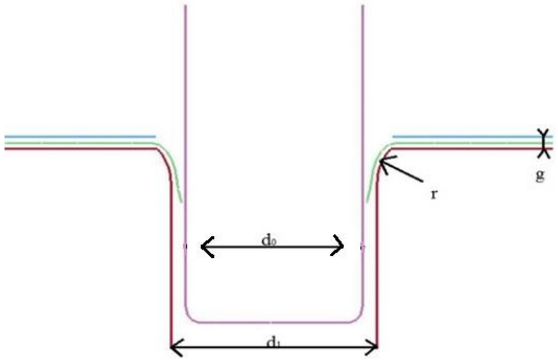

Fig. 10. *Elements of deformation zone*

We measured different parameters presented in tables 2-5. In

Table 2.

F9	Thick. min.	Thick. max.	Height (h_1)	Angle
Exp (mm)	0.63	0.83	4.74	100.50
Num (mm)	0.67	0.80	4.32	106.30
Relative gap (Exp/Num)	5.97	3.75	9.72	5.46
Theoretical	-	-	4.30	-
Relative gap (Exp/Th)	-	-	10.23	-
Relative gap (Num/Th)	-	-	0.47	-

Table 3.

S9	Thick. min.	Thick. max.	Height (h_1)	Angle
Exp (mm)	0.72	0.87	4.30	98.00
Num (mm)	0.68	0.80	3.90	100.80
Relative gap (Exp/Num)	5.44	8.75	10.28	2.78
Theoretical	-	-	4.30	-
Relative gap (Exp/Th)	-	-	0.02	-
Relative gap (Num/Th)	-	-	9.30	-

Table 4.

F6	Thick. min.	Thick. max.	Height (h_1)	Angle
Exp (mm)	0.54	0.86	5.7	1.54
Num (mm)	0.55	0.80	5.9	-
Relative gap (Exp/Num)	1.09	7.25	3.93	-
Theoretical	-	-	5.81	-
Relative gap (Exp/Th)	-	-	1.62	-
Relative gap (Num/Th)	-	-	2.41	-

Table 5.

S6	Thick. Min	Thick. Max	Height (h_1)	Angle
Exp (mm)	0.54	0.84	5.40	91.03
Num (mm)	0.57	0.80	5.47	93.50
Relative gap (Exp/Num)	5.08	5.50	1.33	2.65
Theoretical	-	-	5.81	-
Relative gap (Exp/Th)	-	-	7.11	-
Relative gap (Num/Th)	-	-	5.85	-

Results for the two diameters (6 mm and 9 mm) are almost similar. So we could validate the numerical experiment for both cases. Indeed, the relative gaps between the theoretical values and the simulation is lower than 10% which is acceptable. We can also see that relative gaps between experiments and simulation values are lower than 10% too. This is another argument to validate the numerical simulations.

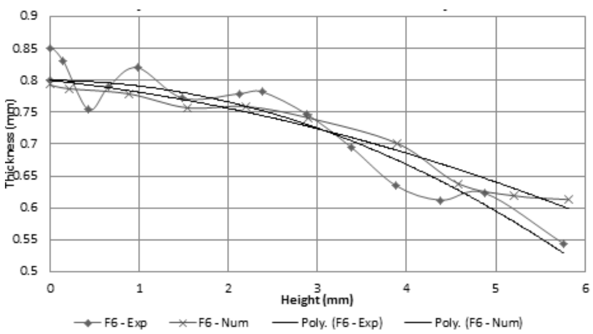

Fig. 11. *Variation along the edge for a hole diameter of 6 mm and a flat punch (experimental and numerical)*

As we can see in the above graphic, the tendency is almost similar even the curve form for the thickness variation in the experimental case is different in comparison with the numerical one.

4.2. Failures Comparison

The numerical simulations results for the hole of 6 mm deformed with the punch of spherical form, are identical, in terms of failure, with those obtained in the experimental work, figure 12.

For 9 mm hole diameter, we obtain the same results both in the simulation and experiments, figure 13. Indeed, there is neither wrinkle nor cracks in the part and experimentally, the greatest part of the deformed area is the safe region.

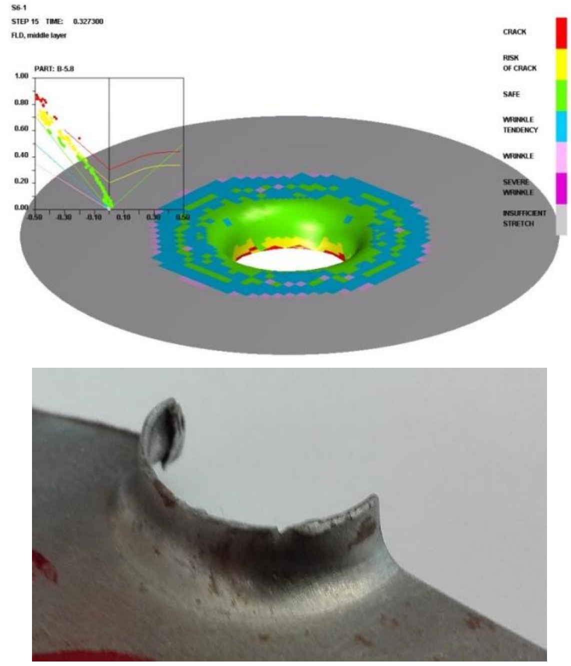

Fig. 12. *Comparison between numerical and experimental studies for 6 mm hole diameter*

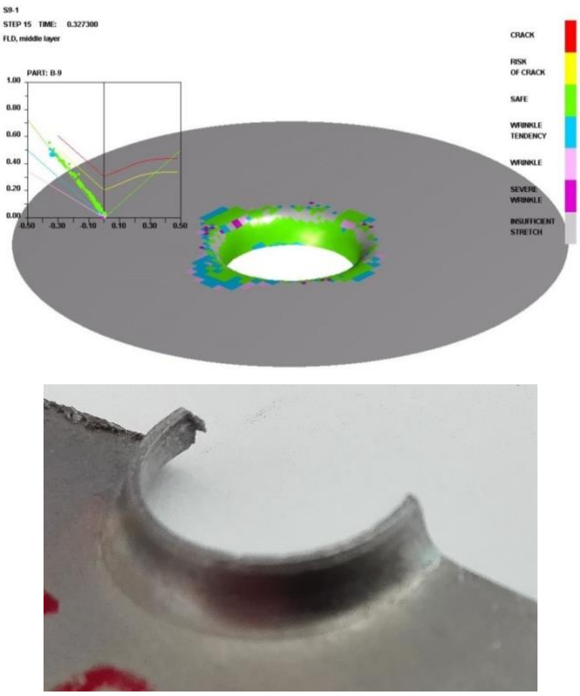

Fig. 13. *Comparison between numerical and experimental studies for 9 mm hole diameter*

For 14 mm hole diameter, the numerical simulations results are difficult to compare with the experimental ones, figure 13. In the experimental work, in this case, the result is not relevant due to the small region of deformation and due to the small deviations of the different components of the die. These two issues added together give the difference between the two results.

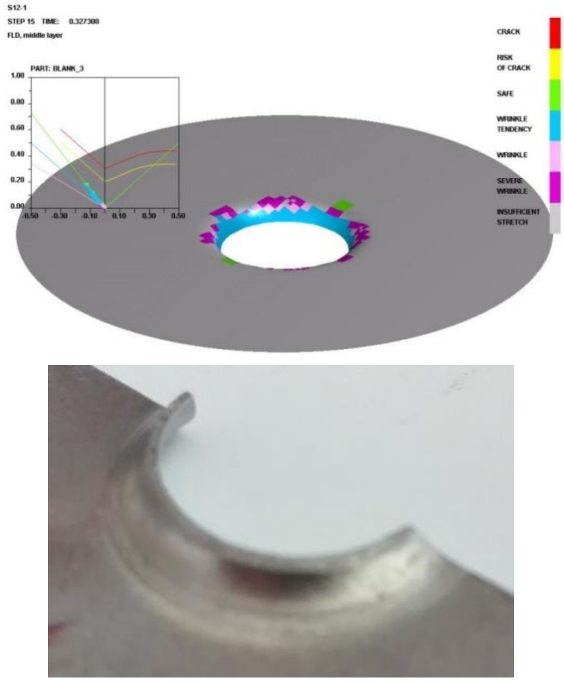

Fig. 14. *Comparison between numerical and experimental studies for 12 mm hole diameter*

5. CONCLUSION

In the paper the hole flanging process, where the blank is held by a rubber pressure plate, is studied in terms of workpiece quality. FLD from FEM simulation are used for predicting the ruptures location. After these investigations, the outcomes can be presented as follows:

- The binder force is important, and it must be uniform on the surface of the blank. If this condition is not respected, the profile is not symmetrical with respect to the axis;
- The profile is influenced by the dimension of the initial hole, which determined the flanged coefficient;
- A thickness variation along each profile is present;
- In some cases, some cracks appear at the end of the profile.
- Maximum diameter of expanded hole depends on the punch geometry. When the punch geometry is concerned the best result was achieved when flanging with the hemispherical punch and the worst in the case of the cylindrical punch.

- For the spherical punch, the thinning of the wall are reduced because the edges of the hole are in contact with the punch surface so that severe friction in the tangential direction is produced which protects the hole periphery from necking or tearing.

6. REFERENCES

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