Comparison between the numerical simulations of incremental sheet forming and conventional stretch forming process

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ABSTRACT: The paper presents a comparison study based on the simulation by the finite element method of incremental sheet metal forming and classical stretch forming process. Four separate different analysis were performed, one for stretch forming and three different process versions for incremental forming. The thinning of the sheet, the variation in time of Von Mises stresses in four nodes, the section profile of the obtained parts and the forces developed in the processes being studied.

Key words: Incremental forming, Stretch forming, Numerical simulation

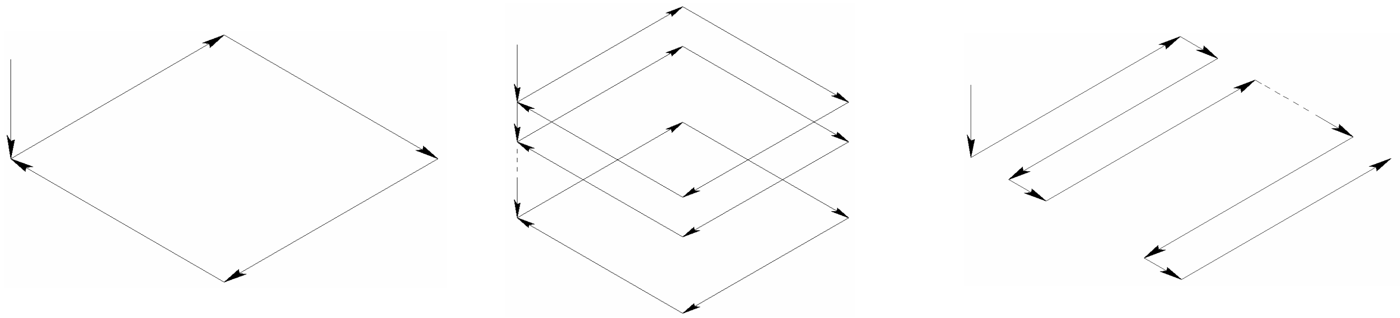
1 INTRODUCTION

The current paper refers to one of the new non-conventional forming process for sheets metal, namely incremental forming. The incremental sheet metal forming represents a complex metal forming process, at which, as compared to classical stretch forming process, the kinematics comprises beneath a movement on vertical direction also a movement in the blank's plane [1, 2]. Problems occur during calculation of stress, strain, thinning and the forces in the process of incremental sheet metal forming and in the conventional stretch forming have been analysed in this paper.

2 THE FINITE ELEMENT MODEL

To tackle the non-linear analysis, a parameterised model, used in the analysis through the finite elements method, has been built, described through the Dynaform software. The forming system that is being used as base for the numerical simulations consists of a die, blankholder and hemispherical punch for incremental forming, respectively rectangular punch for stretch forming. In the case of incremental forming the punch is placed unsymmetrical. It is sought to realise a frustum-shaped part with a height of 8 mm and a side length at the small base of 100 mm. The trajectories followed by the punch for the numerical simulation of the incremental forming process are presented in figure 1. In case 1 (fig. 1, a), in the first stage, the punch has a vertical movement. In the second stage the punch follows a rectangular trajectory around the die borders. In the case 2 (fig. 1, b), the punch has a stepped (8 steps) movement on the vertical direction. After each vertical step the punch follows a rectangular trajectory like in case 1. In case 3, the punch has, in the first stage, a vertical movement. In the second stage, the punch follows a trajectory which tries to cover the all formed surface. The punch moves on Ox direction along the die border, has a stepped movement on Oy direction and back on the Ox direction. In the case of stretch forming (case 4) the punch has only a vertical movement at the sheet level. In all cases, there are no imposed boundary conditions on the nodes placed on the circumference, because the blankholder eliminates this necessity.

A thin circular sheet blank (D = 240 mm), placed on an active die with rectangular working zone is considered. The punch diameter is D_p = 12 mm, the die radius R_{die} = 6 mm, the clearance between punch and die border c = 6 mm and the initial thickness t = 1 mm.



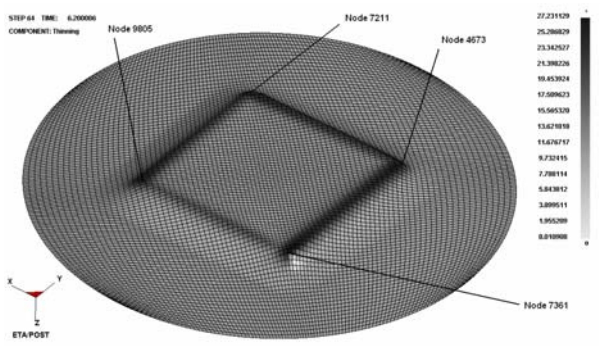
(a) (b) (c)

Fig. 1. The three different trajectories for the incremental forming simulations

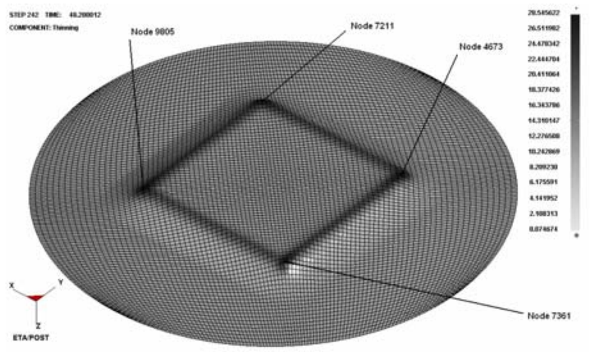
The finite element network associated with the part's geometry is built so that it allows an unfolding of the analysis in good conditions, without necessitating a re-mesh because of its exaggerated distortions. The Thin-Shell-163-type element was used. A shear factor of 5/6 and a total of 7 integration points through the thickness were used in order to catch the variation of the stresses and strains through the thickness. The material associated with the part's elements corresponds to a deep-drawing sheet DDQ. The Dynaform material model 36 (Barlat's 3-parameter plasticity) was chosen. This model combines isotropic elastic behaviour with anisotropic plastic potential developed by Barlat and Lian [3, 4]. The considered elasticity modulus is E = 0.7e+5 MPa, the transversal contraction coefficient is $\nu = 0.28$, while the yield stress is $\sigma_Y = 290$ MPa, the strength coefficient K = 524 MPa and hardening coefficient n = 0.22. The anisotropic characteristic's width to thickness strain ratio values $R_{00} = 1.89$; $R_{45} = 1.61$; $R_{90} = 2.05$.

3 THE RESULTS OF NUMERICAL SIMULATIONS

The numerical results of the simulations were centred on the determination of the thinning (fig. 2), variation in time of equivalent Von Misses stress in four nodes (fig. 3), the precision of the parts obtained by these different processes (fig. 4) and the forces on the process (fig. 5).



(a)



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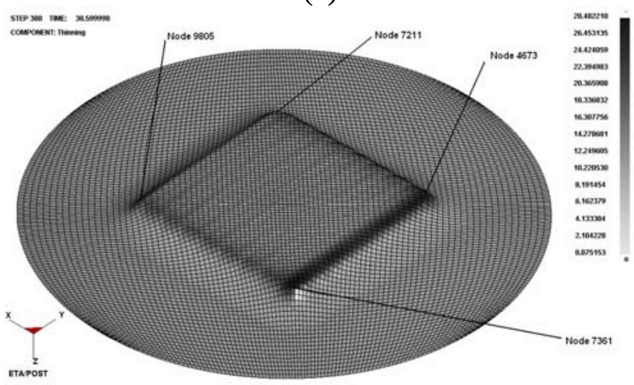
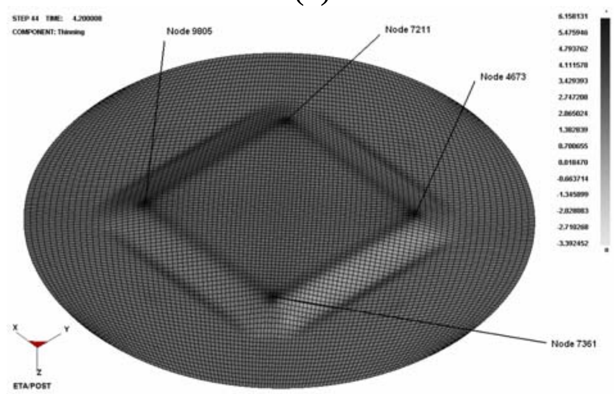
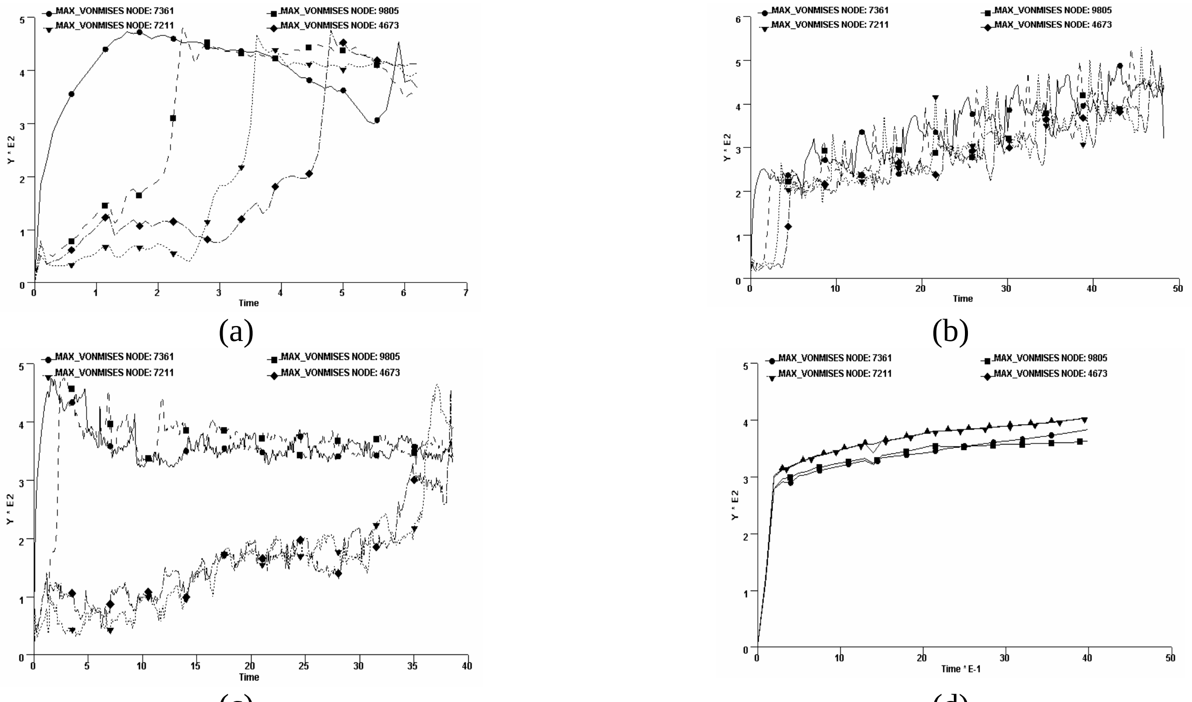


(c)



(d)

Fig. 2. The thinning variation in the four studied cases



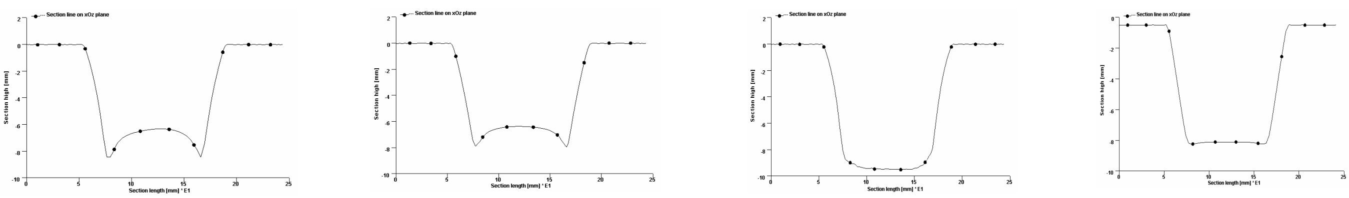
(a) (b) (c) (d)

Fig. 3. The in-time variation of equivalent Von Mises stress for four nodes in the four studied cases

As can be seen from figure 2 (a, b, c), the value of maximal thinning for incremental forming (regardless of the chosen technological variant) is around 27-28% and is located along the part's edges. The maximal thinning occurs for case 3 (figure 2, c), namely for the incremental forming in several vertical steps. In the case of conventional stretch forming, the maximal thinning has a value of 6% and is located in the tops of the formed part. In all four cases, the thinning from the part's central area has values of up to 5 times less than that from the areas located along the part's edges.

We study the in-time variation for four nodes located in the tops of the formed part. Node 7361 is the node located in the very spot where the punch enters the material at the first step during incremental forming. From figure 3, a, b, c it can be seen how in case 1 the stress in the nodes reaches successive maximal values when the punch passes them. In case 2, the stress value in the nodes increases progressively as the part's height increases, but still decalated, and in case 3 the stress increases abruptly in the nodes located at the beginning of the trajectory and then remains almost constant, while in the nodes located at the trajectory's end, the stress increases slowly until the end. For the conventional stretch forming (figure 3, d), in the four nodes the stress increases abruptly in the four nodes and remains relatively constant, its value being equal for all four nodes.

Another problem is the precision of the part formed through the four procedures. For this, the part was cut with the plane xOz. For the case of incremental forming (especially for cases 1 and 2, figure 4 a, b) there can be noticed a rather significant convexity on the part's bottom. From this point of view, the most unfavorable case is the one of the forming in a sing vertical step, where this convexity can reach values of up to 1.7 mm. For the conventional stretch forming, the part's bottom is plane (case 4, figure 4, d). A shape close to the one obtained with conventional stretch forming is achieved in case 3 (figure 4, c), where even a small concavity of the part's bottom can be noticed. This technological variant is unfortunately also the most time-consuming one, the punch going along a complex trajectory.



(a) (b) (c) (d)

Fig. 4. The section profile for the four studied cases

Figure 5, (a, b, c, d) presents the variation graphs of the forces present in the four studied cases. From the start, it can be noticed that the force obtained in the case of conventional stretch forming is almost 7 times bigger than that needed in any of the cases studied through incremental forming. From figure 5, it can be seen that the maximal force – the component of the force on vertical direction (F_z) presents a maximum at the punch's penetration in the material and then local maxima at the final of each line on the horizontal direction of the punch. In figure 5, b it can be seen that the maximal force increases progressively with the increase of the punch's penetration depth.

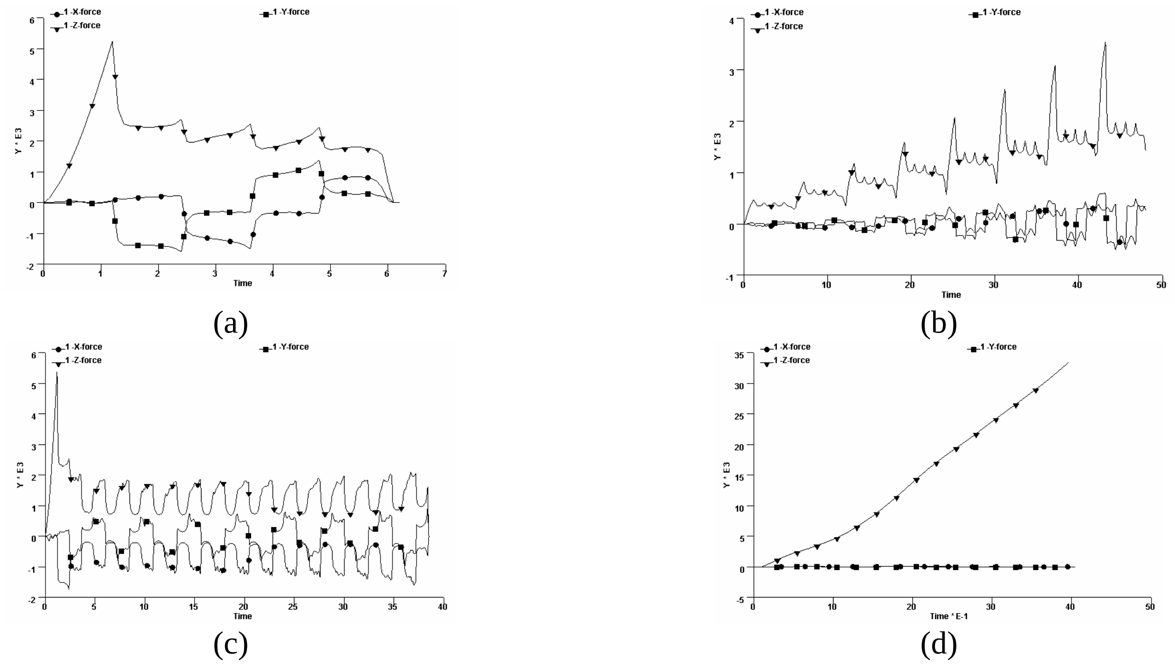


Fig. 5. The time variation of the forces in the four studied cases

In case 3 (figure 5, c) the maximal force also has a maximum at the moment of the punch's penetration in the material, followed by local maxima with close values at the end of each horizontal line. In all 3 cases of incremental forming, the value of forces in the plane xOy is of approximately 5 times less than the force on vertical direction. Of course, the value of these forces on horizontal direction is zero for the case of conventional stretch forming (figure 5, d).

4 CONCLUSIONS

Following the study by numerical simulation of the four technological forming variants it can be concluded that the best variant from the point of view of material behaviour and achieved precision is the variant of conventional stretch forming. Nevertheless, this technology employs complex tools and is thus automatically more expensive and requires also large forming forces. A satisfying variant is case 3, where the results from a qualitative point of view are close to the ones from the conventional stretch forming and the forces are much smaller. A solution can also be to form the part in a first step with a punch whose shape is close to the desired one, followed by the shape's correction through incremental forming.

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