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NUMERICAL INVESTIGATION ON THE EFFECT OF ROLLER-TRACE IN DUAL PASS CUP SPINNING

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ABSTRACT

There is growing demand in several industries for manufacturing parts with very high strength to weight ratios combined with low cost. Spinning processes are very efficient in producing such characteristics in addition to the flexibility that exists in the production process and relative low cost of the required tools. However, geometrical defects such as wrinkling and severe thinning are common problems to overcome in spinning practice. The aim of this study is to investigate the effect of roller-trace on thinning during dual pass conventional spinning. Three different strategies are adopted. The first pass is either a straight line, involute curve or quadratic curve, while in the second pass the roller follow a straight line for each case. The effect of sequence order of these roller-traces on sheet thinning has been examined. It was found that using a roller-trace of an involute curve in the first pass followed by a roller-trace of straight line in the second pass, minimum sheet thinning and a more uniform stress distribution could be obtained.
Keywords: *Conventional spinning, Dual-pass, Roller-trace, Numerical simulation, Sheet thinning*

1. INTRODUCTION

In conventional cup spinning, a circular sheet is clamped between a rotating mandrel and supporting holder and the sheet is gradually shaped over the mandrel through the action of a roller that produces a localised pressure and moves axially over the outer surface of the sheet to produce a symmetrical product**.** Metal spinning is one of a number of flexible sheet forming processes in which the sheet deformation is imparted incrementally through a localised contact region between the deforming sheet and forming tool. The process has a wide variety of applications including parts for the automotive and aerospace industries, musical instruments, art objects and kitchenware.

In cup spinning an important requirement is to control the uniformity of the wall thickness, and to do this multi pass spinning is recommended [1-4]. Multi pass spinning also leads to an improvement in both the surface roughness and forming limit [1]. During multi-pass spinning, a large amount of compressive stress will be introduced in the formed part and this leads to a more uniform thickness distribution. Under these conditions, the roller-trace, i.e. the profile of the path through which the roller moves, determines the required number of passes, the final shape and quality of the part. In conventional spinning processes, there are three main types of roller-trace paths, these are straight, concave and convex. Involute and quadratic curves are the most common types of concave and convex curves respectively.

Kang et al [5] studied experimentally, the deformation mode in conventional spinning of a circular plate using the three main roller-traces. They concluded that the final thickness distribution is highly affected by the amount of deformation that occurs in first pass and this is dependent on the roller. Thus the design of the roller-trace has a great impact on the sheet thinning and final thickness distribution. They also concluded that the straight line trace is less complicated and helps to reveal the deformation characteristics. Concave paths are widely used, while convex paths are more suitable for producing convex cone shapes such as a container head. Liu et al [6] studied the stress and strain distributions during the first pass of conventional spinning under three different roller-traces, as before, these were a straight line, involute curve and quadratic curve using FE modelling. They concluded that the strain and stress distributions during the first pass with an involute curve are small and more uniform compared to those obtained from the other two curves.

In the investigation presented here, a general dynamic explicit finite element model for dual pass conventional spinning is used to study the effect of roller-traces on the cumulative strain distributions in the first and second pass during the forming of cylindrical aluminium cups. In each case, the first pass using either a straight line, convex or concave path is followed by a straight line path parallel to the mandrel axis in the second pass.

2. FINITE ELEMENT MODEL

The models were developed using Abaqus/Explicit v6.8. In the spinning example here, the mandrel has a diameter of 118 mm and rotates with a constant rotational speed of 200 rpm. An aluminium sheet blank with an original diameter of 192 mm and thickness of 3 mm is attached to the mandrel. The holder has a diameter of 112 mm [7, 8]. At the beginning of the finite element (FE) simulation, the holder pushes the sheet toward the mandrel with a small constant load of 100 kN in order to keep the sheet secure between the mandrel and the holder. Thus, the sheet and holder will rotate with the same mandrel speed. The details are shown in figure 1.

The mandrel, holder and roller are modelled as rigid bodies, while the sheet is modelled as an elastic-plastic deformable body using the material properties of pure aluminium (A-1100-O). The plastic stress strain curve for this aluminium is described by, $\sigma = 148\varepsilon^{0.233}$, with an initial yield stress of 100 MPa and a mass density of 2700 kg/m^3. Isotropic elasticity is assumed with a Young's modulus of 70 GPa and Poisson's ratio 0.3. The material data are taken from Long and Hamilton [9], originally presented in Kalpakjian and Schmid [10]. Thermal and rate effects are not included in the present model. Coulomb friction is set with a friction coefficient of 0.2, 0.5 and 0.05 between the sheet and the mandrel, holder and roller respectively as assumed in [8, 9].

In the FE model the mass inertia of the roller is defined so that the roller can rotate about its axis when contacting the sheet. Three-dimensional 8-node linear hexahedral elements are used to mesh the sheet. The number of elements in the thickness direction is two, this is the minimum number of elements required to properly reproduce the bending deformation around the mandrel corner without excessive element distortion [4]. The total number of elements is 5968, with 9102 nodal points. Figure 2 shows the finite element model and arrangement of components for the dual pass conventional spinning process. All simulations were performed on an Intel® CoreTM Dual computer with a 3GHz CPU. Several values of load rate scaling were applied to reduce the simulation time. A maximum scaling factor of 21 was used, which provided a significant reduction in simulation time while maintaining a similar accuracy in the numerical results [4].

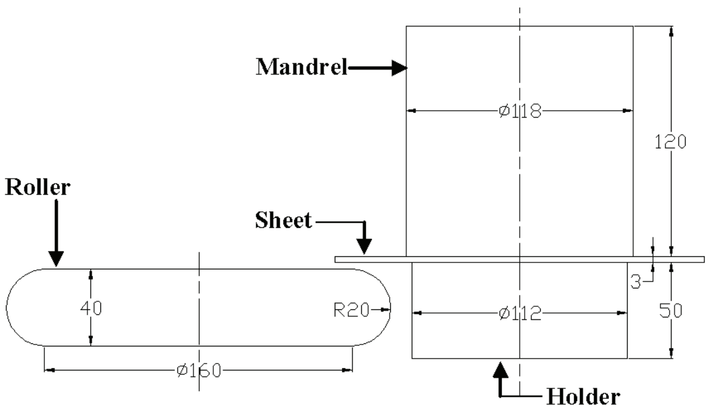

Fig. 1 - Geometries and dimensions of the model (all dimensions in mm)

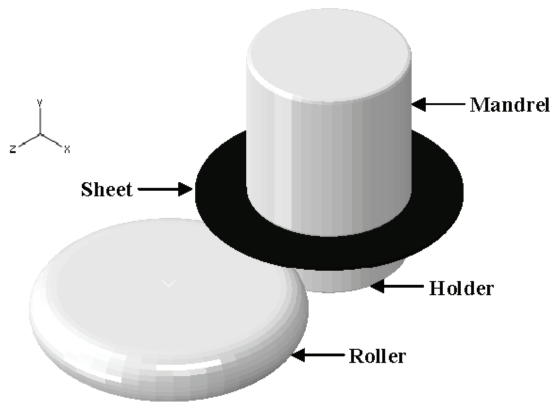

Fig.2 - 3-D FE model for dual pass conventional spinning

An assessment of the stability of the numerical solution has been undertaken to ensure that the solution is close to quasi-static conditions, followed by a comparison of the results to experimental data [4] to verify the model validity. Figure 3(a) shows the shape of the fully deformed cup and figure 3(b) shows a cross-section indicating the thickness distribution of the final cup. The local thinning in the corner region is evident.

Some results for cup deformed by a straight line path during the first and second pass are presented in figure 3. The distribution of Von Mises stress shown in figure 3(a) reveals a reasonably uniform level for much of the deformed wall of the cup, but with some variations, especially on the inner surface of the wall, towards the open end. Figure 3(b) shows a typical distribution of wall thickness variation in which the base of the cup held between the mandrel and holder is almost constant, while there is local thinning around the mandrel corner and slight thickening near the open end.

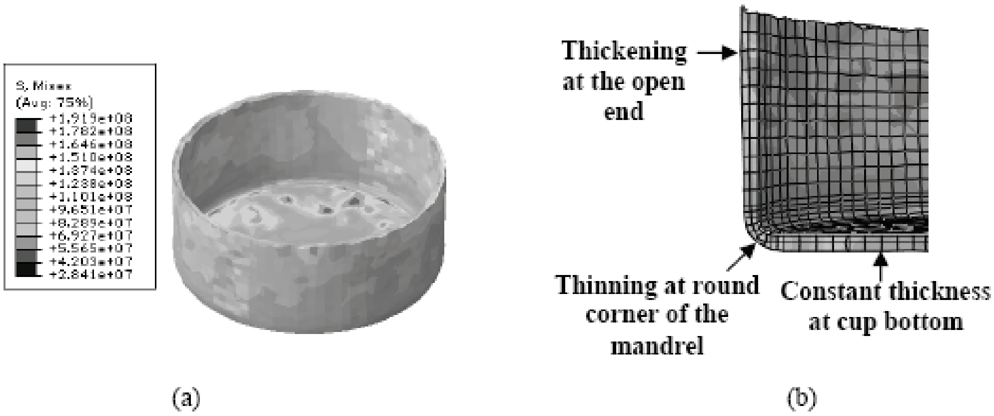

Fig. 3 -. (a) Von Mises stress in the fully deformed cup, and (b) a section through the cup with the FE mesh superimposed revealing the local thinning.

3. SELECTION OF ROLLER-TRACES AND WORKING PARAMETERS

In conventional spinning processes, many types of roller-traces could be selected. For this study the chosen roller traces are straight line, concave curves and convex curves. An example of a concave curve is an involute function and for a convex curve is a quadratic function, as shown in figure 4.

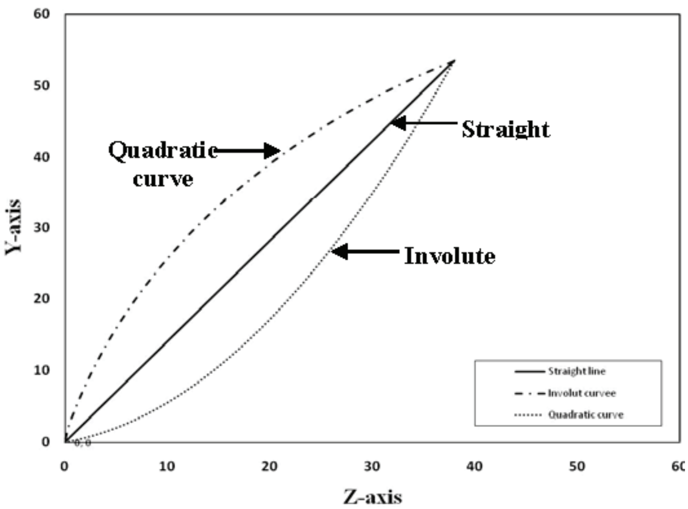

Fig. 4 - Schematic diagram for the three roller-traces curves used in the first pass

It is important to note that Y-axis as shown in figure 4 presents the mandrel axis. In this investigation, three strategies for the conventional spinning process are to be simulated. In each case, during the first pass, a roller-trace of straight line, involute curve and quadratic curve will be applied. In order to produce the final form of a cylindrical cup, the last roller-trace must, in each case, be a straight line. Therefore, during the second pass, the roller-trace for the three strategies is straight line and parallel to the mandrel axis. For accurate comparison, the initial and end point of the three roller-traces are the same along the first and second pass. Additionally, there is no contact between the sheet and mandrel wall under the three roller-traces during the first pass. The roller feed rate is kept uniform along the generatrix direction at 1mm/rev and the mandrel rotates at 200 rpm.

4. RESULTS ANALYSIS AND DISCUSSION

Equivalent strain and stress in addition to strain distributions in radial, hoop, and thickness directions are used to examine the sheet thinning after the first and second pass of the spinning process. Figure 5 shows the equivalent strain distribution after the first pass together with the cumulative equivalent plastic strain after the second pass. After the first pass, most of the plastic deformation occurs in a region that contacts the round corner of the mandrel at a sheet radius between 50mm and 60mm. After the second pass, most of the plastic deformation occurs along the cup wall with the highest value at the cup opening. The increase in plastic strain after the second pass at the cup wall is much higher than that at the round corner of the mandrel. The value of equivalent strain is the lowest under the involute curve-straight line strategy and highest under the quadratic curve-straight line strategy. There is good agreement between the results of the first pass and those obtained by Liu et al [6].

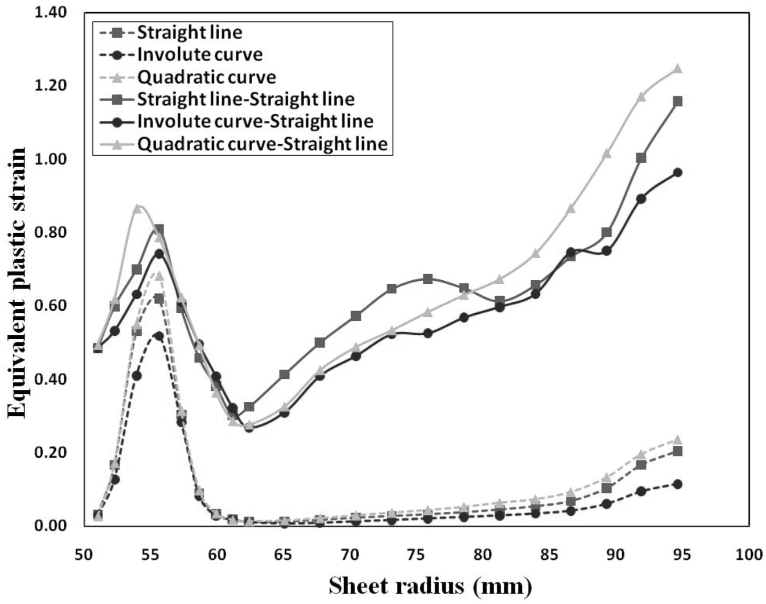

Fig. 5 - Equivalent plastic strain distributions after first and second pass

The equivalent stress distribution after the first and second pass is presented in figure 6. A high level of stress is generated at the round corner of the mandrel compared to that at the cup wall after the first pass. However, after the second pass, a much more uniform level of stress is obtained along the sheet radius. This is because the increase of stress level at the cup wall is much higher than that at the round corner of the mandrel. A more uniform stress distribution is found using a roller-trace of involute curve during the first pass followed by a straight line during the second pass. Greater variation in the stress distribution is found using a straight line roller-trace during the first and second passes.

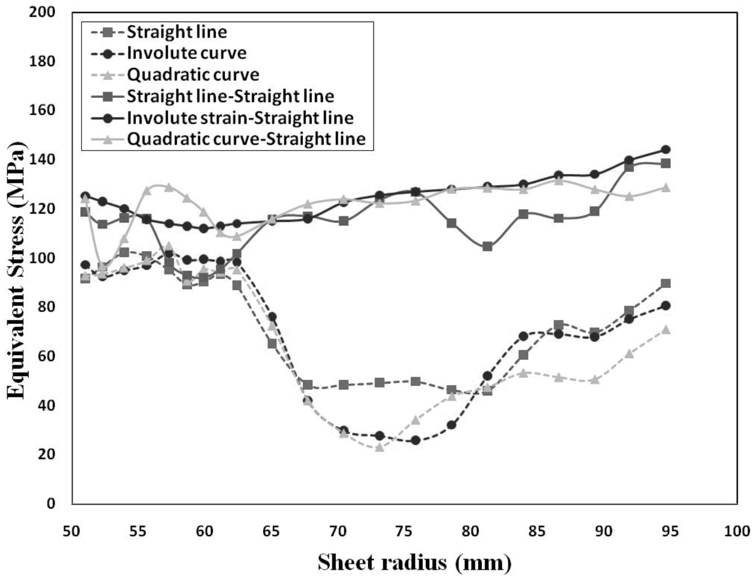

Fig. 6 - Equivalent stress distributions after first and second pass

Figure 7 shows the radial strain distribution after the first and second pass. After the first pass, a high positive radial strain takes place at the region that contacts the round corner of the mandrel. Then, the radial strain tends to be zero along the cup wall. The value of radial strain is lowest with an involute curve and highest with a quadratic curve, which agrees with the results obtained by Liu et al [6]. After the second pass, there is slight increase in radial strain at the round corner of the mandrel followed by a sudden drop to -0.3 at the beginning of the cup wall. Then, the radial strain decreases as the sheet radius increases and becomes close to zero at the cup opening. The radial strain values after the second pass are lowest using an involute curve trace followed by a straight line trace. The distributions of hoop strain after the first and second pass are presented in figure 8. The compressive hoop strain leads to sheet thickening which compensates for the sheet thinning that occurs due to tensile stresses. Hoop strain after the first pass is localised at the round corner of the mandrel. During the second pass, there is slight increase in the compressive hoop strain at the round corner of the mandrel as compared with that quite increase toward the open end. Therefore, after the second pass, the sheet thickness at the round corner of the mandrel is less than that at the open end as will be shown later. The values of hoop strain after the first pass are smallest with the involute curve and largest with the quadratic curve. The difference between the first and second pass hoop strain values are the smallest using an involute curve trace followed by a straight line trace which leads to more uniform thickness distribution.

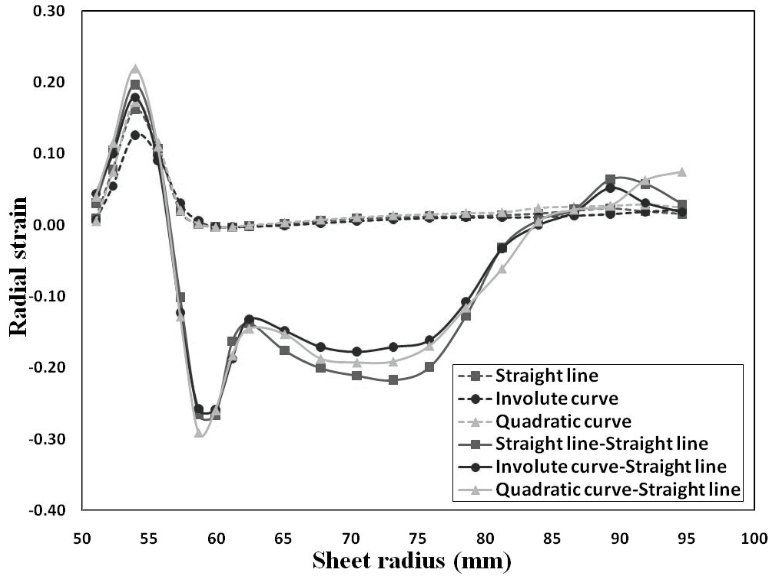

Fig. 7 - Radial strain distributions after first and second pass

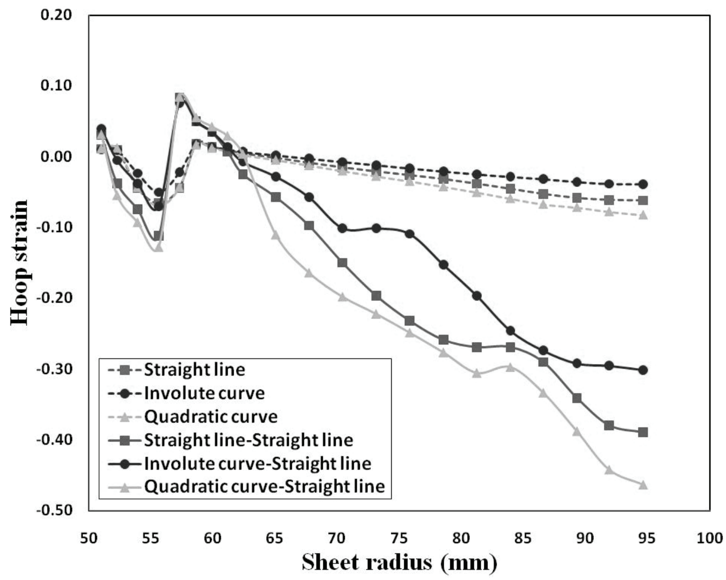

Fig. 8 - Hoop strain distributions after first and second pass

Figure 9 shows the thickness strain after the first and second pass. Negative thickness strain is located at the round corner of the mandrel after the first pass. A positive thickness strain is located in the cup wall after the second pass. At the region that contacts the round corner of the mandrel (at a sheet radius between 50mm and 60mm), there is significant sheet thinning. This thinning decreases as the sheet radius increases and is followed by sheet thickening at the open end. The thickness reduction at the round corner of the mandrel is lowest under the involute curve-straight line strategy and the thickness thickening at the cup opening is highest under the quadratic curve-straight line strategy. The uniformity of thickness strain distribution is better under the involute curve-straight line strategy. This is confirmed by the thickness distribution shown in figure 10.

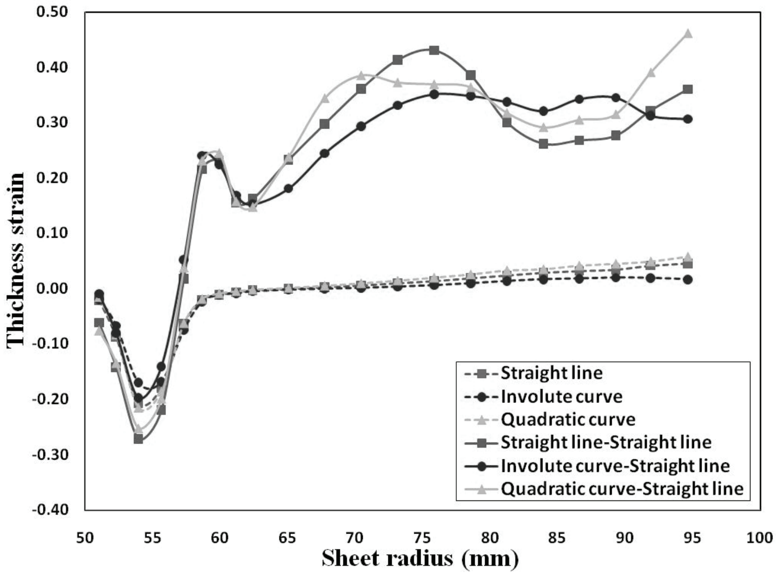

Fig.9. - Thickness strain distributions after first and second pass

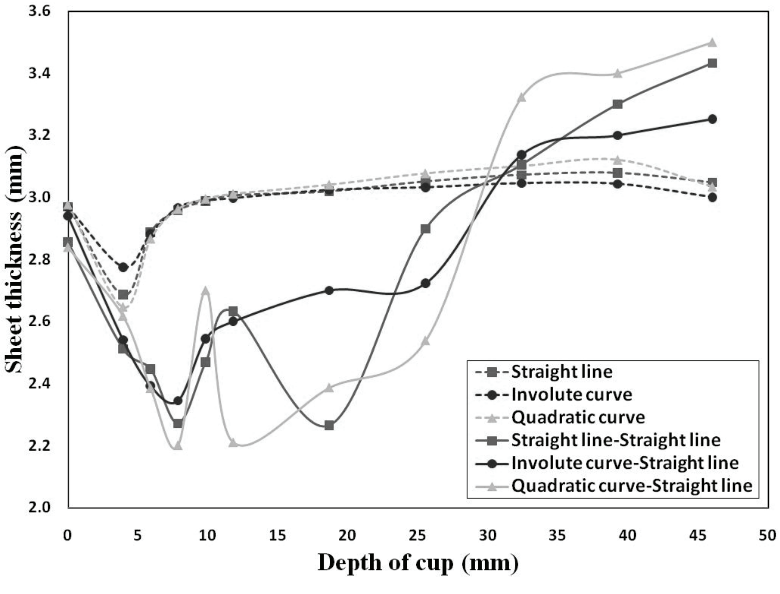

Fig. 10 - Thickness distributions after first and second pass

Less sheet thinning and a more uniform thickness distribution is obtained using an involute curve roller-trace during the first pass followed by a straight line roller-trace during the second pass. The highest sheet thinning at the round corner of the mandrel, highest sheet thickening at the cup opening and worst thickness uniformity is obtained using a quadratic curve roller-trace during the first pass followed by a straight line roller-trace during the second pass.

5. CONCLUSIONS

In this paper, the effect of roller-trace and its sequence on the sheet thinning during dual-pass conventional spinning has been numerically investigated through 3-D FE modelling. It was found that the roller-trace type has a significant effect on the plastic deformation during the first pass and thus, the sequence order of these roller-traces should be carefully selected. The following points can be concluded,

- After the first pass, most of the plastic deformation takes place at the round corner of the mandrel. While, after the second pass, most of the plastic deformation occurs along the cup wall.
- Equivalent plastic strain, radial strain, hoop strain and thickness strain are smallest under the involute curve-straight line roller-trace strategy and highest under the quadratic curve-straight line roller-trace strategy.
- The uniformity of strain distribution is better under the involute curve-straight line roller-trace strategy and worst under the quadratic curve-straight line roller-trace strategy.
- The least sheet thinning at the round corner of the mandrel and more uniform thickness distribution are obtained using an involute curve roller-trace in the first pass followed by a straight line roller-trace in the second pass.
- A more uniform stress distribution along the sheet radius is obtained using an involute curve roller-trace in the first pass and a straight line roller-trace in the second pass.
- The sequence order of roller-traces controls the final part quality and thus, should be carefully designed.
- The stresses and strains generated in the second pass play an important role in the thinning of the final part. Therefore, not only the effect of the first pass is important but also the effect of subsequent roller passes.

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NUMERIČKO ISTRAŽIVANJE EFEKTA PUTANJE ALATA U PROCESU DVOFAZNOG ROTACIONOG TISKANJA

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REZIME

U različitim industrijskim granama postoje različiti zahtevi za komponentama koje se odlikuju visoko povoljnim odnosom: čvrstoća – težina. Rotaciono tiskanje (izvlačenje) je proces koji pruža takve mogućnosti. Pored toga ovaj proces je veoma fleksibilan. Troškovi alata su relativno niski. Ali, u procesu su moguće i pojave greški kao što su naboravanje ili neželjeno stanjenje zida obratka.

U ovom radu istražuje se uticaj putanje aktivnog dela alata kod rotacionog tiskanja- valjčića, na neželjeno stanjenje lima kod višefaznog deformisanja. Usvojene su tri različite strategije: putanja u vidu prave linije, involutne linije ili kvadratne krive. Istraživan je efekat redosleda realizacije pojedinih vrsta putanja na paremetre procesa, posebno na stanjenje zida obratka. Kao optimalna kombinacija pokazala se involutna kriva u prvom prolazu i pravolinijska putanja u drugom prolazu. Za tu kombinaciju putanje valjčića postignuto je najmanje stanjenje zida obratka i najpovoljnije naponsko stanje.

Ključne reči: *Rotaciono tiskanje, dvofazno istiskivanje, numerička simulacija, debljina zida.*