THREE DIMENSIONAL FINITE ELEMENT ANALYSIS OF ALUMINUM 1100 POWER SPINNING

تحليل عددي ثلاثي الأبعاد لعملية التشكيل الرحوي للألومنيوم

I. N. EL-DESOUKY*, M. SAMUEL, TAWFIK T. EL-MIDANY****

*Demonstrator, **Professor,
Production Engineering and Mechanical Design Department
Faculty of Engineering, Mansoura University, 35516 Mansoura, Egypt.
E-mail: ibrahim1886@mans.edu.eg, magdy_s@mans.edu.eg & midany@mans.edu.eg

ملخص البحث:

تم انشاء نموذج تحليل عددي ثلاثي الابعاد يدرس التغير المرن واللدن الذي يحدث في قرص من الالومنيوم النقي بنسبة 99 في المئة عند تشكيله رحويا باستخدام برنامج MARC الذي قامت بتطويره شركة MSC للبرمجيات. الباحثين السابقين قاموا بتقديم تحليلات مختلفة لعملية التشكيل الرحوي. هذا البحث يقدم التحليل العددي للتشكيل الرحوي للمعادن. الأبحاث السابقة حددت عدة مشكلات تواجه عملية التحليل العددي للتشكيل الرحوي سيتم مناقشتها و ذكر الحلول المقترحة للتغلب عليها.

هذا العمل يهدف إلى تخفيض النفقات المبذولة في عملية تصميم القالب والتجارب العملية. النموذج العددي مفيد ايضا في توقع العيوب التي يمكن ان تظهر في المنتج النهائي وتؤدي الى رفضه.

Abstract

A 3-D elastic-plastic finite element model (FEM) of power spinning of an aluminum 1100 sheet was established using the software MARC provided by MSC Software. Previous authors have proposed various analyses of the spinning process. This paper reports the finite element modeling of metal spinning. Earlier papers reported the difficulties that a finite element modeling of spinning presented. An outline is given to show how these problems are tackled.

This work aims for reducing the costs spent in die design and experimental trials. The numerical model is also helpful for predicting the defect which cause rejecting the final product.

Keywords: Power Spinning, Finite Element Model (FEM), Aluminum 1100.

1. INTRODUCTION

Metal spinning refers to a group of forming processes that allow production of hollow, seamless, axially symmetric sheet metal components. The Process consists of clamping a sheet metal blank against a mandrel on a spinning lathe, and gradually forming the blank onto the mandrel surface by a roller, either in a single step or series of steps.

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Components produced by spinning include parts for the automotive and aerospace industries, musical instruments and kitchenware. Some typical examples are components for jet engines and turbines, radar reflectors, satellite nose cones [1].

Metal blanks as large as 6 m in diameter have been successfully formed using power spinning. Plate stock up to 25 mm thick can be power spun at room temperature. Blanks as thick as 140 mm have been successfully spun at elevated temperature [2]. Spinning has a number of advantages as the localized deformation of the material requires low forming forces. Moreover, simple and non-dedicated tooling provides flexibility. Lastly, formed components have high quality surface finish and improved mechanical properties. Power spinning has even more advantages than conventional spinning as the need for a skilled operator is eliminated and the product thickness is uniform.

M.D. Chen et al. (2001) performed a series of shear spinning experiments to produce axi-symmetric cones from blank sheet. The experiments investigated influences of roller nose radius, mandrel revolution and roller feed on the spinning force and the inside/outside surface roughness of spun cone. Statistical analysis was adopted to construct the regression equations governing these parameters [3].

Quigley and Monaghan (2002) investigated the finite element modeling of conventional metal spinning using domain decomposition technique to enable the partition of the FE problem into sub-problems that can be solved using parallel processing techniques in a greatly reduced time [4]. The model achieved a simulation of 0.08 second in a solution time of 7 hours approximately. A significant amount of forming has been done, but the part was far from being fully formed.

K. Mori and T. Nonaka (2005) proposed a simplified 3-D FEM in which, the shear spinning process is approximated as a forming process with a ringed die having the same cross-sectional shape as the roller [5].

Xinyu lu et al. (2006) proposed a 3-D FE analysis to study the flange bending for TC4 alloy during shear spinning [6]. M. Zhan et al. (2007) studied the influence of roller feed rate on forming force and quality of cone spinning using a 3-D finite element analysis [7].

Bai Qian et al. (2008) established a rigid plastic Finite element model of power spinning of thin walled shell with hoop inner rib [8]. The model used a conical preform and focused only on forming the circumferential groove. I. S. Marghmaleki et al. (2011) investigated the thermal effects on the conventional spinning process by an explicit FEM [9].

2. Finite Element Model Definition

Finite element modeling of power spinning operation is a very difficult process resulting from the incremental nature of the operation itself as it involves a combination of mandrel rotation and roller translation to achieve the forming procedure using relatively small forces.

Although the geometry of the mandrel and the blank follow the axi-symmetric configuration, due to the asymmetric nature of loading process and also the local contact between the roller and the blank, a complete 3-D model is needed. A dynamic/explicit finite element model of power spinning that considers work hardening is established in which the blank rotates synchronously with the mandrel and the follower while the roller moves parallel to the generatrix of the mandrel to press on the blank causing local plastic deformation. During the process contact zones of blank/roller and plastic deformation area of the blank change continuously. In order to simplify the simulation of the process some assumptions have been made in this work:

1. Blank material is isotropic and homogeneous.
2. The blank is the only deformable body in the analysis.
3. Strain rate effect and temperature effect are neglected.
4. Friction between the mandrel and the blank is neglected, while friction between the blank and the roller is considered.

2.1. Mesh Definition

The model uses an eight-node, isoparametric hexahedral element with an additional ninth node for the pressure. The circumference is divided into 36 segments of 10°, the thickness is divided into 3 elements, and the radius of the disk is divided into 19 elements as illustrated in Fig. 1.

Fig. 1. Sheet element mesh.

2.2. Adaptive Meshing

Using adaptive meshing is a good compromise between using a fine mesh that gives accurate results but takes a long processing time and using a coarse mesh that gives less accurate results but solves more quickly.

The criterion used to define local adaptive remeshing is the equivalent plastic strain. This criterion keeps a record of the strain change after remeshing for each element. When any element of the body has a strain change greater than the control limit, remeshing will start.

2.3. Geometric parameters

Deformation of the blank core is small, which has little influence on the deformed part, so a hole is made in the core of the blank to improve computational efficiency. The blank used is a flat circular sheet 100 mm in diameter and 3 mm in thickness with a central hole of 24 mm diameter. A simple cone shape shown in Fig. 2 is used for the mandrel. The axis of the mandrel is defined as Y-axis. The roller is modeled as a complete surface of revolution having outer diameter of 310 mm and corner radius of 5 mm. The inclination angle between the axis of the roller and the mandrel side is 10°. The finite element model is illustrated in Fig. 3.

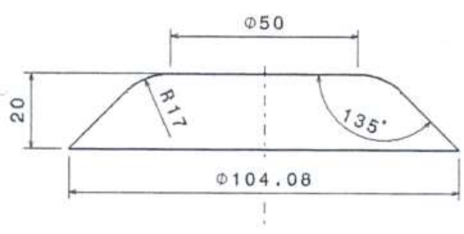

Fig. 2. Mandrel dimensions.

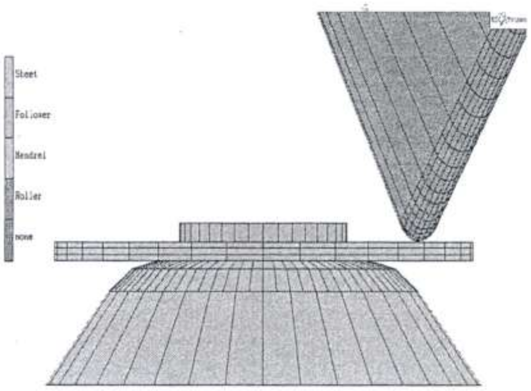

Fig. 3. Finite element model.

2.4. Material Parameters

The material used in the power spinning analysis is aluminum 1100. Some material properties are listed in table 1.

Table1. Aluminum 1100 Properties

Elastic Modulus	68900 MPa
Poisson ratio	0.33
Hardening model	$\sigma = K\,\varepsilon^n$ MPa
Strength coeff. K	141 MPa
Work Hardening Exponent n	0.24
Mass Density	2.71×10^{-6} kg/mm^3

2.5. Processing Parameters

The mandrel rotational speed is taken as 300 r.p.m, while the roller feed rate is taken as 0.2 mm/rev. The friction coefficient between the roller and the blank is set to 0.02. The hardware platform used was HP/Intel dual core processor having 2.26 GHz and 3 GB of ram.

2.6. Contact and Boundary Conditions

During the spinning process, the contact between blank and roller is complex and dynamic. The rotational motion of the mandrel and follower is set during their definition as rigid bodies. The translational motion of the roller is defined by a time table. The shear friction model is adopted in this simulation. Instead of using a clamping load, the follower and the blank were glued together to eliminate the need for any other boundary conditions to restrict the blank degrees of freedom.

2.7. Roller Path

Determining the initial position of the roller is very important both for practical and numerical modeling of cone spinning. In practice the roller's initial position is taken by trial and error. A new equation for defining the initial contact point between the roller and flat sheet is developed as a modification of the original equation proposed by M. Zhan et al [7]. The sketch given in Fig. 4 illustrates the roller start position. Point (F) can be obtained from the equations:

$$F_X = R_M - H_M * \tan\alpha + R_R$$
$$F_Y = t_0$$

Where: R_M is the Mandrel Radius
H_M is the Mandrel Height
α is half the cone angle
R_R is the roller corner radius
t_0 is the blank thickness

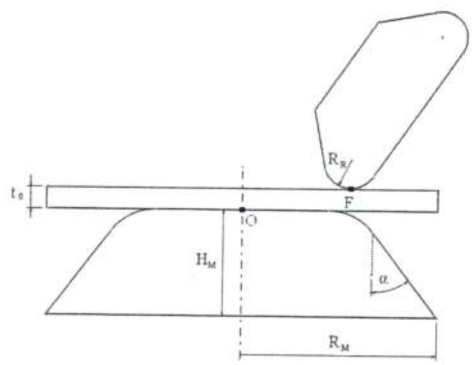

Fig. 4. Roller initial position.

Starting from this point the roller path is divided into two stages, the bending stage and the thinning stage. In the bending stage the roller translates vertically until the blank contacts the sides of the mandrel. Then the thinning stage starts as the roller moves in a direction parallel to the mandrel generatrix. The clearance between the roller and the mandrel is set exactly to the final thickness defined by the sine law.

2.8. Time Step

Selecting the time step is a difficult decision because if you set a large time step, the model may not solve and if you selected a small time step the solution time of the model will increase. The adaptive time stepping technique was used to overcome this problem in which the time step is reduced from 0.01723 second to 0.001 second as the calculation gets more complex.

3. Results and Discussion

The present work analyses the power spinning process of a flat circular disk which is very useful in giving stresses and strains in any portion of the workpiece at any time. Each calculation increment produces a large amount of data. Due to the immensity of the amount of data, illustrating figures can only give examples from the model output. The model began with 2054 elements, and finished with 12293 elements. The mechanism of deformation in power spinning is a combination of shear and bending. Fig. 5 shows the distribution of Von Mises stresses during the spinning process at 8, and 12 seconds from the beginning of simulation.

While the model proposed by Quigley and Monaghan achieved a simulation of 0.08 second in a solution time of 7 hours approximately and did not complete the spinning process [4], this model successfully completed processing 23.6 seconds in only 28.6 hours which makes it more suitable for practical applications.

The majority of plastic deformation is concentrated around the roller and sheet contact zone. The trace of the roller on the sheet can be shown as a skewed ring. The results show for these cases, the locations of maximum stress and strain are near the contact area under the roller. Figure 6 depicts the curves of the total equivalent plastic strain against the arc length for the nodes on a radius of the blank at 4, 8, and 12 seconds from the beginning of simulation.

In the beginning of the spinning simulation minor wrinkling was detected but it was soon vanished by the roller pass which indicates the validity of the established model for detecting sources of failure that can cause product rejection. Wrinkling occurs due to high compressive circumferential stresses buckling the flange. To avoid wrinkling, the combination of tensile and compressive stresses in the material needs to be introduced gradually. This can be achieved by reducing the roller feed rate.

In order to prove the reliability of the finite element model established above, a serious comparison was carried out through the equations in reference [3].

The distribution of forces agrees reasonably with the values obtained from the equations deduced by M.D. Chen et al. [3]. An example of force distribution over the arc length after 8 seconds from process start is shown in Fig. 7.

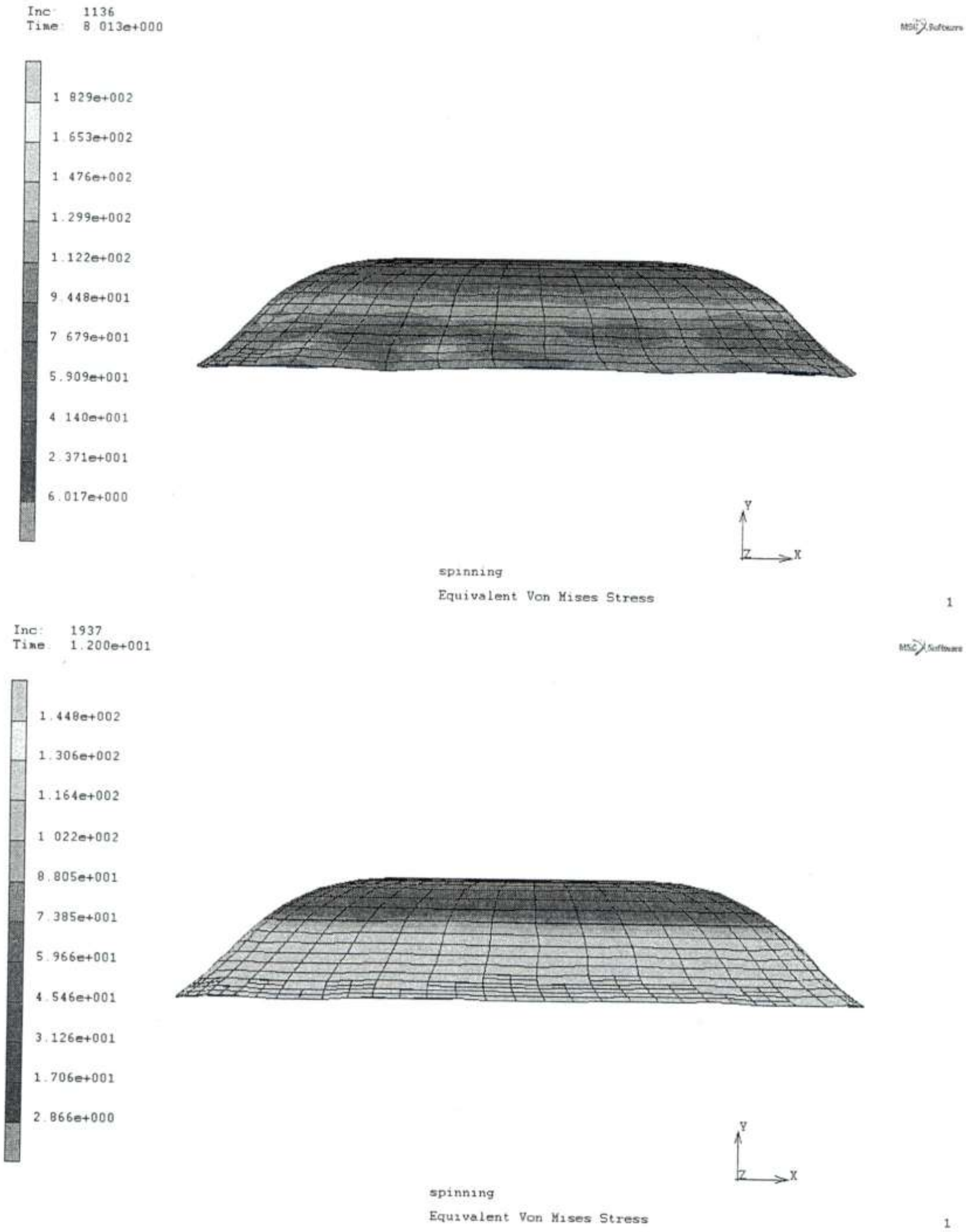

Fig. 5. Equivalent Von Mises Stresses at different time intervals during spinning (8, 12 seconds) in MPa.

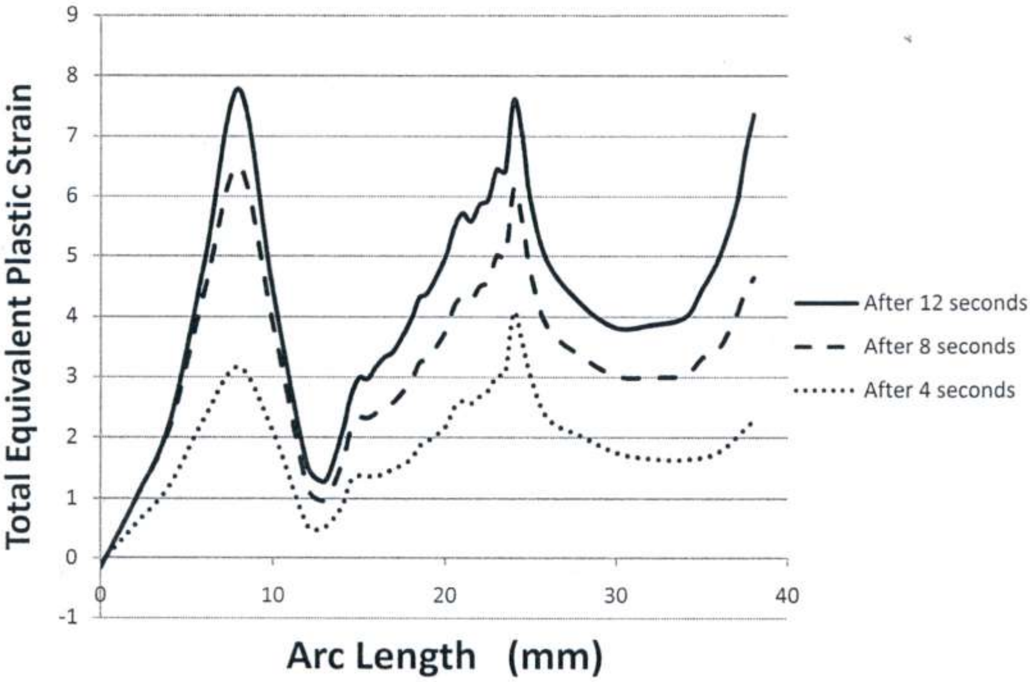

Fig. 6. Total equivalent plastic strain at different time intervals during spinning (4, 8, 12 seconds).

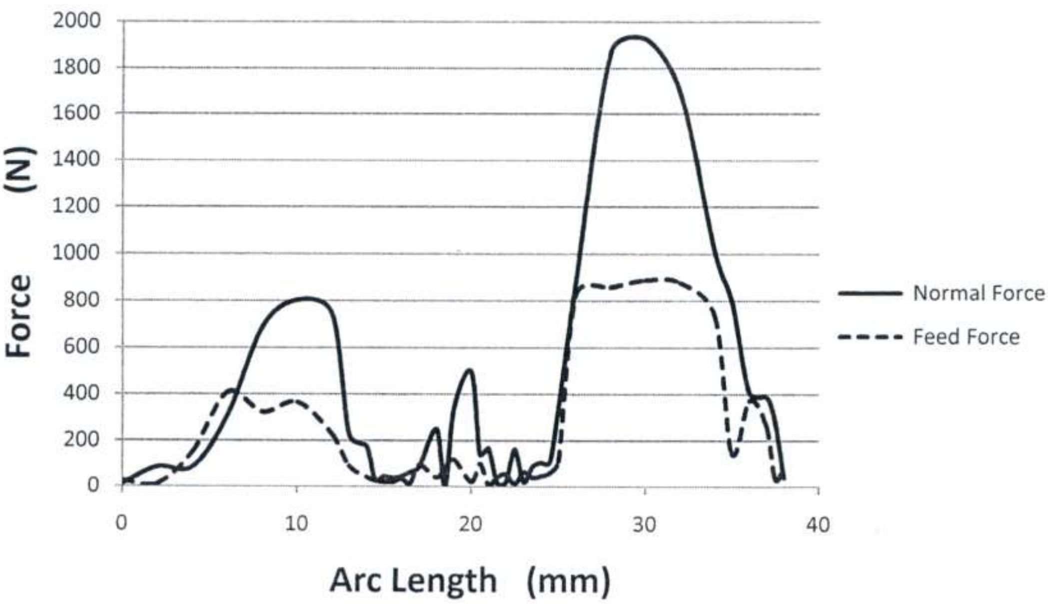

Fig. 7. Force distribution at 8 seconds.

4. Conclusions

An elastic-plastic finite element model of power spinning a conical shape is established under the Marc software, and the key technologies involved in modeling are dealt with reasonably, including contact, boundary conditions, and simplification of the blank.

Based on the finite element model, the given spinning process is simulated. The distribution of stress, strain, and the variations of spinning force in forming process are acquired which serve as a significant guide to study the local deformation mechanism.

The model can be used to help design the mandrel, predict the workpiece defects in the complex spinning process, and also choose the reasonable spinning process parameters.

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