

STRAIN AND STRAIN-HARDENING ANALYSIS OF FORMED PARTS PRODUCED BY MULTI-PASS METAL SPINNING

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Original scientific paper

The paper presents results of experimental study focused on the analysis of radial and hoop strain distributions and effect of strain-hardening of the surface layers of sheet metal hollow parts produced by multi-pass metal spinning. The thin sheets of 1 mm thickness, steel EN 10025-94 (ISO 630-80), were used for experimental study. The results of the study confirm minimal influence of the anisotropy of material on radial and hoop strain distributions and the relatively significant influence of the material anisotropy on the strain-hardening of the spun part's surface layers. It is found higher strain-hardening in the direction 90° refer to the rolling direction of the sheet compared to the direction 0°.

Keywords: *anisotropy, metal spinning, strain, strain-hardening*

Analiza deformacije i otvrđivanje plastičnom deformacijom oblikovanih dijelova proizvedenih višeslojnim utiskivanjem metala

Izvorni znanstveni članak

U članku se daju rezultati eksperimentalnog istraživanja usmjerenog na analizu radijalne i tangencijalne raspodjele deformacije i utjecaja otvrđivanja plastičnom deformacijom površinskih slojeva šupljih dijelova od metalnog lima proizvedenih višeslojnim utiskivanjem (rotacijskim oblikovanjem) metala. Korišteni su tanki limovi od čelika EN 10025-94 (ISO 630-80), debljine 1 mm. Rezultati istraživanja potvrđuju minimalni utjecaj anizotropije materijala na radijalnu i tangencijalnu raspodjelu deformacija i relativno značajan utjecaj anizotropije materijala na otvrđivanja plastičnom deformacijom površinskih slojeva utiskivanih dijelova. Ustanovljeno je da veće otvrđivanje plastičnom deformacijom postoji u smjeru 90° prema smjeru valjanja lima nego u smjeru 0°.

Ključne riječi: *anizotropija, utiskivanje metala, deformacija, otvrđivanje plastičnom deformacijom*

1

Introduction

The last decade has shown an increasing interest in a new class of forming processes known as Incremental Sheet Forming (ISF). In these processes, a forming tool deforms a workpiece to the required geometry by a sequence of small and localized plastic deformation. Regardless of the size of the tool, the forming tool has a small contact area with the workpiece. During the process, the contact area (forming tool) travels all over the workpiece several times in loops or revolutions. Within the loop, a portion of the workpiece deforms plastically for a small time interval compared to the total process time. After each loop, the initial geometry is gradually changed toward the desired final geometry [1].

A particular ISF process which involves forming of axisymmetric hollow parts with advantageous surface layer properties is metal spinning [1, 2], that incorporates conventional spinning, shear spinning and tube spinning [3].

Metal spinning, also known as spin forming (ger.: Metalldrücken), is a method for manufacturing axisymmetric parts and dimensionally undeployable structures which are due to the way new surfaces of the product are generated. It is similar to manufacturing of pottery on potter's wheel dating back to Ancient Egypt era 3000 years B. C. [4]. The core of the process consists in gradual shaping of a pre-sized sheet metal disc according to a model (mandrel). From the technological point of view the material is exposed to plastic deformation provoked by bending moment; indeed, it is not a simple bending but a compound material bending with local plastic deformation. In other words, it is incremental forming based on gradual bending of material in rotation with additional reduction force of the metal spinning tool.

As the tool is applied locally on the workpiece, the total forming forces are reduced significantly compared to conventional press forming. This increases the possibilities

in terms of large reductions and change in shape with less complex tooling and also reduces the required load capacity and cost of the forming machine. Very significant feature of spinning is the ability to produce components with high mechanical properties and smooth surface finish [5].

Metal spinning is frequently used for manufacturing axisymmetric shapes where press tooling might not be justified on grounds of size and production volumes. Spinning also has the possibility of producing parts that could not be deep drawn. [6]

Although knowledge about the instant stresses, accumulated strains and damage evolution, which help to understand final properties of spun parts, have been developed by systematic investigation of the process using both experimental and theoretical techniques [7, 8 and other], several gaps still exist in the knowledge of spinning mechanics, mechanical and structural properties of surface and sub-surface layers of spun parts (residual stresses, microstructure) and more information is needed for precise prediction of failure and cracks, too. There are still many open questions about strains, microstructure and surface integrity of a formed part in multi-pass metal spinning. All studies have mainly concentrated only on one roller pass or the first few, and it is not yet known what happens in subsequent passes [3]. They state that high strains occur when the part reaches the mandrel radius, and in all regions of the part the hoop strains are small compared to radial and thickness strains. The formed region (region between tailstock and sheet edge area of the part) is dominated by high positive radial and negative thickness strains. It was found that the first pass in spinning determines the final thickness and is therefore critical for successful spinning [7, 9, 10, 11].

All previously published works show the importance of investigation of the spun parts strain distributions and surface layers modifications. Because literature about the effects of material anisotropy on this process has less been reported therefore the paper brings partial outcomes of an

experimental research aimed at finding answers to the question how the radial strain distributions and surface microhardness are influenced by material anisotropy.

2 Methods and materials

For production of hollow sheet metal parts, whose shape and dimensions are demonstrated in Figure 1 and listed in Tab. 2, thin sheet has been used, made out of carbon steel, defined in the standards EN 10025-94 (ISO 630-80). Chemical composition of experimental material is shown in Tab. 1.

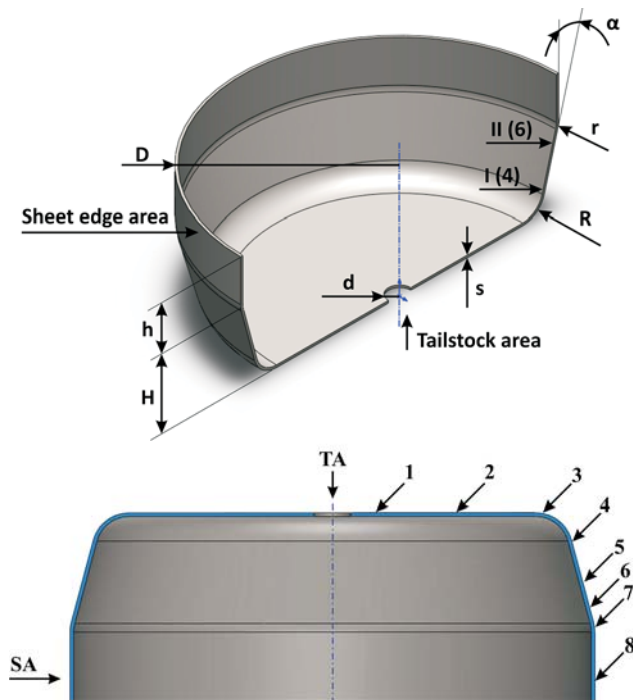


Figure 1 Experimental sample
I – bottom-wall section of part (radius R10), II – conic wall section of part, TA – tailstock area, SA – sheet edge area, 1 – 8 places of radial and hoop strains measurement

Table 1 Chemical composition of the experimental material

C / %	Mn / %	Ni / %	S / %	P / %
0,17	1,4	0,009	0,045	0,045

The chosen basic mechanical properties and facilities defining material plasticity (ultimate tensile strength (R_m), 0,2 % offset yield strength ($R_{p0,2}$), elongation (A), medium value of anisotropy (r), planar anisotropy (Δr)) are listed in Tab. 3.

The experimental samples have been made by multi-pass spinning on a manual metal spinning lathe under the

next technological conditions:

- feed ratio: $f=0,8$ mm/revolution,
- mandrel speed: $n=600$ 1/min,
- number of passes: $p=3$ without lubrication.

2.1 Strain distributions measurement

Strain distributions were obtained from a pattern of circles of known size ($d = 2$ mm) etched onto the blanks before the spinning process. Elliptically deformed circles were measured after spinning and radial (true major) and hoop (true minor) strains were calculated. Measurements were realised on optical microscope Zeiss BK 70 \times 50. The strains in 0° , 45° and 90° , referring to the sheet rolling direction, were studied.

2.2 Microhardness measurement

Mechanical properties of the spun parts surface layers were evaluated using microhardness measuring according to Vickers, method HV 0,025, under the technical standard STN 42 0375, measured on INDETA Met 1100 device. The measurement was carried out in direction from the part's surface to its depth (up to 30 μ m) on positions that are from the aspect of hollow sheet parts production defined as critical – inter-stage spots of bottom to wall (radius R10) and conic wall (see Fig. 1). Microhardness measurement in the surface and sub-surface area was carried out also on base material (BM). The measurement was applied in two directions – 0° and 90° refer to the rolling direction of the sheet.

3 Results and discussion

The results of radial and hoop strain distribution measurements throughout sheet metal part, measured in three different directions referring to the rolling direction of the sheet material, are demonstrated in Fig. 2 and Fig. 3. The places of measurement are shown in Fig. 1 (the place of measurement "1" is located in the area close to the tailstock and the place of measurement "8" is located in the area close to the sheet edge (see Fig. 1)). It can be seen that there are significant positive radial strains (stretching) and negative (compressive) hoop strains.

Graphic evaluation of microhardness values of the sample's surface layer, made by metal spinning, in positions I and II, considering the material rolling direction, is shown in Fig. 4. Measured values of microhardness of non-deformed sheet metal are listed in Tab. 4.

Table 2 Formed part dimensions

D / mm	h / mm	H / mm	R / mm	r / mm	$\alpha / ^\circ$	s / mm	d / mm
140	20	30	10	10	15	1	10

Table 3 Mechanical characteristics of experimental material

$r_s / -$	R_m / MPa	$R_{p0,2} / \text{MPa}$	$R_{p0,2}/R_m / -$	$A_5 / \%$	$\Delta r / -$	$n / -$	$A_{sh} / -$
1,17	340	235	0,69	26	0,34	0,28	27,38

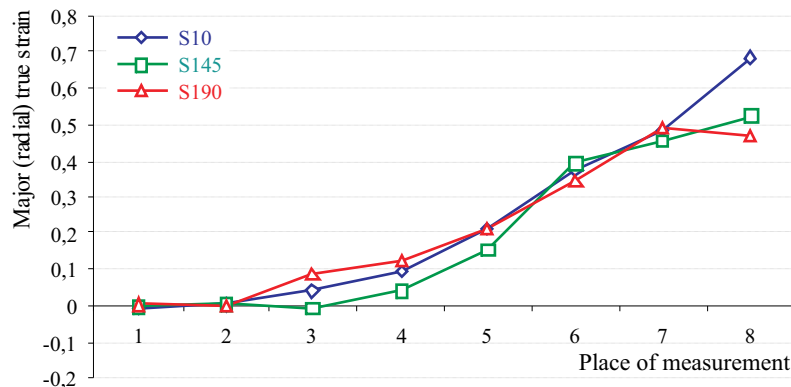


Figure 2 Distribution of radial strains
(S10 – 0°, S145 – 45° and S190 – 90° refer to the rolling direction of the sheet)

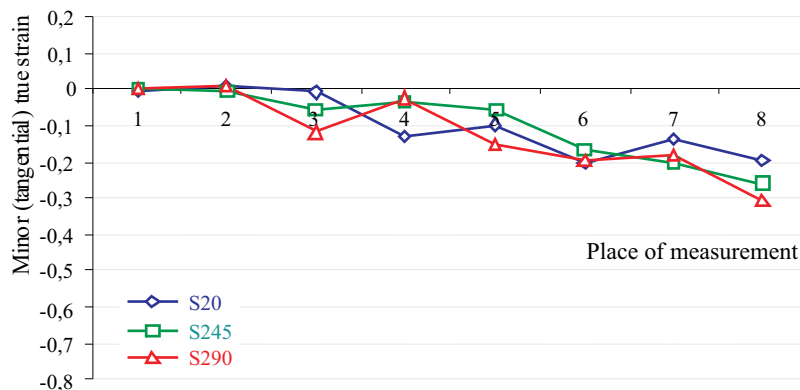


Figure 3 Distribution of hoop strains
(S20 – 0°, S245 – 45° and S290 – 90° refer to the rolling direction of the sheet)

Table 4 Microhardness values of surface layer of non-deformed material

Depth of measure / μm	5	10	15	20	25	Mean average
$HV_{BM/0}$	101,9	101,8	100,2	99,3	98,9	101
$HV_{BM/90}$	101,7	99,4	99,2	98,6	98	101,14

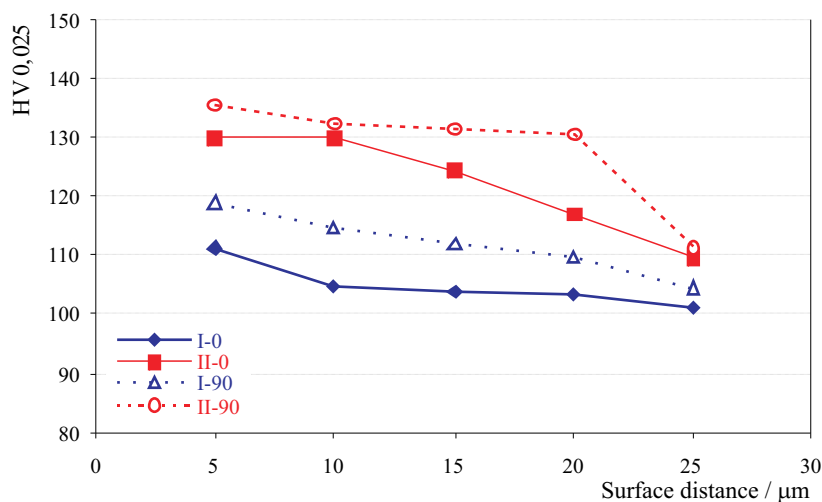


Figure 4 Progress of microhardness values in surface layer in position I and II (places of strains measurement 4 and 6), in direction 0° and 90° refer to the rolling of the sheet

4 Conclusions

The results of the carried out experiments lead to the next conclusions:

- Comparison of the strains in directions – 0°, 45°, 90° referring to the rolling direction of the sheet confirmed the assumption about minimal influence of material

anisotropy in the spinning process. For the metal spinning process the deformation is typical only in a small (local) volume of material.

- Microhardness of surface layers is influenced by initial direction of material rolling. In both measured places on the part we can see higher strain-hardening in the direction 90° refer to the rolling of the sheet.

Acknowledgements

This work was financially supported by the Ministry of Education, Science, Research and Sport of the Slovak Republic (7th FP EU Manunet 2008-SK-001, named *Multivariate optimization of the metal spinning processes – research and development* and project VEGA 1/0254/11).

5

References

- [1] Emmens, W. C.; Sebastiani, G.; Boogaard van den, A. H. The technology of Incremental Sheet Forming - a brief review of the history. // *Journal of Materials Processing Technology*. 210, 8(2010), pp. 981-997.
- [2] Hadoush, A. M. H. Efficient Simulation and Process Mechanics of Incremental Sheet Forming. Dissertation thesis. Twente : University of Twente, 2010.
- [3] Music, O.; Allwood, J. M.; Kawai, K. A review of the mechanics of metal spinning. // *Journal of Materials Processing Technology*. 210, 1(2010), pp. 3-23.
- [4] Palten, H.; Palten, D. From Ancient Art to High-Tech Industry. // *Metalforming*. 9(2002), pp. 30–34. URL: <http://www.metalformingmagazine.com> (17. 3. 2009)
- [5] Wong, C. C.; Dean, T. A.; Lin, J. A review of spinning, shear forming and flow forming processes. // *International Journal of Machine Tool & Manufacture*. 43, 14(2010), pp. 1419-1435.
- [6] Marghmaleki, I. S. et al. Finite Element Simulation of Thermomechanical Spinning Process. // *Procedia Engineering*, 10 (2011), pp. 3769-3774.
- [7] Quigley, E.; Monaghan, J. Metal forming: an analysis of spinning processes. // *Journal of Materials Processing Technology*. 103, 1(2000), pp. 114-119.
- [8] Šugárová, J. Metal spinning technology. Zvolen : Publishing center of TU, 2008.
- [9] Kang, D. C. et al. Study on the deformation mode of conventional spinning of plates. // *Journal of Materials Processing Technology*. 91, 1-3(1999), pp. 226-230.
- [10] Quigley, E.; Monaghan, J. The finite element modelling of conventional spinning using multi/domain models. // *Journal of Materials Processing Technology*. 123, 3(2002), pp. 360-365.
- [11] Liu, J. H.; Yang, H.; Li, Y. Q. A study of the stress and strain distributions of first-pass conventional spinning under different roller-traces. // *Journal of Materials Processing Technology*. 129, 1-3(2002), pp. 326-329.

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