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Preliminary communication

The Effect of Process Parameters on Surface Finish of Metal Spun Parts

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Abstract: The paper brings the results of surface finish analysis of formed parts produced by CNC multi-pass conventional metal spinning. The influence of mandrel speed, spinning roller feed and workpiece geometry on the surface finish of formed parts made of mild steel type of EN 10025-94 (ISO 630-80) have been studied by profile and 3D surface parameters evaluating. For the study, the full factorial design of experiment (3^3) was used and ANOVA (Analysis of Variance) was carried out. It is shown that the optimal roller feed exists within the range of minimal and maximal experimental feed values and the surface roughness measured in different areas of experimental samples (radius R10, conical area, cylindrical area) indicates that the higher surface roughness occurs at the conical surfaces.

Keywords: ANOVA; metal spinning; roughness; surface

1 INTRODUCTION

The increasing interest in the cost-effective manufacturing of short and medium series of sheet metal products results in applying a new type of forming processes known as Incremental Sheet Forming (ISF). One of these processes, which involve forming of axisymmetric hollow parts, is sheet metal spinning. It includes conventional, shear and tube spinning processes [1, 2].

The main principle of sheet metal spinning is step-by-step transformation of metal blank into axisymmetric part by a roller in accordance with a mandrel shape. One or more passes of the spinning roller are used. Because of the incremental forming nature, the process brings some specific advantages. The total forming forces are reduced significantly compared to conventional sheet metal forming processes. 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. It also offers advantages such as short set-up time and the option of performing several process steps in one single clamping. Lastly, formed parts have high quality surface finish and improved mechanical properties [2-5].

Metal spinning is affected by many factors, including material and dimensional characteristics of the blank, roller and mandrel, mandrel speed, roller feed, temperature, lubrication, toolpath and geometry of spun part. Combinations of these variables affect the mechanics of the process and spun part surface integrity, as well.

Research focused on the study of relationship between surface finish and process parameters, which have so far been realized, to be aimed mainly on shear spinning [3, 6, 7, 8]. The effect of machine parameters and tool on surface roughness in conventional spinning of aluminium cups has been studied in [9, 10]. The authors report that lower feed rates, higher speeds and larger roller nose radius resulted in better surface roughness. Lower feed ratio would provide a better surface roughness, but for maintaining the original thickness of blank unchanged, feed ratios should be high. It may be necessary to find a "trade-off" feed ratio, which will guarantee maintaining the blank thickness unchanged, provide good surface roughness and prevent the material failures [11, 12]. The empirical model of the spatial distribution of the surface roughness obtained in the friction spinning process brings Hess et al. [13]. In contrast to the study of surface topology in metal spinning by using so called phenomenological process parameters (machine and material parameters), Groche and Schäfer [14] for examination of in-process correlations introduced so called fundamental parameters (material properties, contact pressure, lubrication, shear stress and sliding velocity).

Although knowledge basis of the metal spinning principles, which helps to understand final properties of spun parts, has been developed many years by way of theoretical and experimental investigation, the process design still highly depends mainly on spinner experiences [1, 15]. In order to increase knowledge about metal spun surface microgeometry formation the series of experiments were carried out. The effect of mandrel speed, feed ratio and workpiece geometry of the sheet on the surface finish was evaluated using experimental approach.

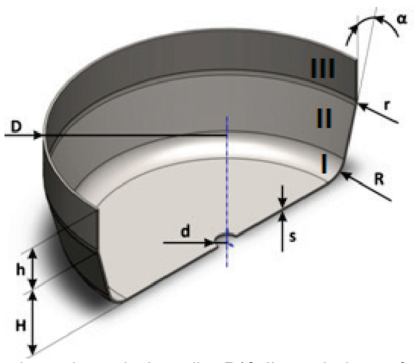

Figure 1 Experimental sample: I – radius R10, II – conical part of the workpiece, III – cylindrical part of the workpiece

Table 1 Geometrical parameters of experimental sample

D / mm	d / mm	H / mm	h / mm
140	10	30	20
R / mm	r / mm	α / °	s / mm
10	10	15	1

2 EXPERIMENT

The experimental samples (shape and dimensions are demonstrated in Fig. 1 and Tab. 1) were made of circular blank with an outer diameter of D_0 = 200 mm. The blanks were prepared by abrasive water jet cutting. The material used was mild steel according to the standards EN 10025-94 (ISO 630-80). Selected mechanical properties and facilities regarding the plasticity (ultimate tensile strength

(R_m), 0,2% offset yield strength ($R_{p0.2}$), elongation (A_5), coefficients of normal and planar anisotropy (r_s), (Δr) and coefficient of material strain-hardening (n)) are depicted in Tab. 2.

Table 2 Mechanical properties of experimental material

Ultimate tensile strength R_m / MPa	340
Offset yield strength $R_{p0.2}$ / MPa	235
Strength ratio $R_{p0.2}/R_m$ / -	0,69
Elongation A_5 / %	26
Coefficient of normal anisotropy r_s / -	1,174
Coefficient of planar anisotropy Δr / -	0,34
Strain hardening coefficient n / -	0,28

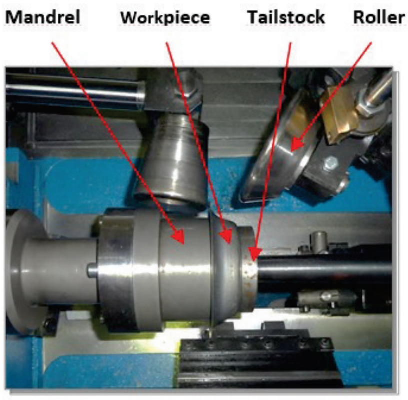

Figure 2 Experimental setup

For experimental study the DENN spinning machine of the type Zenn-80 with a Sinumeric 840-D CNC unit has been employed. A forming tool radius R8 and three different levels of mandrel speed and feed ratio have been used for all of the experimental trials. The off-line designed involute CNC roller paths profiles have been applied: 9 movements towards the blank edge (forward passes), 3 movements towards the mandrel (backward passes) and one forward calibration pass. The lubricant oil of type AVIA GLEITBAHNÖL RSU 220 has been applied for reduction of friction and improvement of the spun parts surface quality.

Three variables, i.e. spindle speed, feed ratio and workpiece geometry at three levels (3^3) were considered as the experimental input factors according to Tab. 3.

Table 3 Control factors and levels

Parameter	Sign	Level 1	Level 2	Level 3
Mandrel speed / min^{-1}	n	300	600	900
Feed ratio / mm	f	1	1.5	2
Workpiece geometry area	wa	(I) radius R10	(II) conical area	(III) cylindrical area

A standard, commercially available, Form Talysurf Intra 50 measurement system (Taylor-Hobson GmbH) with no special adjustment was applied for contact roughness measurements and surface roughness parameters assessment in 2D and 3D. The measurements were taken according to the standards [16-18].

The statistical significance and the effect of the spinning process parameters and their combinations on the spun part surface profile microgeometry were analysed and documented by ANalysis Of VAriance (ANOVA). The ANOVA tables with the results of F-tests (Fisher's ratio value) and main effects plot were used to detect the significance and effect of each factor at 95% confidence level. The greater F-value than the tabulated one detected the parameters and their combinations with significant impact on the response variable.

Table 4 Results of measurement – surface roughness

Experiment number	Process parameters			Average roughness
	n / min^{-1}	f / mm	wa	Ra / µm
1	300	1	I	1,570
2	300	1	II	1,650
3	300	1	III	1,650
4	300	1.5	I	1,000
5	300	1.5	II	1,030
6	300	1.5	III	0,928
7	300	2	I	0,951
8	300	2	II	0,890
9	300	2	III	1,200
10	600	1	I	1,580
11	600	1	II	1,570
12	600	1	III	1,420
13	600	1.5	I	0,818
14	600	1.5	II	1,410
15	600	1.5	III	1,050
16	600	2	I	1,040
17	600	2	II	1,490
18	600	2	III	1,980
19	900	1	I	1,210
20	900	1	II	1,280
21	900	1	III	1,870
22	900	1.5	I	0,920
23	900	1.5	II	1,220
24	900	1.5	III	0,962
25	900	2	I	1,040
26	900	2	II	1,840
27	900	2	III	0,719

3 RESULTS AND DISCUSSION

The results of the spun parts surfaces roughness measurement are listed in Tab. 4.

The images, presented in Fig. 3 to Fig. 5, give a view on the surface morphology of spun parts produced under different spinning conditions.

Fig. 6 shows the main effects plot and the results of ANOVA and F-test results are shown in Tab. 5.

Table 5 Results of ANOVA and F-test

Source	DoF	Sum of squares	Mean square	F-value	P-value
n	2	0,1458	0,0729	0,572	0,506
f	2	1,1191	0,5595	**5,54***	**0,020***
wa	2	0,3019	0,1509	1,49	0,263
$n*f$	4	0,2817	0,0704	0,70	0,608
$f*wa$	4	0,1680	0,0420	0,42	0,794
Error	12	1,2121	0,1010		
Total	26	3.2286			
F-ratio at confidence 95%: F (0.05; 2.12) = 3.89; F (0.05; 4.12) = 3.26					
* significant parameter or two-way interaction, R-squared = 62,5 %					

Generally it can be told that lower values of surface roughness have been observed in the area I of the spun part – radius R10 and higher values have been documented in the workpiece area II – conical part and in the area III – cylindrical part. Maximal values of roughness were reached in these cases when the feed ratio was 1,5 mm.

The surface morphologies in the conical part (II) and cylindrical part (III), compared with the area I (radius R10), are more uniform and the surfaces seen to be "porous" without high peaks and deep valleys. Unintended craters, randomly originated at the surface, have been observed at the surfaces in all workpiece areas (Fig. 4. and Fig. 5) In addition, on the surfaces in the area I (radius R10), a pattern of grooves provoked by the roller has been markedly visible (Fig. 3).

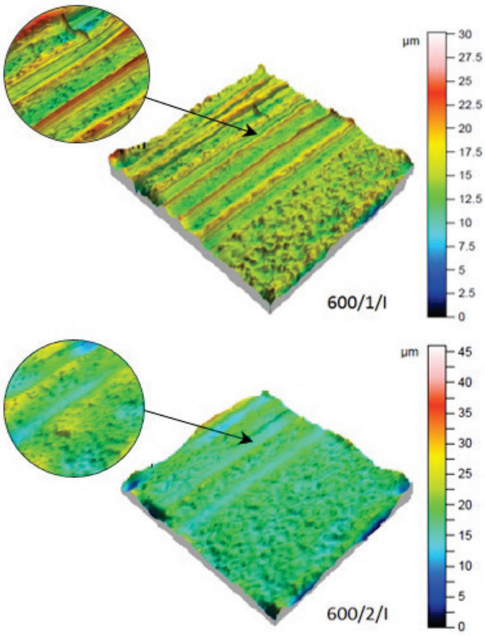

Figure 3 Spun part surface 3D image – R10 area (L_c = 0,8 mm, measured area = 5 × 5 mm); 600/1/I : n = 600 min^{-1}, f = 1 mm; 600/2/I : n = 600 min^{-1}, f = 2 mm

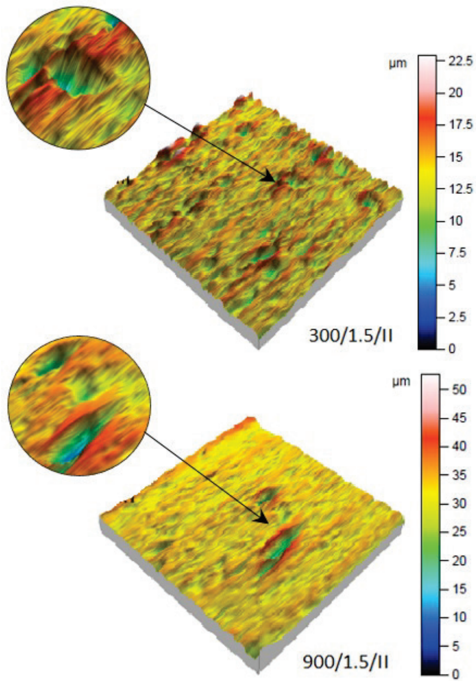

Figure 4 Spun part surface 3D image – conical area (L_c = 0,8 mm, measured area = 5 × 5 mm); 300/1.5/II : n = 300 min^{-1}, f = 1,5 mm; 900/1.5/II : n = 900 min^{-1}, f = 1,5 mm

Based on the main effects plots and ANOVA, it can be declared that feed ratio is a factor, which has relatively strong impact on the surface roughness of spun part. There is an optimal value of the feed ratio, which gives us the best surface finish. It is neither minimal nor maximal value of the feed ratio evaluated range. These results are not in agreement with the general theory based on the statement that higher feed is accompanied with higher roughness. Regarding the phenomenon of minimal values of surface roughness in area of radius R10 it must be told that the spinning process is affected by so called phenomenological parameters (mandrel speed, feed ratio, tool geometry, formed material properties and so on), but also fundamental parameters (normal stresses under roller, shear stresses, strain states) [14]. It explains the lower values of roughness in the areas, where the higher tensile stresses are introduced in the deformed surface layers due to the intense bending.

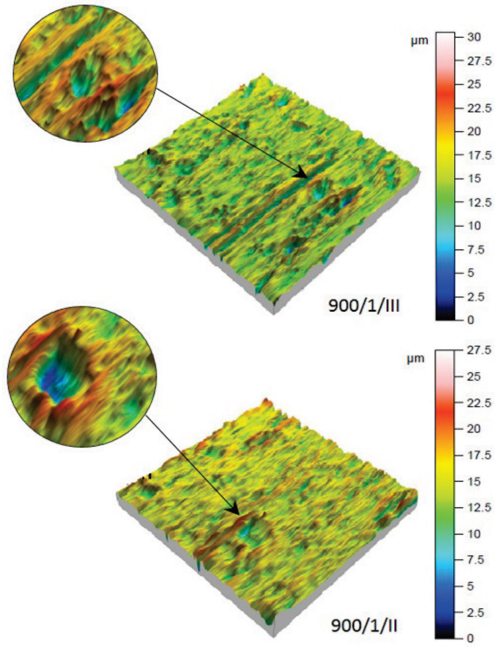

Figure 5 Spun part surface 3D image (L_c = 0,8 mm, measured area = 5 × 5 mm); 900/1/III : n = 900 min^{-1}, f = 1 mm; cylindrical area; 900/1/II : n = 900 min^{-1}, f = 1 mm; conical area

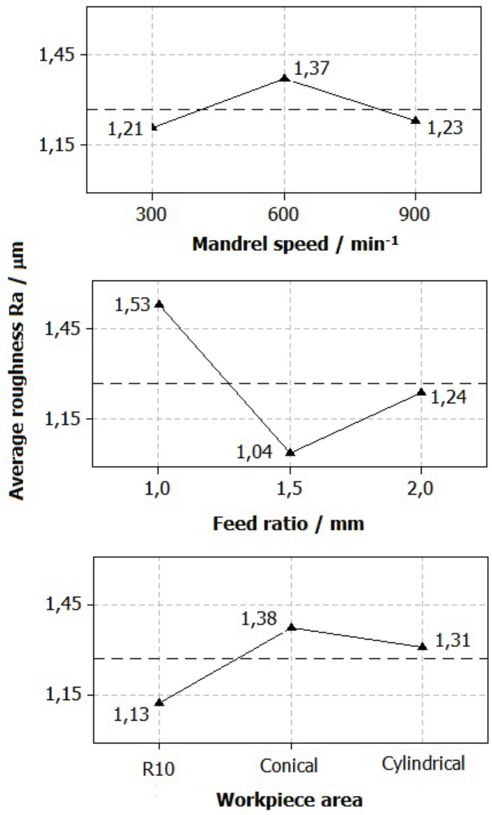

Figure 6 Main effects plots

4 CONCLUSION

In this paper the effect of mandrel speed, feed ratio and workpiece geometry on spun part surface morphology and surface roughness of EN 10025-94 (ISO 630-80) steel has been studied. The major results may be summarized as follows:

- Feed ratio is a factor that intensively affected the surface roughness of the formed parts. The linear correlation between the feed ratio and roughness (higher feed is reflected in higher roughness) has not been confirmed in this case. Optimal roughness has been obtained for middle value of feed rate from the used parameter range.
- The experimental results also showed that the maximal roughness, in relation to the workpiece geometry, has been observed in the conical area of the sample. Minimal roughness has been measured in the area near the radius R10. It is accompanied with the fact of specific stress-strain state under roller and higher degree of tensile stresses in the part surface layer. Every sub-area of sheet is exposed to specific stress state which significantly influences the final quality of spun part surface.
- Only minimal influence of the mandrel speed variability on the final surface roughness has been reported in this study.
- The ANOVA model used in this study shows that three input variables account approximately for 62% of the variability observed in the outcome variable (*R*-squared is 62,5%). The residual variability of 37,5% is caused by the other predictors, that are not included in this model.

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