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EFFECTS OF MATERIAL PROPERTIES AND BLANK HOLDER PRESSURE ON FORMING LOAD IN DEEP DRAWING OF BOX LIKE COMPONENTS

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Abstract: This paper analysis influence of material properties and blank holder pressure on the forming load in deep drawing of box like component. The analysis includes both numerical simulations and experimental tastings. Numerical simulations are performed in ABAQUS software package based on three–level six–factorial Box–Behnken experimental design. Obtained results are then statistically processed by using analysis of variance (ANOVA) and a linear equation for predicting forming load is generated. The mathematical model results for forming load was in good accordance with experimental values.
Keywords: deep drawing, numerical simulation, Box–Behnken design, forming load

1. INTRODUCTION

Deep drawing is an efficient sheet metal forming process that involves complex material flow and stress distributions. It is extensively used in many industries for economical production of part of variety shapes and sizes that are characterized by low weight and good strength [1]. Typical examples are components of automobile bodies, gas tanks, aircraft panels, appliance bodies, kitchen utensils, beverage cans etc. Deep drawing is especially beneficial when producing in large scale since the tools design and tool manufacturing are both time and money consuming operations.

There are many process parameters and other factors affecting the forming process and quality of parts produced by deep drawing. All that factors can be divided into three groups: factors of material (surface quality, sheet thickness, strain hardening exponent, yield stress, ultimate stress, anisotropy etc.), geometrical factors (punch and die radius, shape and size of part, blank shape), and factors (parameters) of the process (temperature, friction, punch velocity, blank holder force). In this paper, the influence of some material properties and blank holder force on the forming load in deep drawing of box–like part was analyzed both numerically and experimentally. The numerical simulations were performed in the ABAQUS software package using Finite Element Method (FEM) approach. The results of the numerical analysis were processed by the Design Expert software and an empirical expression for forming load in deep drawing is derived. Also, based on the simulation results and the statistical analysis, the parameters for the experimental part of the research were selected.

2. NUMERICAL INVESTIGATION

As it mentioned above, the goal of this paper is to determine how material properties and process parameters influence forming load in deep drawing. Parameters of material considered in this investigation are: sheet thickness (s), strain hardening exponent (n), yield stress (Rp), anisotropy (r), and material constant (C). As process parameter, the blank holder pressure/force (Fh) was chosen.

— Materials

Material used in the investigation is DC03 low carbon steel, which is suitable for cold forming. Basic mechanical properties of the selected material obtained in the uniaxial tensile test [2] can be found in Table 1.

Geometry of blank sheet and box–like workpiece are given in Figure 1 and Figure 2, respectively.

Table 1. Mechanical properties of DC03 steel

Rp [MPa]	Rm [MPa]	Amin	r	C [MPa]	n	HV
199.5	340	34%	1.035	541	0,205	116

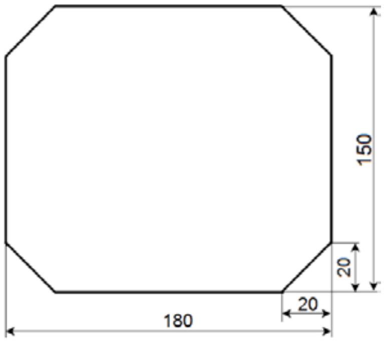

Figure 1. Blank sheet

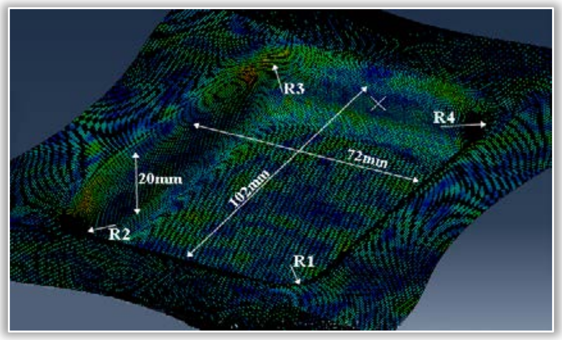

Figure 2. Geometry of workpiece (R_1=5.7, R_2=8.7, R_3=11,7, R_4=15,7

Design of experiment

In the present study, the three–level, six–factorial Box–Behnken experimental design was employed to study the effects of material properties and process parameters on forming load in deep drawing. Box–Behnken design is chosen since it requires fewer design points and experiments than a Complete Factorial Design [3]. Additionally, a Box–Behnken design avoids extremes, allowing one to work around extreme factor combinations. In Box–Behnken experimental design, each investigated factor, or independent variable, is placed at one of three equally spaced values, coded as: low (–1), medium (0) and high (+1) [4]. The range and levels of all the six factors used in the investigation (simulations) are listed in Table 2. The Box–Behnken experimental design with six factors (at three levels) includes 54 runs. This facilitates probing into possible interactions between the factors studied and their effect on the forming load.

Table 2. Independence factors and corresponding levels

level	Factor X_1 s [mm]	Factor X_2 Rp [MPa]	Factor X_3 C [MPa]	Factor X_4 n [–]	Factor X_5 r [–]	Factor X_6 F_h [kN]
low	0.5	166	460	0.17	0.84	9
medium	0.75	199.5	541	0.205	1.035	11
high	1	233	622	0.24	1.24	13

The first five factors given in Table 2 are related to the material properties and their values for the basic–medium level (0) are taken from the uniaxial tensile test (table.1). The factor 6 (blank holder force) was calculated using the Siebel formula [5]. Low and high values for all the six factors are then obtained by expanding the basic level values for ±15%. The experimental design matrix by the Box–Behnken design is tabulated in Table 3 (some data are omitted due to lack of space) and corresponding set of 54 simulations were performed in ABAQUS software package [6]. In the simulations, workpiece was defined as an elasto–plastic body as the die, punch and, blank holder were considered as rigid bodies. The flow curve for DC03 steel in the form of Hollomon curve ($K = 541 \cdot \varphi^{0.205}$) was used [5]. Friction coefficient μ was set to value 0.1.

The simulation results were statically analyzed by applying the coefficient of determination (R^2), response plots and analysis of variance (ANOVA) employing Design Exert software [7]. Central composite design was chosen to estimate the response calculated according to a first order multiple linear regression model. The empirical relationship between the response and the independent variables was obtained according to the Box–Behnken design and input variables and a linear equation for predicting forming load in deep drawing was calculated as follows:

$$F = 19352.86 + 58272 \cdot s + 2.19 \cdot R_p - 0.14 \cdot C - 745.24 \cdot n - 27.35 \cdot r + 0.42 \cdot F_h \quad (1)$$

The results of the analysis of variance (ANOVA) indicates that the model and actual relationship between the response and significant variables represented by the equation (1) are accurate. In addition, it can be seen that there is no (significant) interaction between independent variables. The sheet thickness (s) is the most significant factor as strain hardening exponent (n), anisotropy (r) and material constant (C) have the opposite effect on forming load intensity.

Table 3. Box–Behnken design matrix and corresponding predicted responses

Run	Factor 1 s [mm]	Factor 2 R_p [MPa]	Factor 3 C [MPa]	Factor 4 n	Factor 5 r	Factor 6 F_h [kN]	ResponseF [N]
1	1	199,5	541	0,24	1.23	11	87514.3
2	1	199.5	622	0.205	1.035	13	88122.9
3	0.75	166	541	0.205	1.23	9	62818.2
4	1	199.5	541	0.17	0.84	11	87624.8
5	0.75	199.5	622	0.17	1.035	9	62945.7
10	1	233	541	0.24	1.035	11	87559.1
11	1	199.5	460	0.205	1.035	13	88263.7
12	0.5	199.5	622	0.205	1.035	9	58123.7
13	1	166	541	0.24	1.035	11	87498.9
14	0.75	233	541	0.205	1.23	9	62804.6
15	0.75	199.5	541	0.205	1.035	11	63359.1
16	0.5	233	541	0.24	1.035	11	58946.8
17	0.75	166	460	0.205	0.84	11	63492.7
18	1	199.5	622	0.205	1.035	9	86824.6
19	0.75	199.5	541	0.205	1.035	11	63547.5
20	0.75	199.5	622	0.24	1.035	13	64589.4
27	0.5	199.5	541	0.24	1.23	11	57945.6
28	1	199.5	541	0.17	1.23	11	87568.4
29	1	233	541	0.17	1.035	11	87843.9
30	0.5	199.5	460	0.205	1.035	13	59623.7
31	0.5	199.5	541	0.24	0.84	11	58526.5
32	0.75	233	460	0.205	1.23	11	63699.3
33	1	199.5	541	0.24	0.84	11	87753.3
34	0.75	166	541	0.205	0.84	9	62756.6
35	0.5	166	541	0.17	1.035	11	58223.7
36	0.75	199.5	460	0.24	1.035	9	62701.8
37	0.75	166	460	0.205	1.23	11	63569.4
38	0.5	199.5	622	0.205	1.035	13	59232.4
39	0.5	233	541	0.17	1.035	11	58263.4
40	0.75	233	541	0.205	0.84	9	62679.2
41	0.5	199.5	460	0.205	1.035	9	58026.7
42	0.75	199.5	541	0.205	1.035	11	63562.2
46	1	199.5	460	0.205	1.035	9	86792.7
47	0.5	199.5	541	0.17	1.23	11	58648.6
48	0.75	233	622	0.205	0.84	11	63464.3
49	0.75	233	541	0.205	0.84	13	64609.5
50	0.5	199.5	541	0.17	0.84	11	58019.2
54	0.75	199.5	460	0.17	1.035	9	62797.1

3. EXPERIMENTAL INVESTIGATION

Experimental investigations were performed on double acting hydraulic press LITOSTROJ with a nominal force of 2500 kN. During the process, the forming load and stroke of the tool elements were simultaneously measured using the sensors, which were connected to the computer via an eight–channel amplifier. A special tool with a set of exchangeable punches for processing blanks of different thicknesses was design and made. (Figure 3). In the experiments, sheet thickness (0.5 and 1 mm) and blank holder force (9, 11, and 13 kN) are varied only. For each combination of s and F_h four tests were performed i.e., 24 in total. Figure 4 displays final shape of workpiece.

Figure 3. Tool mounted on press

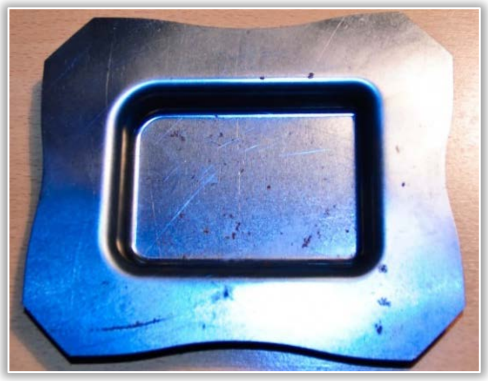

Figure 4. Workpiece of 1mm sheet thickness

4. DISCUSSION AND CONCLUDING REMARKS

The values of average forming load obtained by experiments and numerical simulations for different combination of material thickness and blank holder force are summarized in Table 4 and the differences between the values are calculated.

Table 4. Comparision of experimental and numerical results

EXPERIMENT			SIMULATION	Differences
Material thickness s [mm]	Blank holder force F_h [kN]	Forming load average $F_{ave.}$ [N]	Forming load average $F_{ave.}$ [N]]	[%]
0,5	9	50950	58074	13.98
0,5	11	51189	58274	13.84
0,5	13	52990	59427	12.14
1	9	89375	86808	2.95
1	11	90510	87602	3.32
1	13	91894	88193	4.19

As can be expected, the forming load increases when both material thickness and blank holder force increase. The numerically predicted values are higher compared to experimental ones in case of 0.5 mm sheet thickness (maximum difference is 14%), but less (3 to 4%) for the sheet thickness of 1mm. These differences are within acceptable limits indicating that the FEM model is reliable. The small differences occurring between simulations and experiments may come from variations of the mechanical and physical (thickness) properties of the material used in the experiments as well as inaccuracy related to contact conditions modeling in the FEM model.

The mathematical model derived from ANOVA analysis shows that all investigated factors are significant as material thickness has the greatest impact on the forming load. It can be also noticed that increase in the forming load with increasing material thickness is not linear.

Note:

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References

[1] Singh, C.P., Agnihotri G. (2015). Study of Deep Drawing Process Parameters: A Review. International Journal of Scientific and Research Publications, vol. 5, no. 2, p. 1–15.
[2] ASTM E8 / E8M:2016. Standard Test Methods for Tension Testing of Metallic Materials. ASTM International. 100 Barr Harbour Dr., PO Box C700 West Conshohocken Pennsylvania 19428–2959, United State.
[3] https://www.sharcnet.ca/Software/Ansys/16.2.3/en–us/help/wb_dx/dx_doetype_bbd.html, accessed on 2019–04–12.
[4] Box, G.E., Hunter, W.G. and Hunter, J.S. (1978). Statistics for experiments. John Wiley & Sons, Inc., New York, N.Y
[5] Kuzman, K., Kampuš, Z. (2008) Priporočila preoblikovanja. Fakulteta za strojništvo, Ljubljana.
[6] ABAQUS, Inc. (2011). ABAQUS Analysis User's Manual – ver.6.11.
[7] Montgomery, D C. (2001). Design and Analysis of Experiments (5th ed.). New York: Wiley.

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