中國機械工程學刊第四十卷第五期第 533~538 頁(民國一百零八年)
Journal of the Chinese Society of Mechanical Engineers, Vol.40, No.5, pp 533~538 (2019)

Formability Analysis Of DC01 Sheet In The Incremental Sheet Forming Method

Ömer Seçgin*, İbrahim Özsert**

Keywords：Formability, Finite Element Analysis, Incremental Sheet Forming, Metal Forming.

ABSTRACT

Incremental forming is a new and multipurpose type of prototype manufacturing method where a small forming tool, following a certain tool path, applies localized pressure to a sheet metal. In this study incremental formability of DC01 which widely used in industry is experimentally researched. In the experimental studies, specimens in a shape of frustum cone are formed. Alongside the experimental studies, by using finite element model, sheet thickness variations are investigated.

Feedrate, depth of increment and forming tool diameter, which has a direct effect to the limit forming angle and sheet thickness distribution are taken as parameters. In experiments carried out by using 0.5 mm increment and 1000 mm/min feedrate for DC01 sheet with a thickness of 1.18mm, 64° limit forming angle is reached. Corresponding results are compatible with finite element analysis results. Specimen's thickness is reduced by 65% with 64° limit forming angle and minimum sheet thickness of 0.4 mm is achieved.

INTRODUCTION

In the manufacturing industry, production of a prototype has a very important place (Malwad and Nandedkar 2014).[1] To conduct Research & Development tests on a prototype which has the same material properties as a final product gives advantages to design engineers. However, production of same-material-prototypes, so called m-prototypes, is a challenging job and requires technology. There are various methods and the utilizing of m-prototypes has readily used in wide range of engineering areas from automotive to domestic appliances (Dopazo, J Alberto, 2011). Among these methods, incremental sheet forming method comes forward as a cheap and fast process.

Paper Received July, 2019. Revised August, 2019, Accepted September, 2019, Author for Correspondence: Ömer SEÇGİN.

* *Dr., Department of Maritime High School, Piri Reis University, İstanbul, Turkey*

** *Professor, Department of Mechanical Engineering, Sakarya University of Applied Science, Sakarya, Turkey*

molds, m-prototypes can be easily produced by applying a real pressure on.

Even though this method provides a fast and cheap way of manufacturing prototypes, the method suffers from uneven thickness distribution. In some cases, thickness distribution is variable up to 50% (Mirnia, Dariani and Vanhove, 2014). In reality, no significant thickness change occurs on non-contacting area of the sheet with forming tool, however thinning only occurs on the contacting areas (Jun, Chong and Tong, 2012). The thickness of the sheet is decreased from outside to inside. Therefore, on the base the sheet thickness becomes minimum. However, this uneven distribution of thickness hampers the usefulness of the work piece. Eventually the thickness distribution must be homogenized. For this purpose different applications like multistage incremental forming (Liu, Li and Meehan, 2013) and double tool incremental forming techniques (Ndip-agbor, Smith and Ren, 2016) are used.

DC01 steel is a commonly used sheet material in the deep drawing processes such as machine industry, automotive, domestic appliances, etc (Malyer and Müftüoğlu, 2015). When the literature is searched, it can be seen that there are only few studies about the incremental forming method performed with DC01. In this study, the incremental formability of DC01 steel is researched experimentally and numerically by conducting multiple experiments to determine the variation of sheet thickness and limited forming angle. During the course of the research, ABAQUS CAE program is used for all finite element analyses.

INCREMENTAL FORMING

Incremental forming method was firstly theorized in 1967. At that time as the computer numerical control (CNC) machines and solid modelling programs did not exist, the incremental forming method could not be applied. For this method, the term "dieless" patented by Leszak (Leszak, 1967) and incremental forming method became popular and subject to current researches due to improvement of CNC machines (Arfa, Bahloul and Belhadjsalah, 2013).

Incremental forming method can be put into practice with CNC milling machines, CNC lathes and robotic arms. Sheet metal is formed along via tool path which is obtained by computer aided manufacturing (CAM) programs (J. Paramo and J. Benitez, 2014). Forming steps of incremental forming are shown in Figure 1.

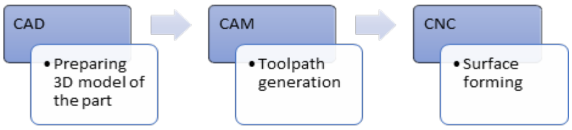

Fig. 1. Incremental forming process.

In incremental forming method, sheet does not flow to mold which is different from in deep drawing process, and sheet tightened to the surrounding holes via some bolts. During forming, due to volume stability rule, sheet thickness gets thinner, and later sheet cracks. The maximum angle which the damage does not occur on the limit forming angle. Forming parameters of incremental forming method are shown in Figure 2. Where α and β are the angle of the part wall with the horizontal and vertical axis, respectively.

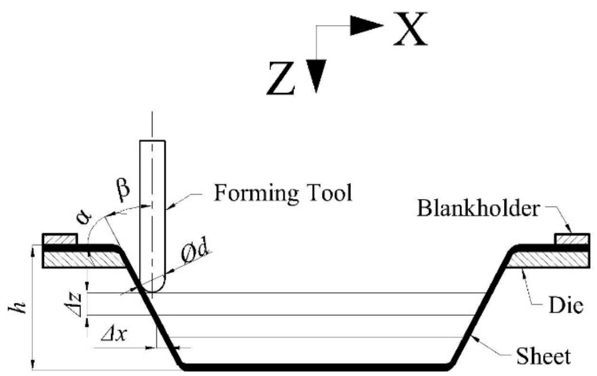

Fig. 2. Incremental forming.

In previous studies, forming of aluminum alloys is mainly studied (Hussain, Lin and Hayat, 2010), (Isidore et al., 2016). On these studies generally effects of feedrate, increment, spindle speed and forming tool diameter are researched.

Park and Kim (Park and Kim, 2003), compare positive incremental forming and negative incremental forming methods by conducting some experiments. Authors use the parameters of 0.2 mm increment and 25 mm/s feed rate in simulations of PAM-STAMP program. In negative forming, tearing occurs on sides and corners, while balanced stress distribution stimulates the efficiency of positive forming.

Iseki (Iseki, 2001) researches incremental forming of tempered 0.3 mm aluminum sheet. The author uses the ANSYS program to simulate the process. In experiments the forming force is measured and compared with simulation results. Eventually it is showed that the experiment and simulation results are matched.

Pohlak et al. (Pohlak et al., 2004) research formability of the tempered aluminum sheet with/without supporting methods. Even though supporting from down side method is more expensive, relatively correct geometry is obtained.

Malyer and Müftüoğlu research effects of different types of coated forming tools and lubricators on DC01 sheet thickness distribution. Finally it is understood that chromium carbonitride (CrCN) coated tool and water soluble drawing oil is better than the other lubricants (Malyer and Müftüoğlu, 2015).

Bambach et al. (Bambach, Taleb Araghi and Hirt, 2009) work upon the car fender with the single and multi-stage forming methods and show that multi stage forming is more effective.

EXPERIMENTS AND ANALYSIS

Experimental Studies

In this study; the incremental forming of DC01 sheet is investigated. The material that used in experiments has a yield stress of 240.3 MPa, and a tensile stress of 336.4 MPa. The related stress-strain graphic of experimented material is given in Figure 3. For planned experiments, sheets which have 1.18 mm thickness are cut in circular form with an initial diameter of 200 mm by using laser cutting machine. While the cutting operation, 8 holes with a diameter of 9 mm are drilled on every piece. During the experiments, sheet pieces are tightened to blankholder with M8 bolts, and each specimen are formed in axisymmetrical frustum cone shape.

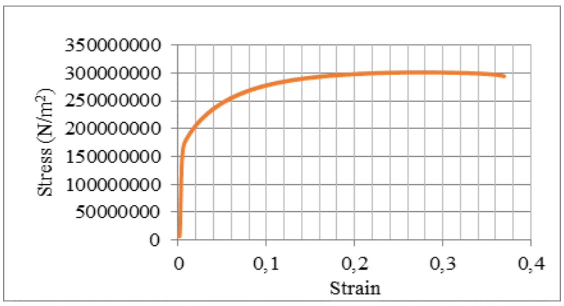

Fig. 3. Stress-strain graphic of DC01 sheet.

Incremental forming experiments are conducted on Dahlih MCV860 CNC milling machine (Figure 4). Throughout the forming operations, a local pressure is applied to the sheet by a 10 mm diameter forming tool. In order to minimize the friction between sheet and forming tool, "Fuchs Titan Ganymet La" lubrication oil is used.

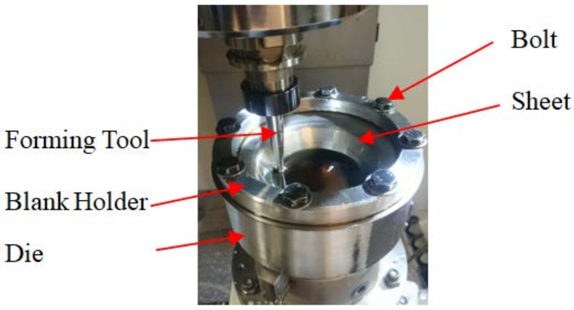

Fig. 4. View of experimental setup.

Experimental parameters and the corresponding test results are given on Table 1. Each experiment is conducted in 1000 mm/min feed rate. Incremental depth (Δz) used in experiments is 0.5 mm. The sheet formed by following the spiral tool path. In all experiments spindle is set in free condition. All specimens are formed up to 40 mm depth. During the experiments specimens with angles (α) 40°, 50° & 60° are successfully formed. The specimen with the angle of 65° and 70° are torn while forming. For verification, the specimen with angle of 65° is reformed and tearing occurred again. The 65° torn specimen is shown in Figure 5. Finally, for the last verification, the specimens with angles of 63° and 64° are formed successfully. The samples obtained from the experiments are given in Figure 6 according to experimental order.

Fig. 5. Failure on 65° formed specimen.

Table1. Examination parameters

Experiment Code	Angle (α)	Result
A	40°	Success
B	50°	Success
C	60°	Success
D	70°	Fail
E	65°	Fail
F	65°	Fail
G	63°	Success
H	64°	Success

Fig. 6: Incrementally formed specimens.

Finite Element Analysis

There are varieties of studies on finite element analysis of incremental forming method. Some of the researchers used the implicit method (Eyckens et al., 2008; Hadoush and van den Boogaard, 2009); as the reduced computing time is more acceptable, explicit method is preferred by most of the researchers (Sbayti et al., 2016), (Golabi and Khazaali, 2014), (Isidore et al., 2016). In this study ABAQUS Dynamic Explicit is used.

Forming tool is modelled as a 3D analytical rigid body while die as a 3D discrete rigid body and sheet metal part as a 3D deformable body. Forming tool's tip radius is 5 mm whereas sheet is with an initial diameter of 200 mm, and a thickness of 1.18 mm.

Between forming tool and sheet and also between die and sheet, surface to surface contacts are defined. The value of the friction coefficient is chosen 0,05 according to the literature. Edges of sheet are chosen and restricted from spinning and displacement. Encastered boundary condition is applied to the die. For the movement of forming tool, spiral tool path is used as in CNC. Later on from this tool path, amplitudes are defined from X, Y and Z directions.

Deformable sheet is meshed with the S4R reduced integration element. Such elements provide faster and more accurate calculations for dense meshed models. As seen clearly in Figure 7, while the forming area of the sheet is meshed with smaller elements (3 mm long elements), a coarse mesh is generated in other areas. This also reduces the computing time considerably. The die is meshed using the R3D4, which is four-node, discrete rigid surface element. It is a rigid element with three-dimensional 4 node. It is used to modeling of three-dimensional solid object as two-dimensional surface model.

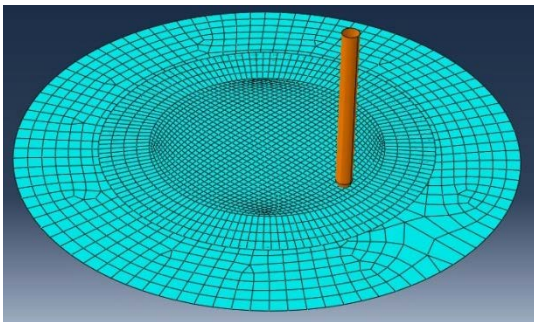

Fig. 7. Meshed parts.

RESULTS

Simulation Results

At the end of the finite element analysis, a path is defined from the center line and measuring of thickness is done from this path. This definition is given in Figure 8.

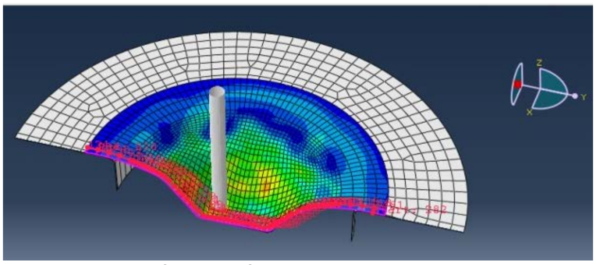

Fig. 8. Path definition for STH.

According to this path, thickness distribution of a specimen formed with an angle of 40° is given in Figure 9.

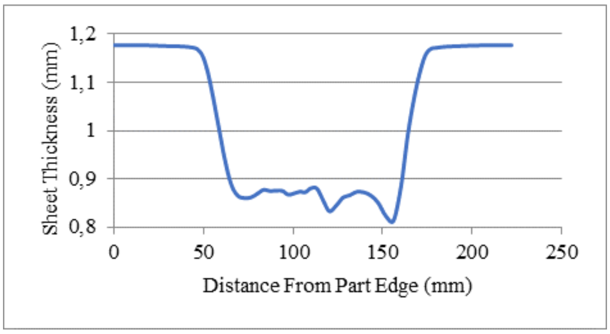

Fig. 9. Thickness distribution for 40° formed sheet according to FEA.

A minimum sheet thickness were detected at the flange starts, which is defined as the furthest point. In this study, also different forming angles were examined. In Figure 10, thickness distributions of specimens formed with angles of 40°, 50° and 60° are given in perspective view. When it is reached to 40 mm depth on 40° in which a few flat areas are left on the bottom of specimen, the chart of thickness distribution of specimen is different than the other angles.

As seen clearly from the figures above, thickness declines during the forming process on the areas where the forming tool contacts on the sheet. The minimum thickness turns out to be at the bottom of the specimen. On the specimens which are formed with angle of 40° and 50°, thickness variations are observed as 26% and 45% respectively.

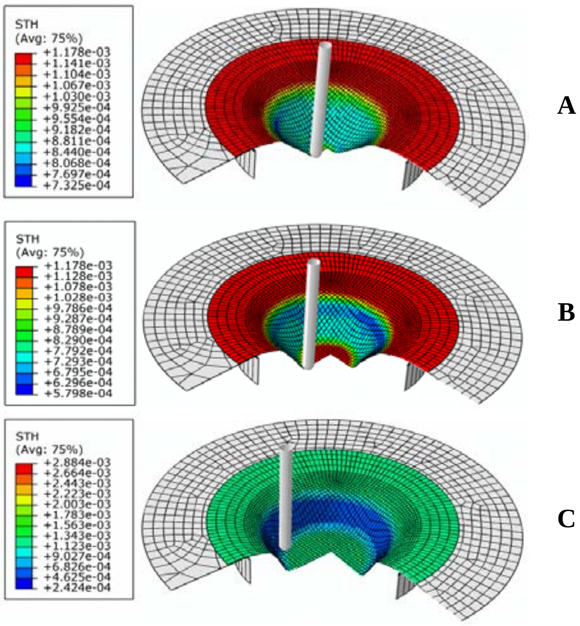

Fig. 10. Thickness distributions according to FEA. (Thickness is in meter). A: 40°, B: 50°, C: 60°

Experimental Results

At the end of the experiments a setup is designed and constructed for measuring of sheet thickness (Figure 11). Thickness measurements are performed with 0.01 mm sensitivity using MITUTOYO Absolute 543-682 comparator which is assembled on the setup.

Fig. 11. Measuring of sheet thickness.

Specimens are marked with 5 mm grid on center line and the thickness distribution chart is tabulated by taking measurements from these marked points. The thickness distribution of a specimen which is formed with an angle of 64° is given in Figure 12. The results obtained from experiment and finite element analysis for thickness distribution of the specimen which is formed with an angle of 50° are given in Figure 13.

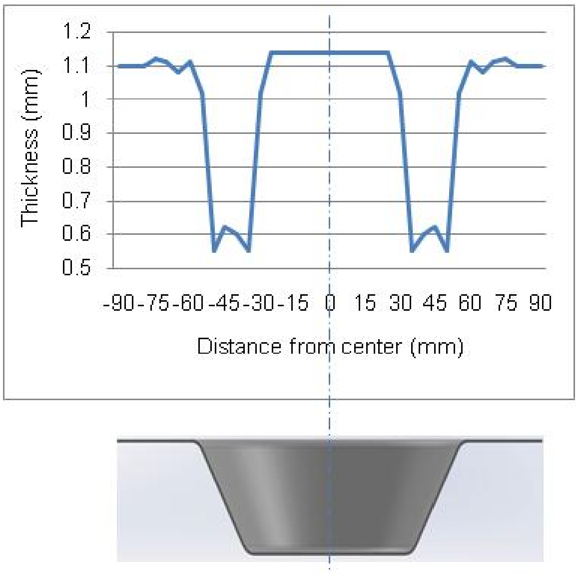

Fig. 12. Thickness distribution for 64° (experimental).

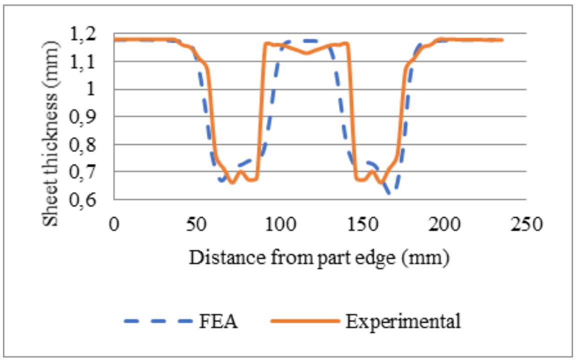

Fig. 13. Thickness distribution for 50° formed sheet.

Experimental and finite element analysis results show a relatively close match. The tool tip effect which occurs on side walls closed to the bottom area could not be eliminated totally, therefore, as a result of this phenomenon; there is a slight shift between results.

DISCUSSION

In this study, a series of experiments are carried out by increasing the forming angle, and tearing of sheet takes place on 65° angle. According to the experiment parameters, the limit forming angle of DC01 sheet is found to be 64°.

According to both experimental studies and analytical analyzes, the forming stress increases as the forming angle increases. For this reason, thickness is also decreasing.

At the end of the experiments, thickness distribution is recorded for each angle increment, and these findings are compatible with literature.

As seen clearly in Fig. 13, experimental and finite element analysis results are mostly matching. The thickness of the specimen which is formed with limit forming angle of 64° is decreased with a ratio of 65%. On this specimen, the minimum thickness is measured as 0.4 mm. Industrial usage of a specimen with large thickness distributions is not practicable. Therefore, for a future development, methods in which thickness distribution is more homogenized must be developed. In order to do that, different parameters such as forming tool diameter, lubrication, feed rate, etc. effects have to be studied intensively.

REFERENCES

Arfa, H., Bahloul, R. and Belhadjsalah, H. (2013) ‘Finite element modelling and experimental investigation of single point incremental forming process of aluminum sheets: Influence of process parameters on punch force monitoring and on mechanical and geometrical quality of parts’, International Journal of Material Forming, 6(4), pp. 483–510. doi: 10.1007/s12289-012-1101-z.

Bambach, M., Taleb Araghi, B. and Hirt, G. (2009) ‘Strategies to improve the geometric accuracy in asymmetric single point incremental forming’, Production Engineering, 3(2), pp. 145–156. doi: 10.1007/s11740-009-0150-8.

Dopazo, J Alberto, J. F.-S. (2011) ‘Experimental evaluation of a cascade refrigeration system prototype with CO 2 and NH 3 for freezing process applications’, International Journal of Refrigeration, pp. 257–267. doi: 10.1016/j.ijrefrig.2010.07.010.

Eyckens, P., Bael, A. Van, Aerens, R., Duflou, J. and Houtte, P. Van (2008) ‘Small-scale Finite Element Modelling of the Plastic Deformation Zone in the Incremental Forming Process’, Int J Mater Form, pp. 1159–1162. doi: 10.1007/s12289-008-0.

Golabi, S. and Khazaali, H. (2014) ‘Determining frustum depth of 304 stainless steel plates with various diameters and thicknesses by incremental forming’, Journal of Mechanical Science and Technology, 28(8), pp. 3273–3278. doi: 10.1007/s12206-014-0738-6.

Hadoush, A. and van den Boogaard, A. H. (2009) ‘Substructuring in the implicit simulation of single point incremental sheet forming’, International Journal of Material Forming, 2(3), pp. 181–189. doi: 10.1007/s12289-009-0402-3.

Hussain, G., Lin, G. and Hayat, N. (2010) ‘A new parameter and its effect on the formability in single point incremental forming: A fundamental investigation’, Journal of Mechanical Science and Technology, 24(8), pp. 1617–1621. doi: 10.1007/s12206-010-0514-1.

Iseki, H. (2001) 'An approximate deformation analysis and FEM analysis for the incremental bulging of sheet metal using a spherical roller', Journal of Materials Processing Technology, 111(1–3), pp. 150–154. doi: 10.1016/S0924-0136(01)00500-3.

Isidore, B. B. L., Hussain, G., Shamchi, S. P. and Khan, W. A. (2016) 'Prediction and control of pillow defect in single point incremental forming using numerical simulations', Journal of Mechanical Science and Technology, 30(5), pp. 2151–2161. doi: 10.1007/s12206-016-0422-0.

Jun, L. I., Chong, L. I. and Tong, Z. (2012) 'Thickness distribution and mechanical property of sheet metal incremental forming based on numerical simulation', Trns. Nonferrous Met. Soc. China, 22, pp. 54–60.

Leszak, E. (1967) 'Apparatus and process for incremental dieless forming'. US.

Liu, Z., Li, Y. and Meehan, P. A. (2013) 'Vertical Wall Formation and Material Flow Control for Incremental Sheet Forming by Revisiting Multistage Deformation Path Strategies', Materials and Manufacturing Processes, 28(5), pp. 562–571. doi: 10.1080/10426914.2013.763964.

Malwad, D. S. and Nandedkar, V. M. (2014) 'Deformation Mechanism Analysis of Single Point Incremental Sheet Metal Forming', Procedia Materials Science. Elsevier B.V., 6(Icmpc), pp. 1505–1510. doi: 10.1016/j.mspro.2014.07.130.

Malyer, E. and Müftüoğlu, H. S. (2015) 'The Influence of Friction Conditions on Formability of DC01 Steels by ISF', IOSR Journal of Mechanical and Civil Engineering Ver. I, 12(3), pp. 2278–1684. doi: 10.9790/1684-1231134138.

Mirnia, M. J., Dariani, B. M. and Vanhove, H. (2014) 'An investigation into thickness distribution in single point incremental forming using sequential limit analysis', International Journal of Material Forming, pp. 469–477. doi: 10.1007/s12289-013-1143-x.

Ndip-agbor, E., Smith, J. and Ren, H. (2016) 'Optimization of relative tool position in accumulative double sided incremental forming using finite element analysis and model bias correction', International Journal of Material Forming. International Journal of Material Forming, 9, pp. 371–382. doi: 10.1007/s12289-014-1209-4.

Park, J. and Kim, Y. (2003) 'Fundamental studies on the incremental sheet metal forming technique', Journal of Materials Processing Technology, 140, pp. 447–453. doi: 10.1016/S0924-0136(03)00768-4.

Pohlak, M., Küttner, R., Majak, J., Karjust, K. and Sutt, A. (2004) 'Experimental Study Of Incremental Forming Of Sheet Metal Products', 4th International DAAAM Conference, Experimental Study Of Incremental Forming Of Sheet Metal Products, 2(April), pp. 139–142.

Sbayti, M., Ghiotti, A., Bahloul, R., Belhadjsalah, H. and Bruschi, S. (2016) 'Finite Element Analysis of hot Single Point Incremental forming of hip prostheses', MATEC Web of Conferences, NUMIFORM 2016 2.2.