Faouzi Hamza[1], *Abdelmoumene Guedri*[2], *Hamid Hamadache*[3], *Mohammed Hadj Meliani*[4*], *Rami K. Suleiman*[5]

INVESTIGATING PLASTIC INSTABILITY OF DD14 STEEL SHEET IN DEEP DRAWING PROCESS: A MATERIAL CHARACTERISATION AND FEM ANALYSIS OF DIE RADIUS IMPACT

ISTRAŽIVANJE PLASTIČNE NESTABILNOSTI ČELIČNOG LIMA DD14 U PROCESU DUBOKOG IZVLAČENJA: KARAKTERIZACIJA MATERIJALA I MKE ANALIZA UTICAJA RADIJUSA MATRICE

Originalni naučni rad /Original scientific paper
Rad primljen / Paper received: 26.09.2024
https://doi.org/10.69644/ivk-2025-01-0135

Adresa autora / Author's address:
[1] Department of Geotechnology, Mining Institute, Larbi Tebessi University,12000, Tebessa, Algeria
F. Hamza https://orcid.org/0000-0002-2948-6281
[2] Department of Mechanical Engineering, INFRA-RES Laboratory, Mohammed Chérif Messaadia University, Souk Ahras, Algeria
A. Guedri https://orcid.org/0000-0001-6406-8678
[3] Department of Mechanical Engineering, Badji Mokhtar-Annaba University, Research Laboratory of Advanced Technology in Mechanical Production (LRATPM), Annaba, Algeria
H. Hamadache https://orcid.org/0000-0002-3373-5738
[4] Laboratory for Theoretical Physics and Material Physics (LPTPM), Hassiba Benbouali University of Chlef, Hay Salem, Algeria
M. Hadj Meliani https://orcid.org/0000-0003-1375-762X
[5] Interdisciplinary Research Center for Advanced Materials, King Fahd Univ. of Petroleum & Minerals (KFUPM), Dhahran, Saudi Arabia R.K. Suleiman https://orcid.org/0000-0002-6776-9266
*email: m.hadjmeliani@univ-chlef.dz

Keywords
- characterisation
- anisotropy
- deep drawing
- die radius
- numerical simulation
- FEM

Abstract

The deep drawing process is one of the most complex forming processes, as several problems related to the plastic instability of the material to be deep drawn are notably necking, rupture and tearing. However, the parameters of the deep drawing process can cause these phenomena as well as the geometry of the deep drawn part. Particularly, a material having the formability for such a deep drawing operation remains the desired solution in this process. In this sense, the aim of this work is to investigate a problem of plastic instability of the material through a characterisation and modelling of the anisotropy of DD14 hot-rolled steel sheet intended for deep drawing prismatic cups, using the Hill48 criterion. In addition, FEM analysis of the die radius influence on the occurrence of lateral and corner ruptures on deep drawn parts is carried out in numerical simulation. For this, an 3D simulation of the stamping operation is elaborated by finite element calculation code Abaqus/CAE Explicite®. Following an incremental approach and from the numerical results, the areas most subjected to plastic strain and that represent a high thinning are located. Thus, the degree of influence of the die radius on the evolution of plastic strain is determined. Furthermore, finite element analysis helps us to predict the material behaviour during plastic deformation as a function of this parameter. As a result, the optimum die radius levels which represent the best distribution of plastic strain and improve product quality, are the highest.

Ključne reči
- karakterizacija
- anizotropija
- duboko izvlačenje
- radijus matrice
- numerička simulacija
- MKE (metoda konačnih elemenata)

Izvod

Proces dubokog izvlačenja je jedan od najsloženijih procesa oblikovanja, jer se pojavljuju nekoliko problema vezanih za plastičnu nestabilnost materijala koji se duboko izvlači, naročito sužavanje, pucanje i cepanje. Međutim, parametri procesa dubokog izvlačenja mogu uzrokovati ovu pojavu, kao i geometrija duboko izvučenog dela. Posebno, materijal koji ima plastičnost za takvu operaciju dubokog izvlačenja ostaje poželjno rešenje u ovom procesu. U tom smislu, cilj ovog rada je da istraži problem plastične nestabilnosti materijala kroz karakterizaciju i modeliranje anizotropije toplo valjanog čeličnog lima DD14 namenjenog za duboko izvlačenje prizmatičnih čaša, koristeći kriterijum Hill48. Pored toga, sprovedena je MKE analiza uticaja radijusa matrice na pojavu bočnih i ugaonih prslina na duboko izvučenim delovima u numeričkoj simulaciji. Za to je izrađena 3D simulacija operacije izvlačenja pomoću koda za proračun konačnim elementima Abaqus/CAE Explicite®. Prateći inkrementalni pristup i na osnovu numeričkih rezultata, locirane su oblasti najviše izložene plastičnoj deformaciji i koje predstavljaju veliko stanjivanje. Tako je određen stepen uticaja radijusa matrice na evoluciju plastične deformacije. Štaviše, analiza konačnim elementima nam pomaže da predvidimo ponašanje materijala tokom plastične deformacije u funkciji ovog parametra. Kao rezultat, optimalni nivoi radijusa matrice, koji predstavljaju najbolju raspodelu plastične deformacije i poboljšavaju kvalitet proizvoda, su najviši.

INTRODUCTION

The characterisation of the material is an essential phase, to identify the materials mechanical characteristics, because it allows us to control its industrial exploitation and its choice for a given deep drawing operation. Furthermore, the characterisation of metal sheets anisotropy requires tensile specimens taken in different directions with respect to the rolling direction. However, success of the deep drawing operation requires first and foremost a material with high formability as well as the adjustment of other process parameters, including punch speed, blank holder pressure, punch radius and die radius. On another scale, numerical simulation and modelling of the deep drawing process is currently useful, it takes its place as an essential aid before any decision on the construction of tools or the introduction of process parameters. With the forming process simulation, we can identify the problems and propose solutions.

Several current and past studies related to material characterisation, process parameters, and simulation of deep drawing have been carried out. In this regard, Yi et al. /1/ studied the formability of two magnesium alloy sheets AZ31 and ZE10 where their deep drawing behaviour is comparatively evaluated, the anisotropy is characterised by a uniaxial tensile test. Bouchaâla et al. /2/ studied anisotropic behaviour of aluminium-lithium alloy sheets by numerical approach and its influence on the deep drawing of a cylindrical cup, a practical method is used to define the thickness distribution during the forming operation. Ben Othmen et al. /3/ studied the influence of constitutive models on the simulation of reverse deep drawing of a cylindrical cup, the material properties are identified using uniaxial tensile tests on specimens taken at 0°, 45°, and 90° with respect to rolling direction. Then, the experimental results such as the distribution of major strain in the stamping and the evolution of punching-displacement force are explored. Simulations are carried out using Abaqus/Explicit® software and compared with the experimental data. Garcia et al. /4/ presented an experimental characterisation of the mechanical behaviour of EK4 deep drawing steel. The experimental procedure includes spectrometry, metallography, tensile tests, and hardness measurements. Anisotropy modelling is based on the Hill48 criterion, and the adequacy of the proposed methodology is evaluated by simulation. Padmanabhan et al. /5/ investigated by numerical evaluation, the anisotropy effect and rolling direction orientation on the forming behaviour of welded blanks made of DC06 mild steel and DP600 dual-phase steel. Yue et al. /6/ studied a ductile damage model used to simulate the occurrence of ruptures in low carbon steel. Uniaxial tensile and deep drawing tests are performed on low carbon steel sheet. The proposed model is implemented using Abaqus/Explicit software with VUMAT material routine and validated through FEM simulations. Also, other research shows the importance of the die radius and its influence on the quality of the deep drawn product. Notably, Gowtham et al. /7/ studied the factors influencing a deep drawing process and analysed the process by varying die radius and keeping constant friction, punch radius, and blank thickness.

The die radius is studied using finite element analysis, and results show that reducing the die radius increases the deep drawing forces and causes quality problems. Jain et al. /8/ studied by experiments and numerical predictions the limit drawing ratios (LDR) and other axisymmetric deep drawing characteristics of AA5754-O and AA6111-T4 automotive aluminium sheet materials as a function of the die radius. Özek et al. /9/ studied the effect of different die and punch radius on the drawing limit ratio of DIN EN 10130-91 sheet metal. The experiments show that the drawing limit ratio increases with increasing punch and die radius. Colgan et al. /10/ investigated by combining experimental and finite element analysis (FEA) the most important factors influencing a deep drawing process. The results seem to be that the punch and die radius have the greatest effect on the thickness of deep drawn steel. Hamza et al. /11/ studied by numerical simulation the influence of deep drawing parameters, notably, punch speed, blank holder force, die radius and friction, on plastic strain evolution during DC04 steel sheet forming.

Sedmak et al. /12/ investigated by numerical simulation using FEM to evaluate the structural integrity of lap welded joints in ammonia transport tanks, focusing on the influence of weld geometry on stress distribution and fatigue performance. Durdević et al. /13/ studied by numerical investigation the mechanical behaviour of critical structural components in container terminals using advanced finite element analysis (FEM) and analysed stress and strain distributions in key structural elements to evaluate structural integrity under operational loading conditions. Radojković et al. /14/ investigated the stress concentration phenomena in isotropic plates containing rectangular openings subjected to biaxial tensile loading through analytical and numerical approaches. Analysis included stress distribution patterns around rectangular cutouts and determined stress concentration factors for various geometric configurations. Alnagasa et al. /15/ studied by combining numerical modelling with theoretical validation a comprehensive stress analysis of spherical LPG (propane-butane) storage tanks under operational and extreme loading conditions, evaluated and the stress distributions in spherical pressure vessels and critical regions under combined loading scenarios. Nguyen et al. /16/ studied by theoretical-numerical investigation of stress concentration phenomena in piezoelectric cylindrical shells using a non-classical elasticity approach, addressing electromechanical coupling effects often overlooked in conventional analyses, establishing governing equations for axisymmetric cylindrical shells. Camagić et al. /17/ studied using experimental-numerical investigation the degradation of fracture toughness in welded joints under combined thermal and temporal aging conditions, providing critical insights for structural integrity assessment, quantifying temperature-time dependency on plane strain fracture toughness and crack propagation behaviour. Banks-Sills et al. /18/ studied how cracks grow between different materials, looking at both elastic and plastic deformation cases, using stress intensity factors and J-integral methods respectively. Maheshwari et al. /19/ investigated the elastic-plastic transition in a functionally graded orthotropic rotating disk with exponentially varying thickness and density, using an analytical model to determine stress distribution and deformation during the transition from elastic to plastic behaviour under high rotational speeds.

The aim of this study is to investigate a plastic instability problem recorded on a deep drawn product in a company's forming workshop during the deep drawing DD14 hot-rolled steel sheets. Firstly, a characterisation of the sheet material is carried out by uniaxial tensile tests on specimens taken in three directions 0°, 45°, and 90° with respect to the rolling direction of the sheet, in order to determine the material's mechanical properties and to evaluate its plastic anisotropy. A numerical simulation model identical to the experimental one is developed by finite element calculation code Abaqus/CAE®. In addition, the material anisotropic behaviour is modelled by Hill48 criterion and implemented in the material properties in numerical simulation. An experimental design is proposed to predict the effects of die radius on plastic deformation during the forming operation and its influence on the evolution of deep drawn product fracture. Also, the logical variation of die radius levels leads us to the optimum choice with acceptable strain distribution without any problems of sheet rupture or tearing. Finally, a FEA of the results is carried out, from which the optimal levels of die radius are chosen to achieve deep drawing operation with good tooling efficiency and better product quality.

METHODOLOGY

The encountered problem is the presence of lateral tears and front ruptures on deep drawn parts at the end of the DD14 hot-rolled sheet forming operation, as shown below.

a)

b)

Figure 1. Lateral tear and frontal rupture on DD14 steel sheet deep drawn parts.

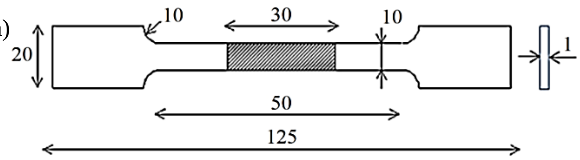
Material mechanical properties answer to the European standard EN 10111, Table 1.

Table 1. Mechanical properties of DD14 steel.

Nuances EN 10111	R_e (MPa) min-max	R_m (MPa) min-max	A90 (%) Min
DD14	220-280	320-370	≥ 33

To characterise the material's anisotropy, uniaxial tensile tests are carried out on specimens taken in three directions (0°, 45° and 90°) with respect to the sheet's rolling direction

a)



b)

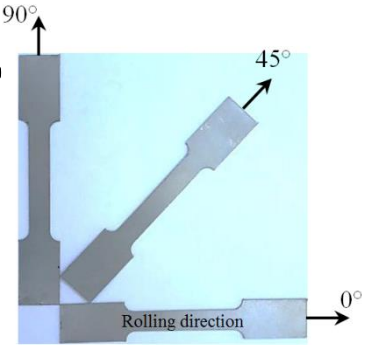


Figure 2. Uniaxial tensile test specimen: a) geometry; b) test specimens.

(Fig. 2b). Tests are carried out according to NF EN 10002-1 standard on Zwick/Roell Z050 uniaxial tensile testing machine at room temperature, at a speed of 50 mm/min. Figure 2a presents the specimen geometry.

Anisotropy modelling and numerical simulation

Anisotropy is taken into account in numerical simulation using Hill48 criterion, /20/. According to this criterion, the classical elasticity function is the most important and most frequently used to account for the plastic anisotropy of metallic materials, Eq.(1), /21/.

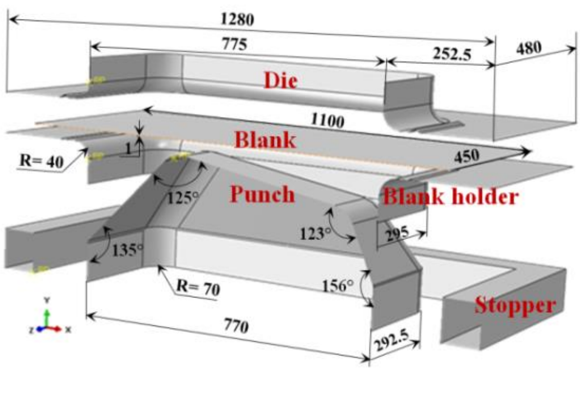
$$2f = F(\sigma_{yy}-\sigma_{zz})^2 + G(\sigma_{zz}-\sigma_{xx})^2 + H(\sigma_{xx}-\sigma_{yy})^2 + \\ +2L\sigma_{yz}^2 + 2M\sigma_{zx}^2 + 2N\sigma_{xy}^2 = 1 . \quad (1)$$

It is necessary to determine the anisotropy coefficients of the Hill48 criterion, respectively, *F*, *G*, *H*, *L*, *M* and *N* /22/, and anisotropy ratio which specifies the anisotropy of the material in the finite element calculation code Abacus, /23, 24/. The anisotropy coefficient (r) is defined by the ratio of transverse strains, Eq.(2):

$$r = \frac{\varepsilon_2}{\varepsilon_3} = \frac{\ln\frac{b}{b_0}}{\ln\frac{t}{t_0}} . \quad (2)$$

The simulation model of the forming operation is carried out in 3D on the finite element calculation code Abaqus/CAE, Fig. 3. The blank is created with a thickness t = 1 mm. Introduced material mechanical properties are obtained by experimental characterisation through module (Property). Furthermore, anisotropy is identified by the implementation of Hill48 criterion constants. Interactions between the die-blank, blank holder-blank, and punch-blank are defined by a friction coefficient f = 0.05. The blank holder pressure is

a)



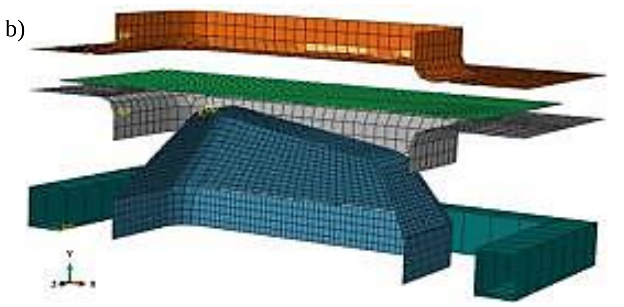


Figure 3. Deep drawing simulation model: a) geometry and initial conditions; and b) mesh.

BHP = 10.7 MPa, and punch penetration is 25 mm. Finally, we launch the calculation after meshing the assembly using the (mesh) module. The visualisation module allows us to visualise the results.

RESULTS AND DISCUSSION

The stress-strain tensile curve shows a tensile hook known by Piobert-Lüders phenomenon, translated by a heterogeneous elastoplastic transition (Fig. 4). A Lüders band can be noticed with a lower stress than the upper stress in the yield point elongation. Also, by defining a high yield strength R_{eH} and a low yield strength R_{eL}, corresponding to the band (Table 2).

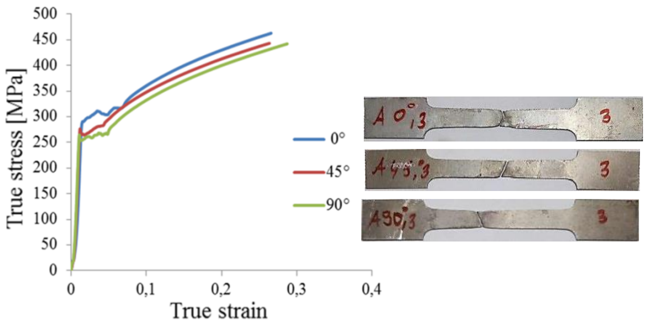


Figure 4. Rational tensile curves for three directions 0°, 45°, and 90° at v = 50 mm/min.

The mechanical characteristics obtained through uniaxial tensile tests are summarised in Table 2.

Table 2. Mechanical properties of DD14 steel.

θ (°)	A (%)	R_{eH} (MPa)	R_{eL} (MPa)	R_m (MPa)	n	K	r
0	32.2	286.30	285.60	354.83	0.26	655.76	1.14
45	32.8	273.41	259.47	340.56	0.24	608.32	0.74
90	35	262.06	250.40	331.78	0.26	617.26	0.82

The comparison of the deep drawn part obtained by numerical simulation with that obtained experimentally is therefore possible, based on the location of the area most subject to plastic strain (Fig. 5). Plastic instability appears on the deep drawn part simulated with BHF = 10 MPa. Figure 5a represents a lateral plastic instability obtained by simulation with D_r = 40 mm, corresponding to that of the experimental (Fig. 1a) generating strain value of 48 %. As well, Fig. 5b shows the rupture located at the deep drawn frontal corner, corresponding to that of the experimental (Fig. 1b) of simulated deep drawn with D_r = 60 mm, generating strain values 40 %.

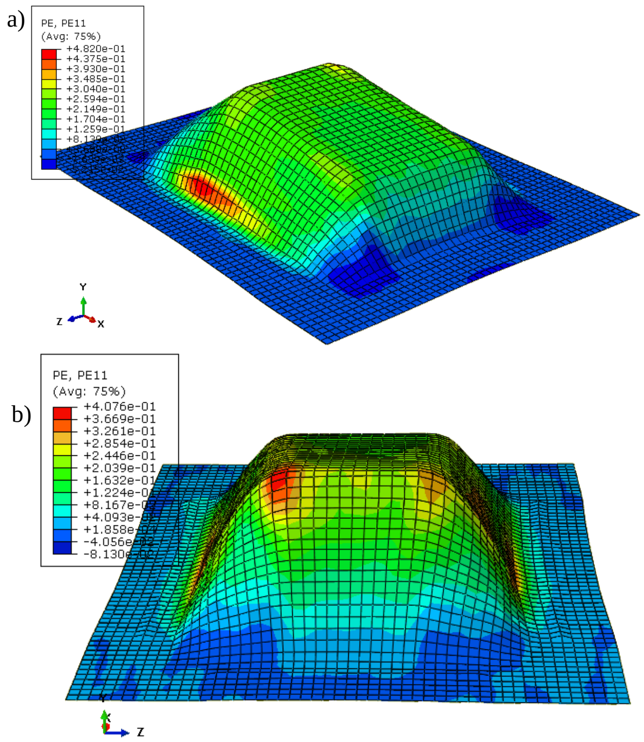


Figure 5. Localisation of plastic instability in numerical simulation: a) lateral; and b) frontal corner.

Numerical simulation results lead us to deepen the analysis through the study of die radius influence on this plastic instability evolution. For this, an experimental plan is chosen in order to examine the plastic strain distribution within the deep drawn material as a function of four levels of die radius (D_r). The maximum plastic strain as a function of four levels of die radius is summarised in Table 3.

Table 3. Numerical results of maximum plastic strain as a function of die radius.

N°	D_r (mm)	PE_{max} (%)
1	30	55.87
2	40	48.88
3	50	42.65
4	60	40.54

First, we represent the trend of maximum plastic strain as a function of the die radius, Fig. 6.

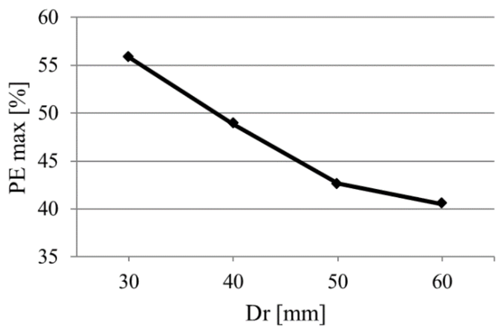


Figure 6. Maximum plastic strain as a function of die radius.

The trend shows that the lowest die radius level generates the greatest plastic strain, compared with all other levels 40, 50, and 60 mm. The results show that plastic strain decreases with increasing die radius. Secondly, by examining the plastic strain distribution as a function of die radius following a node path which passes through the lateral rupture and the deep drawn bottom frontal corners, as shown in Fig. 7.

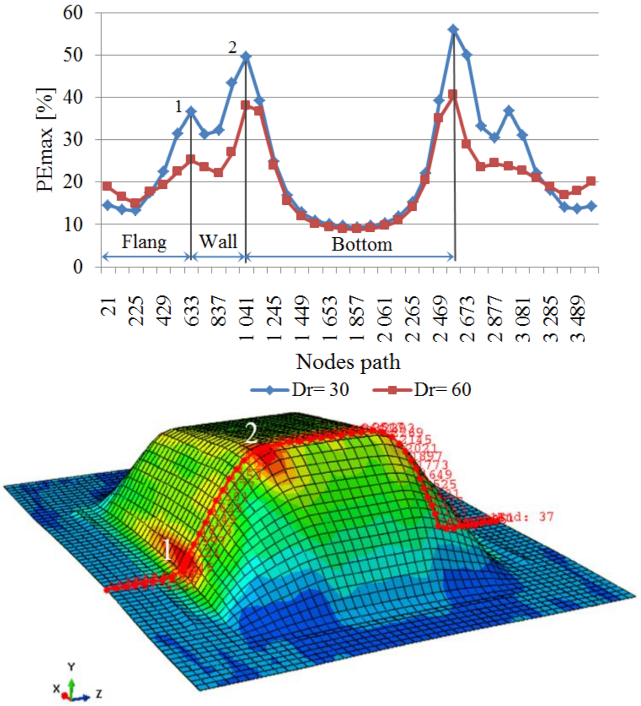


Figure 7. Distribution of plastic strain as a function of two extreme levels of the matrix radius.

The greatest difference in plastic strain recorded between the extreme chosen die radius levels is 15.3 %, at the deep drawn front corners, where maximum strain reaches 40.5 % of radius 60 mm, and 55.8 % for 30 mm. In observation, where to locate peak 1 on the curve and the stamping (Fig. 7), the plastic strain is quite large due to intense friction between the sheet and die radius during the forming operation, leading to poor metal flow and progressive thinning in this area, resulting lateral tearing of the deep drawn part. However, a maximum plastic strain is recorded at the deep drawn corners where peak 2 is located, because it is a propagation of the plastic strain of those at peak 1. Moreover, the plastic strain is often great at deep drawn corners, at the intersection of three constructive planes, respectively the frontal, side, and bottom.

CONCLUSIONS

The characterisation of the material by uniaxial tensile test from specimens taken in three directions 0°, 45°, and 90° with respect to the rolling direction of the sheet, helps us identify the material properties and precisely evaluate the hot-rolled steel sheet DD14 anisotropy. Furthermore, the anisotropic behaviour of the material is successfully modelled and implemented in the finite element calculation code Abaqus/CAE®, thanks to the Hill48 plastic anisotropy criterion. The originality of this work emerged through the results of the numerical simulation model which highlights a perfect localisation of plastic instability areas, similar to those recorded on the component's deep drawn parts. The results of the tests, planned according to the four levels of die radius, have helped us to successfully determine the influence of die radius on plastic strain evolution. On another scale, the finite element method allows us to numerically analyse the phenomenon of plastic instability within the deep drawn part, following a chosen node's path, sufficiently informing us about the probable scenarios of plastic strain evolution according to each chosen level of the die radius.

The characterisation of the material is an essential phase and the choice of the modelling criterion of its anisotropic behaviour plays a primordial role, in order to succeed in an in-depth experimental and/or numerical simulation investigation with scientific, logical results and effective solutions in the deep drawing process.

The numerical simulation model is identical to the experimental one, implicitly and explicitly which helped us to achieve the desired objectives through simulation. Thus, the experimental design allows us to designate the optimal levels of die radius in order to perform the forming operation with the lowest levels of deformation and avoid the phenomenon of plastic instability.

As a result, the highest values of plastic strain are generated by the low level of die radius. However, the increase in die radius decreases the plastic strain during the forming. According to the planning of this investigation, the best results are obtained with the high level of die radius D_r = 60 mm.

To generalise the case in terms of plastic strain and carry out a deep drawing operation with all caution, the optimum is to choose the largest possible die radius. On the other hand, the adjustment and accuracy of other parameters, as well as the adequate choice of the material, are necessary.

REFERENCES

1. Yi, S., Bohlen, J., Heinemann, F., Letzig, D. (2010), *Mechanical anisotropy and deep drawing behaviour of AZ31 and ZE10 magnesium alloy sheets*, Acta Materialia, 58(2): 592-605. doi: 10.1016/j.actamat.2009.09.038
2. Bouchaâla, K., Ghanameh, M.F., Essadiqi, E.H., et al. (2018), *Modeling of anisotropy influence on thickness distribution of deep drawing sheet*, In: Proc. RCAE 2018, Beijing, China, Adv. Mech. Elect. Eng. (AMEE), Int. Conf. Proc. Ser. (ACM), 2018, pp.142-146. doi: 10.1145/3303714.3303737
3. Othmen, K.B., Sai, K., Manach, P.-Y., Elleuch, K. (2019), *Reverse deep drawing process: Material anisotropy and work-hardening effects*, Proc. Inst. Mech. Eng. Part L: J Mater.: Des. Appl. 233(4): 699-713. doi: 10.1177/1464420717701950
4. García, C., Celentano, D., Flores F., Ponthot, J.-P. (2006), *Numerical modelling and experimental validation of steel deep drawing processes: Part I. Material characterization*, J Mater. Proc. Technol. 172(3): 451-460. doi: 10.1016/j.jmatprotec.2005.11.015
5. Padmanabhan, R., Baptista, A.J., Oliveira, M.C., Menezes, L.F. (2007), *Effect of anisotropy on the deep-drawing of mild steel and dual-phase steel tailor-welded blanks*, J Mater. Proc. Technol. 184(1-3): 288-293. doi: 10.1016/j.jmatprotec.2006.11.051
6. Yue, Z., Cao, K., Badreddine, H., et al. (2019), *Failure prediction on steel sheet under different loading paths based on fully coupled ductile damage model*, Int. J Mech. Sci. 153-154: 1-9. doi: 10.1016/j.ijmecsci.2019.01.029
7. Gowtham, K., Srikanth, K.V.N.S., Murty, K.L.N. (2012), *Simulation of the effect of die radius on deep drawing process*, Int. J Appl. Res. Mech. Eng. 2(1): 12-17.

8. Jain, M., Allin, J., Bull, M.J. (1998), *Deep drawing characteristics of automotive aluminum alloys*, Mater. Sci. Eng.: A, 256 (1-2): 69-82. doi: 10.1016/S0921-5093(98)00845-4
9. Özek, C., Bal, M. (2009), *The effect of die/blank holder and punch radiuses on limit drawing ratio in angular deep-drawing dies*, Int. J Adv. Manuf. Technol. 40: 1077-1083. doi: 10.1007/s00170-008-1435-3
10. Colgan, M., Monaghan, J. (2003), *Deep drawing process: analysis and experiment*, J Mater. Proc. Technol. 132(1-3): 35-41. doi: 10.1016/S0924-0136(02)00253-4
11. Hamza, F., Boussaid, O., Tadjine, K. (2017), *Study by numerical simulation of the deep drawing parameters-material during the wheelbarrow forming*, Mater. Sci. Forum, 895: 94-98. doi: 10.4028/WWW.SCIENTI
12. Sedmak, S., Jovičić, R., Sedmak, A., et al. (2017), *Numerical analysis of different weld geometries of lap welded joint in ammonia transport tanks*, Struct. Integr. Life. 17(3): 217-220.
13. Durdević, Đ., Anđelić, N., Maneski, T., Đurđević, A. (2017), *Numerical analysis of stress and strain state of structural elements of container terminal*, Struct. Integr. Life, 17(3): 235-238.
14. Radojković, M., Čamagić, I., Šarkočević, Ž., et al. (2021), *Stress distribution on an isotropic plate with a rectangular opening under biaxial tension load*, Struct. Integr. Life, 21(1): 91-94.
15. Alnagasa, K., Petrović, R., Banaszek, A., et al. (2022), *Stress state analysis of propane butane gas spherical storage tanks*, Struct. Integr. Life, 22(2): 253-256.
16. Nguyen, L.H., Firsanov, V.V. (2021), *Stress concentration state of piezoelectricity in cylindrical shell based on the non-classical theory*, Struct. Integr. Life, 21(1): 53-58.
17. Čamagić, I., Sedmak, S., Sedmak, A., et al. (2017), *Impact of temperature and exploitation time on plane strain fracture toughness, K_{Ic}, in a welded joint*, Struct. Integr. Life, 17(3): 239-244.
18. Banks-Sills, L., Sedmak, A. (2020), *Linear elastic and elasto-plastic aspects of interface fracture mechanics*, Struct. Integr. Life, 20(3): 203-210.
19. Maheshwari, K., Sharma, S. (2020), *Elastic-plastic transition in functionally graded thin rotating orthotropic disk with exponentially variable thickness and variable density*, Struct. Integr. Life, 21(1): 19-28.
20. Rodney, H. (1948), *A theory of the yielding and plastic flow of anisotropic metals*, Proc. Royal Soc. A: Math. Phys. Eng. Sci. 193(1033): 281-297. doi: 10.1098/rspa.1948.0045
21. Nguyen, D.-T., Dinh, D.-K., Thi Nguyen, H.-M., et al. (2014), *Formability improvement and blank shape definition for deep drawing of cylindrical cup with complex curve profile from SPCC sheets using FEM*, J Cent. South Univ, 21: 27-34. doi: 10.1007/s11771-014-1911-x
22. Chinara, M, Paul, S.K., Chatterjee, S., Mukherjee, S. (2022), *Effect of planar anisotropy on the hole expansion ratio of cold-rolled DP 590 steel*, Trans. Ind. Inst. Metals, 75: 535-543. doi: 10.1007/s12666-021-02444-x
23. Yan, Y., Wang, H., Li, Q. (2015), *The inverse parameter identification of Hill 48 yield criterion and its verification in press bending and roll forming process simulations*, J Manuf. Proc. 20(Part 1): 46-53. doi: 10.1016/j.jmapro.2015.09.009
24. Hamza, F., Boussaid, O., Hamadache, H., Guedri, A. (2024), *Experimental investigation and numerical optimization of sheet metal forming limits during deep drawing process of DD14 steel*, Res. Eng. Struct. Mater. 10(3): 1321-1338. doi: 10.17515/resm2024.118me1209rs

ICSID 2025 - 8th International Conference on Structural Integrity and Durability
Dubrovnik (Croatia), 16-19 September 2025
& Summer School - Fatigue and Fracture Modeling and Analysis
September 15-16, 2025
https://icsid2025.fsb.unizg.hr/

The objective of the ICSID 2025 conference is to bring together scientists and engineers from around the world to discuss how to characterise, analyse, predict and asses the fatigue and fracture of structural materials and components. The ICSID 2025 intends to be a forum for discussion of the present and future trends in experimental, theoretical and applied fracture mechanics, fatigue, structural integrity assessment, failure analysis, and other important topics in the field. The Conference will be organised in 'Hybrid Mode', a combination of onsite and online presentation in order to guarantee the maximum safety and conveniences for participants.

Main topics
Advanced testing and evaluation techniques; Analytical models; Applications to components and structures; Artificial intelligence in structural integrity analysis; Corrosion, environmentally enhanced degradation and cracking, corrosion fatigue; Cyclic deformation and crack initiation; Damage mechanics and models; Databases, expert systems and software; Durability and life extension of structures and components; Failure investigation and analysis; Failure of nanomaterials and nanostructures; Fatigue and fracture of polymers, elastomers, composites and biomaterials; Fatigue and fracture of weldments, welded components, joints and adhesives; Fatigue and fracture simulation and testing at all length scales; Fatigue crack path prediction; Finite elements methods and their application; Fracture and damage of cementitious materials; Fracture and failure criteria; Fretting fatigue and wear; Low, medium and high cycle fatigue; Macro scale fatigue prognosis techniques; Microstructure scale computational modeling; Mixed mode and multiaxial fatigue and fracture; Models, criteria and methods in fracture mechanics; Multiscale materials modeling; Nondestructive evaluation (NDE); Probabilistic fracture mechanics; Reliability and integrity of engineering structures; Residual stress effects; Structural integrity assessment; Surface treatment and failure resistance improvement; 3D-printed materials and structures

Conference chair
Željko Božić (University of Zagreb)

Conference co-chair
Siegfried Schmauder (University of Stuttgart)

Important dates

Abstract submission,	June 15, 2025
Notification on abstract,	within two weeks after receipt of abstract
Early registration	July 1, 2025
Full paper submission (optional)	October 30, 2025

Contact
Prof. Dr. Sc. Željko Božić
ICSID 2025 Chair, zeljko.bozic@fsb.hr
Phone: + 385 1 6168536 , Mobile: + 385 98 1863915
Fax: + 385 1 6156940
Faculty of Mechanical Engineering and Naval Architecture
Ivana Lučića 5, 10000 Zagreb, Croatia
email: icsid@fsb.hr
Url: icsid2025.fsb.hr