

Predicting the deep drawing process of TRIP steel grades using multilayer perceptron artificial neural networks

Sevšek, L.^a, Vilkovský, S.^b, Majerníková, J.^b, Pepelnjak, T.^{a,*}

^aForming Laboratory, Faculty of Mechanical Engineering, University of Ljubljana, Ljubljana, Slovenia

^bDepartment of Technologies, Materials and Computer Aided Production, Technical University of Košice, Košice, Slovakia

ABSTRACT

TRIP (Transformation Induced Plasticity) steels belong to the group of advanced high-strength steels. Their main advantage is their excellent strength combined with high ductility, which makes them ideal for deep drawing processes. The forming of TRIP steels in the deep drawing process enables the production of a thin-walled final product with superior mechanical properties. For this reason, this study presents comprehensive research into the deep drawing of cylindrical cups made from TRIP steel. The research focuses on three main aspects of the deep drawing process, namely the sheet metal thinning, the maximum force value and the ear height as a result of the anisotropic material behaviour. Artificial neural networks (ANNs) were built to predict all the mentioned output parameters of the part or the process itself. The ANNs were trained using data obtained from a sufficient number of simulations based on the finite element method (FEM). The ANN models were developed based on variable material properties, including anisotropic parameters, blank holding force, blank diameter, and friction coefficient. A good agreement between simulation, ANN and experimental results is evident.

ARTICLE INFO

Keywords:

Forming;
Deep drawing;
TRIP steel;
Artificial neural network (ANN);
Finite element methods (FEM);
Modelling;
Simulation

*Corresponding author:

Tomaz.Pepelnjak@fs.uni-lj.si
(Pepelnjak, T.)

Article history:

Received 25 March 2024

Revised 24 April 2024

Accepted 26 April 2024



Content from this work may be used under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

References:

- [1] Spišák, E., Majerníková, J. (2014). A study of thickness change of spherical cup made from TRIP steel after hydraulic bulge test, *Key Engineering Materials*, Vol. 635, 157-160, [doi: 10.4028/www.scientific.net/KEM.635.157](https://doi.org/10.4028/www.scientific.net/KEM.635.157).
- [2] Lai, M., Brun, R. (2007). Latest developments in sheet metal forming technology and materials for automotive application: The use of ultra-high strength steels at fiat to reach weight reduction at sustainable costs, *Key Engineering Materials*, Vol. 344, 1-8, [doi: 10.4028/www.scientific.net/KEM.344.1](https://doi.org/10.4028/www.scientific.net/KEM.344.1).
- [3] Bright, G.W., Kennedy, J.I., Robinson, F., Evans, M., Whittaker, M.T., Sullivan, J., Gao, Y. (2011). Variability in the mechanical properties and processing conditions of a High Strength Low Alloy steel, *Procedia Engineering*, Vol. 10, 106-111, [doi: 10.1016/j.proeng.2011.04.020](https://doi.org/10.1016/j.proeng.2011.04.020).
- [4] Thomas, S.K., Ali, A., AlArjani, A., Attia, E.-A. (2022). Simulation based performance improvement: A case study on automotive industries, *International Journal of Simulation Modelling*, Vol. 21, No. 3, 405-416, [doi: 10.2507/IJSIMM21-3-606](https://doi.org/10.2507/IJSIMM21-3-606).
- [5] Visagan, A., Ganesh, P. (2022). Parametric optimization of two point incremental forming using GRA and TOPSIS, *International Journal of Simulation Modelling*, Vol. 21, No. 4, 615-626, [doi: 10.2507/IJSIMM21-4-622](https://doi.org/10.2507/IJSIMM21-4-622).
- [6] Spišák, E., Majerníková, J. (2013). Analysis of variance of mechanical properties of sheets as the input parameters for simulation of processes, *Acta Metallurgica Slovaca*, Vol. 18, No. 2-3, 109-116.

- [7] Dykeman, J., Hoydick, D., Link, T., Mitsuji, H. (2009). Material property and formability characterization of various types of high strength dual phase steel, *SAE Technical Paper 2009-01-0794*, SAE International, [doi: 10.4271/2009-01-0794](https://doi.org/10.4271/2009-01-0794).
- [8] Takahashi, M. (2003). Development of high strength steels for automobiles, *Nippon Steel Technical Report*, No. 88, 2-7, from <https://www.nipponsteel.com/en/tech/report/nsc/pdf/n8802.pdf>, accessed February 7, 2024.
- [9] Bleck, W., Brühl, S., Gerdemann, F.L.H., Prahl, U. (2007). Gefüge-Engineering bei kaltumformbaren Stählen, *Umformtechnik: Stahl und NE-Werkstoffe; der Zukunft Form geben; Tagungsband / 22. ASK, Aachener Stahlkolloquium*, 08/09. März 2007, Eurogress Aachen. Institut für Bildsame Formgebung; Institut für Eisenhüttenkunde, RWTH, Rheinisch-Westfälische Technische Hochschule Aachen, 267-280.
- [10] Heinemann, G. (2004). *Virtuelle Bestimmung des Verfestigungsverhaltens von Bändern und Blechen durch verformungsinduzierte Martensitbildung bei metastabilen rostfreien austenitischen Stählen*, Dissertation, Eidgenössische Technische Hochschule Zürich.
- [11] Behrens, B.-A., Hübner, S., Voges-Schwieger, K., Weilandt, K. (2007). Verformungsinduzierte Martensitevolution zur lokalen Festigkeitssteigerung, *UTF Science II*, 1-4.
- [12] Papaefthymiou, S. (2005). Failure mechanisms of multiphase steels, Dissertation, RWTH Aachen, Aachen, Shaker Verlag.
- [13] Stefanovska, E., Pepelnjak, T. (2022). Development of a flexible tooling system for sheet metal bending, *Advances in Production Engineering & Management*, Vol. 17, No. 3, 311-325, [doi: 10.14743/apem2022.3.438](https://doi.org/10.14743/apem2022.3.438).
- [14] Spišák, E., Greškovič, F., Maňková, I., Brezinová, J., Král, J., Slota, J., Draganovská, D., Viňas, J., Kaščák, L. (2011). *Strojárske technológie*, Strojnícka fakulta TU v Košiciach, Košice, Slovakia.
- [15] Dwivedi, R., Agnihotri, G. (2017). Study of deep drawing process parameters, *Materials Today: Proceedings*. Vol. 4, No. 2, Part A, 820-826, [doi: 10.1016/j.matpr.2017.01091](https://doi.org/10.1016/j.matpr.2017.01091).
- [16] Semiatin, S.L. (2006). Introduction to sheet-forming processes, In: Semiatin (ed.), *Metalworking: Sheet Forming* Vol. 14B, ASM International, Almere, Netherlands, 319-333, [doi: 10.31399/asm.hb.v14b.9781627081863](https://doi.org/10.31399/asm.hb.v14b.9781627081863).
- [17] Spišák, E., Slota, J., Majerníková, J., Kaščák, L., Malega, P. (2012). Inhomogeneous plastic deformation of tinplates under uniaxial stress state, *Chemické listy*. Vol. 106, 537-540.
- [18] Joshi, A.R., Kothari, K.D., Jhala, R.L. (2013). Effects of different parameters on deep drawing process: Review, *International Journal of Engineering Research & Technolog.* Vol. 2, No. 3.
- [19] Benke, M., Schweitzer, B., Hlavacs, A., Mertinger, V. (2020). Prediction of earing of cross-rolled al sheets from {h00} pole figures, *Metals*, Vol. 10, No. 2, Article No. 192, [doi: 10.3390/met10020192](https://doi.org/10.3390/met10020192).
- [20] Hlavacs, A., Szucs, M., Mertinger, V., Benke, M. (2021). Prediction of earing of hot-rolled al sheets from pole figures, *Metals*, Vol. 11, No. 1, Article No. 99, [doi: 10.3390/met11010099](https://doi.org/10.3390/met11010099).
- [21] Dong, W., Wang, Q., Wang, X., Wang, B. (2018). Stress analysis of cylindrical parts during deep drawing based on Dynaform, *IOP Conference Series Materials Science Engineering*, Vol. 423, Article No. 012166, [doi: 10.1088/1757-899X/423/1/012166](https://doi.org/10.1088/1757-899X/423/1/012166).
- [22] Colgan, M., Monaghan, J. (2003). Deep drawing process: Analysis and experiment, *Journal of Materials Processing Technology*, Vol. 132, No. 1-3, 35-41, [doi: 10.1016/S0924-0136\(02\)00253-4](https://doi.org/10.1016/S0924-0136(02)00253-4).
- [23] Seth, M., Vohnout, V.J., Daehn, G.S. (2005). Formability of steel sheet in high velocity impact, *Journal of Materials Processing Technology*, Vol. 168, No. 3, 390-400, [doi: 10.1016/j.jmatprotec.2004.08.032](https://doi.org/10.1016/j.jmatprotec.2004.08.032).
- [24] Huang, Y.-M., Tsai, Y.-W., Li, C.-L. (2008). Analysis of forming limits in metal forming processes, *Journal of Materials Processing Technology*, Vol. 201, No. 1-3, 385-389, [doi: 10.1016/j.jmatprotec.2007.11.279](https://doi.org/10.1016/j.jmatprotec.2007.11.279).
- [25] Chalal, H., Abed-Meraim, F. (2017). Determination of forming limit diagrams based on ductile damage models and necking criteria, *Latin American Journal of Solids and Structures*, Vol. 14, No. 10, 1872-1892, [doi: 10.1590/1679-78253481](https://doi.org/10.1590/1679-78253481).
- [26] Gusel, L., Boskovic, V., Domitner, J., Ficko, M., Brezocnik, M. (2018). Genetic programming method for modelling of cup height in deep drawing process, *Advances in Production Engineering & Management*, Vol. 13, No. 3, 358-365, [doi: 10.14743/apem2018.3.296](https://doi.org/10.14743/apem2018.3.296).
- [27] Sevšek, L., Baressi Šegota, S., Car, Z., Pepelnjak, T. (2023). Determining the influence and correlation for parameters of flexible forming using the random forest method, *Applied Soft Computing*, Vol. 144, Article No. 110497, [doi: 10.1016/j.asoc.2023.110497](https://doi.org/10.1016/j.asoc.2023.110497).
- [28] Cwiekala, T., Brosius, A., Tekkaya, A.E. (2011). Accurate deep drawing simulation by combining analytical approaches, *International Journal of Mechanical Sciences*, Vol. 53, No. 5, 374-386, [doi: 10.1016/j.ijmecsci.2011.02.007](https://doi.org/10.1016/j.ijmecsci.2011.02.007).
- [29] Milutinovic, M., Lendjel, R., Baloš, S., Labus Zlatanovic, D., Sevšek, L., Pepelnjak, T. (2021). Characterisation of geometrical and physical properties of a stainless steel denture framework manufactured by single-point incremental forming, *Journal of Materials Research and Technology*, Vol. 10, 605-623, [doi: 10.1016/j.jmrt.2020.12.014](https://doi.org/10.1016/j.jmrt.2020.12.014).
- [30] Vrh, M., Halilović, M., Starman, B., Štok, B., Comsa, D.-S., Banabic, D. (2014). Capability of the BBC2008 yield criterion in predicting the earing profile in cup deep drawing simulations, *European Journal of Mechanics, A/Solids*, Vol. 45, 59-74, [doi: 10.1016/j.euromechsol.2013.11.013](https://doi.org/10.1016/j.euromechsol.2013.11.013).
- [31] Bandyopadhyay, K., Panda, S.K., Saha, P., Padmanabham, G. (2015). Limiting drawing ratio and deep drawing behavior of dual phase steel tailor welded blanks: FE simulation and experimental validation, *Journal of Materials Processing Technology*, Vol. 217, No. 48-64, [doi: 10.1016/j.jmatprotec.2014.10.022](https://doi.org/10.1016/j.jmatprotec.2014.10.022).
- [32] Dwivedi, R., Agnihotri, G. (2015). Numerical simulation of aluminum and brass material cups in deep drawing process, *Materials Today: Proceedings*, Vol. 2, No. 4-5, 1942-1950, [doi: 10.1016/j.matpr.2015.07.159](https://doi.org/10.1016/j.matpr.2015.07.159).
- [33] Walde, T., Riedel, H. (2007). Simulation of earing during deep drawing of magnesium alloy AZ31, *Acta Materialia*, Vol. 55, No. 3, 867-874, [doi: 10.1016/j.actamat.2006.09.007](https://doi.org/10.1016/j.actamat.2006.09.007).

- [34] Engler, O., Aretz, H. (2021). A virtual materials testing approach to calibrate anisotropic yield functions for the simulation of earing during deep drawing of aluminium alloy sheet, *Materials Science and Engineering: A*, Vol. 818, Article No. 141389, [doi: 10.1016/j.msea.2021.141389](https://doi.org/10.1016/j.msea.2021.141389).
- [35] Luyen, T.-T., Tong, V.-C., Nguyen, D.-T. (2022). A simulation and experimental study on the deep drawing process of SPCC sheet using the graphical method, *Alexandria Engineering Journal*, Vol. 61, No. 3, 2472-2483, [doi: 10.1016/j.aej.2021.07.009](https://doi.org/10.1016/j.aej.2021.07.009).
- [36] Jayahari, L., Balunaik, B., Gupta, A.K., Singh, S.K. (2015). Finite element simulation studies of AISI 304 for deep drawing at various temperatures, *Materials Today: Proceedings*, Vol. 2, No. 4-5, 1978-1986, [doi: 10.1016/j.matpr.2015.07.166](https://doi.org/10.1016/j.matpr.2015.07.166).
- [37] Gondo, S., Arai, H. (2022). Data-driven metal spinning using neural network for obtaining desired dimensions of formed cup, *CIRP Annals*, Vol. 71, No. 1, 229-232, [doi: 10.1016/j.cirp.2022.04.044](https://doi.org/10.1016/j.cirp.2022.04.044).
- [38] Tian, S., Zhang, Z., Xie, X., Yu, C. (2022). A new approach for quality prediction and control of multistage production and manufacturing process based on Big Data analysis and Neural Networks, *Advances in Production Engineering & Management*, Vol. 17, No. 3, 326-338, [doi: 10.14743/apem2022.3.439](https://doi.org/10.14743/apem2022.3.439).
- [39] Kazan, R., Firat, M., Tiryaki, A.E. (2009). Prediction of springback in wipe-bending process of sheet metal using neural network, *Materials & Design*, Vol. 30, No. 2, 418-423, [doi: 10.1016/j.matdes.2008.05.033](https://doi.org/10.1016/j.matdes.2008.05.033).
- [40] Afshari, D., Ghaffari, A., Barsum, Z. (2022). Optimization in the resistant spot-welding process of AZ61 magnesium alloy, *Strojnicki Vestnik/Journal of Mechanical Engineering*, Vol. 68, No. 7-8, 485-492, [doi: 10.5545/sv-jme.2022.174](https://doi.org/10.5545/sv-jme.2022.174).
- [41] Berus, L., Klancnik, S., Brezocnik, M., Ficko, M. (2019) Classifying parkinson's disease based on acoustic measures using artificial neural networks, *Sensors*, Vol. 19, No. 1, Article No. 16, [doi: 10.3390/s19010016](https://doi.org/10.3390/s19010016).
- [42] Sivasankaran, S., Narayanasamy, R., Jeyapaul, R., Loganathan, C. (2009). Modelling of wrinkling in deep drawing of different grades of annealed commercially pure aluminium sheets when drawn through a conical die using artificial neural network, *Materials & Design*, Vol. 30, No. 8, 3193-3205, [doi: 10.1016/j.matdes.2009.01.020](https://doi.org/10.1016/j.matdes.2009.01.020).
- [43] Spaić, O., Krivokapić, Z., Kramar, D. (2020). Development of family of artificial neural networks for the prediction of cutting tool condition, *Advances in Production Engineering & Management*, Vol. 15, No. 2, 164-178, [doi: 10.14743/APEM2020.2.356](https://doi.org/10.14743/APEM2020.2.356).
- [44] Nguyen, T.P.Q., Yang, C.L., Le, M.D., Nguyen, T.T., Luu, M.T. (2023). Enhancing automated defect detection through sequential clustering and classification: An industrial case study using the Sine-Cosine Algorithm, Possibilistic Fuzzy c-means, and Artificial Neural Network, *Advances in Production Engineering & Management*, Vol. 18, No. 2, 237-249, [doi: 10.14743/apem2023.2.470](https://doi.org/10.14743/apem2023.2.470).
- [45] Xia, J.S., Khaje Khabaz, M., Patra, I., Khalid, I., Alvarez, J.R.N., Rahmanian, A., Eftekhari, S.A., Toghraie, D. (2023). Using feed-forward perceptron Artificial Neural Network (ANN) model to determine the rolling force, power and slip of the tandem cold rolling, *ISA Transactions*, Vol. 132, 353-363, [doi: 10.1016/j.isatra.2022.06.009](https://doi.org/10.1016/j.isatra.2022.06.009).
- [46] Czinege, I., Harangozó, D. (2024). Application of artificial neural networks for characterisation of formability properties of sheet metals, *International Journal of Lightweight Materials and Manufacture*, Vol. 7, No. 1, 37-44, [doi: 10.1016/j.ijlmm.2023.08.003](https://doi.org/10.1016/j.ijlmm.2023.08.003).
- [47] Savkovic, B., Kovac, P., Rodic, D., Strbac, B., Klancnik, S. (2020). Comparison of artificial neural network, fuzzy logic and genetic algorithm for cutting temperature and surface roughness prediction during the face milling process, *Advances in Production Engineering & Management*, Vol. 15, No. 2, 137-150, [doi: 10.14743/APEM2020.2.354](https://doi.org/10.14743/APEM2020.2.354).
- [48] El Mehtedi, M., Forcellese, A., Greco, L., Pieralisi, M., Simoncini, M. (2019). Flow curve prediction of ZAM100 magnesium alloy sheets using artificial neural network-based models, *Procedia CIRP*, Vol. 79, No. 661-666, [doi: 10.1016/j.procir.2019.02.050](https://doi.org/10.1016/j.procir.2019.02.050).
- [49] Babu, K.V., Ganesh Narayanan, R., Saravana Kumar, G. (2010). An expert system for predicting the deep drawing behavior of tailor welded blanks, *Expert Systems with Applications*, Vol. 37, No. 12, 7802-7812, [doi: 10.1016/j.eswa.2010.04.059](https://doi.org/10.1016/j.eswa.2010.04.059).
- [50] Manoochehri, M., Kolahan, F. (2014). Integration of artificial neural network and simulated annealing algorithm to optimize deep drawing process, *The International Journal of Advanced Manufacturing Technology*, Vol. 73, 241-249, [doi: 10.1007/s00170-014-5788-5](https://doi.org/10.1007/s00170-014-5788-5).

Napovedovanje postopka globokega vleka jekel TRIP z uporabo večplastnih perceptronskih umetnih nevronske mreže

Sevšek, L.^a, Vilkovský, S.^b, Majerníková, J.^b, Pepelnjak, T.^{a,*}

^aForming Laboratory, Faculty of Mechanical Engineering, University of Ljubljana, Ljubljana, Slovenia

^bDepartment of Technologies, Materials and Computer Aided Production, Technical University of Košice, Košice, Slovakia

POVZETEK

Jekla TRIP (transformacijsko inducirano plastično jeklo) spadajo v skupino naprednih jekel visoke trdnosti. Njihova glavna prednost je odlična trdnost v kombinaciji z visoko duktilnostjo, zaradi česar so idealna za postopke globokega vleka. Oblikovanje jekel TRIP v postopku globokega vleka omogoča izdelavo tankostenskega končnega izdelka z vrhunskimi mehanskimi lastnostmi. Zato je v tej študiji predstavljena celovita raziskava globokega vleka valjastih skodelic iz jekla TRIP. Raziskava se osredotoča na tri glavne vidike postopka globokega vleka, in sicer na tanjšanje pločevine, največjo vrednost sile in višino ušesa zaradi anizotropnega obnašanja materiala. Umetne nevronske mreže (UNN) so bile zgrajene za napovedovanje vseh navedenih izhodnih parametrov izdelka ali samega postopka. UNN so bile naučene na podlagi podatkov, pridobljenih iz zadostnega števila simulacij, ki so temeljile na metodi končnih elementov (MKE). Modeli UNN so bili razviti na podlagi spremenljivih lastnosti materiala, vključno z anizotropnimi parametri, silo prijema surovca, premerom surovca in koeficientom trenja. Ugotovljeno je dobro ujemanje med simulacijo, UNN in eksperimentalnimi rezultati.

PODATKI O ČLANKU

Ključne besede:

Preoblikovanje;
Globoki vlek;
Jeklo TRIP;
Umetna nevronska mreža (UNN);
Metoda končnih elementov (MKE);
Modeliranje;
Simulacija

*Kontaktna oseba:

Tomaz.Pepelnjak@fs.uni-lj.si
(Pepelnjak, T.)

Zgodovina članka:

Prejet 25. marca 2024
Popravljen 24. aprila 2024
Sprejet 26. aprila 2024



Content from this work may be used under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.