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Design and Optimization of Sheet metal forming parameters: A Review

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Abstract

The sheet metal forming operations process involves the Male (Punch) and the female (Die). The procedure is of sheet metal deformation due to the relative movement between the punch tool and the sheet, an interaction that generates friction forces between the elements. The formability of AISI 304 stainless steel sheets is examined in this study using the Nakajima test specimen. The Nakajima test is a widely used method for evaluating the formability of sheet metals. The forming limit diagram (FLD) of AISI 304 steel sheets is experimentally determined in this work using the Nakajima test.

Additionally, the FEA HyperForm Radioss software is used to simulate the forming process and validate the experimental results. The effects of various process parameters, such as punch speed and lubrication, on the formability of AISI 304 steel sheets are also investigated. The results of this study offer valuable insights into the formability of AISI 304 steel sheets, which can be utilized to optimize the sheet metal forming process.

***Keywords**:* FEA, Forming, Hyperform, Nastraw, Optimization, Sheet metal.

1. Introduction

Sheet metal forming is a widely used manufacturing process in various industries, including the automotive, aerospace, and consumer goods sectors. The formability of a material is a critical factor in determining the success of the forming process.

AISI 304 stainless steel is a popular material used in sheet metal forming due to its excellent corrosion resistance, high strength, and formability. Theoretical and experimental analysis of the Nakajima test specimen, making of FLD, and calculating results, the Nakajima test is used to experimentally determine the forming limit diagram (FLD) of AISI 304 steel sheets. Additionally, the Hyper Form Radioss software is used to simulate the forming process and validate the experimental results.

The intricate process of sheet metal forming entails shaping a flat sheet of metal into the required shape without failure, fracture, or undue thinning. The formability of a material refers to the amount of deformation it can undergo before failure, and it depends on several factors, including thickness, manufacturing process, speed, lubrication, and intrinsic material properties.

The FLD of AISI 304 steel sheets are experimentally determined in this work using the Nakajima test. The HyperForm Radioss software is used to simulate the forming process and validate the experimental results. The

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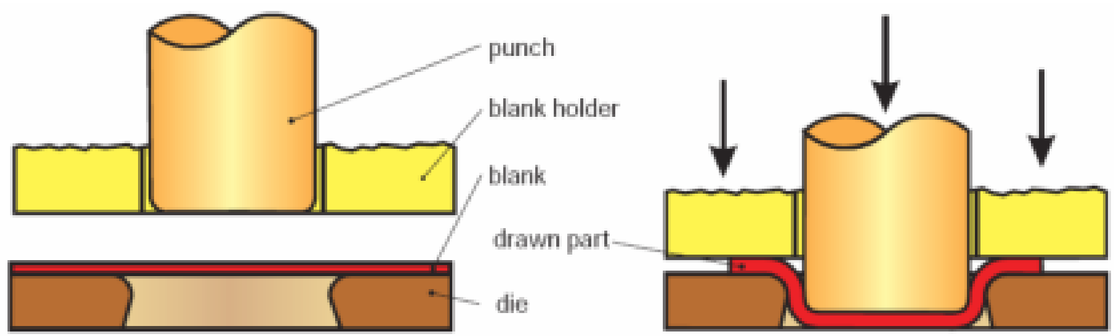

Figure 1 Punch and Die [52]

Stefanos C. Spathopoulos [2020] studied an innovative neural network system that predicts springback in sheet metal forming processes. A meticulous simulation of an S-Rail setup was conducted, and several samples were produced for the ANN training objectives. 1. The Bayesian regularized back propagation neural network was utilized to implement several springback predictions following the validation of the FE model for a test case used in related industrial investigations. With regards to the conclusions drawn from this study, during the FE model simulation, one can observe that errors reach values of 15.4% and 9.9% in the stresses and plastic strains plots, respectively.

Subsequently, no strange indications concerning material failures were detected, except for some wrinkling phenomena, at specific areas. The largest differences between the two unloaded geometries in the spring back condition are 2.02 mm for the E side and 0.26 mm for the D side. Considering the fact that the current analysis is a complex-shaped problem, the material used was nonlinear, as well as some model parameters like mesh elements, punch velocity, etc., were differentiated from the compared simulation, one can say that those error levels could be reasonable. Localized necking in the sheet metal process, including die design optimization, process design parameters, and sheet plasticity prediction, is frequently predicted by the forming limit diagram (FLD) in the forming industries. 3. The ability of a sheet to change shape without rupturing is known as its plasticity. 4. The commencement of localized necking, which ultimately results in rupture, determines the maximum amount of deformation that the sheets can undergo.

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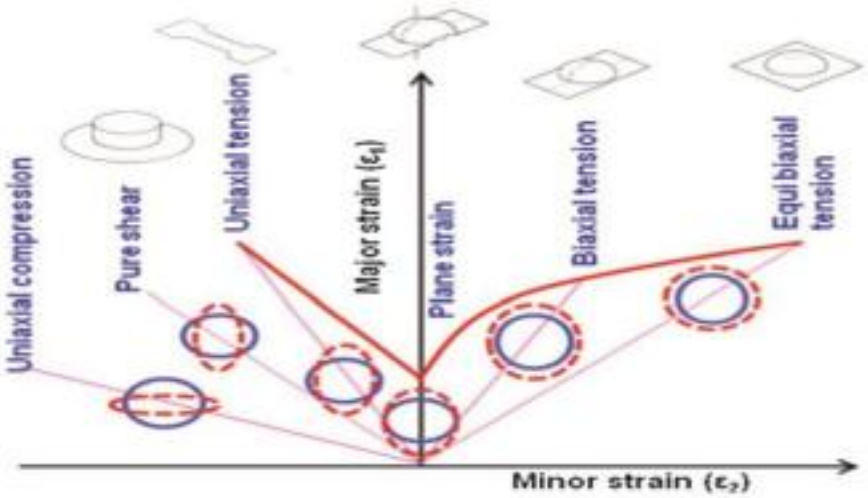

Figure 2 forming limit diagram and strain paths [60]

Shenghua Wu et al [60] studied a formability study of FLD prediction is presented using three different dual phase steels: DP500, DP600, and DP780, with 0.8 mm thickness. Four analytical models, Marciniak-Kuczynski (M-K), Hill-Swift, MMFC (Hora model), were used to predict the FLCs using the Hill1'48 yield criterion. A comparison between the predicted results and the experimentally measured results from Nakajima tests allowed assessing and validating the analytical approaches.

1.1 Sheet Metal Forming Process

Table 1 Basic sheet metal forming process

Design and Tooling Development	The design of the part is created, and the necessary tools and dies are developed.
Material selection and procurement	The sheet metal material is selected and procured.
Blanking and Shearing	The sheet metal is cut into the required shape and size using a blanking die or shear.
Forming	The sheet metal is formed into the desired shape using a variety of techniques, such deep drawing, spinning, or bending.
Trimming and piercing	The excess material is removed, and any necessary holes or features are pierced
Bending and Folding	The part is bent or folded into its final shape.

Rapid prototyping is another significant advantage of sheet metal forming, enabling quick testing and iteration of designs before full-scale production. Furthermore, this process can be seamlessly integrated with other manufacturing techniques, such as welding and assembly, streamlining overall production workflows. Aesthetic appeal is also a consideration, as formed sheet metal can be finished in various ways, providing attractive options for consumer products and architectural elements.

1.2 Reference and citations

The paper investigates the manufacturing of thin-walled five-branched AISI 304 stainless steel tubes using hydroforming technology, focusing on both finite element analysis (FEA) and experimental validation. The authors explore the feasibility of producing these complex geometries with varying diameters, emphasizing the advantages of hydroforming in achieving high precision and material efficiency. Through FEA, the study analyzes stress distribution and deformation patterns during the hydroforming process, providing insights into optimal parameters for tube formation. Experimental trials complement the simulations, allowing for a comparison of theoretical predictions with practical outcomes. The results demonstrate that hydroforming can effectively produce intricate tube designs while maintaining structural integrity.

Additionally, the research highlights the importance of response surface optimization in enhancing the manufacturing process, ultimately contributing to advancements in the production of lightweight and high performance components. The findings have significant implications for industries requiring complex tube shapes, offering a pathway for improved manufacturing techniques and material utilization. Overall, this study provides a comprehensive understanding of the hydroforming process for stainless steel tubes, showcasing its potential in modern manufacturing applications [1]

The paper by Peng Zhao, Cheng Cheng, Ali Abd EI-Aty, Jie Tao, Xunzhong Guo, and Yuting Jia introduces a multi-scale framework for crystal plasticity modeling to investigate the deformation behavior and texture evolution of AISI 304 stainless steel microtubes manufactured through 3D-FBF (3D Fused-Building Fabrication) technology. The authors focus on the intricate relationship between microstructural characteristics and mechanical properties, highlighting how the unique manufacturing process influences the material's response to deformation. By employing a crystal plasticity model, the study captures the anisotropic behavior of the microtubes under various loading conditions, providing insights into the mechanisms of slip and twinning at the crystal level. The research also examines the evolution of texture during deformation, which is critical for predicting the performance of the microtubes in practical applications. The findings reveal that the
Multi-scale approach effectively correlates microstructural features with macroscopic mechanical behavior, offering a comprehensive understanding of the material's performance. This work contributes to the advancement of modeling techniques in materials science, particularly for applications involving complex geometries and demanding mechanical requirements. Overall, the study underscores the importance of integrating multi-scale modeling with experimental observations to optimize the design and manufacturing of stainless steel micro tubes [2]

The paper by Bora Sener, Emre Esener, and Mehmet Firat presents a comprehensive study on the modeling of plastic anisotropy evolution in AISI 304 steel sheets using a polynomial yield function. The authors aim to address the complexities of anisotropic behavior in sheet metals, which is crucial for applications in manufacturing and forming processes. They develop a mathematical framework that captures the yield surface evolution as the material undergoes plastic deformation, allowing for a more accurate prediction of mechanical behavior under various loading conditions. The polynomial yield function is tailored to reflect the material's response to strain and stress, incorporating factors such as texture and microstructural changes. Through experimental validation, the model demonstrates its effectiveness in predicting anisotropic properties, which are essential for optimizing forming processes. The findings highlight the significance of understanding plastic anisotropy in enhancing the performance and reliability of steel sheets in industrial applications. Overall, this

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Pg:- 89 – 101

research contributes valuable insights into the modeling of material behavior, paving the way for improved design strategies in metal forming technologies [3]

The paper by Mohammadali Keshtiara, Sa'id Golabi, and Rasoul Tarkesh Esfahani explores the multi objective optimization of the laser forming process for stainless steel 304 tubes using genetic algorithms (GA). The authors aim to enhance the process by maximizing the bending angle while simultaneously minimizing ovality, thickening, and energy consumption. Through a systematic approach, they identify optimal laser parameters that balance these competing objectives. The study employs experimental and numerical methods to validate the effectiveness of the proposed optimization framework. Results demonstrate significant improvements in the quality and efficiency of the formed tubes, showcasing the advantages of using GA in manufacturing processes. The findings contribute valuable insights into the application of laser forming technologies, highlighting the potential for further research in optimizing similar processes. Overall, this work emphasizes the importance of advanced optimization techniques in enhancing manufacturing efficiency and product quality [4]

The paper by Kamel Bensaid, Atef Boulila, Mahfoudh Ayadi, and Nabil Ben Fredj presents a numerical investigation into the incremental forming process of AISI 304 stainless steel. The authors utilize finite element analysis to study the effects of various process parameters on the material's deformation behavior during incremental forming. They focus on key factors such as tool path, step size, and forming speed, analyzing how these variables influence the mechanical properties and surface quality of the formed parts. The study reveals that optimizing these parameters can lead to improved accuracy and reduced defects in the final products. Additionally, the authors discuss the challenges associated with the incremental forming process, including material thinning and the potential for wrinkling. The findings provide valuable insights for manufacturers looking to enhance the efficiency and effectiveness of incremental forming techniques. Overall, this research contributes to a deeper understanding of the incremental forming process, paving the way for future advancements in the field of metal forming [5]

The study also reveals that the mechanical properties, such as yield strength and hardness, are influenced by the annealing process, demonstrating a trade-off between strength and ductility. Overall, the findings provide valuable insights into optimizing the processing conditions for bilayer sheets, contributing to advancements in manufacturing techniques for lightweight composite materials [65]

Figure 3Compression device used in Nakazima test [65]

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The paper by S.M. Atifeh, R. Hashemi, and M. Sedighi focuses on the investigation and optimization of the formability of bilayer sheets composed of Aluminum 1050 and Stainless Steel 304L, which are fabricated using the cold roll bonding technique. The authors employ the Box-Behnken method, a statistical approach for response surface methodology, to systematically analyze the effects of various processing parameters on the mechanical properties and Formability of the bilayer sheets. The study emphasizes the significance of optimizing parameters such as bonding pressure, temperature, and rolling reduction to achieve enhanced formability and mechanical performance. Through a series of experiments, the authors assess the influence of these parameters on the yield strength, tensile strength, and elongation of the bilayer sheets. The results indicate that the optimal conditions for maximizing formability can lead to improved performance in applications requiring lightweight and high-strength materials.
Additionally, the paper discusses the microstructural characteristics of the bonded layers, highlighting the importance of interfacial bonding quality in determining the overall formability. The findings contribute valuable insights into the processing and application of aluminum-stainless steel bilayer materials, paving the way for advancements in manufacturing techniques and material design. Overall, this research provides a comprehensive understanding of the factors influencing the formability of cold roll-bonded bilayer sheets, offering practical guidelines for optimizing their production in industrial settings [50]

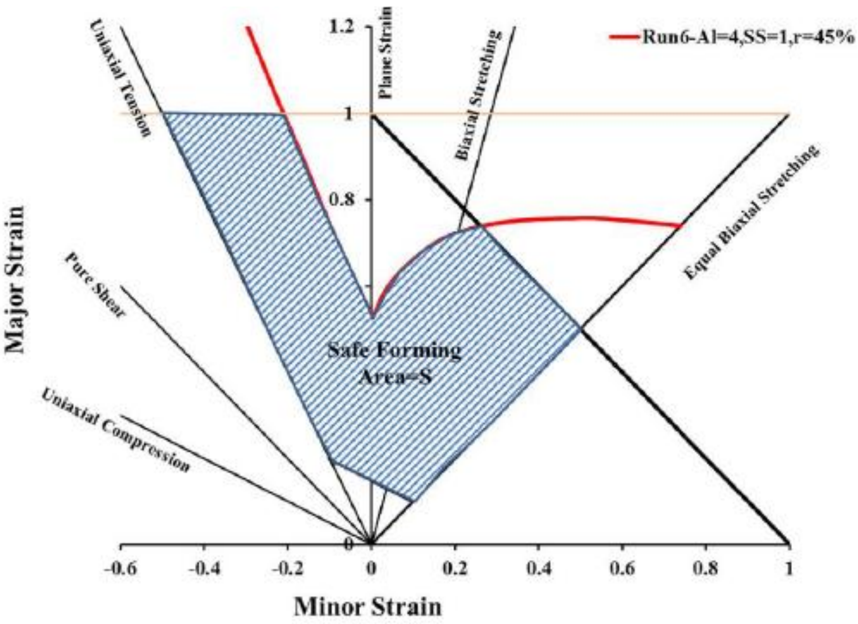

Figure 4 Safe forming areas, defined as design window and formability criterion [50]

The paper by Raghu Echempati and Andrew Fox explores the integration of metal forming processes with vibration analysis for sheet metal parts. The authors highlight the significance of understanding the dynamic behavior of sheet metal during forming operations, as vibrations can adversely affect the quality and accuracy of the final products. They present a comprehensive approach that combines numerical simulations of metal forming with vibration analysis techniques to predict and mitigate potential issues related to vibrations. The study investigates how different forming parameters influence the vibrational characteristics of the material, providing insights into optimizing the forming process to enhance product performance. The authors utilize advanced computational methods to model the interactions between forming forces and vibrational responses, demonstrating the effectiveness of their integrated approach. The findings indicate that incorporating vibration analysis into the design and optimization of metal forming processes can lead to improved quality and reduced defects in sheet metal components. The paper concludes by emphasizing the need for further research in this

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area to develop more robust manufacturing practices that account for dynamic behaviors during forming operations. Overall, this work contributes to the understanding of the interplay between metal forming and vibration, offering valuable insights for both researchers and practitioners in the field [19]

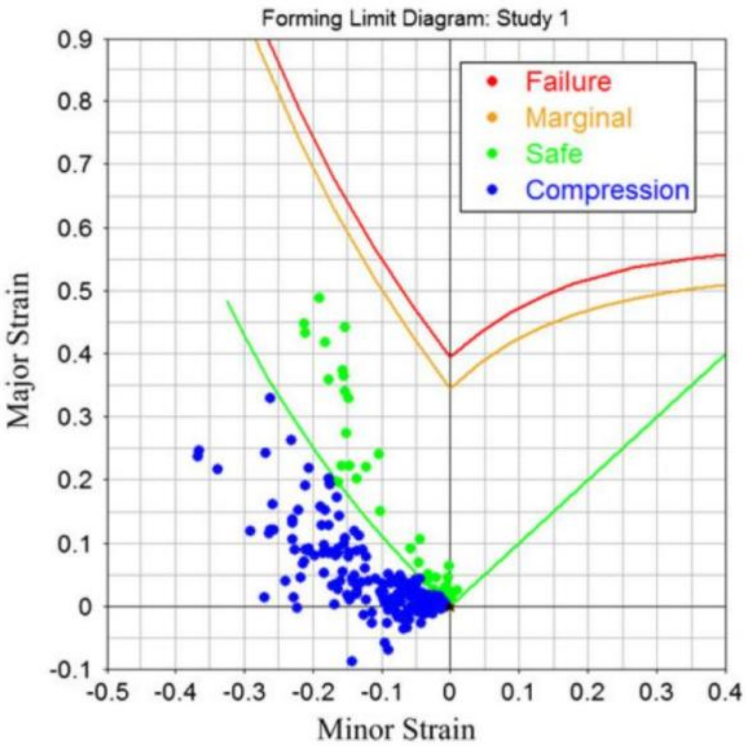

Figure 5 forming limit diagram (FLD) for the material of the bracket [19]

The paper by Yasmine Gabsi et al. focuses on the development and characterization of cladding AISI 304L stainless steel on aluminum, exploring the microstructure and mechanical properties of the resulting composite material. The authors detail the cladding process, emphasizing the importance of interfacial bonding and the effects of various parameters on the quality of the cladding. Through a series of experiments, they analyze the mechanical behavior, including tensile strength and corrosion resistance, highlighting the advantages of this cladding technique for applications requiring lightweight and durable materials. The study also discusses the potential for improved performance in industries such as automotive and aerospace, where the combination of stainless steel and aluminum can lead to enhanced functionality and longevity. Overall, the research provides a comprehensive understanding of the cladding process and its implications for material science and engineering [68]

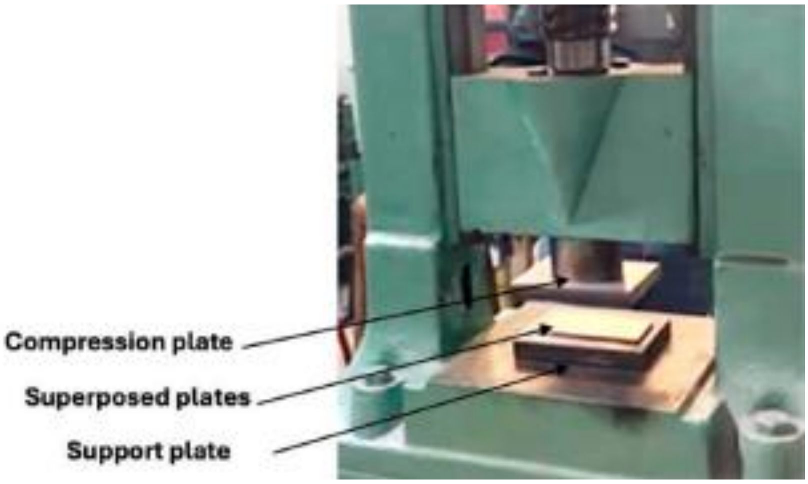

Figure 6 Hydraulic Machine with a capacity of 5 tons [68]

2. Apparatus and Procedures

2.1 Experimental Sets

The process of punching and removing the unusable part plays an important role in developing the required shape so that the sheet created inside should be set into the die set cavity. The strain paths of the cracked sheet were sensed in a computer system and further processed to analyze the forming parameters. The process parameters, such as pressure and axial feeds, affect the material behavior and quality of the components. The pressure and feed range from 0 to 0.05 GPa.The higher hardness properties in AISI304

3. Conclusion

As per the objective of this work, the simulation model results are compared with an experimental analysis for sheets with varying dimensions. According to research, under unidirectional settings, the mathematical and simulation model for austenitic and ferritic stainless steel has a sufficient degree of accuracy. There is a stronger link between the three categories of forecasts. When manufacturing sheet metal parts, the influencing or interacting parameters are taken into account through the optimization of materials, formability, and process parameters, as well as the selection of alternative materials for vehicles, weight reduction, product quality improvement, and customer satisfaction.

1) FLD shifts up and down simultaneously because of the bending effect. The applied normal stress by the punch is the main cause of the rise in the formability limit diagram. Due to the bending action, FLD simultaneously shifts up and down. The primary reason for the increase in the formability limit diagram is the typical stress that the punch applies.

2) In this study, the effect of crack formation on FLD is presented as linear principal (minor and major) strains, and this is given from experimental results.

References

[1] Ali El-Aty,YongXu,WenlongXie, Liang-Liang Xia,YongHou, ShihongZhang,Mohamed M. Z. Ahmed,BandarAlzahrani, Alamry Ali, Xinyue Huang S. Sobh, “Finite Element Analysis and Experimental Study of Manufacturing Thin-Walled Five-Branched AISI 304 Stainless Steel Tubes with Different Diameters Using a Hydroforming Process”, Materials (Basel), Vol17(1):104, 2023

[2] Peng Zhaoa, Cheng Chenga,Ali Abd EI-Atyc,d, Jie Taoa, Xunzhong Guoa, Yuting Jia,“Multi-scale framework-based crystal plasticity modeling and texture evolution of deformation behavior of AISI 304 stainless steel microtubes manufactured through 3D-FBF technology”,Research gate, National Natural Science Foundation of China,vol 5,pp1-15,2024

[3] Bora Sener,Emre Esener,Mehmet Firat,“Modeling plastic anisotropy evolution of AISI 304 steel sheets by a polynomial yield function”, SN Applied Sciences,Vol 3:181,2021

[4] Mohammadali Keshtiara,Sa’id Golabi1,Rasoul Tarkesh Esfahani, “Multi-objective optimization of stainless steel 304 tube laser forming process using GA”, Springer-Verlag London Ltd., part of Springer Nature,pp1-10,2019

[5] Kamel Bensaid, Atef Boulila, Mahfoudh AyadiNabil Ben Fredj, “Numerical investigation of incremental forming process of AISI 304 stainless steel”, Ironmaking & SteelmakingProcesses, Products and Applications, 362559086, pp1-25, 2022

[6] Yong Hou,Dongjoon Myung,Jong Kyu Park, Junying Min,Hyung-Rim Lee, Ali Abd El-Aty, “A Review of Characterization and Modelling Approaches for Sheet Metal Forming of Lightweight Metallic Materials”, MDPI, Basel, Switzerland,10.3390,ma16020836,vol 6,pp1-17,2023

[7] Baloji Dharavath,Ahsan ul Haq,M. Dinesh Varma,Swadesh Kumar Singh, M.T. Naik, “Influence of strain rates on forming characteristics of ASS316 L sheets at elevated temperatures”, Elsevier Ltd,Vol 7,pp1-12,2020

[8] Ashish Gohil and Bharat Modi, “of the effect of process parameters on performance measures in the incremental sheet forming process”, Engineering Manufacture,Vol 6,pp1-17,2020

[9] Stephan Rosenthal1,Fabian Maa,Mike Kamaliev,Marlon Hahn, Soeren Gies A, Erman Tekkaya,“Lightweight in Automotive Components by Forming Technology”,Springer Automotive Innovation (2020) 3:195–209,pp1-19,2020

[10] Amlan Das, “A Comprehensive Review on Incremental Sheet Forming and its Associated Aspects” journal of Engineering Science and Technology Review, 17,159 – 178,pp1-16,2024

[11] Mohaddeseh Tebianian,Sara Aghaie,Nazanin Sadat Razavi Jafari,Seyed Reza Elmi Hosseini, Antonio B. Pereira ,Fabio A. O. Fernandes,Mojtaba Farbakhti,Chao Chen and Yuanming Huo, “A Review of the Metal Additive Manufacturing Processes”, Published by MDPI, Basel, Switzerland 16247514,pp1-19,2023

[12] Antonio Formisano and Massimo Durante, “A Comprehensive Review on the Incremental Sheet Forming of Polycarbonate”, Published by MDPI, Basel, Switzerland, doi.org/10.3390/16213098,pp1- 17,2024

[13] Stefan Holmberg, Bertil Enquist, Per Thilderkvist, “Evaluation of sheet metal formability by tensile tests”, Journal of Materials Processing Technology, Vol 145, 72–83,pp1-35,2004

[14] Torgeir Welo, Francisco Chinesta, “Sheet Metal Forming: An Overview of Advances in Technology Development Based on ESAFORM Contributions in the Period 1998-2006”, researchgate.net/publication/227058810,Vol 1,pp1-7,2007

[15] Vinod Laxman Hattallia, Shivashankar R. Srivatsaa, “Sheet Metal Forming Processes –Recent Technological Advances”, Materials Today: Proceedings, Vol 5 2564–2574, pp1-10, 2018

[16] P. A. Prates, A. S. Adaixo, M. C. Oliveira, J. V. Fernandes, “Numerical study on the effect of mechanical properties variability in sheet metal forming processes”, The International Journal of Advanced Manufacturing Technology 96:561–580, pp1-10,2018

[17] Jae-Jun Lee, Gyung-Jin Park, “Optimization of the structural and process parameters in the sheet metal forming process”, Journal of Mechanical Science and Technology, Vol 28 ,pp1-12,2014

[18] Sunil D Majagi, Dr. G. Chandramohan, “Optimization of Incremental Sheet metal forming parameters by Design of Experiments”, Applied Mechanics and Materials Vol. 527,pp1-3,2014

[19] Raghu Echempati , Andrew Fox, “Integrated metal forming and vibration analysis of sheet metal parts”, Published by Engineering with Computers, Vol 29,pp1-10,2012

[20] Meelis Pohlak, Rein Kuttner, Juri Majak, “Modelling and optimal design of sheet metal RP&M processes”, Emerald Rapid Prototyping Journal, Vol 11/5, pp1-7, 2005

[21] Hakim S. Sultan Aljibori and Abdel MagidHamouda, “Finite Element Analysis of Sheet Metal Forming Process”, European Journal of Scientific Research, Vol.33 No.1, pp57-69, 2009 [22] Tze-Chi Hsu, Chan-Hung Chu, “A finite-element analysis of sheet metal forming processes", Journal of Materials Processing Technology, Volume 54, Issues 1–4, pp70-75, 1995

[23] J. Nithinkumar, D. Gopi Chand, N. Chandra Shekar, “Finite Element Analysis of Sheet Metal Works for Deep Drawing in Manufacturing of Fly Wheel Cup” International Journal Of Engineering Research & Technology (IJERT),Vol 03, ISSUE 09, pp935-939, 2014

[24] Karem M. Younis , Adnan I. Mohammed, Jalil J. Shukur, “Rubber Pad Sheet Metal Forming of Round Metal Blanks into Multi Shape Axisymmetric Cups by FEA and Experimental Methods", Engineering and Technology Journal, Vol. 37, Part C, No. 3, pp370-376,2019

[25] Tomasz Trzepiecinski, “Recent Developments and Trends in Sheet Metal Forming", Metals, 10, 779, pp1-54, 2020

[26] Stefanos C. Spathopoulos and Georgios E. Stavroulakis, “Springback Prediction in Sheet Metal Forming, Based on Finite Element Analysis and Artificial Neural Network Approach”,Applied Mechanics, 1, pp97–110; 2020

[27] OlleSandin Juan Manuel Rodríguez, Patrick LarourSergiPararedа , Davidrómeta, “A particle finite element method approach to model shear cutting of high-strength steel sheets”Computational Particle Mechanics, Vol.11, pp1863–1886, 2024

[28] MarekTkocz, Karolina Kowalczyk, Tomasz Bulzak, Magdalena B. Jabłońska, Marek Hawryluk,“Finite element analysis of material deformation behavior during DRECE: the sheet metal SPD process”,Archives of Civil and Mechanical Engineering, V 23:145, pp1-10, 2023

[29] Baran Güler, Mert Efe, “Forming and Fracture Limits of Sheet Metals Deforming without a Local Neck”, Journal of Materials Processing Technology, Vol 12, pp1-15, 2017

[30] Shenghua Wu, RuiAmaral, Nannan Song, Abel D. Santos, F.M. Pires, " Formability Prediction For Dual Phase Steel Sheets ", International Deep Drawing Research Group IDDRG 2016 International Conference,, Linz, Austria, 2016

[31] Ranjeet Prasad,Manish Oraon and Vinay Sharma, “Exploring advancements in incremental sheet metal forming: a Review by”, Engineering Research Express 012401,volume 7,pp1-7,2025

[32] R. Norz,F. R. Valencia, “Experiments on forming behaviour of the aluminium alloy AA6016”, International Deep-Drawing Research Group Conference (IDDRG 012023),pp1-4,2022

[33] Saad Habeeb Al-Behadili, Abdussalam Salem Abdulmawlah, “Determining The Forming Limit Curves Experimentally By Using Nakazima Approach And Compare Them With Theoretical Data”, journal of sciences and technologies, vol.7, no.1, ISSN: 2959 – 3298,pp1-30,2023

[34] Horst Meier, Oliver Dewald, Jian Zhang, “Development of a Robot-Based Sheet Metal Forming Process”, Steel research int. 76 No. 2/3,pp1-15,2005

[35] Mateusz Kopec and Denis J. Politis, “Advances in Sheet Metal Forming Processes of Lightweight Alloys”, Licensee MDPI, Basel, Switzerland 0.3390/ma16093293,pp1-5,2023

[36] Yong Hou1,Dongjoon Myung,Jong Kyu Park, Junying Min, Hyung-Rim Lee Ali Abd El-Aty, and Myoung-Gyu Lee, “A Review of Characterization and Modelling Approaches for Sheet Metal Forming of Lightweight Metallic Materials”, Published by MDPI, Basel, Switzerland 16020836,pp1-10,2023

[37] Haibo Wang, Qiang Niu and Yu Yan, “Study of Anisotropic Behavior in Sheet Metal Forming”, Published by MDPI, Basel, Switzerland 17092031,pp1-25,2023

[38] Pankaj Wankhede,Nara Guru Narayanaswamy,Suresh Kurra, Amrita Priyadarshini, “A portable device for single point strain analysis in sheet metal forming processes”, HardwareX 12 -e00371,pp1-10,2022

[39] Sherwan Mohammed Najm,Tomasz Trzepieci nski,Salah Eddine Laouini, Marek Kowalik,Romuald Fejkiel and Rafał Kowalik, “Application of the Gradient-Boosting with Regression Trees to Predict the Coefficient of Friction on Drawbead in Sheet Metal Forming”, Published by MDPI, Basel, Switzerland 17184540,pp1-10,2024

[40] Maciej Balcerzak,Stanislav Rusz,Radek C ada,Martin Pastrnk,ndrej Hiler, “An Investigation into Sheet-Inconel 718 Forming with Flexible and Metal Tools-Simulation and Experiment”, Published by MDPI, Basel, Switzerland 17133168,pp1-12,2024

[41] Luca Corallo, Patricia Verleysen, “High-speed sheet metal forming: Numerical study of high speed Nakajima testing”, DYMAT Winter School Proceedings,pp1-5,2020

[42] Meng Chena,Zhipeng Laia,Quanliang Cao, Xiaotao Hana,Chen Wanga,Ning Liua Liang Lia, “Improvement on formability and forming accuracy in electromagnetic forming of deep-cavity sheet metal part using a dual-coil system”, Journal of Manufacturing Processes 57,pp1-30,2020

[43] Gunther Schuha, Georg Bergweilera, Philipp Bickendorfa, Falko Fiedlera, Can Colaga, “Sheet Metal Forming Using Additively Manufactured Polymer Tools”, 53rd CIRP Conference on Manufacturing Systems,pp1-20,2020

[44] Pankaj Wankhede & Kurra Suresh, “A review on the evaluation of formability in sheet metal forming”, Advances in Materials and Processing Technologies,pp1-15,2020

[45] ShamikBasak,Sushanta Kumar Panda,Myoung-Gyu Lee, “Formability and fracture in deep drawing sheet metals: Extended studies for pre-strained anisotropic thin sheets”, International Journal of Mechanical Sciences, Vol. 170, 105346, 2020

[46] Ahmad Ghazanfari, Seyed Soroush Soleimani, Mansour Keshavarzzadeh, Mostafa Habibi, Ahmad Assempuor&RaminHashemi, “Prediction of FLD for sheet metal by considering through-thickness shear stresses”, Mechanics Based Design of Structures and Machines an International Journal, Volume 48, Issue 6, 2019

[47] F. Turki, H. Seyed Salehi1, A. JalaliAghchei,J. BakhtiariDoost, “Analysis of the Process of Forming Stainless Steel Sheets Using the Forming Limit Diagram", Transactions on Machine Intelligence, Vol.6(3), pp166-174, 2023

[48] T. Mayavan, G. Senthilkumar1, L. Karthikeyan, and N. Karthikeyan, “Formability Prediction Of AISI 304 Steel Sheet Based On Forming LimitDiagram Through Finite Element Analysis And Nakazima Test”, Journal of Applied Science and Engineering, Vol. 27, No 4, pp 2335-2343, 2023

[49] Emil Evin, and MiroslavTomas,“Formability Prediction of Laser-Welded Stainless Steel AISI 304 and AISI 430”,Metals, 12, 54, pp1-21, 2022

[50] S.M. Atifeh, R. Hashemi, M. Sedighi, “Investigation and optimization on the formability of aluminum1050 stainless steel 304L bilayer sheets fabricated by cold roll bonding considering the Box-Behnken method”,Journal of Materials Research and Technology, Vol.31,pp3453–3465, 2024

[51] Surajit K Paul, G Manikandan and Rahul K Verma, “Prediction of entire forming limit diagram from simple tensile material properties”,Journal of Strain Analysis 48(6), pp386-394, 2013

[52] Bapurao G. Marlapalle and Rahulkumar S. Hingole, “Numerical and experimental predictions of formability parameters in tube hydroforming process”,Australian Journal of Mechanical Engineering, Vol. 21, Issue 3, Pages 991-1007, 2021

[53] Mr. Rohan d. Ahirrao1, prof. B.g. Marlapalle, “A Review Paper on Analysis and Optimization of Aluminium Casting Parameters”, International Research Journal of Engineering and Technology, Vol 06, pp1-20, 2019

[54] Patrick Link ,Lars Penter, Ulrike Rückert, Lars Klingel Alexander Verl, Steffen Ihlenfeldt,“Real-time quality prediction and local adjustment of friction with digital twin in sheet metal forming”, Robotics and Computer-Integrated Manufacturing, 91,102848, 2025

[55] Frank E Goodwin1, Eduardo A Silva, “North American Zinc-based Sheet Steel Coatings Technology and Production: Status and Opportunities” Research gate publication,pp 1-5,2013

[56] Wei Chen,gyan Wu, Zhongfu Huang, Yi Ding ,d and Fengze Dai, “Studies on the Processes Design of Multi-Step Sheet Metal Forming” Advanced Materials Research, Vol 146-147, pp1-20,2010

[57] D Kohl and M Merklein “Alternative characterization method for the failure behavior of sheet metals derived from Nakajima test”,IOP Conf. Series: Materials Science and Engineering, 1157, 012046,pp1- 20,2021

[58] Affronti, Emanuela , Merklein, Marion, "Metallographic analysis of Nakajima tests for the evaluation of the failure developments",Procedia Engineering 183, pp83 – 88, 2017

[59] G. Venkateswarlu, M. J. Davidson and G. R. N. Tagore, "Influence of process parameters on the cup Drawing of aluminium 7075 sheet",International Journal of Engineering, Science and Technology Vol. 2, No. 11, pp. 41-49, 2010

[60] DepingPeng,Shun Chen,RoyaDarabi,Aria Ghabussi,MostafaHabibi, "Prediction of the bending and out-of-plane loading effects on formability response of the steel sheets",Archives of Civil and Mechanical Engineering, 21:74, 2021

[61] Ankit C. Pambhar , Janak B. Valaki , "Experimental studies of formability in single point incremental forming of Cu-Al bimetallic sheets", Materials today Proceedings, https://doi.org/10.1016/j.matpr.2023.07.158,pp1-22,2023

[62] Stephan Rosenthal1,Fabian Maa,Mike Kamaliev,Marlon Hah,Soeren Gies,A. Erman Tekkaya, "Lightweight in Automotive Components by Forming technology", Automotive Innovation 3:195–209,Vol 7,pp1-15,2020

[63] Arun Prasad Moorthy, Chinnaiyan Sathiya Narayanan, "Improvement of formability and surface finish of cupro-nickel (70/30) alloy during single point incremental forming process using chrome steel laser ablated ball", World Scientific Publishing Company, 2450061,Vol 1,pp1-6,2024

[64] Tomasz Trzepieci,nski,Sherwan Mohammed Najm,Valentin Oleksik,Delia Vasilca,Imre Paniti,and Marcin Szpunar, "Recent Developments and Future Challenges in Incremental Sheet Forming of Aluminium and Aluminium Alloy Sheets", mdpi.com/journal/metals 2010124,pp1-10,2022

[65] Seyed Mehdi Atifeh ,A. Rouzbeh , Ramin Hashemi , M. Sedighi, "Effect of annealing on formability and mechanical properties of AA1050/Mg- AZ31B bilayer sheets fabricated by explosive welding method", The International Journal of Advanced Manufacturing Technology volume 118, pages775–784,pp1-20,2022

[66] Rebar Hama-Saleha,Andreas Weisheita, Johannes Henrich Schleifenbauma, Ismail Unsalc, Alexander Sviridovc, Markus Bambachc, "Analysis of Micro-Alloyed Sheet Metals Reinforced additive manufacturing", Published by Elsevier Ltd,vol 2351-9789,pp1-12,2020

[67] Fatih Civelek1, Ahmet Ozdemir, "Evaluation of formability criteria for sheet metal materials", Journal of Polytechnic1617-1631,pp1-15,2024

[68] Yasmine Gabsi, Sahar Zouari, Mariem Abdennadher, Lamine Dieng, Riadh Elleuch, "Development and Characterization of Cladding AISI 304L Stainless Steel on Aluminum", Journal of manufacturing and processing unit 9020030,pp1-16,2025

[69] Katerina Rubesova,Martin Rund,Sylwia Rzepa,Hana Jirkov,St epan jeni, Pavel Konopik, "Determining Forming Limit Diagrams Using Sub-Sized Specimen Geometry and Comparing FLD Evaluation Methods", Licensee MDPI, Basel, Switzerland 11030484,pp1-6,2021

[70] Stefan Walzera,Mathias Liewalda, "Novel approach to decrease sheet hinning during sheet metal forming by using embossing technique", Procedia Manufacturing 50 - 795–799,pp1-6,2020