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A Review on Sheet Metal Forming: Effects of Process Parameters, Materials, and Optimization Techniques

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Abstract:
The sheet metal forming technique is widely used in automotive industry for manufacturing of various components. Several different processing methods have been implemented in the industries to achive its repeatability and productivity. The current research reviews existing work conducted in sheet metal forming process using numerical and experimental techniques. The study on effect of operational parameters, material type and optimization process has been presented.

Keywords: Sheet metal forming analysis, FEM, forming limit diagram, sheet metal forming process.

1. INTRODUCTION

Sheet metal forming (SMF) is one of the most fundamental and widely adopted manufacturing processes used to produce complex, high-precision components across a broad range of industries, including automotive, aerospace, electronics, and consumer goods. The growing demand for lightweight structures, improved fuel efficiency, and cost-effective mass production has further increased the importance of advanced sheet metal forming techniques. These processes enable the transformation of flat metal sheets into desired geometries through controlled plastic deformation while maintaining structural integrity and dimensional accuracy [1].

Sheet metal forming (SMF) techniques are widely used in many industries to produce final-shaped components from a workpiece. In an SMF process, a thin piece of metal sheet is stretched into a desired shape by a tool without wrinkling or excessive thinning. In the past decade, methods for forming high-strength materials with low plasticity and difficult-to-form metals have been developed for cold, warm, and hot forming conditions [1], [2]. These advancements have significantly expanded the applicability of SMF processes, particularly in the manufacturing of high-performance and lightweight components.

The performance and quality of sheet metal forming processes are strongly influenced by several key factors, including process parameters, material properties, and tooling conditions. Process parameters such as blank holder force, punch speed, lubrication, temperature, and die geometry play a critical role in determining the final product quality. Improper selection of these parameters can lead to defects such as wrinkling, tearing, springback, and non-uniform thickness distribution. Therefore, understanding the relationship between these parameters and forming behavior is essential for achieving defect-free components.

Material characteristics also significantly affect the formability of sheet metals. Properties such as yield strength, ductility, strain hardening exponent, and anisotropy influence how a material responds to deformation. The increasing use of advanced high-strength steels (AHSS), aluminum alloys, and other lightweight materials has introduced new challenges in forming due to their limited ductility and higher strength. As a result, innovative forming techniques and process modifications are required to improve their formability and ensure reliable production.

In recent years, optimization techniques have gained considerable attention in sheet metal forming to enhance process efficiency and product quality. Methods such as design of experiments (DOE), response surface methodology (RSM), genetic algorithms (GA), and machine learning approaches are increasingly being used to determine optimal process conditions. Additionally, the integration of numerical simulation tools, particularly finite element analysis (FEA), has enabled accurate prediction of material behavior, stress distribution, and defect formation, thereby reducing the need for costly experimental trials.

This review paper aims to provide a comprehensive overview of sheet metal forming processes, focusing on the effects of process parameters, material properties, and optimization techniques. It highlights recent developments, challenges, and research trends in SMF, offering valuable insights for improving forming performance and supporting the development of advanced manufacturing solutions.

2. LITERATURE REVIEW

According to Liu et al. [3], numerical formulations in sheet metal forming (SMF) can be broadly classified into three main categories: static explicit, static implicit, and dynamic explicit methods. These numerical approaches play a crucial role in simulating forming processes; however, the modeling of advanced metallic materials, such as multiphase steels, requires the use of full-field models to accurately capture their complex microstructural behavior. Trzepieciński et al. [4] proposed a microstructure-based multiscale modeling approach for large strain plastic deformation by coupling a full-field crystal plasticity spectral solver with an implicit finite element solver. The developed model incorporates both dislocation density evolution and phenomenological hardening laws, making it suitable for materials with complex microstructures, including variations in grain morphology, multiple phases, and crystallographic textures.

Ma et al. [5] utilized a plastic strain-based criterion that accounts for the triaxial stress state to predict fracture in stamped components using simple tensile tests. They employed the Digital Image Grid Method (DIGM) to analyze strain localization behavior and local strain distribution. Based on this approach, a new methodology was proposed to determine the ductile damage limit of steel sheets by considering the historical evolution of nonlinear local strain and fracture strain. Furthermore, the widely used Cockcroft damage criterion, which integrates plastic strain with maximum principal stress, was validated as an effective tool for predicting fracture under various loading conditions.

In a subsequent study, Ma et al. [6] combined experimentally measured transient displacement fields with finite element modeling to develop a measurement-based FEM (M-FEM). This approach enabled accurate computation of local stress and strain distributions, as well as the accumulation of ductile damage in tensile specimens.

For thin metal sheets, non-uniform pressure distribution can lead to localized necking instability, ultimately resulting in fracture. To address this issue, Shen et al. [7] proposed a mechanism involving a rubber-induced smoothing effect on confined laser shock waves. This smoothing effect was attributed primarily to the radial expansion of the plasma cloud on the rubber surface, which helps in achieving a more uniform pressure distribution.

Kayan and Kaftanoglu [8] investigated non-isothermal deep drawing processes applied to DP600 high-strength low-alloy (HSLA) and interstitial-free (IF) steels under elevated temperature conditions. Their findings indicated that warm forming enhances the Limiting Drawing Ratio (LDR) without causing significant changes in the material’s microstructure. Additionally, the proposed process strategy effectively mitigates issues such as springback and high residual stresses commonly encountered under ambient forming conditions.

Xu et al. [9] explored electrically assisted incremental sheet forming by integrating an electrically assisted method with double-sided incremental sheet forming (E-DSIF). A specially designed slave tool force control device was employed to maintain stable contact between the tool and the sheet. The results demonstrated that E-DSIF significantly reduces springback in the final components during unclamping and trimming stages, thereby improving dimensional accuracy.

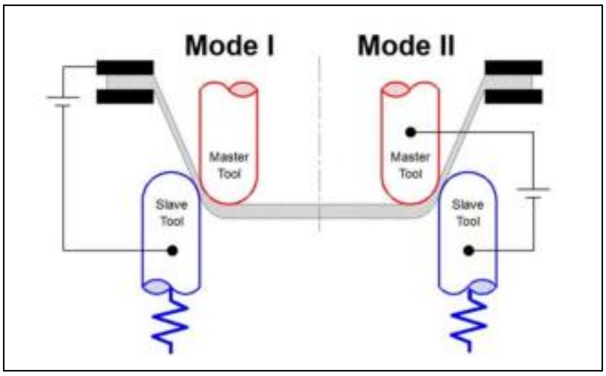

Figure 1: Schematic diagram of the circuit connection in E-DSIF [9]

Al-Obaidi et al. [10] designed a fixture for hot single-point incremental forming of glass-fiber-reinforced polymer (GFRP) supported by hot air. The GFRP sheet was sandwiched between combinations of two poly tetra fluoro ethylene (PTFE; commonly known as Teflon) layers and metal sheets (Figure 2). The Teflon layer was used to reduce the flow of the melted matrix polymer out of the woven fiber. The aim of the work was to develop a way to shorten the production process for medical implants which will dramatically reduce the cost of their manufacture. In general, the relationship between the depth of the formed part and the heat initiated was found to make the overall work piece temperature homogeneous.

Belhassen et al. [11] introduced FEM to analyze the RPF process in AA6061-T4 sheet metal. An elastic-plastic constitutive model with a J2 yield criterion and mixed nonlinear isotropic/kinematic hardening coupled with Lemaitre’s ductile damage has been adopted during forming. Irthiea et al. [12] report the results of FE simulation and experimental research on micro deep drawing processes of 304 stainless steel sheets using a flexible die. Two novel approaches were considered with regard to the positive and negative initial gap between an adjustment ring and a workpiece and a blank holder (Figure 3). Initial gaps affect the final cup profiles, in particular at the shoulder corner radius (Figure 4). The numerical predictions conducted in Abaqus/Standard software reveal the capability of the proposed technique to produce micro metallic cups with high quality and a large aspect ratio.

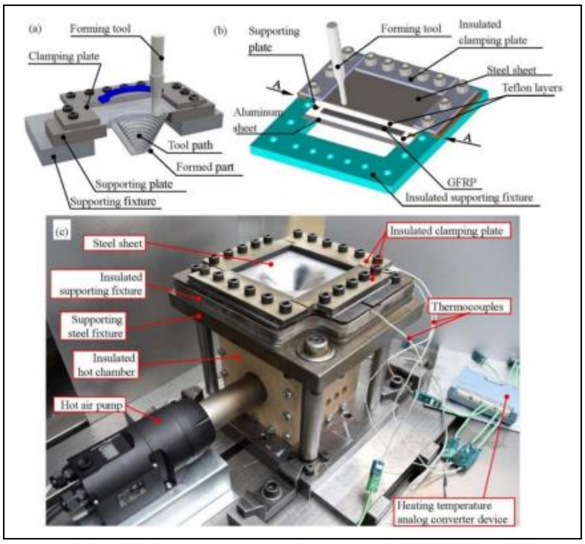

Figure 2: Principle of SPIF, work piece combination [10]

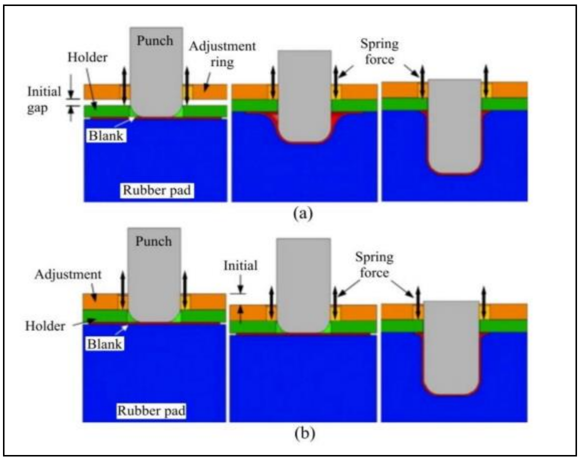

Figure 3. Flexible forming technology with (a) positive and (b) negative initial gap [12]

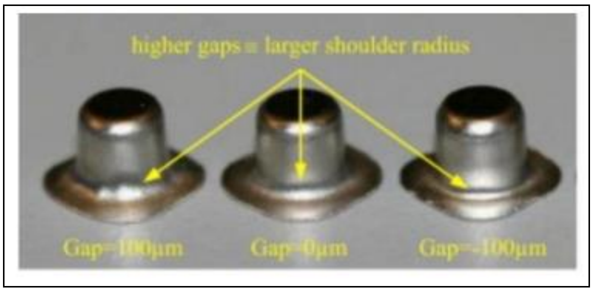

Figure 4. Cups formed with different initial gaps [12]

Prashant P. Khandare [13]. Metal forming is a process in which the desired shape and size are obtained through plastic deformation of a material without any loss of material. Bending is a metal forming process in which straight length is transformed into a curved length. Roller forming process is a continuous bending operation in which a long strip of metal is passed through typical roller adjustments, until the desired curvature shape is obtained. The bending changes according to material and according to the loading condition and thickness of sheet. Panthi et al. [14] used analyzed elastic recovery in sheet metal bending with the help of finite element simulation. This study examined the effect of load on spring b back with varying thickness and die radius. Bahloul R.et al. [15] used finite element simulation for the prediction of punch load and stress distribution during the wiping-die bending process. Here numerical simulation was modelled using elastic plastic theory coupled with Lemaitre's damage approach. They used ABAQUS for finite element simulation. The punch load and stress distribution was be predicted in view of optimization using response surface methodology (RSM) based on design of experiments.

Joshi et. al. [16] studied optimization of variation in wall thickness of deep drawn cup using combined methodology of design of experiments and finite element methodology. They called this methodology as virtual design of experiment. Their investigation involved the effect of die radius, sheet metal thickness and blank holder force on wall thickness variation in cup drawing using finite element simulation. Su et al. [17] proposed a new two-step electromagnetic forming process which combines EMF with electromagnetic calibration for local features of large-size sheet metal parts. During this process, the work piece is first electromagnetically formed by a flat spiral coil and then electromagnetically calibrated by a helical coil with a similar shape to the final profile of the work piece. Su et al. [18] studied the uneven deformation behaviour of a 2219 aluminium alloy work piece formed by electromagnetic flanging. The authors established a numerical model in LS-DYNA 8.0 software to study the effect of different axial angles between the flanging direction and the normal direction of the sheet. They concluded that uneven deformation behaviour is essentially due to the uneven deformation requirement.

3. CONCLUSION

The sheet metal forming process is being analyzed by various researchers using FEM and experimental techniques. The feasibility of different techniques of fault detection i.e. digital image grid method (DIGM), double sided incremental forming (E-DSIF) is determined. Various tests are conducted using LS-DYNA technique and critical regions of high stresses and deformation are identified.

REFERENCES

[1] L. F. Folle, T. N. Lima, M. P. S. Santos, B. Callegari, B. C. S. Silva, L. G. S. Zamorano, and R. S. Coelho, “A review on sheet metal forming behavior in high-strength steels and the use of numerical simulations,” Metals, vol. 14, no. 12, p. 1428, 2024.

[2] E. K. Ibrahim and M. H. Sadoon, “An analytical review of incremental single sheet metal forming technique,” in Proceedings of the International Conference on Engineering and Advanced Technology (ICEAT), Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), vol. 37, pp. 661–675, 2025.

[3] X. Liu, W. K. Sun, and K. M. Liew, “Multiscale modeling of crystal plastic deformation of polycrystalline titanium at high temperatures,” Computer Methods in Applied Mechanics and Engineering, vol. 340, pp. 932–955, 2018.

[4] T. Trzepieciński and H. G. Lemu, “Effect of computational parameters on springback prediction by numerical simulation,” Metals, vol. 7, p. 380, 2017.

[5] N. Ma, K. Takada, and K. Sato, “Measurement of local strain path and identification of ductile damage limit based on simple tensile test,” Procedia Engineering, vol. 81, pp. 1402–1407, 2014.

[6] N. Ma, K. Sato, and K. Takada, “Analysis of local fracture strain and damage limit of advanced high strength steels using measured displacement fields and FEM,” Computers, Materials & Continua, vol. 46, pp. 195–219, 2015.

[7] Z. Shen, X. Wang, H. Liu, Y. Wang, and C. Wang, “Rubber-induced uniform laser shock wave pressure for thin metal sheets microforming,” Applied Surface Science, vol. 327, pp. 307–312, 2015.

[8] E. Kayhan and B. Kaftanoglu, “Experimental investigation of non-isothermal deep drawing of DP600 steel,” International Journal of Advanced Manufacturing Technology, vol. 99, pp. 695–706, 2018.

[9] D. K. Xu, B. Lu, T. T. Cao, H. Zhang, J. Chen, H. Hong, and J. Cao, “Enhancement of process capabilities in electrically-assisted double sided incremental forming,” Materials & Design, vol. 92, pp. 268–280, 2016.

[10] A. Al-Obaidai, A. Kunke, and V. Kräusel, “Hot single-point incremental forming of glass-fiber-reinforced polymer (PA6GF47) supported by hot air,” Journal of Manufacturing Processes, vol. 43, pp. 17–25, 2019.

[11] L. Belhassen, S. Koubaa, M. Wali, and F. Dammak, “Numerical prediction of springback and ductile damage in rubber-pad forming process of aluminum sheet metal,” International Journal of Mechanical Sciences, vol. 117, pp. 218–226, 2016.

[12] I. Irthiea, G. Green, S. Hashim, and A. Kriama, “Experimental and numerical investigation on micro deep drawing process of stainless steel 304 foil using flexible tools,” International Journal of Machine Tools and Manufacture, vol. 76, pp. 21–33, 2014.

[13] P. P. Khandare, D. N. Patel, M. K. Aher, R. S. Parbat, and S. S. Patil, “Study of portable 3 roller pipe bending machine,” in Proceedings of the International Conference on Emerging Trends in Engineering and Management Research, pp. 624–630, 2016.

[14] S. K. Panthi, N. Ramakrishnan, K. K. Pathak, and J. S. Chouhan, “An analysis of springback in sheet metal bending using finite element method,” Journal of Materials Processing Technology, vol. 186, no. 1, pp. 120–124, 2007.

[15] R. Bahloul, A. Mkaddem, P. Dal Santo, and A. Potiron, “Sheet metal bending optimisation using response surface method, numerical simulation and design of experiments,” International Journal of Mechanical Sciences, vol. 48, no. 9, pp. 991–1003, 2006.

[16] M. K. N. Joshi, B. T. Patil, and M. S. Satao, “Review of optimization aspects for metal forming process,” Engineering Science and Technology: An International Journal (ESTIJ), vol. 4, no. 2, pp. 71–75, 2014.

[17] H. Su, L. Huang, J. Li, F. Ma, P. Huang, and F. Feng, “Two-step electromagnetic forming: A new forming approach to local features of large-size sheet metal parts,” International Journal of Machine Tools and Manufacture, vol. 124, pp. 99–116, 2018.

[18] H. Su, L. Huang, J. Li, F. Ma, H. Ma, P. Huang, H. Zhu, and F. Feng, “Inhomogeneous deformation behaviors of oblique hole-flanging parts during electromagnetic forming,” Journal of Manufacturing Processes, vol. 52, pp. 1–11, 2020.