Review of Single-Acting Stroke Deep Drawing Techniques for the Production of Symmetric Low-Depth Components

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Abstract: *This thesis explores the convergence of conventional sheet metal forming techniques with the realm of fibre-based materials, particularly in the context of packaging. While sheet metal fabrication has seen extensive use in various industries, its application in fibre-based materials like paperboards remains underexplored. The aim is to investigate the potential adaptation of conventional sheet metal forming techniques to fibre-based materials to offer sustainable and biodegradable alternatives to traditional plastics and metals. The focus is on deep drawing, a key process in sheet metal forming, and its potential application to fibre-based materials. Through a review of literature and experimental studies, this thesis examines various parameters affecting deep drawing processes, such as die geometry, punch movement, cushioning, and blank holder force (BHF). Additionally, advancements in deep drawing technology, optimization methods, and the environmental impact of the process are discussed. The thesis concludes by outlining future research directions to overcome challenges and enhance the efficiency, versatility, and quality of the deep drawing process for fibre-based materials.*

Keywords: *Sheet metal, fibre-based, efficiency, deep drawing, blank holder.*

I.INTRODUCTION

In recent years, special efforts have thus been made to steadily accelerate process digitalisation, which is becoming increasingly important not only in production, but also in the development departments [1]. The pre- and post-production processes that are required for the manufacture of technical products are also gaining in significance. Shear cutting must be recognized as one of its most widely used methods, particularly in the preparation of sheet materials, that are utilized in the manufacturing chain of practically every technological product. In this case, the industry's most popular process variation is traditional shear cutting. In the fabrication of flexible sheet metal, this method is frequently utilized on single-acting press or machine machines to create complete workpieces. The field of metal sheet production has a distinguished history of technological advancement and inventiveness. Several industries, including the automotive and aerospace sectors, have experienced revolutionary shifts as a result of well-established processes like hydroforming, roll forming, stamping, deep drawing, and roll forming [2].The application of metal sheet production processes is widely recognized across several sectors [3], but its use in fiber-based materials, including paperboards, has not been thoroughly studied. This thesis looks on possible modifications or inventive uses of traditional sheet metal forming methods for fiber-based materials in an effort to close the gap that currently exists.

The increasing need for accountability and transparency in product packaging due to consumer expectations and an enticing solution that provides sustainable development and biodegradable alternative to conventional metals and plastics. The manufacture of sheet metal and fiber-based packaging, two seemingly unconnected disciplines, came together to give rise to this idea. Traditionally, the essential processes in industrial manufacture have been the standard methods of forming sheet metal [4]. These processes offer a high degree of efficacy and precision when it comes to metallic materials. Due to process inefficiencies and limits set by the laws of thermodynamics, as much as 20% - 50% of all energy put into the industrial sector is lost in the form of waste heat. This presents a significant energy resource and, if recovered, can offset the financial and environmental cost of energy production. As a result, waste heat recovery has received considerable research in literature. This research typically categorises waste heat into three temperature ranges: High-grade (> 650°C), medium-grade (230°C - 650°C), and low-grade (< 230°C). High and medium grade waste heat's higher temperatures makes recovery relatively simple and as a result it is adopted widely in industry. However, low-grade waste heat (LGWH) is more difficult to recover. Barriers to LGWH recovery suggested in literature include its weak potential, difficult utilisation, lack of suitable heat sink, and typical poor economic payback period.

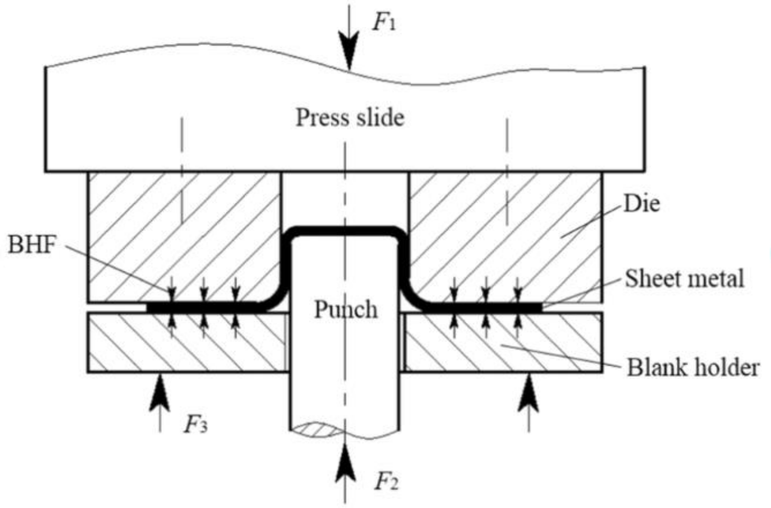

Fig.1. Deep drawing using conventional blank holder [5]

II. LITERATURE REVIEW

In**Shaaban, A. et al. (2021) [6]**, the parameters influencing deep drawing of symmetrical low-depth goods, such as die geometry, punch motion, and cushioning, are studied through numerical and experimental analyses. This study applies its suggested approach to a deep drawing of a frying pan made of AL99.9%. With LS-Dyna, a model of finite elements (FE-model) is created, and its validity is tested by an experiment.The maximum compressing load and maximum width, according to the mathematical and experimental results, have slight deviations of 3.5% and 0.92%, respectively. The factors influencing the maximum compressing load and maximum thinner sections are next investigated using the verified FE-model. It has been demonstrated that cushion stiffness and beginning blank width have the most effects, with punch speed having a little effect. Since the results make sense, the FE-model may be trusted to support more research.

One of the key process variables in the extensive drawing procedure is blank holder force (BHF). By managing metal flow throughout the deep drawing process, BHF contributes to the production of components free from defects. A low BHF results in wrinkles; a high BHF leads the sheet to burst. Consequently, industries consider BHF optimization to be a critical issue. Examining the forming effect, thickness dispersion, and wrinkles to create a deep-drawn cup is one technique for calculating the ideal BHF. This method's primary purpose is to prevent process restrictions and decrease the maximum forming force. As a result, the goal of **Asgharpour, A. et al. (2024) [7]**, work is to use modeling and experimental data to examine the connection between the BHF and forming force. Furthermore, the impact of BHF on the distribution of thickness and wrinkles is taken into account. Therefore, in order to accomplish the goals, St14 and SS304L sheets with thickness of 0.5, 1, and 1.5 mm were treated to numerical and experimental approaches. First, the mechanical behavior was studied by simulating the process. Afterwards, a series of experimental experiments were carried out in order to verify the simulations. Ultimately, the ideal BHF value was ascertained by combining the experimental and mathematical findings. Maximum forming force and maximum thinning were shown to be correlated with the forming process in the absence of BHF. Moreover, the lowest values of formation force and thinness were reached when wrinkling at the part's edge was eliminated by progressively increasing BHF. The maximum forming force for both SS304L and St14 sheets breaks when the thickness is reduced from 1.5 to 0.5 mm, as per the findings of three thicknesses of research. On the other hand, the obtained findings indicated that both sheets achieve the lowest ideal BHF at a thickness of 1.5 mm. All things considered, this study offers insightful experimental and numerical recommendations for applying the deep drawing technique to produce cylindrical components with the least amount of forming force necessary to reduce energy usage.

The sheet metal component is mostly drawn via deep drawing, which is useful for the metal-forming industries. Although it is expensive and difficult, the component may be produced without the need for additional machinery or parts. In the current piece, cylindrical and circular cups are created using a revolutionary deep drawing technique that does not require drawing beads or a blank holder. Using a cylinder head circular punch and a conical dies with a circular aperture, a circular blank is forced through the die to form a cylindrical cup. For the purpose of producing cylindrical metal sheet cup in an experimental manner, a test setup had been established. Al 1100 sheet, 1.5 mm thick, is used to cut the 50 mm and 55 mm blanks. To determine the sheet metal cup's load behavior and cross head travel (CHT), compressive tests were performed. According to the results of the trials, 55 mm symmetrical cups have 32.86% higher extensions than the 50 mm blanks without wrinkles at the same maximum load value, but the 50 mm blank quickly produces an asymmetric cup.**Kaimkuriya, A. et al. (2022) [8]**,suggested method and setup successfully produced a cylindrical cup with a blank of 55 mm.

The technique of meso-and microforming allows for the shaping of items from minuscule metal billets. The geometric dimensions of the parts range from a few millimeters to a few micrometers. Because of its efficiency, precision, and high productivity, the technology of producing tiny components has been explored and utilized with the rapid expansion of the electrical-electronics sector and biomedical engineering. Deep drawing is the process that creates hollow, open-mouthed pieces out of flat sheet metal blanks. It is a crucial step in the stamping of sheet metal.One of the microshaping techniques that has received a lot of attention and use recently is micro deep drawing. Nevertheless, a thorough analysis and evaluation of the foundations for computing the technical and geometrical factors in the micro-deep drawings has not yet been completed. Thus, a theoretical foundation together with simulations applicable to the design of technology has been proposed by **Van Duy et al. (2024) [9],** for the manufacturing of a connecting head part drafting die with a width of 300μm and a height of 1500μm utilizing materials SUS304 material.Evaluation of the thicknesses dispersion on the product wall, the capacity to draw the work piece onto the die, and the internal stress condition of the stamping component are also made possible by numerical simulation. Additionally, experimental testing has confirmed that the stamping components satisfy quality criteria within the established boundaries. This suggests that the suggested computation techniques for the little deep drawing operations are perfect. The deep drawing method may be fully utilized to produce micro-sized cylindrical cup components based on the findings of this study.

Deep drawing is the process of producing cups using a punch to shape the desired shape by pushing the sheet from the center into the die cavity between the die and the blank holder. As the sheet flows into the die cavity between the punch and the die, the cup is formed by convert to the special shape of the die. **Özek, C. (2023) [10]**,carried out to determine the effect of geometric parameters of the die on the limit drawing ratio and cup wall thinning in deep drawing of rectangular cups. The research assigns angles of α=0°, α=3°, α=6°, and α=9° to the lower surface of the blank holder and the die. Punch speed and blank holder force used are 4 mm/s and 1800 daN, respectively. There is 1.2 mm between the die and the punch. The die throat radii, punch and edge bottom radii, and die edge radii were all employed at 6 mm. The trials employed St37 sheet metal with a thickness of 0.9 mm. In order to determine the wall thickness changes of the cups, the cup was precisely cut from the edge corners along its height and the wall surface was divided into grids at 10x10 mm intervals from the end of the base radii towards the rim. Wall thickness changes were measured on Mitutoyo LH-600E precision linear measuring gauge with a precision of 0.001 with a point contact. Significant wall thickness changes is occurred in the cups and ranged from 0.371 to 0.910 mm. The maximum wall thickness change occurred in the lower corners of the cup and was determined as 0.373 mm. It has been determined that the limit drawing ratio is β=1.6 at α=0° and β=2.31 at α=9°. As a consequence, by supplying angles to the top surface of the dies and the bottom surface of a blank holder for the fabrication rectangular cup, it has been shown that the die geometry significantly affects the limit drawing ratios and wall thickness variations.

Deep drawing is the most widely used process for forming cup shaped products in automobile, aerospace, and packing industries. In this research**Kaimkuriya, A., &Balaguru, S. (2024) [11]**,explained that the deep drawing process is used to draw the cylindrical cups of Al1100 and SS202 metal sheets using a new type of conical die and a flat-bottomed punch without a blank holder. This work's experiment examined blank sizes of 50, 55, 60, and 70 mm in both lubricated and dry environments. According to the results, faults including deviation, spring-back, earing, and unequal depth were greatly decreased by the lubricant. For perfect cups, a blank diameter of 60 mm is ideal. In addition, the research observed that lower friction coefficients corresponded to required load. The deep drawing procedure has distinctive effectible process parameters from which an optimum level of parameters and defect-free cups with required mechanical properties can been obtained. Thus, using the mixed response surface methodology for optimization, the research showed an excellent decrease in the maximum required load, mainly under lubricated conditions. In brief, the optimization model for SS202 under dry conditions became incredibly accurate, with less than 1% error compared to experimental results. On the other hand, for Al1100 under dry conditions, the model's predictions deviated more, showing more than a 12% error, indicating a need for additional refinement or extra factors to enhance the accuracy of Al1100.

III. METHODS AND ADVANCES

To the analysis of single-acting stroke deep drawing on symmetric low-depth products without a blank holder, knowledge of the materials and processes is applied. Some common materials used to perform deep drawing are aluminum, steel, and other metal alloys chosen for their tensile, ductility, and formability. Material selection typically is based on tensile strength and formability of the material, in particular, although other factors may come into consideration, such as product necessity, cost, and availability [12]. The single-acting stroke deep drawing process consists of a series of operations in which the punch and die are mainly used. Notably, in most such operations, a blank holder is absent. Principal process parameters like punch speed, lubrication, blank size, and die geometry determine the end results. Variations and improvements to this process may be applied to meet specific demands usually a particular class of product or several products. Experimentally, the setup is as per the general case with specialized equipment in the form of presses, dies, and measuring equipment in accordance with the established procedure of preparing samples and the testing conditions [13].

Optimization and Modeling

Optimization of the deep drawing process is applied to make it efficient and reliable. Some optimization approaches are aimed at minimizing defects, saving raw material, and improving product quality. Different Optimization Algorithms like genetic algorithms, particle swarm optimization, simulated annealing are used [14]. FEA is very effective in presenting the deep-drawing process in detail. In FEA, stress–strain distributions, predicted thinning, and locations of potential defects can be identified and studied to provide new knowledge about how the process can be improved. Other, more general modeling approaches include analytical models based on simplified mathematical representations, or machine learning models, where data can be used to predict and optimize process results.

Recent technological developments have revolutionized deep drawing further. Advanced materials, such as high-strength steels, have undergone development, at the same time as the composites' range of applications has expanded, and product performance has become better. Innovations in tooling, from multi-functional to modular tools, ultimately provide enhanced efficiency for the process. Automation is not left behind, with respect to the influence, as automated press systems have been developed and encompass various robotic arms and real-time monitors—the control algorithms, developed in recent years, making adaptive set point changes within the process to optimize the results per sensor-feedback [15]. The cutting-edge development brings digital twin technology to the field, enabling replication of physical systems virtually. Advantages that exist with the digital twins include enhanced process understanding, advanced and predictive maintenance, and more favorable quality control [16].

Of no less relevance is the issue of the advancement of processes in the context of environmental impact. The development and use of both more ecologically friendly materials and lubricants, and the energy-efficient process undertaken therein, starting with electric presses and finishing with the parameters optimization, make this industry truly sustainable. Practical case studies of technological advancements show the true stage of realization and the picture of the benefits and struggles. The level of impact these advancements have had on this industry is notable, such as changes of practice, cost limitations, and the quality of the resultant products [17].

IV. APPLICATIONS AND CHALLENGES

Compared with the general one-acting stroke deep drawing process, the practical applications of this method for symmetric low-depth work-pieces and the great impact of it on all kinds of industries are highlighted. The process is used immensely in the automotive industry to develop body parts, engine parts, and structural elements, as it works at high capacities and low material consumption to create intricate shapes with tight tolerances [18]. It is used in the aerospace industry to create light and strong parts that contribute to fuel efficiency and performance. Another area of use is the electronics and device industry, where it is employed for producing casings and enclosures with strict dimensional control. The reduction in tool complexity and size leads to lowered tooling cost and shorter lead times, thus increasing the complete productivity of the process. Among the facts shown, regarding the positive aspects of the one-acting stroke deep drawing process, in general, are the following challenges facing the developed process: One major problem is material wrinkling and material tearing due to the absence of a blank holder, which in general is responsible for keeping the material stability under deformation [19]. For example, several process parameters, low coefficient of friction, and appropriate lubrication and coating have to go through careful control in order to limit the problem development while keeping low material sticking and friction. Another is its restriction to apply it to some kinds of materials/thicknesses, which decreases the generality of the application. Producing a uniform thickness distribution and preventing earing or edge thinning also remain as an important concern. These challenges represent the opportunity areas for this process, requiring continuous development oriented to designs for the dies and tools, material features, and process controls [20].

Future research directions in the single-acting stroke deep drawing without a blank holder aim to overcome such challenges and further expand the applicability of the process. Promising research should be directed toward the development of new materials and material treatments that provide higher formability and decrease the risk of defects. Advanced lubricating and superficial treatments can further reduce friction and wear, increase quality, and create more consistency in the products being drawn [21]. Furthermore, the study should incorporate smart sensors and real-time monitoring systems to enable adaptive control of process parameters by making immediate adjustments to avoid defects and optimize performance. Other possible future research could be directed toward hybrid forming, combining deep drawing with other processes, like hydroforming or incremental forming, to increase the capabilities and produce more complex shapes. Finally, data analytics and machine learning-based models should lead to a thorough understanding of the dynamics of the process and support predictive maintenance and optimization [22].

To conclude, the single-acting stroke deep drawing process for symmetric low-depth products without a blank holder is a process with high industrial application but suffers from challenges that hamper its full potential. Further research and technological development will contribute to overcoming these challenges and thus move closer to more efficient, versatile, and high-quality manufacturing processes [23].

V.CONCLUSION

The investigation into the adaptation of conventional sheet metal forming techniques to fibre-based materials, particularly through the deep drawing process, highlights both opportunities and challenges. While deep drawing holds promise for sustainable packaging solutions, challenges such as material wrinkling, tearing, and limited applicability to certain materials and thicknesses remain significant. Future research should focus on developing new materials, treatments, and lubrication methods to improve formability and product consistency. Integration of smart sensors and real-time monitoring systems can enable adaptive control of process parameters, while hybrid forming approaches and data analytics offer avenues for increased capabilities and process optimization. Overall, continued research and technological advancements are essential to unlock the full potential of the deep drawing process for fibre-based materials, paving the way for more efficient, versatile, and environmentally friendly manufacturing processes.

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