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Comparison of Vibration Assisted Single Point and Two-Point Incremental Forming of Sheet Metal

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Abstract: *Vibration-assisted single-point incremental forming (VASPIF) and two-point incremental forming (TPIF) are two innovative techniques employed in sheet metal forming processes, each offering distinct advantages and limitations. VASPIF utilizes high-frequency oscillations applied to the forming tool to reduce friction and improve material flow, resulting in enhanced formability and surface finish. Conversely, TPIF employs two independently controlled forming tools to deform the sheet metal incrementally, allowing for greater geometric complexity and improved accuracy compared to VASPIF. However, TPIF typically requires more complex tooling and setup, potentially increasing manufacturing costs and setup time. Both techniques have shown promise in improving the formability of sheet metal components while offering unique capabilities suited to specific manufacturing requirements. Vibration-assisted single-point incremental forming (VASPIF) and two-point incremental forming (TPIF) are two advanced methods used in sheet metal forming, each with its unique characteristics, advantages, and limitations. In this comprehensive comparison, we will delve into the fundamental principles, process parameters, applications, advantages, and challenges associated with both techniques. Starting with VASPIF, this innovative approach involves applying high-frequency oscillations to the forming tool during the incremental forming process. These vibrations serve to reduce friction between the tool and the work piece, facilitating material flow and enhancing formability. By effectively decreasing the frictional forces, VASPIF enables the deformation of difficult-to-form materials and improves the surface finish of the formed parts.*

Keywords: *vibration assisted, single point and two-point, Incremental forming and sheet metal.*

1. INTRODUCTION

The application of vibrations also promotes strain distribution and reduces spring back, leading to more precise forming outcomes. Additionally, VASPIF offers flexibility in tool design and process control, allowing for adjustments in vibration frequency, amplitude, and phase to optimize forming conditions for different materials and geometries. On the other hand, TPIF involves the use of two independently controlled forming tools to incrementally deform the sheet metal into the desired shape. This technique offers advantages in terms of geometric complexity and accuracy compared to VASPIF. With two forming tools operating simultaneously, TPIF allows for more intricate part geometries and finer details to be achieved. Moreover, the ability to control each forming tool independently provides greater flexibility in forming strategies, such as varying the forming depths and tool paths. TPIF is particularly well-suited for prototyping and low-volume production of complex parts, where traditional forming methods may be impractical or cost-prohibitive. he concept of a particle's motion can be described using both single-point and two-point perspectives. A single-point perspective focuses solely on the position of the particle in space at any given time, often represented by its coordinates. This perspective provides basic information about the particle's location but lacks details about its trajectory or velocity. On the other hand, a two-point perspective considers the positions of the particle at two different times, allowing for the calculation of displacement, velocity, and acceleration over a specific time interval. By analyzing the motion from these two viewpoints, physicists can gain a comprehensive understanding of the particle's dynamics, enabling predictions and explanations of its behavior in various situations. Sheet metal incremental forming (SMIF) is a versatile manufacturing process used to shape sheet metal components with complex geometries. Unlike traditional forming methods that employ dies and punches, SMIF involves the incremental deformation of the workpiece through the controlled movement of a forming tool. This tool, typically a CNC-controlled spindle with a small-diameter tool tip, exerts localized forces on the sheet metal, gradually shaping it layer by layer. SMIF offers several advantages, including flexibility in producing prototypes and low-volume parts without the need for expensive tooling. Additionally, it allows for the creation of intricate shapes with minimal material waste. However, the process typically involves longer cycle times compared to traditional stamping methods, making it more suitable for small-scale production or customized components. Ongoing research in SMIF focuses on optimizing process parameters, enhancing surface finish, and expanding its applicability to a broader range of materials and geometries, thereby further unlocking its potential in various industries such as aerospace, automotive, and consumer electronics.

2. VIBRATION ASSISTED

Vibration-enhanced tooling has demonstrated an enhancement in surface quality as well. When operating at high frequencies and with minimal amplitudes, the surface finish of the produced component shows minimal alterations compared to traditional methods. Conversely, employing low frequencies and substantial amplitudes results in the forming tool causing surface irregularities that compromise surface consistency [1]. Aluminum, stainless steel, and titanium foils were utilized in the creation of microcells to enhance structural precision. Employing an ultrasonic spindle, coupled with incremental micro-farming, this technology—termed ultrasonic-assisted microforming—was deployed. Additionally, to facilitate softening in aluminum foil and thereby enhance its malleability during decomposition, ultrasonic-assisted laser heating was applied. This combined approach effectively addressed various challenges, including the formation limitations of micro pyramids, while investigating accuracy. Notably, micro pyramids measuring 283 µm were successfully produced using ultrasound vibrations, particularly in titanium foil, which proved to be a challenging material to work with. This advancement not only improved building accuracy quantitatively but also had a qualitative impact on reducing deformities, allowing for further exploration [2]. Advanced vibration-enhanced forward and integrated micro extrusion methods have been employed to reduce billets from 10 mm to 0.5 mm in diameter, resulting in high surface area and the production of small, high-quality parts. Furthermore, integrating ultrasonic vibration into sheet metal forming processes has been explored. Research by Oliver and colleagues demonstrated that ultrasonic vibrations applied during cup drawing processes can prevent cracks and improve achievable drawing rates [3]. The measure known as the deviation value quantifies radial precision errors along the sidewalls in five equidistant measuring zones, with accuracy errors calculated through averaging. Each component comprises five layers with generating paths. To enhance measurement precision, three measurements are taken equally across each component, and the accuracy of points is determined through averaging [4]. The paper commences by setting up the foundation for point forming techniques through finite element (FE) simulations. It then delves into investigating the impacts of Ultrasonic (US) parameters such as amplitude, instrument diameter, and the material of the sheet being processed. The effects of these parameters on the process are thoroughly explored. Ultimately, the study derives discussions from these findings, culminating in the conclusion of the article [5]. Ongoing research aims to elucidate Regarding the softening phenomenon, the paper elucidates the fundamental physics principles underlying it. Drawing from two primary sources in the literature, it highlights key theoretical frameworks. The first framework centers on sound softening, proposing a direct relationship between ultrasonic vibration, dislocation movement, and various lattice defects like vacancies, displacements, and grain boundaries. According to this theory, acoustic energy is predominantly absorbed by lattice defects, consequently enhancing mobility and reducing shear stress, which are vital aspects of the softening process [6]. The adoption of modern variations of Single Point Incremental Forming (SPIF) offers notable advantages such as reduced preparation time for new product production and decreased manufacturing costs. SPIF entails localized tool contact with the work piece, resulting in lower forming forces and allowing for larger limit deformations compared to conventional stamping methods. Despite these benefits, drawbacks include reduced geometric precision in products, particularly in areas with small radii, and significant material spring back. However, these issues can be mitigated through the implementation of appropriate algorithms to correct toolpath deviations [7].

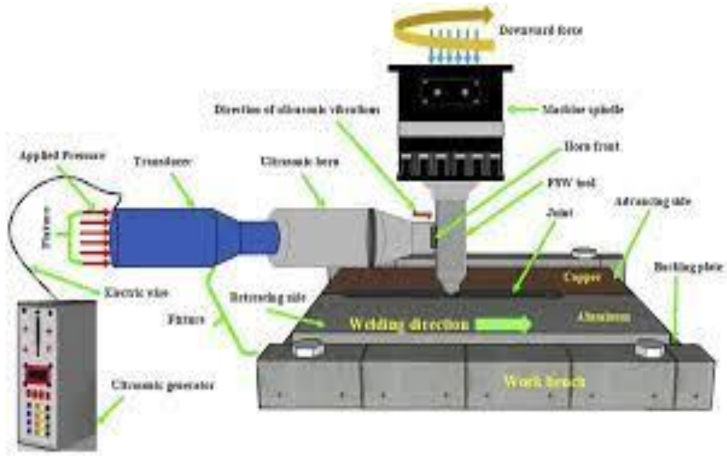

FIGURE 1. Vibration Assisted

3. SINGLE POINT INCREMENTAL FORMING

Single-Point Incremental Forming (SPIF) offers significant energy advantages for various industries, particularly in automotive and aerospace, where prototype and custom part production at low costs is essential. It presents a solution for forming vertical walls in components with optimal residual strain distribution, ensuring they can withstand material strains without fail. However, achieving this often requires multiple passes. This study explores multistage strategies through experimental evaluation, resulting in successful production of complex C-channel geometries via plane vibration-designed testing. Specifically tailored for flat-base geometries, it provides design guidelines and outlines rules for creating high-quality toolpaths. Additionally, a comparative analysis between hemispherical and flat instruments was conducted, determining that for manufacturing flat-base parts, a flat tool is more suitable [8]. Single Point Increment Formation (SPIF) is a manufacturing method rooted in the principle of layered production, typically employed for swift prototyping within the manufacturing realm. This technique involves creating a complex three-dimensional structure through a series of two-dimensional contour plots, incorporating sequential layering. Subsequently, the layers are incrementally formed using continuous tooling, adhering to predefined specifications to shape the object layer by layer. This methodology, as outlined in literature, digitally transforms metal components, facilitating SPIF fabrication. Notably, one of its primary merits lies in its rapidity, streamlining the prototyping process and fostering swift product development. Consequently, it enables cost-effective production of diverse items in smaller batches, circumventing the need for extensive die sets and averting associated high expenses, thereby distinguishing itself from traditional sheet metal forming techniques and mitigating the risk of defects [9]. Single Point Incremental Forming (SPIF) operates subtly within a component, effectively detecting features. The accuracy of these features, particularly the walls containing them, is influenced by angles. In general, sheet metal components, especially those with shallow walls and angled features, tend to undergo significant degradation, while those with steeper walls experience less pronounced decay. This phenomenon occurs in both single point incremental forming and double-sided incremental forming processes. These formative processes offer advantages, particularly for small-scale production, with studies suggesting benefits for up to 300 parts. Additionally, proposed enhancements to the process include the use of lubricants and strategies to reduce electricity consumption, such as minimizing idle running and formative periods [10]. A promising technique has emerged that bridges the gap between large-scale production and prototypes, known as Single Point Incremental Forming (SPIF). Its versatile applications span across industries, including automotive manufacturing, solar cooker fabrication, and the production of medical equipment such as ankle supports, facial implants, cranial implants, and clavicle implants. SPIF offers various benefits, including customization, making it widely adopted. The widespread availability of CNC milling machines in machine shops, combined with the direct system required for sheet metal fabrication, has increased the appeal of SPIF. In SPIF, the CNC work table height is adjusted, and additional devices are utilized to secure the metal sheet edges [11]. Single Point Incremental Forming (SPIF) stands out as a leading technique for sheet metal forming, characterized by its tileless approach. In this method, a sheet is gradually shaped through controlled movement of the punch, typically operated by a standard CNC mill. This innovative approach offers significant adaptability and cost savings, aiming to reduce the buy-to-fly ratio and enhance compatibility with titanium in small-batch manufacturing scenarios. Despite its widespread industrial adoption, SPIF encounters several challenges that must be addressed before achieving widespread use. These challenges include slow processing rates, the need for sufficient geometric accuracy, management of superior residual stresses, and the creation of controlled outcomes, requiring skilled handling [12]. Paraphrasing Symmetrical and asymmetrical components require the design of single-point increment creation toolpaths to ensure geometric accuracy and adherence to maximum scallop height regulations. This process involves optimizing time while considering limitations on scallop heights. Performance evaluation of the method is conducted by measuring compliance with regulations and assessing geometric accuracy. Additionally, the time taken to achieve these objectives is compared with toolpaths generated by commercial CAM software [13].

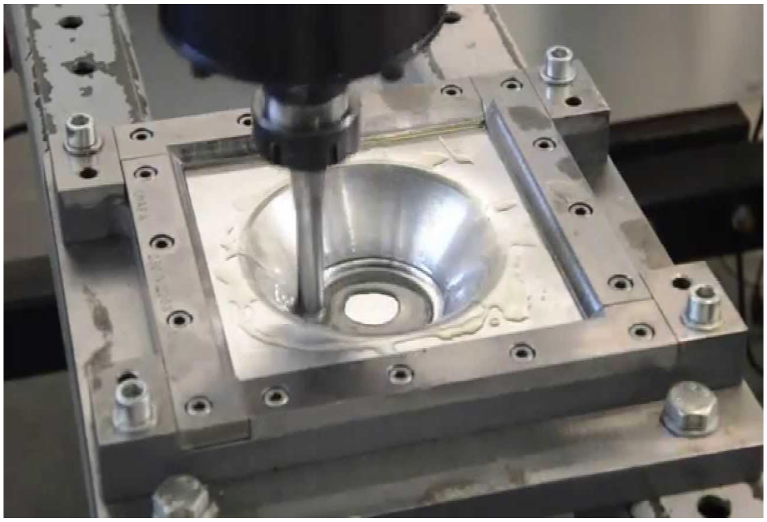

FIGURE 2. Single Point Incremental Forming

The Single Point Incremental Forming (SPIF) process involves securely clamping a sheet and following a predefined 3D path using a small hemispherical-end tool, resulting in localized deformation. This cumulative effect of localized deformations shapes the sheet into its final form. The depth increase (Δz) per sheet, which vertically represents the tool hierarchy, plays a crucial role in the process. Various aspects of SPIF, such as deformation and fracture mechanics, forming forces, toolpath planning, geometric accuracy, limited element and numerical simulations, incremental temperature changes during the process, and surface finish impact, have been extensively researched and detailed. [14]. The study focuses on single-point incremental micro-forming (μSPIF), where it's noted that the optimal tool rotation speed and step size greatly affect material formability. Additionally, the introduction of water between the tool and sheet interface for hydrodynamic lubrication is found to enhance plastic deformation and reduce forming forces. Investigating the impact of size on material formability reveals that μISF yields lower formability compared to macro-ISF processes. Furthermore, a novel buckling mode of failure is introduced, necessitating further experimental and numerical analysis to comprehend its underlying mechanics [15].

4. TWO POINT INCREMENTAL FORMING

Two Point Incremental Forming (TPIF) utilizes a CNC-controlled hemispherical tool to shape a blank sheet, offering flexibility compared to other SPIF variations due to its absence of dedicated dies. Unlike standard SPIF, TPIF employs a drop on the opposite side of the forming tool, which can be either positive or negative in form. This process often leads to localized thinning, heightened elongation due to sheet vacuum, and resultant residual stresses, potentially causing geometric deviations and shortening component lifespan. To address these issues, post-formation stress-relief techniques like annealing are commonly employed [16]. Two Point Incremental Forming (TPIF) involves examining a part with a drop, observing vertical and horizontal toolpath deviations. To enhance control and adjust for these deviations, an algorithm is utilized, incorporating a new horizontal control module that accurately estimates errors in the horizontal section by densely distributed profile points. Adjustments are made based on parameters and instrumentation in both vertical and horizontal directions to optimize each step of the process. A study is underway to physically verify this toolpath editing technique's efficacy in forming shapes with axis asymmetry [17]. Despite the advantages of Two-Point Incremental Forming (TPIF) over Single-Point Incremental Forming (SPIF), TPIF tends to exhibit less flexibility. To enhance the flexibility of TPIF for designing parts with complex surfaces, particularly from aluminum sheets, a coupled subsystem utilizing reconfigurable multi-point dies is proposed in this study. This approach introduces a multi-point die system to augment the flexibility of the TPIF process, enabling the design of various elements, including complex geometries like freeform surfaces, such as ship hulls or scaled-down bow shapes. both experimental and numerical evaluations are conducted to assess the effectiveness of the proposed multi-point die system [18].

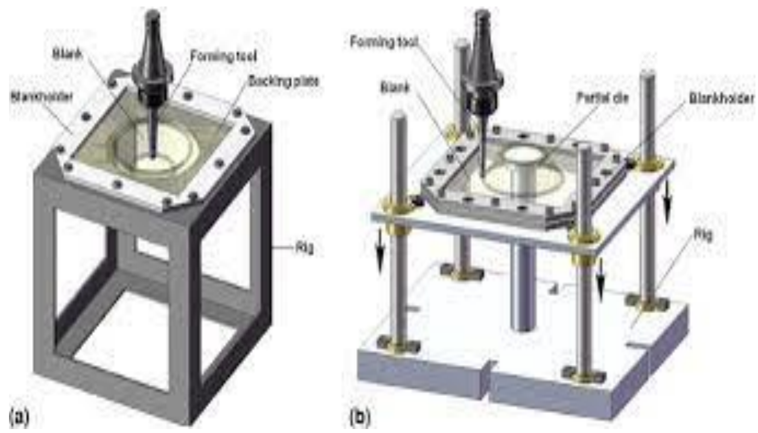

FIGURE 3. Two Point Incremental Forming

Two decades, incremental sheet forming (ISF) has garnered significant attention from various research groups aiming to address the challenges hindering its widespread adoption in manufacturing. In pursuit of enhancing the geometric precision of ISF, the University of Brescia has undertaken research into two-point incremental forming (TPIF), employing both experimental and numerical methodologies. One focal point of previous investigations has been a representative geometry for the ISF process, wherein diverse parameters were manipulated to gauge their impact on outcomes. This approach not only yielded valuable insights but also generated a comprehensive database of experimental findings useful for validating numerical simulations [19]. Two-Point Incremental Sheet Forming (TPIF) is a method that involves utilizing a tie with the forming tool to induce localized material degradation through direct communication with the sheet. This results in improved shaping compared to Single Point Incremental Forming (SPIF) in terms of both format and geometric accuracy. In TPIF, the predefined tool follows a specific path, gradually shaping the desired form through the accumulation of localized deformations [20].

5. SHEET METAL INCREMENTAL FORMING

The Incremental Sheet Forming (ISF) technique represents a versatile and promising approach to shaping sheet metal, particularly suited for small-scale production of intricate and customized parts. Despite offering enhanced formability compared to traditional stamping methods, ISF encounters limitations when dealing with low-ductility materials like magnesium and titanium alloys at ambient temperatures. Additionally, issues such as geometric discrepancies pose challenges for its industrial application. In this study, a novel method called Point-Contact Tool Path (PCTP), which eliminates circumferential friction, is introduced [21]. The investigation delved into the effects of ultrasonic vibrations on aluminum alloys during incremental sheet formation, particularly focusing on surface properties and springback. The study analyzed the outcomes of this process, with ongoing tests being conducted to further explore the results. Utilizing ultrasound assistance in sheet forming processes, as per specified protocols, served as the basis for a more comprehensive understanding. The research scrutinized the surface properties, hardness, and springback of aluminum alloy sheets through the use of a white light interferometer (Bruker Contour Elite K). Sample preparation involved cutting symmetrical aluminum wire and removing the sidewalls of the alloy sheets [22]. The incremental sheet forming (ISF) method utilizes hemispherical forming tools to gradually shape the sheet metal along a predetermined path, offering advantages such as reduced forming load, enhanced forming limits, and flexibility in shaping. Since its inception by Edward in 1967, single incremental sheet forming has garnered considerable attention from both academic and industrial sectors. The mechanical properties of the formed parts are crucial for their performance, prompting numerous scholars to propose diverse strategies for enhancing part properties. These strategies include optimizing process parameters, employing multipoint incremental forming, and implementing multistage incremental sheet forming techniques [23].

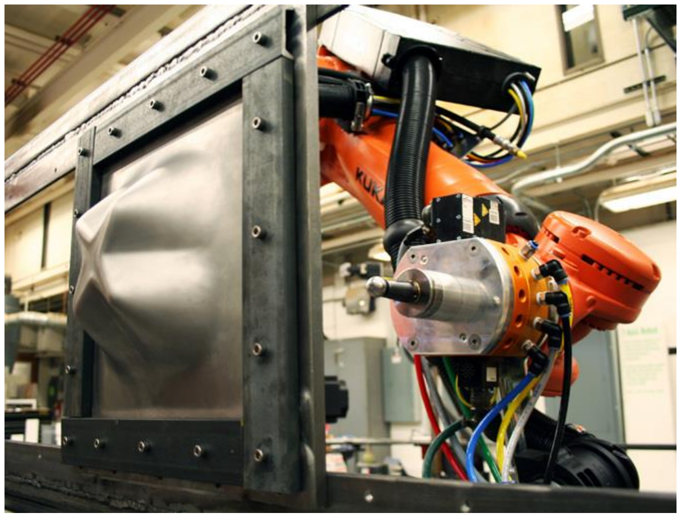

FIGURE 4. Sheet Metal Incremental Forming

Sheet metal forming (SMF) methods are extensively utilized across various metal sheet processing for component design in industries, the Sheet Metal Forming (SMF) processes are pivotal. These processes involve transforming thin metal sheets into desired shapes while ensuring they maintain adequate thickness and avoid excessive thinness or compactness. Over the past decade, advancements have been made in cold, heat, and hybrid techniques to handle metals with high strength and low plasticity effectively. The mechanical properties of the metal sheets are crucial, influencing the design of SMF processes. Ensuring sufficient strength characteristics is essential to prevent issues like excessive thinning, tearing, or component summation regardless of size or complexity. Furthermore, various factors such as tool geometry (e.g., punch-to-die clearance, die and punch radii), friction conditions (e.g., dry or lubricated contact, type of lubricant, contact pressure), technical parameters (e.g., temperature control, forming speed), and properties of tool materials, as well as initial surface texture, significantly influence the final shape achieved [24]. Incremental forming of metal sheet parts offers an intriguing alternative to manually forging blanks or creating resin dies for producing prototypes or small batches of parts. Particularly in scenarios requiring small-volume production, there is a growing need for enhanced automation, potentially leading to the implementation of a robotic cell capable of completing various tasks after forming. In such cases, the robotic system conducting the deformation could seamlessly switch between tools, trim the part, bend or flange edges, and handle loading/unloading operations, among other tasks [25]. the traditional method of panel beating remains prevalent for fabricating sheet metal parts, particularly in tasks like model manufacturing, repair, and maintenance. However, the high cost and scarcity of skilled practitioners are gradually diminishing its widespread use. Nevertheless, there's a growing demand, especially in rapid prototyping scenarios, for cost-effective and adaptable systems in designing sheet metal parts. This article explores the development of Megatroforming, a novel metal forming technique that introduces a featureless sheet metal approach. Unlike traditional methods reliant on skilled labor and costly practices, Megatroforming utilizes robotic arms equipped with hammer tools to integrate manipulation methods for shaping sheet metal parts [26]. The Incremental Sheet Formation (ISF) process has been pivotal in expanding the design possibilities of sheet metal. Various distortion mechanisms have been identified to understand this process better, including factors such as contact pressure, bending effects, shear stress, cyclic loading, hydrostatic pressure, and geometric controls. To gain deeper insights into the effects of friction, an analytical model was developed based on the stress levels of deformation in Single Point Incremental Forming (SPIF). This model directly connects stress levels and generation parameters, facilitating a comprehensive understanding [27]. Incremental sheet forming (ISF) is a method characterized by its cost-effectiveness, adaptability for high customization, and suitability for small-scale production. It operates by gradually deforming localized areas of a sheet metal, employing a computer-controlled hemispherical-head tool. This tool shapes the metal by executing a programmed sequence. The process involves breaking down a designed 3D shape into sequential 2D contours. As each contour is formed, the tool progresses to the next level, with the separation between adjacent contours referred to as the step down size. This incremental approach allows for thorough exploration of the material's formability and potential. Notably, ISF typically requires either no die or only a rudimentary die, making it particularly advantageous for customizable production compared to traditional methods like drawing and stamping [28]. sheet metal-forming industries, there's a pressing need to manufacture products in small quantities, minimize production expenses, and enhance process adaptability. Conventional sheet metal forming methods face challenges in achieving these objectives, primarily due to the escalating costs and time associated with equipment manufacturing and setup, particularly for items with intricate geometries. Consequently, the needs of rapid prototyping and small-scale production, Incremental Sheet Metal Forming (ISMF) has emerged as a complementary solution. ISMF relies on localized plastic deformation of sheet metal, controlled through computer numerical control (CNC) milling programmed instructions, and guided by a hemispherical-head tool. This method encompasses two main processes: Single-Point Incremental Formation (SPIF) and Two-Point Incremental Formation (TPIF). SPIF involves the deformation of sheet metal without the presence of supporting ties underneath, distinguishing it from TPIF [29]. Incremental sheet forming (ISF) presents a notable departure from traditional sheet metal forming methods by substantially reducing reliance on costly dies and minimizing tooling expenses, particularly for intricate part manufacturing. This characteristic renders ISF well-suited for prototype development and low-volume production compared to conventional techniques. Additionally, ISF demonstrates utility in fabricating components for older machinery, where the absence of specific forming dies poses significant challenges. Furthermore, the incremental approach coupled with localized sheet deformation enhances formability while reducing the necessary forming force. Given the advantage of lower forming forces, it becomes imperative to optimize and estimate these forces by adjusting various parameters to ensure safe hardware utilization. This review article undertakes a quantitative literature survey to comprehensively examine different facets of ISF, particularly focusing on the impact of various process parameters and techniques on forming forces. The discussion encompasses an in-depth analysis of the current state-of-the-art ISF processes, highlighting their capabilities and limitations concerning forming forces. Additionally, the review explores the effects of different process parameters and forming techniques on forming forces, providing valuable insights into optimizing ISF processes for efficient and effective sheet metal forming [30]. Incremental Sheet Forming (ISF) encompasses various processes where only a small portion of the product is formed at any given time, with the area of deformation gradually shifting across the entire product. This broad definition includes diverse techniques, ranging from traditional blacksmithing to its mechanical equivalent, the forging hammer press. Another example is panel beating, a traditional method still employed in handcrafted car body production, albeit increasingly automated. Rolling can also be classified as an incremental process, despite not always being recognized as such. Additionally, spinning is a notable ISF process utilized extensively for producing rotational parts in moderate to large series, such as household cooking equipment [31].

6. CONCLUSION

The application of vibrations also promotes strain distribution and reduces spring back, leading to more precise forming outcomes. Additionally, VASPIF offers flexibility in tool design and process control, allowing for adjustments in vibration frequency, amplitude, and phase to optimize forming conditions for different materials and geometries. On the other hand, TPIF involves the use of two independently controlled forming tools to incrementally deform the sheet metal into the desired shape. This technique offers advantages in terms of geometric complexity and accuracy compared to VASPIF. Vibration-enhanced tooling has demonstrated an enhancement in surface quality as well. When operating at high frequencies and with minimal amplitudes, the surface finish of the produced component shows minimal alterations compared to traditional methods. Conversely, employing low frequencies and substantial amplitudes results in the forming tool causing surface irregularities that compromise surface consistency. Aluminum, stainless steel, and titanium foils were utilized in the creation of microcells to enhance structural precision. Employing an ultrasonic spindle, coupled with incremental micro-farming, this technology termed ultrasonic-assisted micro forming was deployed. Additionally, to facilitate softening in aluminum foil and thereby enhance its malleability during decomposition, ultrasonic-assisted laser heating was applied. This study explores multistage strategies through experimental evaluation, resulting in successful production of complex C-channel geometries via plane vibration-designed testing. Specifically tailored for flat-base geometries, it provides design guidelines and outlines rules for creating high-quality toolpaths. Additionally, a comparative analysis between hemispherical and flat instruments was conducted, determining that for manufacturing flat-base parts, a flat tool is more suitable This broad definition includes diverse techniques, ranging from traditional blacksmithing to its mechanical equivalent, the forging hammer press. Another example is panel beating, a traditional method still employed in handcrafted car body production, albeit increasingly automated. Rolling can also be classified as an incremental process, despite not always being recognized as such. Additionally, spinning is a notable ISF process utilized extensively for producing rotational parts in moderate to large series, such as household cooking equipment.

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