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Thin Aluminum Alloy Sheet Flexible Forming: A Review

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Abstract:

Flexible forming is a relatively recent technique in the field of sheet metal forming. It involves utilizing a rubber die or another similarly flexible media to create sheet metal components with complicated geometries Conventional forming procedures like deep drawing, bending, stretching, stamping, and blanking aren't the only ways to make complicated shapes. There are different types of innovative flexible forming methods such as Rubber pad forming, Incremental Sheet Metal forming, also known as flexible die forming, is one kind of sheet forming that makes use of a rubber diaphragm.

Innovative Sheet Fabrication (ISF) is a revolutionary approach to creating sheet metal components. When a piece of work is clamped onto a revolving mandrel and a tool is used to exert stress on the metal, the metal conforms to the shape of the mold. Ultrasonic, electromagnetic increemantal sheet metal forming and creep age forming are new forming procedures for panel components creep age forming was introduced by Textron Aerospace. Low tooling costs, process adaptability, and little damage to the formed components are primary benefits of flexible forming over more traditional methods. Flexible sheet metal can be molded into a variety of different forms for a single piece of work. The time and money required for part-dependent tooling in the traditional sheet metal forming process is prohibitive. Increasing demand for bespoke services has resulted in smaller production runs.

Keywords: Flexible, Incremental, Electromagnetic, Creep-Age Forming, Sheet Metal Forming.
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1. Introduction

Many complicated components are made using sheet metal forming methods, which include relatively simple operations including bending, stretching, blanking, and stamping [1]. Flexible forming is a relatively recent technique in the field of sheet metal forming that involves utilizing a rubber die or another similarly flexible media to create sheet metal components with complicated geometries. Rubber-forming technologies have been drawing attention as of late because of their widespread use in the aviation sector.[2]. Low tooling costs, process adaptability, and little damage to the formed components are the primary benefits of flexible forming over more traditional methods of forming. Late in the nineteenth century, people began experimenting with molding rubber (Thiruvarudchelvan, 1993)[3]. In his 1993 review on the use of elastomers in metal forming, Thiruvarudchelvan identified a number of distinct techniques, including: roll forming, bending; piercing and blanking; deep drawing; free forming; embossing; tube bulging; and the Guerin process (which used an enclosed rubber pad). Urethanes were deemed superior to other flexible tool materials due to their great thermal stability, loadbearing capability, resilience to oil and solvents, and wear resistance. (Müller and Sladojevic, 2001)[4] Sheet metal forming (SMF) is a widely-used manufacturing process for metal components [5]. Since the 1990s, computeraided tolerancing (CAT) has established as a key technology for determining machining sequences that can result in the best accuracy on some special features of a product in response to the rapidly decreasing number of experienced process planners for SMF, the need for shorter product life cycles, and the importance of 3D computer-aided design and manufacturing (CAD/CAM) [6]. bending of sheet metal is a common shaping technique that gives the metal the desired shape while also increasing its stiffness. As required by, a flat sheet or metal strip is usually bent in a circular arc along a straight axis that is perpendicular to the neutral axis [7].

When the tension is removed from a bent metal component, the portion still keeps its original shape because metal flow occurred in the plastic range of the metal. Inward from the neutral axis, the bend's cross-section is compressed, while the remainder of the curve is stretched [8]. There are several types of research have been done to examine innovative types of flexible sheet metal forming methods and their impact on the final product. this research aims to do a review of these procedures.

2. Rubber Pad Forming Process

Conventional forming procedures like bending, deep drawing, stretching, blanking, and stamping aren't the only ways to make complicated shapes.

Sheet-forming techniques that include the use of a rubber diaphragm are referred to as rubber pad forming or flexible die forming. One solid tool half, often a punch, is all that's needed for this technique. When pressing a workpiece around a form block, the rubber pad ensures that the force is distributed uniformly across the whole surface area. Rubber pad shaping is well suited to the assembly of intricate parts. There is often less than 100 mm of form block height when production rates are high and cycle times are typically 1 minute or less [9] Ribs, windows, doors, and frames are just some of the many sheet elements often formed using rubber-pad forming procedures in the aerospace sector. There is no need for accurate assembly of the rubber pad and rigid die, and production time and costs may be considerably reduced as a result of just having to make a single rigid die. Because it can spring back to its original form after being deformed, a single flexible pad may be used to mold a variety of various forms for a single piece of work.[9]. E. Akdemir [10] showed by use of 3D finite element simulation the significance of numerical simulation in the flexible shaping process. Their research revealed how the hardness of the rubber pad and the distribution of stresses affected the formation of various blank materials. They looked at die design, contact friction, and other pre-operational important aspects. Ramezani[11] Examined how stamping an aluminum blank with a rubber pad affects the pad's formation in terms of rubber type and stamping speed. After conducting a finite element simulation analysis of the procedure, the findings were compared to experimental data to ensure the model was accurate. S. Thiruvarudchelvan[12] Sheet metal ashtrays, a tube bulging technique, plates, an unique blank holding technique for deep drawing of cups of varied forms, and redrawing of cups are examples of metal forming techniques that have been introduced and refined as a result of the use of urethane in design.

Yaniong Liu and Lin Hua. [13] used both finite element modeling and experimental approaches to study the process of making concave and convex rubber pads. Also modified were the ratio of channel width to rib width, the forming load, and the thickness variation of the manufactured plate. Figure 1 illustrates the rubber pad formation schematic.

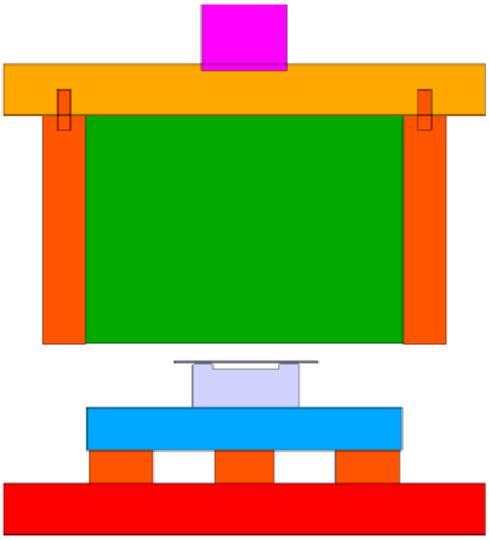


Figure 1. Schematic of rubber pad forming.

3. Incremental Sheet Metal Forming

The process of stamping metal sheets into thinner ones is widely used in manufacturing. Every day, millions of parts are manufactured using stamping. Consumers' increasing demand for bespoke services has resulted in smaller production runs. Some of the limitations of more conventional approaches of finalizing sheet metal forms are as follows: There are several factors that have contributed to the historically high cost of prototyping:

First, it's expensive to create custom pressing or stamping dies; second, it's challenging to manufacture complicated geometries; and third, it necessitates the employment of time-consuming and labor-intensive hand processes. As a result, there is a pressing need for innovative methods of low-volume production and prototype creation [14].

Many industries continue to search for proven Sheet Metal Forming procedures that can create LOW VOLUME sheet metal products at HIGH QUALITY, LOWER COSTS, and are FLEXIBLE enough to design a variety of product geometries with SHORT LEAD TIMES. Incremental sheet forming (ISF) has recently gained a great deal of attention from businesses (M Tizsa, 2012) [15] as a fast and adaptable approach for low-volume production runs. Innovative Sheet Fabrication (ISF) is a revolutionary approach to creating sheet metal components, and it is particularly well-suited to production in small quantities. The car industry in Japan looked to Japan for innovation when they required a cold-forming technology and ISF was the result. In order to do local sheet metal deformation without the use of an expensive die, a smooth-rotating tool is often used. ISF is also known as Die less forming method because of this [16]. Using this technique, complex forms may be made from a variety of materials. By avoiding the constraints of conventional tool design, sheet metal components may be rapidly and simply brought from a 3D CAD model to a finished product with ISF [14].

Flexible forming methods like incremental sheet forming are on the rise in the field of sheet metal engineering. The time and money required for part-dependent tooling in the traditional sheet metal forming process are prohibitive. Highly adaptable forming methods are being developed to provide more variation and customization in sheet metal manufacturing [17].

ISF and spinning are interdependent notions. Both are variants of Incremental Sheet Forming, and although they have certain similarities, there are significant differences between them. During the spinning process, the workpiece is normally fastened to a rotating mandrel as the spinning tools approach it and deform it into the desired form. Standard spinning features an inward-moving blank edge while the thickness of the material stays roughly constant. Shear spinning dramatically reduces the sheet thickness while leaving the blank edge unchanged. In flow forming, the distance between the tool and the mandrel determines the final wall thickness. The mold mainly determines the final shape [18]. Figure.2. displays a different type of the forming processes

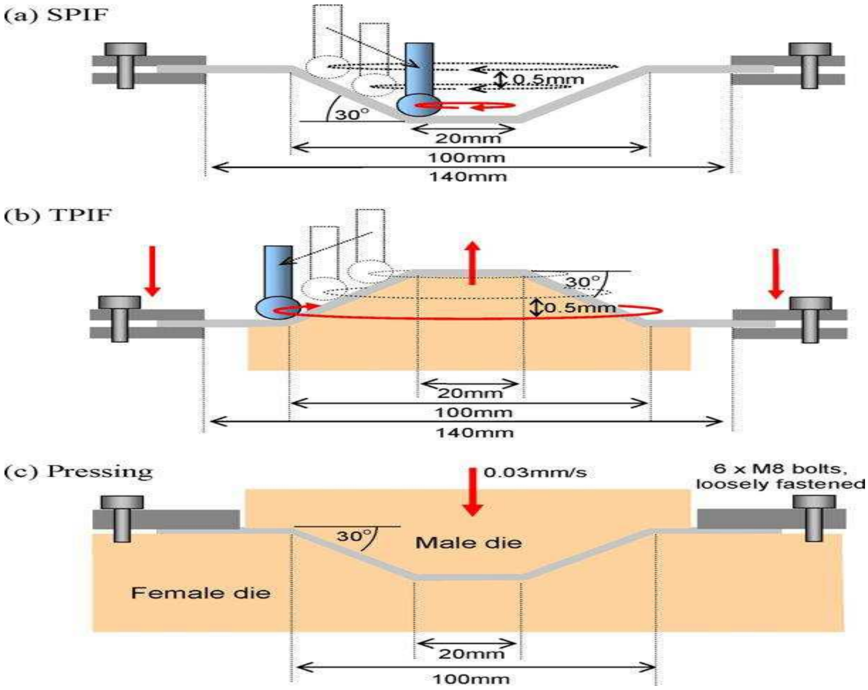


Fig.2. Forming processes: (a) SPIF; (b) TPIF; and (c)pressing

4. Types of Incremental sheet forming

Over the last 30 years, there have been five comprehensive evaluations of the literature on metal spinning, Hagan and Jeswiet [19] Asymmetric sheet metal formation was studied, and the fundamentals of two metal spinning configurations were presented. Also The conventional, shear, and tube spinning techniques were reviewed by Wong et al. [20] In 2009, Music and Allwood[21] wrote a thorough assessment. In this article, we looked at the two most prevalent metal conventional spinning, spinning configuration and shear spinning—and how their deformation characteristics vary. As can be seen in Figure 3, this procedure may be performed in a single pass or in numerous passes.

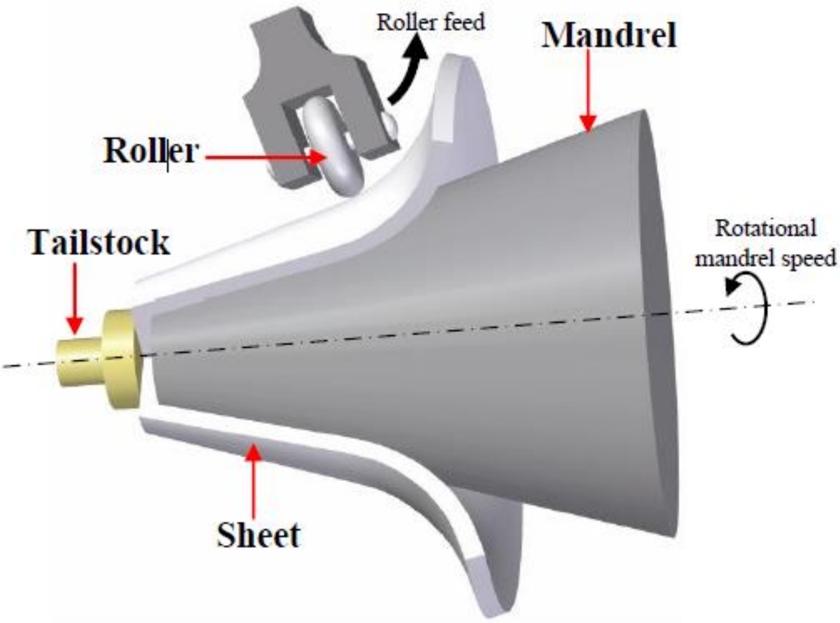


Figure 3: Traditional setup for the spinning process [17].

Although ISF is also an Incremental forming process, like stretch forming, there are important functional differences. Spinning relies on deforming the work item into a predetermined form. When a piece of work is clamped onto a revolving mandrel and a tool is used to exert stress on the metal, the metal conforms to the shape of the mold. Both straight and curved paths are possible for rotation.

Sheet metal always stays the same thickness. As a result, the blank margin is gradually receding [18]. When using the ISF method, the edge of the workpiece is clamped so that it cannot be

drawn inward. The necessary form is taken by the sheet without the need for a die or mold. As it moves in a spiral pattern, the tool pulls the metal inward. The metal sheet's thickness is reduced. [22]. As an outcome of this procedure, asymmetric forms were formed; consequently, the term "Asymmetry incremental formation" was coined to describe this technique (ASIF) [23]
Table 1 displays the results of a comparison between spinning and in-situ fibrogenesis.

Table 1: A Comparison of Spinning vs. ISF [18]

	Spinning	ISF
Blank Edge	Inward Movement	Clamped
The thickness of the wall	More or less constant	Reduces, determined by the process [a]
Die/Mandrel required	Yes	No
Shapes are determined by	Movement of roller or by the mandrel	Movement of punch or roller
Asymmetry shape possible	Limited [b]	Yes

a. Whereas in shear spinning the ultimate wall thickness must be obtained by adjusting the distance between the roller and the mandrel, in ISF the wall thickness is calculated automatically by the process's inherent properties.

b. Asymmetrical structures may be created to some degree when spinning is utilized, even though this process is often used for symmetrical results [18].

5. Ultrasonic Incremental Sheet Metal Forming

Currently, traditional forming procedures using the standard tool and die sets are largely used for small-batch manufacturing or prototyping sheet metal. In the aircraft business, for instance, the typical batch size is about 5,000 components, and each year roughly 200 stamping dies are utilized. [24]. An intricate 3D form gets "discretized" into a collection of smaller shapes using this method. tools based on two-dimensional surface processing and two-dimensional contour layers using a series of layers to follow a predetermined shape. incremental sheet forming (or ISF, also known as Single Point Forming) With this method, sheet metal may be digitally manufactured. One of the benefits of SPIF is the short amount of time it takes to create prototypes. Thus, there is a low barrier to entry for developing and manufacturing several product variants in small quantities. Application Using SPIF technology, product drawbacks like several die sets and expensive prices may be avoided. a time-honored technique of creating metal objects from sheets. The SPIF technique has limitations, however, including high forming force and low-quality complicated shape fabrication is challenging. After conducting finite element simulations and testing, Durante et al.[25] hypothesized that the friction coefficient would fluctuate depending on the rotation speed of the tool, which would then impact the necessary forming temperature, forming force, and forming accuracy. To confirm the size of the forming force at varying forming angles, Henrard et al.[26] employed both finite element modeling and testing. Forming forces at different forming angles were analyzed, as was the impact of the constitutive relation and hardening law. One empirical method for creating load prediction was derived by Aerens et al. [27]. Experiments confirmed the accuracy of this formula, which was used to determine axial force at steady state. The forming force in the SPIF process may be predicted using this formula. To determine what factors affect forming force, Bagudanch et al. [28]looked at spindle speed and tool diameter. They determined that the friction created by operating the spindle at high speeds increased the forming temperature. Using a finite element technique simulation of the SPIF process, Belchior et al.[29] were able to make reliable predictions about the forming force. Ultrasonic vibration molding also had a surface effect, which modified the amount of resistance experienced by the work piece against the mold. Using ultrasonic vibration forming instead of conventional plastic forming greatly increases the forming limit of the material and the quality of the final product while greatly decreasing the flow stress of the material [30]. SPIF relies heavily on pinpointed compression between the tool and the metal sheet. Sheet metal's brittleness and accuracy are affected by the forming force applied to it. The amount of stress in the workpiece may be directly correlated to the amount of force used in the forming process. The stability of the produced component is connected to stress because plastic strain evolves as a function of the stress [28]. The amplitude and varying law of the forming force are also connected to the design of the ultrasonic sheet forming equipment (e.g., stiffness, power, size). Tools and equipment used in the process may be protected from wear and tear if the operators have a solid understanding of the forming forces. These considerations highlight the practical importance of studying the effect of forming force on SPIF [31], [32]

6. The electromagnetic incremental forming process

Companies, particularly those in the aerospace industry, are always striving to improve their cutting-edge gear, and as a result, there is a growing need for lightweight, high-performance components. Using lightweight high-strength materials and thin-walled integrated structures may help to achieve this aim. Aerospace machinery is in dire need of a massive, thin-walled, elliptic-surface aluminum alloy component. However, precise plastic forming techniques are made more difficult by its massive size, integrated nature, and thin wall. Traditional deep drawing methods depend on mechanical equipment, which has limits due to factors such as the platform and load of the machines, the significant spring back after unloading, and the anticipated surface quality problem arising from the contact loading. Electromagnetic forming (EMF) is a new and promising technique that might assist solve the problem of producing large-sized thin-walled aluminum alloy components. Electromagnetic forming is, in a sense, a high-energy-rate forming method since it takes advantage of the pulsed force produced by the opposing magnetic fields in neighboring conductors. The secondary field is generated by the eddy current in the metal workpiece, and it operates in opposition to the primary field generated by the transient discharge of a capacitor through the coil (Mamalis, 2004)[33]. The body force, High-rate deformation, and inertia all work together to increase the metal's ductility, which in turn increases the metal's forming limit(Cui et al., 2011)[34]. The EMF technique improves the maximum and minimum primary stresses of magnesium sheets by 68% and 72%, respectively, according to research by Xu et al. (2012) [35]. Psyk et al. (2011)[36]highlighted a number of additional benefits of this method in contrast to traditional, quasi-static forming procedures, such as reduced springback, improved surface quality, variable loading, cheap cost, and so on.

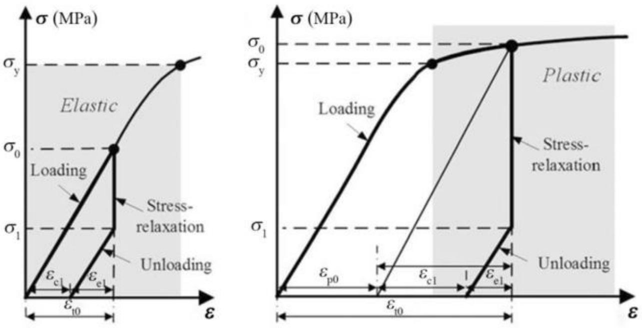
7. Creep-Age Forming Process

The aviation and aerospace industries rely on large-scale aluminum alloy wing panels. They can be made aerodynamic because of their ribbed frame and changeable curvature profile. Traditional panel forming procedures including milling, roll bending and shot peening has been challenged by these structural properties[37]. A new forming procedure for panel components called creep-age forming was introduced by Textron Aerospace to address the aforementioned issues of CAF) [38]. Panel components made from heat-treatable aluminum alloys may be formed precisely using CAF, a sophisticated panel-forming process. Low damage, excellent forming precision, and a quicker production cycle are just a few of how CAF stands out from more conventional manufacturing methods. It's been put to good use in the production of the wing skins and fuselage panels of the B-1B long-range fighter aircraft, as well as the Airbus A330 and A380 [39]

Large, complicated, and thin-walled structures are perfect candidates for CAF's forming process. Thermomechanical coupling, a wide range of strengthening processes (including precipitation strengthening, dislocation strengthening, solid solution strengthening, etc., and their coupling impact), and the interplay of dislocations and precipitates all play a role in its formation. Aerospace, aviation, and other forms of transportation technology might all benefit from CAF's use in product development[40].

Cruciferous organic frameworks (CAFs) are a kind of polycrystalline aluminum alloy that exhibit substantial springback when loaded and unloaded with aluminum alloy components. The main technological problem for CAF process engineers is determining how to precisely forecast and regulate the form, size, and mechanical characteristics of aluminium alloy components[41]. Since air pressure causes the plate to deform and conform to the geometry of the tool, vacuum pumps are used to create a space between the tool and the component. The initial strain injected into aerospace and aviation parts with low curvature is mostly elastic, whereas the persistent plastic strain is created in parts with high curvature. If the component's elastic modulus is excessively high, high-pressure autoclaves or mechanical clamping devices may be used to bring it into close tolerance with the tool surface [42]. When the component has been securely fastened to the tool, the assembly is placed in a high-temperature furnace to be heated to the aging temperature of the aluminum alloy. When elastic tension created during the loading stage is only partially translated into creep strain, we enter the second stage, known as creep accelerating force (CAF). The bent component exhibits a certain degree of springback because of the presence of residual elastic tension. Once the residual tension in the aluminum alloy sheet is relieved, the sheet springs back into shape[43]. Under elastic and plastic loading conditions, the stress-strain relationship in CAF is shown evolving in Fig. 3. In an elastically loaded state, the stress following stress relaxation falls from r0 to r1. The elastic strain responses to ee1 cause springback after unloading when r1 is released. Unlike elastic loading circumstances, in which the first plastic strain ep0 is already there, the loading stage generates the initial plastic strain ep0 in Fig. 3(b), demonstrating that the process of springback is the same[44].

During creeptests, the externally applied stress causes the dislocation structure and density to continually alter, resulting in a greater number of heterogeneous nucleation sites for the aging precipitates and impacting their development. Additionally, persistent precipitation significantly influences both the dislocation movement and the creep strain[45]. Predicting and manipulating component springback under controlled aging circumstances is a major difficulty for CAF technology. Aluminum alloys need to have a lot of springback for CAFed components, often between 50 and 70 percent. For the precise formation of large-scale and thin-walled components (abbreviated as LTC) with complicated forms, springback compensation has emerged as a crucial factor [46]. Few comprehensive reviews exist on the techniques of prediction and control for CAF, and on tool design, whereas the vast majority of studies focus on springback prediction and compensation for a single aging formingprocess. Some potential problems that may need to be addressed and some future directions for its development are explored in light of the potential of CAF for integrated production of the form and propertyping of LTC with complicated shapes [47].



(a) Elastic region (b) Plastic region

Figure. 3 Schematic illustration of CAF's springback mechanism at the elastic or plastic area.

8. Conclusion

Many different industries rely on sheet metal forming (SMF) as a reliable and cost-effective technique of producing metal components. In flexible forming, sheet metal is formed into complex forms by pressing them against a rubber die. Metal spinning, asymmetric metal components are of (SPIF) which can produce Parts with high strength-to-weight ratios that may be made cheaply and efficiently using spinning methods. The different problems of traditional sheet metal forming have been resolved through ultrasonic, electromagnetic, and creep-age forming. . The key advantages of flexible forming over conventional techniques are its low tooling costs, process versatility, and little damage to the formed components. The sheet metal that is easily bent may be used to create several distinct designs for a single project. In the conventional sheet metal forming process, developing specialized tooling for each individual item is an expensive and time-consuming endeavor.

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