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Review on Various Kinds of Die Less Forming Methods

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Abstract—With the increasing demands for low-volume and customer-made products, a die-less forming method, also called Incremental Sheet Metal Forming (ISMF), has become one of the leading research and development topics in the industry. Incremental Sheet Metal Forming (ISMF) is a recently invented die-less forming method that is quite different to the traditional methods. In ISMF, a piece of sheet metal is formed to the desired shape by a series of small incremental deformations. As it does not use dies, ISMF is effective for small batch production and prototypes. There are various kinds of die-less forming methods which can produce sheet metal parts without dies are proposed. This paper can help anyone who is interested in Incremental Sheet Metal forming with insight for future research direction.

Index Terms— Die-less forming, Incremental sheet metal forming, Sheet metal parts.

I. INTRODUCTION

According to Marciniak *et al.* (2002), classical sheet metal forming process includes a variety of stages. The examples of these stages are punching, blanking, drawing, bending, flanging and coining. These stages can occur in single stage operation or they could occur through a series of combined stages. For example, in a drawing process, a blank of sheet metal is clamped around the edges, while the middle section is forced by a punch into a die to stretch the metal into the desired shape. Hence, it requires a press machine to provide sufficient force to push the sheet metal into a die punch to form a part. Moreover, a set or many sets of dedicated dies are needed to be used for different parts of the metal sheet. In addition, making a die is not cheap and takes a long time. When more stages are involved in the metal forming process, more cost would incur, and more time is needed to complete all the processes involved. Hence, to lower the cost and speed up the process, various kinds of die-less forming methods which can produce sheet metal parts without dies are proposed. These methods include laser forming, flexible spinning, multi-point forming, incremental forming and shot peen forming. Today, the die-less forming methods have become important in research in metal industry. One of these methods, which is called the Incremental Sheet Metal Forming (ISMF), has been introduced recently. In ISMF, a piece of sheet metal is formed to the desired shape by a series of small incremental deformations. As it does not use dies, ISMF is effective for small batch prototypes and production. We hope that this research will supply guidelines for future research on sheet metal forming process and provide researchers and practitioners with insight on review of various ISMF methods.

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II. DIE-LESS FORMING METHODS

A. Laser Forming

In metal industry, Laser Forming technique has been developed and applied recently. The basic feature of laser forming is the forming by thermal stresses, induced by irradiation of a laser beam (Edwards *et al*, 2010). These internal stresses induce plastic strains that bend the material, and resulting in the local elastic/plastic buckling. Based on energy conservation, Edwards *et al*, (2010) and Shi et al (2012) proposed three basic modes in the laser forming of sheet metals. They were defined quantitatively as Temperature Gradient Mechanism (TGM), Buckling Mechanism (BM) and Upsetting Mechanism (UM). This is illustrated in Figure 1.

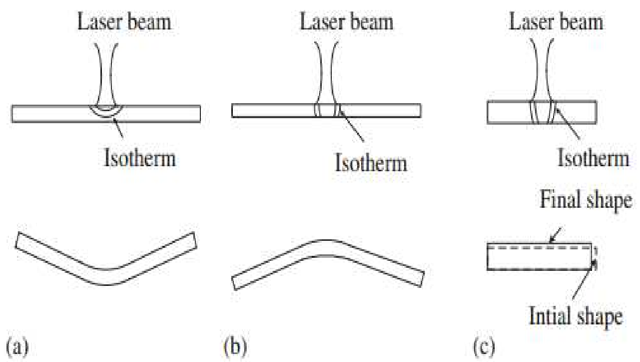

Figure 1. Mechanisms for the Laser-Forming Process Including: (a) TGM, (b) BM and (C) UM (Shi *et al*, 2012)

In a laser forming process, different forming mechanisms have dissimilar deformation behaviors. The aim of laser forming is to obtain plane strain under an upsetting mechanism, while a plate undergoes a small bending deformation (Shi et al, 2012). This process is widely used in ship building industry. Although this process is widely practiced, it has some limitations. First, recent studies have indicated that although this process can produce parts with 2-D bends, it is rather difficult for it to be applied with 3-D parts and not all materials are acquiescent to the laser forming process (Shi *et al*, 2012). Second, this process has low production rate which translates into having higher cost and hence, it is much cheaper if conventional manufacturing process is applied. The components of laser forming system include:

- ➢ The laser source with beam delivery system
- ➢ Motion table unit on which the work piece is mounted, or a robot for holding a fiber-optic system
- ➢ Computer control system
- ➢ Cooling system where necessary temperature monitoring system shapes monitoring system

B. Shot Peen Forming

Shot Peen Forming is a die-less sheet forming process that

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applies a stream of small hard shot with adequate kinetic energy to hit the surface of a metal sheet for forming a specific shape. This forming process is derived from the shot peening surface treatment, which is usually used to enhance the fatigue strength of sheet metal parts for some special applications, especially for the aerospace industry (Kim *et al*, 2010). In shot peen forming, the shot is usually made up of steel balls which are accelerated to a specific velocity and directed in a desired pattern. The size of balls is about 0.05-2 mm in diameter (Gariépy *et al*, 2013). They impact on the sheet metal thousands of times in a random manner. During impacts of the shots, a certain amount of its kinetic energy is transformed into plasticization of the component. When shot velocity is fairly low, only a thin layer of the component's material is elongated, resulting in a convex curvature. If shot velocity is increased, concave curvatures are produced. The mechanism of shot peen forming is shown in Figure 2 (Gariépy *et al*, 2013).

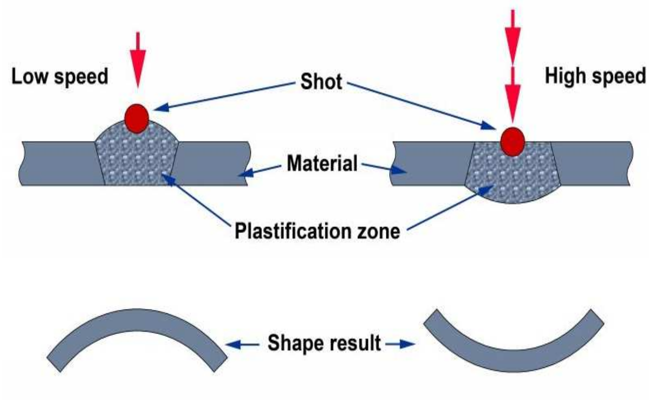

Figure 2. Mechanism of Shot Peen Forming

The shot peen forming process generally has lower manufacturing costs. This is because there is no need for dies and presses or subsequent thermal processes, and once the process parameters have been determined, the process is easily reproduced (Gariépy et al, 2011). It also has better adaptability to modern aircraft designs, for example, the capability to form single and double curved shapes and virtually any size of parts (Gariépy et al, 2013). In addition, it can provide beneficial performance to the peen formed component like the general shot peen hardening process.

C. Multi-Point Forming

Multi-point Forming is a process which forms a sheet metal using a press machine with a reconfigurable discrete dies. The concept of discrete-pin die that was used for forming sheet metal was first introduced approximately 30 years ago (Hardt et al, 1981). Davoodi and Zareh-Desari (2014) explored a discrete-die mechanical design for rapid response production of sheet metal parts. The advancement of computer control technology has made this process available in recent years. Its applications can be extensively found in industries such as in the aero industry (producing airplane skin panel), automotive industry and medical engineering. The application can also be found in industries such as ship and vessel building, metal sculptures, modern architectures, etc. This process is especially convenient for productions which are small in quantity. Davoodi and Zareh-Desari (2014) from Jilin University in China investigated the flexi die method and the stamp multi-point method. The investigation involved several hydraulic cylinders which were working against each other to form a detail. The working principle of Multi-forming is to control the tool system setting a matrix of threaded rods to approximate the designed shape, and then the geometric surfaces of the matrix of threaded rod converts to a dedicated discrete die. The configured discrete die removes from the setting machine and clamps into a rigid stretch forming tool. Hence, the flexibility of this process is largely depending on the resolution of discrete die. Figure 3 shows a reconfigurable discrete die.

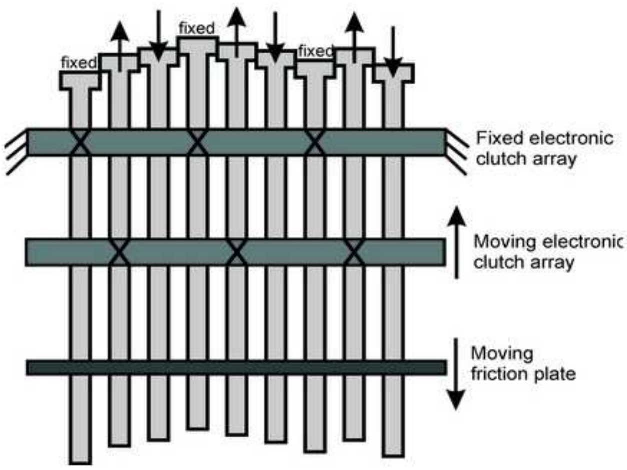

Figure 3. A Reconfigurable Discrete Die

Multi-point forming provides a forming system that can quickly change the set up of the forming tool. Better result can be achieved when the punch size is small (Cai et al, 2009). For the parts with large curvature, the shape errors will be large. In addition, the small punch size will make the machine more complicated and expensive.

D. Flexible Bending

Flexible Bending is a flexible process developed from the general bending process. General bending process bends the work-piece across an entire cross-section using a dedicated die. However, the flexible bending process has two differences against the general bending: 1) allow control of the bend angle at a particular location, and 2) control the distribution of the bend over some length of the product. Cai et al, (2012) explored the first approach for bending sheets along a line. Cai et al, (2012) also applied a related method to 'L-bending' with an intelligent punch tool. Both of these methods are used for creating single sharp bends, but in the second approach, continuous sheet bending is achieved by three-roll bending. Manuelli et al, (2014) reported on the optimal control of this process. The control system included a 'fuzzy learning process' to allow for control of plates and sheets with unknown properties. However, the equipment is expensive. Manuelli et al, (2014) also used fuzzy-set based methodology to determine the optimal bending sequences for the brake forming of sheet metal components, considering the relative importance of handling and accuracy. A new incremental forming process using an adjustable punch set and used it to make a doubly curved sheet metal part. . Cai *et al*, (2012) summarized the flexible bending method as shown in Figure 4. It was reported that Hu at al. (2009) used three bendable rollers to form 3-D surface parts.

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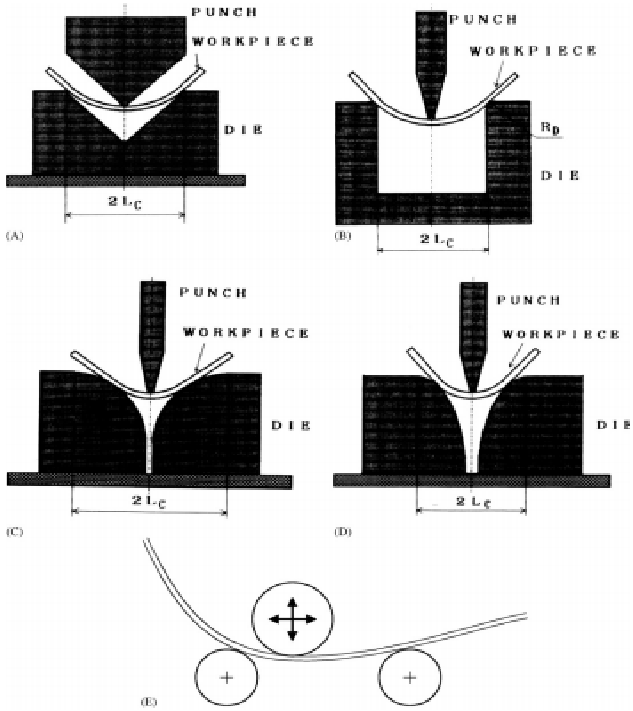

Figure 4. Flexible Bending of Sheets with: (A) Conventional V-Bending, (B) Air Bending, (C) a Curved Die, (D) an Oval Die and (E) Three Roll Bending (Allwood and Utsunomiya, 2006)

A. Incremental Sheet Forming or Die less NC Forming

Incremental sheet forming or dieless NC forming is a numerically controlled incremental process in which complex shapes from various materials can be provided. The process is on the basis of localized plastic deformation in the sheet metal blank. It was developed as an alternative manufacturing method to produce panels in small lot sizes and prototype sheet metal stampings (Dejardin *et al.*, 2010). Incremental sheet forming can provide complex shapes from various materials and produce panels in small lot sizes (1 to 500 pieces per month). Complex sheet components are manufactured by Computer Numerical Control (CNC) movement of a spherically tipped forming tool in combination with stationary die geometry. Computers in CNC machines play an integral part of the control. The process in incremental sheet forming is rapid prototyping, slow and well-suited for small-lot production, and rapid production of service parts and may reduce time to market. The Figure 5 shows CNC ISMF system (Cawley *et al*, 2013).

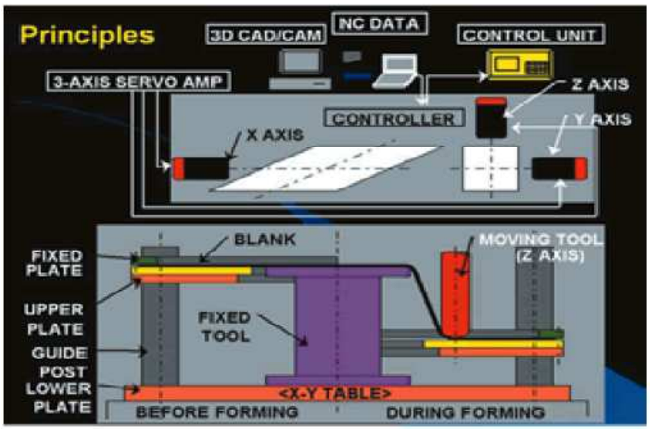

Figure 5. CNC ISMF System

III. Comparison of Kinds of Die-Less Forming Methods

The laser forming process involves thermal stresses being introduced to a metal sheet by irradiation rather than external forces. Laser Forming (LF) is a highly flexible rapid prototyping and is suitable for low-volume manufacturing process. Its advantages include easy to control, does not need tool and contact, energy efficient, it has various applications, and it has possibility to form hard-to-formed materials (Shi et al, 2012). Despite its benefits, the laser forming technique is not entirely free of drawbacks. The forming process is somewhat slow. For some types of forming it is slower by a factor of 5, for others it may be a factor of 20 when compared to traditional methods of stamp and die. The process requires safety protection equipment for the personnel because of multidirectional reflection of the laser beam from the metal (Edwards et al, 2010). Machining and forming metal parts create stress concentrations internally (burns, scratches, welds, etc.) and can cause other additional defects. These problems may be responsible for premature fatigue failure, porosity, deteriorated strength and corrosion, but can be prevented with shot peening. Peen forming is the preferred method of forming aerodynamic contours into aircraft wing skins and it has the following advantages:

- No forming dies are required
- Process is performed at room temperature
- Wing skin design changes are easily accomplished by altering the peen forming procedure
- There is no expensive modification of dies required
- All forming is accomplished using residual compressive stress
- Peen formed parts exhibit increased resistance to flexural bending fatigue and stress corrosion

The cost of a shot peening treatment is determined by the shot material, the process conditions (which will vary from one work piece to another) and by the hardness, dimensions and form of the work piece. The peening speed greatly influences the consumption of particles, but might decrease the working time. The multi-point flexible forming is another recent and flexible technique for manufacturing three-dimensional sheet metal parts. In this process, the sheet metal can be formed between a pair of opposed matrices of punch elements instead of the conventional fixed shape die sets. Having the punches elements at both the upper and the lower matrices; different curved surfaces can be created. By using this technology, production of many parts with different geometry will be possible just by using one same die set and hence, the need to design and manufacturing of various die will be avoided. This means that this technique is a great time and manufacturing cost saver. Another advantage of this technique is that two forming tools (punch or die tools) can be replaced with the use of hydraulic pressure (Cai *et al*, 2009 and Davoodi and Zareh-Desari, 2014). Bending is a manufacturing process that produces a V-shape, U-shape, or channel shape along a straight axis in ductile materials, most commonly sheet metal. Cai *et al*, (2012). Commonly used equipment that undergo this process include box and pan brakes, brake presses, and other specialized machine presses. Other typical products that undergo this process are electrical enclosures and rectangular ductworks. All functions are incorporated in the new process control system and can be

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operated centrally via the Rieter control panel. The monitor with graphics capabilities displays the data relevant to spinning operations in a clear and practical form. The advantages of Flexible Bending are (Manuelli *et al*, 2014 and Cai *et al*, 2012):

- It has user-friendly graphic display.
- Information can be obtained easily and fast.
- The data processed is clearly displayed for smoother operation.
- Data memory for 18 specifications enhances efficiency and ensures quality consistency.

Incremental sheet forming is a sheet metal forming technique where a sheet is formed into the final workpiece by a series of small incremental deformations. Due to process is controlled entirely by CNC processes no die is needed as is in traditional sheet metal forming. The removal of the die in the manufacturing process decreases the cost per piece and improves turnaround time for low production runs due to the fact that the need to manufacture a die is removed. In contrast, there is a loss of accuracy with the ISF process (Cawley *et al.*, 2013). Table 1 compares the advantages and disadvantages of various kinds of die less forming methods.

IV. Conclusion

This paper reviewed the various kinds of dieless forming methods. It discussed the basic ideas behind dieless forming methods. Our research provided information about various kinds of dieless forming methods by examining the publication articles on dieless forming methods that were published in academic journals. As result, to lower the cost and speed up the process, various kinds of die-less forming methods which can produce sheet metal parts without dies are proposed. This paper provided an introduction on various kinds of dieless forming methods. By the comparison, it is not difficult to find out that the research on dieless forming methods is a newly emerged domain. We hope that this paper provides practitioners and researchers with insight and future direction on dieless forming methods.

Table 1. Comparison of Kinds of Die-Less Forming Methods

Dieless forming methods	Advantages	Disadvantages
laser forming	Easy to control Does not need tool and contact Energy efficient Many applications It has possibility to form hard- to- form materials	Difficult for it to be applied with 3-D parts has low production rate which translates into having higher cost forming process is somewhat slow Requires safety protection equipment
Peen forming	No forming dies are required. Process is performed at room temperature. Wing skin design changes are easily accomplished by altering the peen forming procedure. There is no expensive modification of dies required. All forming is accomplished using residual compressive stress. Increased resistance to flexural bending fatigue and stress corrosion. There is no other possibility of forming integral structures in some cases of complex forms except by peen-forming.	The process is getting close to its limits of performance The process should be performed at room temperature Peen Forming has limitations primarily in the thickness of metal
Multi-point Forming	Quickly change the set up of the forming tool Manufacturing cost saver In this technique two forming tools (punch or die tools) can be replaced with the use of hydraulic pressure	The flexibility of this process is largely depending on the resolution of discrete die This process is a great time
Dieless NC forming	Simplified dies result in lowered tooling costs Prototyping can be faster and inexpensive. The process is quiet and safe and requires minimal floor space. It can form intricate shapes.	Suitable only for small production lots Slow forming speed Limited accuracy

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