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A Review of Fundamentals and Advancement in Incremental Sheet Metal forming

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ABSTRACT: *ISF (incremental sheet metal forming) is a technique which uses CNC tools to form sheet metals. The method is not applicable for mass production but found to be very useful in small batch quality production. The study includes fundamentals of incremental sheet metal forming, classifications, tools used and effect of various parameters such as plane anisotropy, tool size and shape, lubrication on it. The study also includes the advance methods incorporated in ISF such as doubly curved surfaces, Hybrid forming etc, their advantages and limitations.*

Keywords: *Incremental sheet forming (ISF), Plane anisotropy*

I. INTRODUCTION

Die and punch molding, drawing and roll bending are the most popular sheet metal forming processes. These methods have been discovered to fulfill the requirements of mass production. In these types of Sheet forming processes, design of die, punches played important roll. But now, with the social and industrial growth, Transformation of mass production era has happened into Quality Production era, which largely depends on the small batch production as well as the prototype of Customized design [1]. For small batch production, say of a few units, conventional sheet metal forming process seems inadequate. Design of dedicated heavy die and punches for small batch production and for prototype production is nothing but the waste of material, time and money [1]. To compensate cost, time and production, new Production method is being developed called Incremental sheet metal forming.

Conventional processes like roll-bending, roll forming are nothing but the incremental processes as the formation of the sheet blank into the final workpiece is done by a series of small incremental deformations. Advanced incremental Sheet Metal forming or ISF process includes the local (point) deformation of the sheet blank by using a simple geometry (spherical or hemispherical) tooling system. In the process, the tool is mounted on a CNC [3] machine having three degrees of freedom (X, Y and Z axis). A tool path is then decided and the tool is moved accordingly over the sheet blank with vertical feed. For simple and symmetrical shapes, no die is required and hence it is also called as 'dieless' process. For forming complex shapes, simple dies of low cost material or simple supporting tool is used. The blank holders used for holding the sheets during the operation are also of simple and universal shapes. Due to the use of CNC machine and low cost production setup, this method is proved to be a flexible one. Some advanced methods adopted in ISF process such as use of Industrial 6-axes robots instead of CNC machine or Hybrid ISF, flexibility of the process is increased further.

Basic setup of ISF

Simple geometry tool is mounted on the tool-post of the CNC machine. The sheet blank is chucked on the blank holder. The tool is moved on the sheet and it imposes deformation locally on the sheet in a consecutive manner [1] as per the given program to CNC. The trajectory along which the tool should move is defined directly from a CAD definition [11]. Generally the path of the tool is chosen spiral (inward or outward) with consecutive vertical feed of required depth. If the geometrical structure of the product is complicated, supporting tools or dies are used below the sheet metal.

3. Parameters affecting the productivity in ISF

3.1. Type of tool

Generally two types of tools are used in ISF process. First one is the hemispherical tool in which hemispherical shape is made on the tool itself. Second is spherical tool in which a ball of hardened steel is made free to rotate inside a case just like a nib of a ball-pen. After experimenting both of the types of tools on the same material, it is found that, spherical tool gives more depth and better surface roughness compared to the hemispherical tool. It is due to its smooth, rolling action over the blank surface without rubbing. As Incremental sheet metal forming process is under development, no standardization of the tools is done. Tools are designed and made by the users, they are not yet part of an assortment made available in the market [11].

3.2. Use of lubrication

The experiment is done with the use of spherical and hemispherical tool, with and without lubrication. It is observed that spherical tool without lubrication gives better formability because the friction at the tool and sheet interface increases the tool pressure, lowering the state of stress in the sheet. As a result, the occurrence of crack is delayed and the formability is improved. However, if the friction increases too much, the sheet will crack. Without use of the lubrication in the case of spherical rolling tool, heat production is also minimized due to rolling friction instead of the sliding friction [11].

3.3. Plane anisotropy

When the property of the material is different in different direction, it is called the plane anisotropy. When the metal sheet is being manufactured by the methods like hot and cold rolling, RD (Rolled direction) and TD (Transverse direction) surfaces are formed. Thus it forms plane anisotropy. While forming with pointed tool, it shows different types of deformations in different directions. In the case of the 5 mm diameter tool, as the stresses in adjacent fibers are dominant, the major strain in RD is greater than that in TD, In contrast, in the case of the 15 mm tool, as the tensile stress in fibers are dominant the major strain in TD is greater than that in RD [2]. The major strain is approximately the same in both RD and TD for the 10 mm tool. Hence, 10 mm tool is preferred.

3.4. Feed rate

Lower the feed rate increases the surface smoothness but also the time consumption, so feed rate should be decided as per the requirements of shape, surface texture and roughness.

3.5. Types of clamping methods

There are two types of clamping methods used in ISF, solid clamping and ball clamping. In solid clamping, sheet blank is attached firmly to the blank holder with the help of nut and bolt while in ball clamping, sheet is held in position with the help of hardened steel balls. In some cases, clamping with hardened steel balls is effective because it provides smooth flow of material as required.

4. Types of Incremental Sheet Metal Forming Technique

4.1. Spinning or Shear forming

In this type of forming, blank is attached to the mandrel. Mandrel is rotated about its own axis and roller tool is swept over the mandrel from top to the bottom. Displacement of the tool is controlled by CAC (Computer aided control). In the ideal shear forming process, no radial displacement of the material occurs. In the spinning and shear forming process, Sine rule of thickness distribution is obeyed.

4.2 Asymmetric Incremental forming

4.2.1 Single point incremental forming (SPIF) (fig. 1.1)

The sheet is held in position with the help of the blank-holder which is fixed in a particular position. A simple geometry tool, fixed to the CNC tool post is moved along the surface and metal is formed.

4.2.2 Two point incremental forming (TPIF) (fig. 1.2)

The sheet is held in position with the help of the blank-holder which is fixed. A simple geometry tool, fixed to the CNC tool post is moved along the surface and subsequently counter tool is moved from opposite side of the blank sheet which gives support to the main tool which increases the formability, reduces the possibility of crack formation, permits the production of smaller wall angles and a metal sheet with higher thickness can be used.

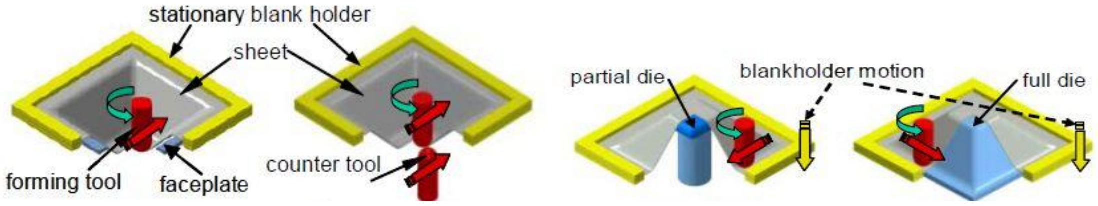

fig. 1.1 fig. 1.2 fig. 1.3 fig. 1.4

Fig.1 Configurations of asymmetrical ISF

4.2.3 Incremental forming with partial die (fig. 1.3)

Sometimes the workpiece used is of certain shapes, which cannot be manufactured with dieless technique. In such cases it is mandatory to use a supporting tool (as shown in figure 6) or which is called a partial die. The use of partial die gives support to the workpiece which is being formed. Stepped or bucket shapes can be manufactured by this method.

4.2.4 Incremental forming with full die (fig. 1.4)

This method is exception for the dieless process. While manufacturing very complex shapes like complex automobile or aviation parts, dedicated dies of the similar shapes are used to achieve the required accuracy. Due to the use of full dies, ISF process is not deviated from its objective because dies used in this process are made up of cheaper materials and instead of acting as a tool of deformation; they only act as the supporting tool. Sometimes this method is classified under TPIF (Two point incremental forming) as the full die used here also plays the role of counter tool.

5. Thickness distribution in pure shear deformation

Prediction of the thickness of the product after the incremental forming is very easy [7, 17] if the deformation is of pure shear type. If vertical feed and solid clamping is used in ISF, we can consider the deformation as a pure shear deformation. Sine Rule of Thickness is used for determination of the final thickness. As no any extra material is provided during the deformation in solid clamping, thickness of the wall totally depends on the wall angle. According to the equation : $t_{(final)} = t_{(initial)} \sin \alpha_{(wall\ angle)}$

As we can see according to the equation if we decrease the wall angle up to 30^0 final thickness of the product decreases up to half of the original thickness ($\sin 30^0 = 0.5$) which is permitted in most of the cases. If we want to decrease the wall angle further below 30^0 we face deficiency of material which leads to the formation of the crack. According to the equation, to produce products with 0 or negative wall angle is not achievable as thickness of the sheet becomes zero. To overcome these limitations, advance methods like Robo-forming are used. In these methods, formation of the sheet metal is done partially by shear deformation and partially by bending. In these cases, rule of thickness is not used to determine final thickness of the product. In such cases some computational methods and closure loop methods are used to analyze the formability.

6. Superimposed pressure incremental sheet metal forming

Conventional incremental sheet metal forming process has certain issues with it. In asymmetric incremental sheet metal forming (AISF) the sheet thickness is reduced due to the local shear forming. According to the sine law of thickness which is used to predict the final thickness, thickness of the formed shape and formability totally depends upon the wall angle. Depending on the material and the forming parameters, a minimum wall angle of about 35^o can be achieved in a single forming step. But in most industrial parts much lower values are necessary. Another issue in AISF is the commonly reduced surface quality. On the side on which the forming tool is acting, grooves and scratches can be found in moving direction. The quantity and depth of the grooves and scratches are dependent on various parameters like tool radius, feed rate, use of lubrication etc.

To overcome these issues with conventional ISF techniques, Duplex Incremental Forming technique is used. [5,12] Applying a superimposed pressure in the forming zone can produce higher strains and products with low wall angles. Machining both sides of the sheet could increase the surface quality and can have a higher accuracy in concave surface areas.

II. SETUP AND OPERATION

The sheet blank is held in position with the help of the blank holders. Two industrial six axes robot (Ex. KUKA KR360) [5, 12] are loaded with the tool. As shown in the figure 10, two tools are moved along the predefined path in synchronous with each other as per the predefined program. A local pressure is applied over the blank and deformation is done incrementally. There are two types of duplex forming. First is P-DPIF (Duplex incremental sheet metal forming with peripheral support) in which one of the tool acts as the main deformation tool and another tool acts as the counter tool which supports the deformation. Second method is L-DPIF (Duplex incremental sheet metal forming with local support). In this method, both of the tools are moved co-centrically and both of the tools act as the deforming tool.

6.2. Quality improvement

With the use of two industrial robots in the duplex forming, negative wall angles up to 7^0 can be achieved. The higher contact force in combination results in a higher average surface roughness. Use of robots improves accuracy in the product. Overall formability increases near about 12.5%.

7. Hybrid forming process

One of the most unavoidable limitations of the Incremental Sheet metal forming technique is its time consumption. Due to the use of local incremental deformation manufacturing a part consumes lot of time. (E.g. it takes more than half an hour to form a sheet of $1m^2$) This huge time consumption is not favorable to any industry. Therefore many researchers are in search of the hybrid [8] processes which could give the flexibility in forming and low time consumption. One of the examples of the hybrid forming technique is combination of the stretch forming and the incremental sheet forming. For every different design, different strategy of forming is used. Here formation of the dome shape with groove over its surface is explained. For the particular operation, combination of stretch forming and the incremental sheet forming is utilized.

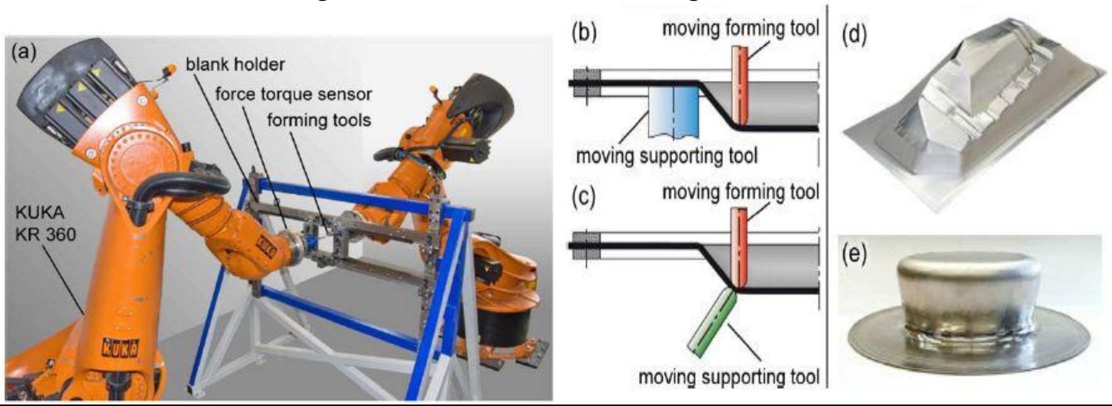

Fig. 2 (a) Roboforming setup, (b) P-DPIF, (c) L-DPIF, (d) Complex automobile part, (e) A part with negative wall angle (-7^0)

7.1. Setup and operation

Sheet metal is firmly clamped on the frame. The frame can be moved up and down by applying force over it. A full die is kept under the blank holding frame. Force is applied over the frame and the frame is moved downward. As soon as a part of sheet comes in contact with the die stretching occurs. The frame is moved until the blank takes the required shape. After the stretch forming, the groove will not come in contact with the sheet hence it is formed further by incremental sheet forming process. A tool is chucked in the tool-post of the CNC machine. The tool is moved over the predefined path to complete formation of the groove.

III. CONCLUSION

For low batch and quality production, Incremental sheet metal forming technique is proves to be the most efficient method. Due to the use of CNC mills and industrial robotics, accuracy of the parts can be increased and more complex parts can be produced. The method is most suitable for the prototype production. Advantages of the conventional processes can be adopted in ISF to increase productivity. Formation of the cold recycling is also feasible with Incremental sheet metal forming technique.[9]

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