Design and Fabrication of Electromagnetic Fixture for Incremental Sheet Metal Forming

Harish K. Nirala[1] and Anupam Agrawal[2 *]

*Emails: [1]harish.nirala@iitrpr.ac.in, Emails: [2, *]anupam@iitrpr.ac.in*
Indian Institute of Technology Ropar, Department of Mechanical Engineering, Rupnagar, Punjab, India – 140001

Abstract

Single Point Incremental Sheet Forming (SPISF) technique is a useful and emerging process for die less forming. It has wide applications in many industries viz. automobile and medical bone transplants. In ISF, forming of the sheet is done by using Numerically Controlled (NC) single point, hemispherical end shaped forming tool, which incrementally deforms the sheet by highly localized plastic deformation. Sheet clamping mechanism is one of the important aspects of SPISF, that dictates the clamping as well as overall manufacturing time. In this study, a novel electromagnetic clamping mechanism for SPISF and other forming processes is presented. From the available literature, it has been found that this kind of clamping mechanism in the metal forming domain has not been investigated. ISF is flexible yet relatively a slow process, when compared with conventional forming processes. The conventional methods of clamping in ISF makes it even slower. The concept of electromagnetic clamping makes the process of sheet clamping faster. By this concept, sheet metal could be clamped in just one click. This results in the less manufacturing time for each component. This concept can take the process of ISF towards better industrial acceptability. One more and very needful advantage of this fixture is that it is capable of clamping magnetic (mild steel, nickel) as well as nonmagnetic (aluminum, copper) sheet blanks. In this study, a setup for electromagnetic clamping is designed and fabricated, and SPISF of circular and conical wall profiles is done to test the feasibility of the concept.

Keywords: Design and Fabrication, Electromagnetic Clamping, Single Point Incremental Sheet Forming, Formability, 3D printing.

1. INTRODUCTION

Single Point Incremental Sheet Forming (SPISF) technique is a generative manufacturing process where geometry or a shape is incrementally generated, as opposed to additive or subtractive processes. The process of backward bulge incremental forming using a single point hemispherical tool was first introduced by Matsubara, 1994 [1]. However, as a concept a patent filed by Leszak [2] in 1967 initiated research in Incremental Sheet Forming (ISF) process. In 1978, work done by Mason [3] at the University of Nottingham gave a new vision to forming by ISF. In 1994, Matsubara [1] developed a two-point ISF technique to improve its dimensional accuracy. A comprehensive review of ISF is very effectively given by Jeswiet et. al., 2005 [4]. The process mechanics of incremental forming have been subsequently well defined experimentally by Jackson and Allwood, 2009 [5] and analytically by Martins et al, 2008 [6]. Incremental Sheet Forming (ISF) is a widely known die-less forming technique as an alternative to traditional forming techniques. In this process, the sheet is clamped from its periphery on a suitable fixture mounted on a CNC Milling machine. Generally, a hemispherical or a ball end forming tool is used for deformation in Single Point ISF (SPISF). The movement of forming tool over the sheet is controlled by the toolpath given as a Numeric Code (NC) to the machine. The tool induces localized plastic deformation in the sheet [6], which deforms the component with higher formability as compared to conventional forming techniques like deep drawing and spinning. Single Point Incremental Sheet Forming (SPISF) has drawn attention because it is very suitable and effective for small batches and customized products in production system [4]. Schematic representation of SPISF process is shown in figure 1.

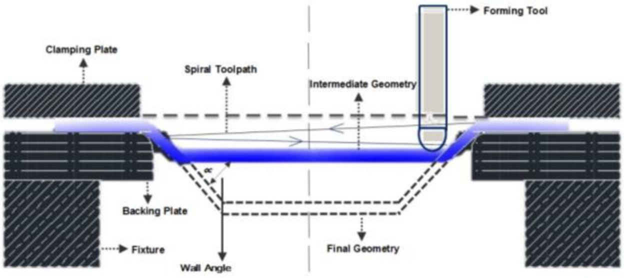

Fig. 1: Schematic representation of SPISF process

The process of ISF has many applications in diversified fields like automobile, nuclear power and biomedical engineering. Figure 2, shows a glimpse of its application in automobile and various sections of bone prosthesis. Fixture is one of the main component of manufacturing process to hold, clamp and support the sheet blank during forming/machining. In ISF, the cost of fixture designing and manufacturing is around 30% of the total manufacturing cost.

Design of fixture should be simple and effective for easy clamping and unclamping of components. It is a very crucial factor for any manufacturing industry to develop a variety of products within short period of time and that can only be possible by flexibility. A lot of detailed work has been done in ISF on toolpath strategies, forming forces, failure analysis, thickness reduction and prediction, deformation mechanisms and lot more. However, the study of clamping mechanism and its effect on forming forces is very limited in literature. The present study proposes a novel design, based on electromagnetic fixturing forces, specifically for ISF process.

*Corresponding Author: Dr. Anupam Agrawal, Associate Professor, Dept. of Mechanical Engineering., IIT Ropar, Email: anupam@iitrpr.ac.in

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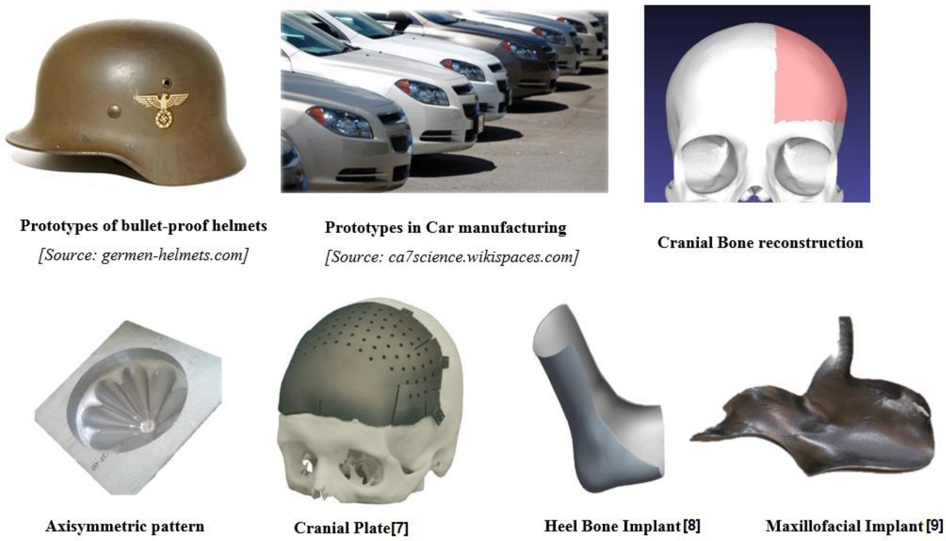

Fig. 2. Some applications of ISF

2. ELECTROMAGNETIC FIXTURE

The proposed design of Electromagnetic Fixture (EF) abides the principles of electromagnetic induction. The electromagnetic field is generated due to eddy currents, which are generated due to electromagnetic induction. The EF enables the sheet metal to be clamped on a magnetic surface i.e. the top surface of the EF. The designed inductors (electromagnetic actuators) enable uniform magnetic force over the entire contact surface without compressing or deforming the sheet metal.

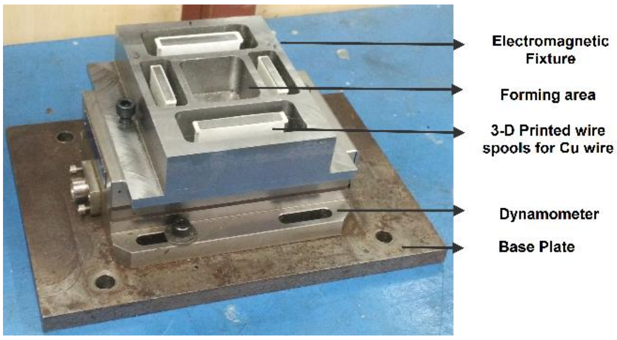

Fig. 3. Primary set-up for Electromagnetic Fixture

Figure 3, shows a primary setup for electromagnetic clamping. As the eddy currents are uniformly distributed over the contact area between the magnetized block and cover plate (figure 6), so the generated magnetic field is also uniformly distributed. Hence, it results in uniform clamping force to the sheet metal blank over the contact area. This design (figure 6) consists of a base plate, cover plate, dynamometer, magnetized block, 3-D printed wire spools (ABS), four electromagnetic actuators, and a rectifier. The base plate assures accurate mounting of the setup over the machine bed. The dynamometer is attached to the assembly in order to monitor the force behavior during ISF. 3D wire spools are selected in order to wrap copper (Cu) wire around it and generate electromagnetic field. The electromagnetic actuators (inductors) are designed and located in such a way to generate nearly uniform magnetic field all over the clamping region. Rectifier is used to convert AC supply into DC. It has been observed from preliminary experiments that AC supply was generating heat and causing undesired vibrations. After connecting the rectifier, the electromagnetic field was smooth, no heat was generated, and no vibrations were observed.

The proposed concept is specifically designed for die-less sheet metal forming operations. This design is different from the available designs in literature [10-12] in terms of its suitability and flexibility for die-less sheet metal forming operations. It has been observed during preliminary experiments that the intensity of magnetic field decreases with increase in the distance above inductors. Hence, to overcome this limitation, it was decided to keep the forming area (figure 3) in between the four inductors. This eliminates the limit of maximum achievable forming depth, by this design. After a very detailed literature survey available in public domain, it has been found that no such kind of fixture has been developed yet. Most of the inventions based on electromagnetic clamping mechanism are for machining or other similar subtractive processes. Further, in metal forming domain, few concepts of electromagnetic forming are invented, which are completely different from this clamping concept [13, 14].

For comparative study, a conventional fixture is also designed and fabricated. Conical and circular wall profiles are fabricated using electromagnetic and conventional fixtures. The CAD model and fabricated conventional fixture is shown figure 4. Both the profiles are successfully fabricated using electromagnetic and conventional fixture. The present design is capable of clamping ferromagnetic materials (for eg. ferritic stainless steel-SS 430) firmly. For forming non-ferromagnetic sheets, by using the cover plate, there is direct contact between the peripheries of cover plate and ferromagnetic electromagnetic fixture. Hence, by this technique, the non-ferromagnetic sheet sandwiched between these two plates can be clamped firmly by the pressing action of electromagnetic force. From experimental investigations, it was found that, there had been almost complete cut-off of electromagnetic force in the region of cover plate which was in direct contact with the non-ferromagnetic sheet (Al 6061). It had been seen during experimental investigations that, strong electromagnetic clamping force was required to withstand high forming forces. Hence, it was decided to use higher value of DC current, and higher number of turns for non-ferromagnetic sheets. Hence, by such set-up both ferromagnetic and non-ferromagnetic materials can be clamped.

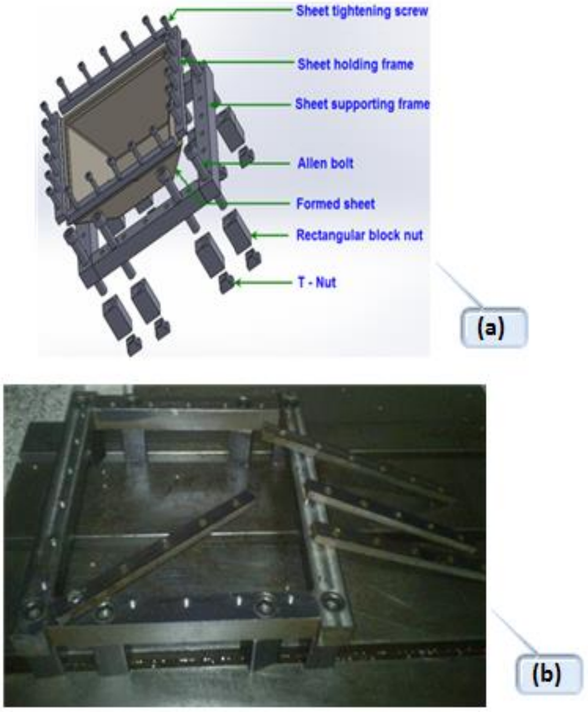

Fig. 4. Conventional fixture a) CAD model b) fabricated fixture

3. NUMERICAL SIMULATION

Numerical investigations using FEA is an effective technique to investigate and predict the forming limits and challenges. Researchers have used various simulation software packages to conduct simulations of ISF like ABAQUS, LS-DYNA, PAMP-STAMP 2G, and HyperWorks in order to do real time-based simulations. In this research wok, real time based simulations are performed for conical and circular wall profiles using commercial software suite (ABAQUS), as shown in figure 5. In preliminary work done so far, the elastic and plastic properties of sheet blank (SS 430, ferritic steel) were considered during simulations. The thickness of sheet and tool diameter were taken as 1mm and 8mm respectively. The interaction between the sheet and forming tool was implemented by a pure master-slave contact algorithm. Additionally, the coefficient of friction between blank and the tool was taken as 0.1 by using coulomb's law of friction [15]. The forming tool moves in a 3D path according to the boundary conditions assigned to it in x, y, z coordinate directions. By post processing, one can view the various results like thickness reduction, stress distribution and spring back. An isotropic sheet blank with 'S4R' shell elements is considered for this study. These shell elements are preferred for simulations of ISF because it gives best results with less processing (CPU) time [16]. The interaction between the sheet and forming tool is implemented by a pure master-slave contact algorithm [17, 18].

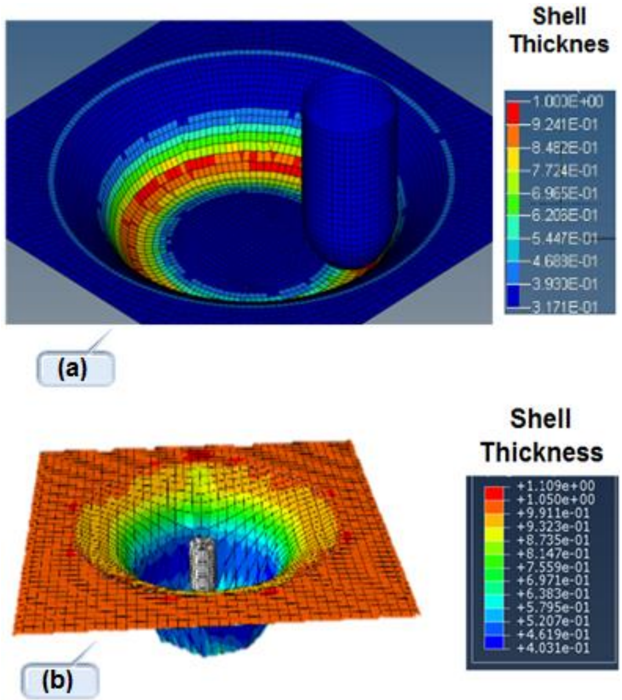

Fig . 5. Numerical simulation results a) conical b) circular wall

In this study, basic simulations of geometries (figure 5) to predict shape, toolpath and shell thickness are conducted. The effect of variable clamping force or electromagnetic clamping force is not considered in the simulations. However, as this design is capable of varying clamping force in real time, hence it is decided to conduct such study in future.

4. EXPERIMENTAL EXPLORATION

This was the most crucial and challenging step to investigate the effectiveness of the developed design. The whole setup for electromagnetic clamping is shown in figure 6. The EF is mounted over the machine bed with the help of a base plate. The base plate was designed according to machine bed specifications. Further, for experiments, HSS made hemispherical end forming tool with 8 mm diameter is used. 1 mm thick stainless steel sheets (140 mm × 140 mm, SS 430) are used. SS 430 has applications in aerospace, nuclear industries, and marine industries. Feed of 500 mm/min and RPM of 500 is assigned to the forming tool. Formed components (conical and circular wall) by SPISF are shown in figure 7. The spiral based toolpath (1 mm increment) is used in all the cases. The results obtained from electromagnetic fixturing process were found satisfactory and in accordance with conventional fixturing. It was interesting to note that less forming forces were required in EF as compared to conventional forming. The clamping force generated by electromagnetic fixture (EF) is more uniform when compared with the conventional fixture. Hence, EF ensures excellent, vibration-free mechanical stability. The magnet is one of the system, which ensures full surface clamp force, this results in the uniform material flow near the clamped region. Hence less forming forces are required for the sheet which is clamped by EF when compared with conventional fixture. A detailed experimental investigation based on forming forces behavior will be conducted in the further studies. Further, in these experiments the electromagnetic actuators

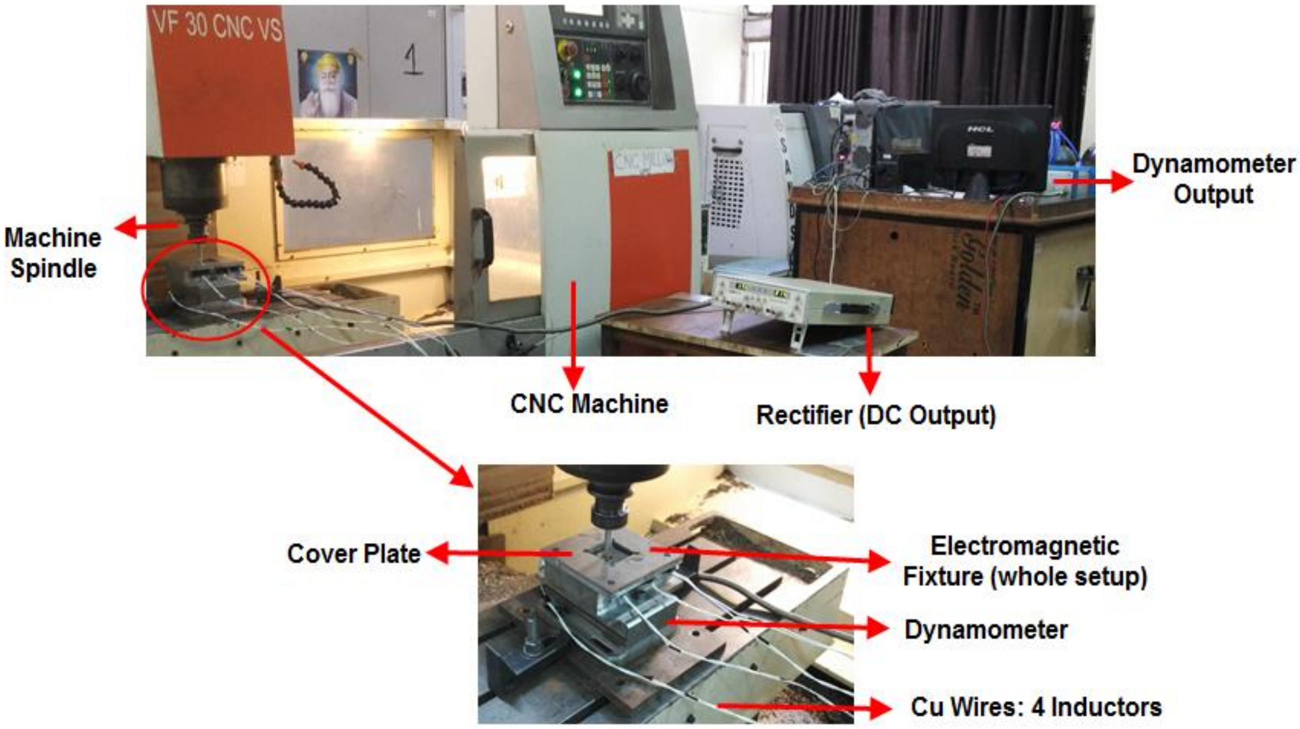

Fig. 6. Machine set-up for Electromagnetic Fixture

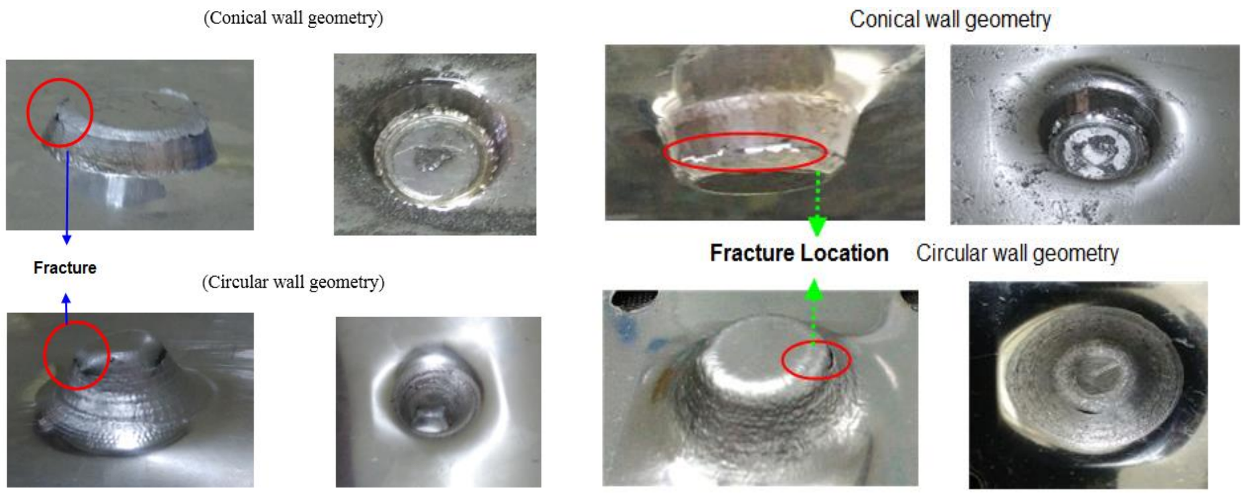

Fig. 7. Components fabricated by ISF: a) by electromagnetic fixture b) and by conventional fixture

were connected in series with input voltage of 25 V. The voltage requirement is dependent on the magnetic permeability of the material.

5. DISCUSSION AND SUMMARY

From the experimental investigations, it has been found that the conical and circular wall profiles are successfully fabricated using EF. This validates the feasibility of EF concept for ISF. Sheet fractured in all the cases. However, in case of EF, sheet fractured at 17 mm and 13 mm for circular (wall angle 30^0-70^0) and conical wall (wall angle 75^0) geometries respectively. In case of conventional forming, sheet fractured at 15 mm and 12 mm for circular (wall angle 30^0-70^0) and conical wall (wall angle 75^0) geometries respectively. Also, it has been observed that the EF was able to withstand (without slipping) maximum forming forces of 600 N during experiments. Further, it was very interesting to note that EF required less forming forces to deform the considered geometries as compared to conventional fixture. Future study will include detailed comparative study of forming forces involved in conventional and EF. Future study will include in-situ clamping force variation to avoid fracture at critical regions. The same may also be incorporated in the simulations. It is well known that being a slow process, ISF is limited to only customize fabrication. The proposed concept could be a stepping stone towards the industrial acceptance of this process. From experimental investigations, it has been found that, clamping - unclamping time is reduced from 10 minutes to 20 seconds. The concept of electromagnetic clamping is proposed as a one-click clamping solution to various metal forming processes.

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