

Experimental and Numerical Investigation on Incremental Forming of IS513Cr3



M. D. Vijayakumar and G. Gopalaramasubramaniyan

Abstract The incremental sheet forming (ISF), also known as die-less forming, has the potential to form complex three-dimensional objects. It has a higher formability limit than the conventional forming. ISF is the method of producing complex sheet metal components with enhanced productivity and improved quality. Further, the ISF can also be applied in various levels of manufacturing. Major advancements in the ISF have proved the manufacturing flexibility of the process. The present research work discusses important findings on various factors like wall angle, tool material, step depth, spindle speed, and feed corresponding to the response which is related to wall thickness, roughness, geometry, and forming angle. Such features are found to be the characteristic formability feature in the ISF. The entire process has been investigated by using numerical analysis software. The final fabrication includes designing the fixtures for clamping sheet metals, and suitable programming inputs have been given to the CNC machine. In addition to the analytical results, various iterations in the ISF of IS513Cr3 have been conducted by changing the wall angle correspondingly. The computational results of the ISF are compared with the actual values obtained from the experimentation, and various process parameters have been investigated and studied.

Keywords Incremental sheet forming · Die-less forming · Formability limit · Manufacturing flexibility · Computational results

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1 Introduction

The sheet metal has a wide variety of application in the engineering stream. Everyday contemporary manufacturing operations have been exploited for the formation of sheet metals to required shapes. Various forming operations have been currently used to produce complex profiles on the basis of the application. In such a case, the incremental sheet metal forming is an emerging technology that focuses on the production of complex structures. Unlike using the conventional method of die forming, the IF is a customized method of manufacturing. This type of forming is highly specialized, expensive, and time-consuming in producing parts. Various studies have been done to understand the current technological developments in the incremental sheet metal forming. Numerous research works in the field have been carried out to investigate the influence of process parameters on surface quality, geometric accuracy, forming forces, thinning, and sustainability. Ambrogio et al. [1] investigated the influence of process parameters on accuracy through the statistical analysis. Durante et al. [2] studied the influence of tool rotation on an incremental forming (IF). He explained the relationship between the tool rotations evaluated at different speeds and also revealed the influence of tool rotation in terms of forming forces, temperature reached, and surface roughness. Hussain et al. [3] has done the work by utilizing varying wall angle conical frustum (VWACF) test. He has attempted to find out the effect of variation in curvature of the part on formability. In order to quantify the formability, it has been defined as the maximum wall angle (θ_{max}) that a sheet would endure without fracturing. Thus, the formability limit gives the tolerance of the sheet during fracturing. The influencing factors affecting single point IF were found to be material type, material thickness, formed shape, tool size, and incremental step size. Experimental work, carried by Ham and Jeswiet [4], presented the graphical response surface that shows the formability limit and its dependent factors. Further, forming limits are presented in terms of forming limit diagrams. The novel idea of producing symmetric parts by a so-called die-less forming method applying a single point tool was patented by Leszak in the USA in 1967. There was significant interest in processes where sheet metal deformed plastically in a small zone enabling really flexible production of complex parts. The accuracy of the sine law for prediction of wall thickness in SPIF or TPIF has been found to be variable across the profile of a formed product. Thus, the various research outcomes have analyzed in detail, and detailed work layout has been used.

2 Experimental Details

Initially, the necessary parameters for the frustum model such as wall angle, the shape of the final form, raw material properties, sheet thickness, feed and speed of operation, machine to be used, and coolant to be applied are studied in detail for better process optimization in IS513Cr3.

The model is kowtowed to be produced from CAD files rehabilitated into 3D CAM files. CNC is applied to direct the tool conduit. More recent studies [5–8] show the operation of IF in polymers. Inferences obtained from the usage of three axes CNC machines evidenced the effectiveness of IFP [9–12].

Particularly on the SPIF modality, [13, 14] the process is defined as a flat metal sheet, adjoined on a mobile device, and it slides matching to Z-axis. CNC with ball nose tools glides on the sheet and progressively during upright augmentation (ΔZ). The outline of the end part is found by the displacement of the tool in three axes.

The sheets are set to imaginative holdup which preserves steady height virtual to the bottom. Hussain et al. [15] mentioned that closures avert the movement through the process and finish the plastic deformation. The wall angles play a major role in the sheet metal deformations. Studies have revealed that the changes in wall angles have a profound effect on the manufacturing flexibility and failure of sheet metal forming.

If there are maximum wall angle values, that allow the plastic forming which does not cause the material fracture due to increase in resistance, leading a little resistance [16]. Be considered to a wall angle, it is formed between the horizontal plane and the wall of the shaped part. For calculating the final thickness ($S1$) of the sheet after forming and wall thickness after forming ($t1$) are used to sine Law as reported elsewhere [12–16]. The experimental set up of incremental forming is shown in Fig. 1.

3 Results and Discussions

Based on experimental studied reported on the literature, IS513Cr3 prototyping and customization of final product was carried out in this research work. Pro-E® software was used to design the blank. Master CAM® software was used for program

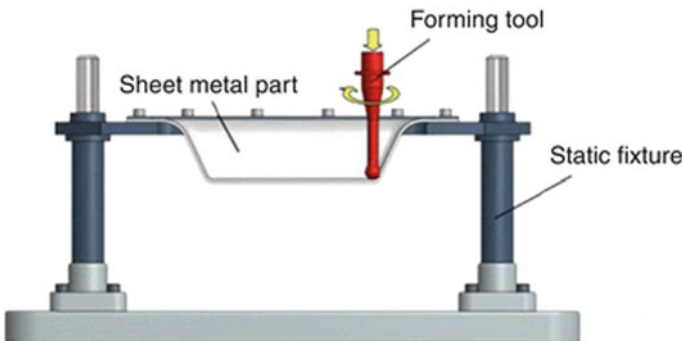


Fig. 1 Incremental forming setup. Source Author

generation. To analyze the true strains (ϕ_1 and ϕ_2), the experiments analyzed were with the wall angle (\emptyset) reached a maximum of 66° .

Initially, the wall angle of 60° was taken for the sheet metal forming, and it is solved by using Hypermesh[®] software. The input parameters include increasing the step depth of 0.2, 0.3, and 0.4, respectively. The experiment is carried out by an increase in the spindle speed in the range of 100, 200, and 300. Further, feed is given as 500, 1000, and 1500. The tool is made up of high speed steel (HSS). Figure 2 shows the stress variation in the sheet metal with a wall thickness of 63° . From the result, it is inferred that there is a maximum concentration of stress in the bottom most point of the frustum element. From Fig. 3, the % thinning of the sheet metal with respect to the feed is identified. Figure 4 shows the plastic strain in the sheet metal after deformation. Further, Fig. 5 shows the forming limit diagram from which the forming of sheet

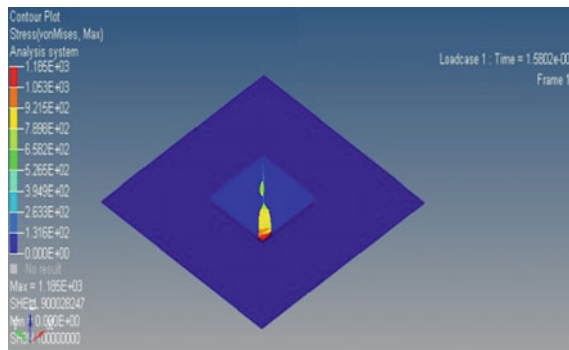


Fig. 2 Stress variation in 60° wall angle

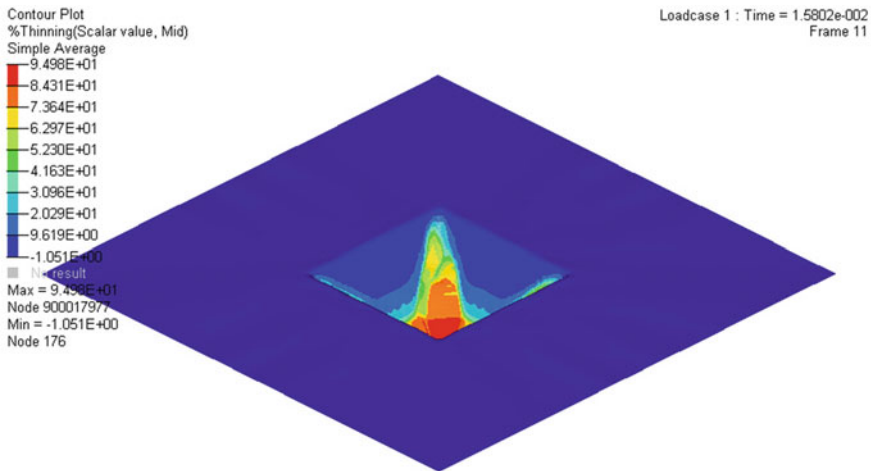


Fig. 3 Percentage of thinning in 60° wall angle

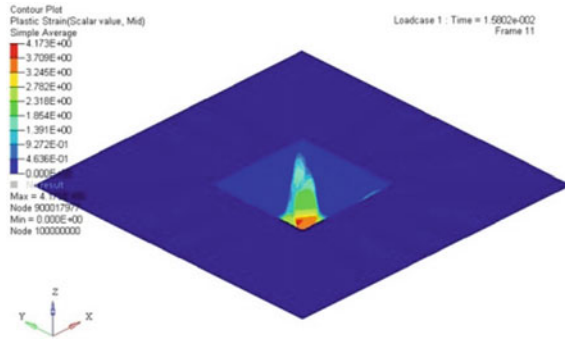


Fig. 4 Plastic strain in 60° wall angle

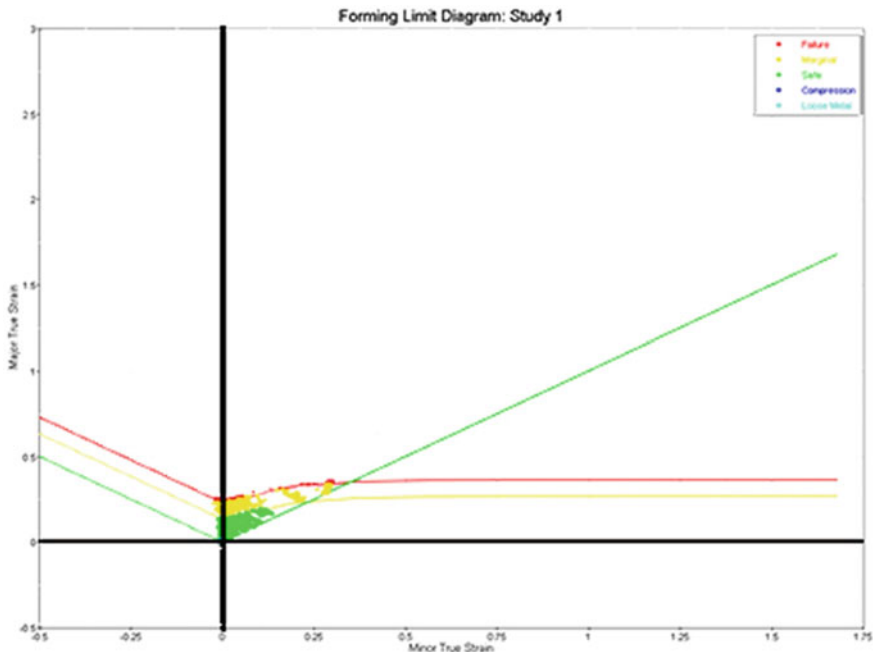


Fig. 5 Forming limit diagram for 60° wall angle

metal is evaluated, and the variation of forming limit with the variation in the depth is studied. After the experimentation of the SIF process with the wall angle of 60°, the prototype model is tested and is compared with the analysis results. It is found that there is a variation in the wall thickness with increasing depth of the frustum. The hardness is also measured at random points along the wall of the component, and the results are tabulated. It is also found that the geometry and forming angle remain constant throughout the sheet metal forming (Figs. 6, 7, 8, and 9).

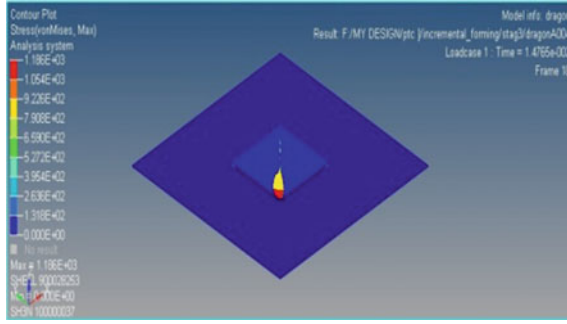


Fig. 6 Stress variation in 63° wall angle

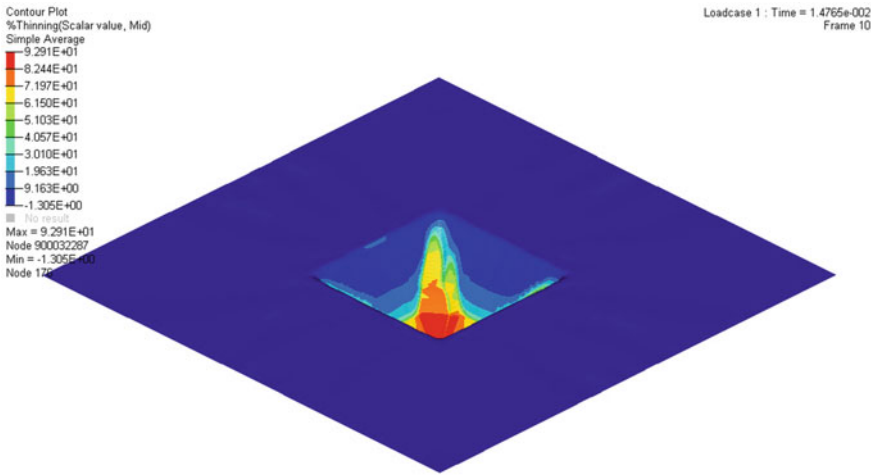


Fig. 7 Percentage of thinning in 63° wall angle

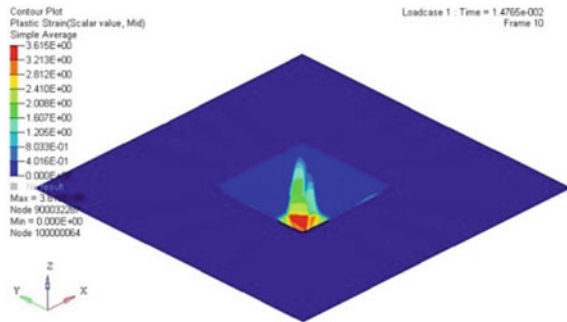


Fig. 8 Plastic strain in 63° wall angle

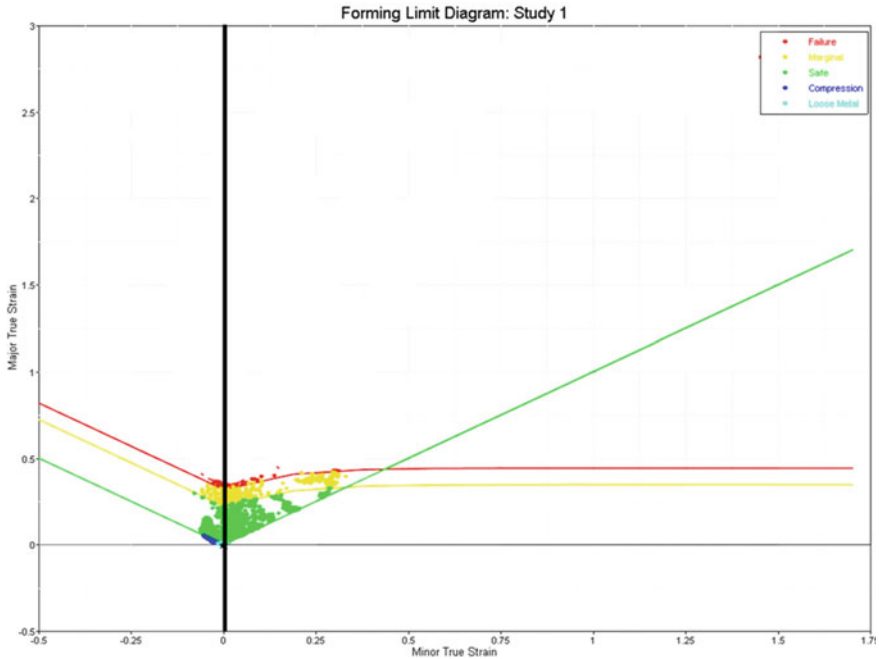


Fig. 9 Forming limit diagram for 63° wall angle

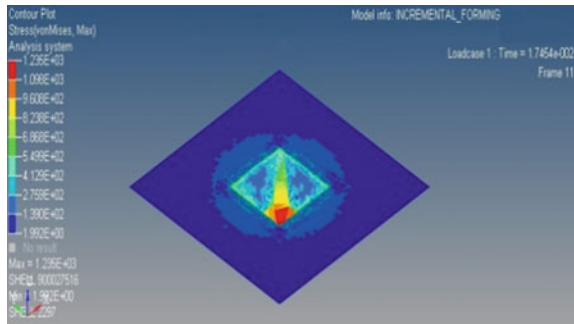


Fig. 10 Stress variations in 66° wall angle

Finally, the experiment was conducted by assigning the wall angle of 66° for the sheet metal forming. It is numerically analyzed by using Hypermesh® software. The input parameters include increasing the step depth of 0.2, 0.3, and 0.4, respectively. Increase in the spindle speed is in the range of 100, 200, and 300. Further, feed is given as 500, 1000, and 1500. The tool is made up of high speed steel (HSS). Figure 10 shows the stress variation in the sheet metal with the wall thickness of 66°. From the result, it is inferred that there is a maximum concentration of stress in the bottom most point of the frustum element. From Figure 11, the % thinning

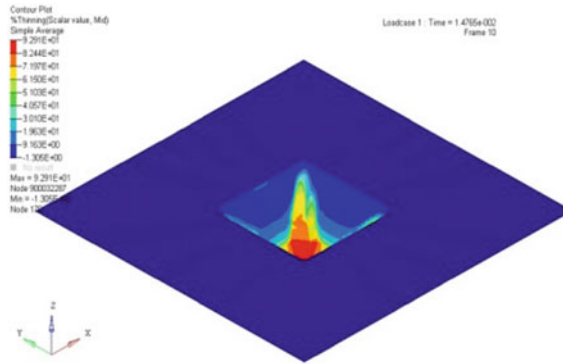


Fig. 11 Percentage of thinning in 66° wall angle

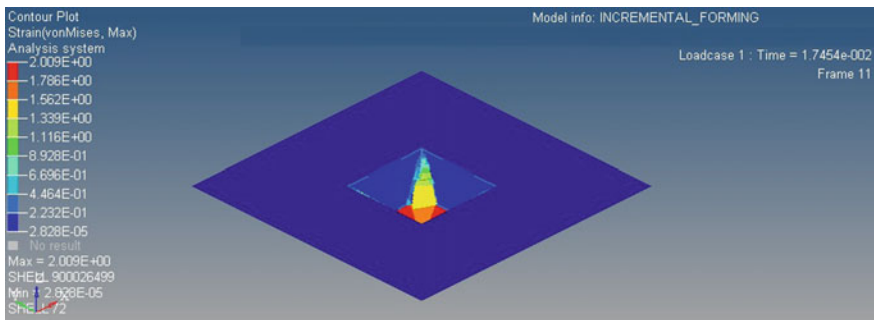


Fig. 12 Plastic strain in 66° wall angle

of the sheet metal with respect to the feed is identified. Figure 12 shows the plastic strain in the sheet metal after deformation. Further, Fig. 13 shows the forming limit diagram from which the forming of sheet metal is evaluated, and the variation of forming limit with the variation in the depth is studied. After the experimentation of the SIF process with the wall angle of 66°, the prototype model is tested and is compared with the analysis results. It is found that there is a variation in the wall thickness with increasing depth of the frustum. The hardness is also measured at random points along the wall of the component, and the results are tabulated. It is also found that the geometry and forming angle remain constant throughout the sheet metal component.

The setup to perform the ISF is a fixture to hold the sheet metal, single point forming tool, computer numerical controlled machinery that controls the motion of tools. Among which the integral component is a single point forming tool. One of the complex processes in the ISF is the design of the fixture for the process that would meet the requirements of the forming. The fixture has been designed according to the size and shape of the sheet metal to be formed. Solid hemispherical tool is used when plastically deforming sheet metal incrementally. Since it is of asymmetric IF,

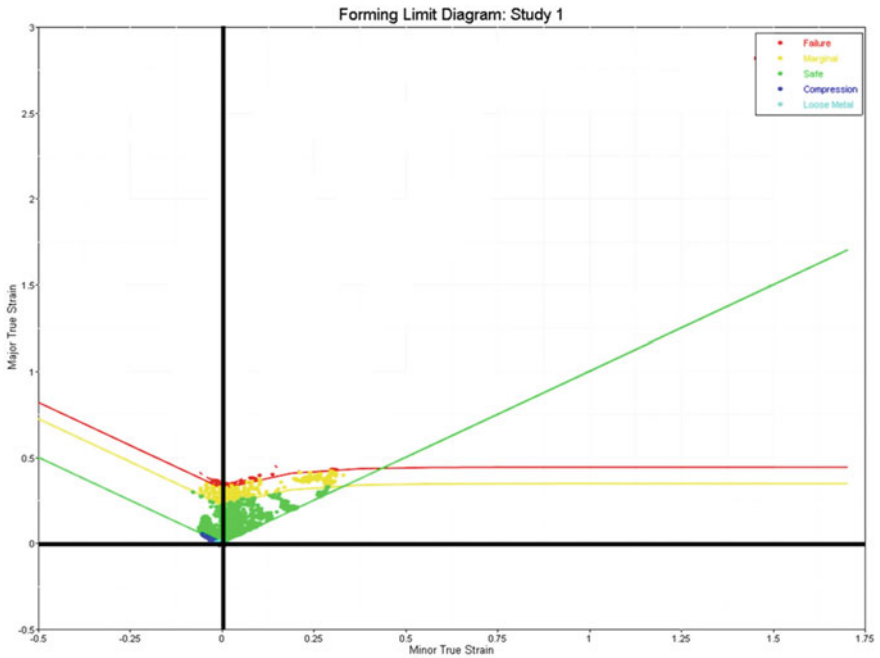


Fig. 13 Forming limit diagram for 66° wall angle

the solid hemispherical tool is used. High speed steel (HSS) tool has been chosen to reduce friction. The tool has been selected depending on the properties of sheet metal and its wear properties. Further, adequate lubrication has been given to the tool. Also, the diameter of the ball head has been chosen. Semi-spherical tool of 8 mm diameter has been chosen for the IF process. It consumes more power during operation since a large contact angle is involved. The tool diameter has also influenced on the surface quality of the product as well as the manufacturing time. The small tools can reach their loading limit while forming materials like stainless steel or titanium. The total length of the tool is found to be 110 mm. The fixture is made up of mild steel plate with the dimensions as shown in the figure. The raw material is a square-shaped sheet made up of IS513Cr3 with the dimension of 200 mm. The manufacturing is supported by the CNC machine with the programs evolved out from the Master CAM software.

4 Conclusion

By practical experiments, it was proved the good applicability of software CAD/CAM and CNC machining center as from IS513Cr3 sheet with 0.5 mm thickness using

the ISF process and SPIF modality. Further, it can be surely stated that ISF is, probably, the answer to the challenge of increasing flexibility in the field of sheet forming. Majority of the last researches, focused on improving the accuracy of the part, were successful, and new strategies of processing occurred, solving one of the weak points—the uncontrolled spring back of the material. The present work also proved the reliability and accuracy of sheet metal IF when compared with other forming operations. Further, developments must optimize the design of the CAM module which controls the tool movement, able to assure the suitable forming strategy according to any kind of hollow shape. A superior deformation of IS513Cr3 sheet metal is potential in SPIF. Small tool size is the favorite to get the obligatory shape at a quicker rate, but the possibilities of breakdown due to localized stress are larger.

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