A STUDY ON USING PRE-FORMING BLANK IN SINGLE POINT INCREMENTAL FORMING BY FINITE ELEMENT ANALYSIS

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ABSTRACT: Single Point Incremental Forming process (SPIF) is a forming technique of sheet material based on layered manufacturing principles. SPIF involves extensive plastic deformation and the description of the process is more complicated by highly nonlinear boundary conditions, namely contact and frictional effects have been accomplished. However, due to the complex nature of these models, numerical approaches dominated by Finite Element Analysis (FEA) are now in widespread use. This paper presents the data and main results of a study on effect of using pre-forming blank in SPIF through FEA. The considered SPIF has been studied under certain process conditions referring to the test work piece, tool, etc., applying ANSYS 11. The results show that the simulation model can predict an ideal profile of processing track, the behaviour of contact tool-workpiece, the product accuracy by evaluation its thickness, surface strain and the stress distribution along the deformed blank section.

KEY WORDS: single point incremental forming, finite element method, metal forming, forming tool.

1 INTRODUCTION

Single Point Incremental Forming (SPIF) is a displacement controlled process performed on a CNC machine. A clamped blank is deformed by the movement of the tool that follows a prescribed tool path (Hadoush & Van den Boogaard, 2009), a sketch of SPIF is presented in Figure 1.

The complicated geometry information is resolved into a series of two-dimensional layers, and then the plastic deformation is carried out layer-by-layer through the CNC controlled movements of a simple hemispherical forming tool to get the desired part (Singh & Goyal, 2014).

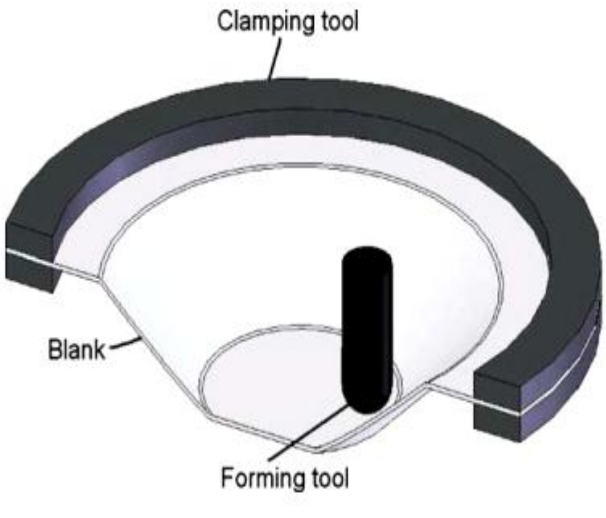

Figure 1. The basic component of SPIF process [1].

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SPIF is a flexible sheet metal forming process with a high potential for small quantities production and for rapid prototyping applications. With this process it is possible to form sheet metal parts without specialized dies (Benmessaoud, 2014).

Advantages of the technology are high process flexibility, relatively low hardware costs and enhanced formability. SPIF enables production of even complex shapes without costly die sets. A die-less forming process leads to a significant lower time-to-market. Applications for which SPIF would be especially useful include prototyping and small-lot production for automobile, aerospace and biomedical industries (Dittrich et al., 2012).

Some of SPIF limitations are a lack of tolerance predictability due to springback, wall angle limitations, the material thinning and the surface quality. Some methods for improving the formability are the followings: warm forming (Ambrogio et al., 2008), laser assisted heating (Duflou et al., 2008) and electric heating through the tool (Guoqiang et al., 2010). A hybrid process concentrates on integrating Asymmetric Incremental Sheet Forming (AISF) and stretch forming (Araghi, 2009). The effect of using this new hybrid process is shorter production time, compared to AISF, especially when the areas to be processed are identified in advance. Also, there are improvement is thickness distribution with a reduced amount of maximum thinning.

Another innovative method is to cut slots and tabs in which the area to be formed is inside the blank (Allwood et al., 2010). The effects were measured by forming a simple and a complex part, with and without cutouts and with and without backing plates. Compared to using conventional blanks, the parts formed using this new method were more accurate when unsupported and less accurate than when using a stiff cutout supporting plate. The results showed low effects in case of partial cutouts and higher accuracy when using stiff backup plate. Adding a backing plate, using a kinematic supporting tool and modifying the final part of the tool path has also been researched in terms of effects on the geometrical accuracy (Essa & Hartley, 2011). The results showed lower sheet bending near to the initial tool contact location in case of adding the backing plates, reduced springback in case of using the kinematic support tool and no pillow effect at the sheet center in case of extending the tool path. The overall effect of these features shows improvement in the general accuracy and in the thickness distributions of the final product. A produced heating unit which includes dedicated laser optics and laser was integrated into the forming machine. This shows that temperature control and reduction of friction and wear are mandatory in SPIF process (Gottmann et al., 2011).

The self-capabilities of the process to rectify inaccuracies when different steps of ISF are carried out on both surfaces of the part was studied (Ambrogio & Filice, 2012). At the second repeated step, the process shows increased accuracy. The subsequent steps do not bring any significant improvement to the accuracy. In case of using a back-drawing strategy, the deviation was reduced by 15-25%.

Hot incremental sheet forming process consists of supplying a continuous current in order to generate local heating, enabling higher formability than cold forming. This process was investigated (Ambrogio et al., 2012) and the results showed a different grain distribution due to electrical heating and induced strain, dependent on the material properties. By increasing the wall angle of inclination, a lower surface accuracy results with higher energy consumption. A new way of using Two-Point Incremental Forming (TPIF) with partial die was proposed (Silva & Martins, 2013). Based on the results, the analytical model is able to handle the deformation mechanics of SPIF and TPIF with partial die while the neck formation is eliminated in TPIF. The incrementally produced parts by TPIF with partial die have a more accurate geometry than the parts produced by SPIF. This is the effect of smaller elastic recovery upon unloading. The effects of friction on the surface finish, forming load, material deformation and formability are studied using a newly developed Oblique Roller Ball (ORB) tool (Lu et al., 2014).

The experimental results show better surface finish, lower forming load and higher formability and considerable through-the-thickness-shear along the tool moving direction, which can be considered as a secondary effect in the SPIF process.

2 DEVELOPMENT OF FE MODEL

An FE model of SPIF process simulation has been developed. The model includes the effect of contact between the tool set - forming tool, die and blank holder - and work piece, as well as the elastic-plastic material behavior of the work piece. To develop the FE model, the effect of using pre forming product was studied with constant features of forming tool, fixture and blank, as illustrated in the Figure 2.

Symmetric elements are used to model blanks that are rotationally symmetric about an axis. The deformed blanks are subjected to the loads from the forming tool and supporting die. A two dimensional analysis of a sector of the deforming blank is carried out in order to yield the complete stress and strain distributions.

A quadrilateral mapped mesh is used for blank. The boundary conditions - displacement, loading and the contact are represented in the Figure 2 and the forming tool motion was specified in profile with constant speed.

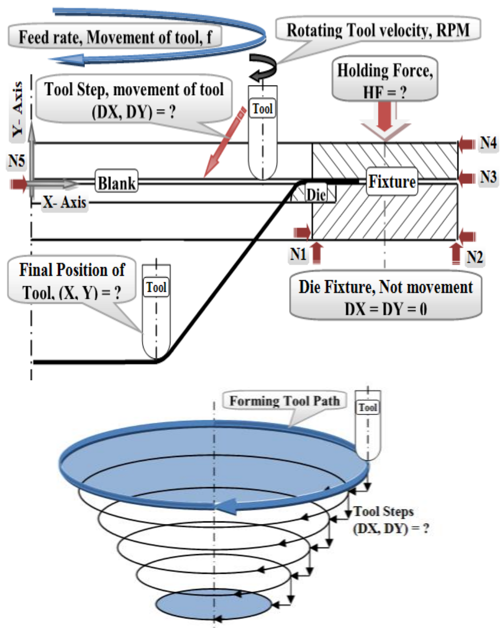

Figure 2. The basic component of SPIF process [1].

For the model, the blank type is of 226 mm outside diameter (Db) and 0.9 mm thickness (t), the friction coefficient (μ) is 0.05, forming tool profile diameter (Dp) of 10 mm, and all six studies are with the same die profile, Dd of 5 mm.

A pure Aluminum Al1050 has been used, with the specific mechanical properties resulted from Stress-Strain curve of a tensile test as shown in the table 1.

Table 1. Material properties of the blank

Variable	Value
Density, ρ, g/m^3	2700
Young's modulus, E, GPa	75
Poisson's ratio, ν	0.3
Yield stress, σ_y, MPa	80
Tangent modules, Eτ, GPa	0.5

The element PLANE42-2D to represent the tool set and the element V15C0106-2D has been chosen to represent the workpiece, and both have translations in the X and Y directions.

The elements representing the contact work piece - tool set, which include the forming tool, die and blank holder, are CONTAC169 and CONTAC171-2D Point-to-Surface Contact, like a Rigid-to-flexible contact. The real constant set has been used for each contact surface. A non-linear analysis, convergence criteria, incremental load and specified load steps is applied. The convergence tolerance was based on minimization of the force residual.

3 RESULTS AND DISCUSSION

Six predicted AutoCAD models to produce dome profile on depths 10, 20, 30, 40 and 50 mm are represented in the Figure 3. Using these products as a primary part to start production a new profile by SPIF process depends on the forming tool path movement, 50 mm depth and with 45^o degree.

Depending on the information detailed in the Figure 3, the FEM models of the dome products are presented. The evaluation of the strains along the deformed dome section is illustrated in the Figure 4.

The springback clearly appeared after removing the forming tool effect, where, the AutoCAD predicted models depth, 10, 20, 30, 40 and 50 mm becomes 7.06, 17.9, 28.86, 39.11 and 49.22 mm depth, respectively. The sprinback is reduced with increasing the depth of the deformation, where, the increasing of stresses by the forming tool causes increasing the strains, especially under the forming tool profile.

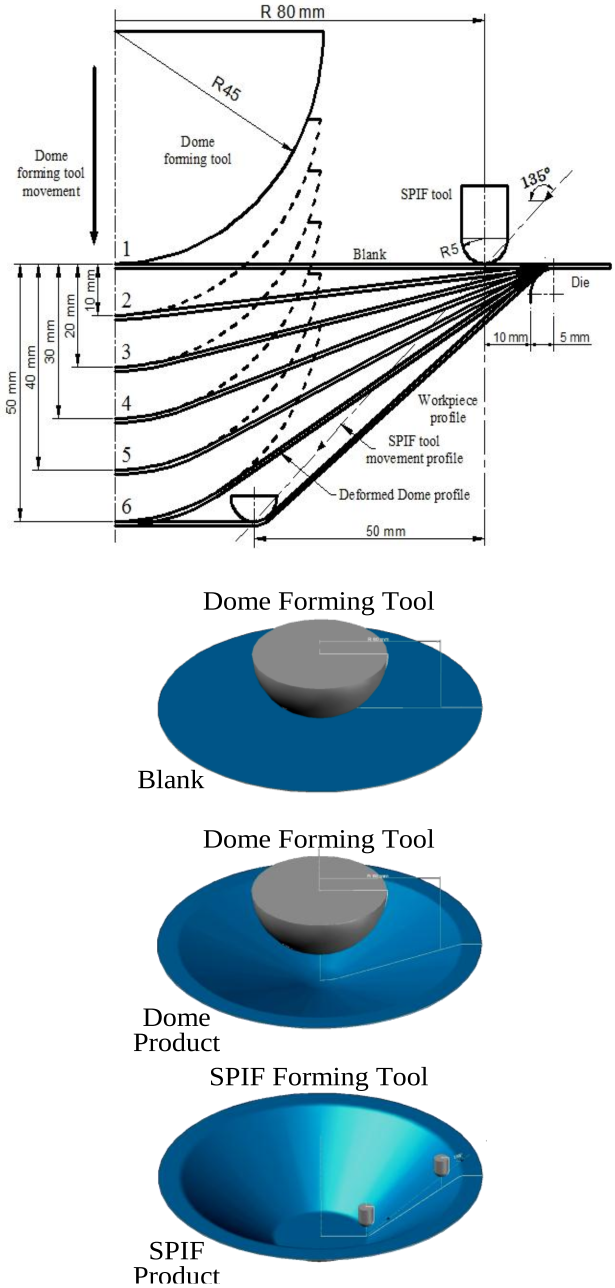

Figure 3. Typical dome profiles and SPIF forming tool movement.

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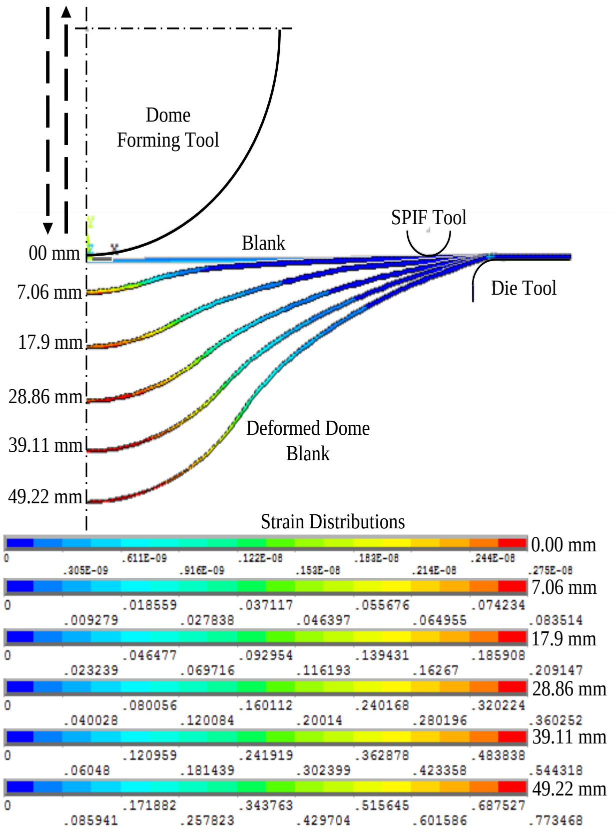

Figure 4. Typical Stress distributions stages of deformed dome parts.

Thickness distribution and strain field across the formed part are necessary to any intermediate formability evaluation. In this section it was determined the thickness variation and localized strain across the formed part. The evaluation of the thickness along the deformed section of dome after removing the tool path effect is represented in Figure 5, it is clear that the maximum thinning is under the forming tool profile and the increases in the thinning with increases the depth of the deformation to get maximum value, 0.415 mm when produce the 50 mm dome depth. Also, there is little reducing in the thickness on the region affected by the die radius.

The lowest thickness values for 0, 10, 20, 30, 40 and 50 mm dome depths are 0.9, 0.84, 0.74, 0.63, 0.52 and 0.415 mm depth and 5 mm distance from the blank center. The location of the maximum thinning depended on the depth of the deformation. In the area where high reduction in thickness happens, a neck results indicating failure of the product at this stage.

The evaluation of the thickness distribution of the SPIF deformed blanks is illustrated in Figure 6 for a 50 mm forming tool stroke when the part is completely drawn. The blank section is divided into four regions, as follows:

- fixed region, 100 to 113 mm from blank center that is not affected by the forming tool movement;
- backing plate radius effect region, 90 to 100 mm from blank center, minimum reducing is 0.8 mm when using 50 mm dome depth;
- forming tool movement effect region, 30 to 90 mm from blank center, clear improvement in thickness distribution when using the dome product deeper (max. pre-deforming product);
- non direct contact region, 0 to 30 mm from blank center, where the thinning percentage of the thickness decreases with increasing the dome product depth used, as is illustrated in Figure 7.

Strain distribution that results from simulation model represents strain value for each node in numerical mode of SPIF and also strain values of all nodes at each step size of forming tool, resulting a huge number of results.

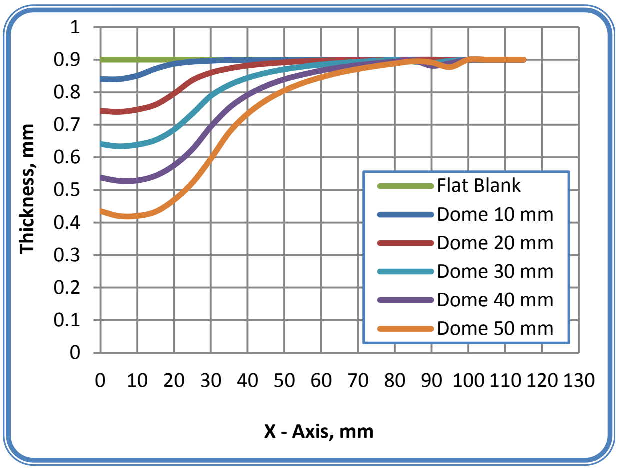

Figure 5. Thickness distribution of deformed dome parts.

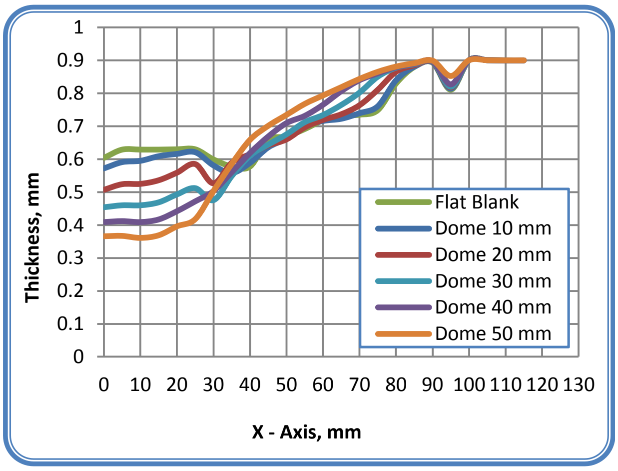

Figure 6. Thickness distribution of deformed SPIF parts.

The effect of using pre-deformed profile on strain distribution at upper surface of SPIF workpiece is represented in Figure 8, for forming tool stroke at 50 mm depth and 45^o angle, i.e., when the part is completely drawn and removed from the die.

It is also concluded that the peak values of strains are concentrated between 20 to 40 mm distance from the blank center and they increase toward the blank center. This means that the maximum values of strain will be concentrated on the places where the forming tool touches and moves, as well as, the places at the center of the blank, even there is no direct contact with the forming tool 0 to 20 mm from the blank center. No forming operation occurs under blank holder, the strain distribution is more uniform and the strain values were reasonable at 40 to 90 mm distance from blank center.

The distributions of upper surface strain of the 50 mm dome depth was more uniform and had more reasonable values than the others.

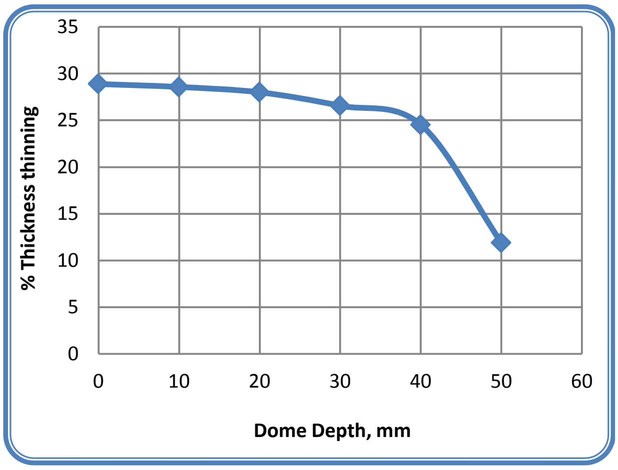

Figure 7. Thickness thinning of deformed blank.

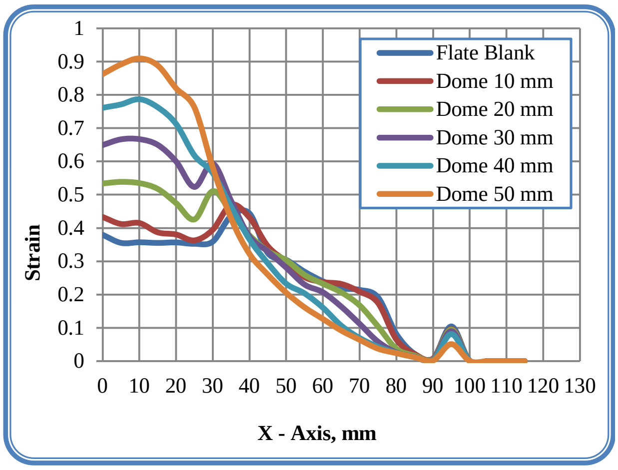

Figure 8. Strain distribution of deformed SPIF parts.

Successive stages that used pre-forming product to produce the SPIF part profile are shown in the Figure 9. It is clear that the forming tool stroke influences greatly the stress values, in which these values increase with stroke. It is seen from the figure that stress peaks are located at the contact places between forming tool profile and workpiece. The peak height appears to be a good indicator to assess whether a forming operation will be successful or not. The severe of the stress distribution is located at the end of stroke and the occurrence of a localized neck is obvious. Fracture was observed along a sharp corner. This was predicted by a high value of the stress.

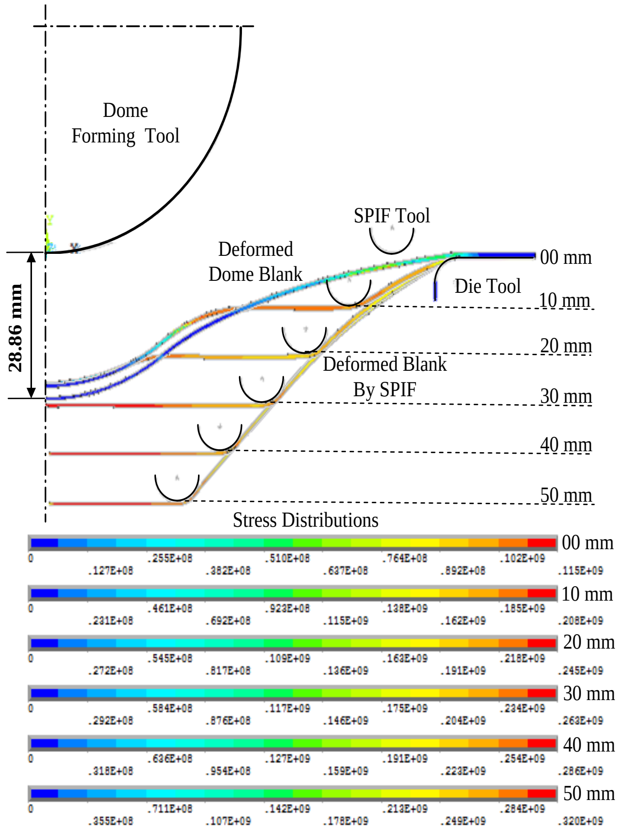

Figure 9. Stress distributions stages of deformed SPIF.

Depending on the dome product depth, the deformation of the SPIF process can be divided into two types of stages:

- the primary stages, are reorientation the blank shape depending on the product profile, with elastic deformation follows the forming tool position; and
- the secondary stages, starts when the forming tool gets to the final depth of the dome product until the required depth of the SPIF product. Both depend on the SPIF tool path.

4 CONCLUSIONS

The simulation model of Single Point Incremental Forming, SPIF by FEM with pre-forming product can predict an ideal profile of processing track, and springback error of SPIF is effectively eliminated. The use of proper simulation system (prediction model) and high accuracy procedure when entering as many variables as possible in the simulation model produce high level prediction of the results.

The high values of stress and strain distributions along the section of the product profile appear to be good indicators to assess whether a product will be successful or not.

The sheet thickness distributions play an important role in the forming of defects, and using pre forming product in SPIF process showed an improvement in thickness distribution along the deformed section of the product profile, especially when using pre forming product depth equal to the SPIF product depth requirement.

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6 NOTATION

The following symbols are used in this paper:
Db = blank outside diameter;
t = blank thickness;
μ = friction coefficient;
Dp = forming tool profile diameter;
Dd = die profile