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*Original Article*

# Design and Analysis of Different Formability Parameters on Single Point Progressive Method

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***Abstract*** - *In the present production process Incremental Sheet Forming (ISF) is a modern malleable forming practice which enables the process of forming with the help of a Computer Numerical Control (CNC) Vertical Milling Machine (VMC). ISF is used with good malleability for conventional milling machines with the less intricate tool and die to make the machining process as much as cost-effective and also make it to automation. This research study aims to provide a solution towards the various ambiguities existing in the ISF process regarding the formability of the part formed with respect to the different operating parameters and materials. With the help of a specially fabricated tool and fixture system, the forming is carried out and compared the formability of metals and polymers. From the final results, it was observed that a more uniform thickness distribution effect is observed in the case of polymers considered, both the metallic sheets were observed to be followed a similar pattern to that of cosine law, and the least percentage of thinning is observed in the case of Polycarbonate and a higher percentage of thinning in the case of brass and there is no relation is observed between the forming angle and the thinning percentage.*

***Keywords*** - *SPIF, Formability, Angle at failure, Thickness distribution, Spherical headed tool.*

## 1. Introduction

ISF generally denotes a collective effect of localized deformation and these distortions proceed one after another on a certain tool path for shielding the entire part to be formed [1, 2]. One of the Single-Point Incremental Forming (SPIF) methods has been processed by the action of a CNC vertical milling machine tool that has a single-point contact with the sheet metal blank [3, 4]. The blank is fixed by a holder that restricts further sliding movement, as shown in Figure 1. In this process, a spherical-headed tool moves along a user-defined path and step by step creates the desired shape.

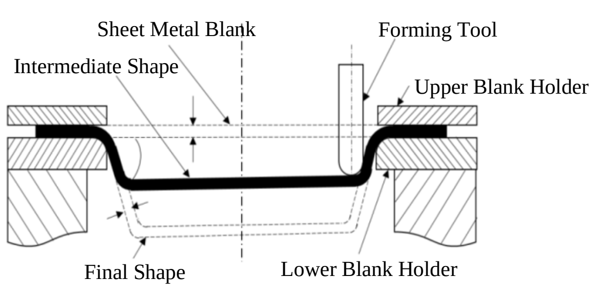



**Fig. 1 Basic principle of SPIF**

In the SPIF process, the material is formed by tensile stretching over a small region of the sheet by the tool movement on the surface. Based on the investigations it was suggested that the SPIF process occurs through the blend of bend, stretch and shear mechanisms [5-7]. An analytical study was conducted and suggested that the deformation is not only occurring in the contact region but also in the neighbourhood region too [8].

That is the previous step and next step are influenced by the current step in forming. They also found out that the fracture always occurs in the transition zone between the bottom and the slanted portion. The forming parameters outcome was investigated in SPIF and the amount by which it is affecting the formability of AA3003 material [9].

The dissemination of strain on the sheet over the length of deformation on Aluminium, Brass and Titanium was studied and they found that it is distributed normally from the centre axis [10-12]. According to the investigation, the sheet body thickness is made with a negative incremental forming forecast by Cosine's law represented in Equation 1 [13].

$$tf = ti * \cos(\Psi) \qquad (1)$$

Where,

tf = final thickness of wall,

ti = initial thickness of sheet,

Ψ = forming angle

This law was used to determine the distribution of the thickness over the depth of form. This relation describes that the product of the initial sheet thickness with the cosine of forming an angle at that point gives the final wall thickness at the corresponding point. Hence the thinning behaviour of a material can be studied with this relation. To study the phenomenon, they conducted an experiment on Aluminium and verified the cosine law of thickness distribution by a specially selected geometry with continuously varying wall angles. In the low carbon steel sheets investigation with dissimilar thicknesses using a tool with a hemispherical shape under different depths found that the thickness of the formed sheet was not uniformly distributed along the depth of forming [14].

A study of SPIF of polymers like polyamide (PA), Polycarbonate (PC), Polyethylene Terephthalate (PET), and polyvinyl chloride (PVC) revealed that there is a good bonding among the experimental strains at failure [15, 16]. A study on the capability of polymer sheets on SPIF at room temperature proved its higher perspective for complex polymer sheet module production with maximum depths. Even though many studies have been conducted on metals and polymers individually, there are not many studies on a comparison between metals and polymers in the SPIF process. Therefore, in this study, a special interest is taken to compare the formability parameters of metals and polymers in the SPIF process to determine which could be more suitable for the process.

## 2. Experimentation

### *2.1. Geometry Selected*

The geometry of the model was selected in such a way that the dependence of the thickness distribution on the wall angle could be easily predicted. For the reason mentioned above, it has been selected a geometry as shown in Figure 2 with a circular generatrix of continuously varying angles so that the formed angle varies with the depth of forming and the thickness distribution can be easily verified with the help of cosine law.

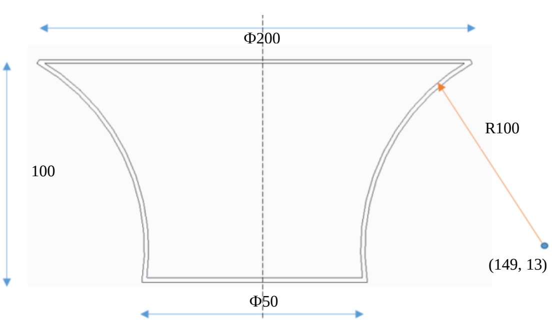



**Fig. 2 Dimensional representation of the model**

### *2.2. Materials Selected*

Since it is a comparison of metals and polymers, it has been selected 2 metals and 2 polymers for the formability comparison in the ISF process. The material has been selected based on the industrial application of sheet materials and their formability in comparison to the previous journals. The metals which are selected are Copper (98% pure) and Brass (Cu-64% & Zn-36%) and the polymers selected are PC and PVC respectively. The mechanical properties of the selected material selected are presented in Table 1.

### *2.3. Experimental Setup*

Since the fixture is designed for a maximum of 400mm x 400mm wide sheet, all the blanks used for the forming process are of dimension 400mm x 400mm with a 1mm thickness. The fixture can provide a maximum depth of forming of 130mm. The holes are provided on the plates of the fixture to arrest the sliding of the sheet unlike in the drawing process. The tool selected for this research is a spherical-headed tool with a tool dia. of 16mm. Both the fixture and tool are made of mild steel material. The CAD model of the fixture and tool is shown in Figure 3. For the accomplishment of this forming process, it has been used a vertical milling machine of series TAL V500+ with a power of 15KW @ 8000rpm. The complete set-up of fixtures on the machine tool table and tool in the machine spindle is shown in Figure 4.

The Table 2 describes the necessary process parameters required for the vertical milling machine to run the tool over the sheet to form the desired profile which is determined after conducting the design of the experiment on polymers for optimum response parameters.

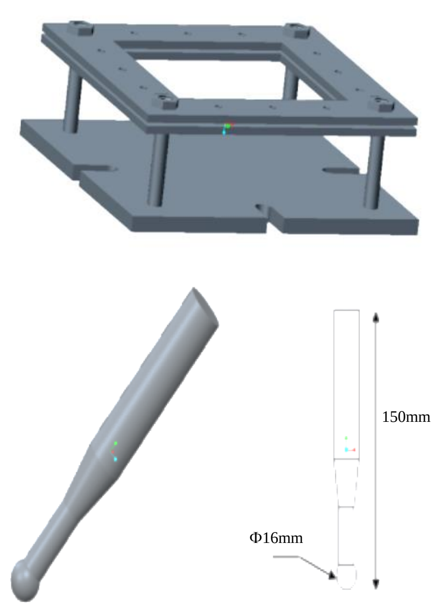



**Fig. 3 CAD model of the fixture and tool setup**

**Table 1. Mechanical properties of the selected material**

| Properties | Brass | Copper | PC | PVC |
|---|---|---|---|---|
| Yiels Strength (Mpa) | 124-310 | 33 | 42-62 | 33-39 |
| Ultimate Strength (Mpa) | 469-550 | 220 | 55-75 | 52 |
| Elastic Modules (Gpa) | 105 | 120 | 2-2.4 | 3.3-4 |
| Elongation at Break | 53% | 60% | 80-150% | 20-40% |
| Poisson’s Ratio | 0.31 | 0.34 | 0.37 | 0.39 |


**Fig. 4 Experimental setup**

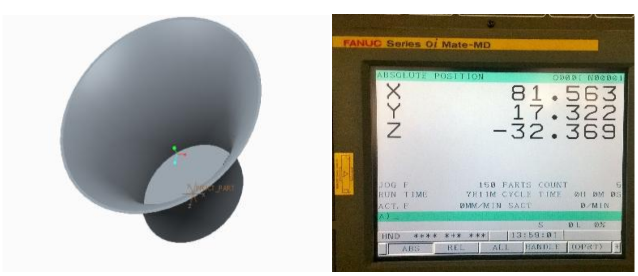
**Table 2. Process parameters**

| | |
|---|---|
| Sheet Thickness (mm) | 1 |
| Spindle Speed (rpm) | 1000 |
| Feed (mm/min) | 600 |
| Step Depth (mm) | 0.25 |

After the tool path is created from the Master CAM, the process parameters are entered into the software as input entities. Then the CNC codes generated by the software are fed into the vertical machine tool.

### *2.4. Experimental Procedure*

Initially, a CAD model shown in Figure 5a is generated with the help of Creo parametric 1.0 as per the dimension mentioned. Then the CAD model is fed into the Master CAM software to generate CNC codes as per the tool path and the process parameters selected. Here the tool path selected is a circular path with decreasing diameter when it goes to each incremental depth. The CNC codes generated are then fed into the CNC vertical milling machine.

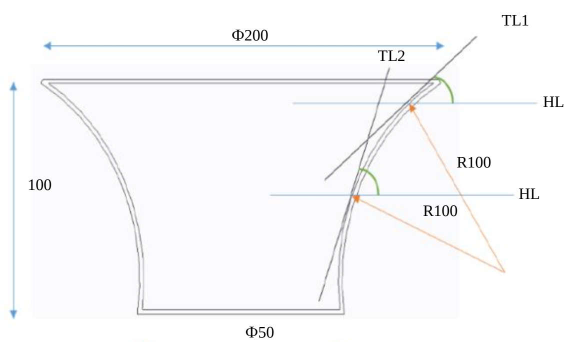



**a) b)**

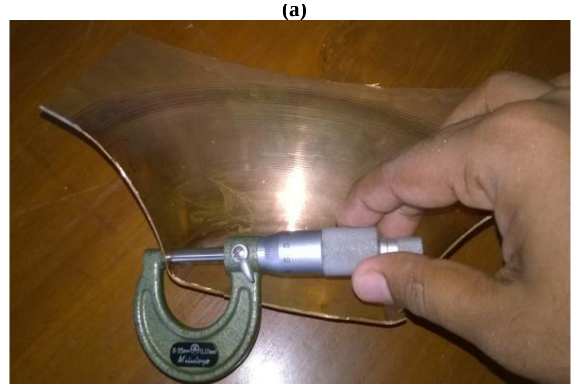
**Fig. 5 a) CAD model of the selected geometry b) Machine display of VMC**

After clamping the sheet with dimensions 400mm x 400mm x 1mm in the fixture, it has been taken to the vertical milling machine to clamp on the machine table. Then the prepared spherical-headed tool is fixed to the machine spindle. During the running of the machine, a small amount of water-soluble coolant Blasocut 4000 has applied to reduce the frictional effect existing between the tooltip and the sheet material.

The machine is stopped when the rupture is observed at the bottom of the cup shape formed. The machine display unit shown in Figure 5b gives the value of depth of failure in terms of Z-coordinate. The forming angle of the sheet is found by drawing a tangent at the point of failure shown in Figure 6a with the aid of AutoCAD. The angle which is formed by the Tangent Line (TL) with the Horizontal Line (HL) is called the forming angle.




**(a)**



**(b)**

**Fig. 6 a) Measurement of forming angle, b) Thickness measurement using a micrometer**


**Fig. 7 Formed parts of PC, PVC, Copper and Brass**

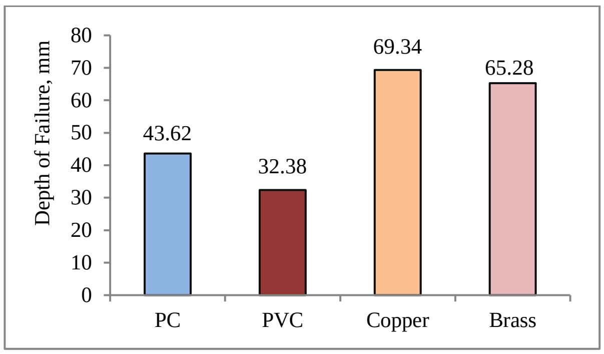



**Fig. 8 Depth of failure comparison chart**

Then the thickness distribution is measured at points with 10mm equal spacing along the horizontal direction by using a micrometre as shown in Figure 6b. The above procedures are followed for each polymer and metal and the following results are obtained. The obtained shape of each material after forming in a VMC is shown in Figure 7.

## 3. Results and Discussions

### *3.1. Depth of Failure*

The bar diagram shown in Figure 8 compares the depth of failure of metals and polymers under the same process parameter in this incremental forming process. The diagram clearly tells that the copper material is more formable compared to other materials with respect to the depth of formation. More depth is achieved by copper than by brass due to its better elongation at break. Copper shows a maximum depth of failure of 69.34mm and PVC shows a minimum of 32.38mm. The early failure of polymers is due to the incapability to withstand the frictional effect and lower mechanical strength.

### *3.2. Forming Angle at Failure*

The following bar diagram shown in Figure 9 shows the angle of the formed cup of different materials at their failure point. It can be seen that the copper material shows a greater angle at failure and hence which can be considered as the highly formable material among the four materials considered for the study. The copper can be formed to an angle of 79.14°. It can also be concluded that if the depth of failure is more, higher will be the angle at failure. Because more cone angles will be covered under a higher depth.

### *3.3. Thickness Distribution*

The thickness distribution shown in Figure 10 gives an idea about the evenness of the thickness along its formed region. This is important because the thinning of the material leads to early failure and it enhances the probability of failure when it is in use. For a good quality incrementally formed component, the thickness distribution should be uniform. Polymers are considered to show an overlapping and metals show a closeness between the curves at the bottom of the profile. This is because of the domination of stretching of material at higher depths. In all the graphs the theoretically calculated value (using cosine's law) comes lower compared to the experimental value. This difference is due to the non-consideration of material properties in the cosine law. The thickness value will be almost constant for a centre distance from -50 to 50mm. This is because this portion is not making any contact with the tool surface.

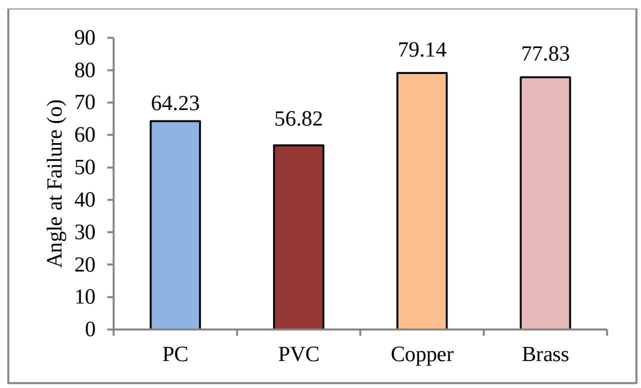



**Fig. 9 Comparison chart of angle at failure**

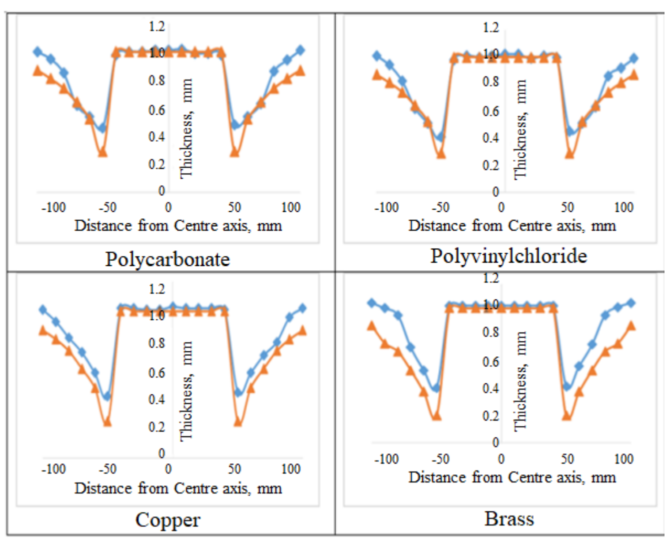



**Fig. 10 Thickness distribution of PC, PVC, copper and brass**

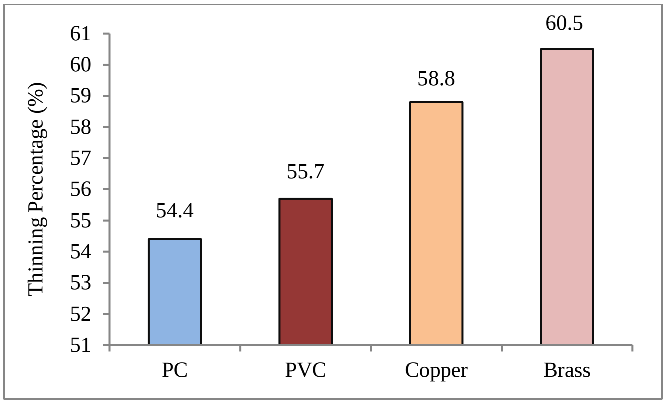



**Fig. 11 Thinning percentage comparison**

The maximum variation of actual thickness from the theoretical value is observed in the case of metals to that of polymers. This can be attributed to the lower Poisson's ratio of the metals compared to that of polymers. The divergence in thickness values at extreme ends is due to the lack of stretching at the initial incremental depths. At those particular points bending is predominant compared to that stretching.

Figure 11 shows the thinning effect in each material after forming. Thinning percentage means the percentage deviation of the final thickness at the failure point from its initial thickness value. For a good ISF component, the thinning percentage should be minimum. The maximum variation of final thickness from its original showed by brass and the minimum is in the case of PC. All the material shows a minimum variation of 55%. The maximum variation is observed in metals due to the formation of metals to a higher depth. But in the case of PC & PVC even at lesser depth, it is observed a minimum of 55% thinning is due to the higher Poisson's ratio.

## 4. Conclusion

The analysis was carried out to provide a solution towards the various ambiguities existing in the ISF process regarding the formability of the part formed regarding the different operating parameters and materials. The final results reveal that,

- Metals are showing a higher depth of failure and forming angle compared to that polymers. Copper can be considered as the best material from these aspects.
- More uniform thickness distribution effect is observed in the case of polymers considered. Both the metallic sheets were observed to be followed a similar pattern to that of cosine law.
- The least percentage of thinning is observed in the case of Polycarbonate and a higher percentage of thinning in the case of brass.
- Cracks are observed during the forming of circumferential direction at the conversion region among the bottom and side wall portion.
- No relation is observed between the forming angle and the thinning percentage.

## 5. Future Work

Comparison of the desired profile versus obtained profile in each material to study the dimensional inaccuracies in the ISF process. Analyze the surface roughness variation with the depth of the shape formed for each material and conduct the microstructure study on the materials before and after forming.

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