COEP Technological University

(A Unitary Public University of Government of Maharashtra, situated in Pune, Maharashtra, India)

Mini Project Report

Single Point Incremental Forming Process

Submitted by: -

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Third Year Manufacturing Science and Engineering

UNDER THE GUIDANCE OF

Prof. Aishwarya Dange

Department of Manufacturing Engineering and Industrial Management

Year: 2024-2025

CERTIFICATE

This is to certify that the Mini Project report entitled Single Point Incremental Forming Process submitted by

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In fulfilment of the requirements for the award of mini project completion certificate, is a record of their own work carried out under supervisors, during academic year 2024-25.

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APPROVAL SHEET

This Mini Project report entitled

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is approved for the fulfilment of the mini project of the Department of Manufacturing Science and Industrial Management, COEP Technological University.

Prof. Aishwarya Dange	**Dr. J.S.Karajagikar**	**Dr. Sandeep S. Anasane**
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DECLARATION

I declare that this written submission represents my ideas in my own words and where other ideas have been included. I have adequately cited and referenced the original source. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that there is no violation of any of the rules and guidelines instructed.

ACKNOWLEDGEMENT

We would like to take this opportunity to sincerely thank everyone who supported us throughout the course of this project. First, our heartfelt gratitude goes to our project guide, **Prof. Aishwarya Dange**, for her constant support, valuable suggestions, and patient guidance from the very beginning. Her insights and encouragement helped us navigate through challenges and complete the project successfully.

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ABSTRACT

Single Point Incremental Forming (SPIF) is an innovative and flexible sheet metal forming technique that has gained significant attention in recent years as a cost-effective alternative to traditional die-based forming methods. Unlike conventional processes, SPIF does not require dedicated dies, making it particularly suitable for low-volume production, rapid prototyping, and customized manufacturing. This project explores the fundamentals of SPIF, focusing on its process parameters, material behavior, and geometric accuracy. The research investigates how variables such as tool path strategy, step depth, feed rate, and spindle speed influence formability, surface finish, and dimensional accuracy of the formed parts. Experiments were conducted using [mention material, e.g., aluminum or mild steel] sheets to form conical and pyramid-shaped geometries, and the resulting parts were evaluated for thickness distribution, wall angle accuracy, and surface integrity. The findings highlight the advantages of SPIF in achieving complex shapes with minimal tooling cost, while also identifying key challenges such as limited material stretchability and spring back effects. The study contributes to a deeper understanding of the process, offering insights into optimization techniques that enhance part quality and expand SPIFf industrial applicability.

CHAPTER 1

INTRODUCTION

1. Background

In the evolving landscape of modern manufacturing, the demand for flexible, cost-effective, and efficient forming processes has become increasingly critical—especially in industries where customization, prototyping, and low-volume production are key. Traditional sheet metal forming methods, such as deep drawing or stamping, often involve the use of complex and expensive dies, making them less viable for short-run or tailor-made products. This has led to the growing interest in alternative forming methods, among which Single Point Incremental Forming (SPIF) has emerged as a promising solution.

SPIF is a dieless, CNC-controlled process that forms sheet metal by incrementally deforming it with a hemispherical-tipped tool along a predefined toolpath. The absence of dedicated dies significantly reduces tooling costs and setup time, offering remarkable flexibility for manufacturing complex, asymmetric, or customized geometries. This makes SPIF highly attractive for applications in aerospace, automotive, biomedical implants, and other sectors requiring rapid product development and design iterations.

The process relies heavily on the control of parameters such as tool diameter, step depth, feed rate, spindle speed, and toolpath strategy, all of which directly influence the material's formability, thickness distribution, and surface finish. While SPIF offers several advantages—including reduced lead time and material wastage—it also presents certain limitations, such as geometric inaccuracy, springback, and reduced wall thickness in steep-angled parts. This study aims to explore the SPIF process in-depth, focusing on its working principles, process parameters, material behavior, and practical limitations. Through experimental investigation and analysis, the goal is to gain a better understanding of how to optimize the process for improved dimensional accuracy, surface quality, and material formability

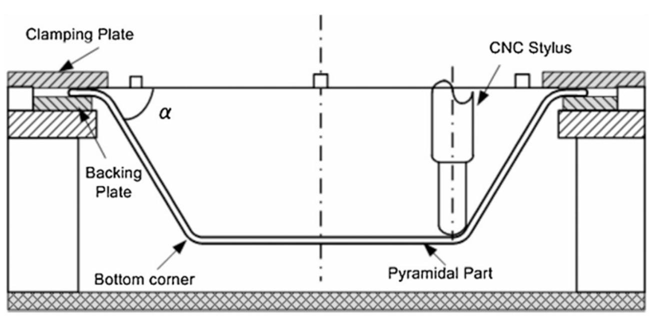


Fig. 1. Schematic of single point incremental forming (SPIF) used to form a truncated pyramid from a flat blank using a CNC style with a hemi-spherical end with a slope ¸; a backing plate corresponding to the top contour of the geometry being formed is typically used to support the part close to the top while clamping plate clamp the sheet to the rig used for SPIF [5] [with permission from publisher].

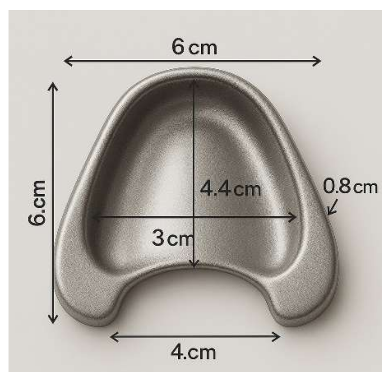
1.2 PROBLEM STATEMENT

Single Point Incremental Forming (SPIF) presents a promising alternative for the fabrication of custom denture plates due to its flexibility, low tooling costs, and capability to form complex shapes directly from digital models. However, challenges such as achieving sufficient dimensional accuracy, maintaining consistent wall thickness, and ensuring biocompatible surface quality remain significant barriers. This project aims to investigate the feasibility and optimization of using SPIF to manufacture customized denture plates, focusing on process parameters, material selection, and post-processing techniques to meet the stringent requirements of dental applications.

1.3 OBJECTIVES

To Investigate the Feasibility of SPIF for Denture Plate Production: To evaluate the potential of using Single Point Incremental Forming (SPIF) as a viable method for manufacturing custom denture plates, focusing on its ability to meet the complex design requirements and geometries typically associated with dental prosthetics. To Optimize Process Parameters for Improved Accuracy and Quality: To identify and optimize key SPIF parameters, such as tool diameter, step depth, feed rate, and spindle speed, that affect the dimensional accuracy, surface finish, and structural integrity of denture plates during the forming process. To Identify Challenges and Limitations of SPIF in Dental Prosthetics: To identify the potential challenges (such as tool wear, geometric accuracy, or material limitations) associated with using SPIF for denture plate manufacturing and propose solutions or improvements.

1.4 EXPECTED OUTCOME



Feasibility Report on SPIF for Denture Plate Production: A comprehensive assessment of the viability of using Single Point Incremental Forming (SPIF) as a manufacturing technique for denture plates. This will include an evaluation of the process's ability to achieve the precision, flexibility, and customization required for dental prosthetics. Assessment of Surface Quality and Biocompatibility: A thorough evaluation of the surface finish and biocompatibility of SPIF-formed denture plates. The outcome will demonstrate whether the process can meet the stringent requirements for patient safety and comfort, including smoothness, non-toxicity, and non-irritation to oral tissues. Optimized Process Parameters for SPIF: A set of optimized process parameters (such as tool path strategy, step depth, feed rate, and spindle speed) that will allow for the production of denture plates with enhanced dimensional accuracy, smooth surface finish, and structural integrity.

Chapter 2

Materials Used

In the present work on Single Point Incremental Forming (SPIF), the selection of materials for the workpiece, forming tool, and fixture plays a critical role in ensuring process stability, formability, and surface finish. The materials chosen are as follows:

2.1 Workpiece Material:

Aluminium Alloy 6061 Sheet The workpiece material used is Aluminium Alloy 6061 in sheet form. Aluminium 6061 is a widely used precipitation-hardened aluminium alloy, known for its excellent mechanical properties, good corrosion resistance, and high formability. These properties make it a suitable choice for incremental forming operations, particularly in aerospace and automotive applications. Key properties of Aluminium 6061: Good strength-to-weight ratio Excellent corrosion resistance.

2.2 Forming Tool Material:

High Speed Steel (HSS) The forming tool used in SPIF is made of High Speed Steel (HSS), which is chosen due to its: High hardness and wear resistance Excellent heat resistance during prolonged contact with the workpiece Ability to maintain sharpness and dimensional accuracy under cyclic loads These characteristics help minimize tool wear and ensure smooth surface finish during the SPIF process, where the tool follows a defined path to incrementally deform the sheet.

2.3 Fixture Material

Mild Steel The fixture used to clamp and support the aluminium sheet during the forming process is made of Mild Steel. Mild Steel offers: High rigidity and structural strength Good machinability and cost-effectiveness Sufficient resistance to deformation under clamping forces It provides a stable base during the incremental forming operation, ensuring accurate replication of the intended geometry.

CHAPTER 3

LITERATURE REVIEW

The literature reviewed suggests that Single Point Incremental Forming (SPIF) holds great potential for the production of customized denture plates due to its flexibility, cost-effectiveness, and ability to produce complex shapes without the need for expensive molds. However, challenges such as dimensional accuracy, material behavior, surface quality, and tool wear need to be addressed through process optimization and material selection. Further research is required to refine the SPIF process for dental applications, ensuring that it meets the stringent requirements of the dental industry in terms of precision, comfort, and biocompatibility. Single Point Incremental Forming (SPIF) is an advanced sheet metal forming process that uses a hemispherical tool to deform a sheet of metal incrementally.

Unlike traditional forming techniques that use rigid molds or dies, SPIF is a dieless process, meaning it does not require pre-made molds. This characteristic provides significant flexibility, allowing for the rapid production of complex geometries with minimal tooling and setup time. The medical and dental industries have begun to explore SPIF for producing custom prosthetics, such as dental implants, hearing aids, and denture plates. Traditional methods in dental prosthetics, like casting or thermoforming, often require long lead times and are less adaptable for creating patient-specific designs. The success of SPIF largely depends on several process parameters, including tool diameter, step depth, feed rate, spindle speed, and toolpath strategy. Studies have shown that the depth of each incremental step plays a crucial role in the forming quality, affecting both the material flow and the accuracy of the final shape.

Despite the promising potential of SPIF, several challenges must be addressed to make it a practical solution for dental prosthetics. One of the major issues is the control of dimensional accuracy, particularly in the formation of complex shapes with steep angles or narrow features. Springback—a phenomenon where the material tends to revert to its original shape after forming—can cause distortions that affect the final fit of the denture plate. furthermore, post-processing techniques can help address issues related to material strength and stress concentration, which may be induced during the forming process

METHODOLOGY

The methodology for investigating the feasibility and optimization of Single Point Incremental Forming (SPIF) for denture plate production involves several stages, including material selection, experimental setup, process parameter optimization, and performance evaluation. The following sections describe the approach and procedures used in this study.

3.1 Material Selection:

The choice of material for denture plate fabrication is crucial to ensure both biocompatibility and durability. For this study, medical-grade titanium alloy (Ti-6Al-4V) was selected due to its superior mechanical properties, corrosion resistance, and biocompatibility, making it a suitable material for dental prosthetics. Titanium alloys are widely used in the dental industry for implants and prosthetics, and their use in SPIF offers the potential for strong, lightweight, and durable custom components.

3.2 Experimental Setup:

The experiments were conducted using a CNC milling machine equipped with a hemispherical tool for the SPIF process. The milling machine's precise control over toolpath and incremental step depth allows for accurate forming of complex geometries directly from digital models. Tool Specifications: A 5 mm diameter tungsten carbide hemispherical tool was used for the incremental forming process

3.3 Machine Specifications:

A 3-axis CNC machine with full control over toolpath, feed rate, and spindle speed was used to carry out the SPIF operations. CAD Modeling and Toolpath Generation: The denture plates to be formed were designed using Computer-Aided Design (CAD) software. The CAD model for the denture plates was based on a standard denture plate shape, with custom adjustments to simulate patient-specific geometry. The CAD models were then converted into G-code using CAM (Computer-Aided Manufacturing) software, which generated the toolpath for the CNC machine.

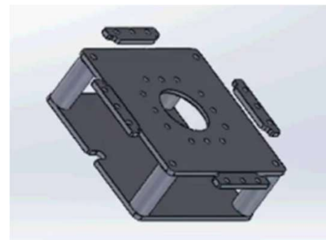
Denture Plate Design: The denture plates were designed with a basic shape, incorporating typical features such as curvature, mounting surfaces, and retention grooves. Toolpath Strategy: The toolpath was designed to move in an incremental spiral motion, with each step corresponding to a small vertical increment in the forming depth. This strategy ensures that the material is deformed evenly, minimizing the risk of excessive thinning or tool marks.

3.3 Process Parameters:

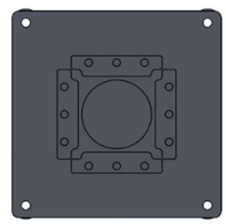
Various process parameters were optimized during the experiments, with a focus on improving the quality of the denture plate and minimizing defects such as material tearing, tool wear, and excessive springback. The following parameters were varied: Step Depth: The depth of each incremental step (e.g., 0.1 mm, 0.2 mm, etc.) was varied to observe its effect on material deformation and surface quality. Feed Rate: Different feed rates (e.g., 50 mm/min, 100 mm/min) were tested to assess the impact on surface finish and forming time. Spindle Speed: Spindle speeds (e.g., 1000 rpm, 1500 rpm) were adjusted to determine the effect on tool efficiency and material formability

Tool Path Strategy: Different tool path strategies, including spiral and zigzag patterns, were tested to evaluate their influence on the final shape and surface finish of the denture plates.

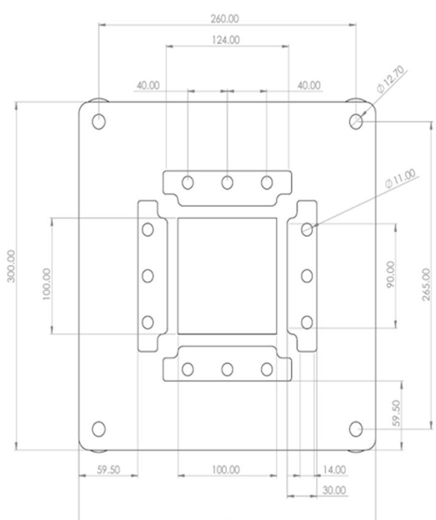
3.4 Fixture Design for PX40 VMC Machine:

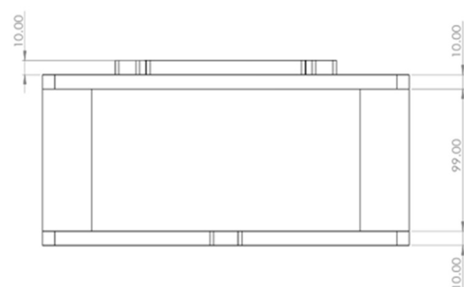


A custom fixture was designed and fabricated to securely hold the sheet material during the Single Point Incremental Forming (SPIF) process. The fixture consists of a rigid mild steel frame comprising top and bottom clamping plates, spacer columns, and guide fasteners to ensure alignment and stability during machining.



The top plate includes a central cutout for tool clearance and is bolted to the base to rigidly clamp the PX 40 or Aluminium 6061 sheet. The design ensures minimal sheet movement during forming and accurate reproduction of the toolpath geometry.





This fixture was successfully used on a CNC milling machine for both demonstration and actual SPIF trials, offering high stability, ease of assembly, and repeatability in sheet clamping.

3.5 Experimental Procedure

Step 1: The selected material (Ti-6Al-4V or PMMA) was cut into flat sheets of a standard thickness (e.g., 2 mm).

Step 2: The CNC machine was set up with the appropriate tool and workpiece. The toolpath was loaded into the CNC machine, and the initial forming process was carried out by incrementally deforming the sheet material.

Step 3: The incremental forming was performed using the optimized parameters for each experiment, ensuring that the denture plate was formed without excessive deformation or material failure.

Step 4: After the SPIF process, the formed denture plate was carefully removed and visually inspected for defects. Post-Processing: Post-processing was carried out to improve the surface finish and overall quality of the formed denture plates:

Polishing: The surface was polished to remove tool marks and improve the aesthetic quality of the denture plate. Polishing was done using a rotary polisher with fine-grit abrasive materials. Heat Treatment:for the titanium alloy material, a heat treatment process was applied to relieve residual stresses induced during forming and improve the material's mechanical properties.

Cleaning: The final product was thoroughly cleaned to ensure that no debris or residues remained on the surface, ensuring its suitability for dental applications. Evaluation of Formed Denture Plates: Several criteria were used to evaluate the success of the SPIF process in producing denture plates

Dimensional Accuracy: The dimensions of the formed denture plates were compared to the original CAD model using 3D scanning and coordinate measuring machines (CMM). The evaluation focused on the accuracy of the formed shape, including the curvature and wall angles.

Surface Finish: The surface quality was assessed visually and using surface roughness testing (Ra values), with the goal of achieving a smooth, polished surface suitable for patient comfort.

Mechanical Properties: Tensile tests were performed on small samples taken from the formed denture plates to assess the material's strength and flexibility. The results were compared to industry standards for dental materials.

Formability and Tool Wear: Observations of tool wear and material deformation were recorded during each test to understand how the material and tool interacted over the course of the forming process. Data Analysis The data collected from the experiments, including dimensional accuracy

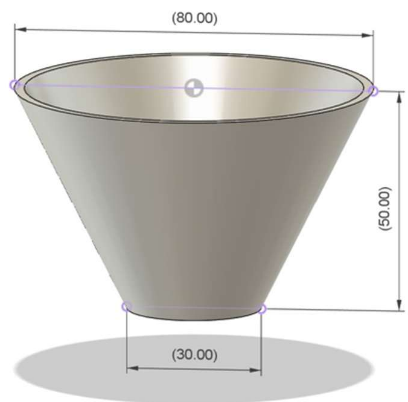
3.7 Data Analysis: The data collected from the experiments, including dimensional accuracy, surface quality, mechanical properties, and tool wear, were analyzed to identify the optimal process parameters. Statistical analysis was used to determine the relationship between different process parameters and the quality of the final product. Regression analysis and design of experiments (DOE) methods may also be applied to optimize the SPIF process for denture plate production.

Comparative Analysis: Finally, a comparative analysis was performed between SPIF and traditional methods of denture plate production, such as casting and thermoforming. Factors such as lead time, cost, material waste, and part customization were compared to evaluate the advantages and limitations of SPIF in the context of dental prosthetics.

3.9 For the Testing Phase:

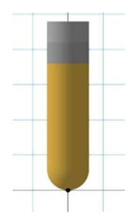
- **Frustum Design and SPIF Toolpath Generation in Fusion 360:**

- **Sketching the Frustum**
  - Created a new sketch in Fusion 360.
  - Drew two concentric circles with diameters *80 mm (base)* and *30 mm (top)*.
  - Added a *vertical height* of 50 mm to define the frustum.
  - Used the *loft tool* to connect the circles and form the 3D shape.



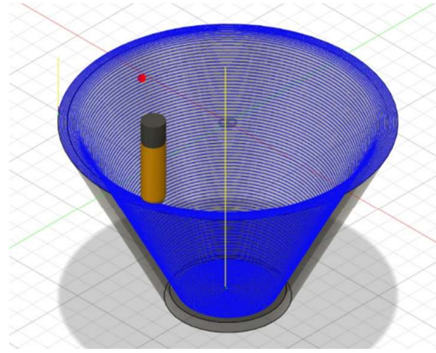
- **Extruding and Finalizing the Model**
  - Selected the *loft feature* to generate the frustum.
  - Ensured proper dimensions and smooth surface transition.
  - Adjusted material properties based on manufacturing needs.

- **Tool Selection and Setup**
  - Added a *Ball End Mill* tool in the Fusion 360 Tool Library.
  - Entered tool specifications such as *diameter, cutting speed, and step-over distance*.



- **Toolpath Generation**
  - Switched to *Manufacture Workspace* in Fusion 360.
  - Selected *3D Spiral toolpath* for smooth incremental forming.
  - Assigned the frustum surface as the machining reference.
  - Adjusted *feed rate, depth of cut, and step-over* for efficiency.

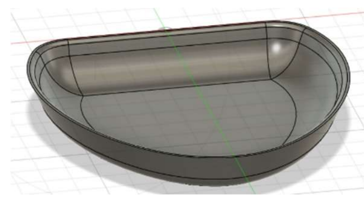
- **Simulation and Optimization**
    - Ran a full *simulation* to check for collisions and toolpath accuracy.
    - Adjusted *step depth and feed rates* to improve surface quality.
    - Ensured uniform material flow to minimize defects.



- **Post-Processing and G-Code Generation**
    - Opened the *Post Process* tool in Fusion 360.
    - Selected the appropriate *CNC machine* and generated the *G-code*.
    - Downloaded the final G-code for execution on the CNC machine.

- **Denture Plate Toolpath Generation in Fusion 360:**

- **Creating the Denture Plate Geometry**
    - Imported or sketched the denture plate profile using Fusion 360's *Form* or *Surface* workspace.
    - Used *boundary surface* and *solid modeling tools* to form a 3D denture shape.
    - Refined the contours to fit the anatomical geometry accurately.



- **Material and Setup Configuration**
    - Chose appropriate biocompatible material for denture fabrication.
    - Defined stock material and alignment in the *Setup* section of the *Manufacture* workspace.

- **Tool Selection**
    - Selected a *Ball End Mill* or *Tapered End Mill* for detailed finishing.
    - Configured tool parameters such as *diameter, flute length, and surface speed*.

- **Toolpath Strategy**
    - Used *3D Adaptive Clearing* for roughing and *3D Contour* or *Parallel Finishing* for fine features.
    - Selected the denture plate surface and defined rest machining parameters.
    - Fine-tuned *feed rate, step-down, and step-over* values for smooth surface finish

- **Simulation and Collision Check**
    - Simulated all toolpaths to verify material removal and collision avoidance.
    - Made iterative changes to improve tool engagement and reduce machining time.

- **Post-Processing**
    - Chose the correct post processor to match the CNC machine.
    - Exported and reviewed the final G-code.
    - Transferred the G-code to the machine for denture plate fabrication.

CALCULATIONS:

Contact Area Estimation (A_c)

For a hemispherical tool with radius R:

$$A_c = \pi R^2 \sin^2(\theta)$$

Frictional forces (F_x, F_y)

$$F_x = \mu F_z$$

$$F_y = \mu F_z$$

Contact pressure and Normal Force (F_z)

$$F_z = P_c \cdot A_c$$

where $P_c = k \cdot \sigma_f$

- Example calculation (Al 6061, 3mm Thick)

Given:

- Flow stress (σ_f) ≈ 180 Mpa
- Tool radius (R) = 5mm
- Wall angle (θ) = 26.57°
- Friction coefficient (μ) = 0.3

1. Contact pressure:

$$P_c = 1.2 \times 180 = 260 \text{ MPa.}$$

2. Contact Area:

$$A_c = \pi (R)^2 \sin^2(\theta)$$
$$= \pi (5)^2 \sin^2(26.57°)$$
$$= 35.13 \text{ mm}^2$$

3. Normal Force:

$$F_z = P_c \cdot A_c.$$
$$= 260 \times 35.13$$
$$= 9133.8 \text{ N}$$

4. Tangential Forces:

$$F_x = \mu \times F_z = 0.3 \times 9133.8$$
$$= 2740.14 \text{ N}$$
$$F_y = \mu F_z = 0.3 \times 9133.8$$
$$= 2740.14 \text{ N}$$

5. Contact Force Magnitude (CFM):

$$CFM = \sqrt{(F_x)^2 + (F_y)^2 + (F_z)^2}$$

$$= \sqrt{(2740.14)^2 + (2740.14)^2 + (9133.8)^2}$$

$$= \sqrt{90937409.8}$$

$$= 9536.11 \text{ N}$$

CHAPTER 4:

Manufacturing Process

Single Point Incremental Forming (SPIF) is an advanced dieless forming process used to shape sheet materials into complex geometries through localized plastic deformation. Unlike conventional forming methods that require expensive dies, SPIF uses a simple hemispherical tool that incrementally deforms the sheet material along a programmed tool path.

4.1 Working Principle

In SPIF, a sheet is securely clamped around its edges using a rigid fixture. A CNC-controlled forming tool, usually with a rounded tip, moves in a pre-programmed spiral or contour path. With each pass, the tool incrementally pushes into the material in the vertical (Z) direction, gradually forming the sheet into the desired shape. The shape is defined through CAD models and translated into toolpaths using CAM software. The process occurs at room temperature (cold forming), and deformation is localized at the contact point between the tool and the sheet. This makes the process highly flexible and suitable for producing customized or low-volume parts.

4.2 Demonstration Using PX 40

For the purpose of this project and report visualization, the SPIF process was demonstrated using PX 40 plastic sheets. PX 40 is a type of rigid polymer sheet (often a trade name variant of PVC or similar plastic), chosen for its ease of deformation and clarity in showing the step-wise forming behavior. Reasons for using PX 40 sheet: Formability: PX 40 is softer compared to metals, allowing easy deformation with low forming forces. This makes it ideal for demonstrating SPIF in lab or project settings. Clarity: Deformation and layer-wise formation can be easily observed on PX 40, aiding in better understanding and visual documentation. Cost-effectiveness: It is an economical alternative to metal sheets for educational and experimental purposes. Safety: The material is safe to handle, requiring no lubrication or special tooling conditions.

4.3 Process Setup Forming Tool:

High-Speed Steel (HSS) tool with hemispherical tip Workpiece: PX 40 sheet (mention thickness, e.g., 2 mm) Fixture: Rigid mild steel frame to clamp the sheet Machine: CNC milling machine or 3-axis CNC setup Toolpath: Generated using CAM software based on the 3D geometry of the desired part

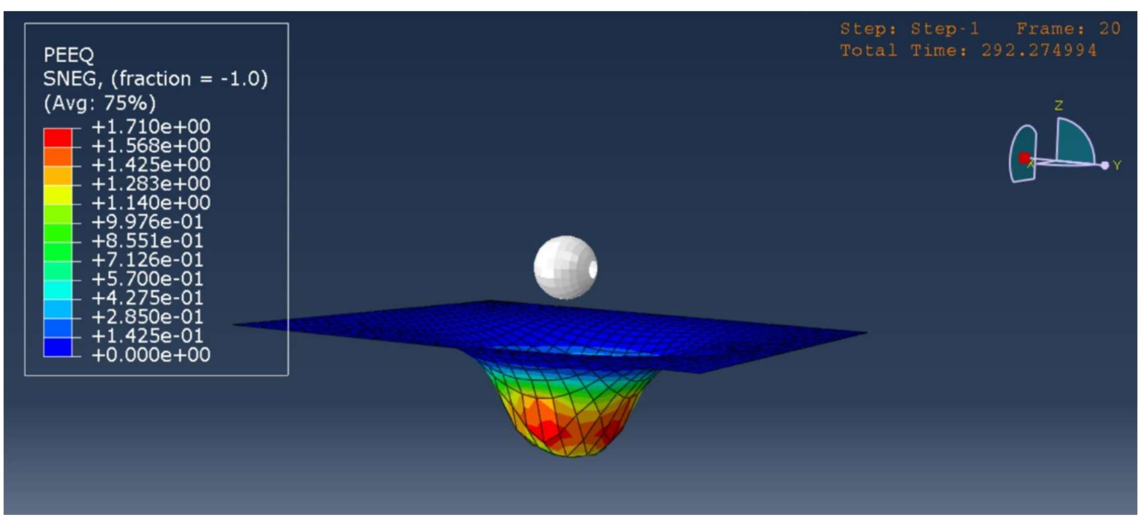
4.4 Summary of Steps

1. Design CAD Model of the required part.
2. Generate Toolpath using CAM software
3. Clamp PX 40 Sheet onto the fixture rigidly.
4. Run CNC Program to move the forming tool incrementally over the sheet surface.
5. Forming Completed as tool moves in layered steps to final depth

Simulation Analysis:

To validate the SPIF process prior to physical manufacturing, Finite Element Analysis (FEA) was performed using Abaqus. The simulation aimed to predict material behavior, thinning distribution, and deformation accuracy during incremental forming of the denture plate geometry.

The NC code generated from Fusion 360 was used to replicate the toolpath in the simulation. Material properties of Aluminium 6061 were assigned, and appropriate boundary conditions and step time data were applied. The results showed localized plastic deformation consistent with the tool movement and confirmed gradual shape formation layer by layer. Thickness reduction was most significant at the side walls, while the base maintained moderate thickness. The simulated results closely matched experimental observations, validating the process setup and offering insights for optimizing toolpath and step depth.



Chapter 5

Testing and Evaluation of SPIF-Formed Components

Upon completing the Single Point Incremental Forming (SPIF) process, it is imperative to assess the quality, accuracy, and structural integrity of the fabricated components. The testing procedures were conducted on two distinct workpiece materials: Aluminium 6061 sheet, used for industrial-grade testing, and PX 40 plastic sheet, utilized for demonstration purposes and toolpath validation.

5.1 Visual Inspection

A thorough visual inspection was performed on both materials to identify any surface defects, including: Cracks Wrinkles or folds Tearing in areas of high deformation Visibility of tool marks or step patterns Aluminium 6061: Minor surface roughness was noted, along with uniform step marks; however, no cracks or wrinkles were observed. PX 40: Clear step-wise deformation was evident, accompanied by a smooth surface finish due to the material's inherent softness.

5.2 Dimensional Accuracy

Check the formed shapes were compared to the original CAD models to evaluate geometric accuracy.

Parameters Measured:
Final part depth Wall angle Opening diameter Base diameter
Tools Utilized:
Vernier Caliper
Depth Gauge
Profile Projector (for Aluminium)

Results:

Aluminium 6061: Minor deviations in depth were noted, attributed to the spring back effect; overall profile remained within acceptable tolerances.

PX 40: The profile closely matched the toolpath, with no spring-back observed due to the material's inherent properties

5.3 Thickness Distribution Analysis

A critical outcome of SPIF is the thinning of the sheet material due to localized stretching. Thickness measurements were taken at the following locations Initial flat region (reference thickness) Side wall (maximum thinning zone) Bottom region (moderate thinning).

5.4 Surface Roughness Evaluation (Aluminium 6061 Only)

To assess the surface quality of the aluminium component, surface roughness (Ra) was measured using a surface profilometer. Measured Surface Roughness (Ra): ~2.1 µm Observation: Slightly rough due to tool-step effect, acceptable for prototyping applications.

5.5 Deformation observation in PX 40

As PX 40 was used primarily for demonstration and visualization, its evaluation focused on: Clarity of step-wise deformation Consistency in shape Adherence to toolpath Result: PX 40 provided excellent visual validation of the toolpath and process sequence with clear, defect-free forming

Chapter 6

Results

The Single Point Incremental Forming (SPIF) process was successfully carried out on an Aluminium 6061 sheet. The results were evaluated based on dimensional accuracy, material thinning, surface finish, and overall formability. The observations are summarized below:

6.1 Geometrical Accuracy

The formed component closely matched the CAD model, with a slight deviation in depth due to spring-back.

The wall angle was consistent throughout the profile, indicating uniform forming.

6.2 Surface Finish

The surface finish was evaluated using a surface profilometer

The average surface roughness (Ra) was measured as ~2.1 µm.

Tool step marks were visible but uniform, and no surface cracks or tearing were observed.

6.3 Visual and Structural Integrity

No cracks, wrinkles, or tears were present in the final component.

The part retained its shape well after unclamping, showing minor spring-back but no permanent deformation or failure.

Overall, formability of Aluminium 6061 was satisfactory, and the part met the geometric and quality requirements for a prototype.

Chapter 7

Conclusion and Future Scope:

The Single Point Incremental Forming (SPIF) process was successfully applied to Aluminium 6061 sheet metal, confirming its effectiveness for producing complex geometries without requiring expensive dies or molds. The formed part closely matched the CAD model, with only minor dimensional deviations due to spring-back. The material showed good plastic deformability, and no cracks, tears, or surface defects were observed.

Thickness variation was within acceptable limits, particularly in the wall region, where expected thinning occurred. The surface finish, while affected by the step-wise toolpath, remained suitable for prototyping purposes. The overall process demonstrated that SPIF is a highly flexible and low-cost solution for customized or low-volume manufacturing.

Future Scope:

To further improve the efficiency and quality of the SPIF process, the following areas can be explored:

- Use of Simulation Tools: Finite Element Analysis (FEA) can help predict thinning, deformation, and spring-back before actual forming.
- Toolpath and Step Depth Optimization: Enhancing toolpath strategies can minimize roughness and improve dimensional accuracy.
- Multi-Point or Support-Tool SPIF: Using a backing or support tool can reduce thinning and allow for more complex shapes.
- Automation and Real-Time Monitoring: Incorporating CNC feedback and sensor systems can lead to better control over forming parameters.
- Post-Processing Techniques: Surface treatments, heat treatment, or annealing may be used to enhance surface quality and mechanical strength.

The SPIF process has strong potential for future development and wider adoption in sectors such as automotive, aerospace, biomedical, and customized prototyping

References

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