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INFLUENCE OF FORMING ANGLE ON GEOMETRICAL ACCURACY IN SINGLE POINT INCREMENTAL SHEET METAL FORMING (SPIF) PROCESS

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ABSTRACT

Incremental sheet metal forming (ISMF) is a highly flexible and versatile process to produce complex sheet metal parts and rapid prototypes. Its adaptability to (CNC) systems is excellent through direct control of CAD data, minimizing the use of heavy machines, high cost tooling and pressing equipment. A sheet of metal is formed by using a simple forming tool driven by a CNC milling machine localizing pressing force to plastically deform the part during progression. In this work, like pyramid shape manufactured by(SPIF) process without using any dedicated dies. The aim is to measure the influence of forming the angle on the dimensional accuracy (depth error) of the formed part. Different angles (30°, 45°, and 60°) used to create pyramid shape and all the experiments carried out on an aluminum alloy sheet with0.5 mm thickness by using a three-axis conventional milling machine, this machine also used to measure dimensions accuracy of the part. Results show that the forming angle (30°) is gives the higher geometrical accuracy when forming the pyramid shape.

***KEYWORDS**: Incremental sheet metal forming (ISMF), Spring back, Single Point Incremental Forming process (SPIF) & Rapid prototyping*

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NOMENCLATURE

(ISMF)	Incremental sheet metal forming
(SPIF)	Single Point Incremental Forming
CNC	Computerized Numerical Control
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
δ avg	Geometrical Error or Depth Error (mm)

1. INTRODUCTION

Deep drawing and stamping are a conventional sheet metal forming operations require a highly cost tooling and designed for mass production process. Nowadays, the production of a single or few complex shapes with shorting the lead-time at low cost is required. Many research works developed to adapt the changing requirements of the market. Thus, a new trail manufacturing operation that has the ability to deform sheet metal into a unique shape with more machining flexibility is still required by many industrial sectors [1]. Consequently, few decades ago, a new non- conventional sheet metal forming process known as Incremental Sheet Metal

Forming (ISMF) technology is developed. ISMF process seems to be a sustainable approach to reach the aim of high operating flexibility as that specialized tooling is no longer required, reducing cost of manufacturing and time-to-market when rapid prototypes or small batch series demanded [2].

(ISMF) is a flexible, novel technology that depends on CAD/CAM system. Part geometry and tool path is created by CAD applications then the sheet forming process is accomplished by a CNC milling machine or a Robot arm replacing the cutting tool by a hemispherical head tool that applies the required force to form the part (either it's a rotated tool or not), while the CNC system positions the part systematically and layer by layer with small Z-intervals to prevent tearing depending on local deformation [3, 4]. There are two kind of (ISMF), Single Point Incremental Forming (SPIF) and Two Point Incremental Forming (TPIF). The former is a sheet metal prototyping that can provide a wide range of parts without the need for expensive tools and dies [5]. The lateral needs additional mold to support the sheet during the process.

As a recapitulation of previous work, Ales Petek et al investigated the effect of tool coating in dry and wet machining on complex tri bology (friction, wear and lubricant) by monitoring tool temperature and tool wear, the author conclude that if good adherence between coating material and forming tool is achieved, then on the basis of carbon (DLC) coatings might be the best improvement on tri bological properties, because they may eliminate lubricant usage[6]. K. Jackson and All wood studied the mechanism of (ISMF), a comparison for the same part produced by (SPIF), (TPIF) and pressing has been made, share in the direction of the tool (tool-WP friction) is the most significant share component, the main distinction between the deformation mechanisms of pressing and SPIF or TPIF is that shear stress in both (parallel and perpendicular) to tool direction [7]. A hard work done by Saad Arshad in his MSC thesis, he used three AL alloys with multi-thickness for each and two tool diameters, then comparing his CAD models of a cone-shape with the results of the tests that had been made (GAT Geometric Accuracy Test, MAT Multiple Angle Test and CAT Constant Angle Test), the author depth vs. wall angle relation comply indicate that part depth can be increased by rising wall angle [8]. Another thesis by Hosein Khalatbari focusing on material formability by optimizing process parameters (tool diameter, spindle speed, feed rate, blank thickness and step size), fracture time was the indication in each experiment the process was optimized in terms of maximum achievable formability, minimum processing time, and minimum sheet thickness [9]. Premika Suriyaprakan also studied tool path and forming tool influence on metal forming ability trying to form a vertical wall maintaining the blank thickness equal along the part [10]. H. Meier et al used resistance heating to worm forming zone in (TPIF) to 600 c° for steel, the results showed the need of second tool to increase geometrical accuracy [11]. Imre Paniti et al presented A (TPIF) tool path planning with a Robot and a C-shaped arm to create convex and concave without releasing the sheet which minimize machining time [12]. L. Ben Ayed et al A simplified numerical approach called ISMF-SAM (for ISMF-Simplified Analysis Modeling) has been developed to simulate the ISMF operation leading to CPU time reduction to about 63% and there was a good compatibility between numerical and experimental work [13]. Singh and Goyal proposed a FEA to study various forming parameters influence on springback of the part, the study proved that springback increase with increasing draw angle, sheet thickness and tool diameter. step size in z-direction has a slight effect on springback but leads to high surface roughness[14]. G. Paramo and A. Benitez compared the Dieless (SPIF) with conventional sheet metal processes (deep drawing/ superforming/ stamping/ spinning) to form a conic shape part, the authors find out the grate flexibility of the process and its benefits related to time, cost, formability and labor [15]. Y. Kumar and S. Kumar analyzed strain distribution on the manufactured part in SPIF by printing grid pattern in the bottom of the sheet to prove the capability of the process to produce complex parts [16]. Krzysztof Karbowski present an ISMF model to create skull bone prosthesis successfully implanted during surgery [17]

In this work the aim is to investigate the influence of draw angle (forming angle) on pyramid shape part accuracy by measuring and evaluating depth error for Al alloy sheet with 0.5 mm thickness.

2. GEOMETRICAL ACCURACY

This ISMF output affected by several errors: Pillow Effect is a curvature occurred at the uniformed minor base of the part, Sheet Bending at the major base caused by poor support and Springback error which is a result of tool movement from one point to another horizontally or vertically then the metal retreated back [14]. This error is directly related to forming angle and metal formability. See Figure1 below.

Z- Increment also a factor that may have an effect on accuracy, an important note should be considered that the small increments provide slower forming forces. If a reduction in forming time along and a good surface quality needs to be achieved then higher increments can be used along with higher tool diameter [18].

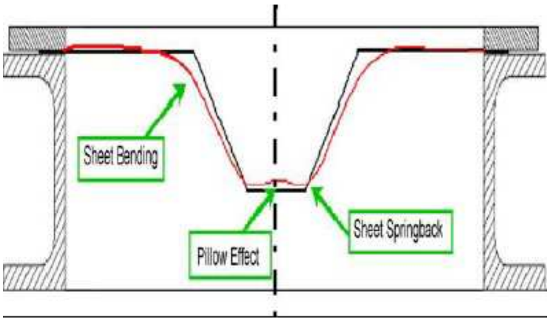


Figure 1: Geometrical Errors during the SPIF Process [14]

3. TOOLS AND MEASUREMENT

The work carried out on a mini CNC Milling Machine Model CNC –SC with a box frame to fix the sheet on the machine table, same machine used to measure dimension accuracy by replacing cutting tool with a probe connected to a DC electrical circuit and a diode, by taking advantage of its accurate positioning system, when the probe makes contact with part surface the diode light is on and the read on machine screen then is recorded as depth point, see Figure 2. A digital micrometer used to measure part thickness. Software that had been used is Auto Cad to create the CAD model and UG-NX8 software for tool path generation and post processing. The forming tool is heat treated low carbon steel with 6 mm diameter hemispherical head. Also, there was a lubricant oil to reduce friction effect.

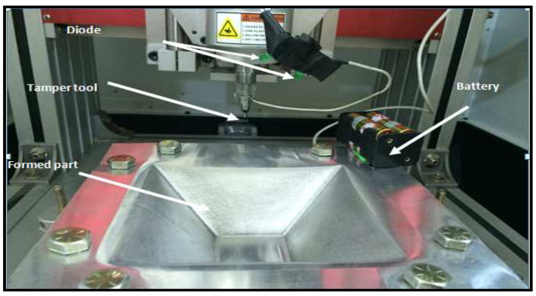


Figure 2: Using CNC Machine for Measurement

4. PART GEOMETRY, TOOL PATH GENERATION AND POST PROCESSING

CAD models created with four-point surface command then exported to UG-NX8 to generate a tool path, the right tool path strategy selection depends on how complex is the part geometry, sheet material properties and the thickness, product surface quality, and CNC machine capability [19]. There are for sure many tool path strategies, yet the one has been used here is helical (spiral) toolpath(HTP) as shown in Figure3. The first cycle starts at zero Z-increment from a selected point in the horizontal plane(x-y) and ends with it. The next cycle begins from the same starting point, but in helical movement on a square path in the downward direction with a gradual Z-increment until the final Z-increment value is reached at the end of the cycle, in other meaning distributing the increments during machining at the same cycle the then cycle after and so on. Thus, the contact between forming tool and sheet will reside till part completion. Post processing is to translate tool path coordinates to a language compatible with CNC machine, G-code and M-code post processing is what had been used, Figure 4 below summarize the CAD/CAM system integration.

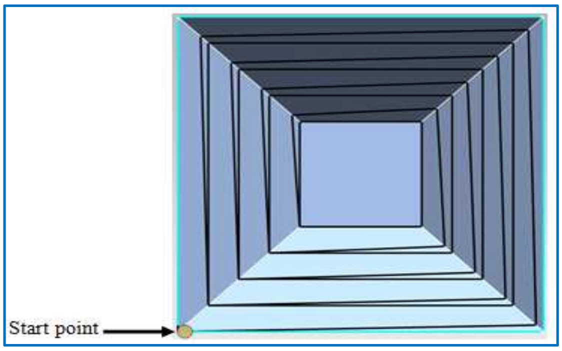


Figure 3: HTP for Pyramidal Shape

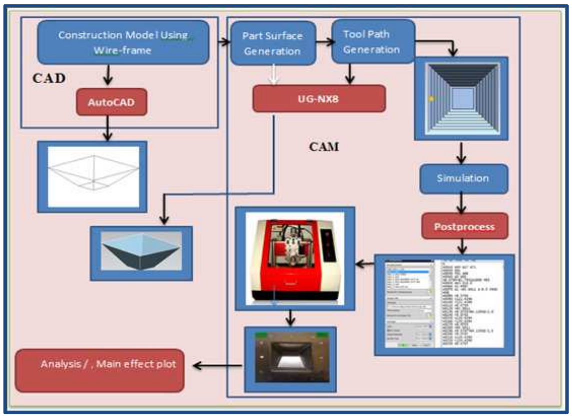


Figure 4: Schema Summarizes the Integration of CAD / CAM

5. EXPERIMENTAL WORK

Table 1 presents the experimental data of the work.

After completion of the part lubricant extraction and cleaning the surface, measuring process takes a place while the part still fixed, in order to maintain work piece zero as a measuring reference Depth error evaluated as the difference between ideal (CAD model) and real profile depth (product) for formed parts as in equation 1. Data points and geometrical accuracy measured along a section of the formed part, i.e. normally to the component sides as shown in Figure 5.

Table 1: Plan of Experiments

Experiment No	Tool	Tool Path	Geometry	Forming Angle (degree)	Feed (mm/min)	RPM	Z-Increment mm
EX 1	Hemispherical 6 mm dia	HTP	pyramid	60°	750	0	0.2
EX 2	Hemispherical 6 mm dia	HTP	pyramid	45°	750	0	0.2
EX 3	Hemispherical 6 mm dia	HTP	pyramid	30°	750	0	0.2

Depth error$\boldsymbol{\delta_{avg}}$ $=\sum$ [$d_{ideal} - d_{real}$]/No. of data points (1)

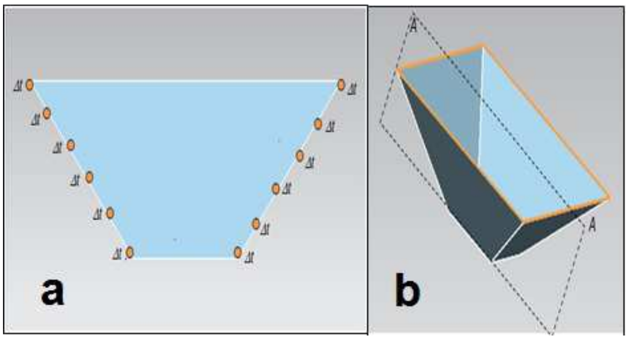


Figure 5: (a) Representation of Average Depth Error (b) Section of the Pyramid Square Shape

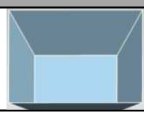
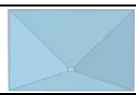
6. RESULTS AND DISCUSSIONS

The aim is to reveal the effect of varying forming angle on product accuracy. The results presented in Table 2 for all three experiments.

6.1: Effect of Helical Tool Path (*HTP)*

This path generated in the square pattern depending on the part periphery. The main tool moves on the helical square path. It is a gradual motion and Z-increment is distributed over the total length of the cycle. Hence, there is no fix increment location where the increment line is distributed over the surface area of the part. Therefore, the increment line was prevented in this tool path. As a result of increment line distribution, the forming forces will be distributed and the forming process will be more consistency leading to reduce the geometrical deviation. So, HTP affect part surface appearance positively, see Figure 6. Another important feature in HTP is that the nature of helical tool path motion results in reducing the gap between given cycles. Therefore, non-deformed regions between cycles were reduced so that the geometrical deviation will also be reduced.

Table 2: Results

Experiment No	Forming Angle (degree)	*Avg-Geometrical Error (depth error)* δ_{avg}*[mm]*	CAD Model	Final Product
EX1	60°	10.51		
EX2	45°	1.04		
EX3	30°	0.66		

6.2: Effect of Forming Angle

At 60° angle with backing plate, many typical forms of geometrical errors have been found. Minor base suffers geometrical deviation (***e*s**) in Figure 7caused by sheet lifting from springback at this angle, the bending did not appear at the top of the product due to the use of the backing plate.

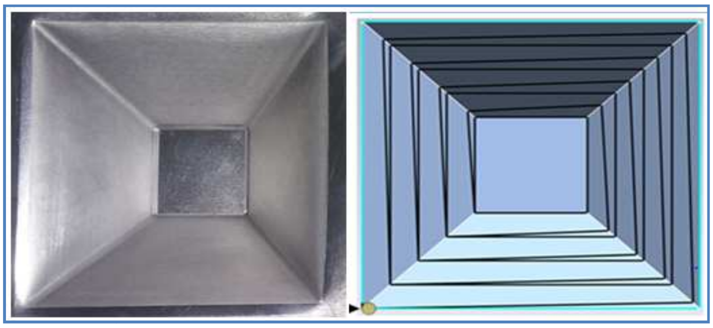


Figure 6: Generated Tool Path and Final Product

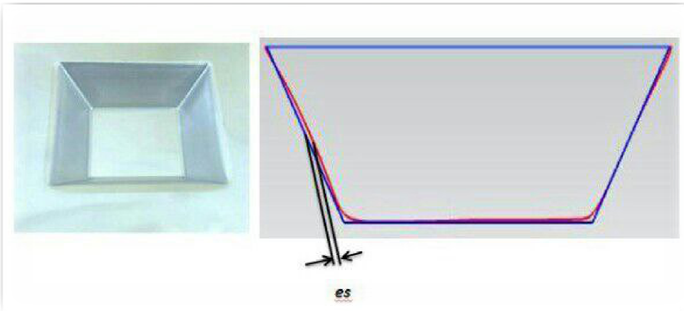


Figure 7: Side View of the Pyramid Square Shape at 60° Angle (CAD Model in Blue Line, Actual Part in Red Line)

When the angle of 45° is used, the results show that there are two typical forms of geometrical error in the product, Bottom base suffers geometrical deviation (***e*s**) caused by sheet lifting from springback and (***eb***)which represents bending of sheet near upper base where caused by tool action when previous loops machined as shown in Figure 8. As for Angle 30° there is very little error in the geometrical deviation as shown in Figure 9, that's because the resulting thickens is more homogenous where estimate to be predicted by Equation 2 below[20]:

$$t_1 = t_o \, sin(90 - \alpha) \quad (2)$$

Where t_1 = formed part thickness (mm), to= initial sheet thickness (mm) and α = forming the angle (degree)

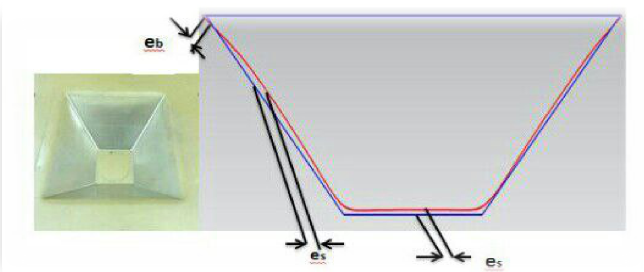


Figure 8: Side View of the Pyramid Square Shape at 45° Angle (CAD Model in Blue Line, Actual Part in Red Line)

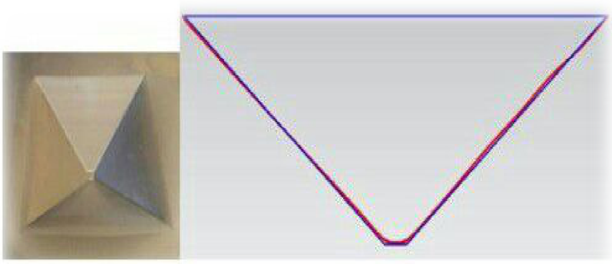


Figure 9: Side View of the Pyramid Square Shape at 30° Angle (CAD Model in Blue Line, Actual Part in Red Line)

Equation 2 proves that parts with angles (80-90) impossible to form. As for thickness results for this work (measured and calculated) are presented in Table 3. Figure 10 combines the forming angle vs. depth error and part thickness.

Table 3: Results

Experiment No	Forming Angle(degree)	Wall Thickness(mm)	
		Calculated	Measured
EX1	60°	0.250	0.272
EX2	45°	0.353	0.368
EX3	30°	0.433	0.450

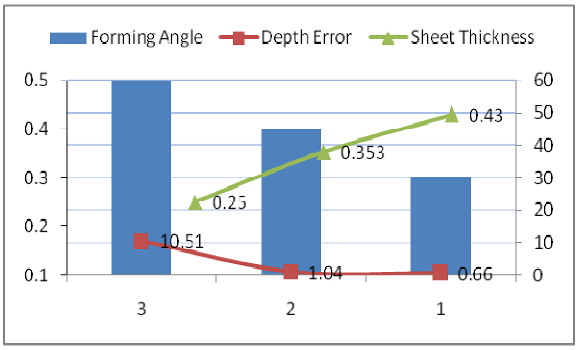


Figure 10: Forming Angle vs. Depth Error and Thickness

7. CONCLUSION AND RECOMMENDATIONS

In the modern manufacturing industry, the flexibility of production technologies is becoming more important. This work is focusing on one of these new technologies (ISMF) and particularly the influence of forming the angle on the whole process. Depending on the former review and results in hand the following points are concluded:

- Lower angles give higher precision, huge difference between forming angle 30° and 60° with springback effect or depth error (0.6697, 10.5108) respectively.
- Helical tool path (HTP) could be described as the "optimal" tool path to achieve higher geometrical accuracy for most simple and complex shapes.
- The vertical pitch has a major effect on product accuracy and thickness distribution.
- Using backing plate will reduce bending and springback at upper base.

Recommendations: increasing plate thickness at high forming angles also using a suitable tool diameter with the smallest Z-increment in SPIF.

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