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Dimensional Accuracy of Single Point Incremental Forming

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Dimensional Accuracy of Single Point Incremental Forming (SPIF) is studied with the use of a Box-Behnken design analysis. The dimensional accuracy of this process is determined by comparing parts manufactured using SPIF with the part drawings used to create the manufacturing toolpaths. Five factors are varied in the manufacturing of the SPIF process, and they are: material type, material thickness, formed shape, tool size, and incremental step size. The Box-Behnken design analysis allows for determination of how these factors affect the dimensional accuracy.

Key words: forming, sheet metal, incremental forming

1 INTRODUCTION

This paper presents a new study of dimensional accuracy in Single Point Incremental Forming (SPIF). SPIF is an inexpensive modern sheet metal forming process capable of making complicated shapes described in the CIRP keynote by Jeswiet et al [1]. Although SPIF is a viable process many challenges still need addressing.

The new information is in the form of comparisons between part drawings and parts formed with SPIF. This work is complementary to work reported previously [1, 2, 3, 4].

Dimensional accuracy is of vital importance in any manufacturing process. All manufacturing processes have different allowable dimensional tolerances. SPIF can not be marketed as a viable forming method unless information like dimensional accuracy has been determined. The dimensional accuracy study is important for determining how accurate SPIF is; this could lead to understanding of possible applications for SPIF.

2 EXPERIMENTAL METHOFOLOGY

Various parameters affect the formability of SPIF; a keynote by Jeswiet et al. [1] discusses many of them and an experimental design (DOE) was utilized to determine the most critical forming parameters [2]. The five main forming parameters (factors) under consideration in SPIF: material type, material thickness, forming tool size, shape of part, and incremental step size; the response to the factors is maximum forming angle [2, 3, 4].

The objective of this study is to determine the effect of the five forming parameters on the dimensional accuracy of parts manufactured using SPIF. The dimensional accuracy results are presented graphically, in 3D, a pictorial comparison between the CAD drawings and the actual parts. A Box-Behnken response surface experimental design methodology is used.

2.1 Experiment Set-up for Manufacturing Samples

A Box-Behnken experimental design is executed using the five forming factors listed above. The five factors are varied at three levels; the factors and levels are given in Table 9.1. Details on the Box-Behnken design can be found in [3, 5]. The Box-Behnken design can analyze five factors in three levels in forty six experimental runs including centre point replication to improve the variance in the design [5].

Table1. Box-Behnken Design Coding of Experimental Factors

Coding	Material Type	Thickness [mm]	Tool Size [mm]	Step Size [mm]	Shape
-1	5754	thin	4.7625	0.0508	dome
0	6451	medium	6.35	0.127	cone
1	5182	thick	9.525	0.254	pyramid
		5754	**6451**	**5182**	
-1	thin	0.93	0.8	0.93	
0	medium	1	0.9	1.15	
1	thick	1.45	1.545	1.5	

2.2 Experimental Methodology for Laser Scanning

Utilizing the parts created using the Box-Behnken design DOE for the maximum forming angle. The parts are scanned using a ShapeGrabber® laser scanning system. Due to the highly reflective nature of aluminum, the parts needed to be coated to ensure scanning without errors. After experimenting with various coatings; carbon black, candle soot, spray starch and spray deodorant, spray deodorant is found to give the most even and thin coat.

Using both the ShapeGrabber® and the IMAlign™ software, the scanned image of the parts can be manipulated or added to. In the case of these parts 10-20 scans are need to capture the full shape and depth of each part. Figure 1 shows the ShapeGrabber® being used to scan a part. Figure 2 shows the image of a part after compiling the multiple scans.

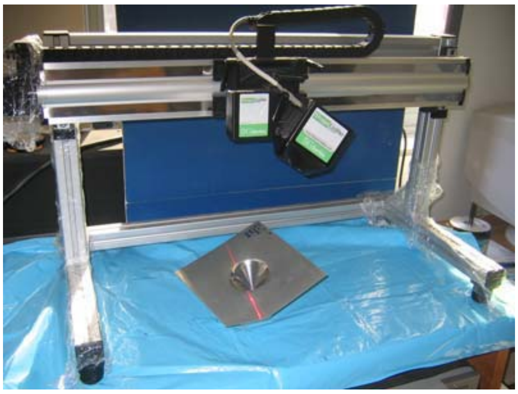

Fig. 1. Scanning of Part# using ShapeGrabber®

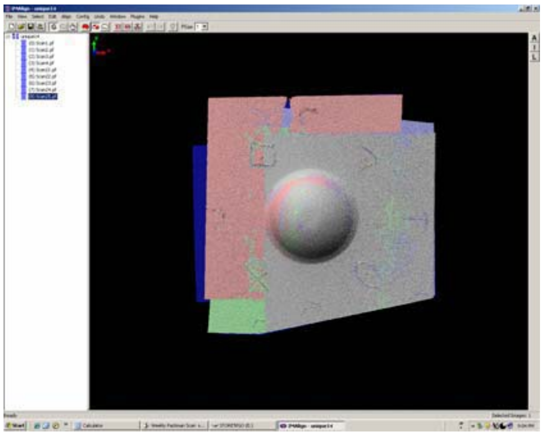

Fig. 2. IMAlign™ screen capture of Part #

After compiling the scans of the part, they can be compared to the drawings used to produce the toolpaths for manufacturing the parts. This is done through the use of IMInspect™. IMInspect™ allows the user to define the scales of the CAD and scanned part file; in this case all measurements are made in mm. IMInspect™ also allows for setting the greatest deviations. The default is 4 mm; this is the setting used for analysis. The scale can be adjusted after to get the best view of the comparison. To do the comparison in IMInspect™, data and a reference is needed; in this case, the data is the scanned part and the reference is the CAD drawing.

Figure 3 shows the IMInspect™ comparison of a dome using the default scale of ± 4 mm and figure 4 shows the comparison of the same part using a magnified scale of 0 to 1 mm error. The comparisons from IMInspect™ determine the deviations between the CAD (reference) and the actual part (data). The 3D colour pictures show the scanned image with a colour coding to represent the deviations between the reference (CAD) and the data (scanned image). The scale for each image is shown on the right of each figure. Figure 3 has a scale ranging from -4 mm to +4 mm in 0.5mm increments. The purple on the bottom of the scale is the -3.50 to

-4.00 mm range and the red is the 3.50 to 4.00 mm range. In this picture the majority of the deviations range from -1.5 to 1.5 mm.

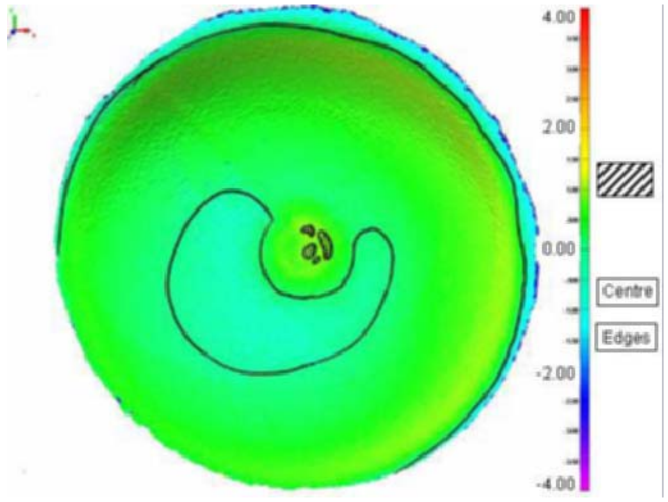

Fig. 3. IMInspect™ Comparison (Scale ±4mm)

In Figure 4, the scale is zoomed in to 0 to 1 mm with increments of 0.05 mm. The purple (Zone F) range is now representing the 0 to 0.05 mm deviations from the reference. The red (Zone A) range is 0.95 to 1 mm. The white areas are out of the 0 to 1 mm range. In this picture it is much clearer that the bottom of the form is closer to the CAD reference than the areas which are formed first and near the backing plate.

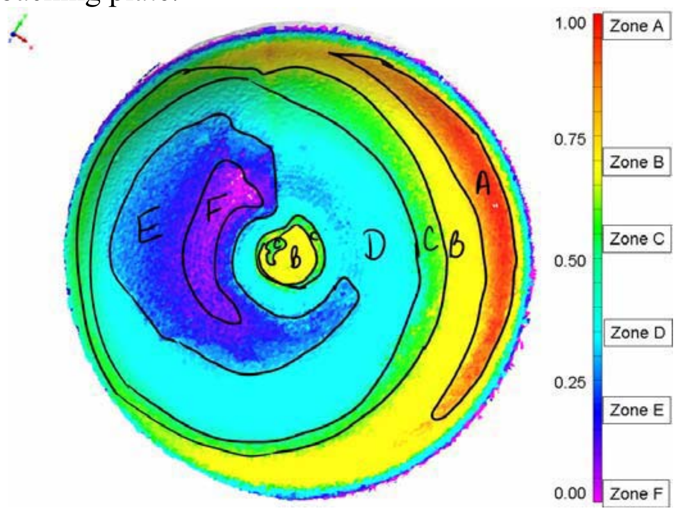

Fig. 4. IMInspect™ Comparison (Scale 0 to 1mm)

3 RESULTS FROM INSPECTION ANALYSIS

IMInspect™ produces not only the graphical comparison shown in figures 3 and 4, but will also give numerical data on the "fit" of the data to the reference.

3.1 IMInspect Comparison for Dimensional Accuracy

Using the experimental methodology explained in Section 2.2, each part is laser scanned to determine the deviations from the reference. Figures 5 to 8, show different shaped parts made using 0.9 mm AA6451 material. The tool size and step size as well as shape are different in different figures.

Figure 5 and 6 below show 48° cones. The scale shown is 0 to 1 mm, with the white areas at the point of the cone and base, being out of the 0-1 mm error range. These cones are formed using all of the same forming parameters and should produce the same cones. As can be seen from the figures, these cones come out to be very similar.

Figure 7 shows a 56° dome; here a large deviation is noted at the tip, just as is seen in the cones. In the dome, the deviation at the tip (last area formed) is still within 1 mm error of the reference. The rest of the dome has errors much less than that of the cone, ranging from 0.150 mm to 0.400 mm.

Figure 8 shows a 39° pyramid, with a large range of colours shown. The tip of the pyramid also shows the largest deviation from the reference. In the pyramid two sides have similar deviations and the other two sides also are similar. In the case of the pyramid, the errors are similar to those found in the cones.

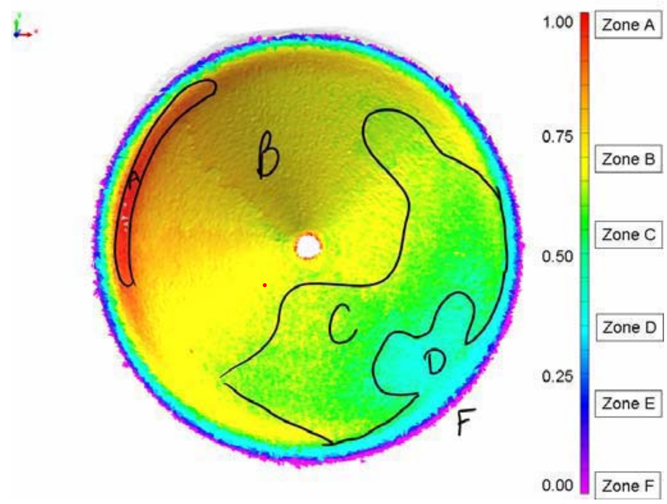

Fig. 5. 48°Cone (Scale 0 to 1mm)

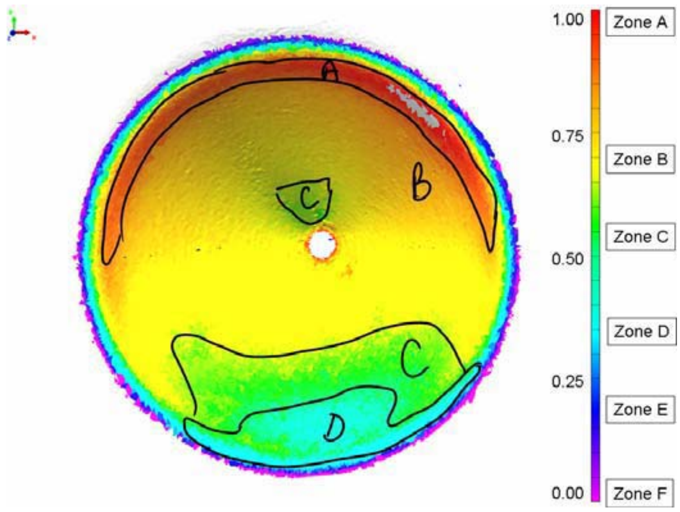

Fig. 6. 48° Cone (Scale 0 to 1mm)

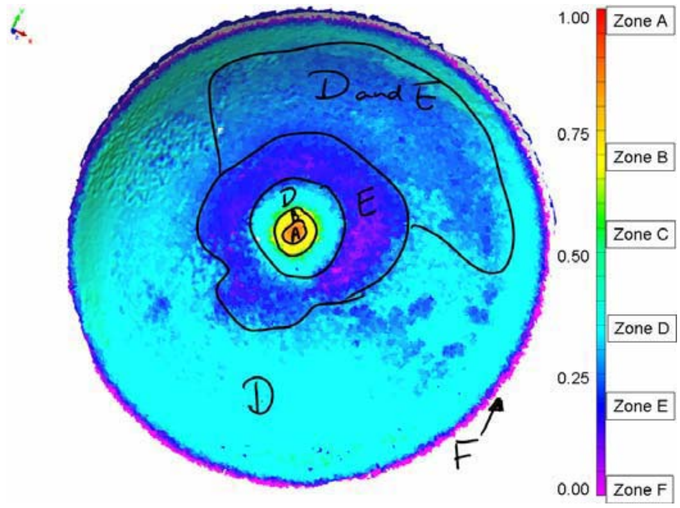

Fig. 7. 56°Dome (Scale 0 to 1mm)

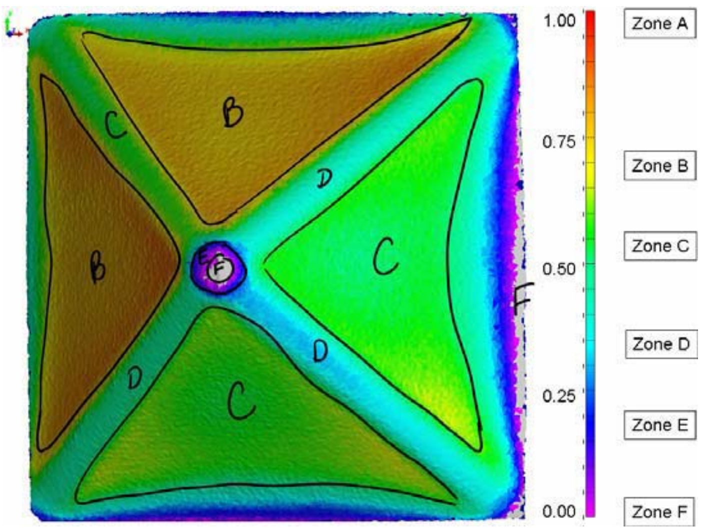

Fig. 8. Pyramid – Part #39 (Scale 0 to 1mm)

In total forty-six parts were made, compared, and analyzed. The analysis includes: mean and standard deviations error from reference, as well as the maximum and minimum errors and the probability of points within one and three standard deviations. 15% of the parts have maximum errors less than ±1 mm, 48% of the parts are within 2 mm, 76% are within 3 mm and all parts are within ±4 mm. The overall average mean is 0.13 mm and all parts have a mean error of less than 1 mm.

4 CONCLUSIONS

- The comparisons show most of the deviations between are within 0 and 1 mm.
- The overall mean deviation is 0.13 mm.
- More analysis is need for more complex parts.

The results of this study have increased the understanding how accurately SPIF parts are to the drawings. These studies can lead to the manipulation of toolpaths to account for the expected deviations and an ultimate increase in forming accuracy.

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REFERENCES

1. J. Jeswiet, F. Micari, G. Hirt, J. Duflou, J. Allwood, A. Bramley, Asymmetric Single Point Incremental Forming of Sheet Metal. *Annals of CIRP* (2005) 54/2/2005 130-157.
2. M. Ham, and J. Jeswiet, Single Point Incremental Forming and the Forming Criteria for AA3003. *Annals of CIRP* (2006) 55/2/2006 241-244.
3. M. Ham, and J. Jeswiet, Single Point Incremental Forming Limits Using A Box-Behnken Design of Experiment. *Key Eng. Mtls* (2007) 344 629-636.
4. M. Ham, and J. Jeswiet, Forming Limit Curves in Single Point Incremental Forming. *Annals of CIRP* (2007) 56/2/2007 277-280.
5. G. Box and D. Behnken, Some New Three Level Designs for the Study of Quantitative Variables. *Technometrics* (1960), 2, 4, 455-475.