Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal 2023, 17(5), 260–268
https://doi.org/10.12913/22998624/172907
ISSN 2299-8624, License CC-BY 4.0

Received: 2023.09.01
Accepted: 2023.09.25
Published: 2023.10.20

Improve Single Point Incremental Forming Process Performance Using Primary Stretching Forming Process

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ABSTRACT

Incremental forming (IF) is one of the sheet metals forming technique where is a sheet formed into a final workpiece using a series of small incremental sheet deformations. In Incremental sheet metal forming process, one of the important steps is to produce the forming part with acceptable performance such as product accurate and uniform thickness distribution with a homogenous grain distribution that consider as the main challenge of incremental sheet metal forming process. This work is carried out to find the best method to control the product performance of the final parts using a new method of applying a primary stretching forming process with a hemispherical forming tool followed by single point forming SPIF. Different primary forming depth (10, 20, 30 and 40 mm) were applied to find their effect on the forming behavior of the final product and compare them to the single point forming product without using a primary forming process. The experimental results showed the improvement in microstructure by applying SPIF process after primary stretching, with grain size of 36 µm at 40 mm forming depth as compared to 52 µm when using pure SPIF, a twining effects presence in both cases. A high improvement with a minimum dimension deviation of (6%) with respect to the forming process in single point incremental forming process without a primary forming process that result forming deviation equal to (11.6%) with respect to the desired design. The thickness distribution of the final product also improved by applying the primary stretching forming process before the SPIF process reaches to (6.9%, 9.1%, 14.9% and 21.5%) at forming depth (10, 20, 30 and 40) mm, respectively.

Keywords: microstructure, thickness distribution, single point incremental forming, dimension accuracy, stretching forming process.

INTRODUCTION

Single point incremental forming (SPIF) is considered as a modern sheet forming process. The steps incremental displacement of the tool in different directions allows deformation the metal sheet to obtain the desired shape [1]. SPIF classified as a progressive process that adapted bed sheet metal forming technology which utilized layered manufacturing fundamental, results in changing the part geometry of several parameters such as 2D layers [2], Figure 1 presented the SPIF process steps. The local plastic deformation is performed layer by layer using the CNC machine motions of low cost and simple forming tool results in the manufacturing of complex geometry products [2]. The main advantages of SPIF process are high formability of the sheets with a reduction in the costs when batches or prototypes have to be manufactured. However, the drawbacks are the long manufacture time with poor geometry respect as well as the non-uniform thickness distribution [3, 4].

The importance of incremental forming process results in interesting of a number of researchers in developing methods that increase its efficiency and increase production with acceptable thickness distribution and dimension accuracy. Aqeel S. et al [6] suggested a hybrid forming (HF) process using Multi Point Forming MPF and SPIF to produce a hemi-spherical part of brass sheet. The results demonstrate a defect free product with improvements in microstructure including a high refinement in grain size

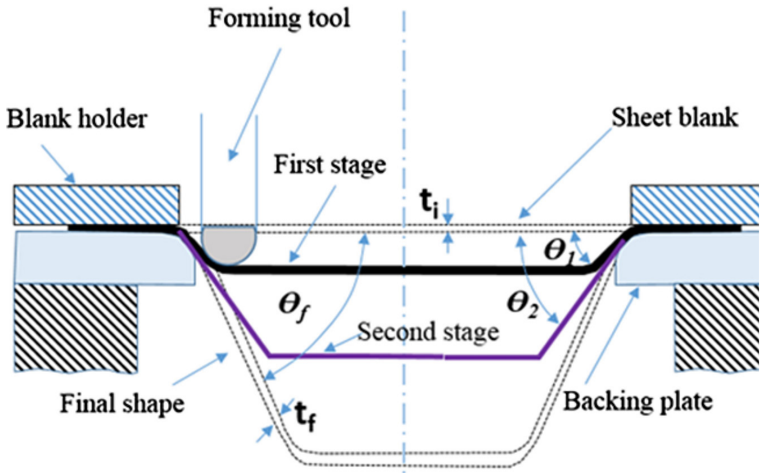

Fig. 1. Singe point incremental forming process steps [5]

and twining effects. The applied hybrid forming process also showed a slight improvement in microhardness as compared to the as received blank sheet. Enas A. and Khalida M. [7] investigate the effects heat treatment of 6061Aluminum alloy on the thinning ratio and thickness distribution of SPIF processed samples, finite element method using Abaqus software also employed to analyze the reduction in thickness along the wall portions. The authors fined 3% and 5% deviation ratio between the numerical and experiment of the original sample and heat-treated samples, respectively. Araghi et al. [8] overcame problems that is faced the incremental sheet forming including low geometric accuracy, thinning, and forming time. The authors used a combined forming process which consists of both stretches forming with Incremental Sheet Forming ISF process. The first step is applying a stretch forming to create the pre-forming parts which is not yielding to the final geometry, followed by a second step of applying ISF process. The Pockets and grooves defects not present during stretch forming, while it formed using ISF process. Ham et al. [9] increase the dimension accuracy through compare the incremental formed part with drawing part which was used to create the tool path. The experimental work performed by using different process parameters such as sheet thickness, material type, formed shape, tool geometry and incremental tool path. In total of 46 components that are formed and analyses, a 15% of the performed components are less than 1mm deviation, about 48% of the components are equal or less than 2 mm deviation, 76% are equal or less than 3 mm deviation and all the formed components are equal to 4 mm. The average value of the mean is about 0.13 mm of the overall components which have a mean error less than 1mm. B. Lu et al [10] suggest a flexible sheet forming method allowing good sheet thickness distribution with reduction in process time as compare to the traditional incremental sheet forming. In this work, a two-step forming process has been proposed consists of a multi-point forming process to achieve the initial shape geometry with the designed the thickness distribution, second is applied the incremental sheet metal forming process to finalize part geometry along with favourable thickness distribution. To predict the thickness distribution of the final part a numerical model using integrating finite element simulation with analytical prediction of ISF process is applied. Zhang et al. [11] investigate the effect of forming parameters of new hybrid incremental sheet forming process, the research dealt with the effect of forming factors on the change of thickness, the dimension accuracy and surface finish of the product. The results of the research show a deviation of the geometry of the final product from the center to the edge of the deformed plates. It was also found that pre-forming affects the relative thickness distribution and dimension accuracy in the SPIF process.

In this work, a new method of applying a pre-forming process using a conventional hemispherical forming tool with different starting pre-forming depth followed by a single point incremental forming process, to enhance the microstructure along with improve the thickness distribution and accuracy of the final products.

Table 1. Mechanical properties of Brass cu-zn 65-35

Property	Value
Young modulus (GPa)	110
Position ratio	0.33
Tensile strength (MPa)	250
Elongation % on 50 mm G.L.	56

EXPERIMENTAL WORK

The experiment was carried out using the INSTRON test machine with a machine capacity of 180 KN, the crosshead speed of the machine was kept constant at 10 mm/min, Brass metal sheet from which it is formed has a dimension of 225 mm, 0.7 mm thickness and is comprised of Brass of the following mechanical properties is listed in Table 1. A typical pyramid forming shape was chosen in experimental work using single point incremental forming process of the final dimension (maximum radius equal to 80) and (minimum radius equal to 30 mm).

The first step of stretching forming process is performed to 10, 20, 30 and 40 mm depth using a conventional hemispherical forming tool with 45 mm radius at forming speed of 10 mm/min, the second step is accomplished using SPIF process at (0.3 mm) incremental steps, Figure 2 illustrated the pre-forming (Dome forming tool) followed by SPIF process steps. The experimental work included the following steps:

- Creating the desired design using solid work packages.
- Data processing and tool path generation from the surface data.
- Transfer the post processing program to the CNC milling machine to apply forming process.
- Investigation the final forming product using SPIF.
- Pre-forming the product using the stretching process at forming depth of 10, 20, 30, and 40 mm.
- Repeated the SPIF after applying the primary forming process to the desired design.

The experimental setup of the machine is shown in Figure 3, the primary forming using a stretching forming process that used in this work with different depth (10, 20, 30, and 40 mm) that illustrated in Figure 3a. However, Figure 3b presents the following single point incremental forming process. The main operational components are forming tool with tool holder, the SPIF-fixture and blank sheet. All samples are processed with constant parameter with different forming initial depth. The microstructure of the samples is examined using optical microscope model (MT9430) after sample preparation for microstructure investigation (200, 400,600,800,1000 and 1220)

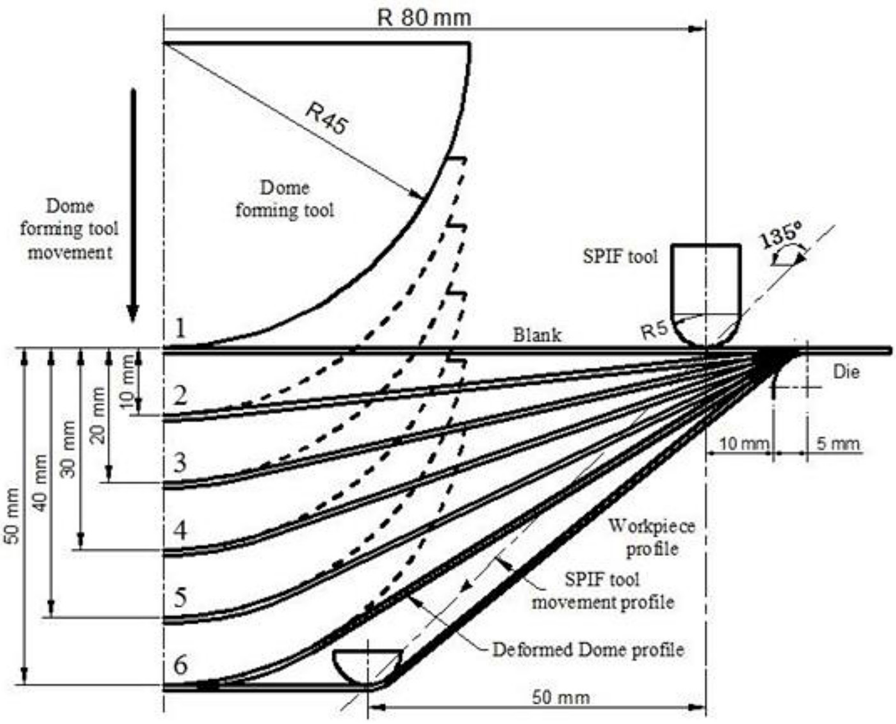

Fig. 2. Pre-forming stapes in SPIF process

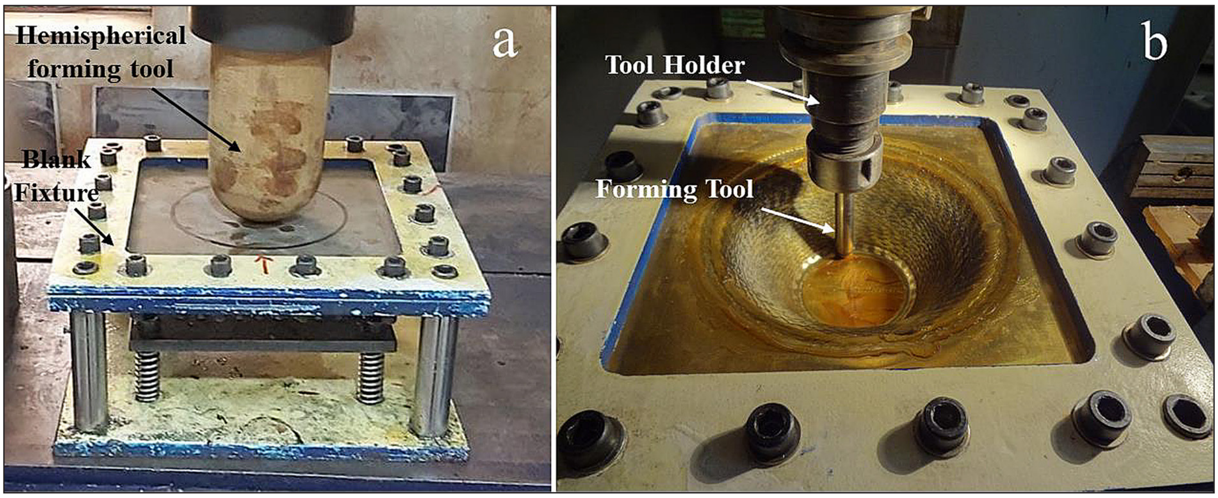

Fig. 3. Experimental setting of (a) Stretching forming process setup, (b) SPIF product after applied stretching forming process

sand paper followed by polished with cloth and alumina, the samples was washed after each step. A (2% Nitric acid with 98% distilled water) was used as an etching solution [12]. The values of sheet thickness were obtained using a micrometer test device with an accuracy of 0.001 mm, the samples were sectioned in cross section using saw machine (Figure 4) and the thickness measured each 5 mm along the section.

RESULTS AND DISCUSSIONS

A cross section of the sample produced using a stretching forming process up to 40 mm depth followed by SPIF product is presented in figure 4, it is clear that there are no defects found in all samples produced using a primary forming process. Figure 5 presents the microstructure as received brass with the microstructure of the SPIF processed sample and stretching parts with different forming depth of 10 mm, 20 mm, 30 mm and 40 mm followed by SPIF processes. The microstructures of the initial brass sheet (Figure 5a) consist of equiaxed grain with different grain size in the range of 20–42 µm. Using SPIF process led to increase grain size of the as received sheet (to reach 52 µm) with the presence of twining effects [6]. Appling the primary stretching forming process led to decrease the grain size with an increase the primary forming depth (Figure 5c-e) to reach 36 µm at 40 mm primary forming depth (Figure 5f), a twining effect is also present in the microstructure of the pre formed samples.

The second important parameters are the dimension accuracy [13, 14] with the desired forming geometry (CAD model) that illustrated

Fig. 4. Cross section sample of the formed part

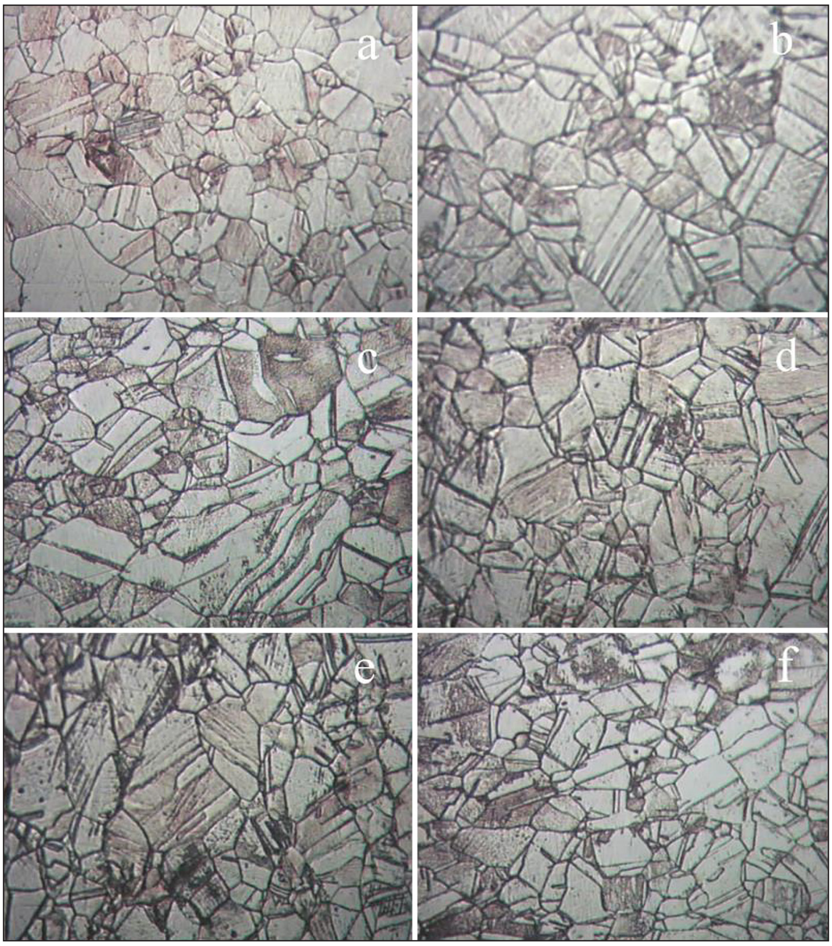

Fig. 5. Microstructure of (a) as received Brass, (b) SPIF process, (c) stretching depth 10 mm+SPIF, (d) stretching depth 20 mm+SPIF, (e) stretching depth 30 mm+SPIF, (f) stretching depth 40 mm+SPIF

Table 2. The of dimension accuracy of the processed samples

Forming radius (mm)	Forming depth (mm)					
	Design	SPIF	Stretching forming 10 mm	Stretching forming 20 mm	Stretching forming 30 mm	Stretching forming 40 mm
0	0	0	0	0	0	0
5	0	0	0	0	0	0
10	0	1.06	1.1	1.28	2.02	1.3
15	0	3.07	3.05	3.05	2.61	3.07
20	2.979598	6.6	6.3	6.12	5.88	6.13
25	8.938794	12.01	11.8	11.39	11.75	10.4
30	14.89799	17.92	17.8	17.6	17.47	16.14
35	20.85719	23.92	23.8	23.2	22.7	22.07
40	26.81638	29.86	29.2	28.8	28.1	27.96
45	32.77558	35.96	34.9	34.3	34	33.85
50	38.73477	40.62	40.5	39.63	40.24	39.64
55	41.5	41.67	41.67	41.78	41.88	41.93
60	42.61	41.81	42.65	42.85	42.825	42.86
65	42.95	42.11	42.47	42.64	42.78	42.90
70	43	42.19	42.61	42.82	42.96	42.94
75	43	42.27	42.87	42.90	42.94	43.05
80	43	42.3	42.77	42.95	42.97	43.04

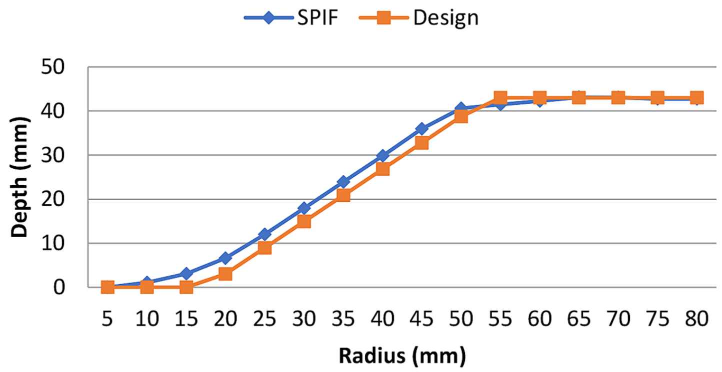

Fig. 6. Comparison between forming part in SPIF and CAD model

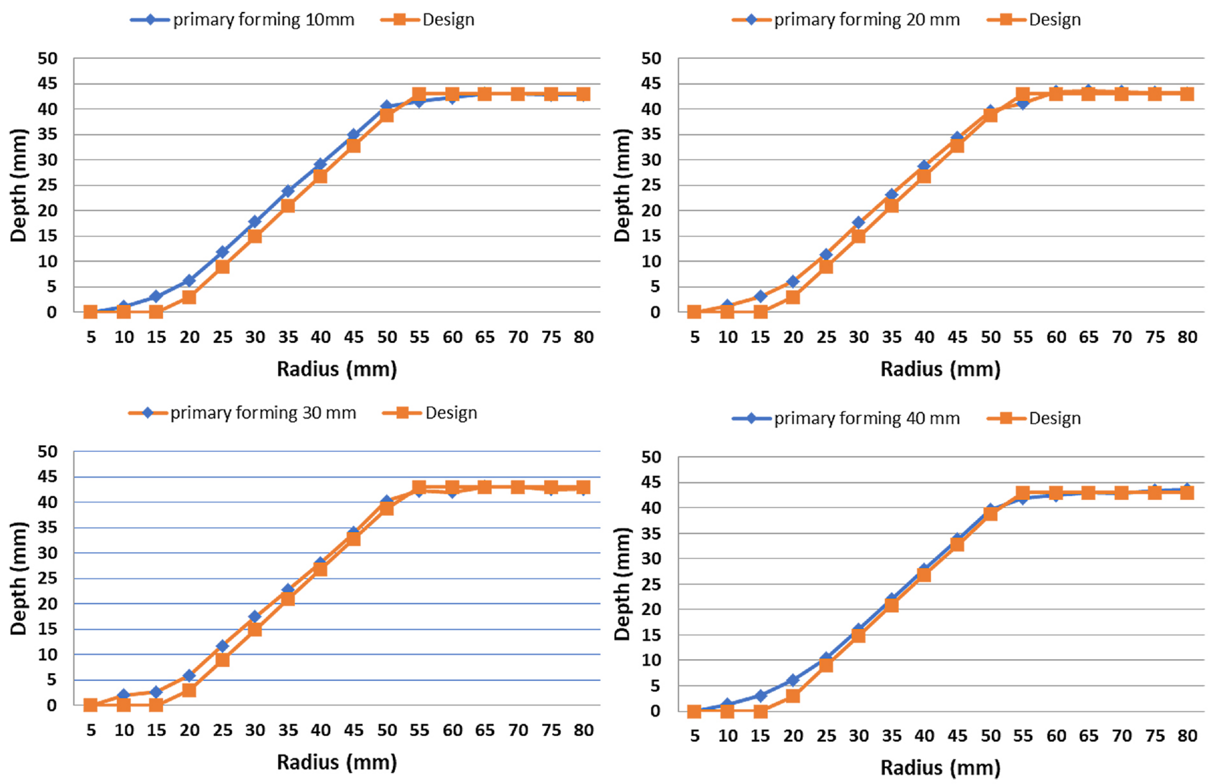

Fig. 7. Forming part using primary forming and CAD model

in Table 2. Figure 6 presents the comparisons between CAD model and the forming parts using single point incremental forming process, it can be seen that the deviation between CAD model and the SPIF about 11.6%. Figure 7 shows the comparison between primary stretching parts with SPIF and CAD model at forming depth 10, 20, 30, and 40 mm, it is clear that increase the Stretching depth from 10 to 40 mm before SPIF led to a reduction in the deviation between CAD designed model and the formed (Stretched + SPIF) (Figure 7). In other word, the improvement of the forming geometry of the final product has been taken when using a primary forming product with high forming depth with respect to low forming depth and SPIF process, the minimum deviation was found in primary forming depth about 6%, while the maximum deviation was found when using SPIF process about 11.6%. Again, figure 8 presents the deviation between formed part using primary forming depth (10, 20, 30, and 40 mm) followed by SPIF process with respect to CAD designed model, the positive deviation between forming part and CAD model was presented near to the fixed point of the fixture this is probably due to high tension load in this location. However, the negative deviation was presented near to the bottom

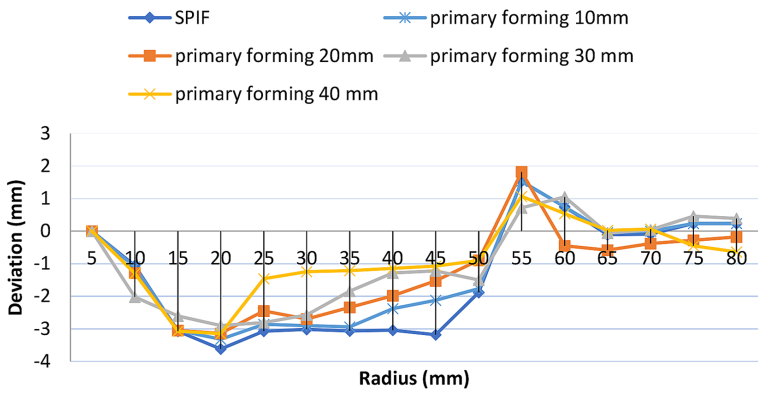

Fig. 8. Deviation between forming part in (SPIF, primary forming) and (CAD) model

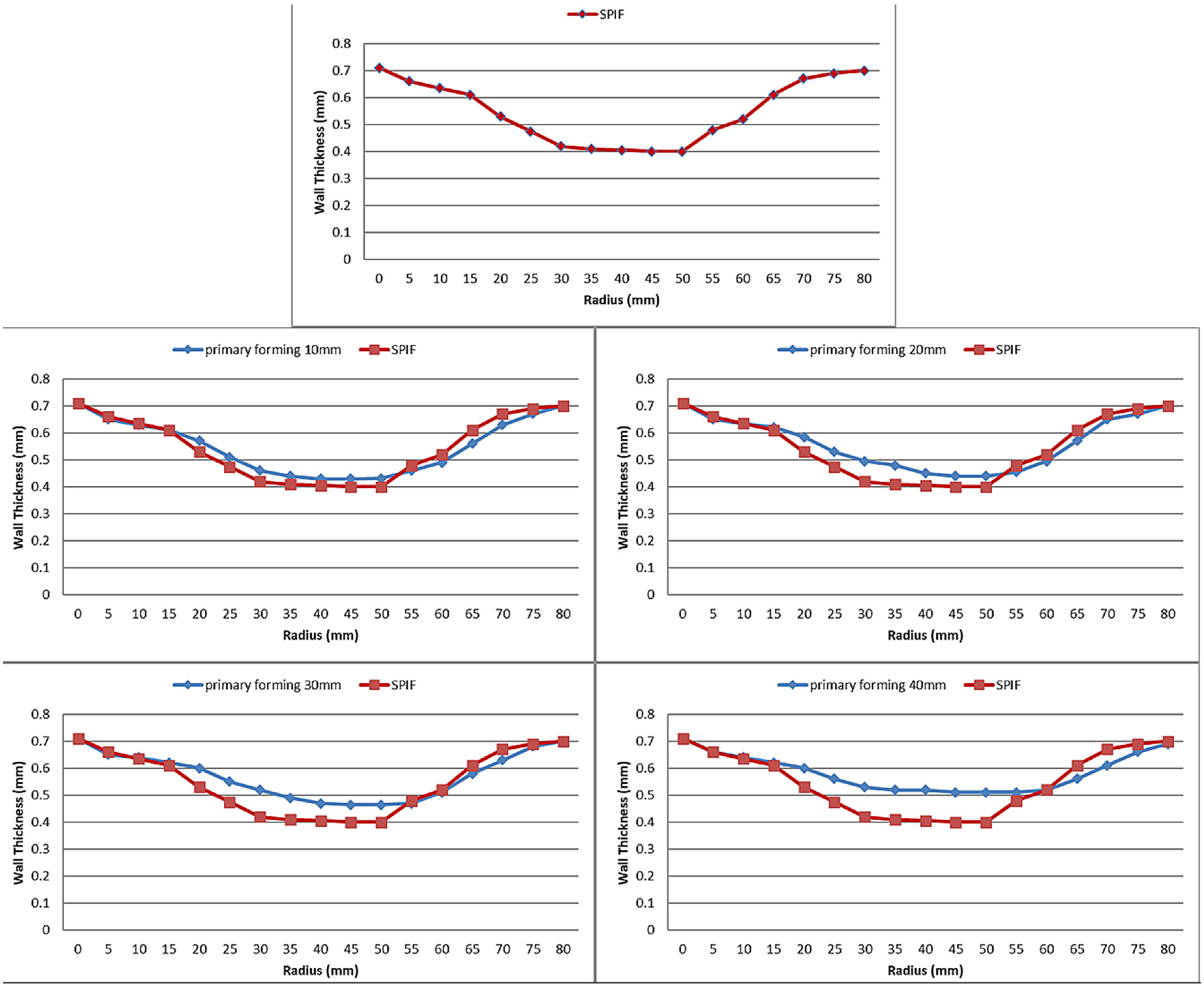

Fig. 9. Thickness distribution of forming part using primary forming at 10, 20, 30 and 40 mm depth and SPIF

of the formed part due to free forming in this location (the effect of spring back).

The reduction in sheet thickness is considered as a critical parameter of the incremental forming techniques [15], especially in SPIF process, which it related directly to the value of formability and failure mode with potentially accrued. Figure 9 present the thickness distribution for both SPIF processed part and Stretching primary forming at 10, 20, 30, and 40 mm forming depth with SPIF process, the minimum thickness was obtained is 0.40 mm in the case of using pure SPIF, however, the plate thickness is reached 0.43, 0.44, 0.46, and 0.51 mm for applying initial forming depth of 10, 20, 30, and 40 mm, respectively. The large reduction in thickness along the wall of SPIF is probably due to the increase in plastic deformation that occurred in the sheet at small forming zone during using the SPIF method [16], the high reduction in wall thickness is not desirables in the engineering application [17]. In the other word, the primary stretching forming process has a significant effect on the distribution of thickness in the SPIF process compared to the effects of other parameters including step size, tool diameter, and feed rate [18]. The final product performed using primary stretching at 10, 20, 30, and 40 mm forming depth with SPIF process led to improve the thickness distribution of about 6.9%, 9.1%, 14.9%, and 21.5%, respectively, with respect to the use of Single Point Incremental forming process.

CONCLUSIONS

The primary forming process is one of the best methods that used before single point incremental forming process to improve the performance of forming product. When using the primary forming process, the microstructure of the product shows the uniform of grain distribution with respect to the parts formed using SPIF process. The effect of the primary forming process with respect to increases forming depth that caused a minimum geometric deviation. Some time when using high stretching forming depth, the product will be failure due to high forming load that applied on forming sheet (at contact area between punch and plate) and wrinkling defect was found in the edge of the final product. The maximum deviation was found when using SPIF process about 11.6% while the maximum deviation was found when using the stretching forming process on depth 40 mm about 6%. The improvement in thickness distribution was obtained when using the primary forming process at 10, 20, 30, and 40 mm forming depth with SPIF process of about 6.9%, 9.1%, 14.9%, and 21.5%, respectively. While, the thinning that happened when using pure Single Point Incremental forming process reach to 44.5%.

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