INVESTIGATION OF SHEET THICKNESS DISTRIBUTION AND WELD-LINE SHIFT DURING SPIF OF TWBs

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Abstract - Incremental Sheet Forming is an advanced sheet metal forming process. The process is gaining a lot of attention due to its lower setup cost and the significant increase in Formability. However, the recent developments in the automobile and aviation industries require materials with a high strength-to-weight ratio. These requirements are addressed by joining sheets of several grades, various thicknesses, and different coatings through the welding process called Tailor Welded Blanks (TWBs). In this work, the Formability of tailor welded AA 6061-T6 blanks joined by Friction Stir Welding (FSW) is examined numerically and experimentally using the single point incremental forming (SPIF). FSW blanks are manufactured using different welding tools from AA6061-T6 sheets having different thicknesses. Then blanks are formed by SPIF using different tool paths and process parameters. The profile of the formed component and weld line shift is studied experimentally on the samples. Additionally, the samples' thickness variation is investigated to determine the influence of the FSW process on the thickness distribution.

The SPIF of Friction Stir Welded blank is simulated numerically using the ABAQUS/Explicit simulation tool. Responses like thickness variation, the geometry of the formed part, and weld line shift are extracted during post-processing. Numerical results were compared with experimental results for the best welding tool and forming tool path combination.

Keywords - Tailor Welded Blanks, Single Point Incremental Forming, Friction Stir Welding, Different thickness, Formability

I. INTRODUCTION

The incremental sheet forming (ISF) was created due to a partial hybridization of stretch forming and metal spinning techniques combining the benefits of both processes. The process is capable of manufacturing 3D complex forms with various characteristics. Stamping, stretch forming, and other classical sheet metal forming methods necessitate specialized tooling specific to the sheet metal component being formed and are thus only suitable for mass production. For single-piece or small-batch manufacturing, these procedures are prohibitively expensive to adopt. The ISF approach, which may be used for single or batch manufacturing, solves this issue.
The incremental Sheet Forming (ISF) process is from a group of processes where localized deformation is produced onto the blank. These deformations are applied step by step with the help of a tool that follows a particular predefined tool path. To form the sheet metal blanks, different types of tools can be used, viz. spherical, hemispherical, elliptical end type, rolling ball type,and flat end type. These tools are attached to a CNC milling machine, robotic manipulator, or special purpose ISF machine. These machines are fed with tool paths in the form of G - codes & M – codes.

Design et al.[1] observed that increasing the sheet thickness increases the Formability as there is more material to flow. Similarly, decreasing the step depth decreases the stresses and thus reducesFormability.Al-Obaidi et al.[2] found the maximum values of stresses in the vertical direction, and it was a compressive stress type. The value was raised by increasing the formed part depth. The thinning of the formed wall angle occurred during the experiment and simulation due to the shear stress.

FSW is a solid-state welding process. Two similar or dissimilar sheets are set up as the butt joint with the help of a fixture—the contact between the tool and sheet that create friction results in heat generation and plastic deformation. FSW can join two dissimilar metals of different thicknesses and hence used to make Tailor Welded Blanks (TWBs). Tailored Blanks are semi-finished products typically made from sheets with different sheets, coatings, materials, or thicknesses. When welding processes join them, generally, they are called Tailor Welded Blanks.

Zhang et al. (xii) observed that the shoulder-less tool offers better mechanical features at high feed and speed for ultra-thin sheets. Liavoli et al.[3] observed that as compared to base metals, TWBs have a significantly lower forming limit angle. In TWBs of varying thicknesses, the corners and walls of the weaker sheet experience the highest and lowest principal stresses. As a result, TWBs in these zones rupture more frequently than in the rest of the TWBs areas. The maximum thinning observed was at 45 ° from the rolling direction.Shalin et al.[4]concluded that the weld line shift during SPIF for TWBs increases as the yield strength ratio increases because a higher yield strength ratio indicates more

inhomogeneity in the TWB material; for theLimiting Dome Height (LDH), the weld line shift is solely towards strong material, whereas for SPIF, it is sinusoidal. Furthermore, compared to the LDH method, the magnitude of weld line shift for SPIF is lower.

In another piece of literature[5], it was found that the tool starting position significantly affect the geometrical accuracy for formed TWB. It was concluded that deformation starting through the strong and weak material centres offers higher geometrical accuracy than starting from the weld line. Ghadmode et al.[6] studied the critical values of spindle speed for forming TWBs using the SPIF process. If the speed is too high, it will generate more heat, and the material will stick to the backing plate creating the surface defect and geometrical inaccuracies. Silva et al.[7] developed an industrial-grade component made out of FSWed TWB through SPIF with the help of a dummy sheet. The dummy sheet does not significantly affect TWBs' formability while protecting the FSW joint.

Its material qualities distinguish SPIF. The tool's beginning location also influences TWB weld line shift. In the case of TWB, the weld line change in stamping is invariably towards the stronger material. With SPIF, this is not the case. Due to the tool dragging impact, weld line shift in SPIF is also influenced by initial position tool movement.Low yield strength and hardening coefficient are useful because they reduce process forces and spring back. However, they also cause excessive, unwanted plastic deformation in zones next to processed areas, which hurts the accuracy of single-point incremental forming.

The weld line shift during SPIF for TWBs increases as the yield strength ratio increases because a higher yield strength ratio indicates more inhomogeneity in the TWB material.The thinning seen in TWBs during the SPIF process is more pronounced in the formed cup's wall section, which is subjected to more bending and stretching.Because SPIF includes localized and gradual deformation of the blank, the force required to create a component is smaller than in the LDH test.

The automobile industry's aggressive and dynamic nature requires constant improvement of products and processes. Because of customer demands and environmental and performance reasons, there is a significant focus on reducing automobile weight. Furthermore, production costs are usually a significant concern while producing mass-produced manufactured goods. Therefore, automakers must find innovative methods to minimize manufacturing costs, increase product quality, and create lightweight vehicles. Tailor Welded Blank is one of the design and production concepts that may help you accomplish these aims (TWB). The present study aims to investigate the sheet thickness distribution and weld line shift of the TWBs formed using the SPIF process.

II. METHODOLOGY

Simulation and experimental approaches were used to investigate the objectives of the SPIF process for the TWBs. The tool path is generated from UG-NX modelling, which is required for both, i.e., simulation study and experimental work. A simulation study has been adopted to simulate the SPIF process and forming of TWBs using the ABAQUS/Explicit simulation tool. In a simulation study, two different thickness of the material is used to analyseits effects on thickness variation, the profile of the formed part, and weld line shift. The experimental investigation involves the FSW process and SPIF process. At the initial stage of the experimental study, welded blanks are developed using the FSW process of the same thickness and forming of homogenous blanks using the SPIF process. In the final stage of experimental work, TWBs are investigated for different thicknesses and different tool initial positions during the SPIF process.

For the simulation purpose,ABAQUS/Explicit was utilized. First, a 3D deformable sheet of 100 mm × 100 mm was modelled and given material properties, as shown in Table 1. Two different sheet thicknesses were considered to form a TWB. An analytically rigid hemispherical end tool and backing plate were modelled to deform the material. It was assumed that the mechanical properties of the weld metal would be in the middle of those of the base materials.Surface-to-surface contact between the backing plate and deformable sheet was given with the friction value of 0.1[8]. All four edges of the sheet were fixed. Two types of tool paths, spiral and constant step-depth, were given. To validate the results of the simulations, it was compared with the published literature with a matching trend[9].

Material	Young's modulus (GPa)	Poisson's ratio	Density (tonnc/mm^3)	Thermal conductivity (W/m*k)	Co-efficient of expansion(^{0}f^{-1})	Hardness (HRC)
AA6061-T6	70	0.33	2.7E-09	167	2.36E-05	58-64

Table 1: Material properties of AA6061 - T6

Pilot experiments were performed to check the feasibility of the SPIF on TWBs produced by FSW. These experiments were performed with sheets of equal thickness (1 mm – 1mm & 1.6 mm – 1.6 mm). FSW was performed at different parameters; however, successful joints were developed at the process parameters shown in table 2.

After successfully fabricating TWB through pilot experiments, TWBs using two different sheet thicknesses, i.e., 1.6 mm and 1 mm using the same FSW process parameters were fabricated. To check the strength of TWB produced using pin-less (Experiment A) and pinned tool (Experiment B), stress-strain graphs were plotted using UTS. The graphs are shown in Figure 1.

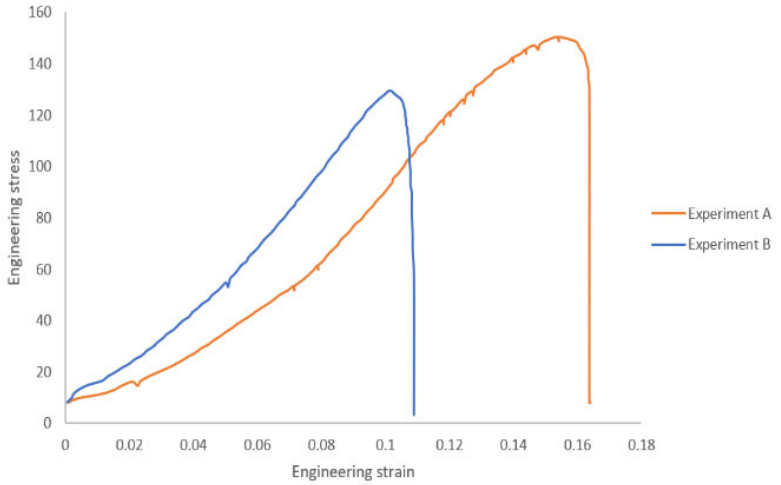

Fig.1. Stress-strain graphs for Experiments A & B

Parameter	Pilot Ex.-1	Pilot Ex.-2	Pilot Ex.-3	Pilot Ex.-4
Sheet thickness (mm)	1mm + 1mm		1.6mm + 1.6mm	
Rotational speed (rpm)	1000	1000	1400	1000
Transverse speed (mm/min)	28	40	28	28
Plunge depth (mm)	0.2	0.1	0.3	0.4
Tilt angle (°)	0	0	0	0
Tool type	Pin-less	Pin-less	With pin	With pin

Table 2: Process parameters for FSW for pilot experiments

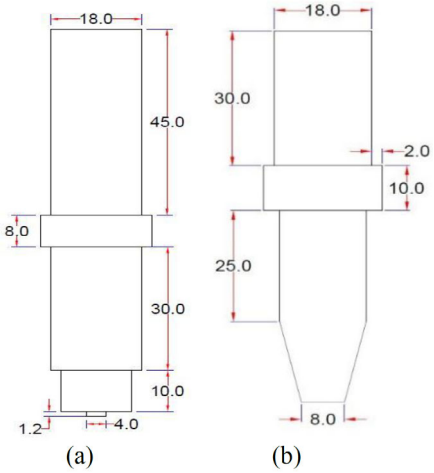

Fig.2. (a) Pinned FSW tool (b) Pinn-less FSW

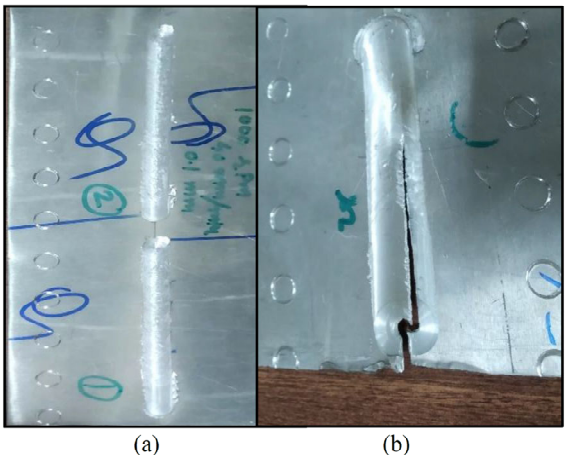

Fig.3. (a) Succesful FSW (b) Failed FSW to produce TWBs

FSW process was performed using two types of tools, pinned and pin-less tools, as shown in Figure 2. However, FSW performed at a higher spindle speed, and the feed rate generates excessive vertical force and heat in the parent materials. This leads to adhesion of the sheet to the fixture, later propagating into weld fracture, as shown in Figure 3b.

III. RESULTS AND DISCUSSIONS

3.1. Sheet thickness distribution

For thickness measurement element path was created perpendicular to the weld line and from thick sheet to thin sheet with the interval of 1mm; the minimum observed sheet thickness was 0.6022 mm, as shown in Figure 4. The experimental results are measured using a needle-type micro meter gauge in the transverse direction to the welding line. The sample's final thickness in the flange zone and the bottom zone is the same as the main thickness in the ISF Process.

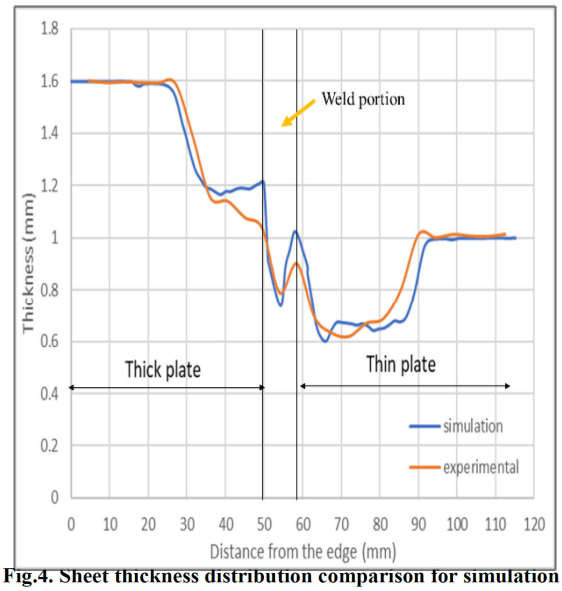

Fig.4. Sheet thickness distribution comparison for simulation and experimental results

The thickness distribution is the minimum between the weld zone and the Base Metal (BM) region, as indicated in figure 4, and the resultswere similar to[10]. The change in material characteristics at the junction of the two regions is responsible for the decrement in thickness in the specified area—the thicknessvariation in the experiment and the simulation resultsmatched by 94%.

The percentage thinning of welded blanks is shown in Figure 5. The values of strain index were determined from the true stress-strain curve for both 1.6 mm and 1.0 mm blank, which were 0.195 and 0.254, respectively. Limiting %thinning was calculated using this traditional equation and compared with experimental thinning. More %thinning was achieved by experiment without failure. The contact area between the blank and the forming tool is very small in the SPIFprocess, resulting in localized deformation of the blank.

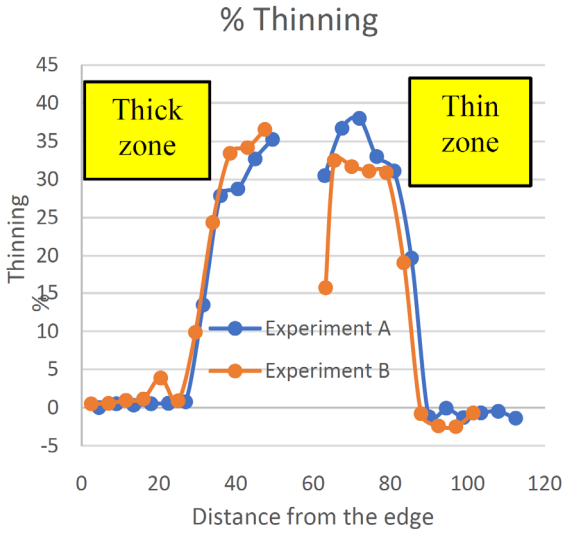

Fig.5. Percentage thinning for experiments A & B

Further, the deformations presented on the blanks are of a minor magnitude.Blanks are stretched against tensile strength and bend owing to the downward movement of the forming tool during progressive deformation. As a result, the blank's capacity to stretch during the process increases, improving the blank's Formability.

3.2. Weld line shift

The tool dragging effect is assisted by weak material deformation, resulting in more weld line movement. Figure 6 shows the difference in weld line shift for Experiment A (Constant step-depth toolpath)& B (Spiral tool path).In the second half of Figure 7, the tool moves from a strong material to a weak material. This makes the tool drag from the strong material to the weak material. On the other hand, a weak material deforms from weak to strong. Because of this, the effect of the tool dragging and the deformation of weak material work against each other in the opening half. As shown in Figures 7 and 8, this makes the weld line move less.

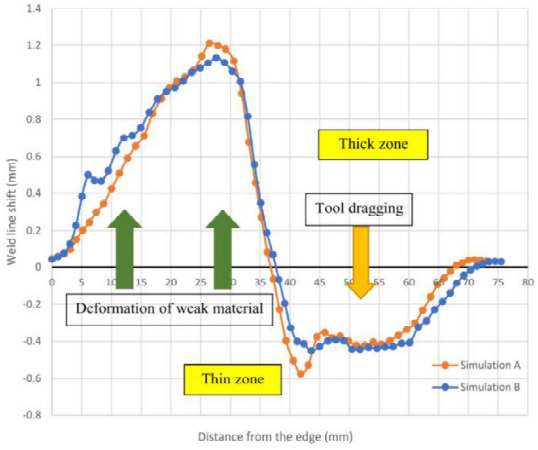

Fig.7. Comparison of Weld line shift in the SPIF formed component from a TWB

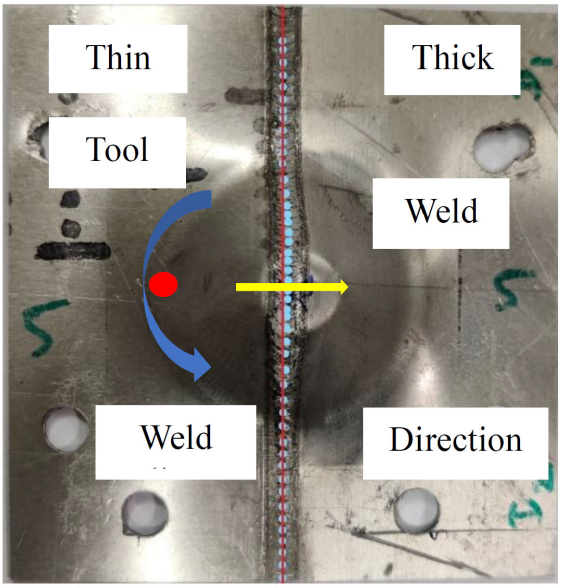

Fig.8.Weld line shift in the formed component

The tool dragging effect and the deformation of weak material are the two factors responsible for weld line displacement.The tool and the blank create friction contact, and as the tool crosses the weld line, it attempts to pull the weld line with it in the direction of movement. The blank is deformed as a result of the tool's downward movement. This deformation occurs more in weak materials than in strong materials. Tool dragging will cause the weld line to shift towards the strong material as the tool passes from weak to strong. The weld line moves toward the stronger material as a result of this.

IV. CONCUSSION

Following conclusions were made from the results and comparisons of the simulation and experimental outcomes:

- The Formability of TWB depends on the strength of the joint. From the present study, it can be concluded that a pin less tool is better for thin sheet welding thana pin tool because it gives high tensile strength (Figure 1) and is not dedicated to a specific sheet thickness.
- As the yield strength of the weld zone increases, the thin base metal of TWBs becomes weaker, resulting in more thinning of thin material and hence more shift in weld boundary between thin and weld zone. Higher the strength of weld zone, the lesser will be the deformation of weld zone(Figure 4).
- Due of the seamless transition between succeeding layers, the spiral tool path produces homogenous thinning (Figure 5) and eliminates the surface scarring found in step depth toolpaths. The spiral tool path is a superior option for ISF procedures. It may not be simple to utilize for complicated geometry.

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