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Research Paper

Research on the effect of ultrasonic vibration on the single-point incremental sheet forming process

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ABSTRACT: *In this paper, the influence of ultrasonic vibration on the axial force F_z in the forming process of Al5052 aluminum alloy sheet by incremental sheet forming (ultrasonic-assisted incremental sheet forming-UISF) is studied. The original billets are aluminum alloy sheets with thickness of 0.5mm and 1.0mm, which are cut into squares of 250 x 250 (in mm). The input parameters of the UISF process are set up including: tool diameter d = 12mm, vertical step Δz = 0.5mm, feed-rate V = 2250 mm/min, tool rotation speed n = 0 rpm, the forming angles are selected in the range of 45-70°, the forming depth is selected to be 20-30-40 mm, the vibration frequency is 27.4 kHz. The results show that, as the forming angle increases, the axial force component F_z is larger. During forming process, when the ultrasonic vibration turn on, the axial force component F_z is significantly reduced (approximately 20%) compared to the absence of ultrasonic vibration. When the forming depth reaches about 20mm, the forming force component F_z hardly increases, it tends to be constant, that is, regardless of the forming depth. In addition, the experimental results also show that the increased wall angle reduces the possibility of plastic deformation, that is, the sheet blank is torn when reaching a very small forming depth. And the transition zone between the flange part and the forming part is bent, causing distortion of the shape, the size of this area depends on the forming profile and the thickness of the product.*

KEYWORDS: *Ultrasonic, incremental sheet forming, axial force, forming depth*

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I. INTRODUCTION

Currently, plastic deformation processing to form shell-shaped products using incremental sheet forming (ISF) processes has attracted many scientists around the world [1],[2],[3]. This processes promise many potential applications to replace deep drawing technology, such as applications in the field of manufacturing plates and shells for the automotive and aircraft industries [4],[5],[6]; or rapid prototyping applications in biomedical technology or other fields [7],[8],[9].

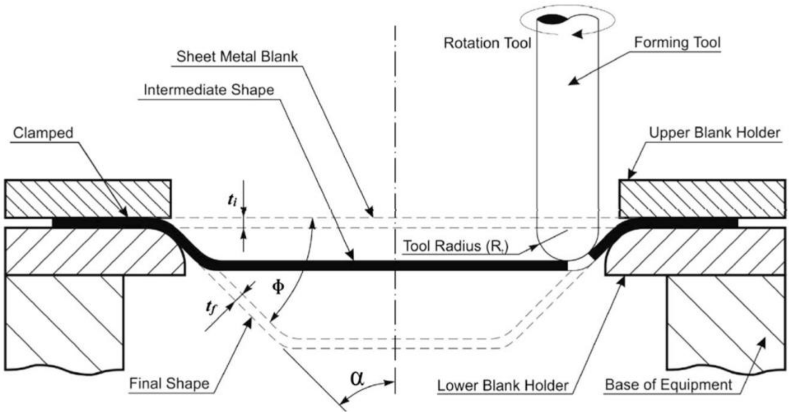

Figure 1. Schematic representation of a cross-sectional view of the rotationally symmetric ISF process [3]

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According to Yanle Li et al [1], there are four configurations of ISF processes, including: single-point incremental sheet forming (SPIF), incremental forming with counter tools, two-point incremental sheet forming (partial die; TPIF), two-point incremental sheet forming (full die; TPIF). Schematic representation of a cross-sectional view of the rotationally symmetric ISF process is shown in the Figure 1.

As shown in Figure 1, during forming process, the deformation tool contacts the workpiece at the tip (with radius *R*). After each path of the deformation tool follows the product circumference, the deformation tool performs a step Δz (mm) along vertical axis Z. This process is continuously repeated until the end of the profile to be formed. The paths of the deformation tool according to the forming profile generally use three forms, as shown in Figure 2.

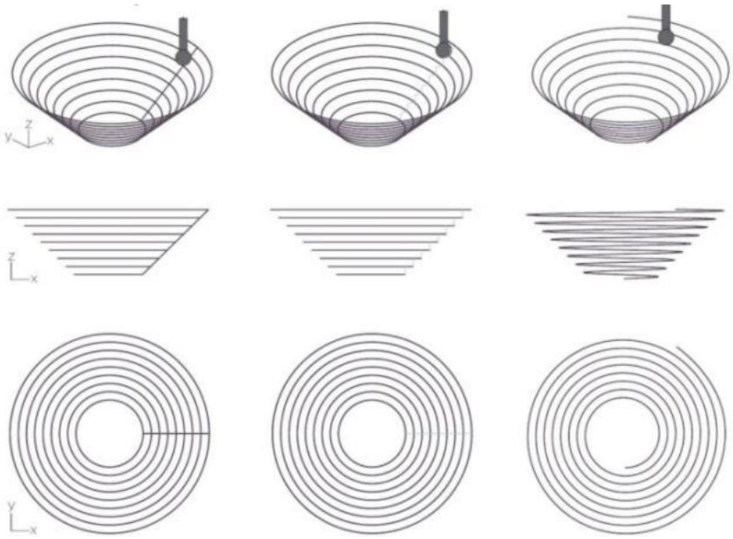


Figure 2. Tool path description [10]

The previous studies show that the product quality as well as the plastic deformation ability and forming force components depend quite a lot on the technological parameters and geometrical parameters, including: tooling diameter (*d*, mm), feed-rate (*V*, mm/min), wall angle (ϕ, degree), initial thickness of sheets (*t*, mm), vertical step (Δz, mm), rotation speed of deformation tools (*n*, rpm), depth of forming (*h*, mm), path form of deformation tools… The former of previous studies showed that, when increasing the tooling diameter *d*, the plastic deformation ability decreased, meanwhile the main forming force component F_z increased [11]. At the same time, the results also show that, when increasing the vertical step Δz, the forming force increases and the plastic deformation capacity decreases [11], and the surface quality decreases [12]. Similarly, when the wall angle and workpiece thickness increase, the main forming force component F_z tends to increase [11],[12]. However, many works show that, when the forming depth *h* reaches a certain limit, the main forming force component F_z hardly increases [11],[12],[13]. In addition, studies show that the rotational speed of the plastic deformation tool (n) and the feed rate (*V*) along the path of deformation tools do not have much influence on the main forming force component F_z, they only affect the quality of the forming surface [14]. In order to expand the applicability of ISF technology, recently, many scientists have deployed the application of ultrasonic vibration assisted the ISF processes. The results show that the forming force is significantly reduced; the plastic deformation capacity is increased [15],[16],[17]; and product surface quality improved significantly [18]. However, these studies usually only focus on forming straight grooves, the forming depth is small or in the form of numerical simulation, the number of experimental studies is not much.

This paper presents some experimental results studying the influence of ultrasonic vibration on the main forming force component F_z when forming Al5052 aluminum alloy sheet by UISF process. The experimental setup is described in detail in the next section.

II. EXPERIMENTAL SETUP

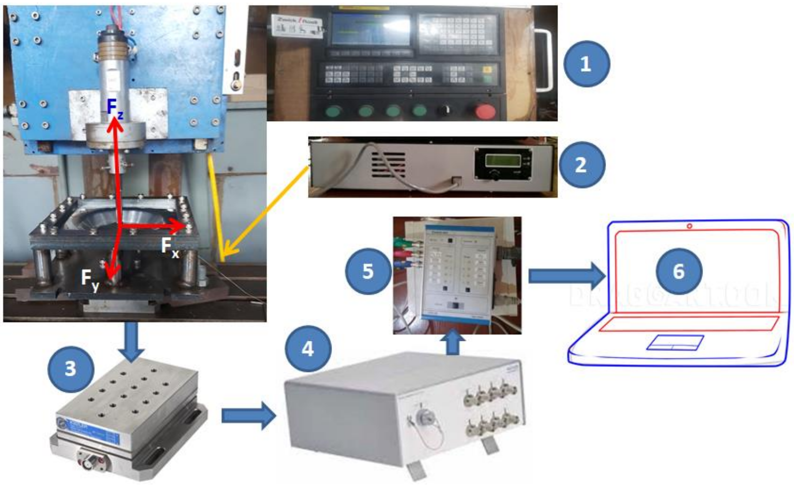
The selected sample test is Al 5052 aluminum alloy plate in annealed state, 0.5mm and 1.0mm thickness; square edge with size 250mm x 250mm. The chemical composition of Al 5052 aluminum alloy is presented in Table 1. Mechanical properties of Al 5052 aluminum alloy are introduced in Table 2. The experimental diagram is described as shown in Figure 3. The main experimental equipment used is the Shizuoka VHR AP vertical NC milling machine, Japan (1), which has been regenerated into a complete CNC machine. The X, Y, Z axes of the CNC machine are driven by 03 hybrid servo electric motors with a nominal torque of 12Nm, these electric motors are controlled by the XC809 commercial CNC controller. This CNC control software allows direct programming or can be programmed on the computer and input the CNC program into the machine by USB port. The ultrasonic power supply (2) MPI_ WG3000W (Switzerland) was chosen because it has a wide operating range in the frequency range from 19 kHz to 100 kHz. The commercial ultrasonic vibration transducer YP-5525-4Z has a standard vibration frequency of 20 kHz with a working power of 2000W. To collect the force signal, this study used a three-component Kistler 9257B dynamometer. The force signal from the dynamometer is collected by the DAQ (4), (5) and transferred to the computer (6) for storage and processing. In the data collection process, the authors used the control program NI SignalExpress 2015, in which force data is converted and collected as potential signal. The plastic deformation tool is machined at the top (the part in contact with the workpiece) in the form of a spherical tip, made from 90CrSi steel with a hardness of 61-62HRC. In this study, the plastic deformation tool did not rotate (n = 0). The machining program is programmed on the computer and imported into the CNC machine via the USB port.

Tabel 1. Chemical element composition of aluminum alloy Al 5052

Element	Mg	Cr	Si	Fe	Cu	Zn	Mn	Khác	Al
Weight (%)	2.2-2.8	0.15-0.35	≤ 0.25	≤ 0.45	≤ 0.10	≤ 0.10	≤ 0.10	≤ 0.15	Remaining

Table 2. Mechanical properties of aluminum alloy Al 5052

Properties	Unit	Value	Note
Tensile strength	MPa	228.0	
Yield strength:	MPa	193.0	
Shear strength:	MPa	138.0	
Young modulus:	GPa	70.3	
Shearing modulus:	GPa	25.9	



(1) CNC milling machine;
(2) Ultrasonic power;
(3) 3-component dynamometer
(4),(5) DAQ;
(6) Computer

Figure 3. Eperimental diagram

The path of deformation tool is spatial, as shown in Figure 4. Structure of the deformed workpiece clamp is depicted in Figure 5. The experimental parameters are shown in Table 3.

Table 3. Experimental parameters

Parameter	Notation	Unit	Values
Spindle rotation	n	rpm	0
Step distance (Vertical step)	Δz	mm/1 path	0.2; 0.5
Sheet thickness	t	mm	0.5; 1.0
Feed-rate (forming rate)	V	mm/ph	2250
Wall angle	ϕ	°	45; 50; 55; 60; 70
Depth of forming	h	mm	20; 30; 40
Tooling diameter	d	mm	12
Vibration Frequency	-	kHz	27.4

III. RESUTS AND DISCUSSION

Some typical investigation results on the influence of ultrasonic vibration on the main deformation force component F_z are presented in the Figure 6. The results show that:

(i) As the forming depth increases, the main forming force component F_z increases significantly.

However, when reaching a certain depth of forming, F_z hardly increases. These results are consistent with previously published studies [18],[19],[20],[21].

(ii) When ultrasonic vibration was turned on, the main forming force F_z is significantly reduced approximately 20%, the amount of reduction depends on the plate thickness and the main forming force F_z, i.e. on the deformation depth. This result may be due to the phenomenon of softening by the effect of ultrasonic vibration and the phenomenon of continuous impact with small amplitude reducing the hardening of the material [18],[19].

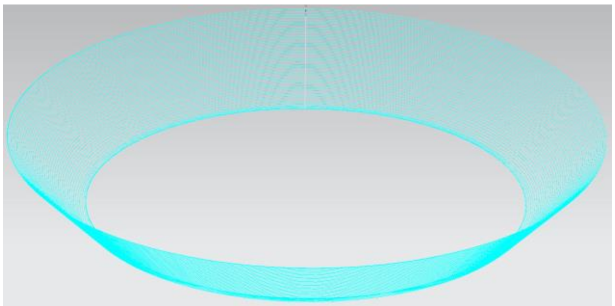


Figure 4. The deformation tool path

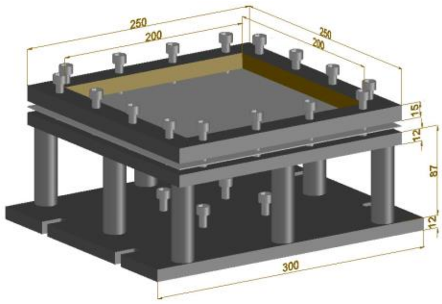
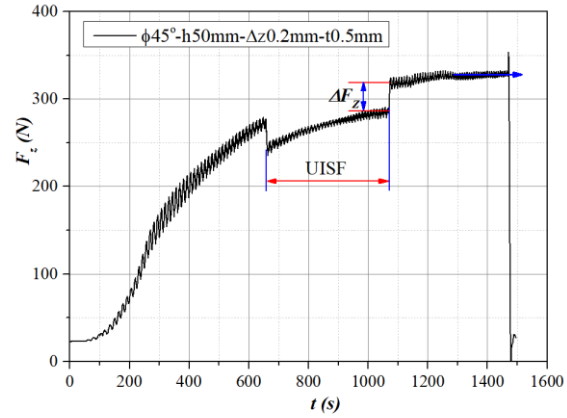


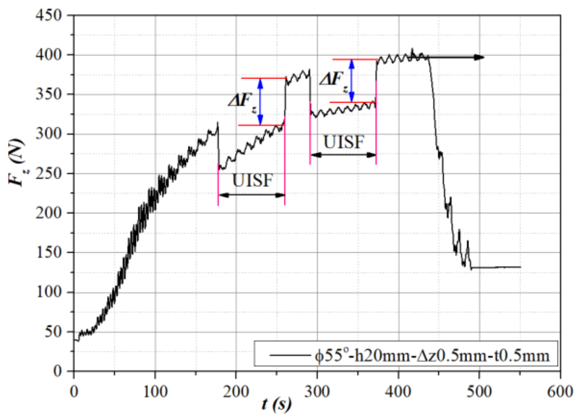
Figure 5. Workpiece clamp mold

(iii) As the wall angle increases, the main forming force also tends to increase. This result is consistent with theoretical calculations when studying ISF processes [8],[9].

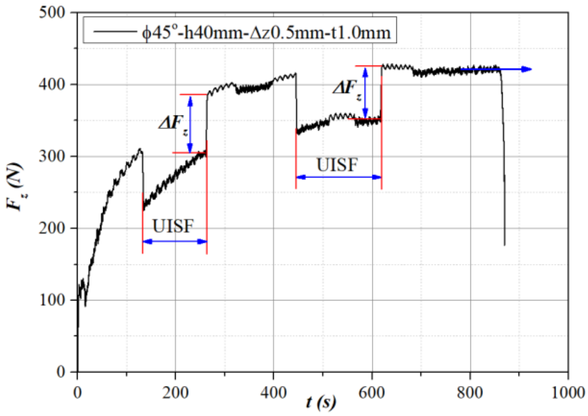
(iv) As the wall angle ϕ increases, the deformability of the material decreases. This result is reflected in the early break of the workpiece (that is, the forming depth h is reduced or the time to perform forming along the same path is short) when the wall angle reaches 60° and 70° (see Figure 7). The product is destroyed when the wall angle is increased because of the principle of this forming process, the larger the forming angle, the larger the thin layer. This means that the product is damaged faster. With smaller wall angles, from 55° and below (as depicted in Figure 8), the forming depth can reach 40mm without the workpiece being destroyed.



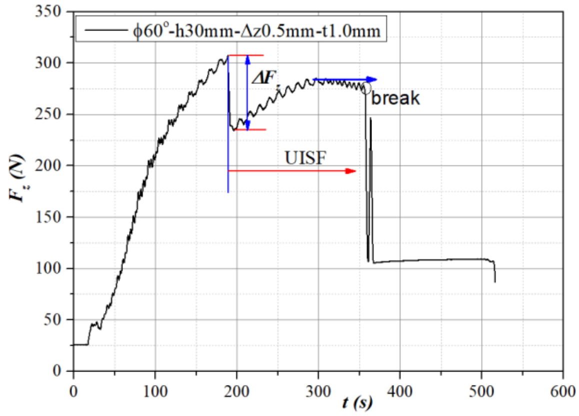
(a) ϕ = 45°; Δz = 0.2mm; t = 0.5mm; h = 50mm



(b) ϕ = 55°; Δz = 0.5mm; t = 0.5mm; h = 20mm



(c) ϕ = 45°; Δz = 0.5mm; t = 1.0mm; h = 40mm

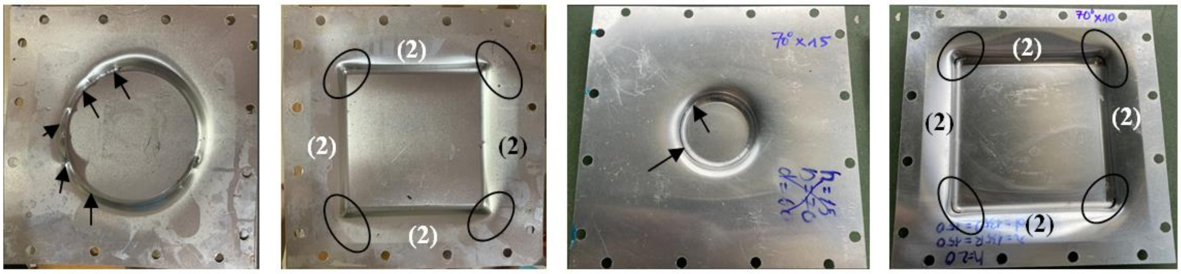


(d) ϕ = 60°; Δz = 0.5mm; t = 1.0mm; h = 30mm

Figure 6. Effect of ultrasonic vibration on vertical force F_z in different conditions

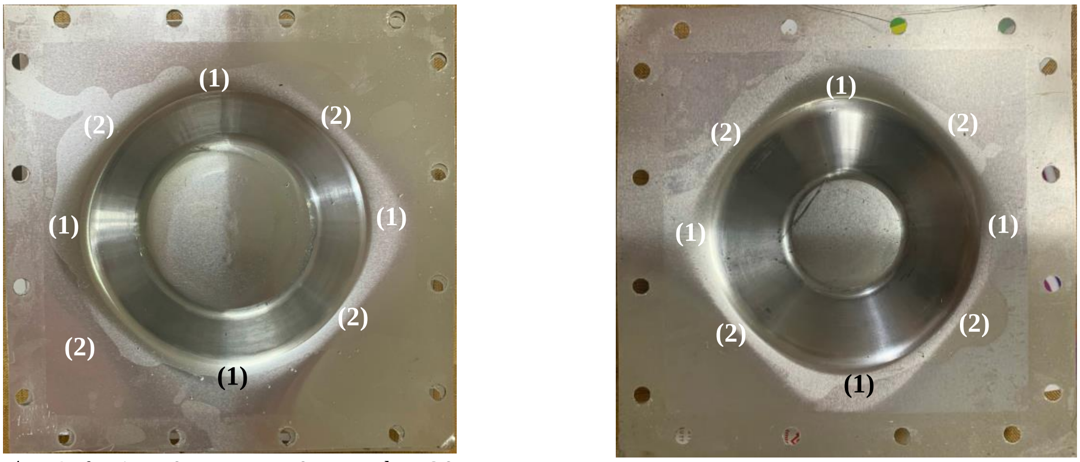
In Figure 7 and Figure 8, it can be seen that the transition between the flange and the plastically deformed area tends to be bent. Obviously, the both path of tool and plate thickness have a great influence on the size of this bent area, zone (2) on figures. When shaping truncated cone products, the size of this area is quite small (see Figure 7 a, c and Figure 8). However, when the profile creates a truncated pyramid shape, the size of this area is quite large; even the larger the thickness of the workpiece, the larger the size of the bending zone (as shown in Figure 7 b, c).

The results of plastic deformation in Figure 8 show an interesting thing, that is, when the profile creates a truncated cone shape with axial symmetry, the size of the bending area is larger when the thickness of the workpiece is smaller. The strongest bending area is on the X and Y axes. These results need to be further studied to find out more clearly.

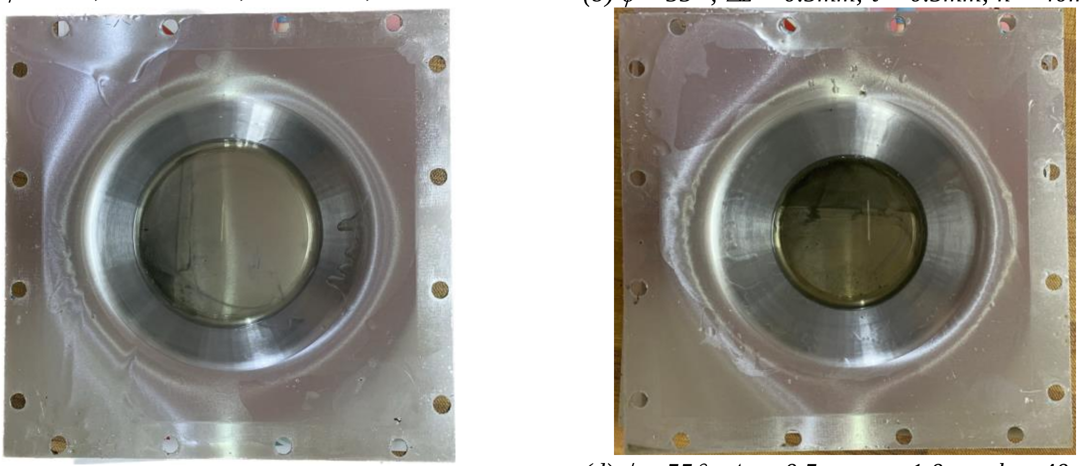


(a) ϕ = 65°; t = 0.5mm *(b) ϕ = 65°; t = 1.0mm* *(c) ϕ = 70°; t = 0.5mm* *(d) ϕ = 70°; t = 1.0mm*

Figure 7. Failure products



(a) ϕ = 45°; Δz = 0.5mm; t = 0.5mm; h = 30mm *(b) ϕ = 55°; Δz = 0.5mm; t = 0.5mm; h = 40mm*



(c) ϕ = 45°; Δz = 0.5mm; t = 1.0mm; h = 30mm *(d) ϕ = 55°; Δz = 0.5mm; t = 1.0mm; h = 40mm*

Figure 8. Forming product without crack

IV. CONCLUSION

Influence of ultrasonic vibration on the axial force F_z in UISF process of Al5052 aluminum alloy sheet is studied. The results show that as the forming depth increases, the forming force F_z increases significantly; however, when forming depth reaches a certain depth of forming, F_z hardly increases. In UISF process, the main forming force F_z is significantly reduced approximately 20% compared with ISF process, depending on on the plate thickness and the deformation depth. The main forming force also tends to increase when increasing wall angle. In addition, the experimental results also show that the increased wall angle reduces the possibility of plastic deformation, that is, the sheet blank is torn when reaching a very small forming depth. The transition zone between the flange part and the forming part is bent; causing distortion of the shape, the size of this area depends on the forming profile and the thickness of the product.

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