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Applying Ultrasonic-Assisted Incremental Sheet Forming to Al 5052 Aluminum Alloy †

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Abstract: In this paper, the influence of ultrasonic vibration on the forming forces and surface quality of products formed using an ultrasonic-assisted incremental sheet forming (UISF) method was investigated and compared with an incremental sheet forming (ISF) method. The elements and parameters used for research include a sheet of Al 5052 aluminum alloy with thickness of 1.0 mm, a lathe with a feed rate of 70–130–225 rpm, and step size of 1.0–1.5–2.0 mm. The results show that ultrasonic vibration significantly reduces the forming forces, of which the main forming force F_{zmax} is reduced by about 20%. Besides, the results also show that the surface quality of products formed via UISF is significantly improved compared to that formed by ISF.

Keywords: incremental forming; ultrasonic-assisted; force; forming

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1. Introduction

Known as a die-less method of manufacturing shell products, incremental sheet forming (ISF) has attracted global attention in the field of sheet forming processes due to its flexibility and elimination of costly dies [1,2]. In the forming process using ISF, as shown in Figure 1 [1], the forming tool only contacts the sheet workpiece in a very small area, so the forming force is much smaller than that of deep drawing. The potential applications of ISF are various: forming panels for cars, airplanes or home appliances [1,3]; rapid prototyping [1,3]; and applications in the biomedical field [1,4]. ISF is especially suitable for products with complex profiles and a small batch production size [1,2]. However, the ISF method is characterized by (1) low surface quality [3,5] and (2) low accuracy [1,3].

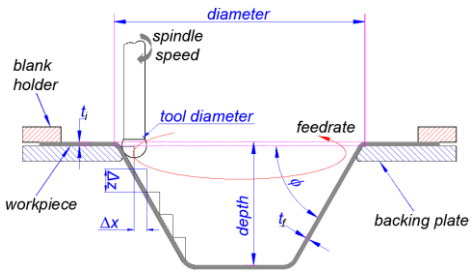
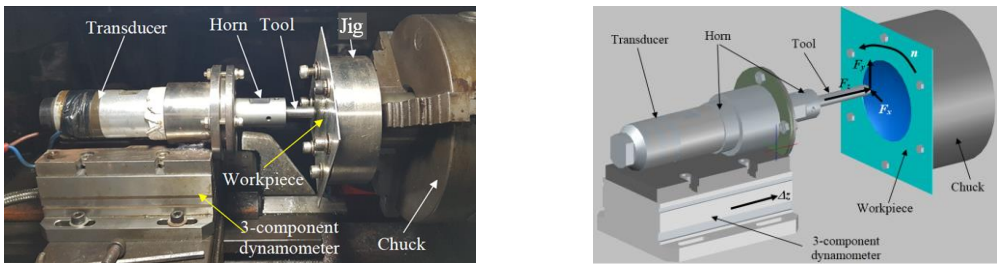


Figure 1. Basic principles of incremental sheet forming [1].

In order to improve forming accuracy while reducing the force component F_z, several research groups have recently implemented the application of ultrasonic-assisted ISF (called UISF or UVISF). When forming using the UISF method, the main force F_z decreases, and the shape accuracy of the product increases [6–8]. However, evaluations of surface quality have not been taken into account. This study aims to investigate the effect of ultrasonic vibration on the forming force and product surface quality formed using the UISF method.

2. Materials and Method

The experimental setup is depicted in Figure 2. The initial sheet is fixed on a jig which is clamped on the lathe chuck. The forming tool, made of hardened 90CrSi steel, and with a diameter of 12 mm and hardness of 61 HRC, is fixed on an ultrasonic transducer YP-5525-4Z. The force sensor (a Kistler three-component dynamometer, type 9257B) fixed to the carriage of the lathe is used to determine the forming forces. After the installation is complete, the system is scanned to determine the true resonant frequency, at 28.4 kHz.



(**a**) (**b**)

Figure 2. Experimental setup: (**a**) photo and (**b**) model of the force components.

The initial workpiece is an Al 5052 aluminum alloy sheet in an annealed state with a thickness of 1.0 mm and a square edge of 120 mm × 120 mm in size. This is an alloy commonly used in the automotive and household industries [9]. In this study, the input parameters of the UISF and ISF methods include feed rate (n, chosen within a range of 70–130–225 rpm) and step size (Δz, within a range of 1.0–1.5–2.0 mm). Others parameters remained unchanged: the wall angle ϕ was equal to 45°, the depth of forming was 5 mm, and the diameter was 60 mm. All the parameters are illustrated in Figure 1. The experiment was designed according to the Taguchi method, with two parameters, three levels of values, and a total of 9 experiments, as shown in Table 1.

Table 1. Experiment results (maximum forming force F_{zmax}).

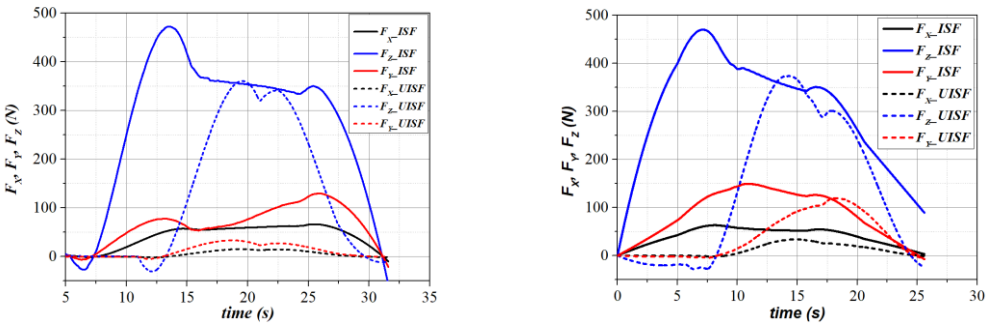
No	Input Parameters		F_{zmax} (N)		Reduction Ratio
	n (rpm)	Δz (mm)	UISF	ISF	$(F_{z(ISF)} - F_{z(UISF)})/F_{z(ISF)}$ (%)
1	70	1.0	359.1	466.4	23.01%
2	70	1.5	361.9	488.2	25.87%
3	70	2.0	387.6	512.5	24.37%
4	130	1.0	323.3	425.3	23.98%
5	130	1.5	347.8	457.5	23.98%
6	130	2.0	375.7	467.7	19.67%
7	225	1.0	297.6	301.2	1.20%
8	225	1.5	336.6	378.0	10.95%
9	225	2.0	353.5	421.4	16.11%

3. Results and Discussion

During the forming process in both ISF and UISF, the forming force F_z gradually increases until a maximum value is reached, as shown in Figure 3.

When the workpiece rotates for one full turn, due to the spring-back phenomenon, this force is still maintained, but tends to decrease gradually. The tangential force F_y and

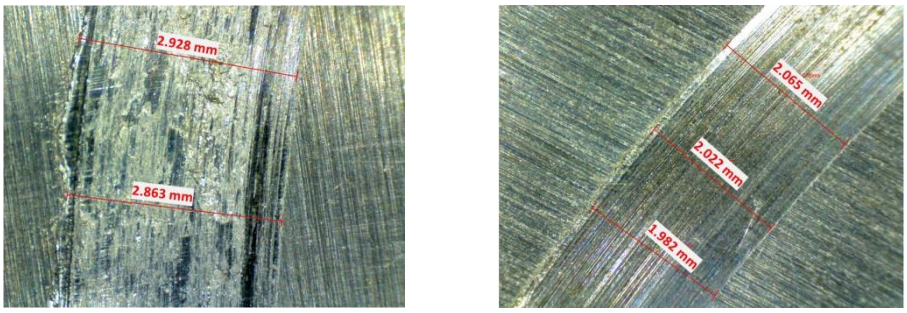
the radial force F_x also tend to be similar. The maximum forming forces (F_{zmax}) according to the input parameters are summarized in Table 1.



(**a**) (**b**)

Figure 3. Force components (solid line—forces in ISF; dashed short line—forces in UISF) in various conditions: (**a**) n = 70 rpm, Δz = 1.0 mm; (**b**) n = 130 rpm, Δz = 2.0 mm.

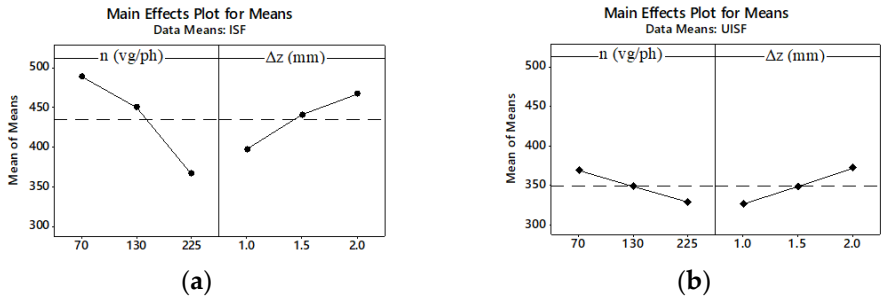
From Figure 3 and Table 1, it is easy to see that under the same forming conditions, the forming force F_{zmax} in the UISF process is significantly reduced compared to that of the ISF process (about 20%). This may be due to the phenomenon of softening under the effect of ultrasonic vibration and the reduction in internal friction during the motion of dislocation when the material is deformed, so the force required for deformation in UISF is less than that in ISF [6–8]. Besides, ultrasonic vibration improves the contact conditions between the forming tool and the workpiece, thus reducing external friction [8]. Figure 4 shows images of the contact trace between the forming tool and the workpiece. It is easy to see that on the surface of the product formed using ISF, quite a lot of cracks appear (Figure 4a). Meanwhile, the product surface made using UISF is quite smooth (Figure 4b).



(**a**) (**b**)

Figure 4. Photographs of (**a**) the area surface formed via ISF; and (**b**) the area surface formed via ISF.

The influence of the input parameters (including n and Δz) on F_{zmax} is also evaluated. As depicted in Figure 5, it can be seen that the main force F_{zmax} increases as Δz increases or/and n increases. When forming via the UISF method, the plot shows that the influence of Δz and n on the F_{zmax} is almost a straight line, with a rather low slope (see Figure 5a). This proves that these factors' influence on the main force F_{zmax} is not large. Meanwhile, when shaping with the ISF method, the effect of n on the main force F_{zmax} is more obvious, as shown by the line with a steeper slope (see Figure 5b).



(**a**) (**b**)

Figure 5. Plot of the influence of input parameters on the main force F_z: (**a**) ISF; (**b**) UISF.

4. Conclusions

In this study, the influence of ultrasonic vibration on forming force and the surface quality of products formed via UISF was investigated and compared with ISF. The results show that the ultrasonic vibration significantly reduces the forming force, within which the main forming force F_{zmax} reduced by about 20%. The results also show that the surface quality formed using UISF is significantly improved compared to that formed using ISF.

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