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Vibration characterisation in new rotational vibration-assisted incremental sheet forming

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Abstract. An experimental study is conducted to measure vibrations of the deforming sheet induced by tool rotations in a newly developed incremental sheet forming (ISF) process, Rotational Vibration assisted ISF (RV-ISF). Two new tool designs, elliptical double-offset tool and rosette tool of four-grooves, are tested in the experiment. Non-contact measurements by Eddy current sensor are obtained to characterise vibration frequency and amplitude of the deforming sheet during the RV-ISF of an aluminium alloy.

1 Introduction

Incremental sheet forming (ISF) has unique benefits for small-batch and prototyping manufacturing when compared with the conventional sheet metal forming processes. However, the conventional ISF process has a number of limitations especially when forming high strength materials at room temperature. To improve the formability of the hard-to-form materials, a number of ISF process variants were proposed, including warm ISF [1], laser assisted ISF [2], electric assisted hot ISF [3], and ultrasonic vibration-assisted ISF (US-ISF). In the recent published studies of the US-ISF, it was observed that vibration frequency of 20 kHz and vibration amplitude of 5~40 μm had resulted in significant forming force reductions when forming aluminium alloys and carbon steels, reported in [4], [5], and [6]. However, additional devices and equipment were required by the US-ISF and other ISF process variants, which compromised the process flexibility of the ISF, and increased the process complexity and manufacturing costs.

Friction stir-assisted ISF (FS-ISF) was firstly developed by Otsu et al. [7] in which a hemispherical headed tool was rotated under a high speed, ranging from 1000 to 10,000 rpm, to generate frictional heating to soften the material. Magnesium and aluminium alloys were tested by the FS-ISF process [8, 9]. However, as frictional heating is the main mechanism to soften the material and improve the formability, it is difficult to control the level of heat generation in the FS-ISF and the surface quality of the FS-ISF parts is also compromised. To reduce friction and to improve surface quality, Xu et al. [10] developed a forming tool with laser etched surface texture and Lu et al. [11] developed an oblique roller-ball tool. The FS-ISF has a simple process setup when compared to other ISF process variants and thus maintains the ISF advantages of the process simplicity and flexibility.

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A new ISF process variant has recently been developed at the University of Sheffield, named as Rotational Vibration assisted ISF (RV-ISF). In RV-ISF, a new type of tool generates vibrations of the deforming sheet at the tool-sheet contact [12]. No additional device or equipment is required in the RV-ISF therefore maintaining the process simplicity. The RV-ISF of magnesium alloy has demonstrated a significant improvement in formability and reduction of forming forces due to the combined effect of thermal and vibration softening [12]. In this paper, the RV-ISF experiment is developed to measure the vibrations of the deforming sheet induced by rotation of the new tool. Two tool designs, elliptical double-offset tool and rosette tool of four-grooves, are studied in the experiment. The sheet vibration during the RV-ISF of AA5052 is measured by a non-contact Eddy current sensor.

2 Experimental methods

2.1 Tool design

New tool designs of elliptical double-offset tool (T2) and rosette tool of four-groove tool (T4) are developed to characterise vibration frequency and amplitude in the RV-ISF. Figure 1(a) shows the conventional ISF tool (T0), and the new tool designs T2 and T4, respectively. Figure 1(b) shows the formed geometry of a 50° truncated pyramid, used in the experimental study. In the RV-ISF process, the tool-rotation generated sheet vibrations vary with the forming depth but mainly in the direction of the wall thickness of the formed geometry. Figure 2 shows an illustration of the localised sheet vibration when it loses contact with the tool surface due to the elastic deformation recovery of the sheet material. By changing the offset size for T2 and length and width of the groove dimensions of T4, varied levels of vibration frequencies and amplitudes of the deforming sheet may be created. In this study, RV-ISF experimental tests are conducted by using T2 and T4 tools operated under different rotational speeds to generate different levels of vibration frequency and amplitude of the deforming sheet, the wall of the pyramid.

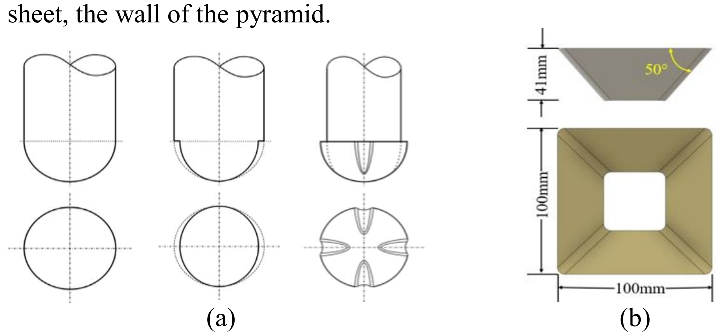


Fig. 1. RV-ISF experiment for vibration measurement: (a) Conventional tool T0, elliptical tool T2, rosette tool T4; (b) forming geometry of 50° pyramid.

2.2 Vibration measurement

To investigate the effect of the tool induced vibration on material deformation and enhanced formability in the RV-ISF, vibration frequencies and amplitudes of the deforming sheet must be measured and characterised first. The RV-ISF experiment of aluminium alloy AA5052 with a sheet thickness of 1 mm is conducted to form the pyramid geometry. An Eddy current sensor (CSH1-CAm1 from MICRO-EPSILON) is positioned at 1 mm to the wall of the pyramid at depth of 30~40 mm to measure sheet vibration frequencies and amplitudes at different forming depth of the pyramid, as illustrated in Figure 3. The time-displacement results are obtained and processed through centralisation and Discrete Fourier's transformation to calculate the vibration frequencies and amplitudes.

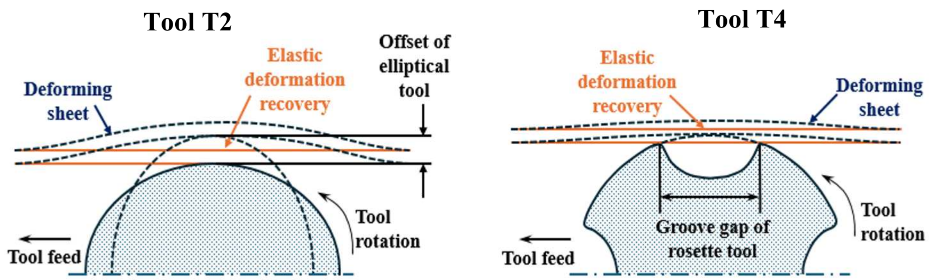


Fig. 2. Illustration of tool induced sheet vibration due to elastic deformation recovery

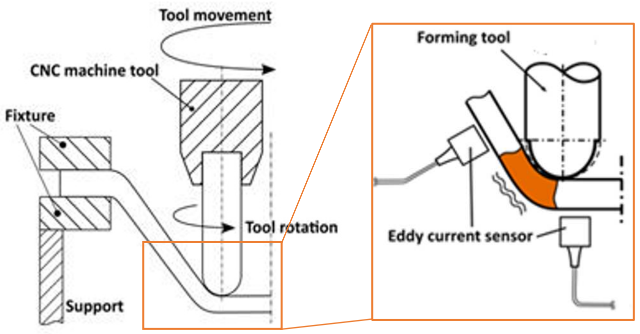


Fig. 3. RV-ISF experiment and sheet displacement measurement by Eddy current sensor

3 Results and discussion

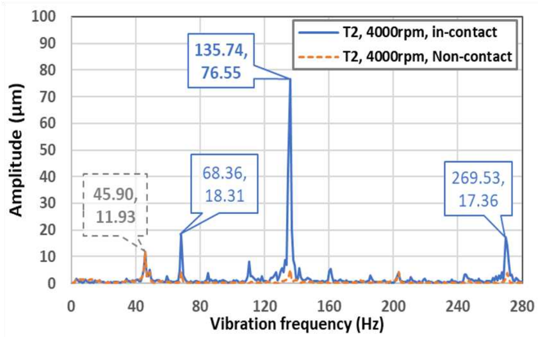
Table 1 summarises the dominant vibration frequency and amplitude by using T2 and T4 tools under different tool rotational speeds, measured by the Eddy current sensor. It can be observed that the measured vibration frequency is very close to the calculated reference frequency, which are much lower than that applied in the US-ISF studies [4-6]. The tool design has a significant effect on vibration frequency and amplitude; the elliptical tool T2 produces much higher vibration amplitudes compared to that by using the rosette tool T4.

Table 1. Measured dominant frequency and amplitude by using T2 and T4 tools

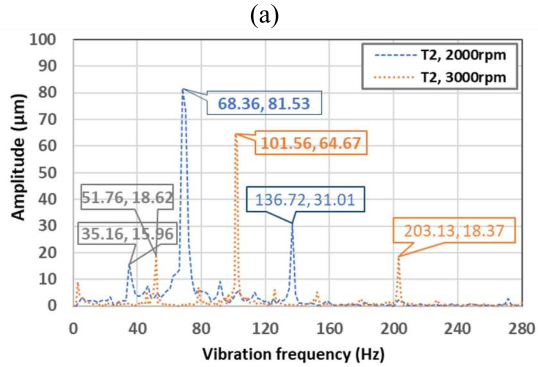
Tool design	**T2**	**T2**	**T2**	**T4**	**T4**
Rotation speed (rpm)	2000	3000	4000	2000	3000
Reference Frequency (Hz)	66.67	100	133.33	133.33	200
Dominant frequency (Hz)	**68.36**	**101.56**	**135.74**	**136.72**	**205.08**
Amplitude (µm)	**81.53**	**64.67**	**76.55**	**11.15**	**4.15**

Figures 4(a) and 5(a) compare the measurements taken when the tool is in contact and not in contact with the deforming sheet at the sensor location using two different tools. Both T2 and T4 tools have shown small amplitudes below 5 µm at different frequencies when the tool is not in contact with the sheet at the sensor location. This indicates that the tool induced sheet vibration in the RV-ISF is localised at the tool-sheet contact point only and it is not a global vibration of the sheet specimen.

Figures 4(b) and 5(b) compare the measured sheet frequencies and amplitudes when a different tool rotational speed is applied in the experiment. With an increase of the tool rotational speed, and thus a higher vibration frequency, the measured vibration amplitude has a decreasing trend. This may be because under higher tool rotational speed, more frequent tool-sheet contacts are produced. There is less time for the sheet material to complete a full elastic deformation recovery, resulting in a reduced vibration amplitude.

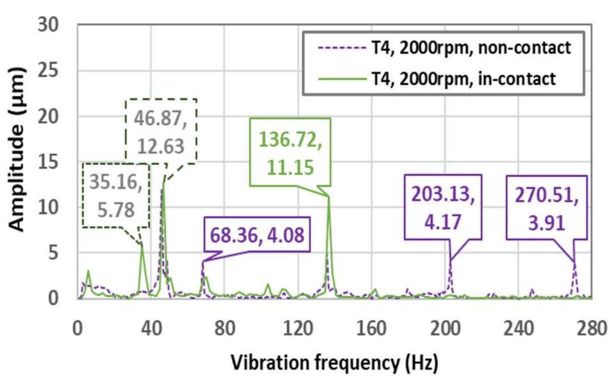


(a)

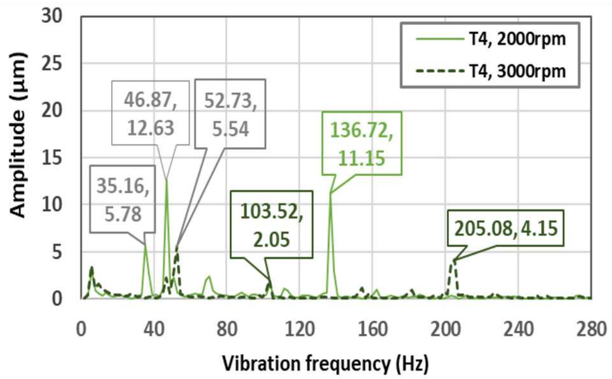


(b)

Fig. 4. Measured vibration frequencies and amplitudes by using T2 tool, measured (a) when the tool contact is and is not at the sensor location; (b) under different rotational speeds.

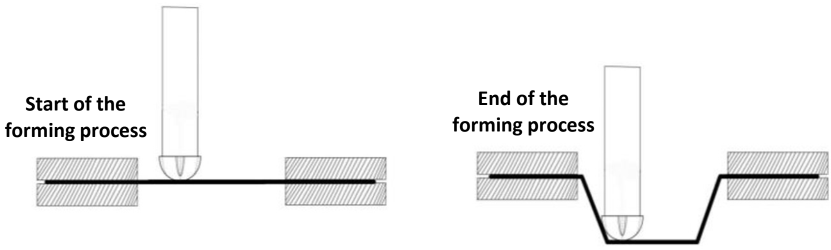


(a)

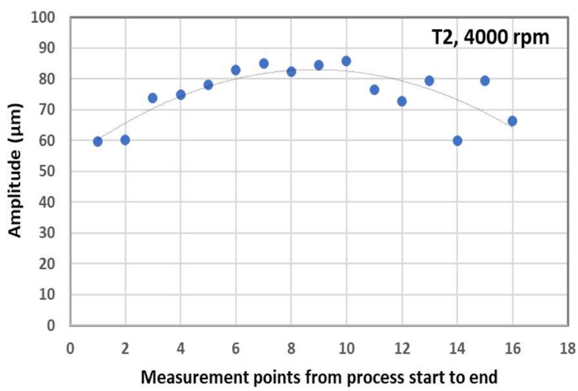


(b)

Fig. 5. Measured vibration frequencies and amplitudes by using T4 tool, measured (a) when the sheet in-contact and non-contact with the tool; (b) under different rotational speeds.



(a) (b)



(c)

Fig. 6. Effect of forming depth of the pyramid on sheet vibration amplitude by T2 tool: (a) illustration of (a) shadow forming depth of tool tip contact with the sheet and (b) final forming depth of full tool head-sheet contact; (c) variation of the vibration amplitude at different measurement positions along the forming depth of the pyramid.

Figure 6 shows the variation of vibration amplitude when the tool moves down along the toolpath to a greater forming depth in forming the pyramid. As shown in Figure 6(a), a greater forming depth means that the formed part gains a better stiffness as well as a short circumference of the pyramid, therefore more frequent tool-sheet contacts, which again leads to a reduced time for the elastic deformation recovery and a reduced vibration amplitude.

4 Conclusions

The vibration measurement in the RV-ISF experiment of forming AA5052 sheets has been conducted. The results show that the measured vibration frequency is very close to the calculated reference frequency. The elliptical double-offset tool (T2) produces much higher amplitudes than that created by the rosette tool of four-grooves (T4). Under a higher tool rotational speed, it is observed a reducing trend of the vibration amplitude. The sheet vibration is local and only captured when the tool is adjacent to the sensor location. Future studies should investigate if forming different materials would change vibration amplitudes.

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References

1. G. Ambrogio, L. Filice, G. L. Manco, CIRP Ann. Manuf. Technol. **57**, 257-260 (2008)
2. J.R. Duflou, B. Callebaut, J. Verbert, H. De Baerdemaeker, CIRP Ann. Manuf. Technol. **56**, 273–276 (2007)
3. G. Fan, L. Gao, G. Hussain, Z. Wu, Int. J. Mach. Tools Manuf. **48**, 1688-1692 (2008)
4. S. Amini, F. Nazari, M. Baraheni, A.H. Ghasemi, Int. J. Adv. Des. Manuf. Technol **11** (4), 91–97 (2018)
5. P. Li, J. He, Q. Liu, M. Yang, Q. Wang, Q. Yuan, Y. Li, Aerospace Sci. Technol **63**, 132-139 (2017)
6. Y.L. Li, X.X. Chen, J. Sun, J.F. Li, G.Q. Zhao, Proc. Eng **207**, 777-782 (2017)
7. M. Otsu, H. Matsuo, M. Matsuda, K. Takashima, Steel Res. Int **81** (9), 942-945 (2010)
8. M. Otsu, T. Ichikawa, M. Matsuda, K. Takashima, Steel Res. Int. Spec. Ed, 537–541 (2011)
9. M. Otsu, M. Yasunaga, M. Matsuda, K. Takashima, Proc. Eng **81**, 2318-2323 (2014)
10. D. Xu, W. Wu, R. Malhotra, J. Chen, B. Lu, J. Cao, Int. J. Mach. Tools Manuf. **73**, 37-46 (2013)
11. B. Lu, Y. Fang, D. Xu, J. Chen, H. Ou, N.H. Moser, J. Cao, Int. J. Mach. Tools Manuf. **85**, 14-29 (2014)
12. H. Long, W. X. Peng, Z. D. Chang, H. Zhu, Y. J. Jiang, Z. H. Li, J. Mater. Proc. Techno. **326**, 118311 (2024)