euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

Incremental sheet metal forming with flexible die

Akshay Chaudhari[1], Jonathan Mohan[1], Maan Tarng Lew[1], Suwat Jirathearanat[2], A. Senthil Kumar[1,*]

[1]*Department of Mechanical Engineering, National University of Singapore, Singapore*
[2]*Singapore Institute of Manufacturing Technology, Agency for Science, Technology and Research (A*STAR), Singapore*

**mpeask@nus.edu.sg*

Abstract
Part inaccuracies due to spring-back and non-uniform material thinning in single point incremental sheet forming (SPIF) are the major concerns. Multiple studies have been conducted to address these issues, for instance, the over forming at the edges is addressed by using backing plate and relatively uniform thinning can be achieved by two-point incremental forming (TPIF) or double point incremental forming (DPIF). However, these methods require fabrication of die or a special purpose machine to carry out DPIF. In this paper, a novel flexible die based on granular jamming concept is proposed and tested for its feasibility in incremental forming applications. The developed flexible die consists of elastic membrane filled with granular material, vacuum pump, and debris entrapment unit. Various granular materials were first tested to assess its suitability for the application in the forming, subsequently the flexible die was employed in the single point sheet forming experiments. Initial experimental results showcase improved accuracy at the part opening; however, more testing is required to optimize the parameters for improved results.

Keywords: Granular jamming, Single point incremental sheet forming, Part accuracy, Hybrid incremental sheet forming

1. Introduction

Single point incremental sheet metal forming (SPIF) is generally used for batch production, prototype parts and forming of complex geometries with deep features. However, part inaccuracies due to spring-back and non-uniform material thinning are the major concerns as shown in Figure 1.

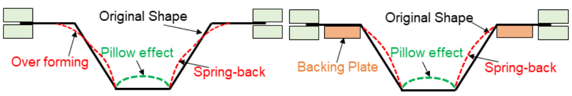

Figure 1. Part inaccuracies in SPIF and use of backing plate

Variants of SPIF such as double point forming (DPIF), two point forming (TPIF), hybrid SPIF and use of backing plate have been proposed to improve part accuracies [1,2,3]. However, these methods require fabrication of die or use of special purpose machine tool. For instance, backing plate needs to be fabricated depending on the opening geometry of the part to reduce the over forming at the part opening which leads to increase in cost. It is important to address inherent inaccuracies in incremental sheet metal forming to ensure precise and accurate formed parts. Hence in this study, a flexible die support based on granular jamming concept is proposed to improve part accuracy for SPIF.

2. Granular jamming and flexible die

Jamming is a physical process in which the viscosity of the granular media increases with increasing particle density. It is commonly observed when granular material is poured into the hopper slowly. In the recent years, the concept of the granular jamming has been widely used in the field of soft robotics and development of universal gripper [4]. Unlike the naturally occurring jamming, the jamming in these applications can be controlled by controlling the density of the particles. Application of vacuum is one of the easiest methods to control the stiffness of the enclosed granular media. The working principle is depicted in the Figure 2. The elastic membrane contracts as the vacuum is applied leading to increase in particle density and jammed state.

A flexible die was developed based on the concept of granular jamming for use in incremental sheet metal forming application. The flexible die set-up consists of flexible die module, debris entrapment container and vacuum pump. The debris entrapment container protects vacuum pump by entrapping any unwanted leaked granular media in addition to control of vacuum pressure. The stiffness of the jammed state depends on properties of membrane, granular media and level of vacuum applied.

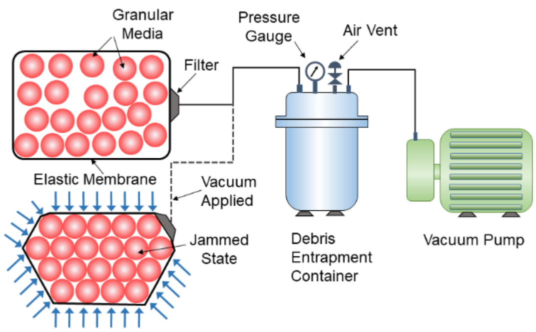

Figure 2. Flexible die set-up based on granular jamming

2.1. Effect of granular media and vacuum pressure

Four materials were tested as a granular media at three vacuum pressure levels. Firstly, Expanded Polypropylene (EPP,2-3 mm) and Expanded Polystyrene (EPS, 2-3 mm) were tested followed by gravel with average size 3-4 mm and sand particles of average size 1 mm. The granular media was enclosed by elastic membrane made up of natural rubber with thickness 0.2

mm. The initial tests were conducted to quantify the effect of granular media and vacuum pressure on stiffness of the jammed state. A tool with 15 mm diameter was pressed against the jammed flexible die to capture resistance force as the tool deforms the jammed die. The results are shown in Figure 3.

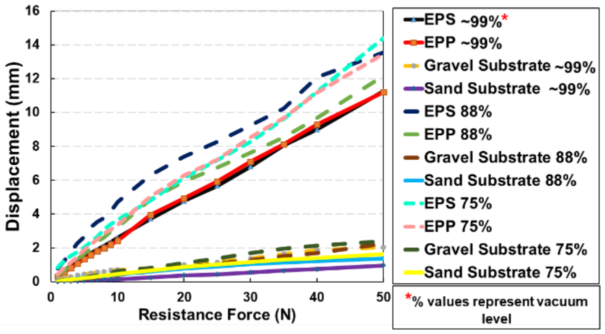

Figure 3. Effect of granular media on stiffness of jammed state

The resistance force depends on the interaction of particles in the granular media inside the elastic membrane. In addition to interaction, resistance force is also affected by the compressibility of the particles. The EPS and EPP beads are compressible and offered limited resistance to displacement in jammed state in addition to spring-back due to elastic recovery. On the other hand, rigid materials such as gravel and sand resulted in higher stiffness without any spring-back due to highr hardness and increased frictional interaction among granular particles. It is clear from the results that size of granular media significantly affects the stiffness in jammed state. Moreover, the vacuum levels can be used for varying the stiffness, for instance the stiffness increased by more than 35% when vacuum is pressure dropped from 75% to 98%. Based on these observations, sand particles were selected as a suitable granular media for the SPIF experiments.

3. Preliminary experimental results

Single point incremental forming experiments were conducted on Makino V66 CNC machine with hardened steel tool (Dia. 15 mm). Two geometries were formed incrementally with and without flexible die support using spiral tool path strategy. Aluminium alloy A2024-T0 sheet metal having 1 mm thickness was used as a forming blank. The experimental set-up is depicted in Figure 4.

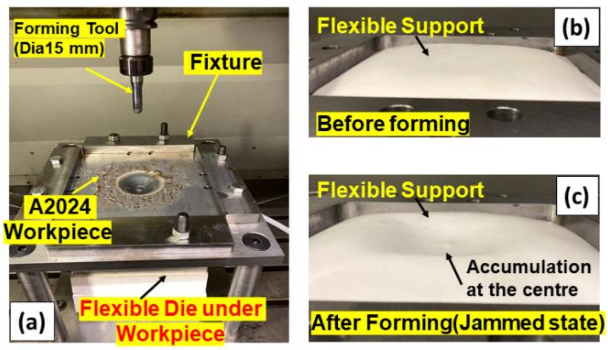

Figure 4. Experimental set-up for incremental sheet metal forming with flexible die

The flexible support in the shape of rectangular pillow (210x230 mm) consists of silicone rubber sheet (thickness 1 mm) as an elastic membrane enclosing 3.8 kgs of sand. To achieve maximum stiffness, 96.3 % vacuum was used during the testing.

Over forming at the opening of the part is reduced with the flexible die which can be attributed to the rigid support provided during forming. However, as the tool moves from periphery to centre, the material is displaced towards centre as shown in Figure 4(c). Accumulation of the material increases the density of the granular media in the centre of the flexible die which results in increased stiffness and forming force. Moreover, it leads to pillow effect observed on the parts formed with flexible die. Additionally, stiffness increases with increasing forming depth resulting in high forming forces and material thinning.

Though the use of flexible support resulted in material thinning and pillow effect, further optimization of vacuum pressure is required to reduce adverse effects. Also, selective use of the flexible die in the beginning of the forming process will reduce the pillow effect.

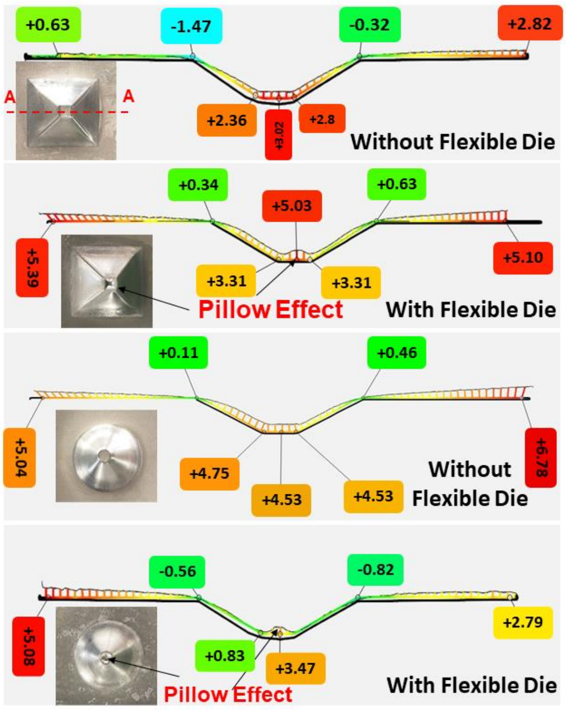

Figure 5. Measurements of formed parts with and without flexible die (dimensions are in mm)

4. Summary

In summary, the fine rigid particle granular media is best suited for the flexible die. Moreover, the stiffness can be varied and controlled by changing the vacuum levels which can be used for in-process accuracy improvement. Based on the preliminary results, the newly developed flexible die has potential to replace backing plate and reduce over forming at the opening of the part. The flexible die can conform to any shape in unjammed state and retain the shape in jammed state which can be used as a support multistep forming process to reduce spring-back. However, more experimental studies are required to optimize the performance of the flexible die.

References

[1] Behera A K, de Sousa R A, Ingarao G and Oleksik V 2017 Single point incremental forming: An assessment of the progress and technology trends from 2005 to 2015 *J. Manuf. Process* **27** 37-62

[2] Duflou J R, Habraken A M, Cao J, Malhotra R, Bambach M, Adams D, Vanhove H, Mohammadi A, Jeswiet J 2018 Single point incremental forming: state-of-the-art and prospects. *Int. J. Mater. Form.* **11**(6) 743-73.

[3] Peng W, Ou H, Becker A 2019 Double-sided incremental forming: a review *J. Manuf. Sci. Eng.* **141**(5).

[4] Brown E, Rodenberg N, Amend J, Mozeika A, Steltz E, Zakin MR, Lipson H, Jaeger H M 2010 Universal robotic gripper based on the jamming of granular material *Proc. Natl. Acad. Sci.* 107 **44** 18809-14.