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Short Communication

Studies on wrinkling and control method in rubber forming using aluminium sheet shrink flanging process

Lei Chen *, Huiqin Chen, Qiaoyi Wang, Zhihua Li

Institute of Mechanical Design, Hangzhou Dianzi University, Hangzhou 310018, China

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ABSTRACT

Thin aluminium sheets have great usage in aircraft manufacturing due to their light weight and high strength. Wrinkling is one of the major defects in the rubber forming of aluminium sheets and may be an obstacle to assembling the parts. In this study, wrinkling was analyzed by shrink flanging in rubber forming process with orthogonal experimental design. Four effect factors (die radius, the flange length, die fillet radius and forming pressure) were analyzed. Three alloy materials (2024-O, 7075-O, 2024-T3) were used as material. The area of wrinkles was introduced to analyze the difference of the effect factors. It was found that different factors had large effect on the wrinkling. The extent of wrinkling of different materials agrees well with their strengths. The best range of the forming pressure is under 300 bar for 2024-O and 7075-O. Wrinkling can be predict using numerical simulation. Three steps forming is a good method to control wrinkling of shrink flange in rubber forming process.

1. Introduction

The deformation problem of sheet metal forming is a nonlinear problem in geometry, material behavior and contact phenomena. The knowledge of the deformation mechanism and the influence of the process parameters are important in the design of sheet metal forming processes. A rubber forming process has a low mold-fabrication cost because only one side of a mold is needed, compared with the two-sided mold needed for the general stamping process, which has been widely studied. Rubber forming has been applied in many different fields. Liu and Hua [1] used rubber forming to fabricate the metallic bipolar plate for a proton exchange membrane fuel cell, which has multi-array micro-scale flow channels on its surface. Maziar et al. [2] used rubber-pad forming experiments to stamp the aluminium blanks. The rubber forming process is very useful for small quantities, such as aircraft parts. Sala [3] used rubber forming to form the frame of MB-339 training aircraft. However, the productivity comes at the expense of length and costly tooling development. Die design is complicated not only by the difficult contours involved, but also by the critical nature of sheet stability. As a result, rubber forming production is often disrupted by compressive instabilities (wrinkling failures). Sun et al. [4] studied the influence of rubber hardness on the wrinkling behavior in rubber forming of Ti-15-3 alloy. Nader [5] studied the shrink flanging of sheet aluminium by rubber forming and found that the wrinkling limit is certainly several times greater in magnitude than that by conventional tools (a rigid punch and die).

Wrinkling prediction is becoming more important in sheet metal forming process. Wrinkling is strongly affected by the mechanical properties of the material, the geometry of the part and contact conditions. The analysis of wrinkling initiation and growth is difficult due to the complex effects of the controlling parameters. Numerous researchers have attempted to explain the critical conditions of wrinkling theoretically. Jeyakrishnan et al. [6] studied the wrinkling of bulged samples of AA 5052 alloy sheets during a restoration process and found that the sheet metals that were annealed at a higher temperature exhibited a better resistance against wrinkling, because of a higher n-value, a higher R-value and a lower yield stress. Pourmoghadam et al. [7] presented an efficient analytical model as well as an finite element (FE) computation of the blank holder force (BHF) leading to controlled local stability failure (wrinkling) and achieved optimum BHF in sandwich sheets forming. Morovvati et al. [8] used a theoretical approach based on a well-known energy method, FE simulations, and experimental observations to study the wrinkling phenomenon in two-layer sheet deep drawing. Results demonstrate that the optimum BHF is dependent on the blank geometry, material properties and lay-up. Shafaat et al. [9] used an energy method approach together with a newly developed deflection function, Hosford and Hill-1948 yield criteria to predict the critical values of stress and cup height at the onset of wrinkling. It was found that applying Hill-1948 yield criterion resulted in prediction of

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* Corresponding author. Tel.: +86 15868187387.
E-mail addresses: chenlei@hdu.edu.cn, ujs_cl@qq.com (L. Chen).

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wrinkling onset closer to the experimental value than Hosford yield criterion. Hassan et al. [10] used finite element method to investigate the effect of bulge shape and height on the wrinkling formation and sheet strength. Different restoration patterns were observed as bulge height increases. Kim et al. [11] studied the effect of plastic anisotropy on compressive instability in sheet metal forming. It was shown that the plastic buckling tendency of sheet metal decreases as the values of normal anisotropy, plastic anisotropy ratio in Hill's quadratic yield criterion, and exponent '*m*' in Barlat's six-component yield criterion increase. Narayanasamy and Loganathan [12] studied the deep drawing of prestrained circular blanks into cylindrical cups when drawing through a conical die using flat-bottomed punch. It was shown that the onset of wrinkling took place when the ratio of the plastic strain increment reached a critical value.

At present there is insufficient experimental data available to validate a theoretical analysis of wrinkling of rubber forming. The present work is motivated by the need to advance the sheet metal forming part/die design in aluminium aircraft sheet applications. In this research, shrink flanging and wrinkling of aluminium materials in rubber forming process were studied by orthogonal experimental design and simulation.

2. Wrinkling experiment

Fig. 1 shows a diagram of a shrink flange. Fig. 2 shows the blank shape for shrink flanging. The flange curvature is convex and the metal in the flange is in compression. The wrinkling tendency in shrink flanging varies with many factors such as the initial sheet thickness, the die geometry, the initial blank shape, and so on. In order to study the effect of the factors, the orthogonal experimental design is used to design the experiment.

The flange length *h* is a key factor in the shrink flange limit. The flange is divided into two regions: a curved portion around the die shoulder and the flange wall [13]. The die fillet radius is important. And in rubber forming process, the forming pressure is a key factor. So the factors are die radius *R*, die fillet radius *r*, the flange length *h* and forming pressure *P*. The effect factors are shown in Table 1. Three levels for each are selected according to the possible region. In this experiment, three alloy materials (2024-O, 7075-O, 2024-T3, $t = 1$ mm) have been used as material for shrink flanging. Among orthogonal tables, the appropriate one for arranging the four factors above with three levels for each is L_9 (3^4). The plan for the experiment is to investigate the effect of these four factors on wrinkling (see Table 2). After the L_9 table is selected, the blanks

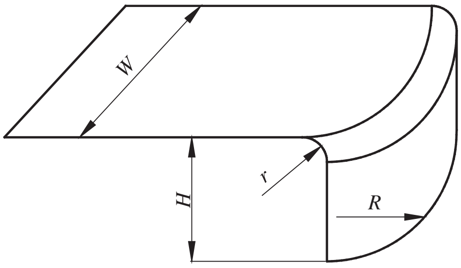

Fig. 1. Scheme of shrink flanging.

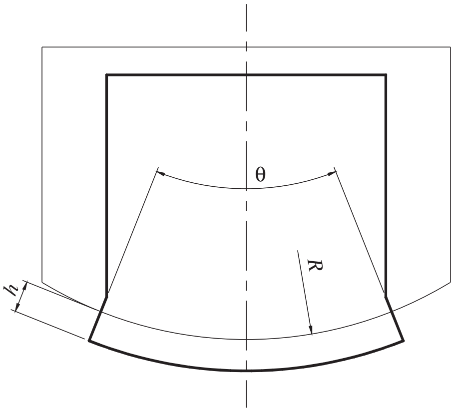

Fig. 2. Blank shape.

Table 1
Different level of effect factors.

Level	*R* (mm)	*r* (mm)	*h* (mm)	*P*/bar
1	150	4	10	200
2	250	5	20	300
3	350	6	30	400

Table 2
The parameters in the experiments.

No.	*R*	*r*	*h*	*P*
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Fig. 3. Blank photos.

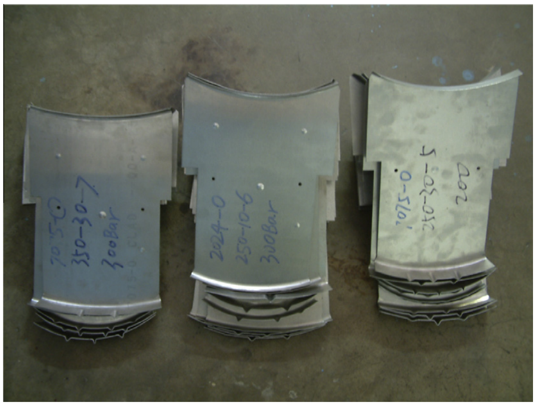

Fig. 4. Photo of the whole experiment parts.