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# Effect of forming parameters on sheet metal stability during a rotary forming process for rim thickening

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ABSTRACT

A new rotary forming process for rim thickening was proposed in this paper, which can be applied on sheet metals to produce parts with thin web plates and thick rims integrally. Via FE simulation, an orthogonal test was conducted to investigate the effects of forming parameters on $\gamma_{max}$, which is the ratio of maximum blank size to thickness and indexes the stability of sheet metals while during forming. It is found that the incline angle of the upper roller groove surface, and the friction condition between the sheet metal and roller groove are the dominant factors affecting the process, while the influence of the feeding velocity and the groove arc radius are relatively slight. It is also proved that interactions exist among these factors. Furthermore, an optimized parameters group is obtained, and a process window plot showing the limits of the forming process is achieved. The facticity of FE simulation is verified by technological experiments.



## 1. Introduction

Since the early 2000s, light-weight design has become imperative for the automotive industry due to its great economic and ecological benefits. Optimizing part shape and manufacturing parts integrally using new processes are two efficient ways to meet the requirement. Sheet-bulk metal forming (SBMF), which is characterized by the application of bulk forming operations to sheet metals according to Merklein et al. (2011), is one of the new processes to make sheet parts having bulk forming features. According to Standring (2009), metal forming processes can be distinguished based on tool motion and sheet thickness variation. The tools in an SBMF process may have either linear or rotational movement and can be combined in various ways. As a result of SBMF, the dimension of the resulting functional elements can be locally increased, decreased or kept as the same in comparison with that of the original blank. In recent years, various kinds of SBMF processes have been developed to meet the complex requirements from different parts.

The linear motion is the most common tool movement type in SBMF processes. Tan et al. (2008) developed a two-stage forming process to manufacture tailored blanks. In their research, the target portion was drawn into a die in the first stage and then compressed by a flat die with flange clamped in the second stage, resulting in the thickening of the target portion. Mori et al. (2011) introduced a new method to improve the drawability of square cups. First, a sheet having a uniform thickness was bent into a hat shape with two inclined portions and later compressed by a flat die. After a right-angled rotation of the sheet, the same sequence was repeated to realize a local thickening action along the perpendicular direction. Finally, the thickness at the four corners of the thickened area was doubled. Luo et al. (2011) proposed a sheet metal stamping-forging process, which included one step of flanging process, one step of reshaping and two steps of upsetting process, to form a tubular part. As a result, the flange of the part was thickened. Wang et al. (2011) studied the forming process of a double-layer cup with the stamping-forging hybrid forming method. In their study, the outer cylinder was first formed via forward drawing, and then the inner cylinder was formed by powerful backward drawing and finally thickened by upsetting. Wang et al. (2013) proposed a novel process for forming bosses on the bottom of a cup made by deep drawing in which the bosses are formed by compression of the cup bottom during deep drawing.

The rotational motion is another type of tool movement in SBMF processes. Groche and Fritsche (2006) produced internally geared wheels using flow forming, during which a cup blank rotated with an externally geared mandrel whilst three rollers moved axially and rotated passively to roll the inner sidewall of the cup into the mandrel's teeth, so as to generate the gear profile. Wong et al. (2008) adopted a two-step forming process, i.e. bending and flow forming,

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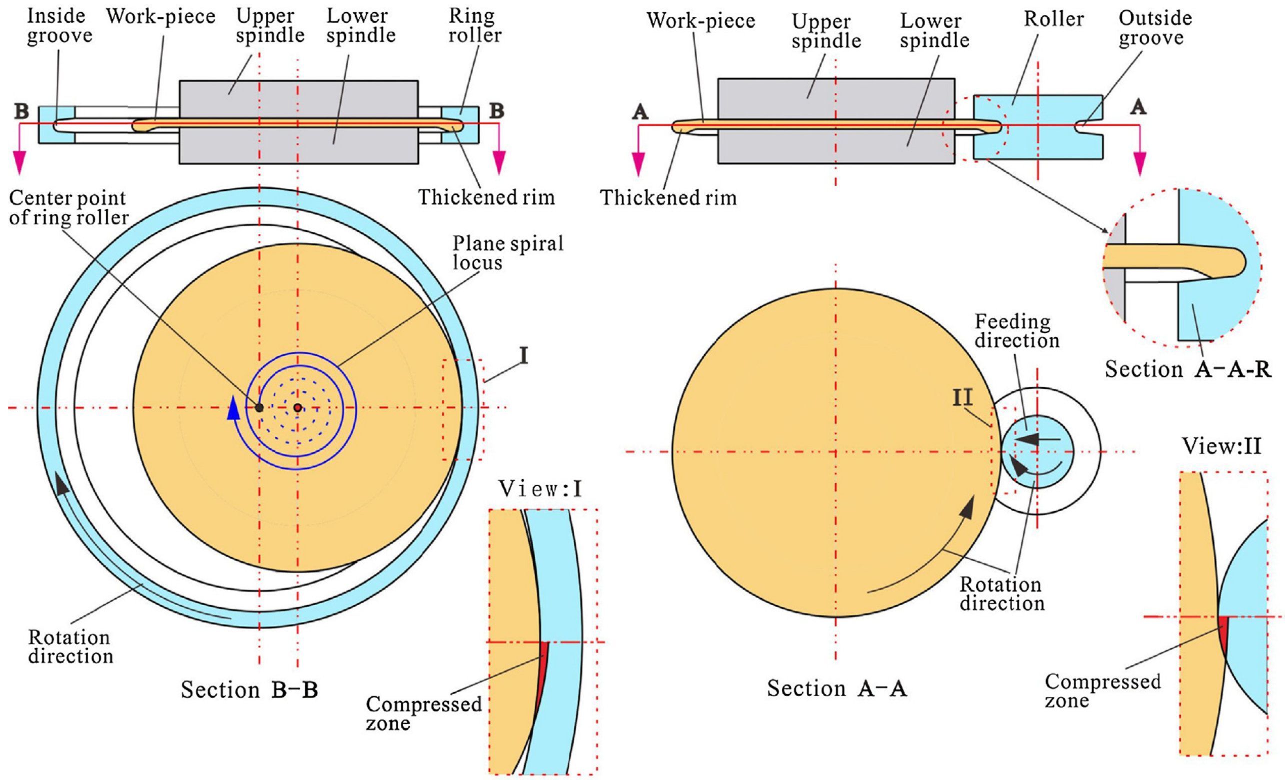


**a) Rotary forming process in Jin et al. (2012)** **b) Newly developed forming process**

**Fig. 1.** Comparison of two rim thickening process.

to enable material to flow axially along the mandrel, aiming to form a thin-walled cup component. They developed a flow forming facility to investigate the forming process of thin-walled cups from flat-disc blanks. Kawai et al. (2007) conducted experiments to survey the boss forming process. Material was driven toward a rotating mandrel by a roller to form a central boss shaped component. As a result, a boss rose between the mandrel and roller with the center area thickened, and the outer blank diameter extended.

As described above, to attain the local thickening of a small target portion in sheet metal parts via the linear movement of tools, multi-step forming processes are required. Due to the difficulty of the material flowing in the plane of sheets, the target portion is mainly thickened in an upsetting way along the sidewall direction. Meanwhile, processes with tools moving rotationally are mainly used to produce tube shaped parts or tube shaped parts with inner gears. In these processes, the materials mainly flow along the axles to obtain an increased length and decreased thickness. However, none of them has referred to how to form a disk like parts with thickened rim which is the typical characteristic of lightweight designed parts.

It is obvious that the SBMF process with linearly moving tools is unable to make disk-like parts with thickened rims due to the difficulty of material flowing in the plane of sheets. Therefore, Jin et al. (2012) proposed a novel rotary forming process as shown in Fig. 1a and manufactured the corresponding apparatus to form this kind of parts. In this process, the center point of a ring roller with an inside groove moved around the axis of a stationary work-piece in a plane spiral locus, so as to thicken the work-piece rim. It had a long compressed zone between the ring roller and the work-piece since the work-piece internally contacted the ring roller. After a four-step rotary forming process, the rim was thickened from 2.5 mm to about 9.5 mm. But in his research, the effect of parameters which were decisive to the forming result was not studied. Furthermore, the ring roller had to rotate in low rotational speeds to reduce the amplitude of vibration, which was caused by the eccentric rotation of ring roller. What's more, the die change unit applied was too complicated, and the time cost of die changing was some high. Thus, there is still much space for the improvement of production efficiency and manufacture cost.

Therefore, a method for rim thickening as shown in Fig. 1b is newly developed in this paper. According to the proposed method, a work-piece is clamped between the upper spindle and lower spindle and all of them rotate together. A roller with outside groove feeds along the radial direction of the work-piece to thicken the rim, and rotates passively under the drive of friction between the roller and work-piece. The forming process stops when the roller contacts the upper spindle. In this process, the roller can rotate at high angular velocities owing to the non-eccentric rotation, and the die changing process becomes much easier since a common spinning machine is adopted instead of dedicated devices. It has a short compressed zone between the roller and the work-piece since the work-piece externally contacts the roller. Both in this new process and the process proposed by Jin et al. (2012), the work-piece can be regarded as an annular thin plate with a fixed internal boundary and under single point radial force, and it is very easy to become instable while forming. Therefore, it is of great importance to investigate the effects of forming parameters on the process stability. An orthogonal test is conducted via FE simulation to investigate the effects of forming parameters on $\gamma_{max}$, which indicates the stability of sheet metals during forming. Technological experiments have been conducted to validate FEA results.

## 2. Orthogonal test based on FE simulation

### 2.1. Finite element analysis (FEA)

#### 2.1.1. Elastic-plastic FEA model

The commercial software DEFORM was used to analyze the proposed forming process. The FEA model was constructed as shown