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Short Communication

Investigation into forming sequences for the incremental forming of doubly curved plates using the line array roll set (LARS) process

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ABSTRACT

The line array roll set (LARS) process [7] proposed by the authors is an effective metal forming process used to manufacture doubly curved metal plates. To obtain a final shape with the desired bend radii and to minimize any possible defects, the process for forming the desired shape should be systematically and accurately designed. The major purpose of the present work is to analyze the effect of the forming sequences in the LARS process. The experiments are conducted using three types of forming sequences, and the final bend radii and the quality of the formed plates produced by the LARS process are evaluated. It is found that it is more effective to form a doubly curved plate through a singly curved shape in order to improve the quality of the formed plate. A series of forming experiments with various bending radii are conducted and the interaction phenomena in double curvature bending are observed.

1. Introduction

In recent years, much attention has been focused on incremental forming processes, which have been intensively developed because it is a highly flexible metal forming system that can handle a small batch production with large varieties. Incremental forming processes based on various forming concepts have been developed through research for diverse industrial applications [1–5]. In addition, an incremental roll forming process based on the principle of bending-dominant deformation that generates minimal thickness strain has been proposed by Yoon and Yang [6]. The incremental roll forming process employs an adjustable roll set as a forming tool. The roll set, which is composed of one upper center roll and two pairs of lower support rolls, plays a key role in this process. The bending deformation occurs within a local contact region of a plate just beneath the center roll, and the plate is deformed throughout its whole region by moving it line by line.

To overcome the problem of low productivity in incremental roll forming, Shim et al. [7] proposed the line array roll set (LARS) process, which uses multiple roll sets arranged in a linear array. Of particular significance is the ability of this process to increase productivity because it generates double curvatures in the whole region of a metal plate with only one pass, unlike the incremental roll forming processes studied by Yoon and Yang [6]. Experimental work showed that a doubly curved plate can be formed using the LARS process. And the quality of formed plate according to types of roll arrangements was investigated to aid in the LARS process design [8]. In the LARS process, in order to obtain a final shape with the desired radii in the longitudinal and transverse directions and also to minimize any possible defects, the process for forming the desired shape should be systematically and accurately designed. The present work reports on the further investigation for industrial applications after the previous introductory work studied by Shim et al. [7]. The present study primarily aims to investigate the quality of shapes formed under different forming sequences. Finally, a number of experiments with various bending radii are conducted for the observation of diverse aspects of interaction phenomena in the LARS process.

2. Experimental procedure

The prototype line array roll set for the experimental study is shown in Fig. 1. The LARS is composed of a pair of upper and lower symmetric roll assemblies. There are three rows in the upper set and three rows in the lower set; each of those sets is divided into driving rolls and idle rolls. The rolls arrayed in the central rows of the upper set and lower set are motor-driven; hence, they can simultaneously deform and move the metal plate using the friction between the rolls and the plate. The remaining rolls are idle rolls. All of the rolls were equipped with servo control units so that they could be positioned in a vertical direction. In the transverse direction, the metal plate is bent by the configurations of the upper and lower roll sets as shown in Fig. 1(a), which can be

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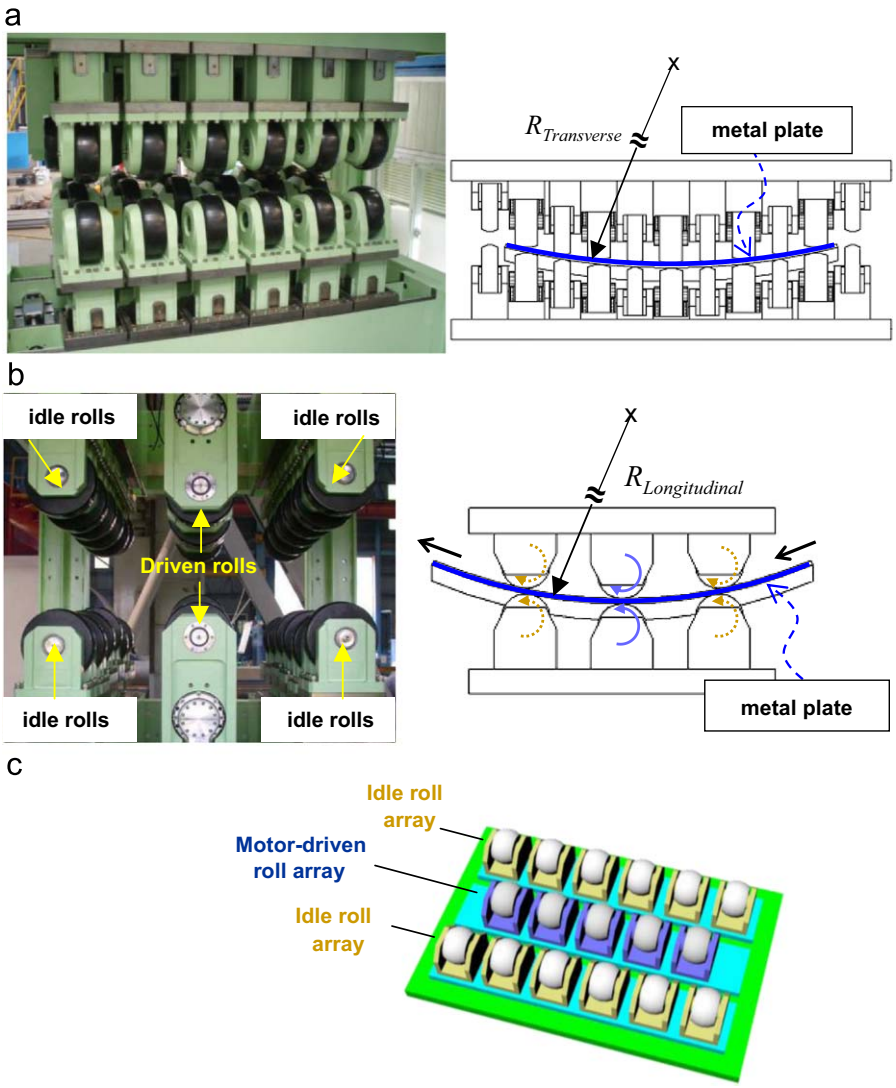

Fig. 1. The prototype line array roll set (a) front view: transverse bending, (b) side view: longitudinal bending, and (c) lower roll set.

configured by adjusting the relative position of each roll. In order to bend a plate in the longitudinal direction, driving rolls in the central rows of the upper roll set and a pair of idle roll rows of the lower roll set bend the plate downward as shown in Fig. 1(b). This phase of bending is similar to the bending deformation of the three-roller bending process [9]. That is, after the metal plate is pressed by the roll sets, it is bent in two directions and transferred in a direction tangential to the rotation of the central roll array using the friction between the central roll array and the plate.

In the incremental forming using the LARS process, there can be many forming routes in the fabrication of a doubly curved plate from a flat plate. The forming sequence for a doubly curved plate can be divided into three types as shown in Fig. 2. First, the plate is bent simultaneously in the transverse and longitudinal directions (path 1), in which the amount of bending in both directions increases at each step. In forming path 2, the plate is deformed by transverse bending during the first 6 steps (stage 1) and then by longitudinal bending during the last 6 steps (stage 2). The final one (path 3), which is contrary to path 2, is that the plate is deformed by longitudinal bending prior to transverse bending. The bending radii 1100 mm in two directions are evenly divided into 6 steps.

Grade-A mild steel plates of width 1000 mm, length 1000 mm, and thickness 8 mm were used. The material properties obtained by tensile tests (Series IX, Instron Co.) are listed in Table 1. To

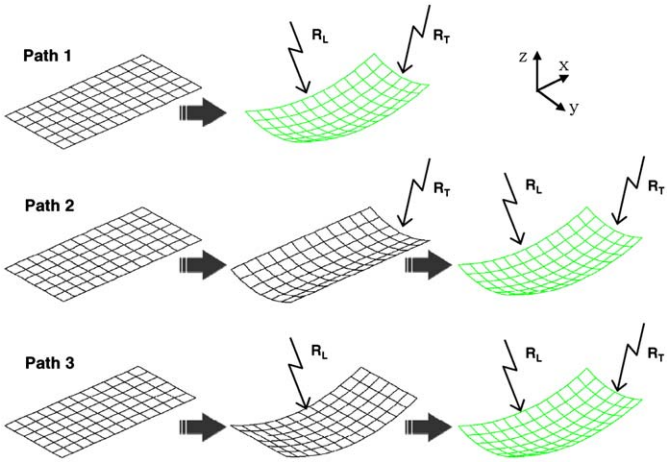

Fig. 2. Three basic types of forming sequences. (R_T: Transverse bending radius, R_L: Longitudinal bending radius.)

obtain the profiles of the formed plates after the experiments, the z-coordinates along the center line of the formed plates were measured using a height gauge. The radius of curvature of the formed plate was calculated by the least square method using the