Journal of Materials Processing Tech. 258 (2018) 259–270

Contents lists available at ScienceDirect

Journal of Materials Processing Tech.

journal homepage: www.elsevier.com/locate/jmatprotec

Experiment and simulation to rolled profile strip with variable thicknesses in lateral direction

X.G. Wang[a], X.H. Liu[a,b,*], S. Wang[a], Y. Zhi[a]

[a] State Key Laboratory of Rolling and Automation, Northeastern University, Shenyang, 110819, China
[b] Research Academy, Northeastern University, Shenyang, 110819, China

ARTICLE INFO

Keywords:
RPS
Tailored blanks
Lightweight

ABSTRACT

Tailored blanks are widespread and gaining increasing use in the market with a competitive edge due to their load adaption, cost reduction through the efficient use of materials, and their lightweight design. In order to meet market demands and efficiently produce lightweight products, a new method is now developed to obtain strips with different thicknesses in the lateral direction, i.e., Rolled Profile Strips (RPS), by cold rolling. The new method includes bending-spreading rolling (BSR) and flattening rolling (FR). Experiments were performed to obtain RPS samples with a thickness ratio of 1:1.3. Then the deformation, metal flow, and stress-strain field in the BSR processes were simulated by FEM with ABAQUS software. The results indicate that the desired strips are obtained, whereby the thick areas undergo compressive deformation while the curved deformation area (thin area and transition areas) undergoes both tensile and compressive deformations. These findings will lay a foundation for the industrial application of RPSs.

1. Introduction

Increasing attention has been focused on lightweight structures due to their great contributions to the reduction of energy consumption, environmental pollution and production cost. A common way to reduce the weight of a structure is to use specially tailored blanks and profiles. Merklein et al. (2014) demonstrated four major approaches to producing tailored blanks such as TWBs (Tailor Welded Blanks) and TRBs (Tailor Rolled Blanks) and their advantages. As a typical lightweight product in the rolling field, TRBs have been widely used. Liu (2011) developed Variable Gauge Rolling (VGR), a new technology to produce flat products with different thicknesses, which is identical to TRB. Despite numerous advantages, TRBs also have several limitations. For example, enough rolling time should be ensured to allow the response time of the adjustment.

Saito et al. (1992) designed a type of compact continuous mill to produce profiled metal strips from flat strips. A test mill was constructed, and rolling experiments have been performed on the production of T-shaped or U-shaped profiled aluminum strip. Kopp and Böhlke (2003) suggested a new rolling process for producing cold rolled strips with a defined cross-section. These strips feature a difference in thickness of 1 mm and an average thickness of 2.75 mm. During the initial period, a single roll system was used which resulted in a total of about 200 passes and the formation of waviness or beads. Through optimization, several rolls were arranged side by side, and the total number of passes was reduced to 30–40. Moreover, since the potential of the process had already been demonstrated in a wide range of products, especially in automotive industries, Kopp et al. (2005) conducted some special deep drawing tests with flexibly rolled blanks. Ryabkov et al. (2008) developed the concept of 3D-Strip Profile Rolling. In this process, blanks with different thicknesses in the longitudinal and lateral direction can be produced. Some early experiments have been conducted which highlight the general feasibility to produce 3D-profiled blanks. However, Saito et al.'s method is still in the test stage. A total of 30 ~ 40 passes are needed in the process proposed by Kopp et al. The products are all featured with shaped upper surfaces and flat bottom surfaces in both processes. Schematic illustrations of the above methods are shown in Fig. 1.

In this paper, a new rolling process has been suggested for making strips with various thickness distributions in the lateral direction (RPS). In addition, a 3D FE model is developed to evaluate this process. The validity of the BSR process is verified through the production of two different kinds of RPS in laboratory experiments. More experiments are also conducted to further evaluate the feasibility of FR. Fundamental formation characteristics are investigated on the basis of the 3D FE model. At present, RPS without any defects such as waves and cracks can be obtained. The number of rolling passes can be greatly reduced with special roll designs and further reductions. In addition, real-time

---

* Corresponding author at: State Key Laboratory of Rolling and Automation, Northeastern University, Shenyang, 110819, China.
E-mail address: liuxh@mail.neu.edu.cn (X.H. Liu).

https://doi.org/10.1016/j.jmatprotec.2018.03.028
Received 7 August 2017; Received in revised form 28 March 2018; Accepted 29 March 2018

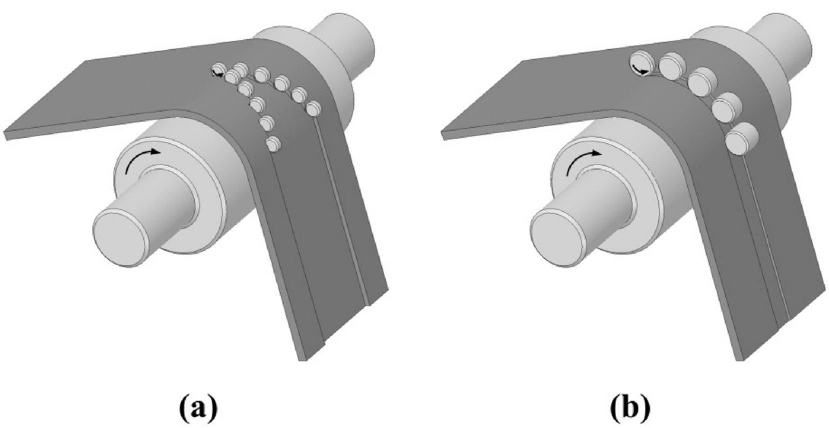

Fig. 1. The schematic illustrations of two other methods (a) Kopp's method (b) Saito's method.

adjustment can be avoided with this new method. A streamline roll design, which fits the workpiece precisely, is crucial to the smooth flattening process.

2. Principle of the new method

Metal flows both laterally and along Rolling Direction (RD) with the special roll pass during the BSR process. This implies that the thickness variation of the target area is caused by both rolling and stamping. As a result, the metal in the target thinned area elongates not only laterally but along RD, and that in the target thickened areas flows only along RD. This changes the strip with the same thickness in all areas into one with different thickness distributions. The new method ensures that the elongation in the target thinned area is the same as that in other areas, thus avoiding waves and other shape defects created by non-uniform elongations in traditional flat rolling.

The new method combines the characteristics of rolling and stamping to achieve thickness reduction in target areas. In order to produce RPS, several specific grooved rolls have been designed. Fig. 2 depicts the application of the new method to common sheets. The raw material was first rolled into a curved sheet using the BSR process. Then FR was utilized to produce RPS with several flattening rolls. The curved deformation area consists of thin area and transition areas. The straight deformation area is also known as the thick areas. In addition, a series of numerical simulations on the stress and strain states were performed to better understand the material behavior during deformation.

Compared with prior methods, the new method proposed in this paper has following advantages:

1. High efficiency. Only four passes are involved.
2. Simple apparatus is needed. The process can be realized on a basic mill.
3. Satisfactory transition areas. Smooth transition between the thick areas and the thin area can be achieved, and the size of the transition areas can be well controlled, which means that even very short transition areas can be obtained without adjusting roll gaps.

3. Finite element modeling for RPS simulation

3.1. Bending-spreading rolling (BSR)

The present study employed an explicit solver in ABAQUS to simulate the rolling of RPS. Dynamic explicit analysis using an elastic-plastic material model and coulomb friction was adopted to describe the material behavior. The geometry model for a FEM mesh consisting of a top profile roll, a workpiece, and a bottom profile roll is shown in Fig. 3. The nominal diameter of the roll is 118 mm. Rolls with different shapes vary in diameters. In addition, diameter as measured along the direction of a profile roll barrel is also different. According to the principles mentioned in section 2, the middle part of the workpiece can be forced to move vertically by this roll design, in which the metal of this part is under tensile stress, which facilitates metal thickness

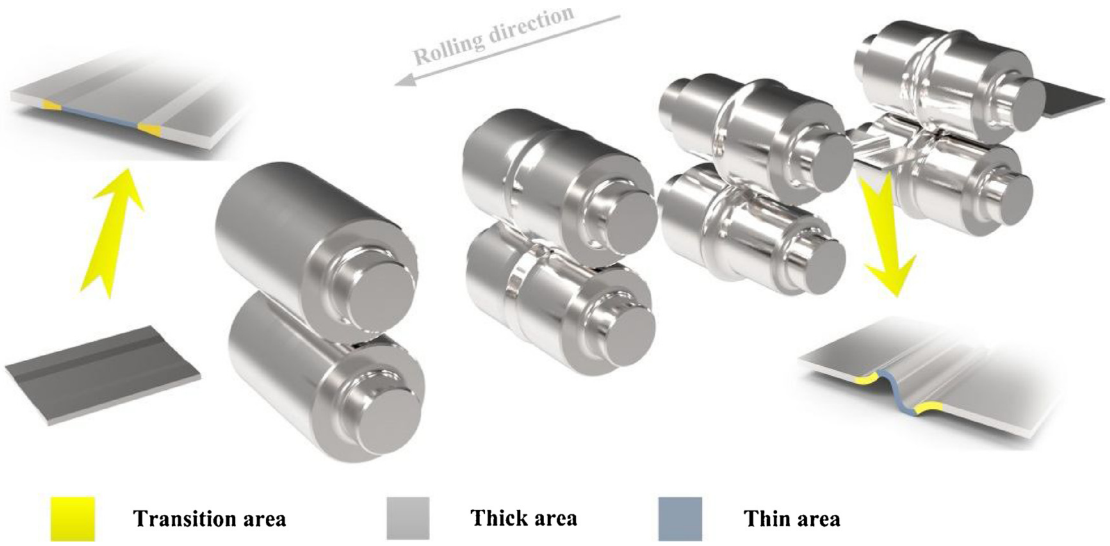

Fig. 2. Diagram of production process.