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Springback Prediction and Compensation of Elastic-Perfectly Plastic Strip in Multi-Square Punch Forming

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Abstract. One-step forming study is a desired hull forming strategy in shipbuilding industry due to its high efficiency and economy. Compared with traditional mold forming, the multi-square punch forming (MSPF) can easily change its target shape by adjusting the height of its square punches. More importantly, MSPF provides uniformly distributed normal loading and a surface-to-surface contact between the punches and the plate, reducing plate wrinkles and dents to a great extent. This paper aims to provide solution to the one-step forming of elastic-perfectly plastic strip formed by MSPF machine. With deeper understanding of the mechanisms of the forming and the springback, accurate prediction of the springback is possible. By investigating the springback feature of the strip under MSPF, the curvature adjustment (CA) method is proposed to compensate the springback. The one-step MSPF model is then established on the basis of both the analytical model and the CA compensation method, which could properly decide the pre-designed die shape that produces the target shape of the strip. The present method is validated by published results and is proven to be in high accuracy. Case studies are also conducted by the present method to obtain the die shape of the flexible dies, which further validates the accuracy. Besides, the critical length is introduced for the particular cantilevered forming approach by the MSPF machine, and its effects on the forming accuracy and the formable range of the MSPF machine have also been discussed.

AMS subject classifications: 65D30, 34B60

Key words: Springback prediction, springback compensation, elastic-perfectly plastic, curvature adjustment (CA), critical length.

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1 Introduction

One important procedure in shipbuilding is to manufacture plates and strips of desired shapes before welding into hulls and segments. Conventionally, this requirement can be fulfilled by either the rigid tool or the line-heating strategy. The rigid tool approach constructs a rigid die shape on which the plate is bent by imposing external forces. It is noted that, due to the uniqueness of the hull plate, massive production is almost impossible, due to which the rigid tool approach is costly and inefficient. The line-heating has been widely used in recent years [1]. Yet this strategy is labour intensive and also inefficient. Meanwhile, the remained thermal residual stress can affect the strength and the capacity of the workpiece, which deteriorates the forming quality. Therefore, the desired plate forming should be in a cold and flexible manner [2]. With that vision, Wang et al. [2] developed a three-dimensional CNC hull plate forming machine (SKWB-400) in 2010. SKWB-400 is a multi-square punch forming (MSPF) machine, consisting of 14×14 upper punches and 15×15 lower dies. When forming the workpiece, the heights of the lower dies are firstly adjusted to form the pre-determined surface (see Fig. 1), and then the workpiece is pressed to the lower dies by the upper punches driven by the hydraulic system. The cold forming process of SKWB-400 removes the remaining thermal residual stress, and specially designed punch heads can rotate to effectively contact with the plate in a larger area, achieving a surface-to-surface contact as much as possible, and thus reducing dimples in the formed plate [4].

A threshold factor for the quality of MSPF is the springback of the workpiece. There have been some reports of this phenomenon in literature. Yuan et al. [5], Xu et al. [6], Shen et al. [7] and Zheng [8] simulated the multi-square punch forming of plate with different target shapes by FEM and investigated the parameters that have effects on the springback. Although these studies provide abundant observation of the springback phenomenon, no reliable method or model for the prediction of springback has been established. Without such model, it is difficult to achieve one-step forming, so re-

Figure 1: Multi-square punch forming (MSPF) by SKWB-400.