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Development of the slope cutting method for determining the residual stresses in roll formed products

Yong Sun [a,*], Vladimir Luzin [b], William J.T. Daniel [a], Paul A. Meehan [a], Mingxing Zhang [a], Shichao Ding [a]

[a] School of Mechanical and Mining Engineering, The University of Queensland, St Lucia, Brisbane, QLD 4072, Australia
[b] Australian Nuclear Science and Technology Organization, Lucas Heights, NSW 2234, Australia

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ABSTRACT

The residual stresses in a roll formed product play a critical role in determining the product quality. They are generally very complex and frequently difficult to predict due to the complicated fabricating process and its parameters. Consequently, they attract many concerns from roll forming scholars and engineers. However, how to inspect the residual stresses in roll formed products efficiently and economically is still a challenge. This paper introduces a novel, highly efficient, operationally simple and accurate residual stresses measurement method for evaluating the residual stresses in roll formed products. It utilizes a modification of the current sectioning methods to firstly obtain the membrane and bending residual stresses components. Then a novel material removal approach, the tapered removal, is employed to determine the layering stresses component by measuring the curvature variations of the remaining sample through its thickness direction. A practical implementation of the method is performed through the residual stresses measurement of a typical roll formed square hollow section (SHS). The method is successfully verified by the neutron diffraction method. The new method is expected to become a routine measuring method to determine the residual stresses distribution in roll formed products, with potentially significant impact on the roll forming industry.

1. Introduction

Roll forming is a highly efficient fabricating method for mass production of long and straight metal products. It can be understood as a continuous bending operation which the metal strips are progressively formed through consecutive sets of rolls into various profiles [1]. Although roll forming has been developed over a century, there are still unsolved issues in predictability and control of the redundant plastic deformation occurring during a roll forming process due to relaxation between roll stands [2]. The distribution patterns of the residual stresses in a roll formed product are generally very complex. And also, they might be difficult or time consuming to predict through simulations due to complexity in formalizing of all effects from various influencing factors and conditions. Consequently, this becomes a bottleneck which greatly restricts the development and application of roll forming. Specifically, the non-uniform plastic deformation results in the residual stresses in a roll formed product. The distributions of residual stresses are responsible for a series of typical roll formed product defects and/or distortions from the desired product shapes, such as curvature, end flare, edge wave, torsion, springback and so on [3]. Thus, the residual stresses are regarded as the crucial factors to judge the quality of a roll formed product. The residual stresses maybe quite different depending on tooling design and manufacturing methods and conditions which brings more challenges to the relevant measuring techniques [4]. Hence, a highly efficient and accurate method for determining the residual stresses in roll formed products is highly demanded from the roll forming industry.

There are several techniques that are used to evaluate the residual stresses in roll formed products which are normally classified as destructive and non-destructive techniques [5,6]. In destructive methods, the residual stresses are determined by the variations of the associated strains after creating a cut, hole, crack or removing layers of material in the experimental specimens [7,8]. The applications of the destructive methods, such as, the hole-drilling, contour, slit method and layer removal, are usually efforts and time consuming, while being frequently limited by the low measuring accuracy [9–10]. The most common non-destructive techniques are the X-ray (laboratory x-rays and synchrotron radiation) and neutron diffraction methods, having a relative high measuring

* Corresponding author.
E-mail addresses: y.sun@uq.edu.au (Y. Sun), s.ding@uq.edu.au (S. Ding).

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accuracy, often just few MPa. However, the measurements require sophisticated instruments, intensive training of operators and high expenditure [11–12]. It should be mentioned that the laboratory X-rays are well suited for stress measurements on surfaces while the neutron diffraction method is better suited for measuring strains in interior of samples [13].

The frequent limitations of the current measuring methods, such as high cost, operational difficulties, time consumed, limited measuring sample size range and unstable accuracy are still inevitable. To break the bottleneck of measuring the residual stresses in roll formed products, a novel residual stresses measurement technique called the slope cutting method is proposed in this study, which was specifically developed, adapted and optimized for stress measurements in roll formed products. It was practically applied and validated for the stress measurements in a typical roll formed square hollow section (SHS).

The structure of the paper is as follows. The methodology of the technique is firstly presented, followed by the detailed illustrations of a practical implementation on a typical roll formed SHS. Then the verification of the technique by the neutron diffraction method is presented and discussed. Finally, some important conclusions for future study are summarized. The study indicates that the method has the potential to further being developed as a routine residual stresses measurement technique for roll formed or similar cold-formed products, having the advantages of high accuracy, low cost, time-saving and satisfactory operational safety.

2. Methodology

Regarding an experimental measurement method as a basic and feasible approach to study and understand the severity of the residual stresses in a roll formed product [14], several variations of the practical stress measurements for roll formed products have been suggested over the years and the main principles and concepts established. Weng et al. [4] performed an extensive experiment on the measurement of the residual stresses in cold-formed steel sections. The experimental specimens were obtained by a wire cutter rather than by a conventional saw-cutting method to reduce the external disturbance on the experiments. The authors proposed a theoretical distribution of the residual stresses in roll formed sections on the basis of their experimental results. Li et al. [14] experimentally investigated the residual stresses of two roll formed sections which were fabricated by different processes using the X-ray diffraction method. They found that the residual stresses along the longitudinal direction are greatly affected by the forming processes. Through the strain gauge measurement technique, the membrane and bending residual stresses in a roll formed high strength SHS were experimentally explored by Ma et al. [15]. They proved that the welding points were expected to reveal the maximum residual stresses along the perimeter of the sections.

A series of deformation types exist in roll forming due to the severity of the material deformation during the forming process. Halmos [16] pointed out all the other deformation types are redundant deformation except for the transverse bending component. The redundant deformation types are responsible for the severity of the residual stresses in a roll formed section. Key et al. [17] performed an experimental study on the residual stresses in a roll formed SHS, and presented the idealized residual stresses distribution in the sections. It was summarized in the study that both the longitudinal and transverse residual stresses in each side of a SHS consist of three components: (1) membrane σ_m, (2) bending σ_b and (3) layering stresses σ_l, as shown in Figs. 1 and 2. Following on Key's approach [17], a novel residual measurement method called the slope cutting method is proposed in this study. It utilizes a modification of the current sectioning methods [8–10] to firstly obtain the membrane and bending residual stresses components. Then a novel feature of the material removal approach, the tapered removal, is employed to determine the layering stresses component by measuring the curvature variations of the remaining sample through thickness direction. The components of the final residual stresses σ_R of a roll formed product and their corresponding measured approaches are graphically shown in Fig. 2.

3. Practical implementation

The methodology of the technique is illustrated through a practical implementation of the slope cutting method on a typical roll formed SHS. The implementation consists of the longitudinal and transverse membrane, bending and layering residual stresses measurements. For roll formed products, both the residual stresses along the longitudinal and transverse directions are significant

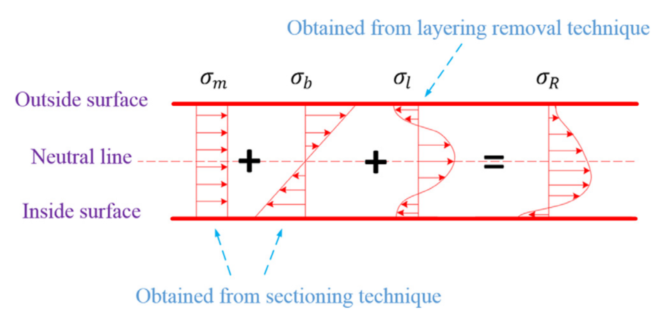

Fig. 2. The final residual stresses and its decomposition into main components.

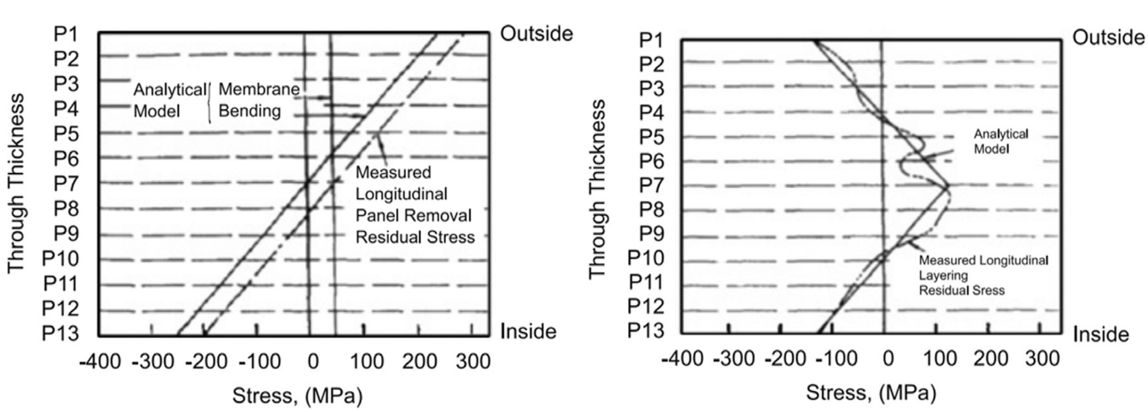

Fig. 1. The idealized residual stresses distribution [16].