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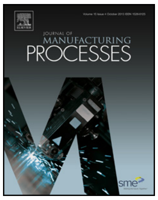

# Experimental and numerical study of required torque in the cold roll forming of symmetrical channel sections

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ABSTRACT

Because of the high complexity of the cold roll forming process, an accurate estimate of the torque required at each stand is not possible and, in many cases, the designs of cold roll forming lines are based on trial and error. This study experimentally investigated the fold angle increment at each stand, internal distance between the stands, strip thickness, flange width, and channel corner radius to determine their effects on the required torque. Also, using finite element simulation, the effect of plastic strain distributions in flange and bend zones on the required torque was studied. Then, a regression method was used to categorize each studied variable based on its effect on the required torque to produce a channel section in the roll forming process. The microstructure of the bend zone was also studied to see its relation with strain distribution. Experimental results indicate that the strip thickness, fold angle increment, and flange width have the greatest impacts on the required torque, in order of decreasing impact. Numerical results indicate that, unlike the flange width, any variable which increases the longitudinal edge strain will increase the required torque. The findings are expected to help designers and researchers to optimize the torque required for the roll forming lines. This can consequently lead to an optimized energy consumption.

## 1. Introduction

The cold roll forming process utilizes rotated rollers that are set on forming stands. Usually, the consumed substance is a metal strip, which is progressively bent along the width direction by rollers in the forming line. During this process, each set of rolls performs an incremental part of the forming to finally obtain a desired cross-section profile [1]. Because of its high economic efficiency, this process has been widely used in the mass production of products that have constant sections and a fixed length. Because several steps are required, this process is highly complex, and it is difficult to control the effects of unwanted deformations [2]. As a result, analysis of the forces involved and of the amount of torque required for this process is not easy, which often leads to production designs that are based on trial and error. Consequently, to avoid the future destruction or repair of a cold roll production line, a design's required capacity must be several times its actual required capacity. This necessity leads to increased material consumption and weight of the devices involved. Moreover, this state requires that designers use higher power actuators than they would use otherwise, thus increasing the production line's energy consumption [3].

So far, a handful of studies have experimentally, numerically, or analytically analyzed the power, torque, and energy required for cold roll forming lines. Bhattacharyya, Smith, Thadakamalla, and Collins [4] experimentally and analytically studied the cold roll forming of aluminum and steel strips with various flange widths and calculated the vertical force that occurred on each roller during formation; they found that increasing the flange width and yield stress increased the vertical force exerted by the strip on the rollers. Through their analytical method, they found that the effects of the strip thickness and fold angle increment on total work done for one bend are greater than those of the other parameters. Lindgren [5] studied the torque and applied force of the strips on the rollers on each stand through the cold roll forming of high-strength strips that were required to produce symmetrical channel sections. He confirmed that when the mechanical strength of the strip increases, its force and required torque also increase; furthermore, he used the obtained data to estimate the motor capacity required for the forming process. Davoodi, Moslemi Naeini, Dadgar Asl, Azizi Tafti,

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Kasaeie and Panahizadeh [6] theoretically and experimentally studied the effects of the strip yield stress, strip thickness, bending angle, and flange width on the required torque and on the vertical forces on each stand. They demonstrated that reducing the strip yield stress, strip thickness, and bending angle at each stand could reduce the vertical force and required torque; they also found that when the strip width was reduced, the vertical force on each stand was also reduced, but the amount of required torque increased. Using experimental and numerical methods, Larrañaga, Galdos, Uncilla and Etxaleku [7] studied the effects of strips' mechanical strength on the springback, required torque, and vertical force on each stand. Their simulations and experimental results agreed well, indicating that when the mechanical strength of a strip decreases, the required torque, vertical force, and springback also decrease. Paralikas, Salonitis and Chryssolouris [8] analytically studied the fold angle increment at each stand, line speed, gap between rollers, roller diameter, and distance between the stands to determine their effects on the energy efficiency of the cold roll forming process. They confirmed that the fold angle increment at each stand, line speed, and distance between the forming stands had greater effects on energy consumption than did the other factors. Paralikas, Salonitis and Chryssolouris [9] analytically and numerically investigated the forming speed, gaps between roller pairs, roller diameter, fold angle increment at each stand, and distance between the forming stands for their effects on energy consumption; they used a robust technique, taking into account some uncontrollable factors such as the friction coefficient between the strips and rollers, strip strength, work-hardening coefficient, and strip thickness. They concluded that considering the uncontrollable factors, the most important factors affecting energy consumption were the gaps between rollers, roller diameter, and fold angle increment at each stand. Through experimental and numerical methods, Groche, Mueller, Traub and Butterweck [10] investigated the effects of rigid and non-rigid forming roller designs by simulating the forces generated between the rollers and strips. Their simulation results revealed that using rigid parts in the roller caused high errors in the forces calculated between the roller and strip; therefore, they suggested that rollers be designed with non-rigid parts to better estimate the forces. Through experimental trials and numerical analysis, Abeyrathna, Rolfe, Hodgson and Weiss [11] investigated the effect of yield strength and material hardening on roll load and torque as well as on longitudinal bow. Their study showed that the level of longitudinal bow, one of the major shape defects observed in roll forming, can be estimated by variations in roll load and torque.

As was mentioned in the previous review of literature, there have been a few studies on the amount of torque required during cold roll forming and most of them studied torque only on a single-stand roll forming line and then developed their findings to the industrial applications. In fact, there is no study in which the torque required for a standard production line was investigated experimentally. In this study, through the production of symmetrical channel sections in a cold roll forming line, the effects of various parameters related to geometrical properties of the products and the cold roll forming setup were investigated. Also, using the finite element method, models were simulated to determine the effect of plastic strain distributions in flange and bend zones on the required torque. Then, using curve fitting in a linear regression method, the effects of each factor on the required torque were specified. Moreover, the effect of roll forming process on the microstructures of products was studied through experimental tests. This paper provides suggestions for evaluating and optimizing the torque required for the cold roll forming process. They can be applicable for designers of cold roll forming lines and manufacturers of steel tubes and profiles to use optimized motors, shafts, couplings, and gearboxes and to reduce the trial and error procedure.

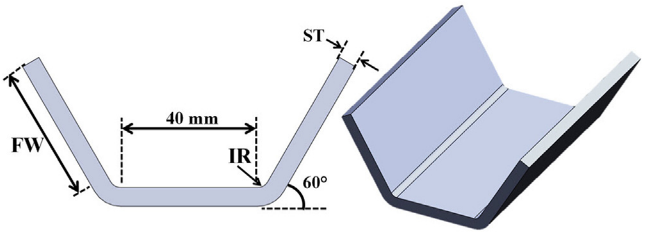

**Fig. 1.** Geometrical characteristics of a symmetrical channel section.

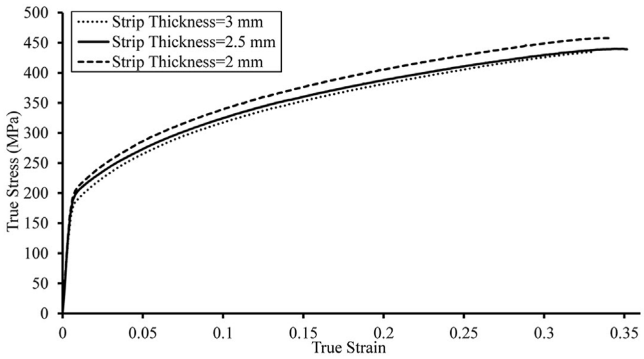

**Fig. 2.** True stress–true strain diagrams for three strip thicknesses.

## 2. Methodologies

### 2.1. Materials analysis, geometric, and mechanical properties of the product

The product was a symmetrical channel section with a 60° angle (Fig. 1) made of hot-rolled steel.

In Fig. 1, the channel web width was considered as 40 mm; IR is the inner radius of the channel corner; FW is the channel flange width; and ST is the strip thickness, each of which was specified according to the model. The strip length in each sample (according to the number of forming stands) was specified such that during experimental testing, the sample was in contact with all the forming stands. The width of each sample (h) was calculated using Eq. (1):

$$h = 2 \times \mathrm{FW} + 40 + \frac{\pi}{3}(2 \times \mathrm{IR} + \mathrm{ST}) \quad (1)$$

In this equation, the neutral surface position is assumed to remain at the middle of the strip thickness during the cold forming process [12].

The chemical analysis of the steel strip used is show in Table 1. As can be seen from this table, the material of the strips is plain carbon, low-alloy structural steel.

This table shows that the main structure of the steel strips should consist of α ferrite and cementite [13].

The mechanical characteristics of the material were extracted from tensile tests as per ASTM Standard E8 specification [14], whose true stress–true strain curves are shown in Fig. 2 and for three investigated strip thicknesses. Based on the results of uniaxial tensile tests, the mechanical properties of the strips were specified that are listed in Table 2.

### 2.2. Parameters affecting the required torque

In this study, the input parameters were the strip thickness, the flange width, the channel corner radius, the fold angle increment at each stand, and the distance between the forming stands. Some researchers have reported that the fold angle increment at each