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Effect of coil set on shape defects in roll forming steel strip

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ABSTRACT

Coil set is a phenomenon occurring in industrial sheet metal in which the strip retains a residual curvature as it comes off the coil. The roll forming of two coils exhibiting coil set is studied; each coil has similar tensile and bending properties. It is shown that there are significant differences in shape defects in the industrial roll forming of a particular channel section depending on whether the strip is fed in with the convex side upwards or downwards. The properties in bending in the longitudinal direction were determined using a free bending test and found to depend on the direction of bending; when bending so that the curvature increased in the direction of the residual curvature, the bending yield stress was almost 50% lower compared with bending in the direction opposite to the residual curvature, i.e. in straightening the strip. In the transverse direction, bending properties were independent of the direction of bending. The defects measured in the roll formed product were twist and flare and the magnitude of both were greatest when the strip was formed with the residual curvature convex upwards in the roll forming line. The process was simulated using the commercial software package Copra FEA; two sets of material property data were used – both were derived by an inverse method from the bending tests. One case used bend test data from tests in which the curvature increased in the same direction as the residual curvature, and the other set for curvature in the opposite direction. The defects predicted by the numerical analyses reproduced the trends observed in the industrial trials regarding twist and end flare even though the levels predicted were too high. Comparison of the bending test results with other work suggests that the strip is subjected to plastic deformation (straightening) as it comes off the coil resulting in an asymmetric longitudinal residual stress distribution through the thickness. Both the experiments and the results of the simulation strengthen the view that differences in the mechanical behaviour in bending near the elastic plastic transition indicate the presence of residual stresses that influence final shape in the roll forming process.

1. Introduction

Roll forming allows the forming of tight radii for materials that show limited tensile elongation [1,2] and springback can be significantly lower compared to that observed in conventional bending applications [3]. The process is therefore increasingly used in the automotive industry for the manufacture of structural and crash components in Advanced High Strength Steel (AHSS) [4]. Even though material splitting can occur when roll forming AHSS [5] it is rare and the most common defects are shape related, such as springback, bow, end flare and twist [6]. To fulfil the tight tolerance requirements of the automotive industry for part shape and process robustness, commercial CAD and FEA systems are increasingly used to investigate and optimize roll forming processes and some previous numerical studies have revealed good correlation of predicted behaviour with experimental results for longitudinal edge strain [7], roll load and torque [8,9] as well as shape defects such as end flare, bow [10], springback and twist [11]. In roll forming, the overall level of strain is low and common shape defects such as edge ripple [12] and oil canning [13] result from extremely small redundant

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plastic strains in the process. This is why changes in the elastic limit and the pre-and post-yielding behaviour in the incoming strip can have a significant effect on shape defects [14]. Additionally, recent studies have revealed that residual stresses due to steel processing influence roll forming shape defects such as springback, bow and end flare [15]. In processing steel, residual stresses can be introduced by skin pass rolling [16], roller levelling and effects related to the coiling of the strip [17]. Some previous studies have shown that residual stresses due to skin pass rolling and roller levelling alter the level of yield stress in a pure bending tests [18] while there is only a minor effect on the material response in the conventional tensile test [19]. The major deformation mode in roll forming is bending and this suggests that material data based on the bending test may be more appropriate to represent material behaviour in roll forming if residual stresses are present.

The present work arose because it was found that with certain coils of stainless steel strip exhibiting coil set, the magnitude of several defects differed when the orientation of the coil was reversed, i.e. when the coil was turned up-side-down so that the residual curvature of the incoming strip was changed from vertically upwards to downwards. Coil set is a common phenomenon in which the strip retains a residual curvature on uncoiling and can occur when the material is bent past its yield point during coiling in a cold or hot rolling mill [20]. Pure bending tests revealed that the strip showed asymmetrical bending properties in that the elastic plastic transition moment for bending in the same direction as the residual curvature was less than half of that in the opposite direction, suggesting the presence of residual stress. A previously published inverse method [21] to derive a stress strain curve from the bending moment characteristic was used to obtain two different stress strain curves that were used as input to a finite element simulation of the roll forming process. The finite element system used a single solid element for the full thickness so that an initial residual stress distribution could not be represented and input was limited to a stress-strain curve. It should be emphasised that the stress strain curve used here in the numerical analysis does not include residual stress information, but reproduces the observed moment curvature behaviour in plane strain bending of strip that does contain residual stresses. The numerical results achieved this way reproduced the trends observed experimentally for the effect of coil feed position on the level of twist and end flare but significantly overestimated the magnitude of shape defects. The results of this study suggest that if there is residual stress present in the incoming strip, material input that is based on bending test data may lead to an improved representation of material behaviour in the numerical analysis of the roll forming process compared with input that is based on the conventional tensile test.

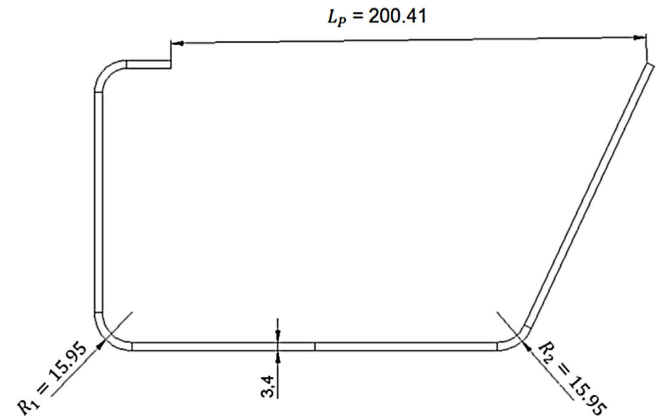

Fig. 1. Channel section shape formed in the industrial trials. (Dimensions in mm).

2. Product and Industrial Process

The product studied was a roll formed channel having the cross-section shown in Fig. 1.

The channel section was formed in 11 forming steps; lubrication was limited to a 12% water soluble oil coolant. The “constant radius method” was used in the roll pass design, where the profile radius is the same at each roll and the bend angle is increased incrementally through the forming steps. The forming sequence is shown in Fig. 2.

The distance between the roll stations in the roll former was 550 mm and the roll gap was set according to the material thickness of 3.4 mm. In forming stations, 1-6, both the top and bottom rolls were driven; in stations, 7-11, only the bottom shaft was driven. In stations 5-11 the bottom cone rolls were split with the outer segments being free spinning rolls that were positioned on bearings to more closely match the line speed of the sheet. This significantly reduced the torque required and prevented scuffing. The material was fed from a un-coiler as shown in Fig. 3a and no levelling equipment was used. After the final forming station (Fig. 3b), sections of 2 m length were cut using the shear cutter shown in Fig. 3c.

Two conditions of feeding the coil were investigated – one in which the lip of the coil and the direction of residual curvature point upwards (Convex upwards) and the other in which the lip of the coil is directed downwards (Convex Downwards) as shown in Fig. 4.

Since it was not possible to change the position of the same coil during the run, two different coils of the same material were investigated (coil 1 and coil 2), with coils 1 and 2 being fed in convex upwards and the convex downwards positions respectively. Sam-

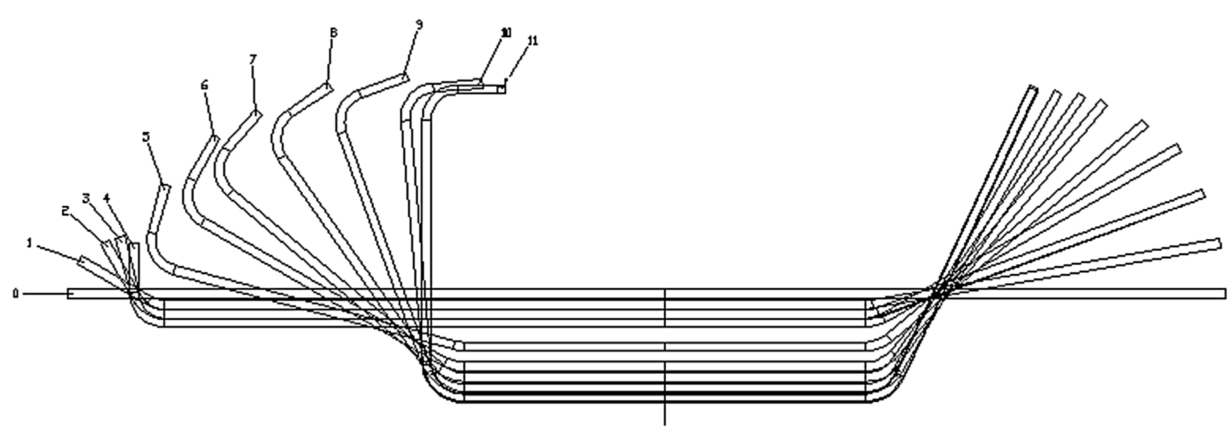

Fig. 2. Forming sequence of the roll forming process.