Edge Profile in Hot Rolling

1. INTRODUCTION

One of the problems arising in the early stages of hot rolling of aluminium is the occurrence of edge cracking. The cracks start at the edge of the sheet and propagate in the width direction. The cracks must be trimmed off and so reduce productivity and can sometimes lead to the scrapping of the entire block. In addition edge cracking during the hot rolling stage of processing generally means that subsequent cold rolling must be carried out at a slower speed. An important factor in the development of edge cracks is the profile of the edge. A concave edge profile invariably develops during the early stages of hot rolling (see figure 1). This results in the edges being stressed in tension, which is one of the requirements for edge cracking to develop. The more concave the profile the greater is the likelihood of severe edge cracking. Hence Comalco is interested in modelling the development of the edge profile because of its influence on edge cracking and the economic implications of the latter. Ideally the model would indicate the rolling variables which could be used to control edge profile and minimize concavity.

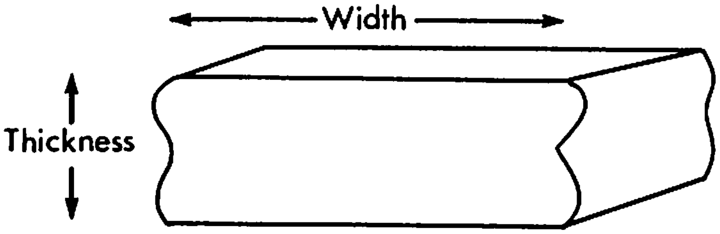

Figure 1: Concave edge profile.

2. EXPERIMENTAL RESULTS

The important parameters for this process (see figure 2) are the block thickness h, the block width w, the roll radius R, the difference δ between the initial thickness and the final thickness of the block after one roll pass and the length l of the arc of contact between the block and the roll (note that $l \approx (R\,\delta)^{\frac{1}{2}}$).

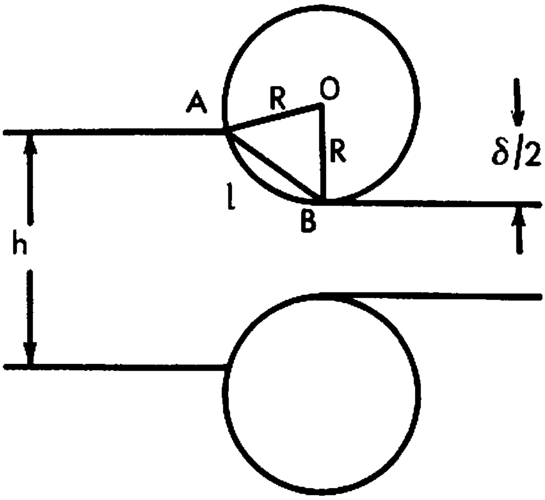

Figure 2: Rolling parameters.

For wide sheets (w/h > 10) it is observed that the increase in width during one roll pass is negligible (less than 5%) relative to the width of the block. In addition the increase in width is observed to be localized to the region immediately adjacent to the edge of the block. Hence it is usual to approximate the rolling process with a 2-dimensional deformation. Experimental research (see [1] and [2]) has shown the importance of the dimensionless parameter h/l. Tselikov et al. [3, p.86] has reported that concave edge profiles develop when $h/l > 2$ and that the contact frictional forces along the length of the arc of contact can be categorized into two groups characterized by the parameter h/l being less than 0.5 or greater than 0.5 [3, pp.81-86]. Actually Tselikov considers four groups which refine our considerations. This division is only approximate, depending on factors such as lubrication and temperature. For $h/l < 0.5$ there exist three zones of contact frictional forces along the length of the arc of contact. The two extreme zones consist of slip zones and the middle portion a zone of adhesion. When $h/l > 0.5$ the adhesion zone occupies the whole length of the arc of contact.

3. MODEL USED

It was decided that as a first step in understanding the edge profile problem we would look at the connection between the parameter h/l and the afore-mentioned experimental results. To model the rolling process we first assumed that the deformation obtained during one roll pass was 2-dimensional, that is, we assumed plain strain. Though a 2-dimensional analysis would not lead to an accurate 3-dimensional description of the edge profile, it was plausible that a 2-dimensional analysis could lead to a qualitative explanation of the significance of the parameter h/l. In addition we assumed that the material behaved as a rigid-perfectly plastic material [4, ch. 1]. The assumption of plain strain and rigid-perfectly plastic material allowed us to use the theory of slip-line fields [4, ch. 5] to study possible solutions of the 2-dimensional rolling problem.

It should be noted the slip-line field is a geometric construction which is essentially independent of the yield stress. The forces are scaled by the yield stress but it does not affect the geometry of the field. It is common to assume that the frictional force is proportional to the yield stress. It then follows that the angle at which the slip-lines intersect the arc of contact will be constant. In the sequel we assume that the roll is rough and so the angle of intersection is 90 degrees except where stagnant regions contact the frictional boundaries (see figure 3a).

There is an extensive literature concerning the accurate solution of slip-line field solutions for rolling problems. Hence for accurate descriptions of the solutions we can refer to the standard papers (see [5] for an extensive biography). On the other hand, it was decided that for our purposes it was sufficient to approximate the arc of contact AB (see figure 2) with the corresponding chord AB (as in [4] and [6]). The qualitative aspects of the solution to this simpler problem should be similar to the solution of the rolling process. In figure 3 we represent some typical slip-line field solutions for a variety of h/l ratios. Figures 3a and 3b represent solutions obtained by Tselikov et al. [3, p.114], whereas figure 3c represents the classic solution obtained by Alexander [6].

It should be noted that preference of one solution over another is determined by choosing the appropriate solution that minimizes the required energy for a particular ratio h/l. This test does not guarantee that the chosen slip-line field is the actual solution of the rigid-perfectly plastic plain strain problem. In fact in addition to the stress field obtained by the slip-line field

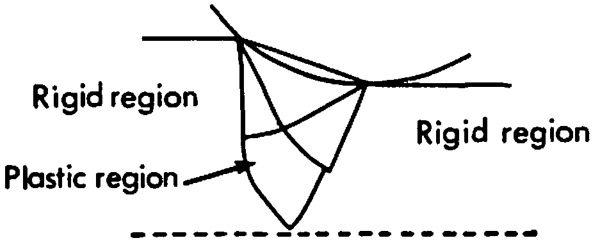

Figure 3a: Slip line field for $1 < h/l < 10$.

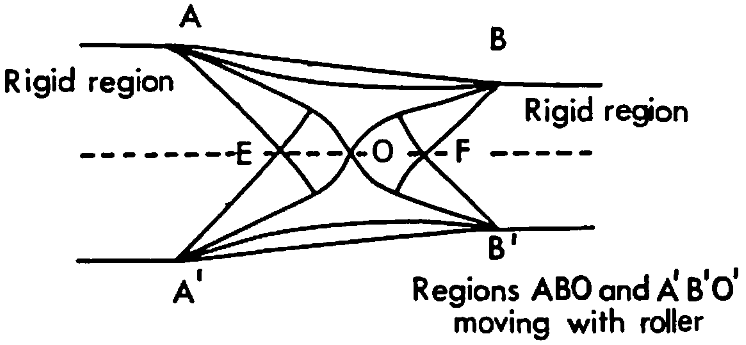

Figure 3b: Slip line field for $1/3 < h/l < 1$.

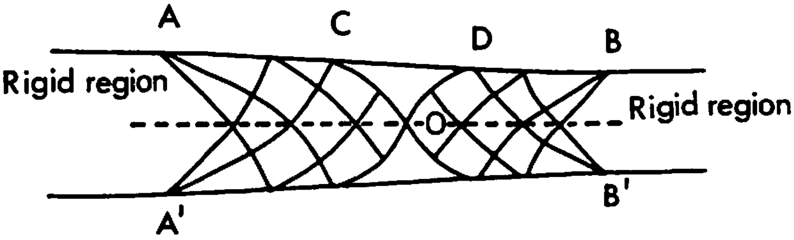

Figure 3c: Slip line field for $h/l < 1/3$.

in the plastic region it is necessary to demonstrate that there exists a stress field in the rigid region which is consistent with the equilibrium equations and which does not exceed the yield condition. We do not claim that the solutions depicted in figure 3 are the exact solutions of the problem but we do claim that they represent the qualitative behaviour of the exact solutions. In particular it should be observed that the whole zone of contact for the slip-line fields given in figures 3a and 3b consist of an adhesion zone whereas figure 3c depicts a field in which there are three zones along the length of the contact arc, two slip zones (AC, DB) and an adhesion zone (CD). This is in reasonable agreement with the experimental observations.

Given a plausible slip-line field, it is then necessary to calculate the corresponding stress field. This can be obtained by using the matrix method developed by Dewhurst and Collins [7]. A study of the stress field thus obtained shows that the character of the fields corresponding to figures 3a and 3c are completely different [4, pp.108-111].

For $h/l < 1/3$, the stress field across the thickness of the block is quite uniform. Near the roll there is a small region where the stress is tensile relative to a surface perpendicular to the direction of flow. Compressive stresses then extend right across the thickness of the block reaching a maximum at the centre. This explains qualitatively why a convex edge profiles develop in this range of h/l. The material will tend to 'bulge' out on the edges when there is a compressive stress and be 'pulled' in if there is a large enough tensile force. As the stress is compressive throughout most of thickness of the material we would expect the edge to bulge out right across the thickness of the block with the maximum at the centre.

For $h/l > 1$, the compressive forces do not extend across the thickness of the material but are restricted to the regions close to the rolls. This causes the material near A to be retarded and the material near B to be accelerated. This leads to the material in the interior experiencing tensile stresses which can be strong enough to produce voids in the material. The regions near the rolls which are experiencing the compressive force will bulge out, whereas the material towards the middle of the edge of the block will be affected by the tensile forces which will hold the edge at a constant width.

4. CONCLUSION

The preceding argument gives a very rough explanation of why a concave edge profile appears for certain values of the parameter h/l. To obtain a more quantitative description of the edge profile the following suggestions were made by members of the study group.

It is possible to approximate the average width increase of a rolled block by assuming that:

(1) the stress is uniform across the thickness of the block,

(2) the edge zone is localized to a small triangular region close to the edge,

(3) the deformation in the edge zone is purely in the width direction, [3, pp.119-125]. A similar analysis using the same assumptions but with the stress field obtained by the preceding two-dimensional analysis should lead to a quantitative description of the edge spread across the thickness of the block.

Finally it was noted that if Comalco needed to model more complex processes, for instance more complex yield conditions, different frictional conditions, work hardening and the problem of residue stresses, then it would be necessary to develop a finite element program (as in [8]) to tackle the full three-dimensional problem.

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