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Effect of Backup Roll Length and Roll Neck Length on Profile for 4-h Mills

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Techniques for achieving product flatness during rolling are compared. Two additional techniques are proposed: reduced backup roll body length and variable screwdown load position.

Effect of backup roll length and roll neck length on profile for 4-h mills

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UNIFORMITY of gage and flatness of rolled strip is being emphasized more than ever. The demand for precision, particularly by the computer industry, has been very strict. When the rolled strip is not uniform, the edges have to be rejected resulting in substantial production losses. In the past, several corrective measures have been taken to insure gage and flatness uniformity. These include skin passes, rolling very narrow strips with very long rolls, and decreasing the reduction per pass, which requires an increased number of passes.

Since the shape and deflection of the work roll controls the shape of the rolled strip, major emphasis has been placed on techniques aimed at controlling the shape of the work roll, the net aim being to reduce its deflection. This has been executed by the use of support rolls; the three most popular configurations of work rolls and backup rolls are shown in Fig. 1. If the work roll can be maintained perfectly flat during the rolling operation, a perfectly flat strip can be obtained. This is normally achieved either by cambering the rolls, or by applying loads to the work roll and at backup roll bearings to control deformation during rolling.

Since no mechanical camber will suffice for the entire product range to be rolled, it is necessary to apportion the product range to several groups of rolls, each group with its own particular camber.[1] Thermal cambering has the disadvantage of slow response to camber variation requirements caused by shape, gage and hardness change. Further, by varying the amount of coolant across the roll bite, some parts of the rolling area will be deprived of an adequate amount of lubricant, making the strip more difficult to roll. There is also the disadvantage of aggravating localized spalling or cracking of the roll surface.

Hydraulic bending, on the other hand, lends to instant response, thus aiding in providing better strip shape. The shapes of the work rolls and backup rolls are fixed (cambered or not), and strip shape is controlled hydraulically by loading either or both rolls.

Shohet and Townsend[2] have investigated and developed mathematical techniques to characterize roll bending methods of crown control in 4-h plate mills. The three systems they considered are shown in Fig. 2. The backup roll length is identical to the work roll length in all three cases.

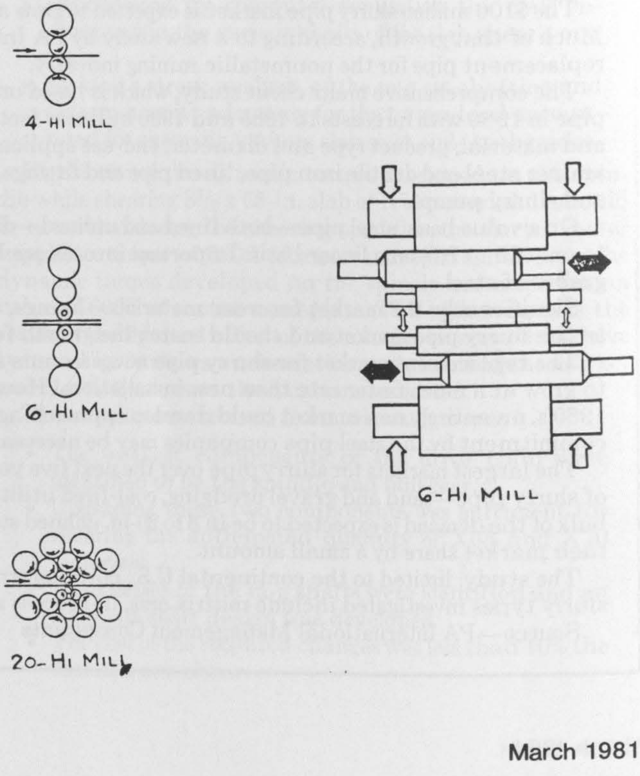
Reduced backup roll length

Constant roll lengths and constant loads tend to deprive the operator of the flexibility that is desirable on the shop floor. Toward this end, mills with backup rolls that are shorter than the work roll have been developed. The sendzimir 20-h mill (Fig. 1, left-bottom) had backup rolls that could be moved horizontally, to give better control over plate gage. However, the extremely small diameter of the work roll led to problems in rolling thin strip. This is due to the increased contact pressure, which also increases roll wear.[3] A recently developed 6-h rolling mill (Fig. 1, right) has large diameter work rolls, and backup rolls that move in a fashion similar to the sendzimir mill. While this solves the problems associated with increased contact pressure, it does not appear to solve the inherent problems of scratching the work roll. The rolls used in strip rolling are polished to a high degree; horizontal movement of the backup roll involves running a rather high risk of scratching these surfaces, which will directly influence product quality. As such, it is thought that this approach could be problematic.

Since the profile of the roll gap determines the plate profile, it is imperative to know the loads that determine the former to estimate the latter. Shohet and Townsend[4] have described this estimation technique which is summarized here. To determine the plate profile and gage, the transverse load distribution between the work roll and the plate, the transverse load distribution between the work roll and the backup roll, and the rigid body movement of the work roll have to be identified.

Calculations — In this theoretical analysis, the principles of 2-dimensional elastic deformation are employed to construct the basic equilibrium equations to solve the unknowns. These equations are derived from the vertical force equilibrium of the work roll, the deformation compatibility between

Fig. 1 — Basic rolling mill configurations.



the work roll and backup roll, and the deformation compatibility between the work roll and the plate. Both rolling mill and workpiece have been assumed to be symmetrical about the mid-span. One half of the roll span has been divided into m elements, and the load distribution replaced by a concentrated load at the middle of each element. The plate width, which is less than the roll barrel length, is divided into n elements, $(n<m)$, with the same loads acting on it. This leads to a problem involving $(m+n+1)$ unknowns, ie, m values defining the load distribution between the work and backup rolls $(p_1, p_2, \ldots p_m)$, n values defining the load distribution between the work roll and the plate $(q_1, q_2, \ldots q_n)$ and the rigid body movement (K) of the work roll.

The three general equations yield $(m+n+1)$ equations. These were solved by matrix algebra on a digital computer using Fortran. Provision was made to insure that the tension during rolling does not exceed the yield stress of the material. The mathematical derivation of these equations is shown in appendices I and II.

Fig. 2 — Arrangements of 4-h mill crown control jacks. Top: jacks between work rolls; middle: jacks between work rolls and backup rolls; bottom: jacks between backup rolls.

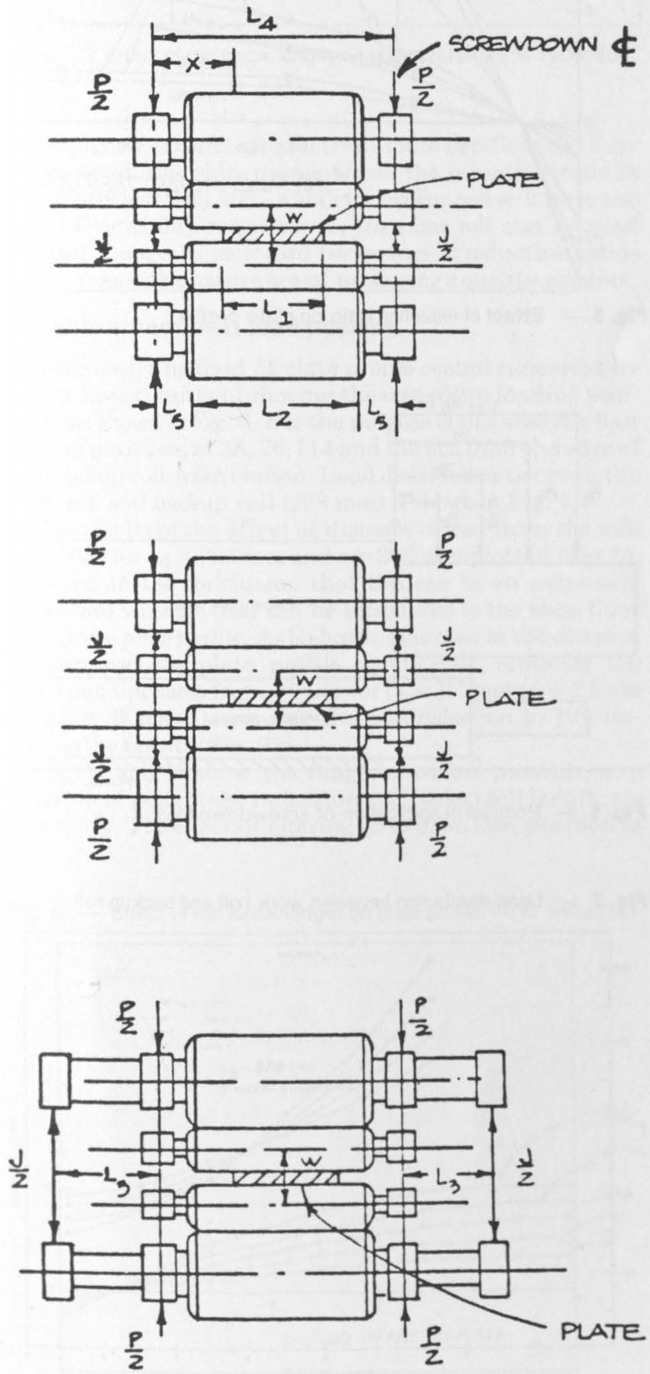


TABLE I Conditions in the analysis

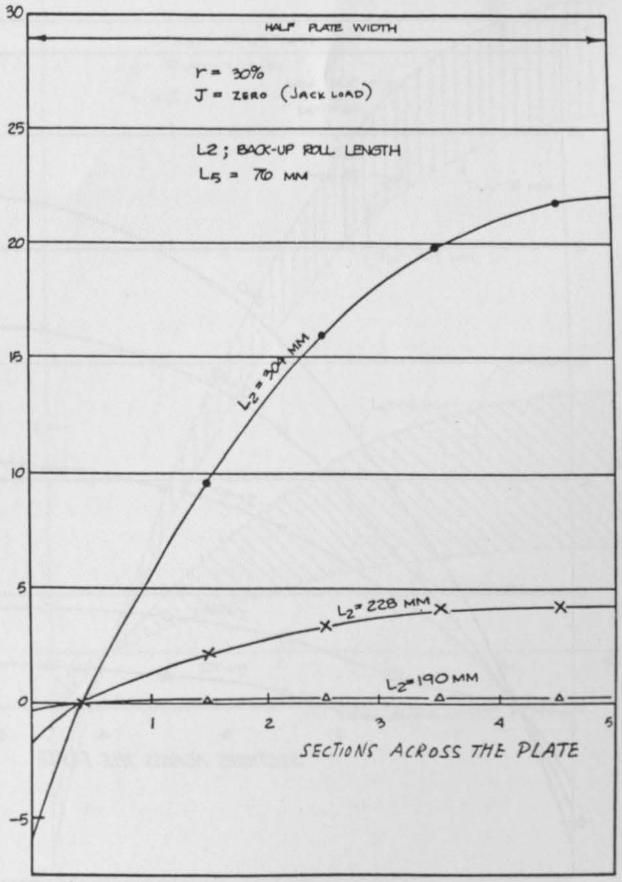
	Case 1	Case 2	Case 3
Backup roll length (mm)	304	228	190
Jack load (kN)	0,20,40,60,70	0	0
Work roll length (mm)	304	304	304
Pass reduction (%)	35,30,20,10	35,30,20,10,5	30
Load position L_5 (mm)	76	38,76,114,158	76
Longitudinal tension (kg/mm^2)	0	0	0
Roll material	Steel	Steel	Steel
Plate material	Copper	Copper	Copper

The conditions used in this analysis are summarized in Table I. The method of control shown in Fig. 2 (top) was employed. Neither work rolls nor backup rolls are cambered. Thermal crown and fatigue have been neglected, and the workpiece feed thickness has been taken at a constant 0.5 mm.

L_1 through L_5 represent the following: L_1 = width of plate; L_2 = backup roll body length; L_3 = distance from screwdown load position to jack load position; L_4 = roll bearing span; L_5 = distance from screwdown load position to end of backup roll body.

Where the backup roll and work roll are of the same length, the method of Shohet and Townsend was used.[3] The modification to the basic equations for use when the backup roll is shorter is outlined in appendix I. Roll flattening was calculated according to the method of Stone.[5] Rolling loads were

Fig. 3 — Effect of backup roll length on plate profile.



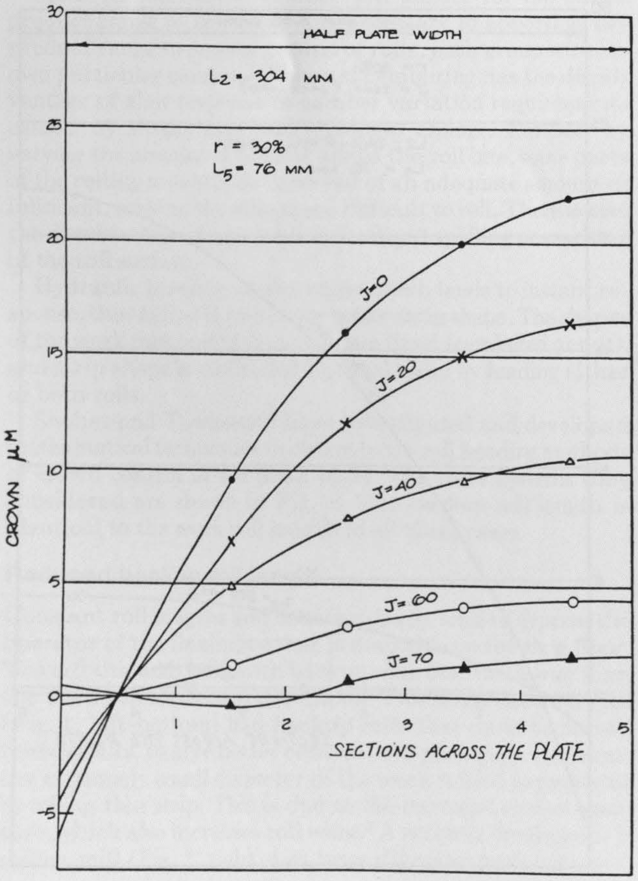
calculated by the method of Cook and McCrum[6] with modifications proposed by Gupta and Ford.[7]

Results and discussion — The results of the computer calculations are shown in Fig. 3 through 11. In addition to investigating the effect of change in backup roll length, jack load and pass reduction on the plate profile, the effect of the distance of the screwdown load from the mill mid-span in plate profile was also investigated.

The effect of the backup roll length on plate profile at 30% reduction and zero jack load is plotted in Fig. 3, showing that a shorter backup roll does yield a more desirable plate profile by a significant margin. The effect of increasing the jack load while maintaining the backup roll length equal to the work roll length is plotted in Fig. 4. Increasing the jack load from zero to 60 kN is found to significantly improve the plate profile. However, from this point on, contraflexing begins to appear in the product, and at 70 kN, the plate profile has quite a bit of contraflexure, denoting a limitation to the effect that can be achieved by increasing jack loads. This is in agreement with the work reported by Shohet and Boyce.[8] It should be noted that the same limitation is not observed when the backup roll is shortened.

The results of the investigation to determine the combined effects of pass reduction and roll length on plate profile were plotted (Fig. 5). For a backup roll length of 304 mm, the plate profile deteriorates rapidly with increasing pass reduction. The mid-span thickness is +3 μm for a 10% reduction, but increases over fourfold to +26 μm at 35% reduction. Shortening the backup roll to 228 mm reduces the deterioration in plate profile with increases in pass reduction. In particular, the difference in mid-span thickness for a 10% and 20% pass reduction is less than 1 μm, and at 35% the mid-span thickness is in the range of +5 μm. This leads to the conclusion that for 4-h mills, shorter backup rolls diminish the detrimental effect increased pass reduction can have in the plate profile, and

Fig. 4 — Effect of jack load on plate profile.



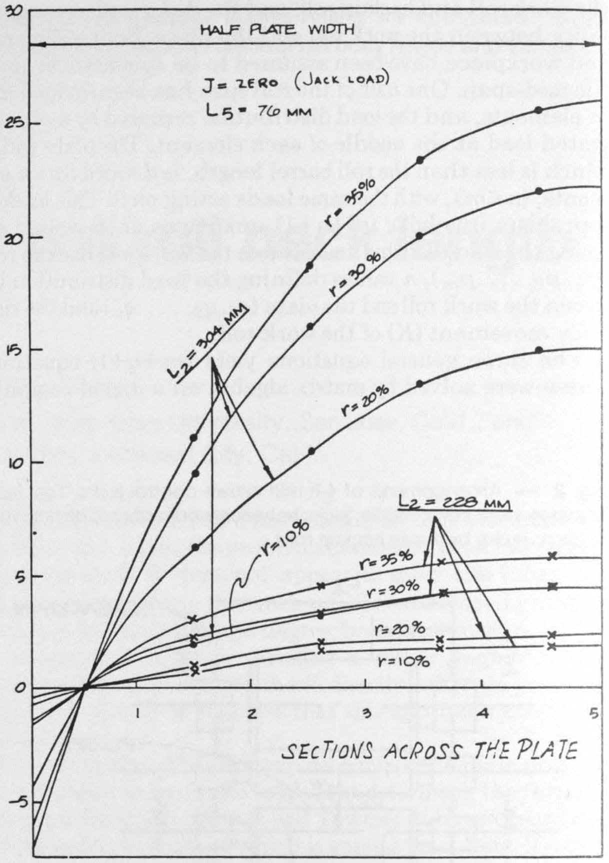


Fig. 5 — Effect of reduction ratio on plate profile.

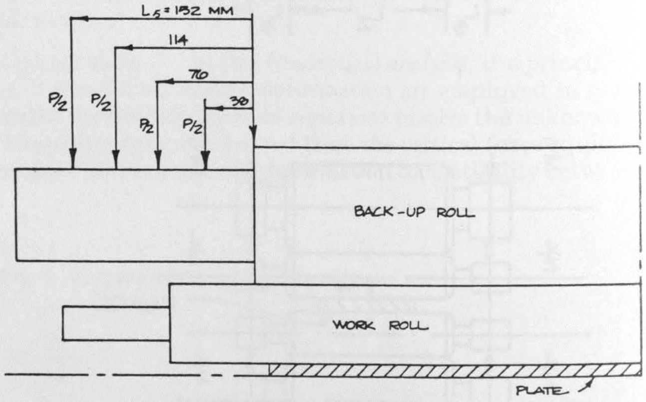
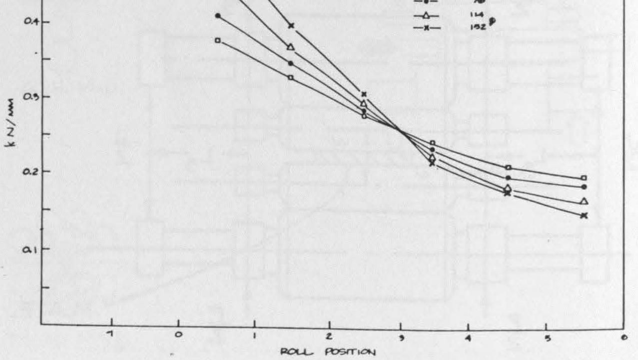


Fig. 6 — Position of application of screwdown load.

Fig. 7 — Load distribution between work roll and backup roll.



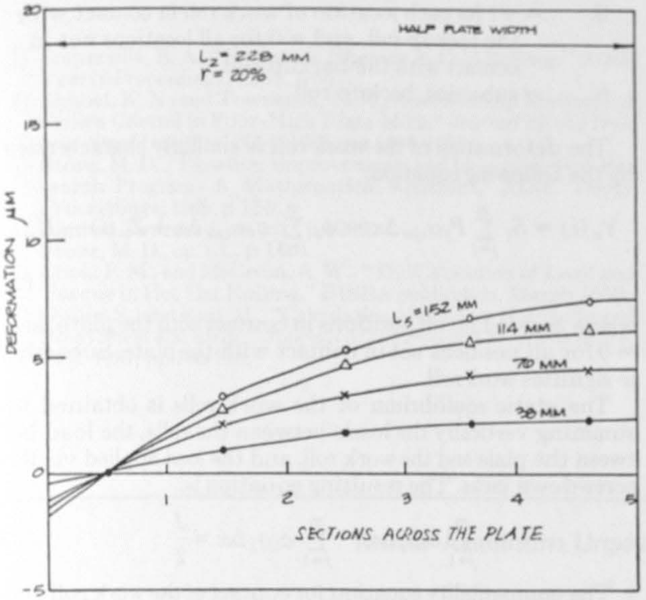


Fig. 8 — Effect of roll neck length on plate profile, 20% reduction.

consequently enhance productivity quite significantly. Furthermore, during skin passes where the reduction ratio is frequently less than 20%, a shorter backup roll will have the type of versatility required, ie, the same roll can be used without changes in jack load for a range of reduction ratios with a reasonable assurance of producing a quality product.

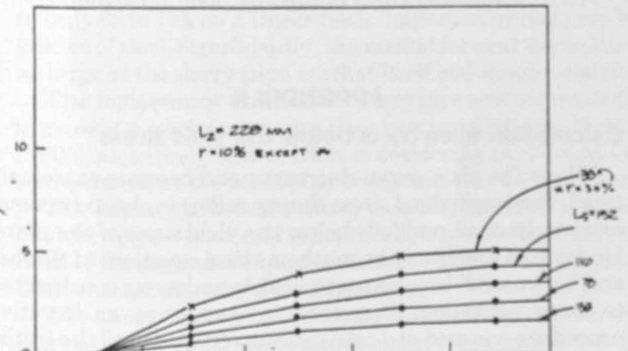
Variable screwdown load position

An alternative method of plate profile control conceived by the authors consists of moving the screwdown loading positions, as shown in Fig. 6. For the purpose of this analysis four loading positions, at 38, 76, 114 and 152 mm from the edge of the backup roll, were chosen. Load distribution between the work roll and backup roll (228 mm) is shown in Fig. 7.

The results of the effect of distance of load from the mill mid-span for $L_2 = 228$ mm and $r = 20\%$ were plotted (Fig. 8). This led to the conclusion that this can be an extremely important variable that can be introduced to the shop floor to improve plate profile. As is shown, a decrease in the distance L_5 improves the plate profile significantly, reducing the mid-span thickness from $+7\ \mu m$ for $L_5 = 152$ mm to $+2.5\ \mu m$ for $L_5 = 38$ mm. Decreasing the pass reduction to 10% improves the results (Fig. 9).

Fig. 10 and 11 show the ranges of control possible, as a function of percentage reduction and backup roll length, respectively. The effect of altering screwdown load position as

Fig. 9 — Effect of roll neck length on plate profile, 10% reduction.



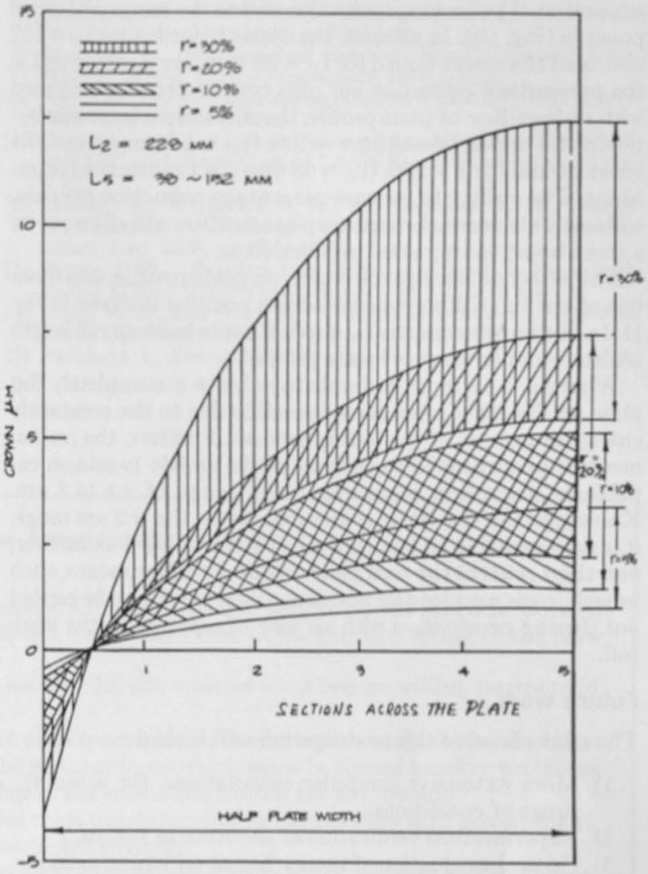
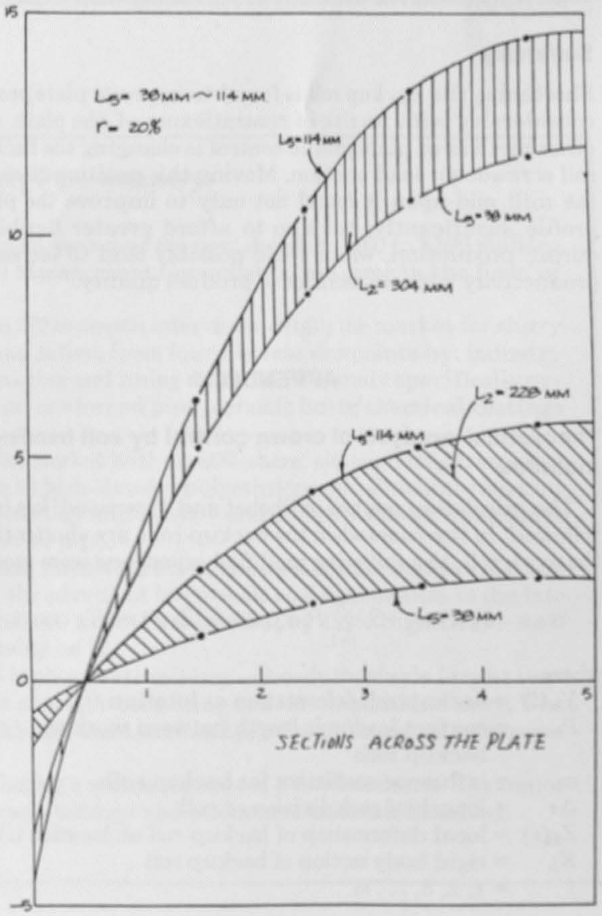


Fig. 10 — Crown control range as a function of roll neck length and reduction ratio.

Fig. 11 — Crown control range as a function of roll neck length and backup roll length.



a function of percentage reduction shows the range of control possible (Fig. 10). In all cases, the upper bound is for $L_5 = 152$ mm, and the lower bound for $L_5 = 38$ mm. By decreasing L_5, the percentage reduction per pass can be greatly increased with no sacrifice of plate profile; the difference in profile between the upper bound for r = 10% ($L_5 = 152$ mm), and the lower bound for r = 30% ($L_5 = 38$ mm), is practically nonexistent. The ability to increase percentage reduction per pass, without detrimental effects on plate profile, will of course be a great boost to increased productivity.

The effect of backup roll length on plate profile, as a function of backup roll screwdown loading position is shown in Fig. 11. In addition to shorter L_5, a reduction in backup roll length is also found to improve plate profile.

Whereas it is most desirable to achieve a completely flat plate profile, this is not always possible due to the constantly changing nature of the rolling process. Further, the instrumentation employed to measure plate profile is seldom capable of achieving accuracies in the range of ±1 to 2 μm. Knowing that the limits achievable are in the +2 μm range, it is now possible to fabricate rolls with this built-in camber, and then control the final plate profile by other means, such as jack loads and loading positions. This latter can be carried out during production with no fear of scratching the work roll.

Future work

The next phase of this investigation will include:

1) More extensive computer calculations for a wider range of conditions.
2) Experimental verification of theoretical results.
3) Critical evaluation of theory based on experimental results, and corrections to theory, as might be necessary.
4) Application of developed theory to rolling of other materials.
5) Consideration of strain hardening effects.
6) Application of this analysis for rolling with tension.

Summary

Shortening the backup roll is found to improve plate profile considerably with no risk of contraflexure of the plate. Another method of plate profile control is changing the backup roll screwdown load position. Moving this position closer to the mill mid-span is found not only to improve the plate profile significantly, but also to afford greater flexibility during production, which could possibly lead to increased productivity with no sacrifice of product quality.

APPENDIX I

Theoretical analysis of crown control by roll bending methods

The calculation method of Shohet and Townsend[2] has been followed. In the cases when the backup rolls are shorter than the work roll, the following modified equations were used:

$$Y_b(i) = -S_i \sum_{j=1}^{m} P_j \alpha_{ijb} \Delta x - Z_b(i) - K_b \qquad (1)$$

where

$Y_b(i)$ = backup roll deformation at location (i)

P = contact load/unit length between work and backup rolls

α_b = influence coefficient for backup roll

Δx = length of each division of roll

$Z_b(i)$ = local deformation of backup roll at location (i)

K_b = rigid body motion of backup roll

j = $1, 2, 3, \ldots m$

S_i = +1 for each location of work roll in contact with the backup roll, and = 0 for all locations not in contact with the backup roll

b = subscript, backup roll

The deformation of the work roll is similarly characterized by the following equation:

$$Y_w(i) = S_i \sum_{j=1}^{m} P_j \alpha_{ijw} \Delta x - \phi_i \sum_{j=1}^{m} q_i \alpha_{ijw} \Delta x + Z_w(i) - K_w \qquad (2)$$

where ϕ_i = +1 for all positions in contact with the plate, and = 0 for all positions not in contact with the plate. Subscript w signifies work roll.

The static equilibrium of the work rolls is obtained by summing vertically the loads between the rolls, the load between the plate and the work roll, and the load applied via the screwdown jacks. The resulting equation is:

$$\sum_{j=1}^{m} S_i P_j \Delta x - \sum_{j=1}^{m} \phi_i q_j \Delta x = \frac{J}{2} \qquad (3)$$

The compatibility equation for contact of the work roll and backup roll is written as:

$$-\sum_{j=1}^{m} S_i \alpha_{ij} \Delta x + \sum_{j=1}^{m} \phi_i q_j \alpha_{ijw} \Delta x - U_p(i) - M \sum_{j=1}^{m} \phi_j q_{ij} \Delta x + K_w = \gamma(i) + MJ + S + V \qquad (4)$$

where

$\gamma(i)$ = the gap between the work roll and backup roll at location (i), this is taken = 0 since the rolls in this analysis are not cambered.

M = stand flexibility, excluding rolls

J = total load in crown correcting jacks

S = toe of mill spring curve

V = toe of mutual flattening curve

The compatibility equation for contact of the work roll and plate is written as:

$$\phi \left[\sum_{j=1}^{m} S_i P_j \alpha_{ijw} \Delta x - \sum_{j=1}^{m} \phi_i q_j \alpha_{ijw} \Delta x - \frac{2Kq(i)}{2K - \sigma_F(i) - \sigma_B(i)} \times \frac{H(i)}{A} - K_W \right] = \phi_i \left[C(i) - H(i) \frac{A+B}{A} \right] \qquad (5)$$

where

$\sigma_F(i)$ = front tension stress in plate at location (i)

$\alpha B(i)$ = back tension stress in plate at location (i)

A = constant

B = constant

$C(i)$ = semi-height of roll gap at location (i) when there is no material between the rolls

$H(i)$ = semi-thickness of ingoing plate at location (i)

APPENDIX II

Calculation when α_F is below the yield stress

When the plate crown decreases and becomes extremely small, the longitudinal stress during rolling (α_F) also becomes extremely small, and falls below the yield stress of the plate. Under this condition, the mathematical equations of Shohet and Townsend[2] become inapplicable, unless α_F is subjected to some regulation. Therefore, in such cases, an iterative procedure was used and calculations repeated until the initial value of $\alpha_F(i)$ and its calculated value are within ± 1/1000 kN of each other. The value of $\alpha_F(i)$ thus obtained was then employed to compute the plate profile.

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Kaiser Aluminum Urges New American Revolution

The American System for solving problems must be revolutionized if the country is to survive the next decade, Cornell C. Maier, chairman of Kaiser Aluminum & Chemical Corp., said in a speech delivered at the annual meeting of the New Orleans Chamber of Commerce.

Nothing less than a new coalition between old adversaries is needed. Old adversaries must become willing partners in the New American Revolution.

Maier said that the 1980 elections showed that the people want and expect a basic, fundamental change in the direction of the U.S. Business leaders should become deeply involved in the new coalitions which must be formed to solve problems of minority unemployment, crime, housing, health, energy, inflation and education during the next decade.

Business cannot solve these problems by itself, but it can solve them through creative partnerships with government, educators, labor leaders, special interest groups, activists and interested citizens.

The revitalization of America's cities is one area which should be high on the business agenda. Corporations and businesses which maintain headquarters in city centers should stay there and others which have left the cities should return.

Life will not become better in the cities if business takes its jobs and economic base out and leaves a bigger problem for government to solve itself.

Source—Kaiser Aluminum & Chemical Corp. ▲

Multi-client Study on the Slurry Pipe Industry

The $100 million slurry pipe market is expected to grow at more than 6%/year over the next decade to $160 to $190 million. Much of that growth, according to a new study by PA International Management Consultants, will come in the form of replacement pipe for the nonmetallic mining industry.

The comprehensive multi-client study, which is based on more than 270 in-depth interviews, details the market for slurry pipe in 1980 with forecasts to 1985 and 1990 by linear feet, pounds and dollars from four discrete viewpoints by: industry and material; product type and diameter; end-use application; and coating and lining material. The study specifically examines steel and ductile iron pipe, lined pipe and fittings, plastic pipe, reinforced pipe, ceramic liners, chemical coatings and slurry pumps.

On a value basis, steel pipe—both lined and unlined—dominates the market with an 80% share, although this translates to only 65 to 70% on a linear basis. Important inroads are being made by high-density polyethylene and abrasion-resistant grades of steel. Significantly, the market for wear materials—linings, coatings and alloys—and pumps is almost three times as large as the slurry pipe market itself and should match the growth for pipe.

The replacement market for slurry pipe now accounts for more than three-fourths of the total market and is expected to grow at a much faster rate than new installations. However, with the advent of large-scale coal liquefaction in the late 1980's, an entirely new market is developing that could approach 200,000 to 800,000 linear ft by 1995. Significant R&D commitment by the steel pipe companies may be necessary to capitalize on it.

The largest markets for slurry pipe over the next five years will be in phosphate mining—already the single largest user of slurry pipe—sand and gravel dredging, coal-fired utilities, copper mining, iron mining and the chemical industry. The bulk of the demand is expected to be in 8 to 20-in. unlined steel pipe, although lined steel and plastics are projected to increase their market share by a small amount.

The study, limited to the continental U.S., covers slurry liquids having a solids content of 4 to 5% or more. The major slurry types investigated include matrix ores, in-process slurries, waste, tailings and pneumatic materials handling.

Source—PA International ▲