Improving Roll Cooling on Cold Tandem Mills

By C J Davenport & J K Smith, Innoval Technology Ltd.

There is a drive to increase productivity and strip speed from cold tandem mills. This increases the energy inputs and transfers further load onto the mill cooling system to achieve stable roll and strip temperatures. The coolant used in a modern mill performs multiple functions. It must remove heat from the rolls, provide lubrication to the rolling process and wash away debris which might otherwise give surface quality problems. The cooling system is also an important actuator in strip flatness control by controlling the roll thermal camber. All these functions must be performed simultaneously.

The addition of oil in the form of an emulsion or a dispersion affects the heat transfer properties of the coolant. This is illustrated in Figure 1 which shows the effect of adding small quantities of oil to the water to provide the lubrication. These data were obtained using the heat transfer rig described in Reference 1 and shown in Figure 2. This consisted of a 500mm diameter rotating roll with cylindrical heaters placed around its circumference just below the surface, amounting to 42kW of heat input. Coolant sprays were directed at the heated surface while the roll was rotated at a set speed and the roll surface temperature measured. The surface area over which the measurement was made was defined using shrouds to limit the circumferential extent of the spray pattern. The heat input required to maintain the roll temperature was measured and this allowed a calculation of the heat transfer coefficient (in kW/m^2K) from the spray. Many different spray configurations and coolants were tested using this equipment. Some of the results are presented in Reference 1.

Although the heat transfer performance of a 4% emulsion is significantly less than that of pure water, it is still very effective compared with mineral oils.

Cooling tandem mills

Tandem mills have particular problems associated will roll cooling. Figure 3 shows a five stand cold mill with typical strip gauges and speeds by stand. If significant reductions per stand are being made then the strip temperature rise through the bite can be significant. This temperature rise is passed on to the next stand. By the time the strip is entering the final stand it may be considerably hotter than when it entered the mill. This increases the load on the final stand cooling system.

The situation may be alleviated by the presence of inter-stand strip cooling. Sometimes, on aluminium strip tandem mills, inter-stand cooling is installed and used to control the strip temperature entering stands. The effect of this inter-stand cooling is to allow the mill to run faster for a given coil temperature and thus increase productivity. Inter-stand cooling has a very rapid effect on the productivity of a mill, assuming there is sufficient power available from the mill motors to take advantage of it.

A second problem with tandem mill rolling is the low speeds at which the early stands must operate. This is seen from Figure 3 where the first stand speed is only 3.2m/s. When the roll surface is moving slowly through a cooling spray, the surface layers of the roll are severely chilled by the cooling action of the spray. This chilling reduces the temperature difference driving heat from the roll to the spray and thus reduces the cooling effectiveness of the spray. The heat entering the roll from the strip must now be removed by a less efficient cooling spray. The only way this can be achieved is for the bulk roll temperature to increase to maintain the driving temperature difference and remove the heat. This is one of the reasons why the work rolls of the first stands of hot tandem mills tend to run hot.

It should be noted that although the outer surface of the rolls is chilled by the sprays, this chilling is confined to only a few millimetres of depth below the surface. A few millimetres below the roll surface the temperature is almost constant around the circumference.
One of the consequences of the sharp temperature gradients in the radial direction within the roll is the imposition of thermal stresses. These stresses are repeated and reversed every rotation of the roll and so contribute to fatigue damage of the roll surface.

Roll cooling illustration

Figure 4 shows the spray pattern produced on a roll from three banks of flat jet sprays with the sprays twisted at 15° to the horizontal. The r oll surface has been opened out into a flat surface so that the bottom of the diagram shows the roll bite and the top is where the work roll meets the back-up roll. The diagram shows the effective extent of each of the spray banks acting on the roll surface and also gives the Cooling Effect of the bank. This is the number written at the right hand side of the pattern. The Cooling Effect is the heat transfer coefficient generated by the spray pattern on the roll surface multiplied by the circumferential extent of the bank Its units are kW/K m width. It depends on both the shape of the spray pattern and the flow rate of coolant supplied to the nozzles. These values are calculated by Innoval software which incorporates a large volume of published data and analysis on cooling sprays to allow the heat transfer calculations to be made. Not shown in Figure 4, but included in the heat transfer calculations, is a layer of coolant active on the roll surface below the Bank 1 spray. This layer provides further cooling of the roll.

The diagram in Figure 4 also shows the sensitivity of the spray pattern shape to the roll diameter. The sensitivity is greater for the off-centre sprays than for those pointing directly at the roll. Note also that the level of lateral overlap of the spray patterns is sensitive to roll diameter and to the position of the spray pattern around the roll circumference. This is more obvious when the sprays are pointing at a small glancing angle to the roll.

In order to illustrate the effect of surface chilling on the cooling effectiveness, the following case is considered:

		Units
Minimum, nominal and maximum roll diameters	510, 530 and 550	mm
Net heat input to the roll from the strip	200	kW/m width
Coolant flow rate	1.15	l/min m width

If all the flow is used in a single bank of sprays, the rolls run at a higher temperature than if the same flow is distributed between three banks. This is seen in Figure 5 which shows the roll temperature as a function of roll speed for one, two and three banks respectively with the same ***total*** coolant flow in all cases. The calculations made here include the effect of the coolant layer below the Bank 1 sprays.

This illustrates that it is far more effective to distribute the flow on the roll surface than to concentrate it at a high intensity on a very small circumferential portion of the roll. This is particularly important for slowly rotating stands. In this situation, little will be achieved by increasing the pressure or the nozzle size of a spray concentrated over a small area on a slowly rotating roll. The roll speed effect disappears at higher speeds. However, even at high speeds there is still a superiority of three banks over a single bank due to the better use of the roll surface area to remove heat.

Sometimes it is not possible to install three spray banks on the mill due to space restrictions. There are ways of making a single or double bank cool over a larger area by varying the major and twist angles for a flat jet and the major angle for a cone spray. These possibilities can all be explored using the appropriate computations of spray pattern as shown in Figure 4. If two spray patterns lie close together on the roll surface then it will not be possible to obtain the sum of the benefits of the banks acting separately. This is because of spray pattern interaction. The sprays from each bank interfere as they attempt to operate on the same area of the roll surface. This is a very common scenario and one which must be included in the calculation of the total effect of groups of banks.

Flatness control

The cooling sprays provide a powerful actuator for strip flatness control by allowing the rapid adjustment of the local thermal state of the roll by switching spray banks on and off. Very small changes in local thermal expansion of the roll will produce measurable flatness changes, so that only the very outermost parts of the roll need to be affected by the spray switching. This means that the changes can be made very rapidly because only a very small mass of the roll is being affected by the spray changes. These changes are normally reviewed by the flatness system every few seconds.

Reference 2 shows a method of quantifying the effects of switching off a spray nozzle on the cooling in the zones to the left and right of it. Algorithms are proposed which can be used in computer models for calculating the distribution of heat transfer coefficient on a roll surface resulting from particular switching patterns.

In flatness control it is important to be able to distinguish the effect of switching individual lateral zones of sprays. If the sprays overlap excessively, then the control will be “soft”. The roll diameter variations affect the degree of overlap and the sensitivity of the overlap to roll diameter depends on the nozzle/roll distance and the other nozzle parameters. The banks need to designed carefully to make the pattern overlap insensitive to roll diameter.

It is also important that the spray patterns do not have excessive lateral asymmetry, since in this case, switching off a bank will affect the zone to the left differently from that to the right. This will have an undesirable effect on the rolled flatness. In designing a roll cooling system it is important to take into account all these factors. When they are included in the proper way, the effect on the performance of the roll cooling system can be quite striking.

References

1. Method of Measuring Heat Transfer between a Rotating Roll and a Cooling Spray
   C J Davenport
   Ironmaking and Steelmaking Vol. 23 No. 1 . 1996

2. Measurement and Modelling of Roll Cooling Distributions
   C J Davenport
   Proc. Institute of Metals. Modelling of Metal Rolling Processes. Symposium 3. Prediction and Control of Thermal Conditions. 12th December 1991. London.

Figure captions

Figure 1. Influence of oil additions on the effectiveness of roll coolants.

Figure 2. Test rig for measurement the heat transfer performance of cooling sprays (Reference 1).

Figure 3 Schematic of a five stand tandem mill showing stand speeds and strip gauges.

Figure 4 Spray patterns on the roll surface from three banks on the entry side of a mill stand. The figures to the right of each pattern are the calculated Cooling Effects of each bank (kW/K m width)

Fig 5 Effect of roll speed and spray distribution (one, two or three banks) on work roll temperature. The total coolant flow is the same in all three cases.

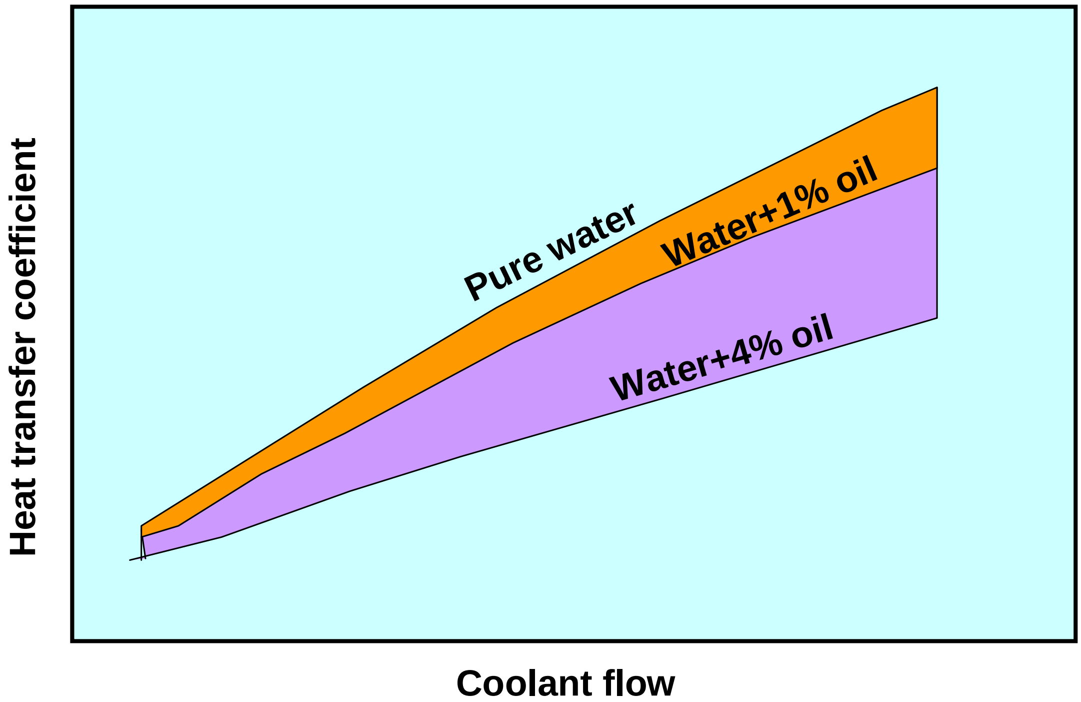

Figure 1 Influence of oil additions on the effectiveness of roll coolants.

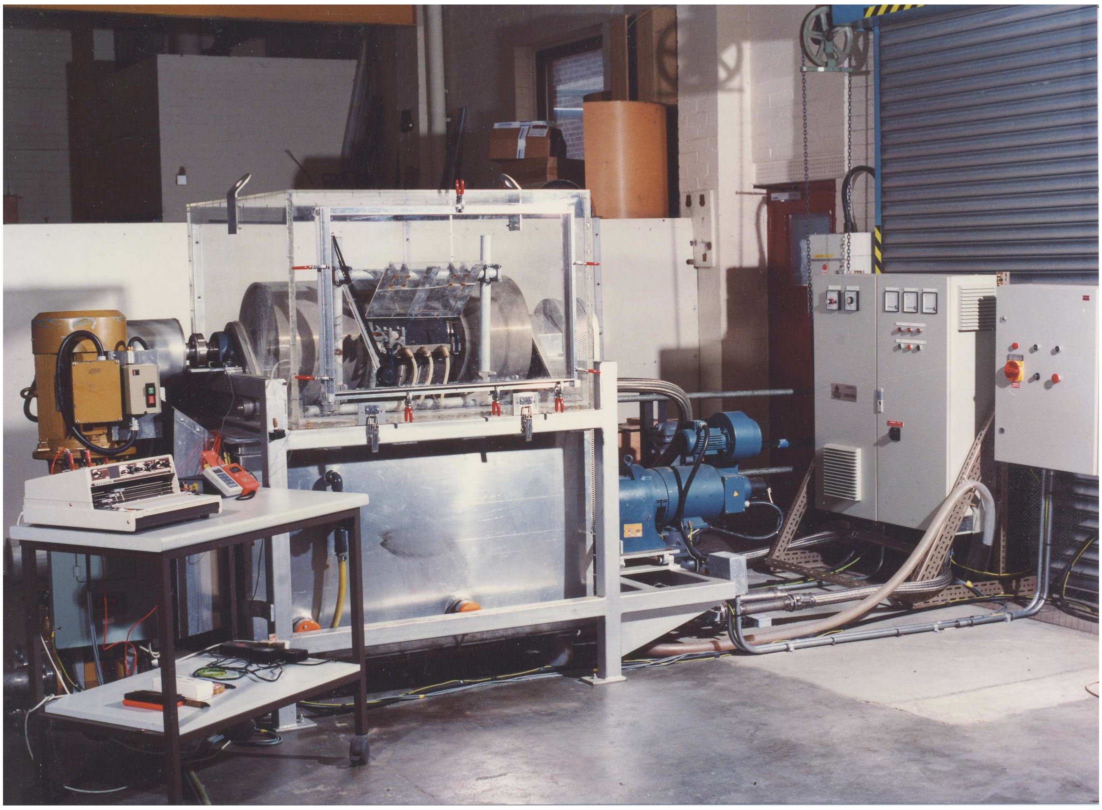

Figure 2 Test rig for measurement the heat transfer performance of cooling sprays (Reference 1).

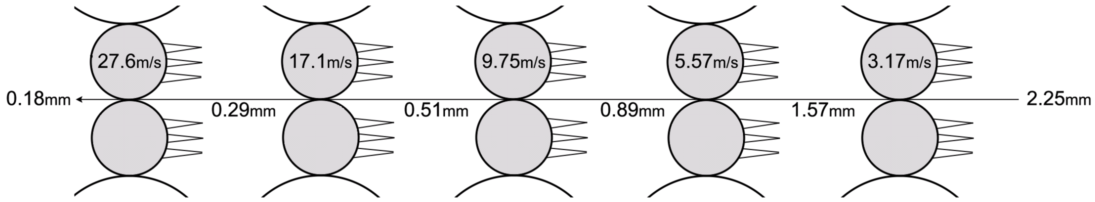

Figure 3 Schematic of a five stand tandem mill showing stand speeds and strip gauges.

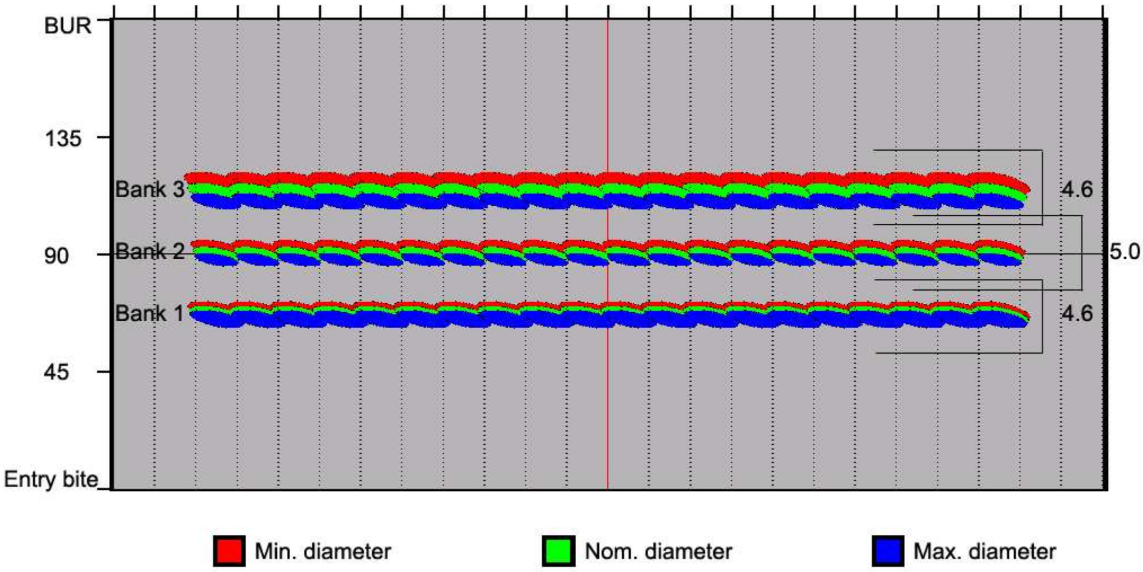

Figure 4 Spray patterns on the roll surface from three banks on the entry side of a mill stand. The figures to the right of each pattern are the calculated Cooling Effects of each bank (kW/K m width)

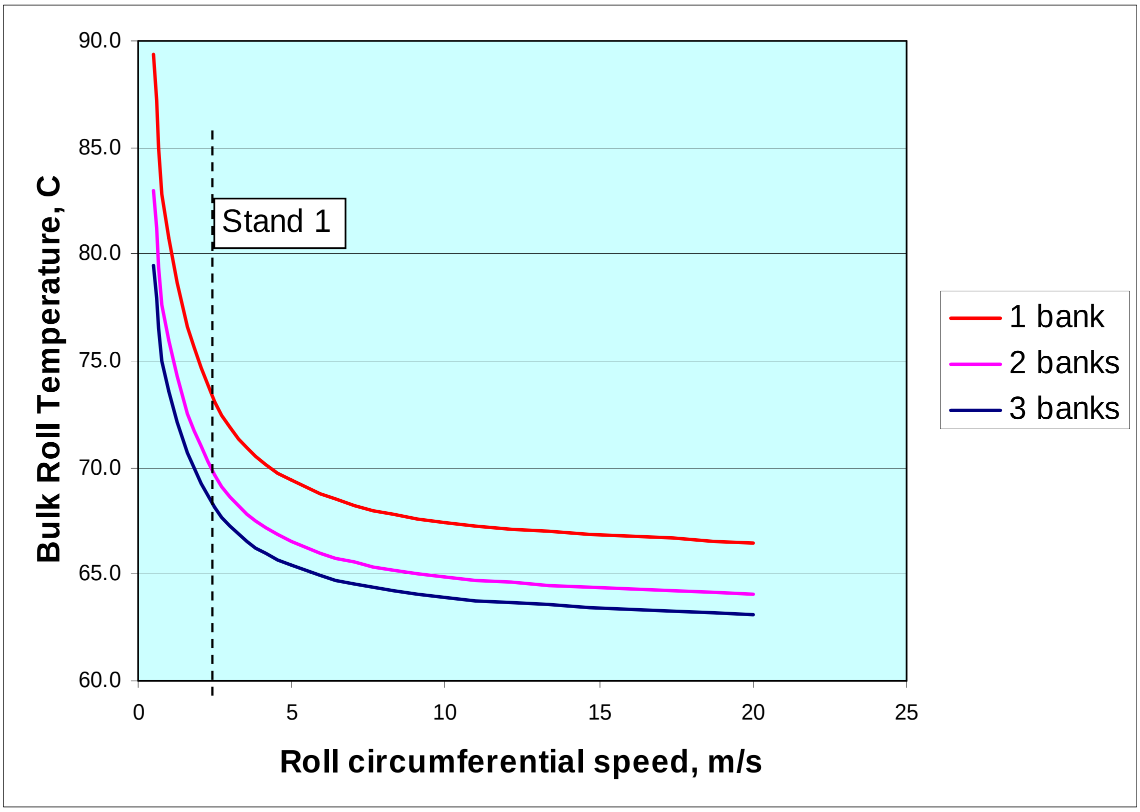

Figure 5 Effect of roll speed and spray distribution (one, two or three banks) on work roll temperature. The total coolant flow is the same in all three cases.