Run of the mill

Innoval Technology (Innoval) specialises in working with aluminium rolling mills and similar processes, in order to achieve a high rate of return on the capital invested. This article covers some of the methods employed by Innoval’s consultants to get the most out of the rolling process. The focus is on the use of computer-based models to supplement their understanding of the process and predict the performance, as well as the best ways of running the equipment. By Dr Rade Ognjanovic*

Rolling mills are expensive machines that are carefully managed. A mill can have a service life of a few decades and it will be regularly upgraded.

It may be that the rolling mill itself is not run in a mode to make it as productive as possible. For example, this may involve running the rolling mill at below its fastest speed in order to achieve a product with the correct characteristics that can be processed more easily downstream of the mill. Software tools and techniques can be used to help optimise a process stream.

In simple terms, the rolling process involves rolling an ingot or sheet into a thinner product. If we consider the ingot, it starts off with straight orthogonal surfaces. After every pass, the sides, the ingot front end (nose) and rear end (tail) will become less planar. Finite element analysis (FEA) models can be used to predict the nose and tail shapes along with the lateral spread of the ingot. After about five passes through the mill the nose or tail may open up (to form an “alligator”), an example of which is shown in Fig 1. The alligator is a common form of deformation in the rolling process. It is guillotined off and discarded before it becomes too large to enter the roll gap or cause other rolling problems such as initiating a crack that can run a considerable length down the ingot along the ingot centre in the horizontal plane.

In order to minimise the amount of alligatoring and wastage of material, the rolling conditions can be varied. A model can be constructed that predicts the formation of an alligator and then that model used to adjust the normal rolling and edge rolling practices to influence the shape of the alligator. This will avoid the expensive trial and error approach to developing the sequence of normal rolling and edge rolling reductions (otherwise known as the pass schedules) that some mills use. There is a limit to the size of the reduction. Too large and the ingot cannot be rolled (a refusal) or the roll forces and motor torque may be too large for the mill stand and motors. However, if the reductions are too small they increase production times and the ingot can cool too much which can make it very difficult to roll.

In Innoval, such a validated FEA model is used to predict the shape of the alligator, see Fig 2. Only the top half of the ingot is modelled because of the horizontal plane.
of symmetry. Similarly, only one side of the ingot is modelled because of vertical plane of symmetry running down the length of the ingot. Both planes of symmetry enable the simulation to run quicker by reducing the number of elements in the simulation and therefore the number of calculations.

The alligator shape depends on the rolling geometry, aluminium alloy, friction and pass schedule. The pass schedule can involve edge rolling to control both the lateral spread and the shape of the alligator so this is included in the Innoval FEA simulation. Rolling schedules can thus be developed to minimise the amount of material lost at the guillotine by varying the reductions and sequence of normal rolling and edge rolling. The cost of developing the schedule on computer is lower than the cost of multiple on line trials.

Innoval also has a fast-running analytical rolling model to predict roll loads and torques amongst other things. Some modules of the model have been developed by using FEA models to predict, for example, forward slip. Forward slip is how much faster the slab exits the roll bite compared to the roll surface speed. It is expressed as a percentage of the roll surface speed and it is easily measured on the mill. Two-dimensional FEA simulations, such as the one in Fig 3, can be used to calculate the forward slip. From the results, analytical expressions can be derived for use in the fast-running model.

A typical relationship between roll friction and forward slip is shown in Fig 4. Extrapolating the curve in Fig 4 to lower values of friction will result in zero forward slip at which point the ingot will refuse (not roll). This type of information is used to calibrate the rolling models and predict refusal conditions.

The same FEA model was used to study the velocity of material through the roll bite. Early rolling models assumed the material passing through the roll bite did not have a velocity distribution through the ingot thickness in order to simplify calculations within the model. This class of rolling model is called a homogeneous model. Recently, more complex and more accurate models allow the material velocity to vary through the ingot thickness and are called non-homogenous models.

The FEA model of rolling predicts a significant velocity distribution through the ingot thickness as shown in Fig 5 at three points – the roll bite entry, exit and the neutral point. The neutral point is where the ingot surface speed matches the roll speed and the roll surface speed was 1 m/s in this example.

At the roll bite entry, the blue curve in Fig 5, the ingot surface is moving faster than the ingot centre. At the exit, the brown curve, the ingot surface, is moving slightly faster than the ingot centre. At the neutral point, the red curve, the ingot surface is moving close to the 1 m/s roll surface speed, the slight discrepancy is a consequence of the discretising of the ingot into finite elements. However, the ingot centre at the neutral point is moving at almost 1.03 m/s, about as fast as the exit velocities.

This type of modelling helps to develop the rolling model so that velocity distributions through the ingot thickness are correctly accounted for.

As mentioned above, the mill is run in a mode that is optimum for the process as a whole. This means the processes upstream and downstream of the mill need to be considered and this is where Innoval can use some of its other process modelling tools to find the optimum conditions for the line or product.

If a multi-slitting line takes sheet from a mill, the sheet has to meet certain specifications for thickness profile and flatness otherwise the slitter cannot wind the slit strips. Innoval has a winding model to develop winding strategies to give stable winding in slitters. The winding model is used to set mill targets for flatness and profile. This is an example of where the whole process chain must be considered to improve process efficiency.

The winding model predicts the contact pressures between laps. If the contact pressures are too small the coil can collapse as it is moved off the slitter. The winding tensions can be adjusted to avoid this. Larger winding tensions can increase contact pressures between laps but at the risk of crushing the core onto which the laps are wound. If the winding tensions are too low and there is a thickness profile or flatness profile on the incoming sheet, the slitter can have winding problems due to loose coiling (where some slit material becomes loose between the knives and the wound slit product).
Loose coiling can cause tangles, which immediately clog the slit and production stops. All the care, resource and energy used to produce the coil is lost. Depending on the amplitude of profile and flatness, the winding tensions can be adjusted during the run to avoid loose coiling and core buckling. The lap compressibility (compliance) which is the deformation of laps as they are compressed, absorbs some of the profile and flatness differences across the width of the sheet during winding.

The lap compressibility is dependent on the lap contact pressures, large contact pressures pack the laps tightly and the laps become less compressible. The winding process cannot cope with too high a value for profile or flatness under these conditions. The task is to tailor the winding tensions during the run to control the lap compressibility to absorb profile and flatness differences during winding.

Lap compressibility will vary through the coil and during the winding process because as each lap is added to the coil, the lap contact pressures already on the coil will change. Although lap contact pressures can be measured it is difficult to do so because the measurement disturbs the coil and the results are error prone. A winding model calculates the contact pressures. Armed with that knowledge, the winding process can be controlled and the process window for incoming flatness and profile increased considerably.

In reality, the profile and flatness will vary along the length of the coil. Typically, profile at the start and end of the coil is worse as the mill accelerates and decelerates either side of the steady state conditions. The varying flatness and profile as a function of position down the length of the coil can be put into the winding programme to provide more accurate predictions of winding stability.

If a levelling process follows the rolling mill then Innoval has two models that can help to define process windows – the Innoval Tension Leveller program (Fig 6) and a FEA simulation of a roller leveller. The Innoval Tension Leveller program is shown with the geometry of the rolls and strip in the top sash window and the strip through thickness stresses and strains in the bottom sash window. The model can predict sheet curvature for example and the levelling conditions such as the roll differential speeds can be varied to find the optimum settings. It has been validated against a FEA model of a sheet going round rolls such as the roller leveller example in Fig 7. The FEA model has itself been validated using rolls with force transducers to measure the levelling forces. The forces are dependent on both the alloy and its temper condition.

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