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Mathematical model brings energy savings for coil annealing furnaces

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Mathematical model brings energy savings for coil annealing furnaces

A mathematical model, originally used in copper smelters, has been used on coil annealing furnaces. It is expected to brig CO2 savings of 8300t of CO2 at a production output of 80kt/y of aluminium compared to 'earlier generation' multi-coil furnaces.

The coils of strip made in aluminium mills by hot and cold rolling are subjected to many intermediate and finish annealing treatments for metallurgical reasons. It is common practice that coils of different alloy composition, geometry and residual heat content are placed in shopfloor buffer storage and allowed to cool before undergoing the actual heat treatment in so-called chamber furnaces. Chamber furnaces may be of single or multi-coil design. A major benefit of single-coil units, as the name implies, is that they allow the operator to anneal each coil individually. As a result, a change of alloy, product geometry or start temperature is easily possible between batches. Drawbacks of this equipment type include the large space requirement, relatively high investment cost and somewhat higher specific energy needs, all of which must be taken into account. In view of these factors, multi-coil furnaces still have their justification. Some recent Otto Junker developments are briefly reviewed, which are expected to implement the aforementioned advantages of the single-coil furnace in the multi-coil unit. One requirement in multi-coil furnace operation is that the coils placed in the furnace should have the same geometry and start temperature so that the desired metallurgical properties can be obtained in a reproducible manner by the recipe-based heat treatment (Fig 1). Major deviations of these two parameters can be allowed if the coil temperatures are measured throughout the heat treatment cycle and these temperature readings are fed to the furnace control system. For control purposes the multi-coil furnace is divided into several individually controlled heating zones with a view to heating each coil separately by the jet heating principle using specially designed nozzle fields. Coil temperature measurements can be taken via contact thermocouples or by means of sheathed thermocouples embedded in the coil. A disadvantage of these methods is that the strip surface quality may become locally impaired, eg by imprint marks.

Fig. 1 Multi-coil annealing furnaces designed by Otto Junker

Mathematical modelling

Moreover, it is necessary to allow set-up time for embedding the sheathed thermocouples into the coil, and the maintenance cost for the contact thermocouples also needs to be considered. In the past few years, Otto Junker has been able to accumulate experience with mathematical modelling of heat treatment processes on copper strip treatment lines and copper billet heaters. It was confirmed that integrated mathematical models can enhance the reliability of the process while also helping save energy1.

The objective defined for the heat treatment of strip coils in multi-coil furnaces was that the temperature distribution of each coil should be calculated in real time, and that the result of the calculation should be used as furnace control input. For metallurgical reasons, a calculation accuracy of better than ± 5K must be repeatedly achieved in this application. As a general rule, mathematical models are intended to describe a system's response to a hange in exterior relations.

Energy transfer

One important task in the present context lies in computing the energy transfer from the fluid to the coil – a step which calls for an accurate understanding of the underlying energy transfer mechanisms. In the case of aluminium the heating process is clearly dominated by the forced convective portion, although for the accuracy required, the radiant heat transfer between the furnace and the coil must not be neglected, either. To this end, basic research was undertaken in cooperation with the Technical University of Aachen (RWTH) to gain a physically correct grasp of key correlations and to ensure that these would be duly represented in the mathematical model 2.

The aim in these investigations was to minimise the number of parameters requiring adaptation to the actual situation during start-up and in subsequent production operations, and to ensure that the programmed modules would be transferable to similar applications elsewhere. The temperature distribution over space and time within the coil can be described with sufficient accuracy by a partial differential equation, assuming consistent metal characteristics. Although, in the case of coils, it is necessary to note significant differences between the radial and axial thermal conductance.

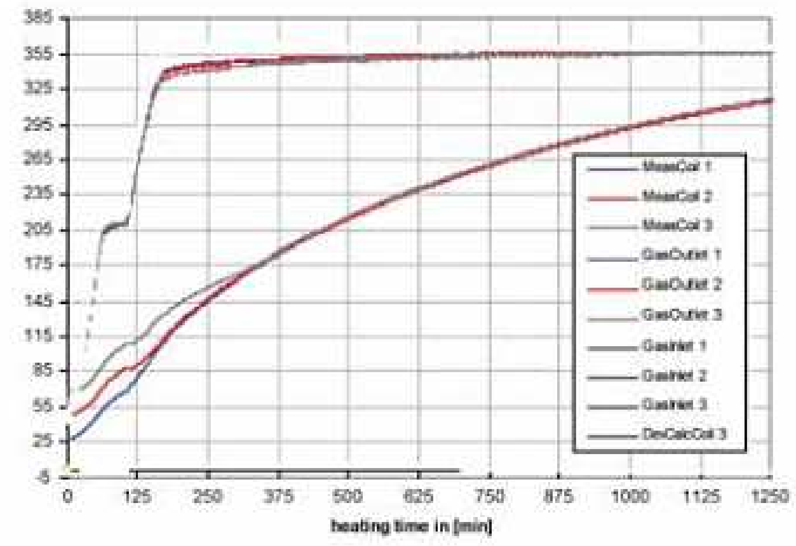

Fig 2 Temperature curves obtained for a multi-coil heat treatment furnace

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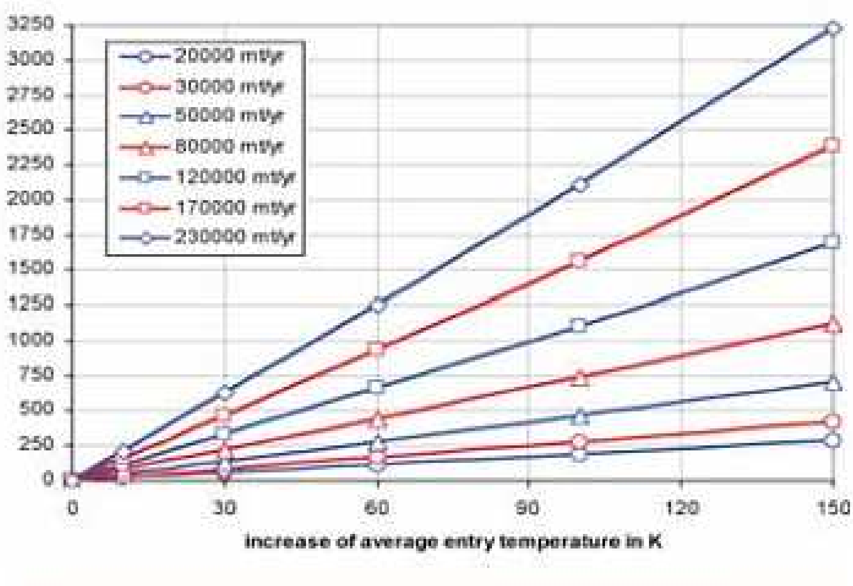

Fig 3 CO_2 savings as a function of the mean coil temperature at the start of heat treatment

The differential equation is solved by the finite differences (FD) method, dividing the coil into layers and the time into intervals. For the FD process to become stable, the time resolution and spatial resolution must at all times be mutually matched on the basis of the coil's thermal conductivity. Once the mathematical model is calibrated and stabilised, the following benefits are to be anticipated:

• Given the ability to support greater geometrical and temperature differences between coils, the furnace can be filled to 100% capacity more frequently, ie, furnace capacity utilisation will be improved while energy consumption is reduced.

• Since greater temperature differences between coils are allowed, it will be possible, ideally, to charge coils in their ‘as rolled’ temperature state. As a result, the mean temperature at the start of the heat treatment cycle will be increased. The energy requirement will diminish accordingly.

• Unlike the physical temperature measuring methods mentioned earlier, a mathematical model will need no set-up time or maintenance in this respect.

Results

The first results obtained with a mathematical model developed along the principles described above are shown in Fig 2. The illustration shows the temperature profiles of three coils as measured during the heat-up phase. The coils were placed in the furnace with starting temperatures of 25 - 75℃, and were heated to the same target temperature of 320℃ ± 3 K from their respective state. For testin g purposes, the furnace was controlled using data from a mathematical model, which has been in use since mid-2010. In the case of Coil 3, the difference between the measured temperatures (MeasCoil 3) and the calculated ones are not greater than -1K and +8K, respectively, at any time (DevCalcCoil 3). During the last third of the heat-up cycle, this difference was even better than -1K and +2K throughout.

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CO2 savings

The rise in mean coil temperature prevailing at the start of the heat treatment will save energy while also reducing CO_2 emissions. Fig 3 illustrates the CO_2 savings achievable at different annual annealing capacities by increasing the mean coil temperature at the start of the heat treatment cycle. The comparison was made between two annealing furnaces of the multi-coil type. The reduction in CO_2 output has been calculated on the basis of specific CO_2 emission figures for the current mix of electricity sources in Germany. Around two-thirds of this reduction are attributable to fuel savings (assuming that the furnace is running on natural gas), the remaining third reflects electrical power savings (assuming that the increased coil temperature at the start of the heat treatment will shorten the heat-up cycle and hence, reduce fan operating times). In mid-2011, Otto Junker will supply five multi-coil furnaces – along with the charging machine and a complete automation system – to Alu Norf GmbH. At the automation level, a computer cluster linking the PLC, HMI and modeling computers is created and tied in with the manufacturing requirements planning (MRP) system. An offline version can be used to load data of coils currently in shopfloor buffer storage; these coils can then be arranged into energy-optimised or time-optimised furnace batches comprising four coils in each case. The batches determined by means of the optimising calculations are then returned to the MRP system and cleared for heat treatment. The heat treatment process is then controlled with the online version, which relies on the same computing core. This innovation project is subsidised by the Federal Ministry of Environment because the integration of a mathematical model is expected to yield a significant reduction in energy consumption and hence, CO_2 emissions. Since the comparison was carried out against 'earlier generation' multi-coil furnaces, the anticipated savings of 8300t of CO_2 at a production output of 180kt/y of aluminium still exceed the results illustrated in Fig 33. The project is slated to be completed by the end of 2011, so that the first reports on operating experience are to be anticipated for 2012.

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