High convection flow – improved performance in coil annealing

by **Mariusz Raszewski**

The annealing of the coil is a very important step during the production of aluminum alloy sheet metal. Coil annealing is performed between the various milling steps and after the final cold milling to achieve the desired material properties. Furthermore, during this annealing, the milling oil is removed from the strip surface by vaporization. If this vapor passes across metal at too high of a temperature, it may crack on the strip surface causing surface quality problems. Production demands require the heating and annealing process be carried out in a tightly controlled environment, eliminating any local overheating of the surface, and in as short a cycle as feasible.

Because the effective thermal conductivity in a strip coil is much lower in the radial direction than in the axial direction, the most effective way of heating the coil is through the edges of the coil wraps. The difference between the thermal conductivity for the two directions is caused by the heat insulating effect of the gas and milling oil layers in the coil between the strip layers.

The heat flux in the axial direction, however, is determined by the thermal conductivity only. In the 1970's and 1980's, so called "jet heating" by gas jet impingement on the coil head surface [1] was developed. The highest possible heat transfer by forced convection is produced by round jets, arranged at the corners of square, or of triangular, patterns with equal side length. The nozzle spacing is about 6 nozzle diameters with the nozzles located about the same distance from the surface they are impinging on. The heat transfer coefficient distribution for such a system is a ratio of approximately 2 between maximum and minimum local value.

There exists the potential for the coil head surface to be locally overheated when the average temperature of the entire coil reaches the set point. To address this problem, in the middle of 1980's there was developed a nozzle system [2] consisting of a star-like array of slot jets, which are inclined against the coil axis in order to avoid the jet impingement zones with extremely high heat transfer.

The limitation of this nozzle system is that if the position of the coil is not in the center of the star-like nozzle pattern, the head surface edges can still be overheated. In addition, as the distance increases from the nozzles to the load, the heat transfer decrease is somewhat higher than for the conventional straight round jet nozzle system.

Fig. 1: Vortex nozzles system

Fig. 2: Straight nozzles plate

Fig. 3: High Convection Rotating Flow system

Fig. 4: Measured surface of the coil

The reason for this larger decrease is the tendency of jet flows from a nozzle which is inclined against the air plenum surface to become attached to the nozzle bottom due to the suction zone created between nozzle bottom and slot jets.

THE NEW NOZZLE SYSTEM: HIGH CONVECTION VORTEX FLOW JET HEATING™

In order to overcome these limitations, there was developed the nozzle system shown in **Fig. 1**. It consists of rozund jet nozzle tubes that are positioned at the corners of square patterns that are inclined against the nozzle plenum wall. The nozzle tubes are arranged to develop a vortex rotation flow. Instead of one big vortex as formed by the old system, the new system employs an array of "vortex brushes" to accomplish the heat transfer without hot spots. This results in minimizing the importance of the position of the coils. Due to the vortex flow rotation caused by the grouping of four jets, a suction is created between the jets that keeps the jets together and minimizes the impact of increasing distance between nozzle plenum and coil head surface. The decrease of the heat transfer with increasing distance is significantly reduced.

The ratio between maximum and minimum heat transfer is approximately 1.2. Furthermore, the open area of the nozzles is increased considerably in comparison to the older nozzle systems. This means that more kilograms of furnace atmosphere are circulated and blown onto the coils in order to heat one kilogram of aluminium. The new nozzle system combines the advantages of high convection jet heating and mass flow principles. Under the assumption that locally on the coil surface a maximum heat transfer coefficient of 170 W / (m^2K) can be tolerated, the allowed average heat transfer coefficient for the jet heating system with straight round jets, is 110 W / (m^2K) and for the new system 150 W / (m^2K). This results in a correspondingly faster heat up rate.

Test furnace

Before entering the market with the new product manufactured the test furnace at its facility to run numerous trials. This furnace was a batch type, single zone car bottom furnace. The interchangeable nozzle plates allowed heating of the coil using different nozzle designs and patterns, as well as changing the nozzle to coil distance. The heat source was four radiant tube natural gas burners with the total installed power of 500 kW. The semi-axial fan powered by a variable speed motor, provided the required flow and pressure for the wide range of nozzle systems. Additionally, the by-pass ducts were used to optimize the flow parameters for every type and size of nozzles.

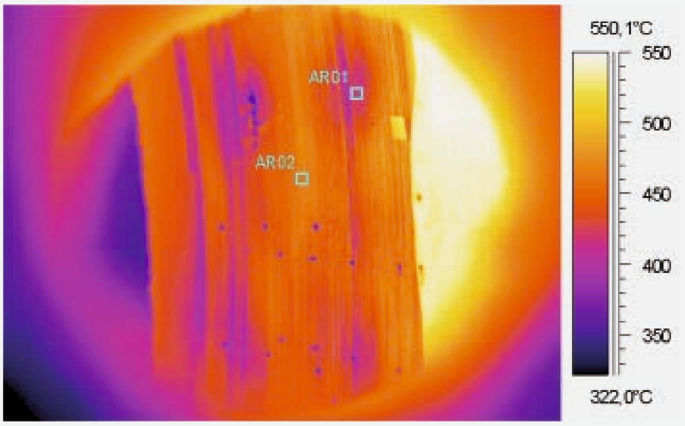

Fig. 5: Thermovision picture of coil heat up using straight nozzle system

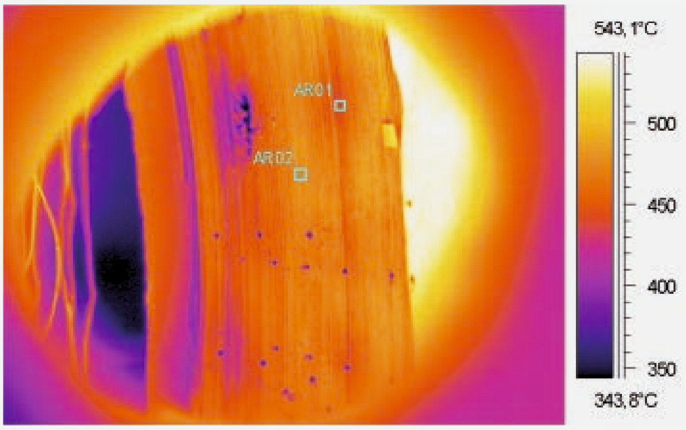

Fig. 6: Thermovision picture of coil heat up using nozzle system

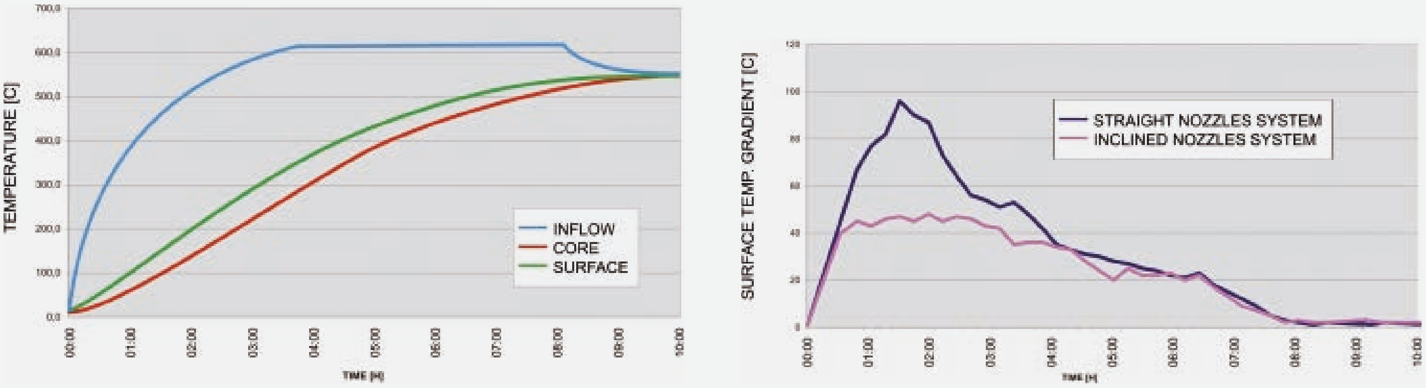

Fig. 7: Temperature uniformity profiles

The PC/PLC control system provided the flexibility to run the process according to the chosen procedure, and to record the temperature profiles from up to 50 thermocouples placed throughout the coil. A thermovision (infrared mapping) camera was used to monitor coil surface temperature as it proved to be the most accurate tool for this application.

Trails

The goal of the trials was to compare the heat transfer coefficient uniformity on coil surface during the heating up phase of the annealing process using the standard straight nozzle system and the new vortex flow nozzle system.

The test coil was made of 1,050 material type, 1.700 mm outer diameter, 800 mm inner diameter, 1.060 mm width and the weight of ca 5,000 kg[1]. Throughout the coil, 33 thermocouples were placed to read the coil temperature. In both the straight and vortex nozzle trials the same nozzle diameter (49 mm) and the same nozzle to coil surface distance (300 mm) was used (**Fig. 2** and **3**). The same inflow air temperature (620 °C) and the same final annealing temperature (550 °C) were considered in both trials. To obtain comparable test conditions, the total time to reach the final annealing temperature throughout the entire coil within a tolerance +/- 3 °C was required.

A preliminary series of tests were designed to establish the air flow (fan speed) specific for each jet system. In both cases the total time to reach annealing temperature was 9 h and 30 min with a tolerance of 3 min.

The main tests consisted of two heat up cycles using 2 different nozzle systems under the conditions as described above. The coil volume and coil surface temperatures were continuously monitored and recorded. Monitoring the coil surface temperature was done with

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[1] The coil for the tests delivered by Aluminium Konin – Impexmetal S.A. company from Konin, Poland

a thermovision technology to eliminate the influence of different contact conditions between the thermocouple wire and coil material. This also provided a simple method of identifying the hottest and coldest areas on the coil surface.

Test results

The first analysis of the pictures from the thermovision camera (**Fig. 4, 5** and **6**), equally scaled, indicated that a more uniform surface temperature was achieved by using the new High Convection Vortex Flow Jet Heating™ system.

The coil surface temperature uniformity profiles (**Fig. 7**) present the overview of temperature uniformity for the entire heat up cycles. This confirms that better surface uniformity was achieved by the new nozzle system.

The profiles are based on the hottest and coldest 1 cm^2 areas of the coil surface. The readings are taken from infrared pictures made in 15 min intervals during the whole cycle.

The α min/α max ratio calculated based on the above data is 1,25 for the new nozzle system and 1,65 for the standard straight nozzle system. For aluminum alloys of lower thermal conductivity, the difference in this parameter is expected to be even higher.

INDUSTRIAL APPLICATION

Until now Seco/Warwick has sold 13 multi-zones furnaces equipped with Vortex Flow Jet Heating™ system: twelve 3-zones furnaces with the charging machine work in Turkey for a leader in manufacturing of flat rolled aluminum products. The annealing line could work with automatic control for the process. One 4-zones furnace, equipped with by-pass cooler and a hot-car, works in Thailand at one of the leading kitchenware manufacturers factory.

The Vortex Flow Jet Heating™ furnaces are equipped with the very high efficiency auto-recuperative burners installed in the radiant tubes. In the combination with the lower motors power for the high efficiency recirculation fans Seco/Warwick annealing lines confirmed the very low energy consumption for gas as well as electricity.

LATEST ANNEALING PROCESS OPTIMIZATION WITH MATHEMATICAL MODELING

After the commissioning of the first Vortex System Lines Seco/Warwick started to work to optimize the annealing process as well as having the reduction of the process cycle and utilities consumptions.

The latest developed product for the Vortex Furnaces

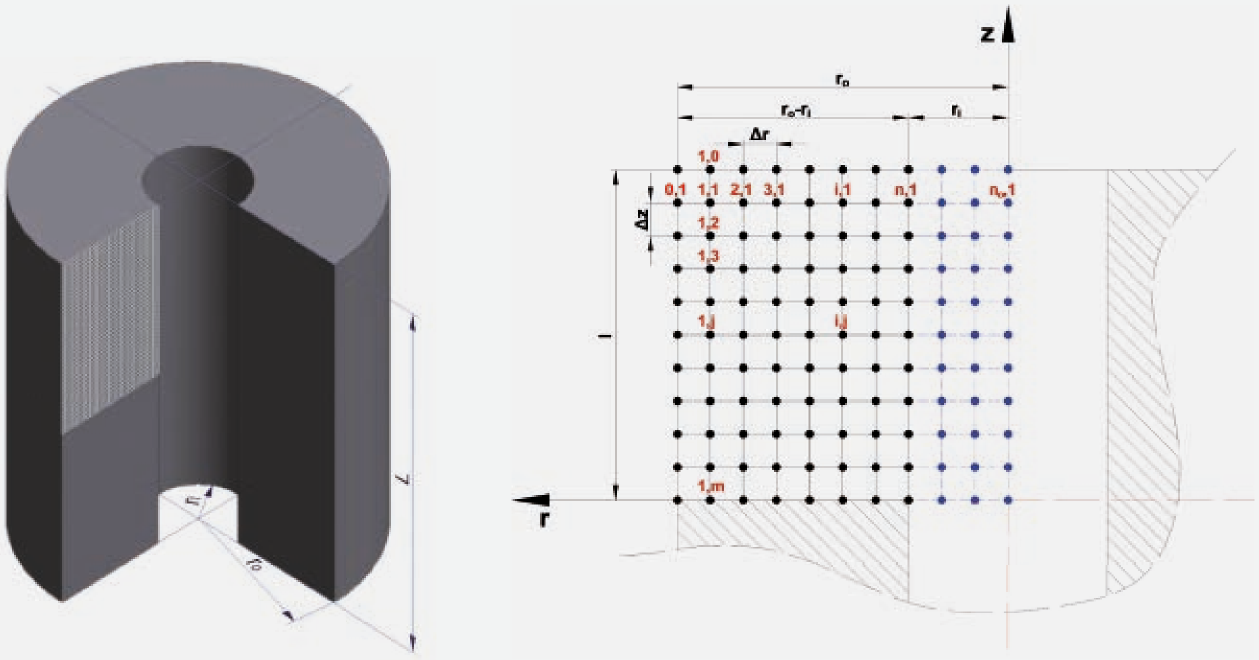

Fig. 8: Differential mesh of the coil for mathematical analyzes [4]

has been the optimization of the annealing process program by mathematical modeling. The goal of that project was to create the automatic control and software not only for the heat up times reduction but also better control of the whole annealing process in one zone and multi-zones applications. The annealing process is controlled in the furnace according to the one point measurement of coil surface with the use of sting, retractable thermocouple (there is no need to destroy the coil surface with the load thermocouple or wire). Thanks to that the process control will automatically inform the operator about the cycle time required to run and finish the process. With the use of that system there is no need for the operator to select each recipe different for each size, aluminium alloy, type of the coil. It will be automatically and online regulated by the control system (**Fig. 8**).

Thanks to annealing process program done according to the mathematical model the process could be reduces in the heat up stage as well as the soak section. The program has to ability to present the online temperatures in the whole area of each coil.

The mathematical modeling and several industrial trails have been made to make the measurement in real and all the necessary correction refer to theoretical and computer analyzes and result in the coils in real (**Fig. 9**).

Optimizing the annealing process in Vortex System Furnaces the program could control the time required to heat and soak each coil. It controls the required volume and the velocity of the heat to be transferred to the each coil separately with the online control of the pressure, velocity and temperature.

CONCLUSION

Considering that the maximum local heat transfer coefficient is the limit of the heating rate, the new High Convection Vortex Flow Jet Heating™ system heat the coil more effectively and uniformly. During the last years several research projects have been done for the optimization of the system and has developed the annealing process to find the maximum reduction in heat up times and the better process technology possible with the Vortex system. During the annealing processes done in the Vortex Flow industrial applications the heat up times reduction could be even up to 30 %, over traditional systems appeared possible, while improving material property uniformity, and avoiding localized overheating of the coil surface.

LITERATURE

[1] Kramer, C.; Knoch, M.: Studies on the optimum design of flow circuits in industrial furnaces (in German language), gas wärme international 10 (1984), p. 497 - 503

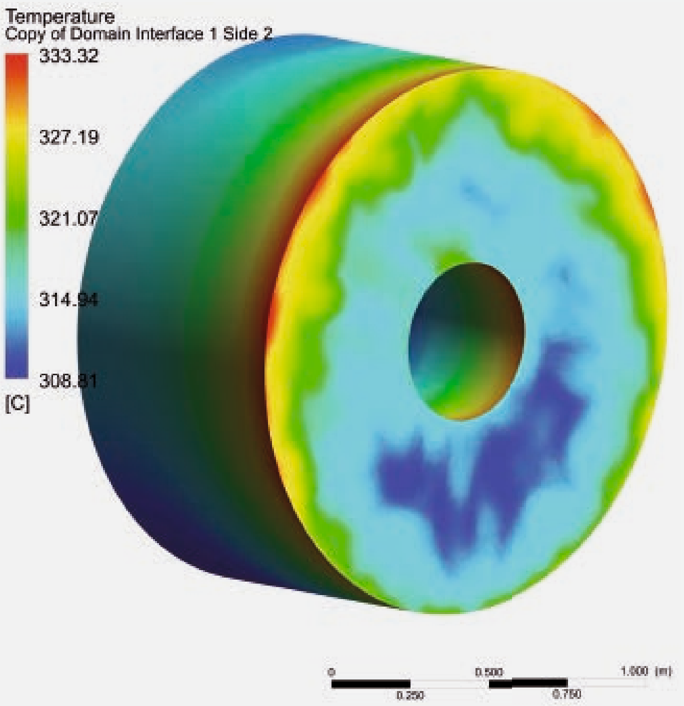

Fig. 9: Model 3D cross section coil temperature during heating stage [4]

[2] Kramer, C. (Inventor): Vorrichtung zur gleichmäßigen Beaufschlagung einer planen Oberfläsche eines Werstücks mit einem Gas (Apparatus for evenly directing a gas towards a flat surface)

German patent DE 350 3 089, applied: 30.01.1985, granted: 08.12.1988

[3] Kramer, C.: Hochkonvektionsanlagen für die Wärmebehandlung von Halbzeugen in: Report about the VIII International JUNKER – furnace conference, 1987

[4] Dr. Piechowicz Ł.; Dr. Wyczółkowski R.; mgr Łukaszek D.: Model matematyczny procesów cieplnych na podstawie instalacji do wyżarzania blachy aluminiowej w zwojach, 2011

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