High Convection Vortex Flow – Improved Performance in Coil Annealing

Introduction

SECO/WARWICK has secured the patent rights for the vortex flow jet nozzle system for improved performance in aluminum process furnaces first developed by Prof. Dr.-Ing. Carl Kramer. A prototype coil annealing furnace with interchangeable nozzle systems was built. A series of experiments have been completed to compare a typical straight nozzle design with the new High Convection Vortex Flow Jet Heating nozzle system. The results have shown that the new system maintains a more uniform coil surface temperature during the heat up phase. This result enables a shorter annealing cycle without local overheating, preventing localized cracking of milling oil, and produces more uniform material properties. This article describes the main features of the new High Convection Vortex Flow Jet Heating system and presents a preliminary report of the trial results.

The Process

Coil annealing is one step in the process of aluminum sheet metal production. Coil annealing is performed after the final cold milling to achieve the desired metallurgical properties. During the annealing process, milling oil is removed from the strip surface by vaporization. If this vapor passes across the 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.

State Of The Art

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 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.

The potential exists 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 1985, Prof. Kramer developed a nozzle system 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.

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.

High Convection Vortex Flow Jet Heating

In order to overcome these limitations, Prof. Kramer developed the nozzle system shown in Fig. 1. It consists of round 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.

Fig 1 Vortex Nozzle System

The ratio between maximum and minimum heat transfer is approximately 1.2. Furthermore, the open area of the nozzles is increased considerably when compared to 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 aluminum. 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.

*Watts/meter^{2}Kelvin

Test Furnace

The test furnace (Fig. 2) is a batch type, single zone car bottom furnace. The interchangeable nozzle plates allow heating of the coil using different nozzle designs and patterns, as well as adjusting the nozzle to coil distance. The heat source is four radiant tube natural gas burners with the total installed power of 500 kW (kilowatt). The semi-axial fan, powered by a variable speed motor, provides the required flow and pressure for the wide range of nozzle systems. Additionally, the by-pass ducts are used to optimize the flow parameters for every type and size of nozzles.

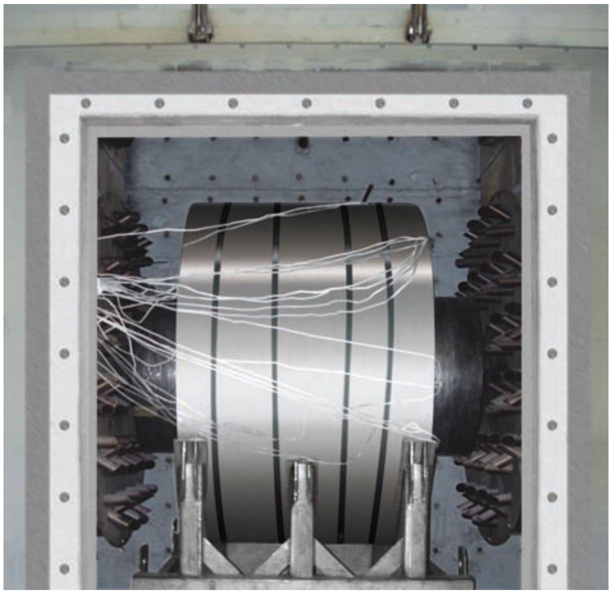

Fig 2 Test Furnace

The PC/PLC control system provides 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. An infrared mapping camera was used to monitor coil surface temperature as it proved to be the most accurate tool for this application.

Trials

The goal of the trials was to compare the heat transfer coefficient uniformity on the coil surface during the heat up phase of the annealing process using the standard straight nozzle system with the new vortex flow nozzle system. The test coil was made of 1050 material type, 1700 mm (67 inch) outer diameter, 800 mm (31.5 inch) inner diameter, 1060 mm (41.7 inch) width and the weight of ca 5000 kg (11,023 pounds). 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/1.9 inch) and the same nozzle to coil surface distance (300 mm/11.8 inch) was used (Fig. 3, 4 & 5).

High Convection Vortex Flow – Improved Performance in Coil Annealing

Fig 3 Straight nozzle plate

Fig 4 Vortex high rotation nozzle

Fig. 5 Close up of coil

The same inflow air temperature (620ºC/1148ºF) and the same final annealing temperature (550ºC/1022ºF) 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 +/- 3ºC 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 hours and 30 minutes with a tolerance of 3 minutes. 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 infrared 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 infrared camera (Fig.6 & 7), equally scaled, indicated that a more uniform surface temperature was achieved by using the new High Convection Vortex Flow Jet Heating system.

High Convection Vortex Flow – Improved Performance in Coil Annealing

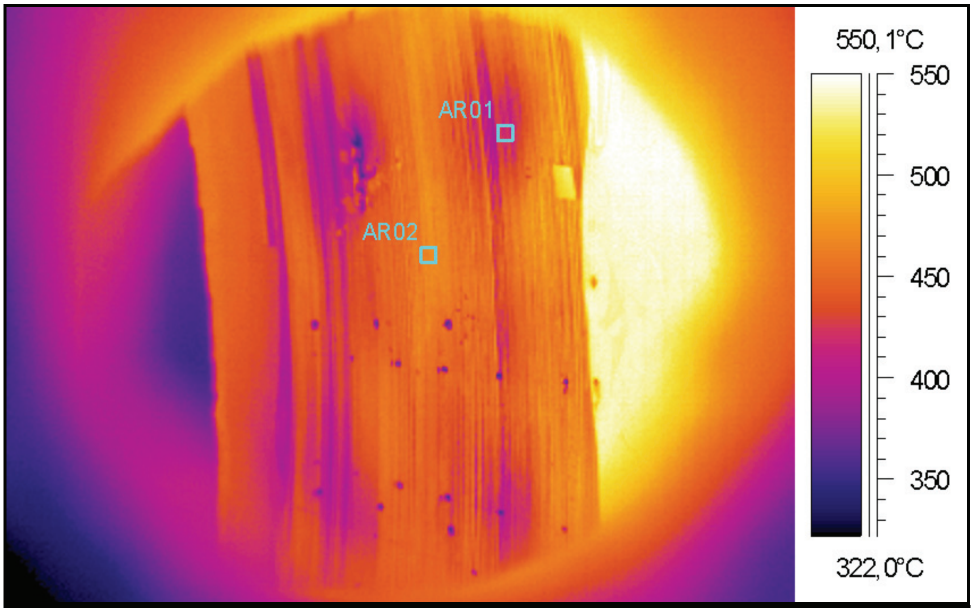

Figure 6

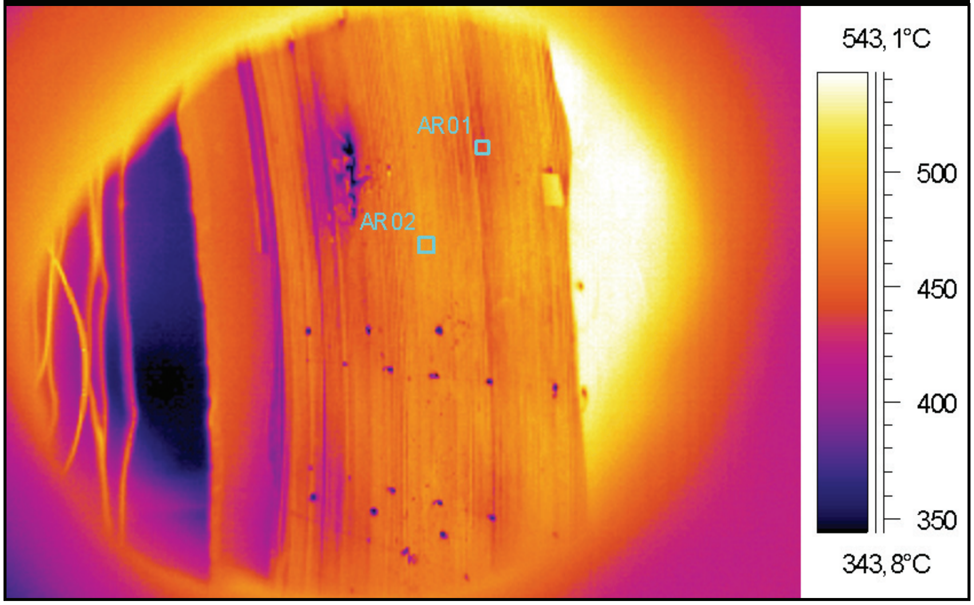

Figure 7

The coil surface temperature uniformity profiles (Fig. 8) 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 square centimeter areas of the coil surface. The readings are taken from infrared pictures made in 15 minute intervals during the whole cycle.

High Convection Vortex Flow – Improved Performance in Coil Annealing

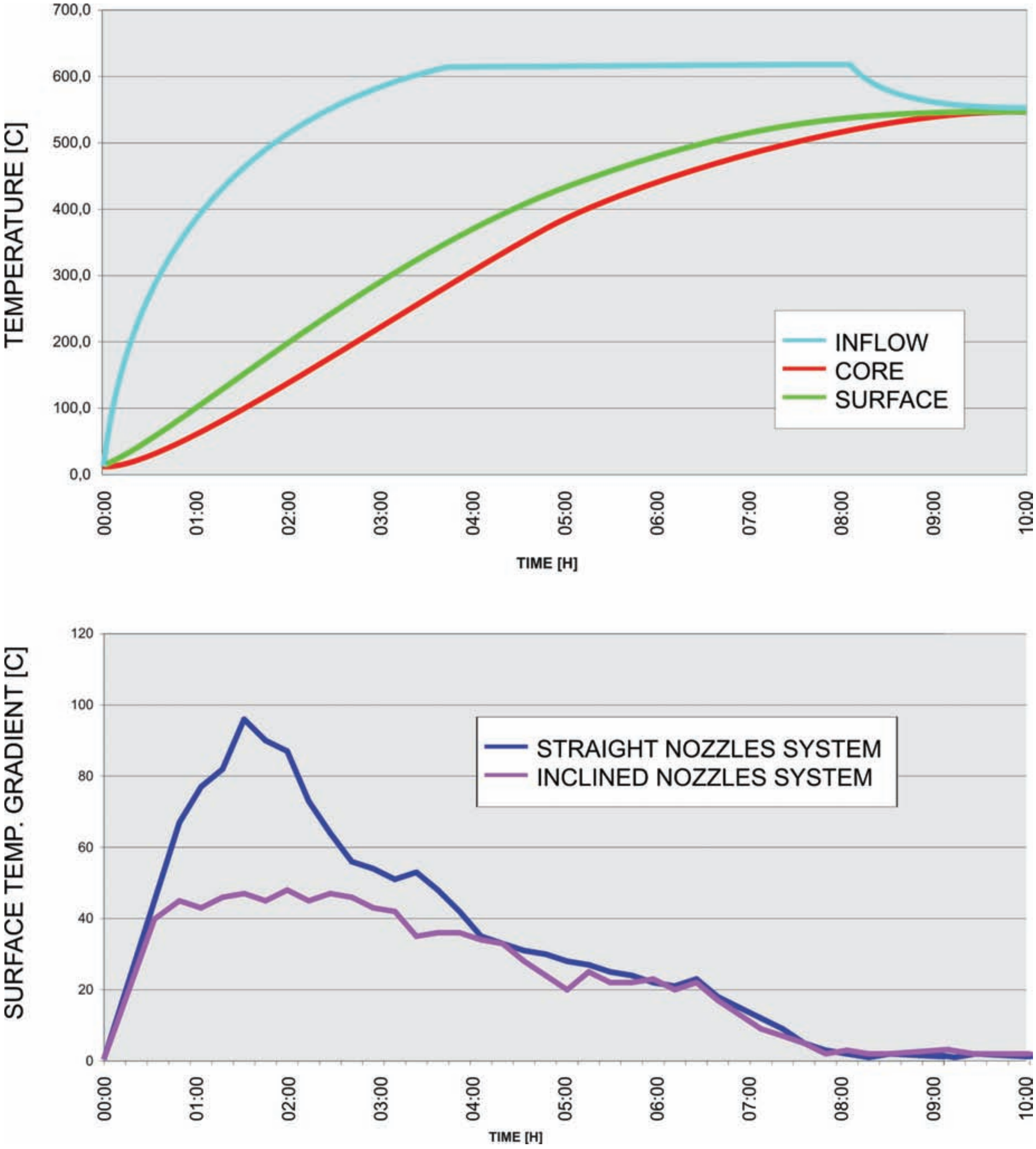

Fig 8 Temperature uniformity profiles

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.

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 can heat the coil more effectively and uniformly. Further testing is under way to determine the maximum reduction in heat up time possible with the new system. A potential heat up time reduction of up to 30%, over traditional systems appears possible, while improving material property uniformity, and avoiding localized overheating of the coil surface.

R1, 2/15/2006, First Printed in HEAT PROCESSING·(3)·Issue 2·2005
R2, 8/10/2006, updated photos, figure numbers