Automated Process Development and Monitoring for Continuous Belt Brazing Processes

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Introduction

There is a growing need for new technology to increase the level of control for continuous belt brazing processes. Consumer demand for lighter, smaller, more efficient products and increased regulation focusing on environmental and recycling issues are just two of the factors that the brazing industry is being forced to respond to. Whatever the reasons, the results are the same: tolerances and specification limits are shrinking and require tighter process windows than in the past. In industries using brazing, the answer to the demand for tighter process windows is the implementation of automated real-time thermal monitoring systems. This paper will discuss advances in thermal process setup and monitoring that make it possible for manufacturers to increase throughput and yield in copper/brass and aluminum Controlled Atmosphere Brazing (CAB) processes.

Overview of the Copper/Brass or Aluminum CAB Process

To successfully process Copper/Brass and Aluminum products in a CAB process the following elements are required: the optimal thermal profile, automated process monitoring to ensure that the process does not drift during production, the appropriate atmosphere specification, and a stable controllable furnace. The Copper/Brass process profile (for example) ramps up to 430°C, spikes to a peak of 650°C, and then cools to room temperature in a specified time. The Copper/Brass brazing compound binder must not flow until the alloy is liquid; therefore the control of the ramp-up and spike (to liquidus) is critical. When the binder is decomposing, it produces CO_2 and H_2O which are exhausted to maintain the oxygen free nitrogen atmosphere. The same concerns are also critical to the processing of an aluminum braze. The furnace design must be capable of addressing these concerns in order to complete the process successfully.

The Copper/Brass and Aluminum brazing processes are very similar in many ways, especially when they are employed in the manufacture of heat exchangers such as automobile radiators. (Fig. 1) **C**ontrolled **A**tmosphere **B**razing (CAB) furnaces for these two processes are almost interchangeable and therefore the case of heat exchanger brazing offers an opportunity to examine the need for real-time thermal process monitoring.

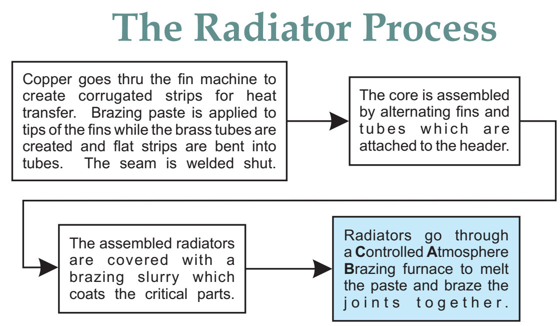

Figure 1: Heat Exchanger Flow Chart

The main difference between the copper/brass system and the aluminum braze system is that the aluminum braze takes place at 40°C-50°C below the melting point of aluminum, whereas the copper/brass braze occurs 450°C below the copper melting point. (The process window for aluminum is very tight!) The aluminum braze depends on clad ribbon and flux; the Cuprobraze is sprayed on and is fluxless. The Copper/Brass (Cuprobraze) system utilizes a non-toxic alloy (75% Copper/5% Nickel/15% Tin/5% Phosphorus) which is self-fluxing**.** The brazing to copper occurs at between 620°C and 635°C. Aluminum brazing occurs between 560°C and 615°C in a controlled nitrogen atmosphere. Copper/Brass and Aluminum Brazing require a level of control not normally associated with brazing. Temperature sensitive factors include keeping temperatures down to avoid annealing of fins and tubes, and also precise control of time at temperature to ensure full flux activation and avoid costly pot-braze clean up.

In Copper/Brass brazing, compound binders must not flow until the alloy is liquid: therefore precision control of the ramp-up and spike to liquidus is critical. Generally, the time above 600°C must be less than 4 minutes in order to limit the penetration depth of the braze. (The exact profile duration is of course dependent on the mass (size) of the part being brazed.) The Cuprobraze profile can be as short as twelve minutes in duration and the ramp-up from 500°C to 630°C (to liquidus) is very steep. The cooling ramp-down (600°C to 100°C) is also abrupt (Fig. 2). This means that careful consideration must be given to process development in order to find process setups that will create large temperature differentials between zones.

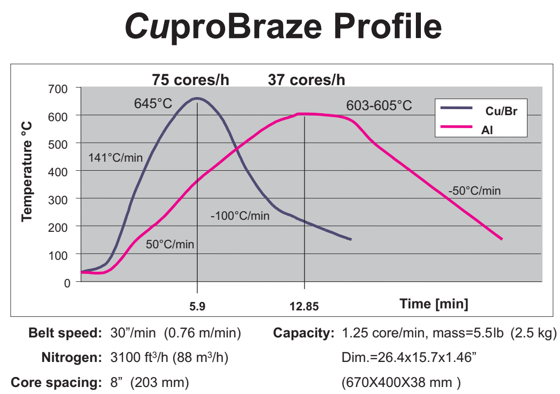

Figure 2: Typical Copper/Brass Brazing Thermal Profile

Based on the descriptions above, the critical factors in Copper/Brass and Aluminum Brazing are:

- The appropriate atmosphere specification
- A stable controllable furnace
- Optimized process setup.
- Automated process monitoring to ensure that the process does not drift during production.

This paper will focus on the last two requirements.

Conventional Thermal Profiling

Thermal Profiling is the process or procedure that insures that product is processed at the proper temperature. Generally, a thermal profile is plotted visually as a Time/Temperature graph with temperature plotted as the X-axis and time plotted as the Y-axis. The more valuable or sensitive the product being processed, the more critical monitoring and controlling product temperature becomes. The conventional method of profiling a conveyorized furnace is to at attach thermocouples to the product and then send it through the oven with a trailing wire. In the past the resulting profile was recorded by a strip chart recorder, but currently most thermal profiling methods have some form of computer interface. (Fig. 3)

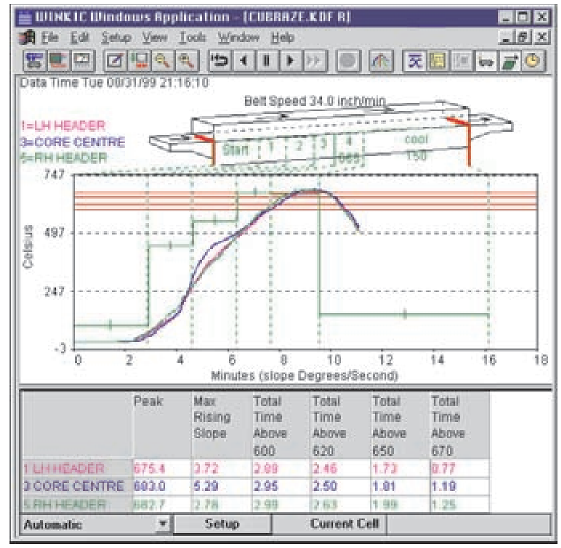

Figure 3: Typical Brazing Profile

The trailing wire/strip chart method was a major improvement on the traditional method of relying on the experience of an operator who adjusted the oven based on how the finished brazed joints looked or some other subjective input. But there are several problems with conventional trailing wire technology. The first, that all users are aware of, is that production cannot be run while the profile is being taken. This is especially problematic when the furnace is being set up, a process that can take hours or even days. Additionally, data from a trailing wire profile that has been recorded on strip chart may be difficult to save, record, and analyze.

For several years pass-through type profilers have been available. Passthrough profilers generally function as dataloggers, though more sophisticated models have real-time RF capabilities. Passthrough profilers have succeeded in reducing disruptions to production, and the best models provide users with a valuable data on their processes, but they are not the optimal solution. Passthrough profiles are typically done on a regular basis: monthly, weekly, or as often as once a shift, to verify that the oven is operating within the process limits. The problem with conventional passthrough profilers is that each profile run is the equivalent of a snapshot taken with a still camera, and the oven user is forced to assume that the oven is not changing in between "snapshots." These "snapshots" will rarely catch an intermittent problem in the oven, and if there is a problem, it is impossible to tell when the process went out of spec.

Traveling Thermocouples for Real-time Profiling

The use of a multi-channel thermocouple harness with a real-time thermal profiler offers significant advantages over trailing thermocouples and the thermal barriers used with conventional pass through profilers. Trailing thermocouples are expensive, have a short life span, and can interrupt production. Profiling with thermal barrier technology also has numerous disadvantages:

- Barriers are expensive to buy, repair, and replace
- Barriers often require heat sinks that must be cooled before reusing
- Barriers can distort product profiles by acting as a heat sink and disrupting furnace air flow
- Barriers are limited by height restrictions in furnaces with low clearances..
- Barriers can interrupt production
- Out gassing from the barrier can alter furnace atmosphere

A multi-channel thermocouple harness with a real-time thermal profiler eliminates these problems and is robust enough that product can be placed on top of it. This means that a process can be profiled without stopping production, and that the resulting profile will accurately show actual production conditions.

Why use a profiler when furnaces already have control thermocouples in each zone? The answer is that control thermocouples do not:

- Show product temperature
- Show variations in product temperature (hot and cold spots)
- Monitor heat at all points on the conveyor
- Troubleshoot process problems
- Facilitate the setup of new product profiles

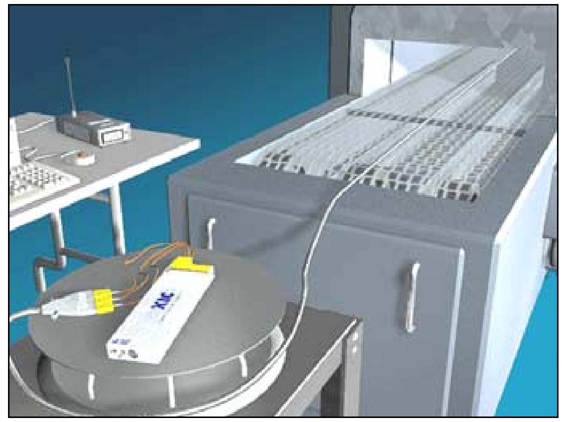

Figure 4: Typical Multi-Channel Thermocouple Harness and Real-time Thermal Profiler

The use of a multi-channel thermocouple harness with a real-time thermal profiler is the first step towards precision process development. The next step is to use an Automated Profile Prediction Tool.

Automated Process Development

An Automated Profile Prediction Tool is a sophisticated software package capable of generating and evaluating thousands of possible oven recipes to find an optimal profile in a matter of minutes. It will then present the recommended profiles, ranked based on their Process Window Index (see below). Upon reviewing the suggested changes, users choose the most appropriate profile based on ease of profile changeover from one product profile to another, faster throughput based on belt speed, or other possible needs specific to their process.

The Process Window Index

The Process Window Index is a statistical method for ranking thermal profiles and thermal process performance which measures how well a profile fits within user defined process limits. This is done by ranking process profiles on the basis of how well a given profile “fits” the critical process statistics. A profile that will process product without exceeding any of the critical process statistics is defined as being inside the Process Window. The center of the Process Window is defined as zero, and the extreme edge of the process window as 99%. A “Process Window Index” of 100% or more indicates that the profile will not process product in spec. A “Process Window Index” of 99% indicates that the profile will process product within spec, but it is running at the very edge of the Process Window. A “Process Window Index” of less than 99% indicates that the profile is in spec and tells users what percentage of the process window they are using: for example, a PWI of 70% indicates a profile that is using 70% of the process spec. The figures below illustrates how the Process Window Index is calculated.

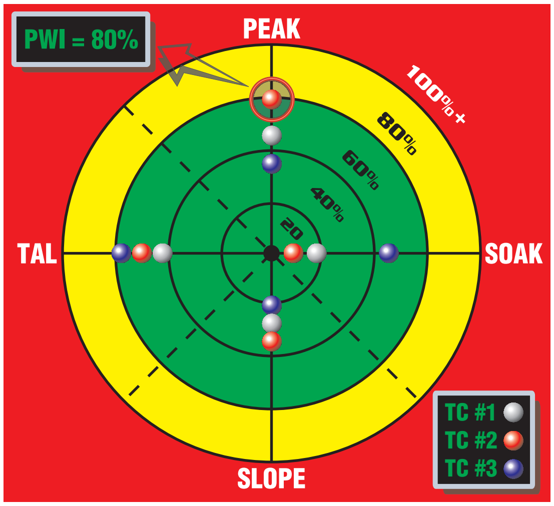

Figure 5: The Process Window Index

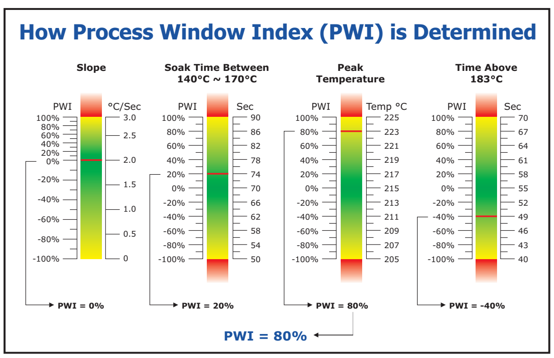

Figure 6: Calculating the Process Window Index

The simplicity of the Process Window Index makes its validity as a statistical tool readily apparent, and that it clearly offers significant benefits for improving brazing processes. Profiles can be easily compared, and users can be confident that they are using the best profile their process can achieve. The PWI reflects the performance of the whole profile, which provides much better indicator of process capability than tracking a single statistic. The PWI thus provides excellent data for SPC and other QC monitoring programs.

Automated Real-time Thermal Management

The optimal system for monitoring processes in conveyorized furnaces is an automated real-time thermal manager. There is no way to avoid running a profile to setup a furnace, and to initially setup the thermal manager, but there is a simple and cost-effective way to avoid running costly and time consuming confirmation profiles. The system consists of two probes (5/8" diameter stainless steel tubes,) each containing fifteen internal thermocouples, which are mounted in the oven chamber in close proximity to the product. (Figs. 7&8) A thermocouple processing unit (TPU) sends the probe data to a computer running a Windows based software package. The key difference between the Thermal Manager and conventional product profilers is that the thermocouples in the probes continuously monitor process temperature. Temperatures are continuously displayed as "Process Profiles" on a PC screen and data is permanently recorded on the hard disk. During production, any temperature drift and its location is instantly visible. Because the Thermal Manager is outside the oven control loop, it can reveal critical process temperature deviations that are often hidden from the oven control thermocouples. This is especially critical in copper-brass and aluminum brazing processes because of their extremely tight process windows.

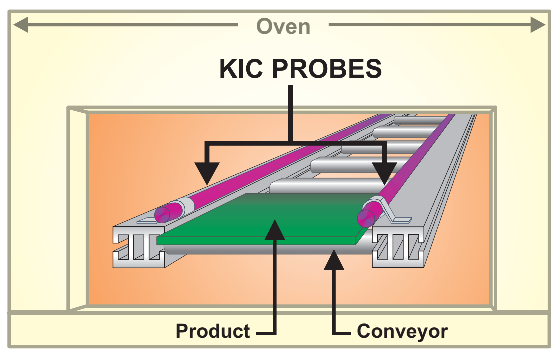

Figure 7: Thermocouple Probes in Furnace

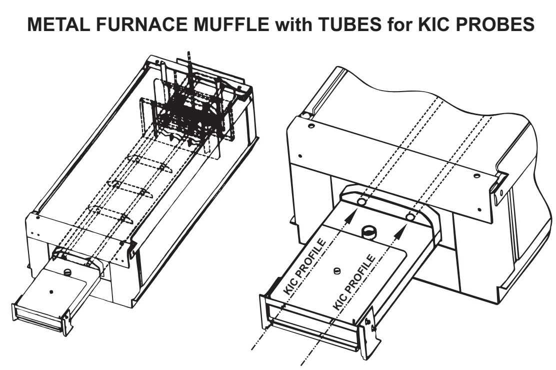

Figure 8: Typical Furnace Muffle Showing Location of Probe Tubes

Once the thermal manager has been installed, a "baseline profile" is established by running a real-time multi-channel thermocouple profile with the Thermal Manager running simultaneously. The Thermal Manager software uses this baseline profile to calculate the relationship between process temperature as read by the probes and product temperature, establishing a "Virtual Profile." During production, the software continuously calculates how the Virtual Profile has changed based on measured changes in process temperature from the probes located permanently in the oven. The Virtual Profile is automatically updated every thirty seconds and permanently recorded, so it can be viewed at any time by entering the date and time in question. If at any point the Virtual Profile falls outside user defined limits, an alarm will show on the screen. If the alarm relay option is used, the alarm feature can be used to sound an audible alarm, activate a light tower, or shut down the feed conveyor, guaranteeing that product is never allowed to enter the oven unless the product profile is within specifications. As process temperature drifts over hours, days, or weeks, the Virtual Profile calculates how the changes will affect the product thermal profile. Virtual Profiling is as close as you can get to attaching thermocouples to every product brazed in your furnace. (Fig. 9)

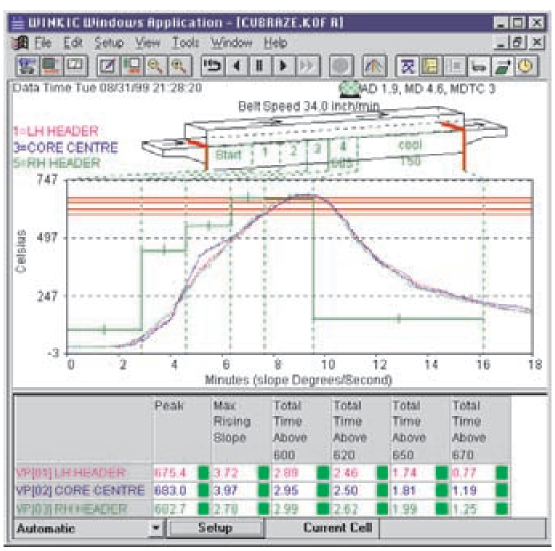

Figure 9: Virtual Profile

Additional features available with the thermal manager include Live Data Output; Auto-Predict; Product Sensors; and Barcode Reader Software. Live Data Output makes process data instantly available for export to a spreadsheet or SPC program. This option is especially valuable for achieving ISO 9000 certification. Live data can also be delivered via an intranet or the Internet to offsite locations for remote process monitoring. Barcode reader software offers users total process traceability, with the thermal profile of every product processed permanently recorded.

Real-time thermal managers have been used extensively in the electronics assembly industry to monitor solder reflow ovens and wave solder machines and are considered to be proven technology by major industry players like Intel, Motorola, & Hewlett Packard.

Conclusion

Aluminum and Copper/Brass brazing is a complex process with a unique set of thermal problems that must be addressed if the process is to be successful. These problems require narrow process windows, and maintaining narrow process windows requires users to have some means of both developing the optimal process setup and then efficiently monitoring and controlling the process. The use of the real-time continuous thermal monitor allows users to develop and maintain profiles to achieve these very tight process windows. Increased yields are achieved with the thermal manager in several ways: by verifying the oven continuously, downtime for profiling is eliminated; defects are avoided because the thermal manager alarms instantly when the process drifts outside of process specifications, and SPC programs can be used to identify and avoid drift before control limits are reached. The use of a real-time thermal manager allows manufacturers using Controlled Atmosphere Brazing processes to achieve increased throughput, significantly higher yields, and reduced defect rates.