Brazing basics

'Thru-process' temperature profiling a means to achieve process understanding, control, optimisation and validation.

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Left: Fig 1. PhoenixTM HTS08 'thru-process' temperature profiling system enters the CAB brazing furnace with product being monitored

In the automotive and increasingly the aerospace industries aluminium brazing is key to many of the manufacturing processes used to produce radiators, condensers, evaporators etc. The quality of the brazing process is important to the performance and product life for its intended function. A critical requirement of the brazing process is the optimisation and control of the product temperatures during the complete brazing process. A valuable tool to achieve such requirements is the use of 'Thru-process' temperature profiling as a direct alternative to the traditional trailing thermocouples as discussed in the following article. Obtaining the product temperature profile through the brazing furnace gives you a picture of the Product/Process DNA which provides you with the data to allow control, optimisation and validation of this key manufacturing step.

The basic brazing principle and its temperature dependence

Aluminium brazing employs the principle of joining aluminium metal parts by means of a thinly clad soldering 'filler' alloy, whose melting point is lower than the base/parent metal.

As part of the brazing process, control of the product temperature is critical to achieve selective melting of the filler alloy 580-620°C (1076-1148°F) to allow it to flow and fill the joints between the parent metal substrate without risk of melting the substrate itself. Often the difference between the melting points of the two materials is small so accurate temperature monitoring through the entire furnace is critical to the success of the brazing process. It is important though to not only focus on the absolute temperature but also ramp rates, time @ temperature and temperature uniformity of the entire product and/or the furnace. Controlled cooling of the filler further results in a solid brazed joint between the elements of the parent substrate.

Critical challenges of the Brazing process

Prior to any brazing process it is important that the substrate surface is prepared correctly to allow the brazing process to work correctly. As we all know with home DIY when painting the surface preparation phase is critical to the end result!

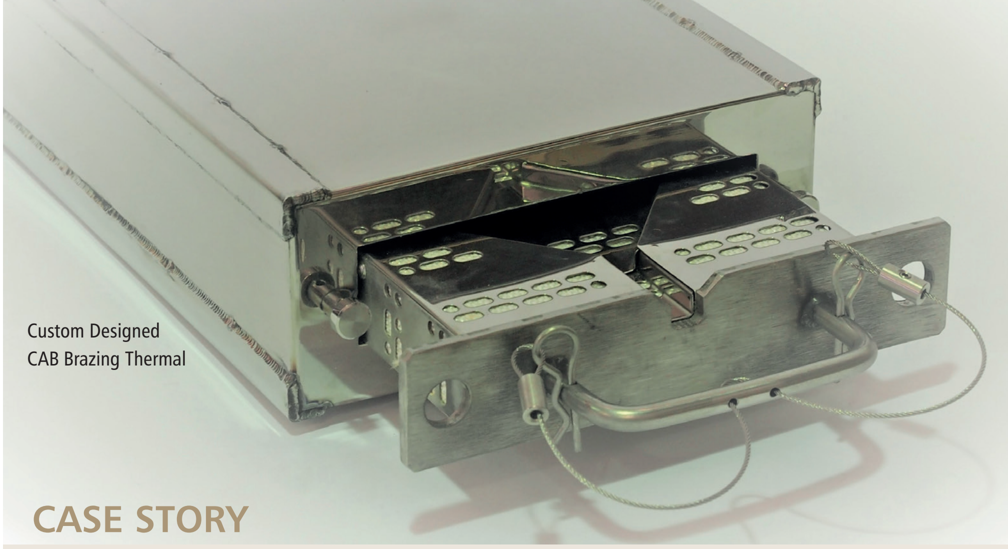
Surface preparation before brazing may involve thermal degreasing where the substrate temperature is elevated to drive off lubricants.

A second more important procedure is the removal of any surface oxide layer to allow wetting, and so flow, of the brazing filler alloy over the parent substrate. Unfortunately, Aluminium is easily oxidised and the resulting aluminium oxide (Al_2O_3) prevents such wetting process. Prior to brazing therefore, the oxide layer needs to be eliminated. Cleaning of the substrate layer is achieved in most cases by the application of a corrosive flux which in a molten state dissolves the oxide layer.

The type of flux used must be matched to the application substrate and filler alloy composition. A common brazing process used today is that of the Nocolok Process® in which the flux is potassium fluoroaluminate K_{1-3} AlF_{4-6} a white powder deposit.

For the reasons discussed above elimination of oxygen and especially water from the brazing process is a critical requirement so the furnace is generally run under a nitrogen atmosphere (Controlled Atmosphere Brazing 'CAB' Oxygen < 100 ppm, Humidity < -40°C)) or gas free vacuum environment (Vacuum 10^{-4}-10^{-6} mBar with magnesium as $0_2/H_20$ scavenger). The design and construction of monitoring systems needs to be carefully considered as discussed later, to ensure that the furnace atmosphere is not contaminated (oxygen and water) in any way.

Fig 2. PhoenixTM PTM1210 Data logger with 10 thermocouple channels and 2-way RF telemetry communication option



Custom Designed
CAB Brazing Thermal

CASE STORY

PhoenixTM work with major automotive radiator manufacturer customising a brazing barrier solution to meet their specific application needs.

In 2016 PhoenixTM was approached by a major automotive radiator manufacturer, USA. The manufacturer had a specific need for a reliable CAB brazing monitoring system that would withstand heavy use, approx 45 runs per week, but which would be easy to install on their multiple CAB lines.

As part of the collaborative relationship the existing PhoenixTM TS08 brazing barrier design, already used by the customer, was subtly modified to meet the customer's specific needs as detailed below.

Easy, Quick, Reliable Protection

- Thermocouple tray was fitted with a probe guide to allow controlled exit of the thermocouples in a bound configuration for easy safe routing direct to the test piece radiator being monitored.
- New simple tray faceplate securing method 'No Catches' - quick vertical cotter pin locking mechanism with pin lanyard to preventing loss during operation.

The customer was quoted as saying in response to the new barrier design -

"The new barrier is great; the operators love them. All those design iterations paid off."

The TS08 design of barrier used since 2011 has proven to be very successful with a life span far in excess of anything achieved with the conventional unprotected glass cloth/insulation. It is estimated that barriers supplied back in 2014, which have seen routine use over five years and are still operational, have accumulated in excess of 2500 successful profile runs without damage or any wear problems. Over the same period many conventionally designed barriers have been scrapped due to HF acid damage of cloth and microporous insulation. The customer for this reason has now standardised on the TS08 design for all their CAB profiling activity.

New Face Plate Lock Mechanism

Process Monitoring Focus	Requirements	Implications if not achieved
Heating Rate	Average heating rate of 20 °C/min Up to 45 °C/min	Slow heating rates flux can dry out and become ineffective. There must be molten flux present when filler reaches its melting point.
Maximum Brazing Temperature	Above 577 °C Typically, 600 °C +/- 5 to 10 °C	Possible problem with excessive substrate erosion from filler metal pool at higher temperatures – Filler metal erosion
Temperature Uniformity	At Brazing Temperature, the product variation should be <+/- 5 °C	Need to guarantee braze quality over whole product
Time @ Braze Temperature	No longer than 3- 5 mins	Filler metal erosion of substrate alloy. (Silicon penetration into base metal)

Table 1. Critical Monitoring Requirements for the CAB brazing process

Design Principles and Challenges of a 'thru-process' Brazing Furnace Monitoring system

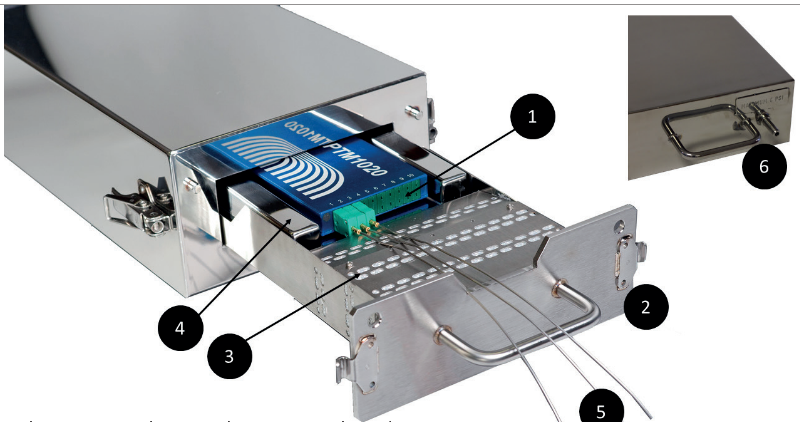
The 'thru-process' profiling system concept is based on the principle of sending a data logger through the brazing furnace which is protected from the heat and harsh brazing environment by a thermal barrier. Multiple thermocouples (typically 10)
connected to the product test piece (radiator), connected directly to the data logger (See figure 2 PTM1200 Data Logger), measure the product temperature (and furnace) as it travels through the furnace storing the information in the data logger memory. This data can with a RF telemetry option also be transmitted live via a 2-way RF telemetry communication link out of the furnace directly to a monitoring PC.

Fig 3. Damage to a conventional Thermal barrier design from flux materials reacting with moisture to form corrosive HF

The resulting temperature profile can be reviewed, analysed and validation report generated. As the system is compact and travels with the product there is no need to use cumbersome and potentially hazardous challenges of feeding (and retrieving) long thermocouples through the furnace as required in the use of traditional trailing thermocouples. Keeping thermocouple lengths to a minimum eliminates the risk of the thermocouple wire becoming tangled in the conveyor mesh and potentially being damaged during use. Monitoring as part of a full production run is possible to allow accurate measurement under normal product load conditions and without compromising line productivity.

Innovative Thermal Barrier Design

The thermal barrier has the job of providing thermal protection to the data logger. Although this is the case for aluminium brazing the barrier also needs to be designed in such a way as to avoid damage to itself from potentially hostile corrosive chemicals generated in the furnace and prevent contamination of the



1. PhoenixTM Data logger with 6, 10 or 20 Channels
2. Front loading logger tray with encapsulated thermal insulation protecting from HF
3. Thermal breaks reduce heat conduction to logger
4. Heat sinks provide additional thermal protection employing phase change technology
5. Mineral Insulated Thermocouple inserted into radiator fins
6. Rear barrier optional Nitrogen feed nozzle for pre-run purging of insulation and barrier cavity of air(O_2(g))

Fig 4. Unique TS08 CAB brazing barrier design to give low height thermal protection to the data logger. Designed with front loading logger tray and metal construction to limit exposure of insulation and cloth materials to corrosive HF. Available with nitrogen purge facility option to remove any risk of O_2 (g) outgassing into the furnace.

CAB atmosphere from barrier outgassing materials.

Traditionally thermal barriers are manufactured employing micro-porous block insulation wrapped in high temperature glass cloth. Moisture trapped in the insulation block, during use, is released within the barrier cavity where it can form hydrofluoric acid in combination with chemicals in the brazing flux. The highly corrosive HF acid, over only a short period of time, can cause significant damage to both the barrier cloth and insulation. This compromises the integrity of the barrier, reduces its thermal performance and potentially creates a dust contamination risk to the process. Air trapped in the micro-porous insulation block and within the barrier cavity during heating can expand and escape from the barrier into the furnace. Obviously being made up of 21% Oxygen (O_2 (g)) the air will contaminate the CAB environment and potentially create a risk of aluminium oxide formation and resulting wetting/brazing problems.

To eliminate the damage to barriers, extend operational life expectancy and minimise outgassing of air (O_2(g) or moisture PhoenixTM developed a unique new TS08 specifically for the demands of CAB brazing.

As shown in **Figure 4** the logger draw loading mechanism significantly reduces the amount of insulation cloth that is exposed to the aggressive flux and the metal surround gives added integrity. Prior to supply the insulation block is preheated in a high vacuum and back flushed with nitrogen (N_2(g)) to drive out any air trapped in the porous insulation structure. For processes where any air outgassing is a significant contamination risk it is possible, with specific barrier configurations, for customers to purge the small barrier cavity of any remaining air with a supply of low-pressure Nitrogen (N_2(g)). The barrier construction is designed to allow the free flow of nitrogen from rear inlet nozzle through the entire barrier. To overcome heat conduction issues with the metal tray, thermal breaks are incorporated, to limit heat penetration via conduction to the data logger.

Unveiling the mystery of your Brazing furnace with a 'thru-process' temperature profile trace

As discussed previously the need for accurate control of the brazing process is critical to the quality of the braze and hence integrity of the finished product. The key temperature transitions/phase of the process are clearly shown on a typical temperature profile shown below in **Figure 5**.

In **Table 1** a summary of the target temperature transitions in the CAB Brazing process and the impact on process and possibly the quality of the brazed final product is provided.

The PhoenixTM brazing system is supplied with Thermal View Plus software which is designed to provide full analysis and reporting tools, for monitoring the brazing process, against the monitoring requirements detailed in **Table 1**. Complimenting this software, a survey software option is available to allow running temperature uniformity surveys in accordance with CQI-9 using the 'plane method' (CQI-9 Standard Section 3.4.2 and Table 3.4.2.).

Overview

The PhoenixTM 'Thru-process' brazing system provides a rugged, reliable and clean solution for performing product temperature profiling of CAB brazing furnaces. Providing the means to Understand, Control, Optimise and Certify the brazing heat treat process. ■

Contact
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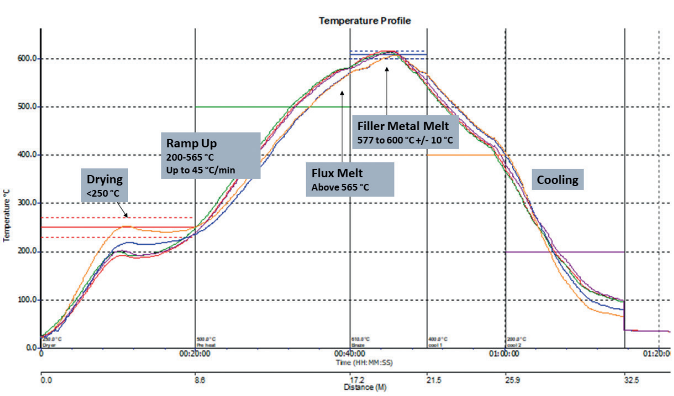

Fig 5. Thru-process temperature profile of a typical CAB brazing furnace showing critical temperature transitions

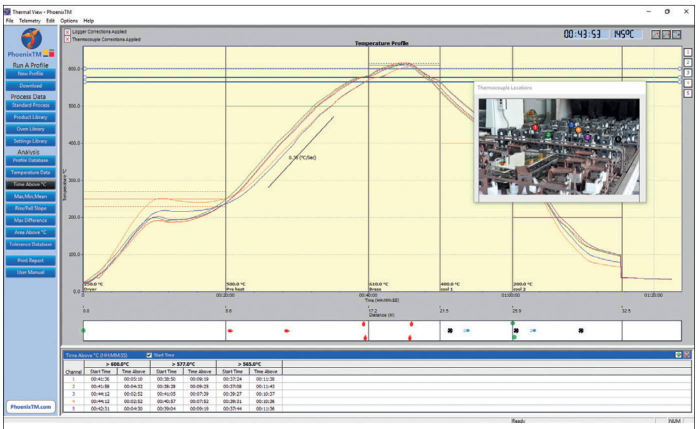

Fig 6. Thermal profile graph displayed in the PhoenixTM Thermal View Plus software package