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A bnp Publication

Improving Through-Process Temperature Profiling

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KINGDOM

Advanced monitoring for T6 automotive aluminum heat treatment boosts efficiency and meets accreditation standards.

In today’s automotive and general manufacturing market, aluminum is increasingly becoming the material of choice because it is lighter, safer and more sustainable. Manufacturers looking to replace existing materials with aluminum need a new methodology to prove that thermal processing of aluminum parts and products is efficiently and economically done to specification.

To add strength to pure aluminum, alloys are developed by the addition of elements dissolved into solid solutions employing the T6 heat-treatment process (Fig. 1). The alloy atoms create obstacles to dislocation movement of aluminum atoms through the aluminum matrix. This provides more structural integrity and strength.

Process temperature control and uniformity are critical to the success of the T6 process to maximize the solubility of hardening solutes (such as copper, magnesium, silicon and zinc) without exceeding the eutectic melting temperature. With a temperature difference of typically 9-15°F (-12.8 to -9.4°C), knowing the accurate temperature of the product is essential. Control of the later quench process (Fig. 1, Phase 3) is also critical not only to facilitate the alloy element precipitation phase but also to prevent unwanted part distortion/warping and risk of quench cracking.

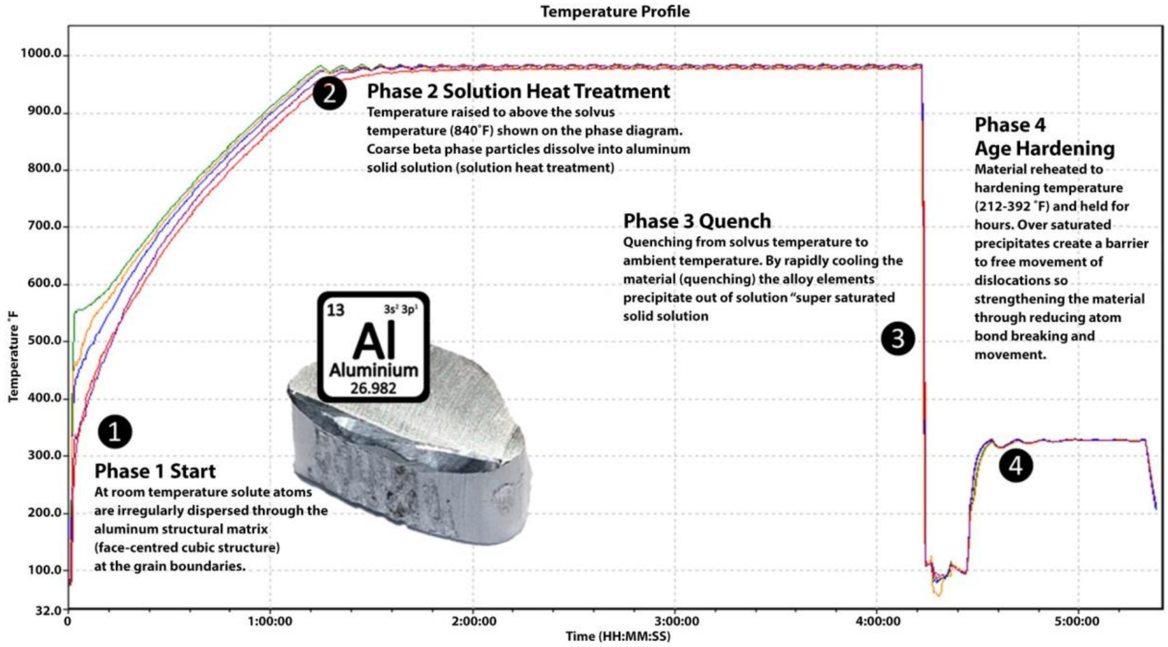


Fig. 1. Critical temperature phase transitions of the T6 aluminum heat-treatment process are shown.

T6 Process Monitoring Challenge

The solution reheat process (T6) comes with many technical challenges where temperature profiling is concerned. The need to monitor all three of the equally important phases – solution treatment, quench and then the age-hardening process – makes trailing thermocouple methodology impossible.

Even when considering applying “thru-process” temperature profiling technology, sending the data logger through the process protected in a thermal barrier (Fig. 2), the T6 process comes with significant challenges. A system will not only need to protect against heat (up to 1020°F/549°C) over a long process duration, but it will also have to withstand the rigors of being plunged into a water quench. Rapid temperature transitions create elevated risk of distortion and warping, which need to be addressed to provide a reliable, robust monitoring solution.

An innovative monitoring system has been developed to suit the T6 process (Fig. 3). The thru-process monitoring system can provide protection at 1022°F (550°C) for up to 20 hours.

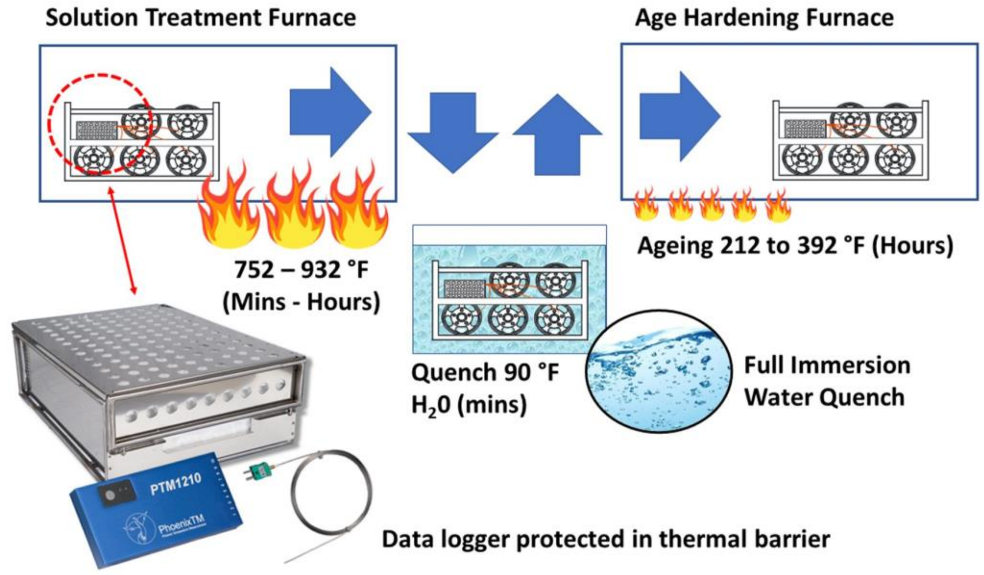


Fig. 2. This diagram illustrates the thru-process temperature monitoring of the three T6 heat-treatment phases.

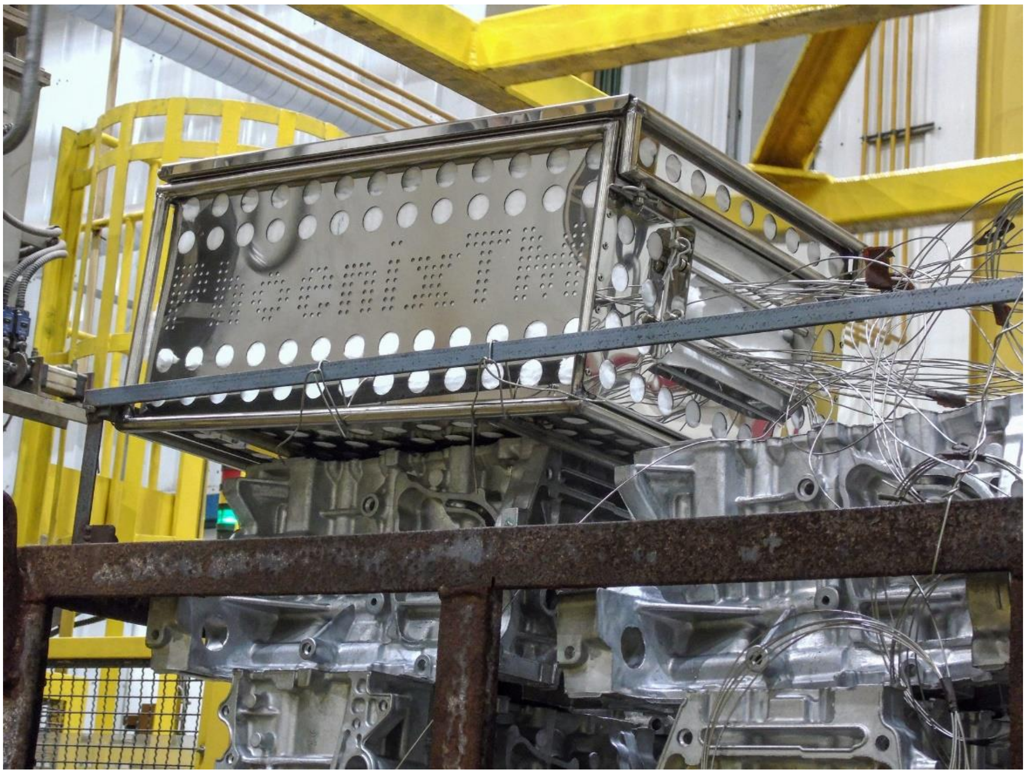


Fig. 3. A PhoenixTM thru-process temperature profiling system is installed in the product cage monitoring the T6 heat treatment (solutionizing, quench and age hardening) of aluminum engine blocks.

Thermal Protection Technology

To meet the challenges of the T6 process, the conventional thermal-barrier design employing microporous insulation is replaced with a water-tank design with thermal protection using an evaporative phase change temperature control principle. Evaporative technology uses boiling water to keep the high-temperature data logger (with a maximum operating temperature of 230°F/110°C) at a stable operating temperature of 212°F (100°C) as the water changes phase from liquid to steam.

The advantage of evaporative technology is that a physically smaller barrier is often possible. It is estimated that with a like-for-like size (volume) and weight an evaporative barrier will provide in the region of twice the thermal protection as that of a standard thermal barrier with microporous insulation and heat sink. The level of thermal protection can be adjusted by changing the capacity of the water tank and the volume of water. Increasing the volume of water increases the duration that the T6 temperature barrier will maintain the data-logger temperature of 212°F (100°C) before it is depleted by evaporation losses.

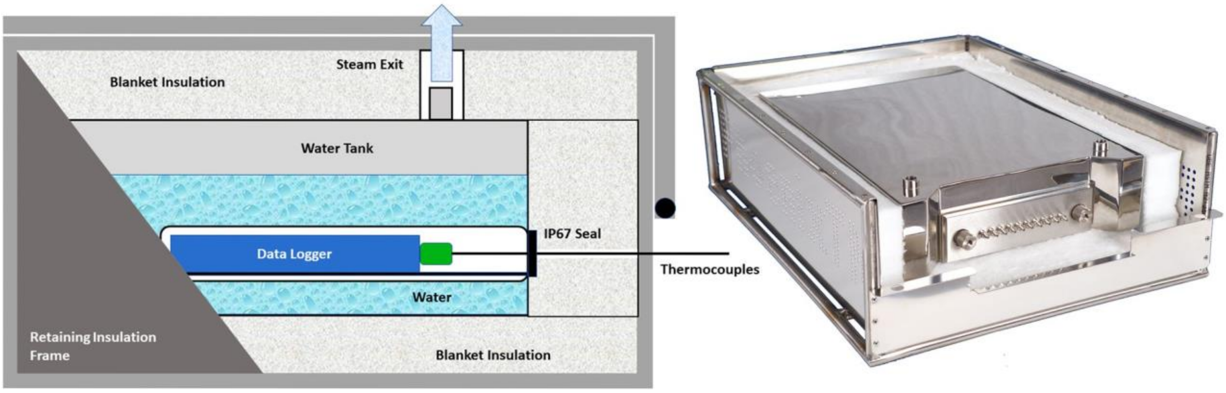


Fig. 4. TS06 thermal-barrier design is installed within a structural frame containing the insulation blanket surface layer. The water tank is shown with a traditional compression-fitting face-plate seal.

The newly developed thermal barrier design (Fig. 4) incorporates a further level of protection with an outer layer of insulation blanket contained within a structural outer metal cage. The key role of this material is to act as an insulative layer around the water tank to reduce the risk of structural distortion from rapid temperature changes, both positive and negative, in the T6 process.

Obviously, the evaporative loss rate of water is governed by the water-tank geometry. A cube-shaped tank will provide the best performance, but this may need to be adapted to meet process height restrictions. A thermal barrier with dimensions of 8.5 inches high x 18.6 inches wide x 25.2 inches long, offering a water capacity of 3.5 gallons, provides 11 hours of protection at 1022°F (550°C). A larger thermal barrier with approximately twice the capacity at 12.2 x 18.6 x 25.2 inches, offering 7.7 gallons, gives approximately twice the protection (20 hours at 1022°F/550°C).

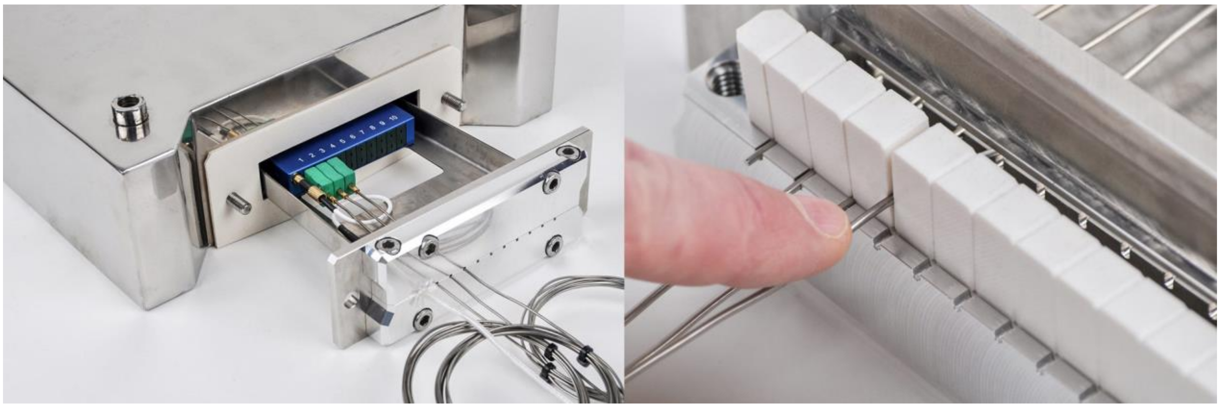


Fig. 5. The TS06 thermal barrier offers an IP67 bi-directional rubber gasket seal. Quick, easy installation of mineral-insulated (MI) thermocouples and RF antenna aerial is possible.

IP67-Sealing Design

Because it passes through the water quench, the data logger needs to be protected from water damage. This is achieved in the system design by combining a fully IP67-sealed data-logger case and water tank front face plate through which the thermocouples exit. Traditionally, mineral-insulated thermocouples in heat-treatment applications are sealed using robust metal compression fittings. Although reliable, the compression seals are difficult to use and require long setup times. The whole uncoiled straight cable length must be passed through the tight fitting, which for 10-foot x 13-foot thermocouples, takes some patience. Thermocouples can be used, as installed, for multiple runs if undamaged. Unfortunately, as the ferrule in the compression fitting bites into the MI cable, removal of the cable requires the thermocouple to be cut, which prevents reuse.

To overcome the frustrations of compression fitting, an alternative thermocouple sealing mechanism has been designed for use on the thermal barrier (Fig. 5).

Thermocouples can be slotted easily and quickly, without tools, into a precision-cut rubber gasket without any need to completely uncoil the thermocouple. The rubber gasket has a unique bi-directional seal, allowing both sealing of each thermocouple and sealing of the clamp face plate to the data-logger tray, which is then secured to the water tank with an additional silicone gasket seal. The new seal design not only offers quick and easy setup, it allows thermocouples to be uninstalled and reused, which reduces operating costs.

Accurate Process Data Considerations

The T6 application comes with a series of monitoring challenges that need to be considered carefully to guarantee the quality of data obtained. Although the complete process time of the three phases can reach up to 10 hours, it is necessary to use a rapid sample interval to provide a sufficient resolution. The new data logger is designed to facilitate this with a minimum sample interval of 0.2 seconds over 20 channels and memory size of 3.8 million data points, allowing complete monitoring of the entire process. A sample interval of 0.2 seconds provides sufficient data points on the rapid-quench cooling curve. The high resolution allows full analysis and optimization of the quench rate to achieve required metallurgical transitions yet avoid distortion or quench cracking risks.

Employing the phased evaporation thermal-barrier design, the high-temperature data logger with a maximum operating temperature of 230°F (110°C) will operate safely at 212°F (100°C). During the profile run, the data logger’s internal temperature will increase from ambient temperature to 212°F (100°C). To allow the thermocouple to accurately record temperature, the data logger offers a sophisticated cold-junction compensation method, correcting the thermocouple readout (hot junction) for anticipated internal data-logger temperature changes.

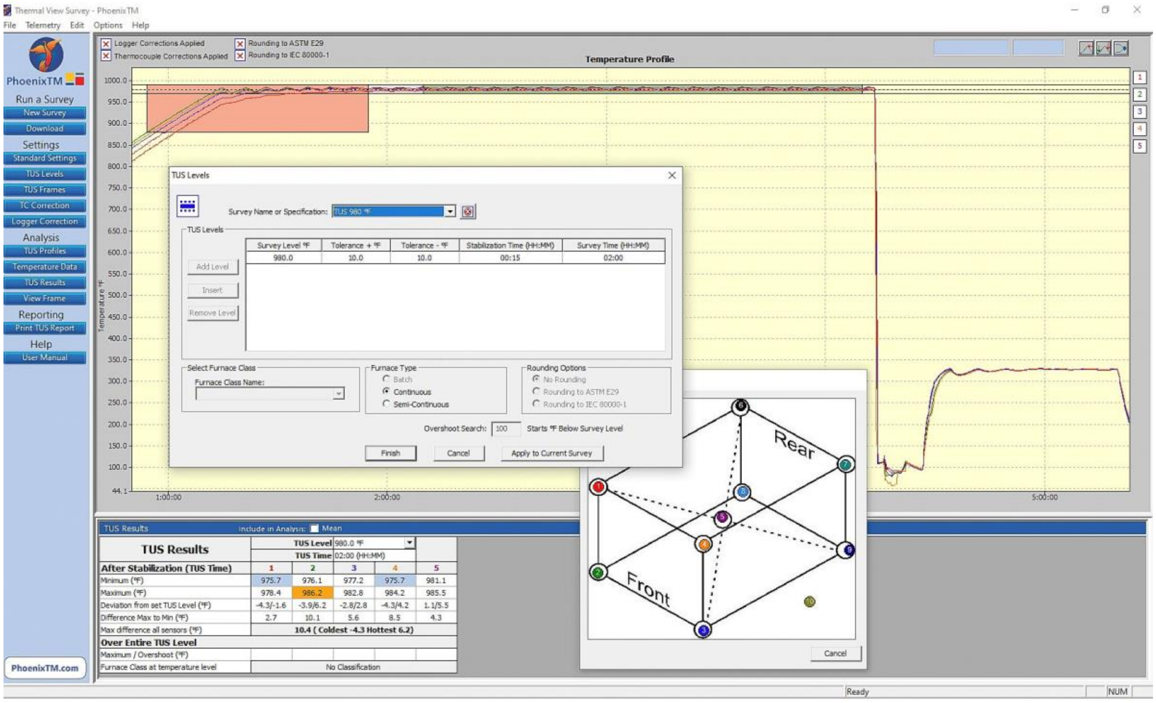
Data logger and thermocouple calibration data cover the complete measurement range, not just a single designated temperature, and can be used to create detailed correction-factor files. Correction factors are calculated by interpolation between two known calibration points using the linear method as approved by CQI-9 and AMS2750G. Such methodology ensures that all profile data is corrected to the highest possible accuracy.

Real-Time, Thru-Process Temperature Monitoring

For a process time as long as the T6, real-time monitoring capability is a significant benefit. The unique two-way RF telemetry system used on the system helps address the technical challenges of the three separate stages of the process. The RF signal can be transmitted from the data logger through a series of routers linked back to the main coordinator connected to the monitoring computer. The routers, being wirelessly connected, are located at convenient points in the process (solutionizing furnace, quench tank, aging furnace) to capture all live data without the inconvenience of routing communication cables.

A major challenge in the T6 process, from an RF telemetry perspective, is the quench step. An RF signal cannot escape from water in the quench tank. To overcome this limitation, an innovative catch-up feature is implemented. Once the system exits the quench and the RF signal is re-established, any previously missing data is retransmitted, guaranteeing full process coverage.

Fig. 6. This temperature uniformity survey of the T6 process illustrates Phase 1 solution reheat.



TUS Levels

Survey Name or Specification: TUS 980 °F

TUS Levels

Survey Level °F	Tolerance + °F	Tolerance - °F	Stabilization Time (HH:MM)	Survey Time (HH:MM)
980.0	10.0	10.0	00:15	02:00

Select Furnace Class
Furnace Class Name:

Furnace Type
○ Batch
● Continuous
○ Semi-Continuous

Rounding Options
● No Rounding
○ Rounding to ASTM E29
○ Rounding to IEC 80000-1

Overshoot Search: 100 Starts °F Below Survey Level

TUS Results Include in Analysis: ☐ Mean

TUS Results	TUS Level	980.0 °F			
	TUS Time	02:00 (HH:MM)			
After Stabilization (TUS Time)	1	2	3	4	5
Minimum (°F)	975.7	976.1	977.2	975.7	981.1
Maximum (°F)	978.4	986.2	982.8	984.2	985.5
Deviation from set TUS Level (°F)	-4.3/-1.6	-3.9/6.2	-2.8/2.8	-4.3/4.2	1.1/5.5
Difference Max to Min (°F)	2.7	10.1	5.6	8.5	4.3
Max difference all sensors (°F)	**10.4 (Coldest -4.3 Hottest 6.2)**				
Over Entire TUS Level					
Maximum / Overshoot (°F)					
Furnace Class at temperature level	No Classification				

Process Quality Assurance and Validation

In the automotive industry, many operations will be working to the CQI-9 special process heat-treat system assessment accreditation. As defined by the pyrometry standard, operators need to validate the accuracy and uniformity of the furnace work zone by employing a temperature uniformity survey (TUS).

The thru-process monitoring principle allows an efficient method by which the TUS can be performed by employing a TUS frame to position a defined number of thermocouples over the specific working zone of the furnace (product basket). As defined in the standard, with particular reference to the application assessment process Table C (aluminum heat treating), the uniformity for both the solutionizing and aging furnace needs to be proven to satisfy ±10°F of the threshold temperature during the soak time.

Complementing the TUS system, custom-designed software provides a means by which the full survey can be set up automatically, allowing routine, full analysis and reporting to the CQI-9 specification (Fig. 6).

Interestingly, a significant benefit of the thru-process principle is that – by collecting process data for the whole process – many of the additional requirements of the process Table C can be achieved with reference to the quench. From the profile trace, key criteria (such as quench media temperature, quench delay time and quench cooling curve) can be measured and reported with full traceability during the production run.

Conclusion

To fully understand, control and optimize the T6 heat-treat process, it is essential that the entire process is monitored. Specially designed thru-process monitoring solutions allow not only product temperature profiling of all the solutionizing, water-quench and age-hardening phases but also comprehensive temperature uniformity surveying to comply with CQI-9.

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