Space Shuttle Tile

Batch Furnace Technology for Space Shuttle Tile Manufacture

With more than 20,000 ceramic tiles covering a space shuttle vehicle, it is often necessary to replace a great many tiles after the shuttle returns from a mission in space.

Replacement is required because the fragile tiles are easily damaged in flight and flight data being measured in or around a tile may require their replacement. To achieve a greater speed and economy of tile manufacture in small quantities, NASA engaged Rockwell Manufacturing to create a Single-Tile Manufacturing Line at the Kennedy Space Center (KSC). Essential to the firing of new tile on this Single-Tile Manufacturing Line are precisely controlled high temperature FastHeat batch furnaces developed by the Keith Company.

Switching to Ceramics

When the shuttle was first designed and built over a decade ago, it utilized standard aircraft technology. The ordinary metal alloys involved could not sustain the tremendous heat generated by the friction with the earth’s atmosphere upon reentry; therefore, there was a need for a lightweight Thermal Protection System (TPS). After scientific evaluation, NASA officials decided to use ceramic-fiber heat shielding tile.

The TPS of the shuttle features ceramic materials in several different forms. Rigid Surface Insulation (RSI) consisting of several different fibrous fused-silicacomposite materials covers 90% to 95% of the exterior surface area of the vehicle. Reinforced carbon-carbon shapes shield the remaining surface area of the vehicle, where maximum strength and thermal protection are needed.

Black tile, known as High-Temperature Reusable Surface Insulation (HRSI), protect over 50% of the exterior of the vehicle against the 1260 to 1370 C temperatures that must be quickly radiated during reentry. HRSI tile, according to NASA, must have a 100-mission life at these temperatures. On the other hand, white-colored heat-reflecting tile, known as Low-Temperature Reusable Surface Insulation (LRSI), cover only 10% of the vehicle. The latter tile must be capable of a 100-mission life at 650 C. High-purity; fused-silica blanket that is also white in color covers the remaining surface area of the vehicle where temperatures are the least. Being blanket-type material, it must be strengthened by being sewn with quartz thread on 1-in, centers and then rigidized with a colloidal silica.
Single-Tile Manufacturing

Historically, Rockwell had manufactured their tile in Palmdale, CA, from fiber production billets made by Lockheed Missile and Space Company in Sunnyvale, CA. In order to provide the shuttle orbiter with TPS repair materials and replacement hardware more quickly, NASA subsequently contracted with Rockwell to establish a new Thermal Protection System Facility (TPSF) at the launch site at KSC. The analysis by Rockwell of the Single-Tile Manufacturing facility requirements showed that small batch furnaces capable of firing from one to six tiles at a time would be a cost-effective alternative to the continuous-roller hearth kilns currently certified to fire the TPS tile coatings.

Basically, Rockwell receives the production billets of fiber from Lockheed Missile and Space Company out of which they machine individual tiles to proper dimensions. Computerized numerically controlled (CNC) machining was an ideal means for making any one of 20,000 different tiles that are each a special size or shape. After machining, the tile is sprayed on the outer surface and sidewalls with a glass slurry coating. To complete the manufacture of a single tile, the glass coating must be sintered in a furnace that is capable of firing batch after batch with exceptional temperature accuracy and repeatable performance.

Designing the Batch Furnace

Rockwell approached Keith Company about the feasibility of a batch furnace that would be capable of ambient to 1260 C in less than 20 mm. Rockwell then formalized a set of specifications including 1650 C capability, 4-ft³ setting volume, ceramic-fiber insulation with a very low alkaloid content, excellent temperature uniformity, and <2% cristobalite growth in the shuttle tile after firing. Four cubic-foot setting volume and 1650 C firing capability meant the ceramic-fiber insulation for the furnace had to have better-than-average mechanical strength at high temperature.

Designing the fiber insulation for the furnace in which the tiles are fired took nearly as much thoughtful consideration as did making the actual tile for the shuttle. Furnace insulation for such a large sized chamber and high temperature had not previously been accomplished with any good degree of commercial success. Ceramic fibers from various vendors were tested before a suitable fiber construction was chosen. The strongest fiber was still not strong enough by itself, so a mechanical anchoring mechanism had to be used in combination with the fiber insulation. This support system proved to be very adequate at peak furnace-operating temperatures.
Solution to the remaining equipment requirements was based on a standard fast firing 1700 C furnace. The improved furnace had the capability of reaching the temperature which NASA required in the specified time by increasing the capacity of the power supply and the number of molybdenum disilicide heating elements. The large size of the furnace chamber required that two zones of control be utilized to ensure good uniformity of temperature. Top and bottom heating zones were controlled by a single dual-channel instrument that was capable of interfacing to a computer.

After the furnace was completed, numerous acceptance tests were begun by Rockwell personnel. Tests were performed to determine the maximum ramp rate (with and without a load) and temperature uniformity. With a full load of tile, the ramp rate exceeded specifications by 15% without any appreciable temperature overshoot. Temperature uniformity at 1260 C was well below the specifications at 6 C. The final test for cristobalite susceptibility was performed by placing an uncoated shuttle tile in the furnace for 16 hours at 1260 C and subsequently X-raying it for cristobalite. All tests passed without any difficulty and Rockwell accepted the furnace for delivery.

The furnace was first delivered to the Rockwell facility at Palmdale, CA, to complete the process-engineering project phase. The preliminary acceptance at Rockwell (Palmdale) was completed in January 1989, and the furnace has subsequently been delivered to NASA at KSC less than 2 months later, where it is being incorporated into the single-tile manufacturing capability of the new Thermal Protection System Facility.