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Technical Considerations for the Use of Carbon/Carbon Composite Materials For Fixtures and Grids

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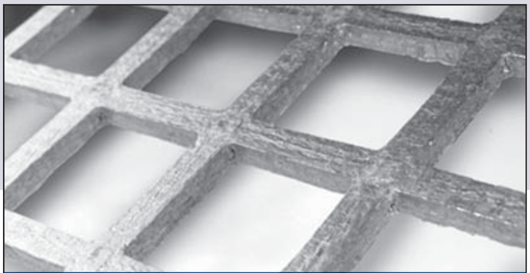

Fig. 1. UniGrid® composite grid system
(Courtesy of Schunk Graphite Technology)

Advanced material solutions for fixtures, grids and internal furnace components are available today. They are designed to allow for higher processing temperatures, larger loads, increased production rates, energy savings and lower overall cycle costs.

Carbon/carbon composite materials offer technical advantages to the heat-treatment industry.

Carbon/Carbon Composite Basics

Carbon/carbon (C/C) composite material consists of two primary components, carbon fibers and a carbon matrix (or binder). Carbon fibers are extremely thin strands of carbon atoms, typically 0.005-0.010 mm (0.0002-0.0004 inches) in diameter. They are interlaced in such a way as to provide mechanical strength, stiffness and thermal conductivity. The carbon matrix that encases them allows for uniform weight transfer and chemical resistance to attack. Properties vary depending on how they are measured, either parallel or perpendicular to the surface.

C/C composite material has low thermal mass, high strength-to-weight ratio at temperature and negligible thermal deformation, creating favorable net/tare load weight ratios when used for fixtures and grids. This allows for rapid heating and cooling rates, heavy part loading and improvements in part distortion. C/C also has excellent fatigue resistance, which minimizes issues with crack propagation. Various manufacturers offer a variety of sizes, shapes and grades. Purity levels in the range of 300 ppm total impurities are acceptable for general-purpose heat treating, with specialty applications available to as low as 10 ppm. A fully densified C/C material will be 1.50 g/cm^3 or higher. It is important to view all properties together when evaluating the quality of a composite material.

Selection Guide

Common assembly techniques for fixtures and grids include unitized construction (Fig. 1) and/or press-fit joints (Fig. 2). Hybrid systems combining both C/C materials and alloy baskets or screens are also popular. When deciding if C/C is right for you, it is important to talk with your supplier to convey your specific needs and system constraints (if any) before purchase.

To facilitate this discussion, a simple template (www.industrialheating.com/c-template) can be used to act as a guideline and help understand what information needs to be supplied. Providing this information allows the manufacturer to offer a customized solution and to identify potential issues that may negatively affect the life of a C/C fixture. This information can be broken down into four main categories:

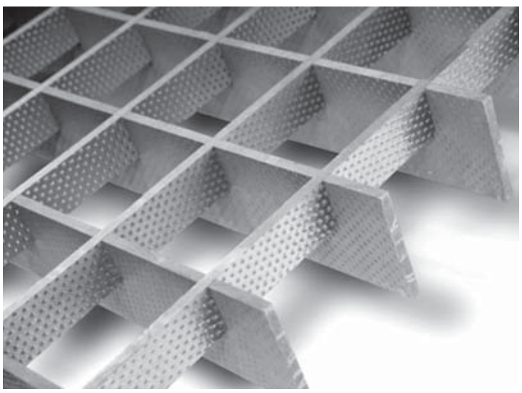

Fig. 2. Press-fit "egg-crate" C/C grid construction
(Courtesy of Schunk Graphite Technology)

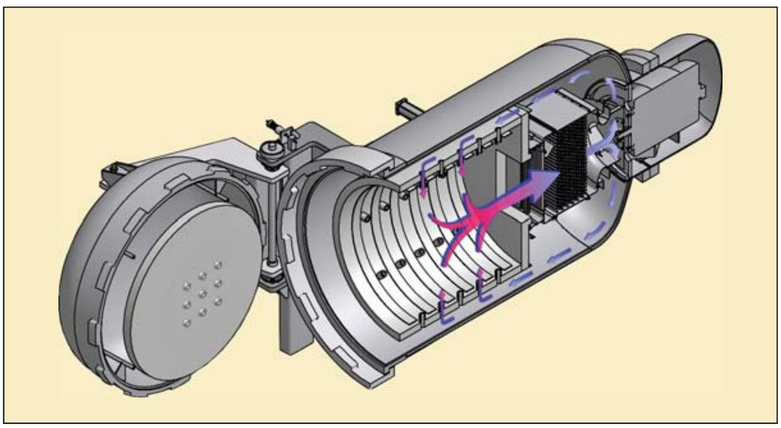

Fig. 4. Vacuum-furnace design elements (Courtesy of Solar Atmospheres, Inc.)

Fig. 5. C/C test-fixture assembly with test pieces

Fig. 6. Alloy test-fixture assembly with test pieces

- Furnace data
- Part data
- Application data
- Ancillary data

Do's and Don'ts

Eutectic melting can occur with C/C materials at temperatures exceeding 1050°C (1922°F), but it is highly dependent on the alloy(s) being run. Using ceramic barrier layers, Refrasil® cloth and (in some cases) 300 series stainless steel (SS) alloy mesh screens often negate the concern over eutectic reactions. C/C fixtures can be run at or above the processing temperatures used for alloy fixtures with significantly heavier loading. If 304-SS alloy screens are used as barriers, temperatures should not exceed 1120°C (2050°F).

Care must also be taken when attempting to unload these materials into open air at temperatures above 350°C (662°F) because C/C readily oxidizes over time, destroying or severely degrading mechanical properties.

Physical damage is another concern whether due to extremely rough handling, inadvertent dropping of the fixture or during loading/transport. Using hoist hooks, for example, is never recommended. When performing these types of operations, the breaking off of corners is one of the most commonly reported problems.

Case Study: Hardenability and High-Pressure Gas Quenching

High-pressure gas quenching of production loads in a vacuum furnace is often problematic when trying to run traditional water- and oil-hardening alloys, especially in larger cross sections. Schunk Graphite Technology and Solar Atmospheres of Western PA conducted a joint study to ascertain whether C/C composite material would provide hardenability improvements over conventional alloy fixturing for alloys such as 4130, 4140 and 8620. Energy usage and production savings were also investigated.

These trials examined the improvement in hardenability that could be gained by utilizing lightweight fixturing in an advanced 20-bar vacuum furnace design (Fig. 3, online only). As is often the case, heat treaters face situations where tare weight (grids, baskets, fixtures) limits the number of parts that can be loaded or the actual part weight that can be run.

Test Parameters

The test furnace had a workload space of 915 mm wide x 915 mm high x 1270 mm deep (36 inches W x 36 inches H x 50 inches D). The furnace was equipped with a 300-HP blower motor, 333-418 km/hour (207-260 mph) internal gas velocity and reduced gas-flow restriction technology, which included sliding radiation baffles to allow for direct exiting of the cooling gas from the hot zone into the gas-to-water

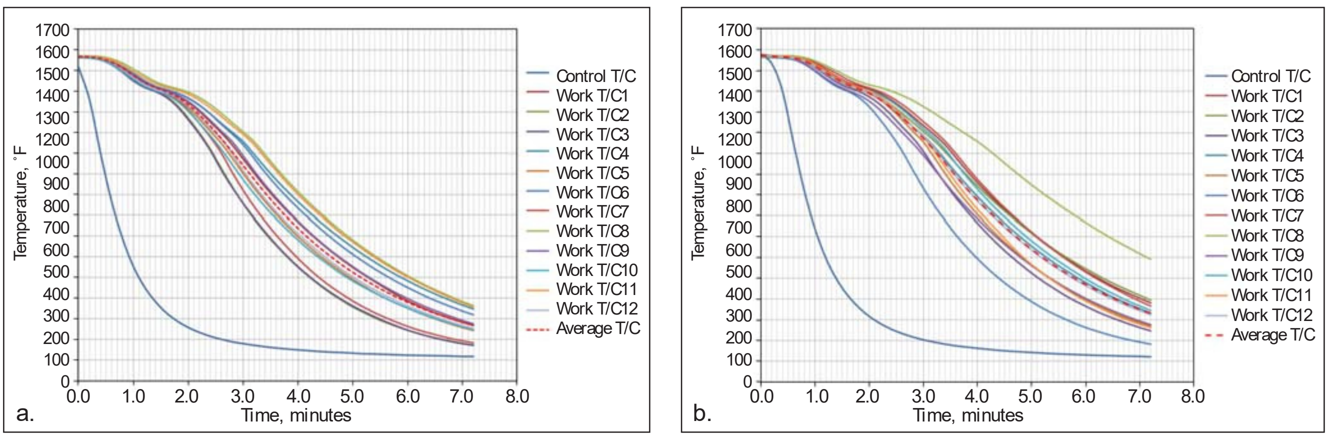

Fig. 10. Cooling performance comparison: (a) C/C fixture; (b) alloy fixture

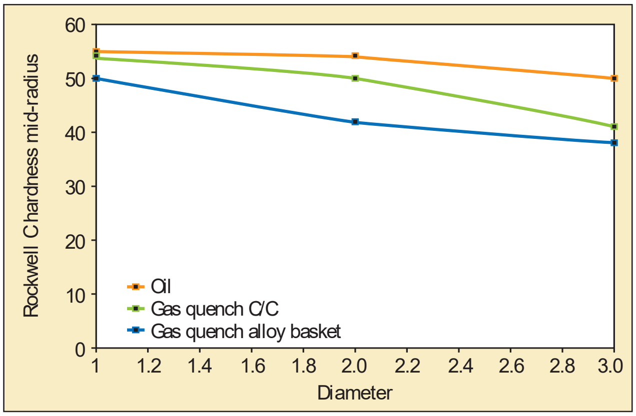

Fig. 12. Hardenability comparison – 4140 material

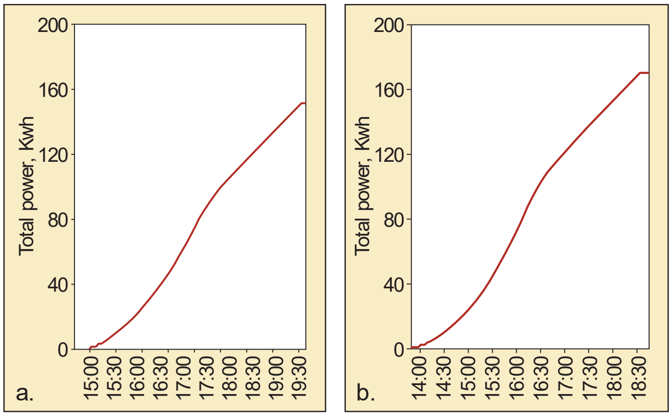

Fig. 14. Power consumption comparison: (a) C/C fixture; (b) alloy fixture

heat exchanger (Fig. 4).

The C/C fixtures consisted of eight Unigrid® pieces, each 610 mm wide x 915 mm long (24 inches wide x 36 inches long) complete with 36 graphite standoffs – each 75 mm (3 inches) in diameter – to provide 178 mm (7 inches) spacing between layers. The empty fixture weight was 54 kg (120 pounds).

The alloy fixtures consisted of eight RA330 rod mesh baskets with 304-SS liners. Each basket was 600 mm wide x 864 mm long x 178 mm high (22 inches W x 34 inches L x 7 inches H) set atop a cast-alloy work grid. The empty fixture weight was 225 kg (496 pounds). The total fixture weight (including the SL96A alloy base grid) was 347 kg (776 pounds).

The gross weight of the C/C fixture assembly (Fig. 5) was 275 kg (606 pounds), while the gross weight of the alloy fixture assembly (Fig. 6) was 572 kg (1,262 pounds).

The test load consisted of three different alloy steels, namely 4130, 4140 and 8620. Three different diameters of each material were run: 25 mm (1 inch), 50 mm (2 inches) and 75 mm (3 inches). Each was 100 mm (4 inches) in overall length. Ballast material consisted of 56 rounds of 75 mm diameter x 100 mm overall length. The total ballast weight was 203 kg (448 pounds) plus the net load (test parts only) of 17 kg (38 pounds) for a total weight of 220 kg (486 pounds).

Workload thermocouples were placed in 12 locations throughout the load (Fig. 7, online only) and buried 50 mm (2 inches) deep inside each of the test pieces (Fig. 8, online only).

The test cycle involved pumping the furnace down to 100 microns, ramping at 315˚C (600˚F) per hour to 857˚C ± 8˚C (1575˚F ± 15˚F) for 30 minutes, with the soak time starting at -0˚C, +8˚C (-0˚F, +15˚F). A 20-bar nitrogen quench commenced at the end of the soak cycle, and the load was allowed to cool to 65˚C (150˚F) prior to unloading.

Test Results

The cycle chart for each test load (Fig. 9, online only) illustrates both the uniformity of heating and time savings achieved. Heating (Fig. 9) and cooling (Fig. 10) times were reduced using the C/C fixture (Table 1).

Hardenability improvements were realized for all alloys tested when C/C fixtures were used. This is shown in Fig. 12 as well as Figs. 11 and 13, which are available online only. An outside testing laboratory evaluated the corresponding microstructures. For example, running 4140 material on C/C fixturing produced a predominately (>95%) martensitic structure with some bainite present in the 25 mm (1 inch) in diameter. For the 50 mm (2 inch) and 75 mm (3 inch) diameters, the martensite percentage dropped to 60% while the bainite percentage rose to 40%. By contrast, running 4140 material on alloy fixturing also found the 25-mm-diameter samples having a predominately (>95%) martensitic structure with some bainite present. However, the 50-mm- and 75-mm-diameter samples saw the martensite content drop to 25% while the bainite percentage rose to 75%.

Finally, an analysis was done on the power and cost savings (Fig. 14, Table 2).

Table 1. Cooling time comparison (minutes)

Average temperature	< 650˚C (<1200˚F)	< 540˚C (< 1000˚F)	<315˚C (<600˚F)	<150˚C (< 300˚F)
C/C fixture	2.5	3	5	7
Alloy fixture	3	4	7	10

Table 2. Power and cost savings

Power (kW)	Heat-up	Soak	Total	Cost[a]
C/C fixture	63	32	151	$10.57
Alloy fixture	69	30	170	$11.90
Notes: [a] Based in $0.07/Kwh (including demand charges)				

Test Conclusions

The following conclusions could be drawn from the test conducted.

1. The hardenability of quenchable alloys in production increases with the use of 20-bar quenching and the increased velocities achieved in the furnace.
2. For typical production loads, 4140 material shows great promise using 20-bar pressure and increased gas

velocity.

3. For typical production loads, the hardenability of 4130 and the core hardening of 8620 alloys in horizontal batch vacuum furnaces are less than optimal even at 20-bar pressure and increased gas velocity.
4. For typical production loads, the hardenability of all the alloys in this study benefited from the use of C/C fixturing versus traditional alloy fixturing.
5. Overall cost savings in electrical power when using C/C fixturing is 10% ($1.33).
6. Overall cost savings in production hours when using C/C fixturing is 15%, equating to $140 per cycle.

The production savings is significant, and these savings can offset the cost differential between C/C fixtures and alloy fixtures.

1. The workload comes to temperature 35 minutes faster with the C/C fixture as compared to the alloy fixture.
2. The workload cooling is 10 minutes faster with the C/C fixture as compared to the alloy fixture.
3. The resultant overall cycle time savings (door to door) was 45 minutes, which translated to a total cost savings of $140/cycle (based on a furnace cost of $200/hour).

Final Thoughts

The uses for C/C material as fixtures and grids for heat-treating applications are almost limitless. As with all other advanced technology solutions, matching the material's capabilities with the production requirement is an important first step.

Users should also keep records of the service history of their grids, baskets, fixtures and internal furnace components, including a history of duty cycles as a function of application, performance life and failure modes of the material. This field data helps the suppliers add to their technical expertise and improve the useful product life. IH

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