Issue 44

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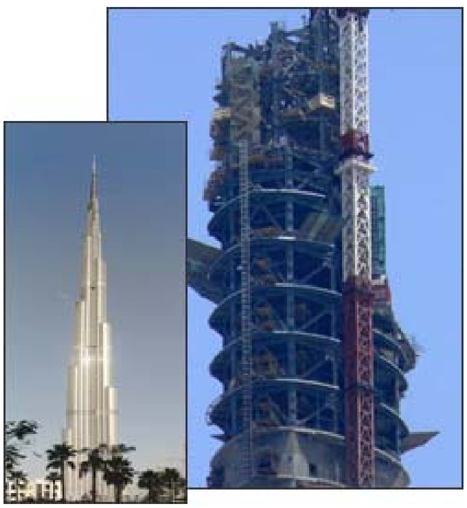
The Burj Khalifa – Cast in Concrete

The Burj Khalifa, the world's tallest building, has a laundry list of superlatives. Greatest number of stories, highest occupied floor, longest travel distance elevator, world's highest swimming pool. Perhaps none of these would have been achievable without the great advances that have been made in concrete technology over the past 20 to 30 years.

Until the 1990s, concrete wasn't a cost-effective solution for the construction of tall buildings – it had limited strength, it was heavy, and fabrication was longer than for steel construction. Generally steel was looked at as the solution for super-tall buildings. However, there have been significant advances in many aspects of concrete technology with great increases in strength, modulus and durability. High-performance concrete (HPC) mixtures provide a wide range of mechanical and durability properties to meet the design requirements of a structure. Even so, the challenges facing the structural and construction engineers on the Burj Khalifa project have been huge.



Most of the Burj Khalifa is a reinforced concrete structure, except for the top, which consists of a structural steel spire with a diagonally braced lateral system. 330,000 m3 (431,600 yd3) of high-performance concrete is used throughout the building.

One of the major requirements for the successful completion of this project was the ability to pump the concrete slurry up to a height of 600 meters (1968 feet) in a short enough time span (around 30 minutes) to ensure the concrete remained workable and retained its high performance properties. Three high-pressure pumps were used at the construction site to lift concrete up to crews working at unprecedented heights.

To decrease construction time, the concrete was designed to be self-consolidating (SCC), meaning a concrete mix that leveled itself solely due to its own weight, with little or no vibration. It spread into place, filled formwork, and packed tightly into even the most congested reinforcement, all without any mechanical vibration.

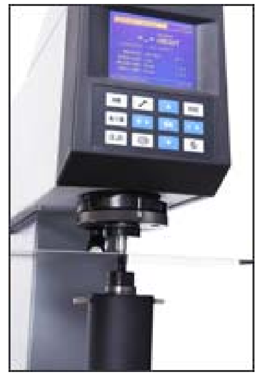
Great care was necessary to achieve and maintain the desired performance of concrete in this region. The Middle East is not a benign environment for concrete due to the extremely wide range of temperatures experienced throughout the year. The ability to pump and place concrete at high ambient temperature to significant heights while preventing excessive cracking and possible service life issues in the strong drying conditions was vital for the efficient and economic use of HPC. During the summer months, when shade temperatures can exceed 50°C (122°F), the concrete's water content was almost completely composed of flake ice to achieve the common limit of 32°C (90°F). Whenever possible, and in particular during the hottest months, all pumping of concrete took place at night.

The importance of extensive testing of the concrete could not be overstated. Prior to the construction of the tower, extensive concrete testing and quality control programs were put in place to ensure that all concrete works were done in agreement with all parties involved. These programs started from the early development of the concrete mix design until the completion of all test and verification programs. Five different concrete mixture designs were tested. The testing regimes included, but were not limited to the following:

- Test the mechanical properties of each mixture, including compressive strength, modulus of elasticity, and split tensile strength.
- Test and measure the concrete properties (fresh and hardened) before and after pumping.
- Test for creep and shrinkage for all mixtures.
- Test for water penetration and rapid chloride permeability.
- Test the shrinkage of the concrete mixtures.
- Pump simulation testing for all concrete mixtures grades up to at least 600 meters (1968 feet).

The Burj Khalifa is the current state-of-the-art in super-tall buildings, exploiting the latest advances in construction materials and methods. The result is a structure that surpasses anything that has been achieved before.

Look After Those Anvils

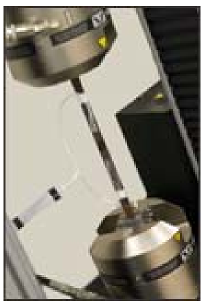


Specimen support is critical in Rockwell testing. Any specimen movement is transferred to the indenter and the measurement system, resulting in an induced test error. A movement of only 0.001 inches could cause an error of more than 10 Rockwell points. You should select a supporting anvil to match the specimen geometry and to provide full and uncompromised support. It must be rigid enough to prevent any deformation during use. Certain criteria must be met on all anvils; a good reference is ASTM E18, which offers basic guidelines including anvil hardness recommendations.

The supporting shoulder and the surface that the specimen sits on must be parallel to each other, and the anvil must present the test specimen perpendicular to the indenter. Both the supporting surface and the shoulder must be free of nicks, scratches and dirt, and be of sufficient design to properly support the material under test. You should examine anvils regularly, typically prior to each use, and replace them when necessary.

Many standard and custom-made fixtures exist to accommodate various specimen geometries. Plane or flat anvils support flat surfaces, the V-style anvil supports cylindrical work and the cylindron anvil is used for larger-diameter parts. The pedestal spot anvil has a small raised flat spot and is used when checking small, thin or irregularly shaped pieces, as well as testing materials not having a truly flat bottom. The small raised spot reduces the surface area of contact thus minimizing errors. The diamond spot anvil consists of a slightly raised, flat, polished diamond surface that supports the specimen and prevents damage and anvil influence on thin sheet materials that might occur with a standard anvil. The gooseneck anvil lets you test the outside diameter surfaces of thin-walled tubing. Support larger parts using test tables or a T-slot table that clamps the specimen to the table. Another useful fixture is the Vari-Rest, which extends horizontally to support elongated pieces.

Q. There's a new acronym in town. What is NADCAP?



A. The aerospace industry is keen to find new ways to reduce the weight of their flying fleets. Reduced aircraft weight leads to smaller engines and, the ultimate goal, less fuel consumption. Today, aerospace manufacturers are turning to carbon-fiber-based composites to replace metal parts. Carbon fiber composites are akin to super-strong textiles locked into shape with epoxy. Pound for pound they are much stronger and lighter than their metal counterparts. However, this enhanced stiffness makes it ever more critical to perform mechanical tensile and fatigue tests in precise, repeatable conditions. Metals can tolerate some amounts of misalignment and they exhibit plastic deformation after yield. Composites are not so forgiving. They are very stiff and often burst on failure without any plastic deformation. It is critical to ensure that tensile or fatigue specimens are subjected to completely uniform stresses to get a proper, maximized test of their strength.

For this and many other reasons associated with proper testing, a consortium, called the National Aerospace Defense Contractors Accreditation Program (NADCAP), has formed to establish standards for suppliers to the industry. The most recent edition of NADCAP AC7122 (Non-Metallic Materials Testing Audit Handbook) lists the requirements that laboratories must meet in order to sell their materials to anyone requiring NADCAP accreditation. For mechanical testing of composite materials, perhaps one of the most critical and challenging criteria to meet is the 8% maximum bending strain. Proper selection of load frame, grips, and testing technique are required in order to meet this requirement in a repeatable manner. Attention to this detail ensures that the highest possible tensile strengths are reported, since misaligned test setups can cause uneven stress distributions and lower tensile or fatigue results.

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