In This Issue - Year at a Glance:

In case you've missed some of our issues throughout the year, we've compiled this Special Edition Issue - Year at a Glance. You will find the most popular articles, technical tips, and Q&A of 2011. Here's to a fantastic year and the hopes of a great 2012!

Ouch, That's Gonna Leave a Bruise

Composite materials that copy the body's ability to bruise and self heal when damaged should simplify and reduce the costs of examining and evaluating structures.

The demand for composite materials is increasing worldwide. Their light weight, combined with exceptional strength, make them ideal for use as wind turbine blades, major aircraft components such as wings, and so on. However, they have low fracture toughness and a low resistance to crack propagation. In other words, they don't tolerate impact damage well.

All structures in service deteriorate over time. Designers build in overcapacity to cater for the stresses from normal operation when designing structures and components. However, impacts from clumsy handling, bird-strikes, and so on, can cause damage that may be severe but almost impossible to detect without expensive testing methods and equipment. Many researchers are looking to nature, more specifically to the ability of living systems to bruise and to heal after injury.

In nature, bruising occurs when tiny blood vessels near the surface are ruptured by an impact. Blood leaks from the damaged vessels into the surrounding tissues and the subsequent discoloration is visible through the skin.

Bruising in composite materials is achieved in a similar fashion. Microcapsules containing dye chemicals are incorporated into a surface coating, typically a gel coat. An impact ruptures the capsules and releases the chemicals. In the simpler types, the ruptured capsules just spill their colored contents, while other types use a chemical reaction to create the bruised effect. Where cosmetics are important, such as the surface of an aircraft, the bruise may be actually colorless, but will fluoresce under ultraviolet light to indicate areas where deeper inspection may be required.

Healing in nature similarly involves bleeding at the wound site, and continues with clotting and scabbing of the blood in the wound. To reproduce this process in composite materials, researchers are experimenting with incorporating hollow glass tubes and microcapsules into the material itself during manufacture. Some of the tubes or capsules contain a resin, and others contain a catalyst or hardening agent. The theory is that an impact that causes cracks in the material will cause the tubes to rupture, releasing their contents into the crack. The resin and catalyst mix and harden into an epoxy plug, thereby healing the damage. Further, the chemical action can be made to cause a color change or to fluoresce, "bruising" the material.

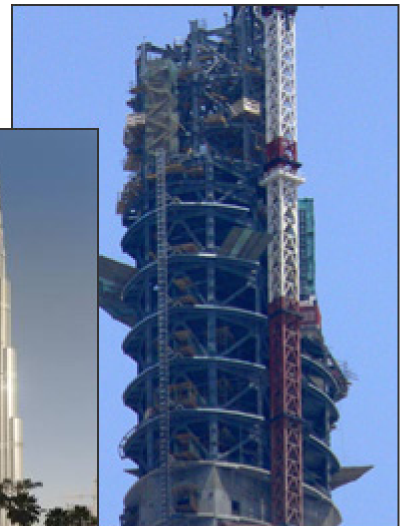
As with any new technology, there are problems to solve. Incorporating glass tubes or microcapsules into a composite material is bound to cause some reduction in the structural integrity of the material. There must be a sufficient number of hollow tubes or capsules within the material to create the healing effect, but not so many that it destroys the integrity of the original material. Other factors include the sort of damage that is anticipated. If you have the glass fibers nearer the surface, they are more likely to be damaged in an impact, but it may be that it is the deeper damage that is structurally more compromising. The arrangement of the tubes or microcapsules is therefore very dependent on the type of risks that are likely to occur in service.

This research and development exemplifies a growing interest in the wider field of biomimicry for engineering materials and structures. The challenge is to understand the functional characteristics of natural systems in order to produce systems that work with engineering structures, feasibly and economically.

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.

Full Fluid Jacket – Liquid Body Armor

Humans have waged war on one another for centuries. Weapons have evolved from sticks and stones through cutting and bludgeoning implements to today's smart bombs and missiles. But the evolution of the means to protect oneself from the impact of those weapons has not kept pace. However, a new technology combining two advanced materials – Kevlar and shear-thickening fluid – may hold the promise of light, flexible and effective full body armor.

Today's body armor is a compromise between protection and agility. Most modern body armor comprises many layers of woven Kevlar, sometimes with ceramic plates to give extra protection. Kevlar is an aramidic fiber, which forms hydrogen bonds between its chains of molecules and thus has a very high tensile strength and high toughness. It is five times stronger than steel on an equal weight basis and it already saves countless lives.

Although Kevlar offers vastly increased protection for the wearer, it does have some drawbacks. For effective protection, up to 30 or 40 layers of Kevlar are needed. This many layers, together with additional ceramic plates, make the armor bulky, stiff and heavy, meaning that the wearer cannot move around as easily. Also, body armor does not offer protection for extremities, such as arms, legs or the neck because the number of layers of Kevlar needed to offer sufficient protection would be too stiff and bulky for use as sleeves, trousers, and so on.

Photo courtesy of US Army, taken by Specialist Kirby Rider

A great deal of largely US-military-funded research has taken place over the last few years into combining Kevlar fabric with a shear-thickening fluid. Shear-thickening fluid is an example of a "smart material," a class of materials that can sense and respond to changes in the environment, for example through the application of electricity or magnetism, or to changes in temperature. Shear-thickening fluids increase their viscosity in response to changes in pressure. An example of a fluid under research is ethylene glycol containing suspended nano-particles of silica. Under normal conditions, the particles are weakly bonded to each other and can move around with ease. The shock of an impact strengthens those chemical bonds and the particles lock into place. Once the force from the impact dissipates, the bonds weaken again.

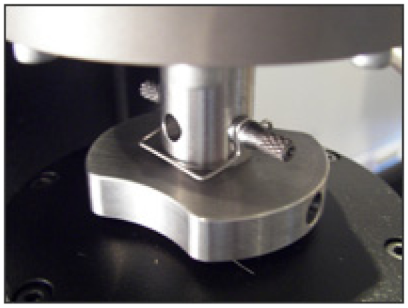
The liquid technology can improve both the performance and the utility of Kevlar fabric. Saturating Kevlar fabric in a shear-thickening fluid causes the fluid molecules that are already bonded with each other to also form weak chemical bonds with the polymer chains of the Kevlar fibers. The weak bonding allows the fabric to remain flexible. When a projectile strikes the fabric, it becomes rigid within two-thousandths of a second, preventing penetration. Furthermore, the reduced flow of the fluids in the liquid armor restricts the motion of the fabric yarns in relation to each other, resulting in an increase in the area over which the impact energy is dispersed. As a result, the material does not distort as much as the standard body armor, which generally extends inwards substantially when a projectile strikes, causing considerable pain and injury. Once the event is over, the fabric returns to its former flexible state.

The mechanical properties of the material are being evaluated using a wide range of tests and test equipment. Drop towers test puncture resistance with knives and icepicks as well as various shapes and sizes of instrumented tups. Load frames are used to test resistance to abrasion, fiber pullout, and tearing. Gas guns are used to fire ballistics such as bullets and shrapnel.

Impregnating Kevlar with a shear-thickening fluid strengthens the fabric to such an extent that improved protection can be achieved with a material that is one-third the thickness of Kevlar alone. Therefore the body armor can be lighter, more flexible and yet offer greater protection from projectiles, shrapnel and explosive devices – the major causes of injury and death in modern conflicts. Seventy per cent of all non-fatal injuries and sixteen per cent of deaths in a war zone are due to trauma to extremities. Because fewer layers are necessary with the new material, supple armor for arms and legs is now possible. Extremity armor using shear-thickening fluid impregnated Kevlar could significantly reduce the number of injuries in battle as well as saving lives.

Accurate Testing Starts with the Preload

Often when visiting customer sites, our service engineers find machines that have basic setup problems that can have a large effect on the accuracy of test results. A very common problem is testing with poorly preloaded grip locknuts. Placing a specimen under tension also places all items in the load string – grips, grip adapters, load cell, and so on – under tension as well.



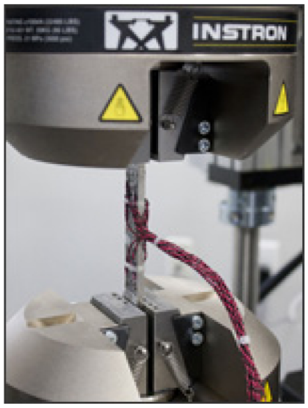
Grips Supplied with Locknuts

If the locknut is insufficiently tight, the forces experienced during a test, particularly a cyclic test, can cause backlash in the load string leading to errors in the test data. Before testing, make sure that you preload the load string, using a load greater than the expected maximum load, and tighten the grip locknuts while the load is applied.

Importance of Accurate Alignment

Your testing system represents a major capital investment for your organization. You make sure it is regularly calibrated for load, strain, and displacement, and that it is regularly serviced. But when did you last make sure that the alignment was correct?

Misalignment takes two forms: concentricity misalignment, in which the centerline of the upper grip or fixture is offset from the centerline of the lower grip or fixture; and angularity misalignment, in which the two centerlines are at different angles to each other. Both impose unwanted bending stresses into a test piece under load and can therefore affect the behavior of the material.



Load frame alignment can change for a number of reasons, including:

- Changing grips
- Installing new or replacement load string components, such as load cells, adapters, and fixtures
- Repositioning the fixed crosshead
- Wear or damage to load string or load frame components

The importance of accurate alignment is recognized more and more by accreditation bodies, aerospace corporations, and others. You must be able to demonstrate that your systems meet the alignment requirements specified in many ASTM standards that reference tolerances for either bending stresses or alignment.

ASTM has produced ASTM E1012, which outlines the requirements and calculations for assessing load frame alignment. This standard is frequently quoted as an acceptable method for checking and quantifying materials testing machine alignment.

So, consider requesting an alignment check during your next service visit. You never know when you may need to show that your system is ready for everything.

Keep It Consistent

Consistency is the key to accurate and repeatable test results. Variations in the test setup, test procedure, environmental conditions, and operator input can all affect the test results.

- Make sure that the appropriate gauge length, test speed, type and capacity of load cell, and grip and grip jaw selection are appropriate.
- Insert the specimen in the grips correctly and clamp it securely. Manual wedge grips are difficult to tighten consistently even with the same operator. You can minimize this variation by using pneumatic grips that always grip at the same pressure.
- Control the temperature and humidity to standard laboratory conditions or record the actual conditions when a test is performed.
- Ensure that your testing system and accessories are regularly serviced and calibrated to keep them at the peak of efficiency.

Q. How can I minimize variability when testing stiff materials such as composites?

A. Achieving consistent, repeatable results requires consistent, repeatable testing conditions. The major sources of variability when testing stiff materials such as composites are gripping and alignment.

Proper gripping of stiff materials or coupons is best done with a powered grip. Powered grips are most often driven by hydraulics or pneumatics, and offer the most repeatable conditions since the operator is not directly involved. Manual grips are subject to variability due to different operators applying different forces when tightening the grip onto the specimen. Furthermore, it is best that these powered grips are rigidly mounted and preloaded. Flexible couplings or loose joints can easily cause bending strains outside of NADCAP or ASTM bounds, and introduce a significant amount of scatter in results.

Finally, the location of the specimen in the grips also plays a significant role in producing repeatable results. Round specimens are less of an issue, since the "Vee" in the grip face positively locates and centers the specimen. Flat specimens, however, require specimen alignment stops to ensure that they are located in exactly the same place for every test. You should reset these alignment devices with every change in specimen geometry.

Rigid load strings, powered grips, and specimen location alignment devices are all technologies which, when combined with careful testing technique, can go a long way to maximizing measured mechanical properties, and minimizing variability.

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