Nature does it again

There is a crush-resistant insect, which may have lessons for the engineer

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Natural structures have often done better than carefully designed man-made shells of the best materials. The structure of cellulose, the material of wood, the shells and wings of insects, all better iron and steel in their strength, given their weight.

But nothing seems to compare with the shell of a diminutive wood insect which is found in the drier parts of western US. This is *Phloeodes diabolicus*, now known as *Nosoderma diabolicum*. It may be quite right that "devilish" is its second name, as the beetle has a shell so hard that steel pins used to mount insect specimens are ineffective. The shell protects the beetle from bird-pecks and all predators, and is so strong that being run over by a car does it no harm.

Jesus Rivera, Maryam Sadat Hosseini, David Restrepo, Satoshi Murata, Drago Vasile, Dilworth Y Parkinson, Harold S Barnard, Atsushi Arakaki, Pablo Zavattieri and David Kisailus, from the Universities of California at Riverside and Irvine, Purdue University, University of Texas, Lawrence Berkeley National Laboratory and Tokyo University of Agriculture and Technology, describe in the Journal, *Nature*, their study of what makes the shell of the *diabolicum*, or the diabolical ironclad beetle, so strong, and whether we can borrow the principles to design our own engineering structures.

Through the ages of evolution, animals that lack speed and the arsenal for defence have evolved protective armour – one such is the group of arthropods, or animals that have an exoskeleton. Beetles, of which there are over 350,000 species, are the best example – their outer shell provides structural support, water collection and retention, and defence. In particular, the paper says, is the *Zopherinae* (Ironclad) family, which can resist being crushed and whose forewings are so hard that steel pins bend before they can pierce them.

These beetles no longer have the membranous hind wings which enabled their ancestors, and most other current day insects, to fly and evade their predators. Instead, the beetles have adapted by hardening the forewing, to fuse with the hind parts and form an outer covering, more robust, with density of 0.97 gm/cc, compared to 0.51 gm/cc which is more commonly found, as a shield or protection. The rough exterior acts as camouflage – the beetle looks a lot like a bit of rock, and is so hard that it can withstand piercing strikes by predators, or even heavy impact, like being run over by a car, the paper says.

To get a hold on how well *P.diabolicus* dealt with loads that it encountered, the team carried out compression tests and compared the results with what other beetles which had the same needs, of resisting crushing and pecks by predators, could do. They found that the *P.diabolicus* shell increases its stiffness, by over two and a half times, when the load is put on and can stand a load as high as about 15 kg. Considering its own weight, this is equivalent to a load, on a human who weighs 60kg, of more than 2,300 tonnes! Other beetles of the same kind do pretty well too, but only half as well as *P.diabolicus*. There was a species that showed comparable stiffness at the start of the loading but was not better than the others when the load increased. This suggests that the shell of *P.diabolicus* has a different composition or structure, the paper says.

The shells, wings, and outer coverings of insects are known to have evolved microstructure that multiplies strength and makes the material more hardy than metal sheets or other human fabrications. The Fullerian geodesic dome was a sally into this world, it represents architecture that is present at the nano-scale in materials like graphite, but its application is more in the design of large structures. The arrangement of the molecules that make up natural materials follow similar principles, and are formed in layers, which gives the materials great capacity to absorb impact and resist damage. All of this however, is not good enough to explain the much greater resilience of the *P.diabolicus* shell.

The team went into the details of how *P.diabolicus*' shell is built, using methods like micro-CT scans and scanning electron microscopy. While the normal X-ray only throws a shadow, to help make out the kind of tissue the radiation has traversed, the CT scan is a series of X-ray images of slices of an organ. By viewing the slices together, one can build a 3D picture of the internals of an organ. And the scanning electron microscope produces surface images of fineness that is not possible with optical microscopes.

The investigation revealed that the secret of *P.diabolicus* is a pair of hardy, left and right halves, connected by a central suture on top and with supports to connect the upper shell to the shell on the underside. While the material of the shell has a complex structure and is formed in layers, the connections have their own complexity. The supports themselves stiffen and stay strong under compression, while some of the connections allow an extent of deformation, which enables impact to be distributed, so that no one portion bears a large impact, which could make it collapse. The study has revealed an air-filled cavity within the shell, which enables the shell to deform, to absorb shock, without damage to internal organs.

The paper describes analysis of the jointing of the shell to the underside and between the two halves of the shell along the central suture. The connections to the base are found to vary along its length, with maximum stiffness in the region of the thorax. The connections in the central suture and to the underside use "mechanically interlocking jigsaw blades", a connection method that is found in other beetle shells too. The shapes and numbers of the blades in *P.diabolicus*, however, makes for greater distribution of stress and "maximum tensile and shear stiffness, strength and fracture toughness," the paper says.

The connectors that keep together the parts of the *P.diabolicus* shell, the paper finds, create "robust joints with more predictable failure than in other beetles." For failure to be "predictable", rather than "sudden" is a great advantage in the design of structures. In the case of the beetle, which needs to squeeze into cracks and crevices, it can judge when to stop increasing the pressure. Even if there is damage, the "layered" structure localises the effect and prevents spread.

The authors draw a parallel of comparable shaping of turbine blades or the landing gear of aircraft. These are devices that need to take high loads and sudden failure can have serious consequences. The authors hence constructed models which mimicked biological materials, in shapes and the layered structure. The mimics were found to do significantly better than the same devices made of standard materials. While composites that mimicked the *P.diabolicus* suture were positively stronger, they also distributed stress more evenly. And a layered architecture reduced the possibility of a local failure that could lead to the collapse of the device.

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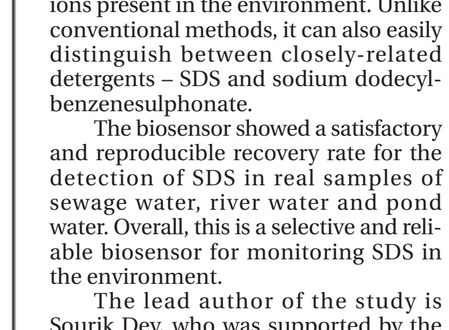
PLUS POINTS

Sensing pollutant



A five-member team of researchers at the Indian Institute of Technology-Roorkee has developed the world's first specific bacterial biosensor to detect the presence of the common environmental pollutant, sodium dodecyl sulphate /sodium lauryl sulphate. SDS is extensively used in soaps, toothpaste, creams, shampoo, laundry detergents for households, agricultural operations, laboratories and industries. Its subsequent disposal in waterways causes harmful effects on aquatic organisms, ecosystems and associated living organisms besides deteriorating the quality of drinking water.

The objective of the study was to develop a novel biosensor for the detection of SDS in environmental samples. Until this piece of research, there were no specific biosensors for the detection of SDS with high precision. The IIT-Roorkee team developed a whole-cell biosensor using pseudomonas aeruginosa strain as a framework (chassis). The system involves a highly specific regulator along with a fluorescent protein that is produced only when SDS is present in the sample.

This biosensor is highly specific for SDS and has minimal interference from other detergents, metals and inorganic ions present in the environment. Unlike conventional methods, it can also easily distinguish between closely-related detergents – SDS and sodium dodecylbenzenesulphonate.

The biosensor showed a satisfactory and reproducible recovery rate for the detection of SDS in real samples of sewage water, river water and pond water. Overall, this is a selective and reliable biosensor for monitoring SDS in the environment.

The lead author of the study is Sourik Dey, who was supported by the department of biotechnology MSc programme at IIT-Roorkee. The project was executed in professor Naveen Kumar Navani's laboratory at the department of biotechnology. The other members of the team are Shahnawaz Ahmad Baba, Ankita Bhatt and Rajat Dhyani.

SDS has diverse applications in the industrial sector as an emulsifier, food processing agent, stabiliser, leather softener, foaming, flocculating and cleaning agents. SDS has harmful effects on the survival and breeding of organisms in the aquatic ecosystem as it hampers their biological processes such as solubilisation of phosphate, reduction of ammonia, nitrogen fixation and photosynthesis. It can cause dermal and ocular irritation, cardiac anomaly, haemolysis, tachycardia, kidney failure, and even death.

Cooking rice

A new paper from the UK's University of Sheffield in *Science of the Total Environment* shows that cooking rice in a certain way removes over 50 per cent of the naturally occurring arsenic in brown rice, and 74 per cent in white rice. Importantly, this new method does not reduce the micronutrients in the rice we need in our diet.

This new study tested different ways to cook rice to try and reduce the arsenic content. The team from the university's Institute for Sustainable Food found that by using a home-friendly way of cooking rice, the "parboiling with absorption method", most of the arsenic was removed, while keeping most nutrients in the cooked rice. The method involves parboiling the rice in pre-boiled water for five minutes before draining and refreshing the water, then cooking it on a lower heat to absorb all the water.

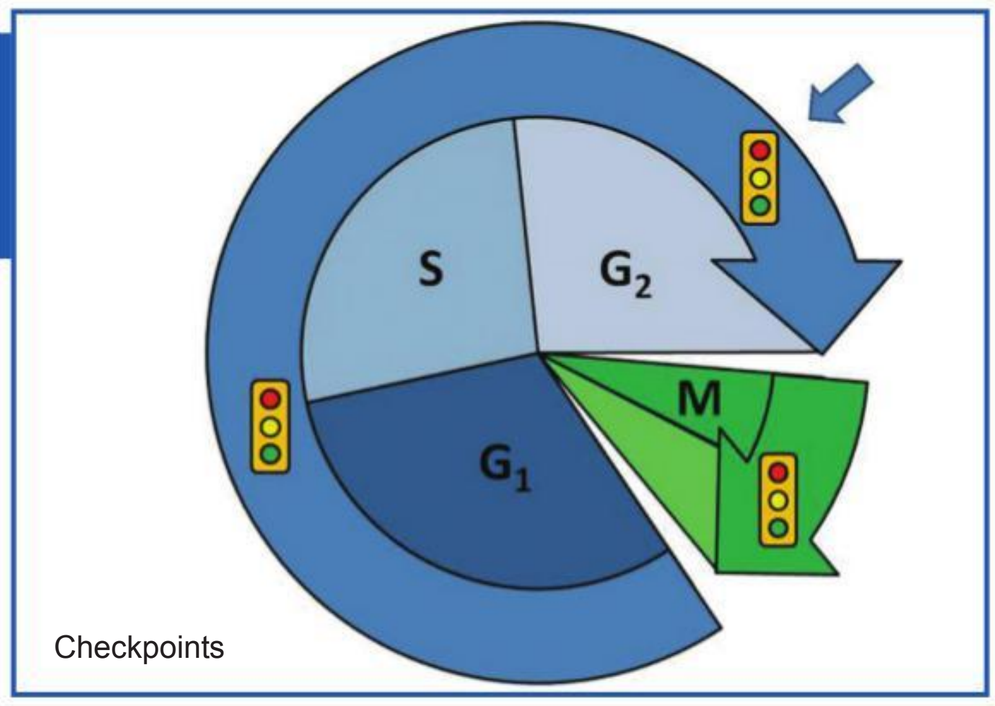
Rice is known to accumulate around 10 times as much arsenic as other cereals. In rice grains, arsenic is concentrated in the outer bran layer surrounding the endosperm. This means that brown rice, (un-milled or unpolished rice that retains its bran) contains more arsenic than white rice. This milling process removes arsenic from white rice but also removes 75-90 per cent of its nutrients.

Manoj Menon, environmental soil scientist in the department of geography, University of Sheffield and lead author of the study, said, "For rice consumers, this is excellent news. Our aim was to optimise the method to remove arsenic while keeping maximum nutrients in the cooked rice. With our new method we are able to significantly reduce the arsenic exposure while reducing the loss of key nutrients."

PUTTING IT ALL TOGETHER

Here's how the cell-cycle regulation machine works

TAPAN KUMAR MAITRA



The ability to grow and reproduce is a fundamental property of living organisms. Whether an organism is composed of a single cell or trillions of cells, individual cells must be able to grow and divide in an appropriately regulated fashion.

Cell growth is accomplished through the synthesis of new molecules of proteins, nucleic acids, carbohydrates and lipids. As the accumulation of these molecules causes the volume of a cell to increase, the plasma membrane grows to prevent the cell from burst-ing. But cells cannot continue to enlarge indefinitely; as a cell grows larger, there is an accompanying decrease in its surface area/volume ratio and hence in its capacity for ef-fective exchange with the environment. Therefore, cell growth is generally accompanied by cell division, whereby one cell gives rise to two new daughter cells (The term *daughter* is used by convention and does not indicate that cells have gender).

For single-celled organisms, cell division increases the total number of individuals in a population. In multicellular organisms, cell division either increases the number of cells, leading to growth of the or-ganism, or replaces cells that have died. In an adult human, for example, about two million stem cells in bone marrow divide every second to maintain a constant num-ber of red blood cells in the body.

When cells grow and divide, the newly formed daugh-ter cells are usually genetic duplicates of the parent cell, containing the same (or virtually the same) DNA sequences. Therefore, all the genetic information in the nucleus of the parent cell must be duplicated and carefully distributed to the daughter cells during the division process. In accomplishing this task, a cell passes through a series of discrete stages, collectively known as the cell cycle.

The cell cycle begins when two new cells are formed by the division of a single parental cell and ends when one of those cells divides again into two cells. To early cell biologists studying eukaryotic cells with the mi-croscope, the most dramatic events in the life of a cell were those associated with the point in the cycle when the cell actually divides. This division process, called the M phase, involves two overlapping events in which the nucleus divides first and the cytoplasm second. Nuclear division is called mitosis, and the division of the cytoplasm to pro-duce two daughter cells is termed cytokinesis.

The stars of the mitotic drama are the chromosomes. The beginning of mitosis is marked by condensation (coiling and folding) of the cell's chromatin, which generates chromosomes that are thick enough to be individually discernible under the micro-scope. Because DNA replication has already taken place, each chromosome actually consists of two chromosome copies that remain attached to each other until the cell divides. As long as they remain attached, the two new chromosomes are referred to as sister chromatids. As the chromatids become visible, the nuclear envelope breaks into fragments. Then, in a stately ballet guided by the mi-crotubules of the mitotic spindle, the sister chromatids separate and -- each now a full-fledged chromosome -- move to opposite ends of the cell. By this time, cytokinesis has usually begun, and new nuclear membranes envelop the two groups of daughter chromosomes as cell division is completed.

While visually striking, the events of the mitotic phase account for a relatively small portion of the total cell cycle; for a typical mammalian cell, the mitotic phase usually lasts less than an hour. Cells spend the majority of their time in the growth phase between divisions, called interphase. Most cellular contents are synthesised continuously during interphase, so cell mass gradually increases as the cell approaches division. During interphase the amount of nuclear DNA doubles, and ex-periments using radioactive DNA precursors have shown that the new DNA is synthesised during a particular portion of interphase named the S phase (S for synthesis). A time gap called G1 phase separates the S phase from the preceding M phase, and a second gap, the G2 phase, separates the end of S phase from the beginning of the next M phase.

Although the cells of a multicellular organism divide at varying rates, most studies of the cell cycle involve cells growing in culture, where the length of the cycle tends to be similar for different cell types. We can easily determine the overall length of the cell cycle -- the generation time -- for cultured cells by counting the cells under a microscope and determining how long it takes for the population to double. In cultured mam-malian cells, for example, the total cycle usually takes about 18-24 hours.

Once we know the total length of the cycle, it is possible to determine the length of specific phases. To determine the length of the S phase, we can expose cells to a radioactively labelled DNA precursor for a short period of time and then examine the cells by autoradiography. The fraction of cells with silver grains over their nuclei represents the fraction of cells that were somewhere in S phase when the radioactive compound was available. When we mul-tiply this fraction by the total length of the cell cycle, the result is an estimate of the average length of the S phase.

For mammalian cells in culture, this fraction is often around 0.33, which indicates that S phase is about six to eight hours in length. Similarly, we can estimate the length of the M phase by multiplying the generation time by the percentage of the cells that are actually in mitosis at any given time. This percentage is called the mitotic index. The mitotic index for cultured mammalian cells is often about three to five per cent, which means that M phase lasts less than an hour (usually 30-45 minutes).

In contrast to the S and M phases, whose lengths tend to be quite similar for different mammalian cells, the length of G1 is quite variable, depending on the cell type. Although a typical G1 phase lasts 8-10 hours, some cells spend only a few minutes or hours in Gl, whereas others are delayed for long periods of time. During Gl, a major "decision" is made as to whether and when the cell is to divide again. Cells that become arrested in Gl, awaiting for a signal that will trigger re-entry into the cell cycle and a commitment to divide, are said to be in G0 (G zero). Other cells exit from the cell cycle entirely and undergo terminal differentiation, which means that they are destined never to divide again; most of the nerve cells in our body are in this state. In some cells, a transient arrest of the cell cycle can also occur in G2. In general, however, G2 is shorter than Gl and is more uniform in duration among different cell types, usually lasting 4-6 hours.

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