Nature’s strongest glue: A potential alternative to commercial super glue

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Bacterial adhesion to various surfaces, including water, can play an important role in the environment, disease and industry. Bacterial adhesion and biofilm formation often cause biofouling, a process which can severely damage ships, marine pipelines as well as naval vessels. Governments and industries spend more than US$ 5.7 billion annually to prevent and control marine biofouling. Strong attachment of single bacterial cells to surfaces provides the first essential step of understanding this interesting natural phenomenon. However, detailed study of adhesion of a single bacterial cell responsible for biofouling has not been carried out so far. Such a study will not only provide a fundamental understanding of the biofouling process, but can also be utilized in potential adhesive applications.

Water-dwelling Caulobacter crescentus bacterium has the ability to live in extremely nutrient-poor conditions. This explains its existence as a common fixture in tap water at low concentrations. This bacterium produces no human toxins, and as a result it is harmless to the human body. The Gram-negative bacterium, C. crescentus initiates the process of biofouling. C. crescentus cells attached to a surface resist washing with strong jets of water, suggesting the strong adhesion of this bacterium to any surface.

Researchers in Indiana and Brown University, USA have discovered that the adhesive made by this bacterium can withstand a huge shear force of 68 N/mm² in the presence of 1 μN detachment force, making it the strongest biological adhesive ever measured. The adhesion measurement of single bacterial cells in micronewton range was carried out using a special micromanipulation technique. In their experiment, Tsang et al. first allowed the individual C. crescentus cells to attach to a thin flexible pipette made of borosilicate glass. The force constant of this thin pipette was calibrated by atomic force microscope (AFM). Thereafter, they used a suction pipette to trap and pull at each cell, measuring the force needed for its detachment. The movement of the suction pipette was controlled by a micromanipulator, whereas suction pressure was applied using a syringe. Figure 1 illustrates the schematic diagram for the single bacterial cell adhesion force measurement using the micromanipulation technique. Tsang et al. measured the adhesion force for 14 individual cells and found that a pulling force of 0.11–2.26 μN/cell had to be applied for detachment of the bacterial cell. Inset in Figure 1 shows the image of a cell of C. crescentus with elongated stalk. The strong bacterial adhesiveness comes from holdfast, a polysaccharide that mediates the strong attachment of stalked cells to the surfaces (holdfast is situated at the end of stalk). A group of polysaccharides named N-acetylgalactosamine (GlcNac) were the only characterized components of holdfast.

When the researchers digested the GlcNac polysaccharides by treating with lysozyme, the bacterial cells lost much of their strong adhesiveness. At concentrations of 2.3, 0.1 and 0.01 mg/ml of lysozyme, all cells were readily pulled-off from the pipette by syringe suction. This result provides clear evidence that the GlcNac polysaccharide is a critical component of the strong adhesive force of holdfast. The holdfast size and thickness were measured by AFM. Figure 2 shows the AFM image of a C. crescentus cell grown on a glass coverslip. A part of the image in Figure 2 a is marked with a square box, indicating the presence of holdfast at the end of the stalk. Figure 2 b shows the magnified view of this holdfast area. AFM imaging was carried out for 12 stalks to obtain an average diameter of 119 nm for dried stalk with measured average height of 40 nm. Assuming the stalk to be a solid rod, the average threshold shear force that the stalk could withstand was found to be 53 N/mm². This value was calculated using the values of stalk diameter and average detachment force as 119 nm and 0.59 μN respectively. Finally, the average adhesion strength between the holdfast and substrate in the central region of contact was found to be greater than 68 N/mm².

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Figure 1. Schematic diagram illustrating the single bacterial cell adhesion force measurement using the micromanipulation technique. (Inset) Image of a Caulobacter crescentus cell with elongated stalk. Reprinted with permission from Tsang et al. Copyright (2006) by National Academy of Sciences, USA.
This value was calculated from the stress distribution using numerical finite element analysis method. It is important to mention here that this is the largest value measured for a biological adhesive so far.

The remarkable climbing ability of geckos to almost any surface depends on the high adhesion strength of the tiny nanosized foot-hairs known as setae. Autumn et al. first measured this adhesion strength and found that a single seta on the toes of geckos can generate up to 10 N/mm². The adhesion strength of the holdfast of C. crescentus cell is stronger than that of the toes setae of the gecko and far stronger than all other known cellular attachments. This high adhesion strength of the holdfast of C. crescentus cell makes it stronger than the commercial 'super' glue, which breaks under the application of a shear force of 18–30 N/mm². It is stronger than the commercial dentin adhesive, which can give adhesive strength up to 30 N/mm². Thus, it is expected that such a natural adhesive can be utilized for potential medical and engineering applications. Due to its effectiveness in wet environment, this natural glue may be a promising biodegradable adhesive for various medical procedures such as surgery. Thus, it is challenging to use this concept of natural glue and produce it in large quantities for potential medical applications.


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