Nano-adhesives to create near-unbreakable metal and rubber bonding

Adhesives are used throughout industry, but many contain toxics and others are not reliable or durable. But what if you could merge two materials together using clean molecular bonding? That is exactly what scientists are working on right now.

Have you ever hassled with tearing off a glass bottle label, getting more and more agitated as the label just shreds when you try to peel it off and its remains seem moulded onto the bottle – impossible to get off?

Adhesives are used for a great many purposes in our world (from an annoying fly sticking to the window to the space industry) and can sometimes lead to frustration when they adhere too well – or not well enough.

But sometimes it is desirable to 'glue' two things together intending the materials to remain linked forever – no matter what conditions the bond is exposed to. Imagine bonding metal plates together instead of bolting or welding them. That is not an easy job though, particularly if the binder should not be toxic.

The solution could very well be a molecular nano-adhesive which binds two materials together with an almost unbreakable chemical adhesion.

"Rubber is usually bonded to metal via a standard kind of adhesive that's quite toxic, not very reliable, and not very durable. That's a big issue, first of all because of the toxicity – we want clean products. So the idea is to develop a new kind of adhesive on a molecular level using covalent bonding – without any third material. In essence, we're trying to bond the rubber directly to the metal by means of chemistry in an effort to develop a clean, reliable product without any toxicity issues. From our mechanical engineering perspective, the challenge comes from another fact: rubber and metals lie on opposite sides in terms of elastic properties. Once they are bonded together, such a material mismatch leads to severe stress gradients," says Assistant Professor Michal Kazimierz Budzik.

Developing special molecules

Molecules have different electrical charges in their chemical structure. This leads to van der Waal forces – relatively weak repulsive or attractive forces that occur between atoms of different materials. Ordinary adhesives stick to materials using weak attractive forces and can then bind the materials together when they have cured.

In comparison, covalent bonds are considerably stronger, and do not have the problem normal adhesives have when they come in contact with water.

"Think of the situation when the rubber and metal interface is subjected to high stress. In addition, water is one of the most aggressive environments for polymers and interfaces. Water is polar in nature, which means that hydrogen bonds can form between it and the adhesive, thereby breaking up the bond. This leads to situations such as the rubber coating in the valve becoming loose so that it gradually loses its function and provides access to bacterial growth. This is definitely not the easiest situation to deal with in mechanics," says Assistant Professor Budzik. And as if that is not enough, cleaning processes involving steam and high temperatures in industries where adhesives are used can easily destroy the bond line between 'glued' materials.

Aarhus University researchers therefore aim to develop special molecules that form chemical bonds with a metal surface and then adhere to rubber using surface-grafted polymer brushes – a recent nanotechnology breakthrough in binders.

Considerable potential

Through an electrochemical process and polymerisation on the metal surface, this surface-bound polymer layer is combined with the rubber. The combination creates chemical bonds criss-crossing among the polymer chains in the mixture, including the surface-bound polymer layer, which thus acts as the adhesive between the metal and the rubber. It ensures an incredibly strong bond and a variety of desirable effects.

For example, scientists forecast that material/adhesive consumption can be reduced by a factor of 1,000, and that food industry safety will be significantly increased.

So far, the researchers have managed to bond rubber to metal using the novel formulation. A big milestone. However, there is still a way to go before such a molecular adhesive is validated and ready for use.