New approach to scratch resistance: Improving coatings with polymer-based nanocomposite materials

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A new way to analyze how coatings of tiny particles alter the properties of transparent plastic could help researchers create lightweight windows with nearly the strength of glass. The same method could also lead to high-strength, scratch-resistant coatings that could be applied to many different materials, according to the MIT researchers who developed the analysis.

The analysis used a polymer called poly(methyl methacrylate), or PMMA, which is widely used as a glass substitute. Known generically as acrylic, and sold under trademarks such as Lucite or Plexiglas, this material can be brittle and is far less resistant to scratching than glass.

Other researchers have added silica particles measuring just nanometers across to PMMA, creating a polymer-particle nanocomposite with much greater strength. But the MIT team, for the first time, has found a way to analyze the particle-polymer interactions of such coatings at the nanoscale, which could facilitate the discovery of improved coatings. Their work was reported in July in the journal Soft Matter.

The analysis was carried out by Meng Qu, a postdoc in MIT's Department of Materials Science and Engineering, along with Associate Professor of Materials Science and Engineering Krystyn Van Vliet and several researchers at DuPont Nanocomposite Technologies in Delaware. The work was partly funded by the DuPont-MIT Alliance.

Silica particles were used for the coating because they are transparent, so the finished material maintains its transparency. But silica and acrylic are not compatible, which would ordinarily cause clumping of the tiny silica grains — which measure only about 10 to 20 nanometers across, or about one ten-thousandth the width of a human hair. In order to overcome this, the silica was treated with other "functional groups" of molecules, changing its surface chemistry so it disperses evenly on the polymer surface.

Then, the researchers heated the polymer to soften it slightly, and used an atomic force microscope to observe the particles as they slowly sank into the surface. Such observations of the dynamics of the process had never been carried out before, allowing the MIT team to see how fast the particles sink in and determine exactly how they interact with the polymer.

The resulting data allowed the team to figure out the optimal coating materials and particle densities for strengthening the polymer surface, making possible stronger window substitutes. The work could also lead to spray-on scratch-resistant coatings for everything from cars to cellphones, Qu says. "Any surface that needs coating" is potentially a candidate for such a treatment, she says. "We demonstrated that putting a small amount of particles on the surface increases the stiffness."

The work could also make a difference in many current uses of PMMA, such as the windows used in aquarium tanks. At present, such windows are made very thick to resist the enormous water pressure in large tanks. But if the material is stronger, the windows could be made thinner and lighter, and therefore less expensive, Qu says.

Mark VanLandingham, chief of the Materials Response and Design Branch at the U.S. Army Research Laboratory in Adelphi, Md., says there has been much research activity in the area of polymer nanocomposites, but this new work provides a unique approach to studying the fundamental chemical and physical properties of such materials. "There has been an incredible mix of research that is all over the board," he says: Some studies have found significant benefits from the addition of nanoparticles, while others found little improvement. So, he adds, there is much interest in understanding the basics of how these materials interact "in a fundamental and quantitative way."

The MIT team's approach could provide a new method for studying how the materials interact, VanLandingham says, and potentially a new way of making such composites. "This provides some additional directions" for future research that could lead to useful applications, he says.

Provided by Massachusetts Institute of Technology

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