Nanocomposites made from powders have the potential to revolutionize materials science and usher in a new era of advanced functional materials. But while there have been many advances in nanocomposites, Hiroyuki Muto and his assistant, Wai Kian Tan, of Toyoohashi University of Technology in Aichi prefecture, Japan, believe that they have yet to come close to fulfilling their full promise.

“A lot of material scientists are trying to make many new nanostructures, but the potential of nanocomposites is still to be realized because conventional powder-mixing methods and suspension-based techniques are inadequate for achieving precise structural formation,” explains Muto.

The problem boils down to a lack of control over nanoparticle mixing. “Nanoparticles are so small that agglomerating, thereby producing larger structures or an inhomogeneous mixture, which affects the desired properties. For example, agglomeration can mean more material is needed to form electrically conductive pathways in ceramics and polymers. “Nanoparticles enable a simple powder metallurgy process to fabricate advanced nanocomposites. Specifically, it involves modifying the surfaces of additive nanoparticles and primary microparticles with polyelectrolytes. It’s a simple but very effective concept: imparting opposite charges to the two types of particles prevents the nanoparticles from agglomerating, while causing them to attach to the larger particles. This in turn allows greater positioning control of the additive nanoparticles on the primary (larger) particles.

3D PRINTING USING CERAMIC COMPOSITES

While three-dimensional (3D) printing can be done using a wide range of materials, including polymers, resins and metals, 3D printing of ceramics is still in its infancy. One of the main reasons is that ceramic powders have poor light absorption at laser wavelengths but exhibit an infrared-shielding effect, making them ideal for applications such as the windshields of vehicles and energy-saving windows. Muto’s team fabricated the filters using the electrostatic adsorption assembly method by incorporating indium tin oxide (ITO) nanoparticles within a matrix of poly(methyl methacrylate) (PMMA). The level of infrared shielding it provides can be controlled by varying the amount of the ITO nanoparticles.

SAVING RESOURCES WHILE BOOSTING FUNCTIONALITY

The technique efficiently utilizes materials and resources, in line with the 12th Sustainable Development Goal of the United Nations, namely Responsible Consumption and Production. Its precision allows materials to be deposited just where they are needed, minimizing the use of natural resources, while offering enhanced functionality. An excellent example of this is the fabrication of electrically conductive ceramics or polymers through incorporating conductive carbon nanotubes. Conventional techniques require large quantities of carbon nanotubes because of the problem of agglomeration. In contrast, the electrostatic adsorption assembly method enables formation of a conductive path using a mere 0.01% by volume of carbon nanotubes —roughly ten times less than conventional techniques.

Muto’s team has demonstrated the potential of their technique for composite material design by using it to realize controlled assembly of different materials in various structures including nanosheets, whiskers and fibres. These composite materials are highly promising for a range of applications such as selective laser sintering, transparent composite ceramic films with controlled optical properties and renewable energy technologies.

REALIZING NANOPOWDERS’ FULL POTENTIAL

Muto and his team are excited about the potential of the electrostatic adsorption assembly method to turn around some previously disappointing results in nanocomposite materials. “Trying to use conventional processes to manufacture products containing nanoscale additives often leads to products that fail to live up to expectations,” notes Muto. “Conventional processes effectively become counterproductive when nanoscale additives are involved.” Despite the rapid advancement of technologies such as additive manufacturing, a limiting factor to their widespread application is the inability to realize precise powder integration technology that can produce various composites on nano- and microscale levels. In many cases, Muto notes, the problem is that, when a nanopowder is used, it becomes challenging to control the composite’s microstructure. “Our electrostatic adsorption assembly method enables good control over the final microstructure formation,” he says. “Our goal is to show that conventional material processes can be improved by using this kind of technique.”