Sustainable manufacturing conference in South Africa highlights importance of materials

By Rachel Berkowitz

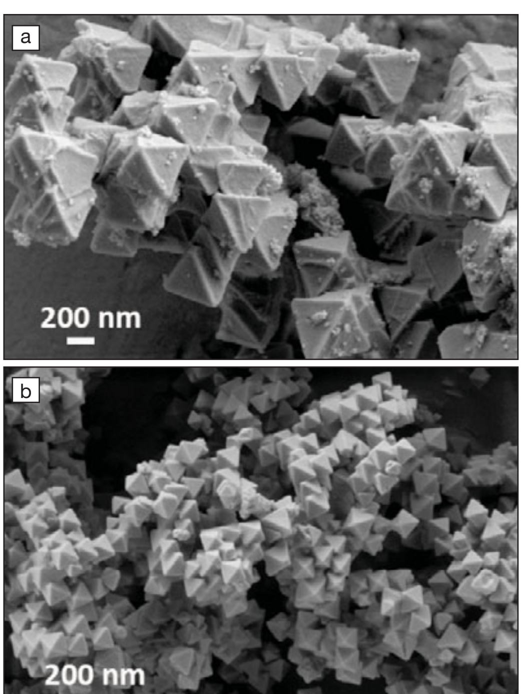
We humans use a lot of stuff. Indeed, a January headline from *Science News* observed that "humans have created 50 kilograms of things for every square meter of Earth's surface." In a world with finite resources and growing populations, this statistic indicates the scale of the impact that increased consumption poses, and illustrates the necessity of doing more with less.

The First International Conference on Sustainable Materials Processing and Manufacturing in South Africa was designed to address this concern. Organized by Professors Esther Akinlabi and Tien-Chien Jen of the Mechanical Engineering Department at the University of Johannesburg, this meeting brought together industry and academic talent from around the world to Kruger National Park in South Africa on January 23–25, 2017, to exchange ideas on sustainable development.

The United Nations defines sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." At the conference, a diverse mix of students, professors, and industry professionals shared new materials research projects that address clean energy systems, corrosion resistance, machining processes, and clean water.

In her welcoming speech, the Hon. Angela Thokozile Didiza, elected member in the 5th Parliament of the Republic of South Africa, said, "2016 marked an important milestone in our world when for the first time the outcomes of the negotiations on Climate Change were finally made operational. It has been a long road since the 1992 Rio Earth Summit convened by the United Nations in which the discussions were not only environmentally based, but rather ensuring that development is undertaken in a sustainable way."

Specific needs and sustainability challenges vary regionally, as do the resources available to meet these challenges. While research and manufacturing powerhouses are the repositories of general knowledge that can inform local efforts, local problems often benefit from solutions tailored to their region. And small-scale regional innovation can spread to have a global effect.



(a) Plastic-derived and (b) commercially produced zirconium metal–organic frameworks (MOFs), UiO-66 (Zr). In (a), the organic linker molecule component of the MOF, 1,4-benzenedicarboxylic acid, is derived from recycled poly(ethylene terephthalate). Credit: Jianwei Ren.

"For us to find answers to these and many other questions, we … need to invest in basic and applied research," Didiza said in her opening remarks. "Research remains vital to national and global prosperity and it is an important indicator of the global stature of a nation."

Results discussed at the conference included new ways to store hydrogen for use in energy production, technologies that make use of byproducts of mineral mining, ideas for how plant-based fluids can be used in metal manufacturing, and ways to provide clean water for Nigeria. But the conference also demonstrated that, fundamental to implementing technologies that improve the quality of life, is the basic need for greater access to higher education.

From plastic waste to hydrogen storage

Jianwei Ren, senior researcher at the Council for Scientific and Industrial Research (CSIR) in South Africa, is interested in materials-based solutions for long-term hydrogen-storage systems.

In a situation created by historical isolation, South Africa continues to rely on coal as the primary source of energy. Long considered one of the economic powerhouses of the continent, South Africa has faced energy challenges such as load-shedding in recent years. With an appeal from the Paris Climate Summit, the nation is endeavoring to transition its energy system from fossil fuels to renewable energies.

"Our world needs an energy revolution!" Ren says. "From the industrial revolution through to the modern energy revolution, hydrogen content [in the fuels used] has increased as the fuel stream moved from wood, coal, oil to natural gas."

Hydrogen has the potential to become a widely used fuel in the future, but its

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storage remains a challenge. Scientists have developed high-pressure storage tanks, but these are unsatisfactory with regard to safety and storage capacity. However, binding hydrogen inside highly porous metal–organic frameworks (MOFs) helps achieve low-pressure and room-temperature hydrogen storage with reversibility and good kinetics, and may prove to be an alternative storage technology.

"As a new generation of porous materials, after the conventional materials such as zeolites [commercial adsorbents and catalysts], MOF materials are able to solve problems that couldn't be solved before they were discovered," Ren says.

Companies currently sell MOF products only in small quantities and at extremely high cost. Ren is working to fill the knowledge gap between MOF discovery and MOF-enabled applications. Rather than synthesizing them from commercial high-purity chemicals, he is developing a way to produce kilogram-scale quantities of MOFs from recyclable plastics that currently are the cause of environmental pollution around the world.

Poly(ethylene terephthalate), or PET, contains the organic linker that is critical for producing MOF materials. Using a high-pressure reactor, Ren can break down the plastic and mix it with chromium or zirconium metal to produce two desirable MOFs—UiO-66 (Zr) and MIL-101 (Cr)—from the widely available PET recyclate stream. This means using waste PET as a key ingredient, which would otherwise cause pollution and often is not even recycled in developing countries.

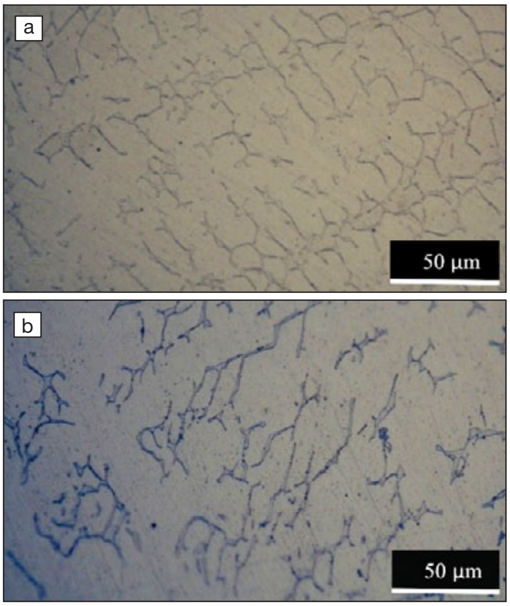
Implementation of this technology reduces the volume of waste plastics while producing high value-added functional MOF materials. It will give Africa a new opportunity to gain more value from waste plastics. Ren's long-term goal is to use the MOFs to achieve enhanced hydrogen storage.

Preventing corrosion at lower costs

When we build something intrinsic to a country's infrastructure, we want it to last for a long time. But corrosion has cost the steel industry money in maintenance and mechanical failures— such as where splashes have corroded the lower bases of marine structures or other such examples in infrastructure, transportation, and production industries.

Preventing or reducing corrosion in steels is important. The challenge is to find economic ways to do so. "There are laser technologies for preventing corrosion, but local companies can't afford them and are reluctant to learn to use them," says Bridget Zuma, a master's student who works with Josias van der Merwe at the University of the Witwatersrand in Johannesburg.

Even the most corrosion-resistant grade of stainless steel is prone to breakage at weld joints, which can result in significant economic loss. Previous research shows that small additions of platinum (Pt) group metals to stainless steels improves their general corrosion resistance in acidic environments; but the high cost of Pt has been a major hindering factor to alloying stainless steels to improve corrosion resistance. Researchers have explored the possibility of ruthenium (Ru) as an alloying element. It is the least expensive metal of the platinum group metals and is readily available in South Africa as a byproduct of the copper and nickel industry, also in the production of silver and gold. However, the effect of Ru on steel microstructure is poorly understood.



Etched optical microstructure of (a) 0.1% and (b) 2% Ru steel button welds. The weld metal solidifies without any detrimental effect on solid-state transformation. Different concentrations depict similar metallographic features (shown); additional Ru can improve the weld metal hardness. Credit: B. Zuma and J. van der Merwe.

Zuma found that adding Ru to the weld material, which was then used in the common method of gas tungsten arc welding, led to a stainless steel with superior mechanical properties. That means increased hardness without detrimental effects to the steel microstructure.

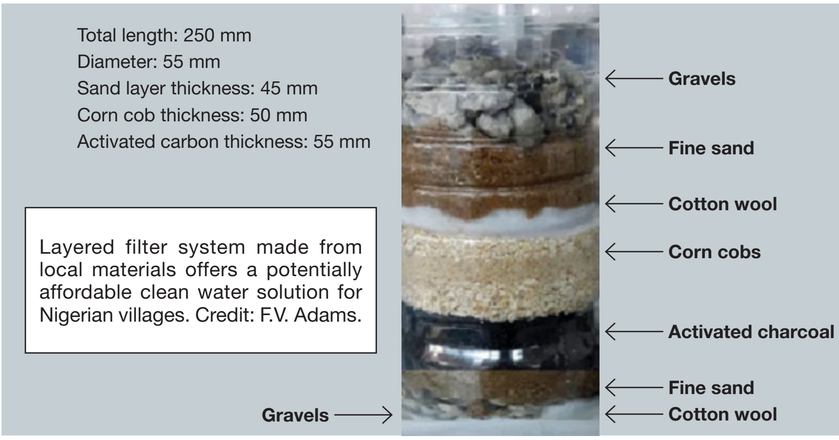
Her efforts stand to help where laser manufacturing techniques face hurdles to widespread use. "You can't just give somebody an expensive new technology and expect them to use it," Zuma concludes, referring to laser hardening of steel to prevent corrosion. Rather, the availability and affordability of Ru in South Africa make her alloying method an accessible alternative for obtaining higher quality steel.

Clean oils

When processing metals, the cutting fluids required to stabilize the work zone temperature and lubricate the chip-tool interface have an environmental cost. Manufacturing in the United States alone currently consumes over 380 million liters of cutting fluids each year.

Mineral oil and chemical additives that form the basic ingredients in cutting oils rely on scarce fossil fuels to which toxic, nonrenewable, and nonbiodegradable have been added. Disposal is a problem, often resulting in water, soil, and air contamination.

Satish Kailas, professor of mechanical engineering at the Indian Institute of Science in Bangalore, applies his knowledge of interactive moving surfaces to develop metal manufacturing methods that are not harmful to the environment and do not deplete scarce resources. His particular interests center on biodegradable, nontoxic and plant-based cutting fluid alternatives that may reduce the environmental impact of these tools.



Layered filter system made from local materials offers a potentially affordable clean water solution for Nigerian villages. Credit: F.V. Adams.

"Sustainability is a binary problem. A process is either sustainable, or it's not," Kailas says.

Kailas and colleagues contribute to the growing body of work to find alternative lubricants in the form of vegetable oils and synthetics. A stumbling block is that many current vegetable oil bases degrade in oxidative conditions, hindering their cutting properties and leading to severe metal corrosion. To circumvent this problem, Kailas developed a cutting fluid that uses coconut oil as a base. It contains more saturated fatty acids than other vegetable oils, making it less prone to degradation.

Added food-grade emulsifiers and essential oils extracted from plants give the cutting fluid the emulsion stability, desired pH, and bactericidal properties, without toxicity. How successful were they in reducing the environmental impact? Traditional commercial cutting fluid at concentrations less than 100 mg/L is known to have a significant effect on zebra fish, an indicator of aquatic system health. In contrast, Kailas's coconut oil-based version left the fish healthy at concentrations of over 1000 mg/L.

In addition, in a series of steel drilling tests, Kailas's new cutting oil reduced wear and friction between moving metal bodies; and in fact, under certain conditions, it had superior cutting properties compared to commercial cutting fluids.

But cost and availability limit its widespread use. According to Kailas, the cost of the coconut oil-based fluid, using ingredients from retail sources, amount to <USD$5 per liter. Cheaper, highly toxic, commercial oils are USD$2 per liter. However, synthetic oils touted as eco-friendly cost >USD$10 per liter in India, making the coconut oil base an appealing alternative.

"The other issue is the availability of coconut oil at the scale that would be required if it were to replace even a fraction of the cutting oils," Kailas says. "With the present rate of production in India, this would not be possible, but would definitely give a much better price for the coconut farmer." Still, world coconut oil production would meet demand.

Clean water for Nigeria

"Local" and "affordable" take on a new meaning for Feyisayo Victoria Adams, assistant professor at the American University of Nigeria's Department of Petroleum Chemistry. She tackles the problem of heavy, toxic metals leached from crude oil into Nigeria's rivers and deltas. Their presence can cause respiratory diseases and cancer, while crude oil contamination on soil reduces soil fertility and crop yields.

Adams has a personal interest in this. "The crude oil contaminated water problem in Nigeria is not overplayed; it's very real. I see it for myself on the television," Adams says.

Reverse osmosis and advanced oxidation can counter the problem; but these water-cleaning techniques are expensive for households and complex to implement in the villages that need the most help. Instead, Adams is developing an adsorption/absorption filtering system using materials that are locally available to these villages.

Her design places layers of gravel, fine sand, cotton wool, corn cobs, and activated charcoal in a cylindrical tube to create a 250-mm long, 55-mm diameter filter bed. She compared the pH, total dissolved solids, heavy metal content, turbidity, total hydrocarbon, and nitrate concentrations of both treated and untreated water at the end of the first 14 days of the experiment.

The filter removed 90% of the Zn, 40–60% of the Co and Cd, and 23% of the Cu from contaminated water, as well as 95% of nitrates. It also completely removed certain hydrocarbons and greatly reduced others.

Adams plans to optimize layer thickness and determine the optimal order of the various layers before presenting her solution for practical use. After that, she believes her country's government will welcome a straightforward solution to help its citizens lead healthier lives.

She is also positive about the future. "They need somebody to test and prove a solution that works. We're still in the lab, but will take this to [working] scale."

A sustainable future

These are just a few of the resources being developed to assure a sustainable environment for the future. But taking sustainable solutions to a practical scale demands more than just scientific knowledge: for these and many other ideas to be brought to fruition requires an educated and concerned population.

South African Parliament member Didiza reminded the audience, "Through education we can produce a human resource capacity that will enable us to move toward these directions. At the moment, in our country, we are faced with challenges of access in higher education … at the core … it is also about issues of access and the transformation of our education system."

Developing new technologies is only half of the solution to our continuing production of "stuff." The other half is building an educated workforce with the skills and desire to minimize or reduce this "stuff" and produce a more livable world for all of us.

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