Innovating the Sealing Sector: The Untapped Potential of Materials Science

An understanding of materials science may influence the future of engineering.

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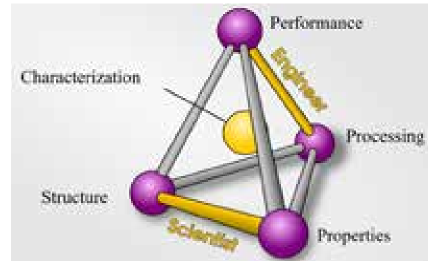

IMAGE 1: The materials science and engineering tetrahedron. (Image courtesy of Triangle Fluid Controls Ltd.)

Engineering Lessons From Disaster

On April 15, 1912, the Titanic, once celebrated as a remarkable achievement in engineering, faced a tragic turn of events. When it struck an iceberg, the hull buckled, and the ocean poured in. Within hours, more than 1,500 lives were lost as the Titanic slipped beneath the cold Atlantic.

Beyond the human tragedy lies another layer, one that materials engineers recognize well: how material selection and performance can shape the outcome of entire systems. Decades later, studies of the Titanic's remains revealed that its steel hull contained unusually high levels of sulfur, which contributed to a phenomenon known as ductile-to-brittle transition. In the frigid waters of the North Atlantic, the steel became more brittle, and instead of plastically deforming upon impact with the iceberg, the steel fractured, leading to catastrophic and rapid flooding. It is a stark reminder that in any industry, whether shipbuilding, aerospace or sealing, materials science is not just a supporting detail. It is the foundation on which reliability, safety and innovation are built.

A New Lens on Sealing Challenges

Fast-forward to the sealing sector, where fluid sealing devices such as gaskets ensure efficiency and safety across countless applications. Many designs such as spiral wound gaskets date back over a century, and while they have served well, the industry has often been slow to embrace innovation. This slow pace creates risk as evolving demands in emission control, chemical compatibility and sustainability continue to grow, but it also creates opportunity, as materials science can breathe new life into a sector ready for transformation.

Traditionally, sealing device manufacturing has been led by mechanical engineers who understand stresses, equipment design and assembly mechanics. Their expertise is indispensable; yet, materials science—a discipline sitting at the intersection of physics, chemistry and engineering—has often been underutilized. At its core, sealing is a materials challenge. A gasket, for instance, must compress to create a seal, resist aggressive chemicals, withstand extremes of heat and pressure and often perform under conditions where failure is not an option. Bringing materials science in transforms how these challenges are addressed. This interdependence is captured by the materials science and engineering tetrahedron (Image 1), which illustrates how structure, processing, properties and performance are inseparably linked in determining how a material behaves in real-world applications.

Reliability Starts at the Micro-Level

Consider the raw materials in filled polytetrafluoroethylene (PTFE) gasket production. At first glance, PTFE resins, fillers and other additives may appear straightforward; however, on a microscopic level, characteristics such as particle size distribution, surface chemistry and phase transformations, along with many other material properties, dictate the final product properties. Particularly, in skived, filled PTFE sheet production, understanding polymer chain mobility, crystallinity and sintering behavior helps optimize the compression molding and the sintering of massive, filled PTFE billets. Overlooking such details leads to inconsistent performance and recurring quality problems.

Characterization sits at the heart of the tetrahedron, bringing all corners together. By applying advanced materials characterization techniques, manufacturers can strengthen failure mode and effects analysis (FMEA) and enhance both formulations and processes. For instance, scanning electron microscopy (SEM/EDX) provides insight into microstructure, surface morphology and elemental composition, while differential scanning calorimetry (DSC) complements the widely used thermogravimetric analysis (TGA) by identifying thermal transitions. These methods help move the industry toward more deliberate, data-driven designs.

The story continues into semimetallic and metallic gaskets, where processes like machining, welding and metal forming play a central role. Here again, materials science adds value, not only in optimizing these processes but also in guiding material selection. For instance, when selecting metals for high-temperature applications, factors such as oxidation resistance, thermal expansion and microstructural stability are critical. Choosing an alloy with a higher modulus of resilience can improve recovery performance, an essential property in equipment subject to thermal cycling and shear/compressive interaction, such as heat exchangers.

Materials-Centered Solutions for Emerging Challenges

Beyond manufacturing, materials knowledge also shapes how end-user challenges are solved. Consider the case of bolts used in bolted flange joint assemblies undergoing extreme temperatures. While gasket selection is often the focus, maintaining bolt load under service conditions is just as critical. Elevated temperatures can reduce the yield strength of many alloys, causing load relaxation and ultimately, leakage. An end user may assume the solution lies in choosing a better gasket, but the more effective fix could be selecting a precipitation-hardened, fatigue-resistant bolt alloy with a microstructure that resists dissolution under high heat. Another example is the role of corrosion science, a subdomain of materials science, in sealing against harsh or aggressive chemicals, particularly when combined with the effects of pressure and temperature in the application.

This perspective extends naturally into research and development. As global industries confront megatrends such as hydrogen energy, electrification, renewable power and sustainability, the sealing sector faces challenges that cannot be solved by tradition alone. Here, materials science provides essential tools. Nanomaterials, whether used as nanofillers or protective coatings, can enhance performance and extend gasket lifetimes. Advanced alloys and composites address the unique demands of hydrogen storage and transportation, where embrittlement and permeability remain critical concerns. In electric vehicles, gaskets for battery packs must deliver reliable sealability along with chemical stability, flame resistance and electrical insulation, which requires a materials-centered approach to design. Even sustainability targets, such as shifting from linear "take-make-dispose" models to circular economies, depend on rethinking materials (e.g., developing recyclable gaskets, incorporating bio-based or eco-friendly polymers and engineering seals that reduce fugitive emissions).

Embracing Innovation

The sealing sector's slow pace of innovation is a challenge, as mature industries often rely on incremental improvements until forced by external pressures. With rising environmental regulations, critical mineral demands and complex applications, the industry cannot remain stagnant. Materials science is now a necessity for staying competitive and leading rather than reacting.

Integrating materials science into sealing complements mechanical engineering, expanding the problem-solving toolkit. Mechanical engineers address system-level design and performance, considering stresses, loads and overall mechanics. Materials engineers, in turn, examine the fundamental properties and behaviors of materials at the microscopic scale. Together, they deliver solutions that are both practical and robust, reflecting the broader trend of innovation at disciplinary intersections. ■

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We invite your suggestions for article topics as well as questions on sealing issues so we can better respond to the needs of the industry. Please direct your suggestions and questions to sealingsensequestions@fluidsealing.com.

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