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Structural adhesives composed of epoxy resins and hydrogen bonded styrenic block polymer based TPEs

Reduction of zinc oxide in 10 compounds of a model passenger car radial tire

Latex foam and its applications

Unique engineered molded product from scrap tires

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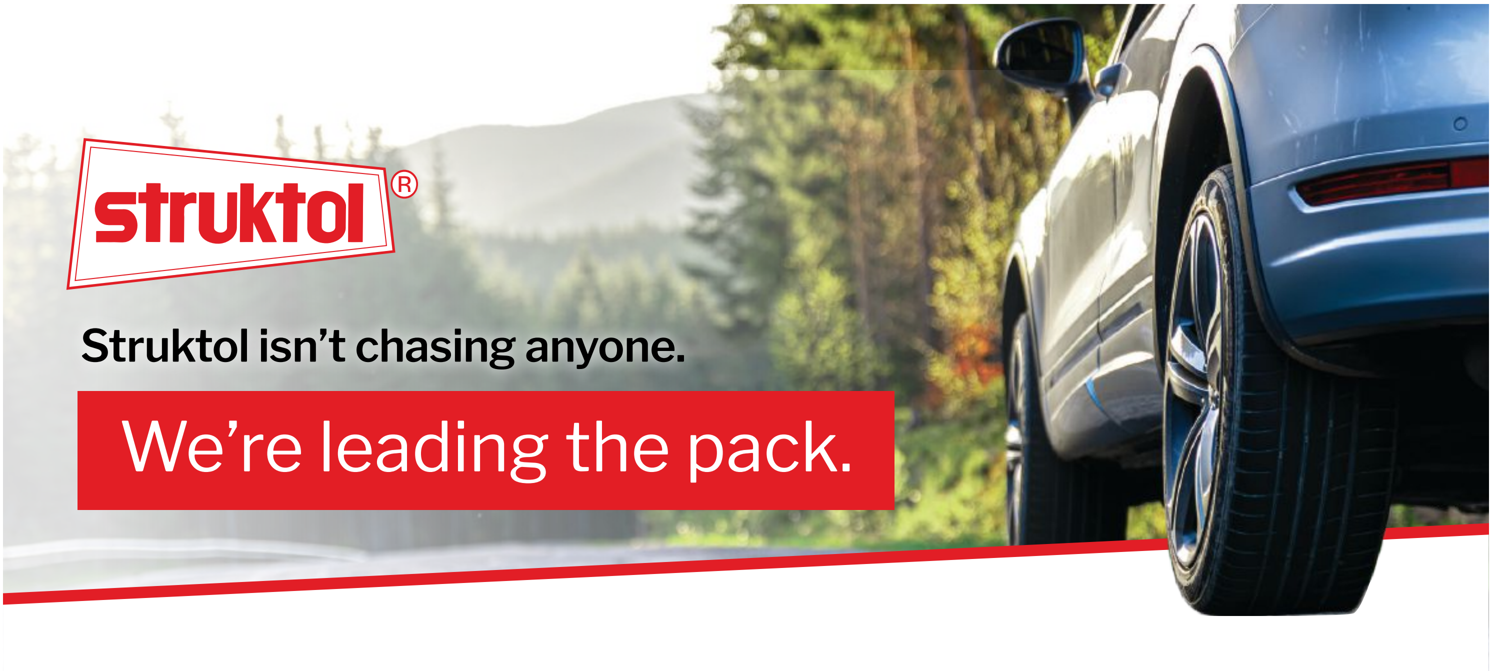

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by Saya Yamada, Takato Kajita, Mio Nishimoto, Junko Horiuchi, Yoshirou Fujii, Kazumasa Sakaguchi, Kazuo Hattori, Hiroshi Tamura, Tatsuya Kano, Takenobu Sakai and Atsushi Noro, Nagoya University. Structural adhesives were prepared that exhibit both high peel strength and high impact strength by mixing an epoxy resin with a curing agent and polystyrene-b-polyisoprene-b-polystyrene (SIS), and the mechanism leading to the excellent physical properties of the adhesives is discussed.

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by Boontham Nithi-Uthai, consultant. Applications for latex foam are described by the author, including as a replacement for silicone and plastic in various products, use for absorption of liquid, and use in anti-bedsore mattresses, pads for wheelchairs and other hospital surfaces. Compounding of latex foam for extra properties is also highlighted.

DEPARTMENTS

From the Editor

Jill Rohrer

USTMA urges pavement outlay

The U.S. Tire Manufacturers Association (USTMA) and its member companies applaud the introduction of the Innovative Mitigation Partnerships for Asphalt and Concrete Technologies (IMPACT) Act, H.R. 1534, and its complement, IMPACT Act 2.0, H.R. 2122, both introduced by U.S. Representatives Valerie Foushee (NC-04) and Max Miller (OH-07). The bills promote research and deployment of innovative pavement technologies, including rubber modified asphalt (RMA), which is said to deliver proven economic, environmental and performance benefits.

RMA, a mixture of recycled ground tire rubber and asphalt, is reported to increase pavement service life and reduce road maintenance needs, creating significant cost savings compared to traditional asphalt. It is said to provide performance and safety benefits by increasing skid resistance and reducing tire wear, road noise and road spray, and could also reduce CO_2 emissions by 32%, lowering energy consumption over the lifetime of pavement.

"Rubber modified asphalt fits the IMPACT Act goals of increasing performance metrics and protecting the environment by encouraging reuse and recycling," said Anne Forristall Luke, president and CEO of USTMA. "Supporting this bill puts us a step closer to ensuring America remains competitive in infrastructure design and resilience, through American leadership in advanced asphalt solutions like RMA."

The IMPACT Act fosters collaboration between industry and the Department of Energy (DOE) to support research aimed at improving production methods and exploring new, low-emission manufacturing techniques for pavement materials. The bill also provides technical assistance to promote the commercial application of low-emission cement, concrete and asphalt, aligning with national efforts to modernize America's transportation infrastructure. Additionally, the IMPACT Act 2.0 establishes performance based, low emissions transportation materials grants of $15 million through the Federal Highway Administration (FHWA) to facilitate the purchase of low emissions concrete and asphalt goods, and incentivize states to improve state level specifications and standards.

"Federal funding through the IMPACT Act 2.0 will reduce financial barriers for states seeking to adopt new and innovative paving methods and scale the use of rubber modified asphalt (RMA) across the United States," said Forristall Luke.

Jill Rohrer

RubberWorld

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Business Briefs

Goodyear expands Oklahoma tire plant

ACQUISITIONS, EXPANSIONS

Goodyear Tire & Rubber (www.goodyear.com), Akron, OH, unveiled plans for a significant expansion of its Lawton, OK, facility, said to be the largest tire factory in its global network. The expansion aims to increase the plant's production capacity by nearly 30%, adding 10 million units of annual capacity for premium tires. The project is part of a $320 million, four-year investment designed to enhance the plant's capabilities to meet the growing demand for larger rim diameter tires. The expansion will focus on producing tires for electric and autonomous vehicles, aligning with Goodyear's strategic goals to cater to emerging automotive technologies.

Hexpol (www.hexpol.com), MalmÖ, Sweden, has signed an agreement to acquire 80% of the shares in **Kabkom Kimya Sanayi ve Ticaret Anonim Şirketi (Kabkom)** from the founders. Kabkom specializes in high performance thermoplastic and thermoset cable compounds for the cable market. Kabkom operates a state-of-the-art manufacturing facility outside Izmir, Turkey, with 70 employees.

Hankook (www.hankooktire.com), Seongnam, South Korea, has broken ground on the expansion of its European production plant in Rácalmás, Hungary. The building phase, which is scheduled for completion in 2027, will culminate in a new production line for truck and bus tires at the site, with a capacity of up to 800,000 units per year.

Nexen Tire (www.nexentire.com), Yangsan, South Korea, is establishing a dedicated winter tire testing center at the UTAC proving ground in Ivalo, Finland.

RadiciGroup (www.ridicigroup.com), Gandino, Italy, recently inaugurated its new production site in Brazil.

Quality registrations

Dow (www.dow.com), Midland, MI, announced that its propylene glycol (PG) manufacturing facility in Map Ta Phut, Rayong, Thailand, has earned the International Sustainability and Carbon Certification (ISCC) Plus. This certification is said to reinforce Dow's ongoing commitment to advancing sustainable production and offering circular and bio-circular products to customers in the Asia Pacific region.

Huntsman (www.huntsman.com), The Woodlands, TX, announced that its thermoplastic polyurethane (TPU) manufacturing sites in Jinshan, China and Osnabrück, Germany have successfully secured ISCC+ certification, the globally recognized standard for sustainability and traceability in supply chains.

Sartorius (www.sartorius.com), GÖttingen, Germany, has earned its first certificates from the ISCC for its production sites in Aubagne, France and Stonehouse, U.K.

Business Briefs

Linglong Tire awards Rodolfo Comerio

CONTRACTS, LICENSES

Rodolfo Comerio (www.comerio.it), Varese, Italy, announced that on the occasion of **Linglong Tire**'s 50th anniversary event, Rodolfo Comerio was awarded the title of Excellent Partner by Linglong, a recognition said to celebrate Comerio's outstanding performance of its calendering lines, constant commitment to offering innovative solutions, the quality of its after sales service and its continuous and solid presence in China.

Nordmann (www.nordmann.global/en), Hamburg, Germany, an international distributor with expertise in silicone elastomers, announced a strategic partnership with **Wacker Chemie AG**. Effective April 1, Nordmann is supporting Wacker's sales and distribution activities in the field of liquid and solid silicone rubber throughout Europe.

Continental (www.continental.com), Hanover, Germany, has extended its project to enhance sustainability in smallholder natural rubber cultivation with the **Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH** by three years. Since 2018, around 5,000 local smallholders in West Kalimantan, Borneo, Indonesia, have been trained to cultivate high quality natural rubber in line with clearly defined sustainability criteria. By 2027, a further 1,000 smallholders are to be involved in the project, which is co-funded by Continental and the **German Federal Ministry for Economic Cooperation and Development (BMZ)**.

Continental announced that in 2024, they supplied tires to 18 of the world's 20 highest volume manufacturers of fully electric vehicles. These include manufacturers such as **BYD**, **Geely**, **Volkswagen**, **NIO**, **Mercedes-Benz** and **Renault**.

Biesterfeld (www.biesterfeld.com), Hamburg, Germany, is expanding its strategic relationship with ExxonMobil Petroleum and Chemical BV and adding new Vistalon EPDM grades to its product portfolio in Europe, including Turkey and Africa, with immediate effect.

Ecore International (www.ecoreintl.com), Lancaster, PA, a recycler of reclaimed rubber into high performance surfaces and solutions, has been awarded a group purchasing agreement with **MedTrust Health Alliance**.

Business Briefs

CORPORATE, FINANCIAL NEWS

GRI wins innovation award at ProMat 2025

Global Rubber Industries (GRI) (www.gritires.com), Colombo, Sri Lanka, was awarded the Material Handling Industry (MHI) Innovation Award for Best Innovation in Sustainability at ProMat 2025's Industry Night, held last month. The award recognized the Ultimate Green XT as the world's most sustainable material handling tire, made with 93.5% sustainable and bio-sourced materials.

NewtonWorks (www.newtonworks.com), Tokyo, Japan, announced that the NewtonSuite eSeal, said to be an easy-to-use tool designed to revolutionize rubber seal and weatherstrip analysis, was awarded Most Innovative Product at the Gasket & Seals Show in Amsterdam.

Balkrishna Industries Ltd. (BKT) (www.bkt-tires.com), Mumbai, India, announced that its Waluj plant was honored with the Global Energy & Environment Foundation Global Safety Award 2025 in the Gold category for the tire manufacturing industry during the Global Clean Energy Summit in Delhi, recognizing companies that distinguish themselves by adopting excellence in safety, health and sustainability standards.

NovationSi and R.D. Abbott host middle school students for tour

NovationSi and **R.D. Abbott** (www.rdabbott.com), Garden Grove, CA, recently introduced 21 middle school students to the rubber and polymers industry. The seventh graders from **Roberts Middle School** in Cuyahoga Falls, OH, toured R.D. Abbott's Barberton Service Center, a materials science and distribution hub that is also NovationSi's headquarters. Instructors described opportunities for career growth, and provided an overview of the companies' history, expertise and collaboration. The students were then split into three separate groups and toured the laboratories, mixing rooms and warehouse. In the laboratories, students were introduced to the testing equipment elastomer technicians use and observed some of the tasks the technicians regularly perform. The students observed formulation development, color matching, physical properties testing and LSR process engineering in action. The students also learned about the various mixing machines on the production floor used for custom dispersions and compounding. Students then created oven-cured custom silicone molds using pigments and RTV (room temperature vulcanizing) materials in a hands-on experiment.

Growth predicted for bio-based polymers

The market and trend report, “Bio-based building blocks and polymers: Global capacities, production and trends 2024-2029,” from Nova-Institut GmbH, confirms 2024 was a respectable year for bio-based polymers, with an overall expected compound annual growth rate (CAGR) of 13% to 2029. Overall, bio-based biodegradable polymers have large installed capacities with an expected CAGR of 17% to 2029; but the current average capacity utilization is moderate at 65%. In contrast, bio-based non-biodegradable polymers have a much higher utilization rate of 90%, but will only grow by 10% to 2029.

Epoxy resin and polyurethanes (PUR) production is growing moderately at 9% and 8%, respectively, while polypropylene (PP) and aliphatic polycarbonate (APC) capacities are increasing by 30%. Despite a decline in production of biodegradables, especially for polylactic acid (PLA) in Asia, capacities have increased by 40%. The same applies to polyhydroxyalkanoate (PHA) capacities. Commercial newcomers such as casein polymers and polyethylene furanoate (PEF) recorded a rise in production capacity and are expected to continue to grow significantly until 2029, the study says.

Additionally, the total production volume of bio-based polymers was 4.2 million metric tons in 2024, which is 1% of the total production volume of fossil based polymers, and the CAGR of bio-based polymers is, with 13%, significantly higher than the overall growth of polymers (2% to 3%). This development is expected to continue until 2029. With these growth rates, the share of bio-based polymers will increase up to 2%.

Of the total 4.2 million metric tons (mmt) of bio-based polymers produced in 2024, cellulose acetate (CA) with a bio-based content of 50%, and epoxy resins with a bio-based content of 45%, account for more than half of the bio-based production, 26% and 32%, respectively. This is followed by 30% bio-based polyurethanes (PUR) with 9%, 100% bio-based PLA with 8%, polyamides (PA) (60% bio-based content) with 7%, and polytrimethylene terephthalate (PTT) (31% bio-based content) with 6%. The share of APC (circular and linear), poly(butylene adipate-co-terephthalate) (PBAT), polyethylene (PE), PET, PHA and starch containing polymer compounds (SCPC) was less than 5%. Casein polymers (CP), ethylene propylene diene monomer rubber (EPDM), polybutylene succinate (PBS), PEF and PP accounted for less than 1% of the total bio-based polymer production volume.

The report says the increase in production capacity from 2023 to 2024 is mainly due to the expansion of PLA capacity and epoxy resin production in Asia, as well as a global increase in PUR production. PP, PHA and PEF are particularly expected to grow continuously by 65% on average until 2029. While PHA capacities will increase mainly in Asia, and PEF in Asia and in Europe, PP capacities will increase mainly in North America.

The Nova study says the market remains challenging, especially in Europe. While Asia and North America will continue to strengthen their global role in the supply of bio-based polymers, Europe’s market share is expected to decline by 2029. With new investments in several large scale bio-based polymer production capacities, Asia and North America will increase their market share by 4% and 5%, respectively; and together they will account for more than 80% of the global supply of bio-based polymers. Although some new large scale plants are also planned in Europe, this will not be enough to prevent Europe’s market share from falling from 13% today to 10% in 2029. Although the European policy landscape for bio-based polymers is constantly evolving, it does not yet provide a consistent policy framework that sufficiently incentivizes the benefits, properties and applications of bio-based polymers, unlike other regions of the world, according to the report.

The global polymer market includes functional and structural polymers and rubber products, as well as man-made fibers. This report focuses on the bio-based share of the structural polymers market. Bio-based structural polymers are composed of the polymers that will later form the structural mass of the finished plastic part. Together, they total 4.3 mmt. On the other hand, the total amount of bio-based functional polymers consists of bio-based functional polymers and paper starch, totaling 13.7 mmt. In addition to these two groups, which account for 18 mmt of bio-based functional and structural polymers, rubber products and man-made fibers can also be bio-based. In total, 15 mmt of rubber products and 7.8 mmt of man-made fibers are made from bio-based resources, 51% and 9%, respectively.

Total installed capacity in 2024 was 5.2 mmt, with an actual production of 4.2 mmt. Capacity is expected to increase to 9.5 mmt in 2029, indicating an average CAGR of around 13%. The following polymers show an even higher increase, well above the average growth rate: PP, PHA and PEF are expected to grow continuously by an average of 65% until 2029.

Asia, as the leading region in 2024, has the largest installed bio-based production capacities worldwide at 59%, with the largest capacities for PLA and PA. North America had 16%, with large installed capacities for PLA and PTT; and Europe had 13%, mainly based on installed capacities for SCPC and PA. South America had a share of 11%, with major installations for PE; and Australia/Oceania had less than 1%.

With an expected CAGR of 25% between 2024 and 2029, North America has the highest growth in bio-based polymer capacities compared to other regions of the world. This increase is mainly due to expanded and new production capacities for PHA and PP, the report says.

Oil, Gas & Energy

Cooling hydrogen powertrains developed

Continental has developed a line for cooling in the hydrogen powertrain of commercial vehicles, which considerably reduces the penetration of ions into the media circuit. The synthetic rubber line has a mixture of materials whose special properties make them less susceptible to the leaching of ions from the line material. This reduces the transfer of ions into the cooling circuit of hydrogen drive systems. The product innovation increases the service life of vehicle components in hydrogen drive systems.

If ions from the line material enter the cooling circuit, this can lead to degradation of the material, reducing efficiency and increasing the risk of a short circuit or leakage currents in the fuel cell. Washed out ions can, for example, damage the proton exchange membrane and shorten its lifespan.

To combat this, Continental is using a mixture based on high performance EPDM (ethylene propylene diene rubber) that offers the necessary high resistance against the unwanted leaching of ions.

As part of the move away from oil and gas, many bus and truck fleets, as well as commercial vehicle manufacturers, are pinning their hopes on hydrogen as a source of energy for drive systems. However, compared to the use of battery generated drive energy, engineers in the vehicle industry currently still face a large number of challenges when it comes to hydrogen.

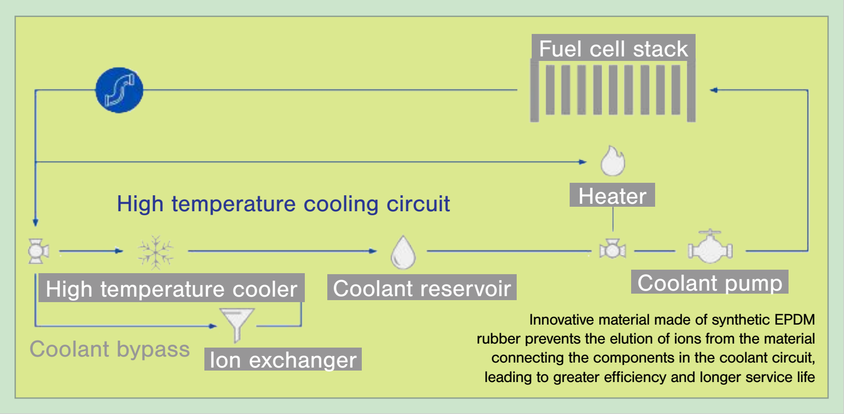
The extremely low density of hydrogen atoms also presents problems for developers. Harald Kreidner, head of research and development at the ContiTech business area OESL, explains: "Permeation resistance, anti-static and high pressure are challenging requirements. We are combining our material expertise so we can tailor elastomers, thermoplastics and metals for use in hydrogen powertrains." As the smallest molecule with the lowest density, hydrogen is so light and volatile that conventional lines do not form a barrier.

In the fuel circuit of hydrogen powered commercial vehicles, Continental is addressing this challenge with a hose construction featuring a thermoplastic barrier layer which prevents the hydrogen atoms from being released, despite their low density. This guarantees the safe operation of the vehicle, as it minimizes the probability of a flammable hydrogen-air mixture occurring in the area of the hydrogen carrying line. In addition, the range of the fuel-cell vehicle is increased, as the loss of fuel is reduced.

"In the original equipment solutions business area, we have decades of experience as a system partner for media circuits and engine mounts in combustion technology. Our customers benefit hugely from this experience and the joint development of lines, splices and mounting components for hydrogen and battery drive systems in commercial vehicles," explained Mark Klein-Hietpas, director of CV sales in the OESL business area at Continental. "As with combustion technology, we have also succeeded in finding the materials and material compounds that can cope with the sometimes contradictory requirements for hydrogen and battery circuits. Our research and development in this area bridge the gap, and transfer and adapt existing technologies to new forms of drive systems."

If, for example, a high level of imperviousness is required, but the lines also need to be flexible, it takes material expertise, as well as application experience, to find a technically suitable solution that can also be industrialized economically. Continental has pooled its expertise in vehicle media circuits in its new business area, OESL, within the ContiTech group sector in order to offer integrated support for the commercial vehicle industry as a transformation and development partner. For this reason, this organizational unit is currently being made independent, with the aim of giving it the necessary freedom to support vehicle manufacturers in the dynamic development of combustion technology, the company said.

Lines in the cooling circuit for H_2 fuel cells



Innovative material made of synthetic EPDM rubber prevents the elution of ions from the material connecting the components in the coolant circuit, leading to greater efficiency and longer service life

by Ben Chouchaoui,
Windsor Industrial Development Laboratory

Unique engineered molded product from scrap tires

Traditionally, one of the biggest issues facing the transportation ecosystem has been what to do with scrap tires. When no longer suitable for use on vehicles because of wear or irreparable damage, used tires lead to huge health and ecological hazards. Certainly, there have been major strides in developing sustainable practices for both the disposal and recycling of scrap tires. However, some of these are still not convincing. Moreover, with new developments in technology and recycling practices continuing to emerge, sustainable tire recycling continues to be a moving target.

In an exclusive interview, Ben Chouchaoui discusses some of the more recent trends in scrap tire disposal and recycling, as well as some of the opportunities new practices are bringing to the industry. Chouchaoui is a graduate of the École Polytechnique de Montréal and the University of Waterloo in Canada. His expertise is in materials and computer based simulations, including computer-aided engineering (CAE), finite element analysis (FEA) and computational fluid dynamics (CFD). Chouchaoui runs Windsor Industrial Development Laboratory (WIDL) (www.onlab.ca) which helps rubber manufacturers and users develop optimal products through simulation rather than trial and error. An offshoot of WIDL, EcoUS makes engineered rubbers and rubber products to aid in rubber circularity and the rubber product circular economy.

When we look at the disposal of scrap tires today, what changed over the years?

Let us first recognize that there are about 285 million passenger vehicles registered throughout the United States (https://www.statista.com/statistics/196505/total-number-of-registered-motor-vehicles-in-the-us-by-state/). Each such vehicle replaces all four tires every three to four years. This comes down to a tire a year on average, which means the United States scraps about 285 million tires each year. This figure will grow over time due to more vehicles on roads, electric vehicles which are heavier, cheaper tires that need replaced more often, requirements to drive on bad and non-paved roads, etc. Tires are also needed for off-the-road vehicles, trucks, buses, construction machinery, non-registered vehicles, etc. Moreover, the rubber industry comprises another 30% of non-tire rubber products. And there are two types of wastes, post-industrial and post-consumer, with the latter, in particular scrap tires, catching the eye of the public and solid waste authorities.

In the past, old tires typically went to local landfills or were burned, neither of which were good environmental strategies. Burning old rubber and tires releases dangerous toxins and pollutes into the atmosphere. Moreover, since thermoset rubbers are not biodegradable, they take up more and more space in landfills over time, quickly becoming breeding grounds for rats and mosquitoes, transmitting deadly diseases. They also leach into the ground, contaminating underground waters and decreasing soil fertilities.

Before the various states began to pass scrap tire laws in the 1980s, there were approximately 2 to 3 billion tires stockpiled in landfills throughout the United States, in particular in Colorado. Today, as many as 90% of those stockpiled tires have been dealt with somewhat successfully. Old tires have gone from an environmental nuisance to various uses over the last 25 years. According to the U.S. Environmental Protection Agency (EPA), about 85% of (or roughly a quarter million) scrap tires now get recycled for energy or material recovery each year.

In the past decade, local governments switched to extended producer responsibility (EPR). Reasons for this include:

- Shifting end-of-life costs to the producers in the product chain
- Relieving municipalities and taxpayers from the burdens of paying for end-of-life products
- Encouraging producers to redesign products to minimize end-of-life management costs
- Obligating producers to remove harmful substances from products
- Encouraging development of greener future designs which are easier to recycle
- Promoting innovation in recycling technology
- Encouraging potential reductions in consumer costs
- Creating solid frameworks for continual program developments
- Relieving governments from issuing, managing and imposing legislation
- Reducing the carbon footprint through increased use of recycled materials

EPR works by turning all tire vendors, car dealers and any other retailers who deal with tires into collectors. They must accept tires, regardless of whether they sold them or not, from consumers who drop them off at their location (as long as the tires are of a similar shape and size to the tires they sell) for no cost to the disposer. The collectors must then enter into commercial agreements directly with a producer responsibility organization (PRO), which will organize the transportation of the used tires for no cost to the collector.

When buying a new tire today, the dealer usually recoups the old tire for recycling. Of course, some people might use their old tires for a new purpose, such as turning them into tire swings or garden planters. Alternatively, local community recycling centers constitute drop-offs for old tires to be recycled. Public awareness and educating younger generations to dispose of used tires properly is important so that they redirect to commercial reprocessing plants to be treated and broken down into materials that can ultimately make up new products.

What are the responsibilities of organizations or entities overseeing the recycling of scrap tires?

Those responsible for handling worn out tires should continue to embrace new developments to do better jobs. Scrapped tire recycling should be industry driven with some government support; two aspects that vary widely from state to state. Not long ago, authorities burned scrap tires (and other organic wastes) as alternative fuel sources to generate power; an undertaking still practiced called waste-to-energy programs. The process was a matter of getting rid of large amounts of scrap tires quickly. In fact, the tire industry itself often uses incineration to dispose of production waste and rejects, and to self-produce heat and electricity. The process is also common in cement kilns, industrial boilers, sewage treatment installations, steel mills, thermal power plants, and pulp and paper mills. In cement manufacturing, very high temperatures (in the range of 3,632°F) ensure complete combustion of tire components, converting steel to iron oxide and sulfur to sulfates, useful ingredients in final products.

A tire burned is rubber lost that needs replacement. Today, mechanical downsizing of scrap tires for civil engineering and manufacturing is widespread. Recent applications include mulch for agriculture and landscaping, covers for playgrounds and sport tracks, etc. Ground rubber is added into basic products like tiles and interlocking bricks. Shredded, crumb and ground rubbers replaced gravel, sand and filler material.

Various levels of ground tire rubber (GTR) are blended with thermoplastics, such as polyethylene (PE), polystyrene (PS), polypropylene (PP) and polyvinyl chloride (PVC), for use in extruded and molded products. Rubber with increased (still vulcanized) GTR content is used in the production of conveyor belts, shoe soles and heels, profiles, car mats, mattresses, battery boxes, etc. However, directly incorporating GTR in virgin rubbers lacks reactive sites for filler-matrix adhesion and deteriorates physical properties. Moreover, GTR can also affect the behavior of rubber during curing, with migrating sulfur or accelerators in vulcanized GTR.

Still, many researchers and industries successfully included up to 30% of GTR in natural and synthetic rubbers without dramatically impairing the main mechanical properties of final products. To the contrary, they reported advantages like increased damping. Besides, poor GTR-matrix adhesion called for increasing GTR surface reactivity by introducing polar groups. Techniques classify as physical (plasma, ozone, high energy gamma or ultraviolet irradiation) and chemical (acids, coupling agents and chlorination treatments).

Researchers and industries also used GTR for cement, concrete and asphalt modification over the past decade: GTR improves the fracture resistance of concrete, decreases its density, and favors heat, sound and vibration absorption. Blending GTR with asphalt improves performance and longevity of roads, reduces vehicle noise, revamps crack resistance and enhances driving comfort. Finally, in sludge treatment plants, a GTR base absorbs heavy metals, mercury (II) and organic solvents, such as thiol and sulfur immobilized metal ions.

New products derived from waste tires generate more economic activity than combustion or other low value production, while reducing the waste stream without generating excessive pollution and emissions related to recycling operations. There are tire recycling business opportunities in the United States. The process is sequential, and continues to evolve from TDF (tire derived fuel) to mulch (natural or colored), to crumbs and fine powder. Steel and fibers from processed tires are recycled. Devulcanization (or reversing the vulcanization) of thermoset rubbers appears more promising to rubber sustainability and the rubber product circular economy.

What are your thoughts on recovering rubber compounds and other scrap materials to make new tires?
Let us first admit that this is very difficult from various angles. About 450 tire factories around the world manufacture pneumatic tires. Tire production starts with bulk raw materials such as rubber, carbon black and chemicals, and produces numerous specialized components which are assembled and cured. Many kinds of rubber are used, the most common being styrene butadiene copolymer (SBR). Each manufacturer uses internal recipes which are mostly kept secret.

Besides, tires of extensive designs and complex manufacturing are produced to withstand the harshness of service lives over extending schedules. Consequently, their recycling creates monumental technical and industrial challenges. Current disposal strategies to focus on worn tires, consisting of incineration, crumb rubber generation and landfilling, are not effective. Waste tire rubber recovery or regeneration is highly desirable for rubber sustainability and a rubber product circular economy. Multiple devulcanization processes over the past decade introduced selective cleavages of vulcanizate crosslinks, while attempting to retain backbone polymeric networks. EcoUS (a trademarked spinoff of Windsor Industrial Development Laboratory, or WIDL) is proposing devulcanization of thermoset rubbers. This will enable infinite recycling of rubber to then turn into useful materials (such as devulcanized rubber pellets for road surfaces) or products. And the idea is to develop large products because of the magnitude of the scrap tire problem.

In 2019, $258 billion worth of tires were sold worldwide. Over three billion tires emerge annually, making tire manufacturing a major consumer of rubber. It, therefore, makes sense to use recycled rubber in making new tires, even if tires are highly critical components on vehicles. Essentially, two options are possible: first, using fine powder rubber from recycling tires as fillers in compounds for new tires; and second, devulcanizing crumb rubber and mixing it with non-recycled rubber for manufacturing new tires.

What options are currently available when it comes to the processing of scrap tires?
The recycling of tires is not that different from addressing other waste products, particularly from the viewpoint of protecting the environment. There are four basic choices in dealing with scrap, commonly referred to as the “four Rs”: Reduce, Reuse, Recycle and Recover.

First in the hierarchy is “reduce,” which means reducing the generation of waste. It is the best method to reduce greenhouse gases, and it saves natural resources and avoids the upstream generation of solid wastes.

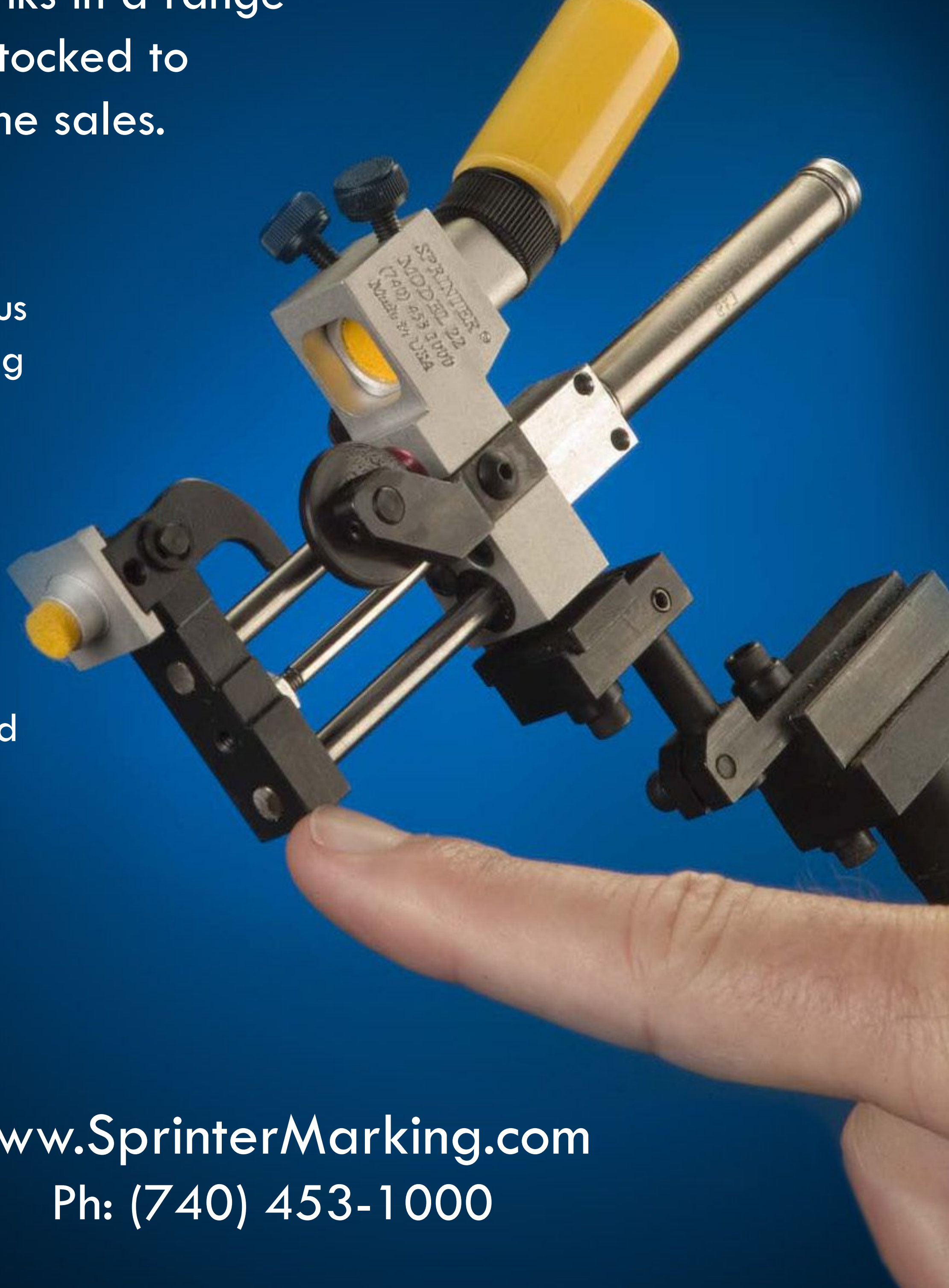
As for the “reuse” of tires (while limited because of safety issues), there still is a strong market for retreading worn tires. The United States annually ships truckloads of worn tires to Mexico for retreading and use. Truck tire retreading is one of the best examples of extending the use of a tire. In fact, most commercial vehicle and aircraft tire casings are retreaded several times before being discarded. Passenger tires, however, are very different and offer little opportunity for retreading, except in small niche markets.

Tire manufacturers, through ever evolving technologies, have prolonged the life expectancy of automobile and truck tires (the need for new tires drops; however, automobile manufacturers continue to sell more new cars every year). The public, too, can make useful contributions: Tire life can be extended by as much as 30% simply by motorists maintaining proper tire pressures, rotating tires as recommended, keeping wheels properly aligned and practicing good driving habits.

“Recycling” rubber and other materials from scrap tires damaged beyond repair is the biggest market. Most technologies focus on material “recovery” and the generation of new products resulting from it. However, the products seen so far on the market consist of gluing crumb rubber with epoxy or polyurethane (PU) for use in playgrounds and sports fields (which are not sustainable solutions), or transforming recycled rubber into simple three-dimensional products like mats or pavers. A paradigm shift is to devulcanize the rubber (breaking the bridges between long molecular chains), with which to make new products (mixed to given ratios with non-recycled rubber, an operation known as compounding in the industry, depending on the stringencies of the applications).

How does devulcanization play out for rubber sustainability and the rubber product circular economy?
Vulcanized rubber cannot be remolten (like thermoplastics) and put to new uses. Today, the main end-of-life tire (ELT) and other rubber products solutions are landfilling, incineration (i.e., use by cement plants or in waste-to-energy programs) and grinding to fine granules. The latter generates huge quantities of powder and represents a lack of sustainable recycling of valuable rubbers.

Additionally, tires have become high-tech products, where the simultaneous improvements of wet traction, rolling resis-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tance and abrasion resistance are hard to achieve. About 285 million motor vehicles were registered for road use in Canada in 2022, which equals about 330,000 metric tons of scrap tires each year. Further adding to that are scrap tires from OTR (off-the-road) vehicles, trucks, buses, tractors, farm and construction machinery, etc. By devulcanizing ELTs, it is possible to produce new raw materials with good mechanical properties and a superior environmental footprint over new materials. Devulcanization or the breaking up of sulfur bonds by mechanical, chemical, thermo-physical or biological means is promising for rubber sustainability and the rubber product circular economy.

In vulcanization, sulfur can form bonds between unsaturated polymer chains found in latex to yield natural rubber, and also for synthetic rubbers; accelerators added in the process at elevated temperatures speed manufacturing. Accelerated sulfur vulcanization classifies into conventional (CV), semi-efficient (semi-EV) and efficient vulcanization (EV), depending on accelerator/sulfur ratios (A/S) between 0.1 and 12.

Vulcanization gives the properties to natural or synthetic rubbers. Devulcanization aims at selectively cleaving the C-S bonds while leaving the C-C bonds intact. The devulcanization of waste rubber applies energy to the material in order to break up, totally or partially, the three-dimensional network formed during vulcanization. The process is difficult to achieve, since the energies needed to break the S-S and C-S bonds (227 and 273 kJ/mol, respectively) are lower, but close to the energy required to break the C-C bonds (348 kJ/mol).

The higher the selectivity of the devulcanization process, the better the mechanical properties of the material. Scientists developed a tool for investigating the mechanism of network breakdown in a vulcanized rubber network. Accordingly, the rate of increase of the soluble (sol) fraction of the rubber as a function of the measured crosslink density of the remaining insoluble (gel) fraction is different for cleavage of carbon-sulfur and carbon-carbon bonds. Thus, sol fraction and crosslink density measurements of devulcanized rubber samples yield an indication of the dominant mechanism of network breakdown.

Regarding useful life, there are two types of tires: reusable tires and non-reusable ones. Those tires that cannot be retreaded because of advanced damage, structural deformation or high degradation are the starting materials for ELT recycling.

For devulcanization, waste tires are typically processed into ground tire rubber (GTR) that can be imbedded into rubberized asphalt, bitumen, cement, concrete, tiles, thermal and acoustic isolations, etc. However, simply mixing untreated GTR into an (elastomeric) matrix greatly decreases its mechanical properties, because the crosslinked rubber particles show poor interfacial adhesion and dispersion. Use of a twin-screw extruder for thermomechanical devulcanization proved to be the most practical method, as that type of machinery is commonly used in the polymer industry. In addition, scalability to industrial volumes appears to be the best solution when it comes to extruders. For thermochemical extrusion, the use of supercritical CO_2 ($scCO_2$)

showed benefits. Chemically non-toxic, inactive, non-flammable and inexpensive, the critical point of CO_2 can be reached easily (at 31.1°C and 7.38 MPa), and residual $scCO_2$ from the devulcanized rubber removes easily to the ambient.

How can real scrap tire recycling mechanisms be implemented in the industry, including devulcanization?

With an increasing global population, consumption of polymers such as thermoplastics, thermosets and elastomers has shown significant growth since the 1950s, with thermoplastics representing by far the largest group. The worldwide production of plastics reached a staggering 400.3 million metric tons in 2022. This marks an increase of about 1.6% from the previous year, even factoring in a global pandemic, as well as political and economic instability. Plastics production has soared since the 1950s with continued growth in production and market share. However, such a steady historic yearly growth rate should flatten in the coming years because of pressures toward recycling plastic products (like water bottles).

Feedstock recycling appears to be the ultimate goal for polymers with original monomers recoveries. This seems feasible for some pure polymers; but for complex product mixtures such as rubbers (the bulk of which are made into tires), feedstock recycling back to isoprene and other constituents is not feasible today. However, a process to reverse vulcanization (known as devulcanization), makes the elastomeric material meltable and processable again, offering a route to recycling ELTs back into high value-added materials and products. Through devulcanization, natural and synthetic rubbers can be partly replaced and saved, leading to multiple economic and environmental benefits.

How does the tire recycling process typically work?

Tires are used on all sorts of vehicles. After several years, they need to be replaced because their profiles wear out and/or they become brittle and crack under repeated stressing and the elements. Retreading is done for truck tires; while passenger car tires are mostly single use items. End-of-life tires can be mainly recovered through two routes: the recovery of material or the recovery of energy. The calorific value of ELTs is close to that of coal, and they are often used in paper mills and cement kilns. Through pyrolysis, oils can be made, though this tends to result in substantial emissions. Another possible outlet is oil spill remediation. Material recovery requires the granulation of ELTs. Grinding encompasses ambient, wet and cryogenic processes. Most technologies for tire recycling involve the separation of metallic and textile (cord) materials, and a grinding process leading to a significant reduction of the tire's dimensions. During grinding, which typically yields granulates of a few tens of thousands of an inch or below, the temperature can be lower than the glass transition temperature (i.e., cryogenic grinding) of the polymers in the tires at room temperature. The resulting powder can be used as a filler; e.g., in new tire compounds, but only in small amounts. To improve the compatibility between the new rubber compound and ELT powder, the latter must be devulcanized by breaking the three-dimensional crosslinking network, or at least by modifying the surface of the granules.

Twin-screw extrusion for mechanical devulcanization is the most practical way to treat scrap tires for commonality in the polymer industry. The process uses no chemicals and no heat, and can be scaled up to industrial volumes. The use of supercritical CO_2 ($scCO_2$) helps swell the rubber and stretch the crosslinks between long molecular chains; CO_2 is chemically non-toxic, inactive, non-flammable, inexpensive and compatible with the environment. Good rubber is obtained, and extruders can process between 0.5 to 3 metric tons of scrap tires per hour, which over three shifts can treat 18,000 metric tons, or about 1.5 million scrap tires yearly. The devulcanized rubber can be turned into pellets to mix with asphalt to rubberize roads, or as a masterbatch for polymers in molded or extruded products.

What are some of the research findings from your laboratory?

EcoUS developed technologies to recover rubber from products containing rubbers like tires; devulcanize the recovered rubber; compound the devulcanized rubber; and manufacture with recycled (devulcanized and compounded) rubber materials and products. Currently, EcoUS offers two lines of products:

- Recycled rubber can include recycled SBR (styrene butadiene rubber) pellets to replace SBS (styrene butadiene styrene) polymer in asphalt to rubberize roads, parking lots, driveways, etc. EcoUS also offers devulcanized rubber that can be used in mixing to reduce the cost of new compounds.
- Recycled rubber products molded by EcoUS under contract include a small solid idler for the mining industry for a heavy machinery manufacturer in the greater Toronto area). EcoUS is also launching a first product of its own, namely a front parking block for passenger vehicles.
- EcoUS offers services in terms of receiving and treating post-industrial polymeric wastes involving rubbers, as well. One such application is temporary seals around vehicle doors from General Motors at its facility in Warren, MI. Talks are underway with various other vehicle original equipment manufacturers (OEMs) and different level tire suppliers, as well.

Many products are under development under the EcoUS brand, as well, and include various markets and industrial sectors spanning automotive, oil and gas, leisure, etc. Some of the current applications include truck front parking blocks, bus front parking blocks, lane dividers (between bikes and vehicles), barrier-post joints along highways, sleeve covers to bollards, entrance and anti-fatigue pads, fenders for boats and fenders for docks.

Windsor Industrial Development Laboratory has developed these recycled rubber parking blocks under the name of EcoUS as a substitute for traditional cement pieces found in most parking lots (figure 1).

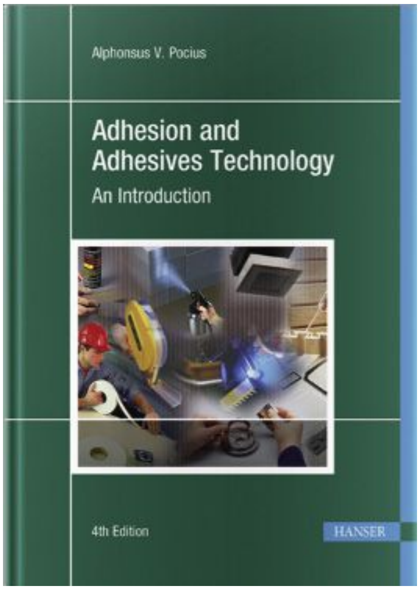
Figure 1 - recycled rubber parking block

Additionally, EcoUS is open to engineering applications for customers. Developing engineered (functional) products from rubber recouped from scrap tires involves three main technical ingredients: rubber chemistry (in particular, the devulcanization of vulcanized rubber); rubber product design and engineering (based on computer-aided design and simulations); and rubber manufacturing with rheology and tooling design and machine processing (manufacturing) to optimize in a computer and then produce. The EcoUS team and additional associates are made up of veterans in the rubber industry; and each member offers advanced academic credentials and decades of industrial experiences in material development and characterization, rubber chemistry, product design and optimization, manufacturing, processing and fine tuning, tooling, prototyping and testing.

What are some of the advantages of the products EcoUS is developing compared to existing solutions?

The EcoUS recycled rubber parking blocks offer:

- ***Weather resistance***: Cement parking blocks crack, break, change color with the elements and grow mold. They are heavy to move around and damage the pavement below. Rubber blocks eliminate these issues and avoid scratching underneath the fenders of vehicles when parking close to a block.
- ***Greater longevity***: Rubber blocks resist the weather compared to cement blocks. Water in cracks can freeze to break the cement blocks.
- ***Improved economics***: Cement blocks are steel reinforced and require many molds as curing takes around 24 hours. Conversely, one single mold makes several rubber blocks per hour.
- ***Increased safety***: Markings stand out on rubber blocks, making parking at night and in poor weather conditions easier. Rubber absorbs hits, cushions slips and falls, and does not damage vehicles. It is also easy to install and remove, and is light to transport to and take away from job sites.
- ***Environmental responsibility***: Using scrap tires to make parts reuses masses of rubber that would otherwise be wasted every year. Recycled rubber blocks eliminate 200 scrap tires in a 60-slot parking lot. It does not take a large project to make a sizable dent in our huge ELT waste problem. The United States alone discards about 3.6 million metric tons of scrap tires each year. Three quarters of these can be diverted away from incineration and landfills into similar product development endeavors.



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Patent News

Method of generating virtual tire slip sound in vehicle

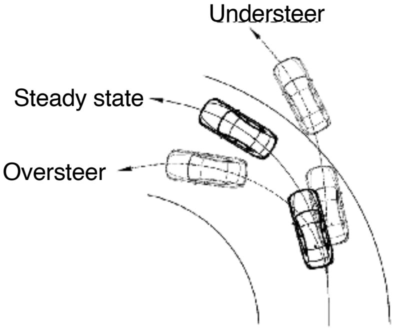
U.S. patent: 12,051,290

Issued: July 30, 2024

Inventors: Ki Chang Kim, Jin Sung Lee, Dong Chul Park, Tae Kun Yun and Jin Hong

Assigned: Hyundai and Kia

Key statement: A method of generating a tire slip sound is capable of producing a virtual tire slip sound in a driving situation in which tire slip may occur during vehicle driving. The method includes collecting vehicle driving information while a vehicle is traveling; determining a characteristic of a virtual tire slip sound based on the collected vehicle driving information; generating and outputting a tire slip signal for generating and outputting the virtual tire slip sound according to the determined characteristic; and operating sound equipment of the vehicle according to the tire slip signal output from the controller to generate and output the virtual tire slip sound according to a vehicle driving state.



Composition, crosslinked rubber molded article and fluorine containing polymer

U.S. patent: 12,060,445

Issued: August 13, 2024

Inventors: Takahiro Furutani, Rina Tamai, Eisaku Sumino, Yusuke Kamiya, Junpei Terada and Masaki Irie

Assigned: Daikin Industries

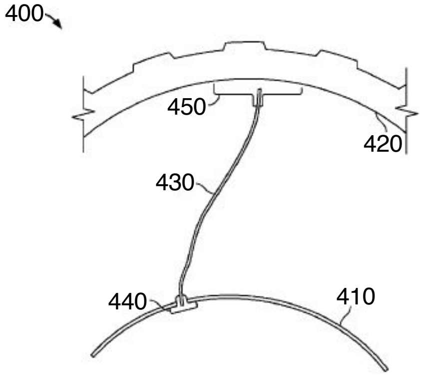
Key statement: A composition including a fluorine containing polymer and a crosslinking agent, wherein the fluorine containing polymer contains a vinylidene fluoride unit, a unit of a fluorine containing monomer (1) represented by the following general formula (1):

$$CHX^1{=}CX^2Rf \qquad (1)$$

wherein one of X^1 and X^2 is H, the other is F and Rf is a linear or branched fluoroalkyl group having 1 to 12 carbon atoms and a unit of a monomer providing a crosslinking site. The monomer providing a crosslinking site is a monomer having at least one crosslinkable group selected from a cyano group, a carboxyl group,

an alkoxycarbonyl group and a hydroxyl group. Also disclosed is a crosslinked rubber molded article obtained by crosslinking the composition.

Flexible metallic web elements for non-pneumatic tire
U.S. patent: 12,043,070
Issued: July 23, 2024
Inventors: Benjamin E. Rimai and Anthony B. Duncan
Assigned: Bridgestone Americas Tire
Key statement: A non-pneumatic tire includes an inner ring, an outer ring and a plurality of bent metal spokes. The non-pneumatic tire further includes a first overmolded foot at a first end of each bent metal spoke. Each first overmolded foot is attached to the inner ring. The non-pneumatic tire also includes a second overmolded foot at a second end of each bent metal spoke. Each first overmolded foot is attached to the outer ring.



Rubber composition and tire
U.S. patent: 12,060,490
Issued: August 13, 2024
Inventor: Kensuke Washizu
Assigned: Sumitomo Rubber Industries
Key statement: The present invention aims to provide rubber compositions and tires which provide improved overall performance in terms of wet grip performance, dry grip performance and fuel economy. The present invention relates to a rubber composition having a hardness that reversibly changes with water and satisfying the following relationships (1) and (2):

$$\text{Hardness when dry} - \text{hardness when water - wet} \geq 1 \quad (1)$$

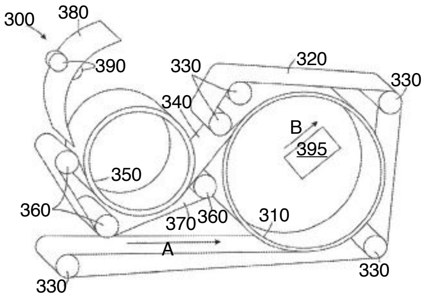
wherein each hardness represents the JIS-A hardness at 25°C of the rubber composition; and

$$\tan\delta \text{ at } 70°\text{C when dry} < 0.14 \quad (2)$$

wherein the tan δ at 70°C represents the loss tangent measured at 70°C, an initial strain of 10%, a dynamic strain of 2% and a frequency of 10 Hz.

Patent News

Elastomer impregnated fiber cooler belt
U.S. patent: 12,059,892
Issued: August 13, 2024
Inventors: Varun Sambhy, John Patrick Baker, Santokh Singh Badesha, David Scott Derleth and Piotr Sokolowski
Assigned: Xerox
Key statement: Disclosed herein is a substrate cooling unit for use with a duplex aqueous ink jet image forming device. The substrate cooling unit including a first cooling roll. a first transport belt, a second cooling roll positioned downstream of the first cooling roll in a process direction and a second transport belt. The first and second transports belts include a bottom layer of a fiber mesh impregnated with a polydimethylsiloxane, where the fiber mesh is selected from cotton, polyester and nylon. The first and second transport belts include an optional intermediate adhesive layer and an optional top layer of silicone having an extractable level of less than 4%. The substrate cooling unit includes an invertor.



Tire comprising a rubber composition having a pro-oxidant and a rubber crumb
U.S. patent: 12,060,487
Issued: August 13, 2024
Inventors: Nathalie Coste, Severin Dronet and Guillaume Hennebert
Assigned: Michelin
Key statement: A tire comprises a rubber composition based on at least a rubber crumb, a diene elastomer, a pro-oxidant, a reinforcing filler and a crosslinking system, said rubber crumb representing 30% by mass or more of the composition, and exhibiting a ratio of the chloroform extract to the acetone extract of less than 2, the chloroform and acetone extracts being expressed as percentages by mass.

Rubber composition, processing method thereof, rubber hose using the same
U.S. patent: 12,060,476
Issued: August 13, 2024
Inventors: Tao Xu, Zhi Sheng Fu and An Yang Wu
Assigned: Hangzhou Xinglu Technology and Shaoxing Pinghe New Material Technology
Key statement: The present invention dis-

closes a rubber composition, a processing method for obtaining the rubber composition, a rubber hose using the rubber composition and a production method thereof. The rubber composition comprises, in parts by weight, 100 parts of a rubber matrix, 1.5-8 parts of a crosslinking agent, 50-200 parts of a reinforcing filler, 10-100 parts of a plasticizer and also 0.2-8 parts of an auxiliary crosslinking agent, 2-15 parts of a metal oxide, 1-3 parts of a stabilizer and 1-5 parts of polyethylene glycol, wherein, with respect to 100 parts by weight of total amount of said rubber matrix, said rubber matrix comprises a branched polyethylene with a content represented as A, in which $0 < A \le 100$ parts and both an EPM rubber and an EPDM rubber with a total content represented as B, in which $0 \le B < 100$ parts. The beneficial effect is that a rubber hose with good mechanical strength can be prepared from the rubber composition provided in the present invention.

Tire provided with an inner layer made from at least an isoprene elastomer, a reinforcing resin and a metal salt
U.S. patent: 12,060,489
Issued: August 13, 2024
Inventors: Auriane Frisch and Joel Barbouteau
Assigned: Michelin
Key statement: The present disclosure relates to tires, at least one internal layer of which exhibits good mechanical properties and reduced rolling resistance, the said internal layer comprising a rubber composition based on at least 80 to 100 phr of an isoprene elastomer, a reinforcing filler predominantly comprising carbon black, 1 to 45 phr of reinforcing resin, a salt of an alkaline earth, alkali or lanthanide metal and a crosslinking system.

Rubber composition for a tire tread
U.S. patent: 12,064,996
Issued: August 20, 2024
Inventors: Christine Nourry and Floriandre Volisin
Assigned: Michelin
Key statement: A tire exhibits an improved performance compromise, the tread of which comprises a rubber composition based on an elastomeric matrix comprising from 25 to 95 parts by weight per hundred parts by weight of elastomer, phr, of copolymer based on butadiene and on styrene having a glass transition temperature of less than -70°C and from 5 to 75 phr of polybutadiene, the elastomeric matrix comprising less than 15 phr of isoprene elastomer; at least one reinforcing filler; from 25 to 100 phr of at least one plasticizing resin having a glass transition temperature of greater than 20°C; and a vulcanization system.

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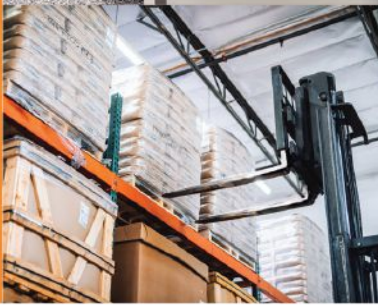

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Structural adhesives composed of epoxy resins and hydrogen bonded styrenic block polymer based TPEs

by Saya Yamada, Takato Kajita, Mio Nishimoto, Junko Horiuchi, Yoshirou Fujii, Kazumasa Sakaguchi, Kazuo Hattori, Hiroshi Tamura, Tatsuya Kano, Takenobu Sakai and Atsushi Noro, Nagoya University

A wide range of polymer materials with excellent performance and functionality has been developed in recent years to address diverse and complex material applications. Adhesives are one such example of these polymer materials (refs. 1 and 2). In general, adhesives are composed of a liquid substance (prepolymer) that is first used to fill in the rough surface of one substrate, and then the adhesive on the substrate is sandwiched by another substrate. Polymerization and crosslinking of the prepolymer in the adhesives are induced by heat or other external stimuli, leading to curing of the adhesives between substrates. Chemical or physical bonding of the cured adhesives to the substrate surfaces occurs, thereby joining the two substrates. Recently, structural adhesives (ref. 3), which are strong and used to meet strength and durability requirements, have received increasing attention for use in the assembly of automobiles (refs. 4 and 5), aircraft (refs. 6 and 7) and buildings (refs. 8 and 9). Typical structural adhesives are epoxy (refs. 10-14), acrylic (refs. 15-17), urethane based adhesives (refs. 18 and 19), and so on (refs. 20 and 21). In particular, epoxy adhesives have been the most widely used due to their excellent mechanical strength and durability (refs. 11 and 12).

Recent attention has also been focused on reducing greenhouse gas emissions, such as carbon dioxide, through materials research and development. In the automotive industry, there is a strong demand to lower both fuel consumption and exhaust emissions, and various technologies related to weight reduction of vehicles have been developed for this purpose (refs. 22 and 23). One example of vehicle weight reduction is a thinning of the steel plates used for automobile body panels. However, the thinning of steel plates inevitably leads to a decrease in their strength, requiring stronger adhesives to improve this property.

Another example of an application of adhesives is in multimaterial design, where materials with lower density than steel, such as aluminum, magnesium alloys and other materials, are combined with steel plates. In these applications, conventional spot welding cannot be used to join steel plates in the multimaterial design, because different materials have different thermal expansion coefficients. To address this issue, a weld bonding process was developed that combines the point joining of spot welding and surface bonding by use of structural adhesives in order to bond dissimilar materials (refs. 24 and 25). In the weld bonding process, an epoxy adhesive composed of an epoxy resin is a major component that has been widely used as a structural adhesive. Curing this epoxy resin results in a high mechanical strength thermosetting resin. However, since cured epoxy resins are rigid, brittle and inflexible in general, the peel and impact strength of epoxy adhesives is typically low. Therefore, assemblies bonded with epoxy adhesives have low toughness and tend to easily break when subjected to external forces (refs. 26 and 27).

To toughen epoxy adhesives, the macroscopic dispersion of soft rubber components into epoxy resins has been attempted (refs. 12 and 28). However, since rubber components are generally insoluble in epoxy resins, it is difficult to disperse them homogeneously throughout the cured epoxy resins. To improve their dispersibility, researchers reported using a modifier of carboxy-terminated acrylonitrile butadiene rubber (CTBN), which is a carboxy-terminated copolymer composed of butadiene and acrylonitrile (refs. 29-31). CTBN can be dissolved in an epoxy resin before curing due to its highly polar carboxy groups and acrylonitrile units. As the molecular weight of the epoxy resin increases by polymerization and crosslinking, the solubility of CTBN decreases in the epoxy resin. Therefore, phase separation starts to occur between the cured epoxy resin and CTBN. However, in practice, the rubber phase tends to be insufficiently or unclearly separated from the cured epoxy resin matrix phase. As a result, the typical cured epoxy resin mixed with CTBN does not exhibit sufficient strength.

On the other hand, cured epoxy resins with a macroscopically dispersed rubber phase have been developed by mixing with a core-shell rubber (CSR) (refs. 12, 28 and 32). In CSR, rubbery particles, such as polybutadiene (refs. 33 and 34), acrylic rubber (refs. 35 and 36) and silicone rubber (refs. 33, 37 and 38) are covered with a layer of glassy components such as acrylic resins that are highly compatible with epoxy resin. In contrast to nitrile butadiene rubber (NBR), the rubber component in CSR is insoluble in an epoxy resin, allowing for complete phase separation between the rubber phase and the epoxy resin matrix phase. Meanwhile, CSR is well dispersed macroscopically in the epoxy resin due to the high compatibility of its shell layer with the epoxy resin, resulting in a tough cured resin. However, CSR is generally an expensive additive because the CSR synthesis process is more complicated than that of common rubber materials.

Attempts have also been made to microscopically phase separate the hard epoxy resin matrix phase from the rubber phase by mixing with inexpensive block polymers (refs. 39 and 40) that consist of covalently bonded incompatible polymer components (refs. 41-44). For example, it has been reported that the toughness of cured epoxy resins was improved by mixing epoxy resins and poly(methyl methacrylate)-b-poly(n-butyl acrylate)-b-poly(methyl methacrylate) triblock copolymer (MAM) used as a thermoplastic elastomer (TPE) (refs. 45 and 46). The poly(n-butyl acrylate) phase can be dispersed in the epoxy resin since the rubbery poly(n-butyl acrylate) middle block, which is insoluble in epoxy resin, is chemically bonded to the glassy poly(methyl methacrylate) end blocks, which are soluble in epoxy resin, providing flexibility to the cured epoxy resin. However, the market size of MAM as a TPE is small at several thousand metric tons per year (ref. 47), and hence structural adhesives containing MAM have not yet been commercialized due to mass production and cost issues.

Polystyrene-b-polyisoprene-b-polystyrene (SIS) (refs. 48-50) and polystyrene-b-polybutadiene-b-polystyrene (SBS) (refs. 51 and 52) triblock copolymers are representative ABA triblock copolymer based styrenic TPEs with a much larger global market than that of MAM, at more than several hundred thousand metric tons per year (ref. 53). Therefore, flexible structural adhesives can be prepared at low cost by mixing SIS or SBS with the epoxy resins. Considering the compatibility of SBS with epoxy resins, SBS with polybutadiene blocks that incorporate epoxy groups has been studied (refs. 54-56). For example, a cured material composed of an epoxy resin and an SBS with incorporated epoxy groups, with 47 mol % epoxy groups in the polybutadiene block, exhibited higher impact resistance compared to a cured sample without the epoxidized SBS (ref. 55). However, since the epoxy groups in polybutadiene blocks easily react with an uncured epoxy resin at the beginning of the curing process, insufficient or unclear phase separation of the rubber phase, consisting of polybutadiene blocks from the cured epoxy resin phase, is likely to be induced, resulting in a decrease in the glass transition temperature, T_g, of the cured epoxy resin phase (ref. 56). Therefore, epoxy adhesives containing epoxidized SBS as a modifier could have low heat resistance (refs. 57 and 58). Based on the above previous studies, a better structural adhesive could be obtained by simply mixing non-epoxidized SIS or SBS with epoxy resins, if polystyrene is soluble in epoxy resins and polyisoprene or polybutadiene is insoluble in epoxy resins.

Hydrogen bonded SIS (h-SIS) with the hydrogen bonding groups of amide and carboxy groups in the I middle block (ref. 59 and 60) were recently developed. Due to the preferential dissociation of hydrogen bonds when stress is applied to h-SIS, the stress concentration in the hard domain consisting of S blocks was suppressed, leading to suppression of the hard domain breakdown. Therefore, an epoxy resin mixed with h-SIS is expected to be a tougher structural adhesive than an epoxy resin mixed with neat SIS without hydrogen bonding groups.

In this study, structural adhesives were prepared that exhibit high peel strength and high impact strength simultaneously, i.e., high toughness after curing, by mixing an epoxy resin with a curing agent and SIS that is one of the typical styrenic TPEs. Furthermore, by mixing an epoxy resin, a curing agent and h-SIS with hydrogen bonding groups in the I block of SIS, tougher structural adhesives than the adhesives containing SIS are prepared (figure 1). To evaluate adhesive properties, tensile lap shear tests, t-peel tests and impact wedge-peel tests are performed on the adherends that are bonded by thermally curing the adhesives between two substrates. In addition, the nanostructure and the dynamic behavior of the cured adhesives are investigated using transmission electron microscopy (TEM) observations and dynamic mechanical analysis (DMA), respec-

Figure 1 - chemical structures and schematic molecular levels of (a) EP, (b) dicyandiamide (DICY), (c) SIS and (d) h-SIS; schematic molecular levels of cured adhesives composed of (e) EP*, (f) SIS/EP* and (g) h-SIS/EP* at room temperature are also shown, along with (h) some of the major curing reactions proposed for epoxy/DICY adhesives; the yellow lines and orange dots represent the EP chains and the crosslinking points derived from DICY, respectively; the black short lines and the pink curved lines depict polystyrene and polyisoprene chains, respectively; the light green rectangles composed of two L-type shapes of a hydrogen bonding group represent hydrogen bonds; the region composed of yellow lines and orange dots represents the cured EP* phase; the region composed of black short lines, yellow lines and orange dots represents the S and EP* mixed phase; the region composed of pink curved lines represents the I phase; and the region composed of pink curved lines, light green rectangles and green L-type shapes represents the h-I phase

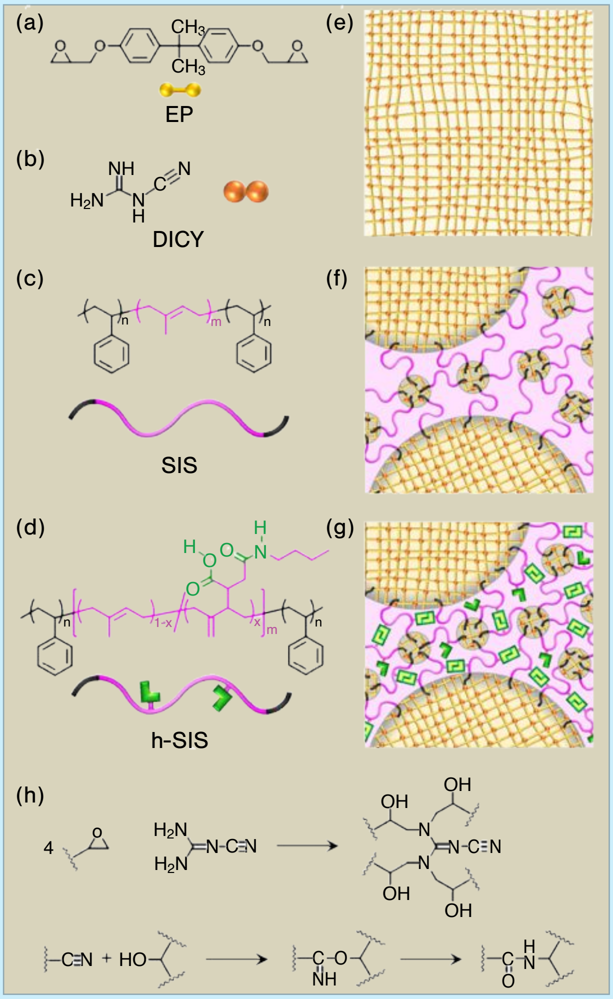


Table 1 - composition of the adhesive samples

Sample	ω_{TPE}[a,c] (phr)	ω_{DICY}[a,d] (phr)	ω_{AA}[a,d] (phr)	ω_{CaCO_3}[a,d] (phr)	ω'_{TPE}[b,c] (wt%)	ω'_{EP}[b,d] (wt%)	ω'_{DICY}[b,d] (wt%)	ω'_{AA}[b,d] (wt%)	ω'_{CaCO_3}[b,d] (wt%)
EP*	0	7.0	1.0	19.1	0	78.7	5.5	0.8	15
SIS (5.6)EP*	5.6	7.0	1.0	20.0	4.2	74.8	5.2	0.7	15
SIS(9.6)/EP*	9.6	7.0	1.0	20.8	6.9	72.3	5.1	0.7	15
SIS(19)/EP*	19	7.0	1.0	22.4	12.7	66.9	4.7	0.7	15
SIS(26)/EP*	26	7.0	1.0	23.6	16.5	63.4	4.4	0.6	15
h-SIS(6.0)/EP*	6.0	7.0	1.0	20.1	4.5	74.6	5.2	0.7	15
h-SIS(9.0)/EP*	9.0	7.0	1.0	20.6	6.5	72.6	5.1	0.7	15
h-SIS(19)/EP*	19	7.0	1.0	22.4	12.7	66.9	4.7	0.7	15
h-SIS(24)/EP*	24	7.0	1.0	23.3	15.5	64.4	4.5	0.6	15

[a] ω represents parts of additives by weight per hundred parts of resin (EP) by weight. The type of additive is indicated in subscripts. TPE in the subscripts indicates SIS or h-SIS.

[b] ω' represents the weight fraction of substances in the adhesives, where the type of substance is indicated in subscripts.

[c] The values were estimated by ^{1}H NMR.

[d] The values were determined by the feed ratio.

tively. Based on these results, the mechanism leading to the excellent physical properties of structural adhesives composed of an epoxy resin and SIS (or h-SIS) is discussed.

Experimental

Materials

Bisphenol A diglycidyl ether (Nan Ya Plastics) with epoxy unit equivalent weight of 170 g mol^{-1} was used as an epoxy prepolymer (EP). Dicyandiamide (DICY, CVC Thermoset Specialties) and epoxy-amine adduct of Amicure TMMY-24 (AA, Ajinomoto Fine-Techno) were used as a latent curing agent and an amine-adduct curing agent, respectively. Calcium carbonate ($CaCO_3$, Viscoexcel 30HV, Shiraishi Calcium Kaisha, Ltd.) was also used as a filler. SIS (Quintac, Mn = 185 kg mol^{-1}, weight fraction of polystyrene block: 19 wt%) was supplied from Zeon. Polystyrene homopolymer (S) with Mn = 22 kg mol^{-1} was purchased from Polymer Source for compatibility evaluation with EP. Polyisoprene homopolymer (I) with Mn = 175 kg mol^{-1} that was synthesized by anionic polymerization was used for compatibility evaluation with EP. Maleic anhydride, N-(1,3-dimethylbutyl)-N′-phenyl-1,4-phenylenediamine (6PPD), di-n-octyl phthalate (DnOP) and n-butylamine were purchased from TCI.

Compatibility evaluation between EP and polymers

The compatibilities of EP with SIS, S or I were evaluated using an optical microscope at room temperature. The samples for observations were prepared by dissolving the polymers and EP in tetrahydrofuran (THF) at a polymers:EP weight ratio of 1:9, 5:5 and 9:1, and drop casting the prepared solutions onto cover glass substrates at room temperature. The observations were performed using a BX51 optical microscope manufactured by Olympus.

Synthesis of hydrogen bonded SIS (h-SIS)

H-SIS from neat SIS was synthesized according to previous reports (refs. 59 and 60). The synthesis of h-SIS with hydrogen bonding amide and carboxy groups in the I block used an ene reaction between maleic anhydride and carbon-carbon double bonds in the I block of SIS, followed by an acyl substitution reaction between the succinic anhydride units and n-butylamine. ^{1}H NMR spectroscopy revealed that the ratio of the succinic anhydride units attached to the I block was 4.4 mol %.

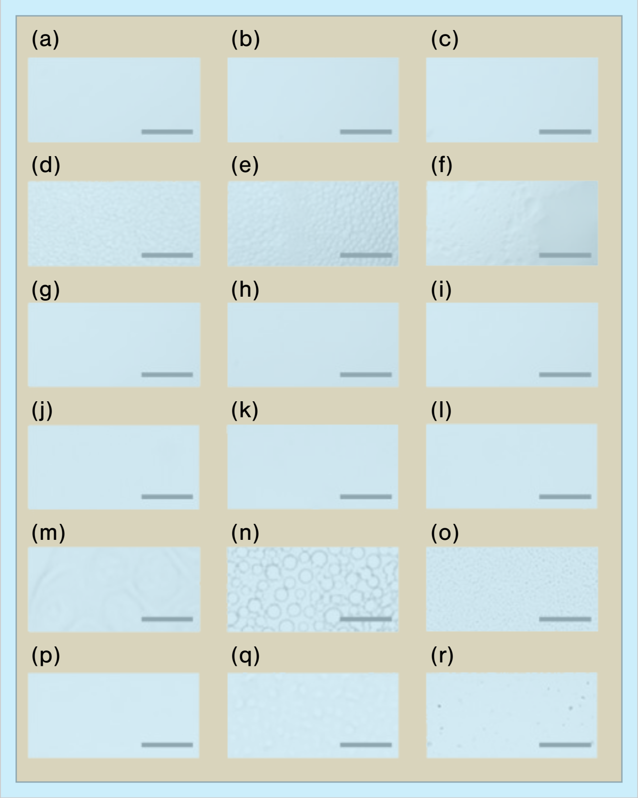
Preparation of adhesives composed of TPE and EP

In a three-necked flask, 5.0 g of SIS and 25 g of EP were dissolved using 50 g of THF. The THF in the solution was subsequently evaporated using a rotary evaporator, and then the solution was vacuum dried at 55°C for about five hours to prepare a homogeneous mixture with less than 1 wt% THF. In the same way, mixtures with different weight ratios of SIS and EP were prepared. The mixtures were coded as SIS(X)/EP, where X represents the part of SIS by weight per hundred parts of EP by weight. In addition, mixtures consisting of h-SIS and EP were prepared using h-SIS instead of SIS, and the samples were coded as h-SIS(X)/EP. To prepare adhesives in this study, seven parts of DICY by weight and one part of AA by weight were added to 100 parts of EP by weight for both SIS(X)/EP or h-SIS(X)/EP. Adhesives were prepared by further adding $CaCO_3$ as a filler and mixing well, where the weight ratio of $CaCO_3$ in the whole mixture was set to 15 wt%. An adhesive without SIS or h-SIS was also prepared as a control sample in the same way. The resulting adhesives were cured by heating in an oven at 170°C for 50 minutes. Figure 1h shows some of the proposed reaction schemes during the curing of adhesives composed of an epoxy resin and DICY (refs. 61 and 62). The cured samples were coded as SIS (X)/EP* and h-SIS(X)/EP*, where the asterisk means that the sample was cured. Table 1 summarizes the composition of the adhesive samples, where ω represents parts of additives by weight per hundred parts of EP by weight, and ω' is the weight fraction of substances in the adhesives.

Characterizations

Fourier transform-infrared (FT-IR) spectra were measured by a FT/IR-6100 (Jasco) spectrometer to confirm the formation of hydrogen bonding in cured adhesives at room temperature. For measurements, the adhesive samples between two potassium bromide plates were cured by heating at 170°C for 50 minutes. The neat SIS or h-SIS sample was prepared on a potassium bromide plate by the drop casting method.

Figure 2 - optical microscope images of blend samples observed at room temperature for (a) S/EP = 1/9, (b) S/EP = 5/5, (c) S/EP = 9/1, (d) I/EP = 1/9, (e) I/EP = 5/5, (f) I/EP = 9/1, (g) SIS/EP = 1/9, (h) SIS/EP = 5/5 and (i) SIS/EP = 9/1; optical microscope images of blend samples observed at 170°C for (j) S/EP = 1/9, (k) S/EP = 5/5, (l) S/EP = 9/1, (m) I/EP = 1/9, (n) I/EP = 5/5, (o) I/EP = 9/1, (p) SIS/EP = 1/9, (q) SIS/EP = 5/5 and (r) SIS/EP = 9/1; scale bars represent 100 μm



TEM observations were conducted to observe the nanostructures of SIS/EP*, h-SIS/EP*, SIS and h-SIS. For TEM observations, SIS and h-SIS films obtained by a solution casting method were embedded in an epoxy resin, and ultrathin sections with a thickness of ~80 nm were prepared by a cryo-microtome method at -196°C under a wet condition. Ultrathin sections of SIS/EP* and h-SIS/EP* were also prepared by a cryo-microtome method at -196°C. The sections were stained with osmium tetroxide (O_SO_4) vapor overnight. The instrument used for TEM observations was a JEM-1400 Flash electron microscope (JEOL Ltd.), and the acceleration voltage was 100 kV.

Dynamic mechanical analysis (DMA) was conducted with a Rheogel E4000 rheometer (UBM) using a strip shaped sample with a length of 35 mm, a width of 4.5 mm, and a thickness of 2 mm to evaluate the temperature dependence of mechanical properties for cured adhesives. With a heating rate of 10°C min^{-1} under a 0.1% strain at a frequency of 10 Hz, measurements were performed from -100°C to 230°C or until reaching a temperature when the sample starts to flow. Neat SIS and neat h-SIS were also measured as reference samples.

Differential scanning calorimetry (DSC) was performed with a Q2000 calorimeter (TA Instruments) to investigate glass transition temperatures, T_gs, in the temperature range from -80°C to 230°C with a heating rate of 10°C min^{-1} at a nitrogen gas flow rate of 50 mL min^{-1}.

Evaluation of adhesive properties

Tensile lap shear tests were conducted with reference to ISO 4587:2003 (JISK 6850:1999) (ref. 63). Test pieces were prepared by sandwiching the adhesives between steel plates together with glass bead spacers (approximately 0.2 mm in diameter) and then curing the adhesives at 170°C for 50 minutes. The tests were performed three times for each sample (refs. 64 and 65) at room temperature using an AGS-X mechanical tester (Shimadzu) with an elongation rate of 50 mm min^{-1}.

To determine the peel strength of the cured adhesives, t-peel tests were conducted with reference to ISO 11339:2022 (JISK 6854-3:1999) (refs. 66 and 67). Adhesives were sandwiched between steel plates together with glass bead spacers (approximately 0.2 mm in diameter) and cured at 170°C for 50 minutes to prepare the t-peel test pieces. After curing, the test piece was bent vertically using approximately 50 mm of the adhesive uncoated part for gripping, and the test piece was fixed in the grip of a test machine. The tests were conducted three times for each sample (refs. 65 and 68) with an elongation rate of 200 mm min^{-1} at room temperature using an AGS-X mechanical tester (Shimadzu). Peel strength was estimated from the average value of peel force in the range from a displacement of 50 mm to 210 mm.

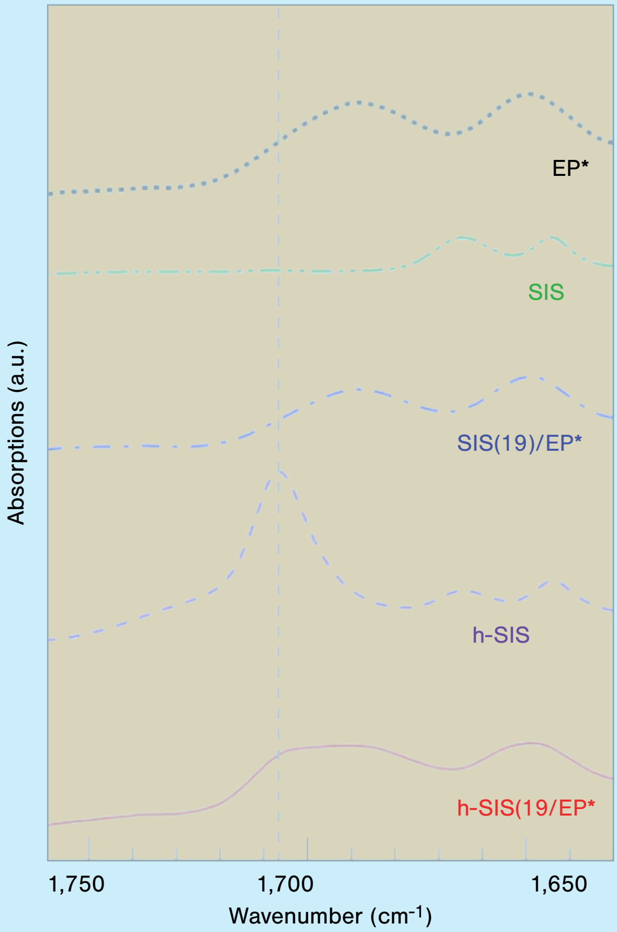
The impact resistance of the adhesives was investigated by impact wedge-peel tests with reference to ISO 11343:2019 (JISK 6865:1999) (refs. 67 and 69). Wedge-peel test pieces were prepared by sandwiching adhesives between steel plates and curing them in a hot air circulation oven at 170°C for 20 minutes. The thickness of the adhesives was adjusted to approximately 0.2 mm using glass bead spacers. The impact wedge-peel tests were conducted at room temperature using a Charpy impact tester (Yonekura Mfg., Ltd.) with a hammer lifting angle of 44.9°, where the velocity of the hammer just before impacting the test piece was ~2 m s^{-1}. The tests were performed three times. The dynamic resistance to cleavage of cured adhesives was estimated by averaging the impact forces per width of the test piece, 25 mm, in the stroke range of 25% to 90% over the entire stroke, during which the impact force was kept approximately constant.

Results and discussion

Compatibility of EP and polymers

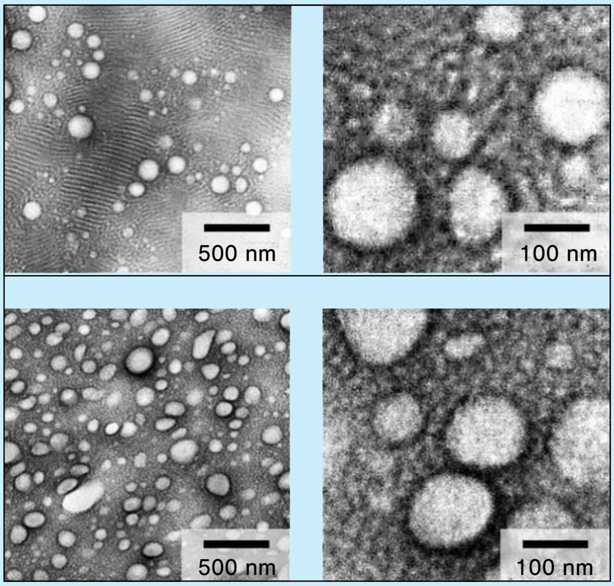
The compatibility of EP with S, I or SIS was investigated by optical microscopic observation. Figures 2a through 2i show optical microscope images of the samples of S/EP, I/EP and SIS/EP at room temperature. The images of S/EP were homogeneous for all compositions from 1/9 to 9/1, revealing that S and EP are compatible for the compositions. In contrast, the images of I/EP were heterogeneous for all compositions from 1/9 to 9/1, suggesting that I and EP are incompatible for the compositions. Even though SIS has an I block that is incompatible with EP, the

Figure 3 - FT-IR spectra of EP* (black dotted line), SIS (green dashed two-dotted line), SIS(19)/EP* (blue dashed dotted line), h-SIS (purple dashed line) and h-SIS(19)/EP* (red solid line) within a wavenumber range from 1,630 to 1,760 cm^{-1}; the vertical gray dashed line represents the 1,707 cm^{-1} position



images of SIS/EP were homogeneous for all compositions from 1/9 to 9/1. This is because the S block in the SIS mixes well with EP, allowing SIS to be well dispersed into the EP matrix, while not causing macroscopic phase separation. Figures 2j through 2r also show optical microscope images of the samples of S/EP, I/EP and SIS/EP at 170°C. Even at 170°C, S and EP are still compatible for all compositions from 1/9 to 9/1, while I and EP are incompatible for the compositions. SIS and EP are also compatible for the composition of 1/9. However, macroscopic phase separation appeared to occur in the SIS/EP blends with a large SIS weight fraction at 170°C (figures 2q and 2r). This is probably because the compatibility between I and EP is much poorer at 170°C than at room temperature.

Figure 4 - TEM images of (a) SIS(19)/EP* and (b) h-SIS(19)/EP*, where scale bars in the left and right images represent 500 and 100 nm, respectively



Hydrogen bonds in h-SIS and cured samples

FT-IR spectroscopy was performed to confirm hydrogen bonds in h-SIS (19)/EP*. Figure 3 shows the FT-IR spectra in the region of 1,630 to 1,760 cm^{-1}, where absorptions derived from the stretching vibration of C = O carbonyl groups are observed. There is an absorption band at around 1,707 cm^{-1} in the spectrum of h-SIS, which is derived from carboxy groups forming hydrogen bonds (refs. 59, 70 and 71). It was observed that h-SIS(19)/EP* also has an absorption band at around 1,707 cm^{-1}, whereas EP* and SIS(19)/EP* did not have the absorption band. This indicates that the carboxy groups in the I block of h-SIS formed hydrogen bonds even after curing. Note that the absorption at around 1,688 cm^{-1}, which is observed in the spectra of cured EP*, SIS (19)/EP* and h-SIS(19)/EP*, originates from the carbonyl group in the urea and/or urethane bonds generated by the curing reaction between EP and DICY (figure 1h) (refs. 61 and 72-75).

Nanostructures in cured samples containing SIS or h-SIS

Figure 4 displays typical TEM images of SIS(19)/EP* and h-SIS(19)/EP*, where the S, EP and S/EP phases look brighter, while phases of I and I with hydrogen bonding groups (h-I) appear darker due to O_SO_4 vapor staining. Both SIS and h-SIS presented similar nanophase separated structures with cylindrical S domains in the rubber matrix, adopting a d-spacing of ~36 nm and ~32 nm, respectively. SIS(19)/EP* and h-SIS(19)/EP* presented nanophase separated structures with similar d-spacings (~37 nm and ~32 nm, respectively) to that of SIS and h-SIS; while relatively large spherical domains of several tens to hundreds of nanometers were also observed in the TEM images. The nanophase separated structures with a d-spacing of ~37 nm were probably periodic structures with domains formed by mixing a small amount of EP with S in SIS, since S and EP were compatible with each other, while I and EP were incompatible. Also, the excess amount of EP that cannot mix into the S in SIS formed the

Figure 5 - temperature dependence of tan delta acquired by DMA for EP* (black triangles), SIS (green circles), SIS(19)/EP* (blue squares), h-SIS (purple plus signs) and h-SIS(19)/EP* (red diamonds)

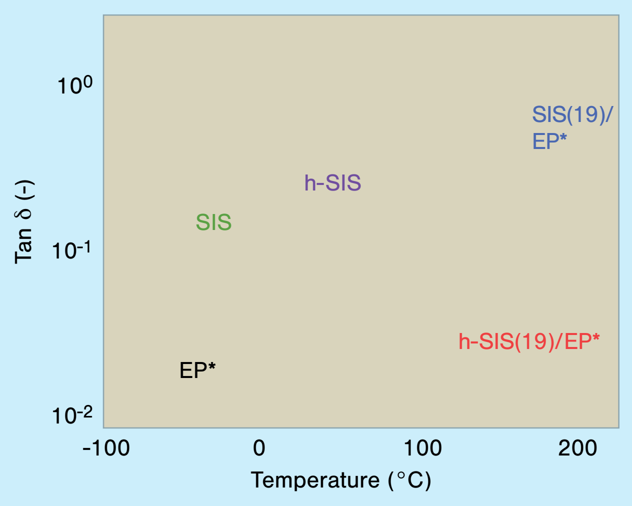
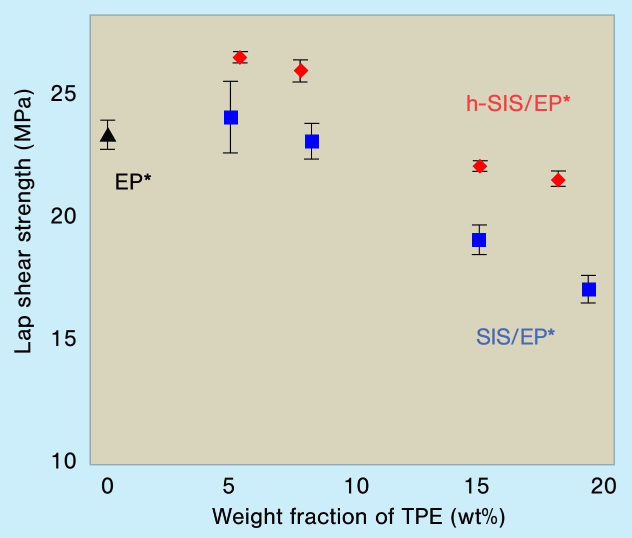


Figure 6 - relationship between lap shear strength and weight fraction of TPE, such as SIS (blue squares) or h-SIS (red diamonds) in the cured adhesives composed of EP and TPE



huge domains with diameters of several tens to several hundreds of nanometers. Note that the diameters of the huge EP* domains were not larger than several µm; in other words, macroscopic phase separation that can be seen when water and oil are physically mixed did not occur in SIS(19)/EP* and h-SIS(19)/EP*. This is because these huge EP* domains were surrounded by SIS or h-SIS, and EP was mixed into S blocks in the block polymers due to good compatibility between EP and the S blocks, which prevents the domains composed of EP* and the S blocks from becoming too large. It should be noted that a block polymer acts as a compatibilizer for formation of a similar phase separated structure in a blend of a block polymer and a homopolymer (ref. 76). Meanwhile, the number of huge EP* domains was smaller in SIS(19)/EP* than in h-SIS(19)/EP*. This is because EP is less likely to contact the I block than the h-I block, probably due to the larger repulsive force between EP and the I block compared to the force between EP and the h-I block.

Dynamic mechanical properties of cured bulk samples

DMA measurements were performed over varying temperatures to investigate the temperature dependence of the mechanical properties of the cured samples, neat SIS and h-SIS. Figure 5 shows the temperature dependence of tan δ for EP*, SIS, SIS(19)/EP*, h-SIS and h-SIS(19)/EP*. EP* without the TPEs exhibited a sharp tan δ peak originating from the α relaxation (T_g) at around 170°C and a broad tan δ peak originating from the β relaxation at around -52°C (refs. 77 and 78). On the other hand, in the tan δ curves of SIS(19)/EP*, a new distinct peak was observed at around -46°C, as well as the peak derived from a T_g of EP*. The peak at around -46°C probably represents the α relaxation derived from the T_g of the I component in SIS(19)/EP* because the temperature of the peak was roughly consistent with the T_g of the I block of SIS, at around -41°C (ref. 59). Note that the tan δ peak originating from the β relaxation of EP* cannot be clearly seen in the curve of SIS(19)/EP* due to the overlap with the tan δ peak derived from the I block.

A clear peak derived from the β relaxation of EP* is not observed in h-SIS(19)/EP* either, and there is a peak tailing from around -40°C to 50°C in h-SIS(19)/EP*. A peak originating from the relaxation of hydrogen bonds is observed at around 8°C in the tan δ curve of h-SIS (ref. 59). Thus, the peak tailing in the tan δ curve of h-SIS(19)/EP* is probably derived from a combination of the α relaxation (T_g) of the I block, the β relaxation of EP* and the relaxation of hydrogen bonds. Comparing the different samples' values of tan δ at room temperature (around 25°C), SIS(19)/EP* exhibited 2.9×10^{-2}, which was larger than the value for

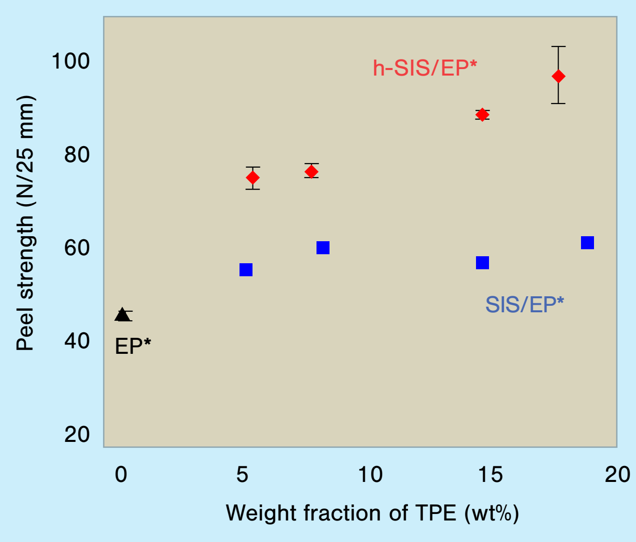
Table 2 - adhesive properties of the samples

Sample	*T_g*[a] *(°C)*	*Lap shear strength*[b] *(MPa)*	*Peel strength*[b] *(N/25 mm)*	*Dynamic resistance to cleavage*[b] *(kn/m)*
EP*	148	23 ± 0.6	45 ± 0.8	45 ± 0.8
SIS (5.6)EP*	148	24 ± 1.4	55 ± 0.2	55 ± 0.2
SIS(9.6)/EP*	153	23 ± 0.7	60 ± 1.0	60 ± 1.0
SIS(19)/EP*	-53, 149	19 ± 0.6	57 ± 0.1	57 ± 0.1
SIS(26)/EP*	-51, 156	17 ± 0.5	61 ± 0.5	61 ± 0.5
h-SIS(6.0)/EP*	144	26 ± 0.2	75 ± 2.3	75 ± 2.3
h-SIS(9.0)/EP*	150	26 ± 0.4	77 ± 1.4	77 ± 1.4
h-SIS(19)/EP*	-50, 150	22 ± 0.2	89 ± 0.7	89 ± 0.7
h-SIS(24)/EP*	-49, 153	21 ± 0.3	97 ± 6.0	97 ± 6.0

[a] Glass transition temperature acquired by DSC measurements. Note that T_gs of the I block in SIS and h-SIS were -60°C and -48°C, respectively.

[b] Average value estimated by measuring three test specimens of the same sample, where the standard error of the mean for three measurements is also shown.

Figure 7 - relationship between peel strength and weight fraction of TPE, such as SIS (blue squares) or h-SIS (red diamonds) in the cured adhesives composed of EP and TPE



EP*, 2.2×10^{-2}. This suggests that the presence of the soft I phase contributes to stress dissipation. Furthermore, the $\tan\delta$ of h-SIS(19)/EP* at room temperature was 3.3×10^{-2}, which is 1.5 times larger than that of EP*, indicating that h-SIS/EP* can more easily dissipate stress than SIS/EP* due to the reversible dissociation/reassociation of hydrogen bonds.

Tensile lap shear strength of SIS/EP and h-SIS/EP**

Tensile lap shear tests were conducted using steel plates bonded with cured epoxy adhesives containing SIS or h-SIS to evaluate both the effect of the macroscopic dispersion of the rubber phase and that from incorporating hydrogen bonding groups into the I phase on lap shear strength. The lap shear strength of all samples is summarized in table 2, and the dependence of the lap shear strength against the weight fraction of TPE (SIS or h-SIS) is shown in figure 6. The standard errors for all the data were sufficiently small. SIS(5.6)/EP* and SIS(9.6)/EP* exhibited almost the same lap shear strength as EP*, while the shear strength of SIS/EP* decreased as ω_{SIS} further increased. The decrease of lap shear strength against the increase in ω_{SIS} was caused by the increase in the amount of the soft I component because this softness contributes little to the lap shear strength of the cured adhesives.

Similar to SIS/EP*, the lap shear strength of h-SIS/EP* also decreased as $\omega_{h\text{-}SIS}$ increased. However, both h-SIS(6.0)/EP* and h-SIS(9.0)/EP* exhibited higher shear strength than did EP* without h-SIS, and the shear strength of h-SIS(19)/EP* and h-SIS(24)/EP* was almost the same as that of EP*. This is because the strength enhancement effect of hydrogen bonds was larger at small $\omega_{h\text{-}SIS}$ compared to the softening effect from the h-I blocks of h-SIS in the cured adhesives.

Peel strength of SIS/EP and h-SIS/EP**

To evaluate the effect of the TPEs on adhesive strength in a mechanical mode different from the tensile shear, T-peel tests were performed using steel materials bonded with SIS/EP* and h-SIS/EP*. Table 2 summarizes the peel strength of the samples, and figure 7 shows the dependence of the peel strength on ω'_{TPE}. The standard errors for the data were sufficiently small. The peel strength of the cured adhesives containing SIS was 55 to 61 N/25 mm, which was 1.2-1.4 times larger than that of EP*, 45 N/25 mm. EP* cannot easily dissipate the applied force because the cured adhesive was hard and did not contain soft components; whereas SIS/EP* can dissipate the stress during peeling since the hard EP* or S/EP* domains with diameters of several tens to several hundreds of nanometers were surrounded by the easily deformable I phase, resulting in the improved peel strength of the cured adhesives. On the other hand, the effect of ω'_{SIS} on the peel strength was not remarkable. An increase in the fraction of the soft I component resulted in an increase in the stress dissipation capability, and had the effect of softening the cured adhesive. Therefore, the peel strength of SIS/EP* did not increase, even by adding more SIS to the adhesives, and did not remarkably depend on ω'_{SIS}.

Meanwhile, the peel strength of the cured adhesives containing h-SIS significantly improved by increasing the amount of h-SIS added to the adhesives, and the peel strength of h-SIS/EP* was 1.7-2.2 times higher than that of neat EP*. This remarkable improvement in peel strength is attributed to both the strengthening effect of the cured adhesives by the formation of hydrogen bonds in the rubber phase, and the effective stress-dissipation capability originating from the reversible mechanism of dissociation/reassociation of hydrogen bonding groups, as well as the softness of the I phase. In general, the peel strength of h-SIS/EP* monotonically increased as $\omega'_{h\text{-}SIS}$ increased, in contrast to the trend seen with SIS/EP*. For instance, h-SIS(9.0)/EP* and h-SIS(24)/EP* with 6.5 and 15.5 wt% of $\omega'_{h\text{-}SIS}$ exhibited 77 N/25 mm and 97 N/25 mm, respectively, which were 1.7 and

Figure 8 - relationship between the dynamic resistance to cleavage and the weight fraction of TPE, such as SIS (blue squares) or h-SIS (red diamonds) in the cured adhesives composed of EP and TPE

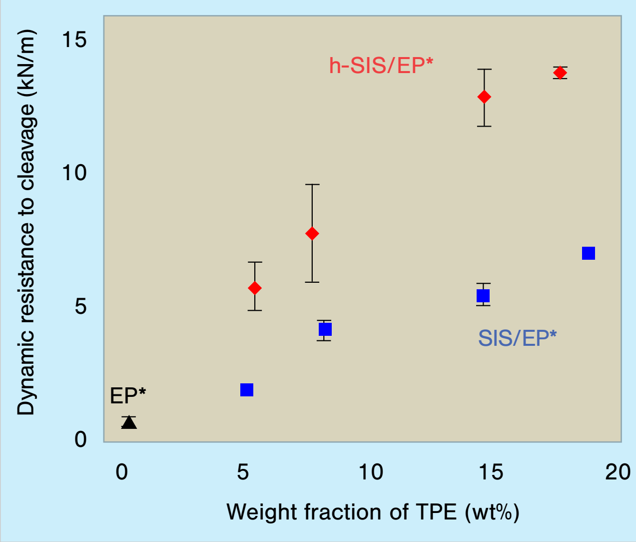


Figure 9 - (a) EP*, (b) SIS/EP* and (c) h-SIS/EP* when a wedge is inserted in the cured adhesive

2.1 times higher than the values for EP*. As $\omega'_{\text{h-SIS}}$ increased, the fraction of the soft component in the cured adhesive increased, while the number of active hydrogen bonds also increased. This probably resulted in the increase in the peel strength of h-SIS/EP*.

Dynamic resistance to cleavage of SIS/EP and h-SIS/EP**

It is important to evaluate the impact resistance of cured adhesives, especially in automotive structural adhesive applications, because impact forces due to crashes, sudden starts or sudden braking will act on adhesive joints. Therefore, impact wedge-peel tests were conducted on adhesives containing SIS and h-SIS. Table 2 summarizes the dynamic resistance to cleavage, and figure 8 shows the dependence of the dynamic resistance to cleavage on ω'_{TPE}, where the horizontal and vertical axes are ω'_{TPE} and the dynamic resistance to cleavage, respectively. The standard errors for the data were sufficiently small.

The dynamic resistance to cleavage of the cured adhesives of SIS/EP* became dramatically higher than that of neat EP* when the amount of SIS added to the adhesive was increased. Namely, SIS(5.6)/EP* with a small weight fraction of SIS, ω'_{TPE} = 4.2 wt%, exhibited the approximately three times higher impact resistance of 1.8 kN/m compared to that of EP* (0.62 kN/m). The dynamic resistance to cleavage increased further with increases in ω'_{TPE}, and SIS(26)/EP* with ω'_{TPE} = 16.5 wt% exhibited an impact resistance of 7.1 kN/m, which was 11 times higher than that of neat EP*. Neat EP* was easily broken because it lacked a soft component, making it difficult to absorb impact forces (figure 9a), whereas the impact resistance of SIS/EP* was higher than that of neat EP*. This latter effect probably occurred because the applied impact was absorbed by the soft I component surrounding the hard EP* domains with a size of several hundreds of nanometers and the hard S/EP* mixed domains with a size of several tens of nanometers (figure 9b). It should be noted that if a random copolymer (ref. 79) composed of styrene and isoprene units is used as an additive in the adhesive, the styrene units cannot be dissolved in EP because the styrene and isoprene units are randomly distributed in the polymer chain, resulting in no formation of the above mentioned domains composed of the S block and cured EP* after EP is cured; therefore, the mixing of the random copolymer with EP probably does not enhance the adhesive properties.

More interestingly, h-SIS/EP* showed higher dynamic resistance to cleavage compared to SIS/EP*. The dynamic resistance to cleavage of h-SIS/EP* also increased as ω'_{TPE} increased. For instance, the dynamic resistance to cleavage of h-SIS(6.0)/EP* with ω'_{TPE} = 4.5 wt% was 5.8 kN/m, which was approximately 9.4 times higher than that of EP*. Also, that of h-SIS(26)/EP* with ω'_{TPE} = 15.5 wt% was 14 kN/m, which was approximately 22 times higher than that of neat EP*. Namely, h-SIS(26)/EP* with ω'_{TPE} = 15.5 wt% exhibited twice the dynamic resistance to cleavage compared to SIS (26)/EP*. The reason why h-SIS/EP* exhibited higher impact strength than SIS/EP* was attributed not only to the softness of the I phase, allowing it to absorb the applied impact, but also to the reversible dissociation/reassociation of hydrogen bonds (figure 9c). The results were also supported by a previous study on the excellent impact resistance of the block polymer based thermoplastic elastomer with a noncovalently bonded rubber phase (ref. 60). In addition, as the ω'_{TPE} of h-SIS/EP* increased, the number of active hydrogen bonds in the cured adhesives, as well as the fraction of the soft I phase, increased; hence, h-SIS/EP* with larger ω'_{TPE} exhibited a higher impact strength.

Conclusions

In this study, the authors attempted to prepare structural adhesives that are tougher than rigid and inflexible epoxy based adhesives by mixing EP with SIS. In addition, the authors aimed to prepare structural adhesives that are tougher than adhesives containing SIS by mixing EP and h-SIS with hydrogen bonding groups in the I block of SIS. The compatibilities between EP and polymers were evaluated using optical microscopy. A homogeneous optical image was observed in the mixtures of SIS and EP, suggesting that SIS was macroscopically dispersed in the EP due to the good mixing of EP with an S block in SIS at the nanometer scale. Hydrogen bonds were confirmed in h-SIS and h-SIS/EP* by FT-IR spectroscopy. In the TEM images of SIS/EP* and h-SIS/EP* after curing, domains of the mixed S/EP* phase on the order of tens of nanometers and huge EP* domains with diameters of one hundred to several hundreds of nanometers were observed, where these domains were dispersed in the

I or hydrogen bonded I matrix phase. According to DMA measurements, the tan δ of SIS/EP* at room temperature was larger than that of neat EP*, and the tan δ of h-SIS/EP* at room temperature was larger than that of SIS/EP*, suggesting that h-SIS/EP* can more easily dissipate stress compared to neat EP* and SIS/EP* due to the reversible dissociation/reassociation of hydrogen bonds, as well as the presence of the soft I phase.

The lap shear strength of SIS/EP* decreased as ω'_{SIS} increased, while the peel and impact strengths of SIS/EP* were approximately 1.2 to 1.4 and three to 11 times higher than those of EP*, respectively. These results were probably caused by the dissipation of the stress applied to the cured adhesives by the soft I component. Meanwhile, the lap shear, peel and impact strengths of h-SIS/EP* were higher than those of SIS/EP* with similar ω'_{TPE}. In particular, the peel and impact strengths of h-SIS(26)/EP* were 2.1 and 22 times higher than those of neat EP*, respectively. The reasons why h-SIS/EP* was tougher than neat EP* and SIS/EP* were not only the stress dissipation from the flexible I component, but also the increase in active physical crosslinks due to the formation of the hydrogen bonds in h-SIS and the efficient stress dissipation originating from the reversible dissociation/reassociation of the hydrogen bonds. Therefore, the mixing of SIS, which is low cost (approximately several U.S. dollars per kg^{-1}), with epoxy based adhesives efficiently enhanced the adhesive properties of epoxy structural adhesives. In other words, SIS/EP adhesive exhibited good physical properties, while keeping the preparation cost low. In particular, the mixing of a hydrogen bonded thermoplastic elastomer, h-SIS instead of SIS, with epoxy based adhesives significantly enhanced the peel and impact strengths of the cured adhesives compared to neat EP*, while maintaining the lap shear strength. The cured h-SIS/EP* also exhibited higher lap shear strength, peel strength and impact resistance than the cured SIS/EP*. Moreover, h-SIS can be synthesized on a large scale without high cost by optimizing the synthetic scheme. Thus, the cost of h-SIS/EP could be reasonable. In the future, the authors will investigate the fatigue resistance, long term stability and durability of SIS/EP* and h-SIS/EP* in detail. Application of the structural adhesives developed in this research to automobiles and other vehicles is expected to contribute to their weight reduction, reduced consumption of fuels and lower exhaust emissions, contributing to the attainment of a net zero carbon society.

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Reduction of zinc oxide in 10 compounds of a model passenger car radial tire

by Majid Aman-Alikhani, consultant

Zinc plays a vital role in the body of living organisms; however, its excess is problematic in nature. One of the main ways in which zinc enters the environment is through the impact of rubber articles, especially automobile tires (refs. 1 and 2). After the discovery of vulcanization in 1839, zinc oxide (ZnO) was one of the first materials used in the rubber industry. ZnO was apparently used initially as a filler, especially for light colored compounds. But gradually it found its place in the compound curing systems and alongside stearic acid as an activator to increase the vulcanization rate and improve crosslinking efficiency (refs. 3 and 4); and today, common compounds in the rubber industry use ZnO usually between 3 and 5 phr for the optimal properties (ref. 5).

Apart from participating in curing reactions, ZnO also plays other roles in compounds, including excellent protection of white and colored compounds by absorbing ultraviolet rays (sunlight) and increasing adhesion of rubber to metals (e.g., steel cord) after vulcanization (ref. 6).

At least half of zinc oxide consumption is in the rubber industry, mainly in tire production (ref. 7). One of the problems with ZnO is its hydrophilic nature, which is not compatible with hydrophobic elastomers; so when formulating compounds, it is necessary to use a larger amount to achieve a homogeneous distribution in the compounds. In addition, since not all of ZnO participates in the curing reactions, some of it remains free in the cured tire and rubber articles (ref. 8).

In 1995, Scandinavian experts proved that the heavy and dangerous element zinc enters surface waters from the primary zinc oxide due to abrasion, contact and immersion of rubber parts, especially tires, and causes poisoning of aquatic animals. There is also a possibility that this element will eventually reach the bodies of fish and humans (ref. 9). This finding caused some concern regarding the use of ZnO in various countries. For example, the U.S. Environmental Protection Agency (EPA) has set a maximum allowable level of zinc in drinking water of 5 mg/L and a maximum allowable concentration of dissolved zinc in water of 120 µg/L (ref. 10).

Among the solutions to reduce or eliminate zinc oxide from compounds, one can note the use of other metal oxides, some special activators and nano zinc oxide. Of course, the use of other oxides brings problems such as the confusion of properties, high price and toxicity of some of them. Also, with the current machinery available in the rubber industry, the use of nano ZnO is practically difficult or impossible, and its price is also significant (ref. 11).

Despite the long history of sulfur vulcanization, there is still no consensus on its mechanism because the number of reactants in the compounds is relatively too large, and many complex interactions are possible among them. This is what makes the replacement of zinc oxide very difficult. In any case, some have proposed this mechanism as ionic, or as radical; and finally, some have proposed it as a combination of these two methods (ref. 12). Also, the majority of researchers believe that initially, complexes are formed from the various materials of the curing system (sulfur, accelerators, activators, etc.), which then react with the polymer chains in such a way that, overall, curing occurs at a suitable speed (ref. 13). Perhaps one of the best mechanisms has been proposed by Morrison and Porter, in which there are the following four steps:

- An active complex is formed from the reaction between zinc oxide, stearic acid and the accelerator
- This complex reacts with sulfur to produce a sulfurating agent
- The active agent reacts with the polymer chains to form a curing intermediate with polysulfide bridges
- Finally, by interaction between the polymer chains, the sulfur bridges are shortened and the final crosslinking state results (refs. 14 and 15)

Experimental

Raw materials

All raw materials used in this work were from the current materials in a tire factory production line.

Recipes

The 10 recipes in this work were originally from the compounds of a 185/65 R 14 economic all-season tire. In each compound,

Table 1 - main ingredients of compounds

Compound	*Tread, cap*	*Tread, base*	*Sidewall*	*Anti-abrasion*	*Innerliner*	*Bead*	*Apex*	*Carcass*	*Belt*	*Cap ply*
NR		80	50	60	20	30	70	50	90	80
SBR	100	-	25	-	20	70	-	30	-	-
BR	-	20	25	40	-	-	30	20	10	20
BIIR	-	-	-	-	60	-	-	-	-	-
N326	-	-	-	-	-	-	-	-	70	50
N339	85	50	30	70	-	-	65	-	-	-
N660	-	-	-	-	50	80	-	50	-	-
Silica	-	-	-	-	-	-	-	-	10	10
China clay	-	-	-	-	30	20	-	-	-	-
Oil	20	8	10	5	15	15	5	8	5	8

without any other changes, the amount of ZnO was reduced by half phr-half phr, and then tests were conducted until getting the best overall properties. Table 1 lists the polymer base, fillers and oil of each compound.

Mixing

The mixer from Kobe Company, Japan, was a two-liter type using two speeds of 50 and 80 rpm. All compounds were produced in two stages (masterbatch and final), with 80 rpm used for the masterbatch stage and 50 rpm for the final stage.

In all masterbatch stages, the polymer(s) and all other ingredients except oil were added to the mixer first, and mixing continued under ram pressure up to 90°C. At this temperature, oil was added to the mixer and mixing continued up to 110°C. Then, the compound was mixed up to 125°C, and finally up to 145°C under ram pressure and discharged onto a laboratory two-roll mill (except for the innerliner masterbatch compound, which was discharged at 135°C). On the mill, the operation continued until the compound had a uniform appearance. For each compound, the interval between each masterbatch stage and the final one was one night.

For the final stage of all compounds, all ingredients, along with the masterbatch, were added to the mixer at the beginning; and for all of them, four steps of 50 seconds mixing under ram pressure were applied. Each compound was discharged onto a two-roll mill, and milling continued until a homogeneous and uniform appearance was achieved.

Tests

The interval between production and consumption of the compound for the tests was one night.

The laboratory tests and their reference standards were:

- Mooney viscosity: ML (1+4)/100°C, ASTM D 1646
- Rheometer: MDR 160°C in all the compounds for 20 minutes except for the innerliner compound which was tested for 30 minutes, ASTM D 5289

For the following tests, the samples were cured based on ASTM D 3182 at 145°C, and the rheometer time was t95 @ 145°C. In each test, the median of four measurements was used to judge the test results:

- Tensile strength tests: ASTM D 412
- Hardness: ASTM D 2240
- Resilience: D 7217 Method B

Results and discussion

For each compound, the zinc oxide phr in the initial recipe was taken as a reference and then, without any other changes, the amount of the material was reduced half part by half part until it reached 2 phr. This way, a large number of data were generated.

Table 2 - properties difference between the innerliner reference and the experimental compounds in %

ZnO phr	3.5	3	2.5	2
ML (1+4)/100°C	-9	+5	+2	0
T90/MDR 160°C	+5	+8	+1	+10
Ts2/MDR 160°C	+15	+5	+3	+6
Tensile strength	-13	-11	-3	-9
M300%	-9	-15	-5	-21
Elongation	+25	+5	-5	+15
Hardness	-19	-9	-3	-7
Rebound resilience	-16	-18	-5	-12
Total (sum of the absolute values)	111	76	27	80
Total/8	13.9	9.5	3.4	10.0

For an easier and more accurate judgment, in each change for each compound, each property was compared with the same property of the reference compound as a percentage. Then, for each change in each compound, the sum of the absolute values of these percentage differences was calculated, and the result was divided by 8. It is clear that the smaller this final number, the closer the properties of that test compound are to the properties of its reference compound.

In table 2, the difference in the properties of the test compounds compared to the reference one, the sum of the absolute values of the differences in these properties for each test compound and the result of dividing this sum by 8 are given as an example for the innerliner compound initially including 4 phr ZnO. As indicated in the last row of the table, the smallest difference in properties among compounds with less zinc oxide than the reference compound is related to 2.5 phr of the material.

With these calculations, table 3 was obtained, in which the best experimental condition of each compound with the lowest amount of zinc oxide was determined.

As can be seen from table 3, theoretically between 25% and 60% of the ZnO reduction was achieved among these compounds. Of course, to implement these reductions in an actual tire production line, it is necessary to conduct more laboratory tests, and also to verify and modify the final optimized compounds in the real tire performance conditions.

Conclusion

For all 10 compounds of a typical passenger car radial economic tire, it is possible to reduce the zinc oxide by at least 33% without any significant decrease in the important laboratory properties. Obviously, in order to continue the work until an executive decision is made to enter in the production scale, it is necessary that after completing the laboratory tests, test com-

Table 3 - theoretical amount of ZnO reduction for each compound

Compound	*Tread, cap*	*Tread, base*	*Sidewall*	*Anti-abrasion*	*Innerliner*	*Bead*	*Apex*	*Carcass*	*Belt*	*Cap ply*
Initial ZnO phr	3	4	5	5	4	6	5	5	8	6
Minimum optimal phr	2	2.5	2	3	2.5	2.5	3.5	2.5	6	3.5
% decrease	33	38	60	40	38	58	30	50	25	42

pounds are prepared on the production line, and full tests are carried out on the resulting test tires.

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Latex foam and its applications

by Boontham Nithi-Uthai, consultant

Latex foam was industrially created in 1929 by Dunlop Rubber (ref. 1). The latex was foamed with fatty acid soap and gel by using sodium silico fluoride. The process is now known as the Dunlop process. The method for making this type of foam can be a simple cake mixture. The mold for foam is also a simple mold made from aluminum, stainless steel or resin, or even plaster of paris. Vulcanization can utilize a simple steam oven or hot air oven, or sometimes self-curing takes place if using the correct type and amount of sulfur and accelerators.

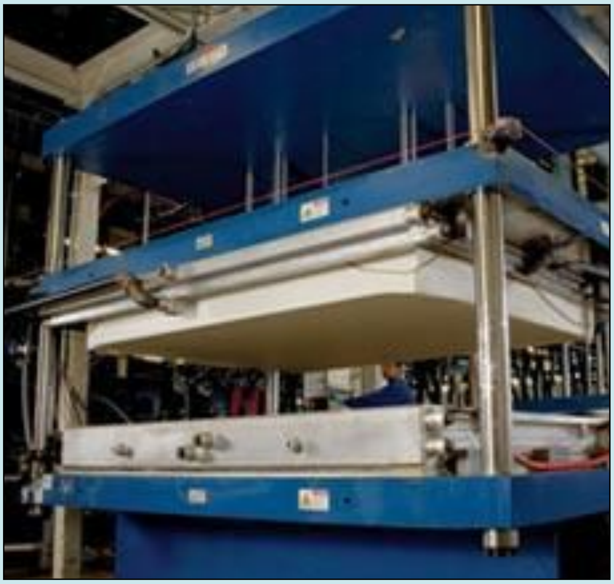
The primary benefit of the Dunlop process is the low cost of investment. But there are also several disadvantages, including product loss due to foam collapse, and latex foam scraps can amount to around 18% to 20% of the total amount of product. However, the Dunlop process is still the main one used today in the latex foam industry. The typical products of this process are mattresses and pillows.

The second process was created by Sam Kay & Co. in 1931 (ref. 2). Latex was foamed with fatty acid soap and added ammonium salt, such as ammonium acetate. The foam was then gelled by heating in an oven. This is a heat gelling process, and is also known as the Sam Kay process. Since heating is the main function to gel this type of foam, the latex foam has to be thin to facilitated the gelling process. Primary applications of this process include the manufacturing of masks, carpet underlay and shoe soles.

The third process is called the Talalay process (figure 1), named after the inventor, Josef Anton Talalay, who patented the process in 1935 (ref. 3). In that patent, vacuum was used to expand latex foam to fill the mold. However, the patent was not sufficient to obtain good foam at that time. Three more patents were needed to complete the process.

- Use very cool temperatures to freeze the latex foam (ref. 4), 1946
- Use carbon dioxide gas to gel the foam (ref. 5), 1950
- Use mold pins for the transfer of heat in freezing and vulcanizing (ref. 6), 1953

Figure 1 - latex mold for a mattress using the Talalay process



It took 18 years before the Talalay process was completed. There are several benefits of the Talalay process, such as the very low density of the latex foam, no foam collapse and no foam scraps; i.e., all good foam is produced. Typical applications of this process include mattresses and pillows. But there are also several disadvantages, such as high investment and high energy cost due to freezing and heating requirements.

During the early 1960s, about 35% of all the latex foam produced in North America was manufactured by the Talalay process (ref. 7). In 1973, there was an oil crisis. In 1960, the oil price was only $1.33/barrel. In 1973, the oil price rose to $11/barrel, and in 2023, the oil price was over $90/barrel (ref. 8).

Also in 1974, the method for the continuous production of a foamed polyurethane (PU) slab was established (ref. 9). Most of the latex foam factories in the U.S. turned to PU foam factories. In the United States, only one producer, Latex Foam Products, manufactures foam using this process (ref. 7). In 2015, the company's name was changed to Talalay Global (ref. 10).

In Europe, there is only one latex foam manufacturer that uses the Talalay process: Radium Foam in The Netherlands. Radium Foam was originally Vita Foam in the U.K., founded in 1961. It moved to The Netherlands in 1991 and was renamed Radium Foam (ref. 11).

The fourth latex foam process was invented by Crown Rubber Company in 1966 (ref. 12). This process is called the Crown process. The process uses very stable soaps like sulfate soap, succinate soap or alkane sulfonated soap. These soaps are used in high quantities of 7-12 parts/100 latex. The latex foam is foamed in a normal way and applied as a thin layer on a substrate with a thickness up to 20 mm. The surface of the foam is then formed by drying it with hot air or an infrared heater. The total foam continues to be heated with hot air until vulcanized. There is no gelation of the foam in this process. Thus, it is called the no-gel process. Typical applications for this process include carpet underlay (figure 2) and thin foam for spring mattresses.

New applications of latex foam

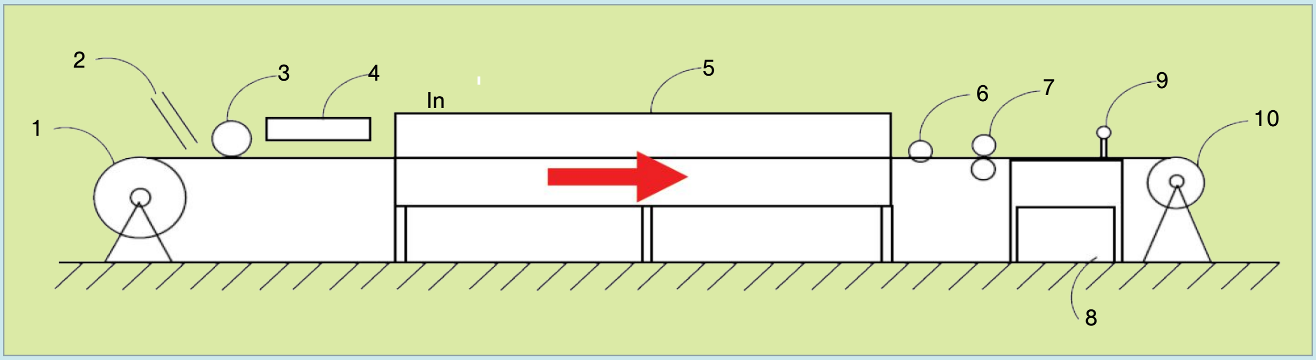
Applications for latex foam depend on its useful properties. There are many materials that can be replaced by latex foam, which can be better than the original material.

Replace use of silicone products

For artificial breasts, instead of the silicone breast which is soft and heavy, latex foam can be made in the correct shape and is lighter. With a minor change in the structure, one can get a breast cancer screening model.

Silicone products are widely use as stitching practice pads.

Figure 2 - carpet underlay using the Crown process



But silicone pads are too tough. The feeling of the stitching pad is not like real human tissue. By using a latex foam coating on fabric and spraying a thin layer of pre-vulcanized latex, it can be used for stitching practice pads which give a feeling very similar to stitching on real body tissue.

Pillow and mat pads used in hospital rooms are made from silicone rubber. The feeling of these silicone products can seem dense and not soft enough to be comfortable for the patient after a long operation. The pressure which a patient will apply on these silicone products is about 100-110 mm Hg. By using latex foam with the similar shape of a silicone pillow and mat pad, the body pressure on the pillow and mat pad is much lower than that obtained from silicone products. Usually, the pressure is normally less than 65 mm Hg, which is said to result in superior blood circulation in the body.

Replacement of plastics

Normally, an imported cardiopulmonary resuscitation (CPR) manikin body is made from plastic. The mechanism for the compression of the body uses a spring. By making a new manikin totally with latex foam, one can select the density or hardness of the foam in any position of the manikin. For the heart, a latex foam portion will need about 20-25 kg to compress down to the depth of 5 cm. The rest of the CPR manikin is also made from latex foam which has a lower density than the heart part. This is a new application of latex foam, and has been patented in several countries (refs. 13-17).

Foam use for absorption of liquid

Latex foam has porosity which can absorb liquid. If some chemicals like methyl eugenol are applied to latex foam, the foam will slowly release the smell of methyl eugenol. This method can be used as a rubber fly lure. Or latex foam can be used to absorb water in injection trainer pads. This is also a new item which has been patented in Germany (ref. 18). With the addition of a latex tube on top of this injection trainer pad, one can obtain a blood vessel injection trainer pad, as well (refs.19 and 20).

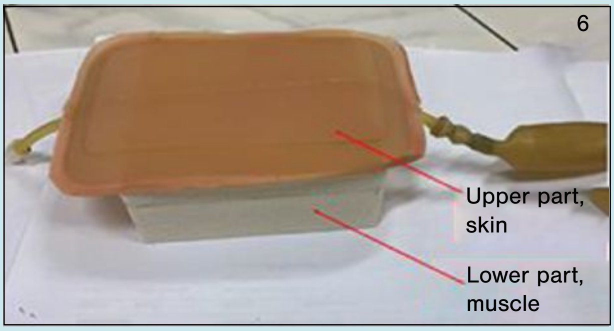
Latex foam use for an anti-bedsore mattress

In 1930, E. Landis found that pressure in the blood capillaries was approximately 32 mm mercury (ref. 21). In 1974, S.M. Dinsdale showed that if there is pressure higher than 64 mm mercury on body tissue for more than two hours, permanent tissue damage can occur (ref. 22). There are two key phrases in the work of Dinsdale. One phrase is “pressure not to be more than 64 mm mercury,” and the other phrase is “two hours maximum with continuous pressure.” Since then, the key words “two hours” are kept as the target maximum; never press any part of the body longer than two hours.

In 1988, Jacques Busseuil patented an inflatable anti-bedsore mattress with alternately inflated air sacs (ref. 23). In 1993, David Jurus (U.S.) and Kevin Jurus (U.S.) patented the pressure relief bed (ref. 24). The bed has two racks which move alternatingly side by side. These two ideas are the same, but the cost of making air sacs is much cheaper than producing the moving bed rack. Hence, only the alternately inflated air sacs are widely used. However, as the support surface for the whole body is only half the size of the total body, the surface pressure obtained by this type of support is much greater than 64 mm Hg. Sometimes, the mattress from this alternating air sac does not help to relieve bedsores.

Anti-bedsore mattresses from latex foam (figure 3) were produced using the key words, “pressure not to be more than 64 mm Hg.” Latex foam can be made with different softnesses, depending on how much air has been introduced into the latex. By combining latex foam layers of three different densities, an anti-bedsore mattress with body pressure less than 64 mm Hg was created. The product was so successful that this innovation was patented in many countries (refs. 25-37).

Figure 3 - injection trainer pad with injection to blood vessel, skin and muscle



Latex foam contours to body shape

For those who sit in a wheelchair, their body must move once every 15-30 minutes (ref. 39). This is because of the weight of the half body that is on the seat. It is not the same as when lying in bed, where the whole body weight is more evenly distributed. Hence, the pressure while sitting is much higher than when lying on the bed. In this situation, the size of the latex foam is relatively small when compared to the whole body. However, by shaping the latex foam according to the contour of the person who sits on it, the whole area of the seat can support the body at the same time. Also, the modulus of the latex foam must be a bit high so that it can really support the weight of the person who sits on it. By doing it this way, one can get a latex foam seat with low pressure on the bottom of the patient. This product has been successfully produced and patented (ref. 40). With some improvement by adding a hole approximately 12.5 cm in size in the center of the seat, latex foam seats for patients with hemorrhoids and perineal wounds have been designed (refs. 41 and 42).

Casting of latex foam for an anti-choke trainer

Latex foam can be produced by casting the latex compound in a plaster of paris mold. However, since there is specific timing in the gelation, then it is necessary to know the quantity of latex foam to be used and the rotation time before gelling can completely take place. An example of this application is a product used in making an anti-choke trainer.

Compounding for extra properties

Latex foam can be formulated to have extra properties by adding chemicals to prevent destabilizing its liquid state. For example, if a fire retardant chemical is added into the latex foam, the latex foam will have fire retardant properties. This is useful for latex foam used in hospitals and tall buildings.

Many kinds of fire retardant chemicals are available, such as melamine, arsenic, phosphate and aluminum compounds, expanded graphite, etc. Or, if chemicals are added that emit electrons or negative ions, such as tourmaline powder, the final latex foam will emit negative ion radiation from the foam. But this type of latex foam is banned in Korea. And charcoal powder is sometimes added to latex foam to provide a deodorant property, etc.

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- Material / Product Validation
- Hose Burst & Fatigue Cycling
- Custom Engineered Solutions
- Electrical Testing Material/Part

TESTING SERVICES

- Compression Stress Relaxation (CSR & CCSR)
- Carbon Arc
- Xenon Weathering
- Fluid Immersions
- Fogging
- Abrasion Resistance
- Flex & Fatigue Resistance
- Aged vs. Unaged Properties
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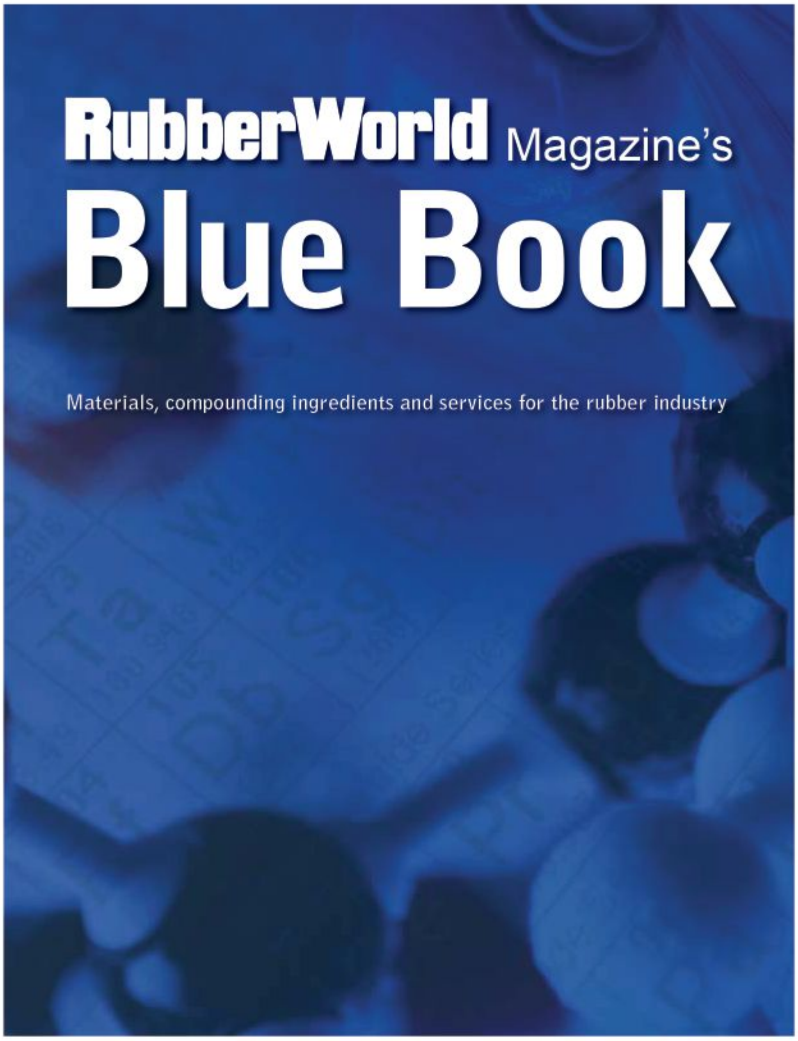

RubberWorld Magazine's
Blue Book

Materials, compounding ingredients and services for the rubber industry

LSR 2025 conference includes R.D. Abbott

R.D. Abbott is participating in LSR 2025 as an organizer, exhibitor, sponsor and presenter. LSR 2025, a global event for professionals in the liquid silicone rubber (LSR) industry, will be held June 16-19 at the Hilton Irvine/Orange County Airport in Irvine, CA. The event is organized by Executive Conference Management, which is offering a discount to attendees who register before May 2.

Tom Jenkins, R.D.Abbott's vice president of business development, is a member of LSR 2025's organizing committee. Other committee members include Steven Broadbent of ACH Solution USA; Amos Golovoy of AG Research; Juergen Giesow of Arburg; Kurt Manigatter of Elmet GmbH; Markus Landl of Engel; Mike Fil of Extreme Molding; Geri Anderson and Rick Finnie of M.R. Mold & Engineering; Daniel Schoelmberger of Rosti; and Oliver Franssen of Sigmasoft.

R.D. Abbott will co-exhibit with Dow, a supplier partner, and with NovationSi, RDAbbott's manufacturing subsidiary

Rubber Group News

The **Chemical Institute of Canada, Rubber Chemistry and Technology Division**, will hold a conference June 15-19 in Ottawa, Ontario, Canada. Further information is available at www.cheminst.ca.

The **Detroit Rubber Group** will hold a Tech and Teardown at Caresoft event in Livonia, MI on June 10. The DRG will hold a fishing outing July 10 at the Toledo Beach Marina in La Salle, MI. Details on both events are available at www.rubber.org/detroit-rubber-group-inc.

The **Mexico Rubber Group** will hold the course, Rubber Compound Engineering, instructed by Luis Mayorga, on June 5 at the Rubber Chamber facilities in Mexico City, Mexico. The MRG will hold the course, Chemicals for Rubber Protection, instructed by Jose Gazano, at the same location on July 24. Details are available at www.rubber.org/mexico-rubber-group.

The **Ohio Rubber Group** will hold its early summer golf outing on June 18 at the Brookledge Golf Club in Cuyahoga Falls, OH. Further information is available at www.ohiorubbergroup.org.

The **Southern Rubber Group** will hold its summer technical meeting June 22-24 at the Hilton, Myrtle Beach, SC. Details are available at www.southernrubbergroup.org.

that specializes in custom silicone solutions. Rick Ziebell, Technical Fellow and vice president of technology for R.D. Abbott, will present, “Electrically conductive silicones using carbon-nanotube matrices,” on Tuesday, June 17. R.D. Abbott and NovationSi have developed new silicone compounds with patented carbon nanotube materials said to provide high electrical conductivity with low loading levels that were previously unobtainable in silicone rubber. Articles fabricated from these advanced silicone compounds form an electrical circuit where a low voltage can deliver a stable, selectable current across the article’s shape.

Ziebell’s presentation will examine ideal applications, product types, physical properties and fabrication methods for these new materials. He will also cover electrical circuit characteristics, testing and performance methods, design considerations for finished articles and long term electrical behavior.

Two of RDAbbott’s supplier partners will also provide technical presentations at LSR 2025. On Tuesday, June 17, Leanna Foster, research investigator for DuPont Liveo Healthcare Solutions, will present, “Advancing healthcare innovation through material selection and manufacturing excellence.” Foster will examine how low viscosity silicone formulations are enabling the creation of intricate components, such as thin-walled designs, while supporting faster injection speeds.

On Tuesday, June 17, Jason Reese, a senior scientist for Dow, will present, “Driving sustainability and circularity in silicone elastomers.” Reese will examine environmental sustainability across the silicone value chain, from innovations in silicon metal processing and silicone fabrication to advancements in recycling technologies. His presentation will emphasize the importance of life cycle assessment in analyzing the product carbon footprint.

Additional technical presentations will be held on Wednesday, June 18. A live demonstration by Arburg at the company’s Irvine, CA, facility will take place on Thursday, June 19.

Further information on LSR 2025 is available at www.lsrconference.com.

Calendar

Rubber Division
American Chemical Society
Future
Meetings/
Expos
2025
Cleveland September 8-11

2026
Louisville Sept. 28 - Oct. 1
www.rubber.org

University of Akron, Akron Polymer Training Services, ASTM Rubber Testing: Selecting, Performing and Interpreting ASTM Rubber Test Methods online course, www.uakron.edu/apts/ - April 21-22.

Rubber Division, ACS, Processing and Testing of Rubber course, www.rubber.org - April 24.

Ohio Rubber Group, spring technical meeting, University of Akron, Akron, OH, www.ohiorubbergroup.org - April 29.

Leistritz Extrusion, Twin Screw Devolatilization Workshop, Branchburg, NJ, www.leistritz-extrusion.com - April 29-30.

Mettler Toledo, Volumetric Karl Fischer Titration webinar, www.mt.com - April 30.

Rubber Division, ACS, U.S. Regulatory Compliance in the Rubber Industry webinar, www.rubber.org - April 30.

Emissions Analytics, Tire Emissions and Sustainability USA 2025, Irvine, CA, https://conferences.emissionsanalytics.com/tyres-us25 - April 30 - May 1.

May

University of Akron, Akron Polymer Training Services, Rheological Theories and Their Direct Applications in the Polymer Industry online course, www.uakron.edu/apts/ - May 5-7.

Association for Rubber Products Manufacturers, Product Liability Training, Indianapolis, IN, www,arpminc.org - May 6-8.

University of Akron, Akron Polymer Training Services, Rubber Injection Molding online course, www.uakron.edu/apts/ - May 7-9.

University of Akron, Akron Polymer Training Services, Structure/Property Relationships in Polyurethanes online course, www.uakron.edu/apts/ - May 8-9.

TechnoBiz, Synthetic Rubber Conference 2025, Bengaluru, India, https://conference.technobiz.org - May 9-10.

Association for Advancing Automation, Automate 2025 Show and Conference, Detroit, MI, www.automateshow.com - May 12-15.

Association for Rubber Products Manufacturers (ARPM), Product Liability Training, www.arpminc.com/events - May 13-15.

University of Akron, Akron Polymer Training Services, Rubber Technician Training online course, www.uakron.edu/apts/ - May 14-16.

Informa Markets Thailand, Plastics & Rubber Thailand, BITEC, Bangkok, Thailand, www.plasticsrubberthailand.com - May 14-17.

University of Akron, Akron Polymer Training Services, X-ray Diffraction Characterization of Polymers, National Polymer Innovation Center, Akron, OH, www.uakron.edu/apts/ - May 20.

UK Industry Events Ltd., CHEMUK 2025, NEC, Birmingham, U.K., www.chemicalukexpo.com - May 21-22.

University of Akron, Akron Polymer Training Services, Polymer Compounding, Formulating and Testing of Plastics, Rubber, Adhesives and Coatings online course, www.uakron.edu/apts/ - May 21-23.

University of Akron, Akron Polymer Training Services, Introduction to Polymer Characterization, National Polymer Innovation Center, Akron, OH, www.uakron.edu/apts/ - May 22.

University of Akron, Akron Polymer Training Services, Introduction to Polymer Chemical Characterization, National Polymer Innovation Center, Akron, OH, www.uakron.edu/apts/ - May 26.

Applied Market Information, GreenPlast 2025 Exhibition and Conference for a More Sustainable Plastics and Rubber Industry, Milan, Italy, www.greenplast.org - May 27-30.

June

University of Akron, Akron Polymer Training Services, Essentials of Rubber Science and Technology online course, www.uakron.edu/apts/ - June 2-4.

University of Akron, Akron Polymer Training Services, Rubber Extrusion Technology online course, www.uakron.edu/apts/ - June 3.

ACI Europe, Biobased Coatings Europe 2025, Madrid, Spain, www.wplgroup.com/aci/event/biobased-coatings-europe - June 4-5.

Mexico Rubber Group, Course: Rubber Compounds Engineering, Rubber Chamber Facilities, Mexico City, Mexico, www.rubber.org/mexico-rubber-group - June 5.

University of Akron, Akron Polymer Training Services, Rubber Compounding Materials and Methods online course, www.uakron.edu/apts/ - June 5-6.

Detroit Rubber Group, Tech & Teardown at Caresoft event, Livonia, MI, www.rubber.org/detroit-rubber-group-inc - June 10.

University of Akron, Akron Polymer Training Services, Extrusion, Compounding and Applications in the Food, Medical Devices and Pharmaceutical Industries online course, www.uakron.edu/apts/ - June 10-11.

University of Akron, Akron Polymer Training Services, Understanding Raw Materials, the Building Blocks of Rubber Compounding online course, www.uakron.edu/apts/ - June 11.

University of Akron, Akron Polymer Training Services, Rubber Compounding for Performance online course, www.uakron.edu/apts/ - June 12-13.

Chemical Institute of Canada, Rubber Chemistry and Technology Division, Canadian Society of Chemistry (CSC) Conference, Ottawa, Ontario, Canada, www.cheminst.ca/about/cic - June 15-19.

University of Akron, Akron Polymer Training Services, Solving Problems in Rubber Compounding and Processing online course, www.uakron.edu/apts/ - June 16.

Executive Conference Management, LSR 2025, Irvine, CA, www.lsrconference.com - June 16-19.

TechnoBiz, Middle East Rubber and Tire Expo, Sharjah, United Arab Emirates, https://expo.technobiz.org - June 17-19.

Ohio Rubber Group, early summer golf outing, Brookledge Golf Club, Cuyahoga Falls, OH, www.ohiorubbergroup.org - June 18.

University of Akron, Akron Polymer Training Services, Polymer Science Based Product Development for Engineers and Scientists online course, www.uakron.edu/apts/ - June 18-20.

University of Akron, Akron Polymer Training Services, Aircraft Tire Technology online course, www.uakron.edu/apts/ - June 19.

Southern Rubber Group, summer technical meeting, Hilton, Myrtle Beach, SC, www.southernrubbergroup.org - June 22-24.

Rubber Division, ACS, WORD (Women of Rubber Division) Conversation (via Zoom), www.rubber.org - June 25.

July

Latin Expo Group, 2025 Latin Tire and Auto Parts Expo, Panama Convention Center, Panama, Republic of Panama, www.latintyreexpo.com - July 9-11.

Detroit Rubber Group, fishing outing, Toledo Beach Marina, La Salle, MI, www.rubber.org/detroit-rubber-group-inc - July 10.

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American Chemical Society
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NEVER STOP LEARNING!

CONVENIENCE: Most all our learning opportunities are virtual only with some in-person courses at our partner's locations.

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Visit rubber.org/training for details about these courses, including full descriptions and pricing.

UPCOMING LEARNING OPPORTUNITIES

- **April 15, 2025**
  Webinar: *Communicate & Captivate – Your Guide to Engaging Connections*
- **April 17, 2025**
  Webinar: *The Function & Selection of Ester Plasticizers*
- **April 24, 2025**
  Course: *Processing & Testing of Rubber*
- **April 30, 2025**
  Webinar: *U.S. Regulatory Compliance in the Rubber Industry*
- **May 8, 2025**
  Webinar: *Global Rubber Technology – Processes, Current Status & Future Trends*
- **May 15, 2025**
  Course: *An Introduction to Continuous Vulcanization*
- **May 21, 2025**
  Webinar: *Case Studies in Failure Analysis*
- **June 2, 2025**
  Course: *Compounding Fluoroelastomers*
- **June 4, 2025**
  Course: *Thermoplastic Elastomers – From Fundamentals to Novel Applications*
- **June 5, 2025**
  Course: *Mastering Elastomer Molding – Reduce Costs & Improve Production Efficiency with Simulation*
- **June 9, 2025**
  Webinar: *Strength & Endurance in Rubber*
- **June 11, 2025**
  Course: *Carbon Black & Non-black Fillers*
- **June 12, 2025**
  Course: *Sustainability in the Rubber Industry*
- **June 18, 2025**
  Course: *Scientific Rubber Molding*
- **June 25, 2025**
  Webinar: *Maintaining High Performance in Challenging Testing Laboratories*
- **June 26, 2025**
  Webinar: *How to Extend Lifetime of Elastomers & Rubber Products*

All webinars are FREE for Rubber Division, ACS Members and all Rubber Division, ACS courses are FREE for undergraduate Student Members (discount for masters & graduate Student Members)!

THV alternatives for automotive use

To meet the demand for high performance automotive materials, Fluon+ flexible compounds and Fluon LM-ETFE resins are offered as alternatives to the polymer THV. Both fluoropolymers are said to exhibit exceptional chemical resistance and strong mechanical properties comparable to those of THV.

Fluon+ flexible compounds and Fluon LM-ETFE are said to be ideal for demanding applications such as tubing, film and wire and cable insulation where flexibility, temperature resistance and durability against harsh chemicals are critical.

Fluon+ flexible compounds are ETFE based blends with fluoroelastomers, offering performance and processing benefits similar to THV, according to the company. These compounds are said to retain the desirable properties of ETFE, while providing flexibility greater than other fluoropolymers. They are also melt processable using conventional extrusion from pellet feeds. In addition, Fluon+ grades offer higher temperature resistance and lower processing temperatures than standard ETFE, according to the firm.

Fluon LM-ETFE modified resins have lower melting points, enabling processing temperatures up to 50°C lower than regular ETFE. This expanded temperature range is said to improve processability, flexibility and strength, allowing continuous use at temperatures up to 180°C.

Fluon LM-ETFE is said to offer superior heat and chemical resistance, enhanced thermal stability, reduced susceptibility to stress cracks and greater transparency compared to traditional ETFE. It is said to be an ideal choice for wire and cable coatings and hose and tube due to its outstanding electrical insulation properties and mechanical strength. (*AGC Chemicals Americas*)

www.agcchem.com

Automotive compounds

This global leader in polylactic acid (PLA) bioplastics has joined Benvic, a compounding expert, to drive the adoption of sustainable Luminy PLA based compounds. This collaboration is said to expand the use of plant based solutions in durable applications such as automotive, healthcare and medical, cosmetics packaging, appliances, and electric and electronics. Through the partnership, Benvic's Plantura portfolio, which incorporates Luminy PLA, is said to offer biobased alternatives with a significantly lower carbon footprint. These solutions are said to provide sustainable alternatives to conventional materials such as ABS, PS and PP compounds. By compounding Luminy PLA with other biobased materials, the collaboration is said to enhance the functionality and performance of PLA, supporting the global transition to eco-friendly manufacturing practices. (*TotalEnergies Corbion*)

www.totalenergies-corbion.com

Gasketing sealant range

As the automotive industry pivots towards electrification, OEMs are said to be seeking new solutions to enable them to incorporate more electronic components in their product designs, sustainably and effectively. This company offers an extensive portfolio of high performing innovations. Its latest development is Loctite AA 5885, a one-part (1K) polyacrylate UV curable solution for cured-in-place gasketing applications created to seal electronic units against high temperatures and harsh environmental conditions. (*Henkel*)

www.henkel.com

Fluoroelastomer products

Tecnoflon fluoroelastomers (FKM) and perfluorelastomers (FFKM) are said to be highly resilient synthetic rubbers that retain critical properties in chemically aggressive environments at extreme temperatures. Unlike traditional elastomers based on carbon-hydrogen or silicon-oxygen bonds, Tecnoflon products are said to derive their uniquely superior properties from the strength of carbon-fluorine bonds. Tecnoflon FKM and FFKM are also highly resistant to UV light and ozone, according to the company. O-rings, seals and gaskets made from Tecnoflon FKM and FFKM retain their shape, strength and flexibility at extreme temperatures. They are said to exhibit low permeability to a broad range of fluids and chemicals, including gases, oils, lubricants, fuels and additives. This makes them highly sought after for critical sealing applications in semiconductor, oil and gas, automotive, chemical processing and healthcare industries where high purity and long service life are essential, according to the company. (*Vanderbilt Chemicals, LLC*)

www.vanderbiltchemicals.com

Light transmissible TPE

This global manufacturer of custom thermoplastic elastomers offers Light Effect TPE, an advanced light transmissible material. It is said to be an ideal material for consumer electronics and automotive interiors, combining aesthetics and performance. Whether used in electric vehicle (EV) interiors, smart home devices or consumer electronics, it consistently delivers reliability, while its soft-touch property adds a premium feel to the design of a product, according to the company. Exceptional light transmissibility is said to enhance automotive and electronic components with an ambient glow. (*Kraiburg TPE Technology*)

www.kraiburg-tpe.com

Patented seal design

Patented sealing geometry is designed to support original equipment manufacturers (OEMs) and manufacturers of engines ranging from small electric cars to commercial vehicles right at the development stage. In-wheel motors for electric vehicles are said to offer numerous benefits: Components such as transmissions, brakes and suspensions can either move much closer to the point of power transmission or be completely eliminated. The decisive advantages of battery-electric vehicles include wheel specific torque control, enhanced comfort and more design space within the vehicle, according to the company. This is said to result in a better driving experience, greater range and more flexibility for developers. In-wheel motors are also of interest for buses due to their lower center of gravity, tighter turning radius and higher load capacity, according to the firm. They can also offer added value as a combined trailer drive for e-trucks or as a generator for refrigerated trailers during recuperation. At low speeds, the seal is said to provide optimal protection against dirt and water, and as speeds increase, this sealing effect decreases exponentially. This is said to prevent major friction losses. (*Freudenberg Sealing Technologies*)

www.fst.com

Carbon efficient adhesive

A next-generation adhesive promises to revolutionize material bonding by offering unprecedented impact strength, 22 times higher than traditional epoxy based adhesives that do not incorporate any rubbery additives, according to the developers. By connecting car parts with the stronger, more flexible adhesive, cars that use lighter components, such as aluminum and fiber-reinforced plastic, are said to be produced. Structural adhesives with high strength and durability are said to be essential in the assembly of automobiles, aircraft and buildings. Epoxy resin based adhesives are widely used; however, they lack flexibility, which is said to make them susceptible to damage under impact. To overcome this, a hydrogen bonded styrenic TPE is combined with an adhesive, resulting in a new type said to offer both flexibility and outstanding impact resistance. The adhesive was created in collaboration with Aisin Chemical with support from the New Energy and Industrial Technology Development Organization. (*Nagoya University*)

www.nagoya-u.ac.jp

Gear pump metering

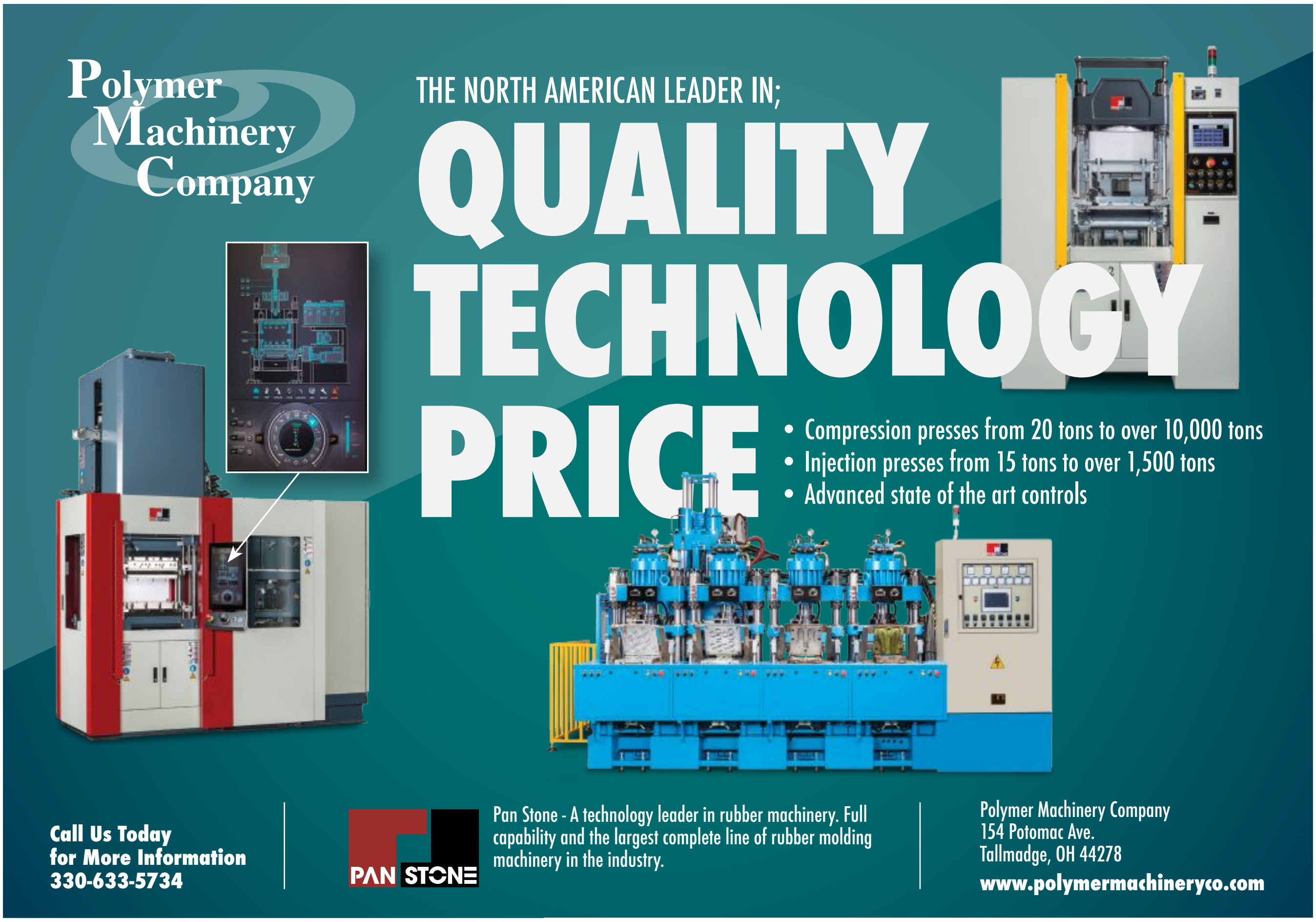
This manufacturer and marketer of differentiated technology products and sub-systems offers Zenith 2K precision gear metering systems. Designed with the needs of the foam, adhesives and sealants industries in mind, these durable systems are poised to redefine precision and efficiency in multi-component material dispensing, according to the company. The Zenith 2K systems are said to be engineered to meet the rigorous demands of multi-component applications, delivering unmatched accuracy in metering and mixing processes, according to the firm. These systems are said to offer exceptional accuracy and consistency by using high precision rotary gears to provide a smooth, continuous and pulseless flow, which is said to ensure impeccable results across applications such as sealants, adhesives, potting compounds and sealing foams. This level of precision is said to help manufacturers optimize their production processes, reduce waste and maintain consistent product quality. (*Circor International*)

www.circor.com

Salt bath vulcanization

VulcanoClean eco-friendly technology is said to represent a new era in sustainable manufacturing. With a zero wastewater discharge system and a closed circuit salt recycling process, it is said to achieve a 95% reduction in salt consumption, while significantly decreasing water usage by 20 to 40 times. Additionally, its advanced filtration technology is said to ensure effective VOC emissions control, reinforcing the company's commitment to a cleaner and more sustainable industry. VulcanoClean sets a new standard in energy efficiency, consuming two to three times less energy than conventional methods, according to the company. Its gas heating system is said to significantly reduce operational costs, making it an optimal solution for high volume production, exceeding 800 to 1,000 kg per hour. This equipment is said to deliver maximum productivity with production speeds two to three times higher than alternative technologies. Its advanced design allows for the simultaneous vulcanization of four to eight profiles, reaching speeds of up to 100 meters per minute for peroxide mixtures, said to ensure unparalleled efficiency in high performance manufacturing. (*M.D.C. Engineering*)

www.mdc-engineering.net



Contract rubber testing

Contract testing and consultancy assignments in rubber and plastics are performed by the company. Specialties include aging tests, estimation of lifetime and testing of low temperature properties on rubber materials. The company has been accredited for 16 rubber testing methods, including tear strength, tensile stress-strain properties, hardness IRHD, durometer hardness, accelerated aging and heat resistance, compression set, low temperature compression set, low temperature stiffening (Gehman test), resistance to liquids, density, low temperature retraction, stress relaxation in compression, cycling relaxation in compression, aging characteristics by measurement of stress relaxation in tension and estimation of lifetime and maximum temperature of use. A TGA 4000 can be used for determination of the composition of vulcanizates and uncured compounds by thermogravimetry according to ISO 9924. The DSC 4000 is an instrument for differential scanning calorimetry (DSC). It can be used for determination of melt interval and phase transitions. Fourier transform infrared spectroscopy (FTIR) is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. (*Elastocon AB*)

www.elastocon.com

High frequency testing

Understanding how materials respond under very high frequency conditions is said to be critical for industries such as automotive, aerospace, medical devices, electronics and consumer products. However, traditional dynamic mechanical analyzers (DMAs) often operate at comparatively lower frequencies, requiring data extrapolation to estimate high frequency properties; a process that can introduce uncertainty, according to the company. The firm's very high frequency analyzer (VHF104) is said to address this challenge by enabling direct measurement of viscoelastic properties from 100 Hz to 10 kHz, improving both the accuracy and efficiency of material characterization. No extrapolation is needed to obtain the direct high frequency measurements from 100 Hz to 10 kHz. Faster testing allows a full frequency sweep to take minutes instead of hours. The very high fequency testing provides the ability to crosscheck data in overlapping frequency areas. The firm provides research and industrial laboratories with advanced instruments for the characterization of the viscoelastic properties and thermo-mechanical properties of materials using DMA, including instruments for fatigue testing. (*Metravib Material Testing*)

www.metravib-materialtesting.com

Engineered foam in EPDM

This maker of closed cell silicone sponge and inventor of the original rolling diaphragm has expanded its product line to include engineered foam in polychloroprene and EPDM. These products are said to be in high demand for use as seals in various industries. They are highly resistant to environmental conditions like UV rays, ozone and weathering, and maintain excellent elasticity even in temperatures as low as -40°C, according to the company. They do not offer the extreme heat resistance and sterile properties of standard silicone; but those products are already a key part of the company's product mix. Products offered by company include work-a-day elastomers like EPDM and polychloroprene foam used to counter noise, vibration and harshness. The manufacturer is said to have invested heavily in the market, building a new production line that includes a new heated extruder and temperature control units (TCUs) specially suited to the manufacture of synthetic rubber engineered foam. (*Bellofram Elastomers*)

www.belloframelastomers.com

Silane terminated polymers

Geniosil STP-E 140 and Geniosil STP-E 340 silane terminated polyethers can be formulated into tin-free sealants and adhesives that are highly elastic and achieve a low modulus of elasticity, properties that are most desirable in the construction sector and a first in the adhesives and sealants world, according to the company. Tin-free assembly adhesives are said to be yet another area of application that can benefit from these products. With these polymers, property profiles are now possible that comparable binders fail to provide, according to the firm. The silane crosslinking binders Geniosil STP-E 140 and Geniosil STP-E 340 are based on the company's state-of-the-art Alpha^3 technology. The polymers in question consist of both alpha- and gamma-silyl groups. The alpha-silyl groups are said to lead to greater reactivity, while the slower reacting gamma ends have a positive impact on elastic recovery. This technology is said to combine the advantages of both alpha and gamma silane crosslinking polyethers. Both binders can be processed into creep resistant, fast curing adhesives, and also facilitate the production of low modulus sealants. These are flexible and, even without the application of much force, retain elasticity. (*Wacker Chemie AG*)

www.wacker.com

EPDM o-ring compound

The company’s 70 EPDM 335DW compound for o-rings is designed to meet stringent drinking water application requirements, and is said to ensure protection for both health and the environment. O-rings from 70 EPDM 335DW have obtained all relevant market approvals, making them suitable for global drinking water use, according to the firm. Global climate change has increased the need for safe drinking water. According to a 2024 report by UNESCO, 2.2 billion people worldwide live without access to clean drinking water, and 3.5 billion lack access to safely managed sanitation. This is where solutions like the o-ring made from the 70 EPDM 335DW compound are said to be needed: This material is specifically designed for drinking water applications. The o-ring compound is said to offer several advantages which ensure a long service life and reliable sealing. It also boasts heat resistance, withstanding hot water, steam and hot air up to 150°C, while remaining effective in cold conditions down to -50°C (static). (*Freudenberg Sealing Technologies*)

www.fst.com

Enhanced rubber mixing

This company is said to have strengthened its U.S. manufacturing footprint through the acquisition of Loc Performance, a move designed to enhance its capabilities in vehicle systems, precision manufacturing and rubber mixing operations. The acquisition of Loc Performance is said to mark a significant milestone for the company. While primarily aimed at enhancing expertise in defense and industrial manufacturing, it also provides an opportunity to integrate well established rubber compounding operations into its portfolio. This expansion is said to align with the company’s mission to deliver cutting edge material solutions that meet the evolving needs of defense, agriculture and industrial applications. By incorporating Loc Performance’s rubber mixing capabilities, this company is said to enhance its production capacity and material expertise. This move is said to position the company as a key player in the high performance rubber compounding sector, with an emphasis on durability, precision and innovation. With over 150 years of combined compounding and mixing experience on staff, the company’s facility is said to produce high quality rubber materials with precision and consistency. (*American Rheinmetall*)

www.rheinmetall.com/arv

Corporate Sponsor

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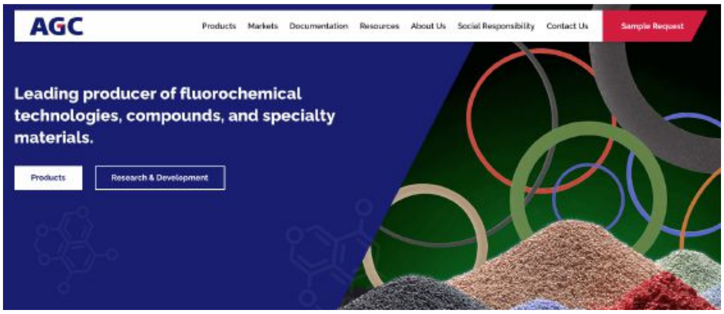

Leading producer of fluorochemical technologies, compounds, and specialty materials.

AGC Chemicals Americas, Inc, (www.agcchem.com) is a wholly owned subsidiary of AGC Inc., a $13.6 billion multinational corporation and one of the world's largest manufacturers of glass, electronic displays and chemical products. The company was formed in 2004 through the merging of sister companies Asahi Glass Fluoropolymers USA and AGA Chemicals. Headquartered in Exton, PA, including a state-of-the-art technology center, AGC Chemicals Americas maintains manufacturing operations in nearby Thorndale, PA, a satellite sales office in Sao Paulo, Brazil, and warehouses and distributors located throughout North America.

AGC Chemicals Americas manufactures, markets and sells fluoro products, including Fluon fluoropolymer resins, Fluon+ enhanced fluorinated materials and compounds, and AFLAS fluoroelastomers. AGC also markets and sells specialty chemicals, including AsahiKlin fluorinated solvents, Lumiflon PEVE resins, AsahiGuard E-Series water and oil repellents, Solesphere fine silica additives, polyols for polyurethanes, Cytop amorphous fluoropolymers and various fluoro intermediates for pharma and agro products. Specialty materials offered include FORBLUE ion exchange membranes, Fluon film and F-CLEAN greenhouse films.

AFLAS fluoroelastomers are the material of choice for parts and components that need to perform reliably in the world's harshest environments. AGC formulated AFLAS resins form alternating polymers of tetrafluoroethylene and propylene to achieve unique properties over a conventional FKM type fluoroelastomer. These properties include outstanding resistance to heat, chemicals, fuels, acids, bases, solvents, ozone and steam. Several AFLAS grades are approved for contact with food.

Fluon+ melt processable compounds are based on copolymer resins FEF, ETFE, ECA, PFA, PVDF, MFA and ECTFE. These compounds extend the fluoropolymer properties of chemical resistance, toughness and lubricity. All Fluon melt processable compound products are manufactured to precise specifications.

CHEMICALS AND MATERIALS

R.D. Abbott
AGC Chemicals Americas
AirBoss Rubber Solutions
Akrochem Corporation
APV Engineered Coatings
Arduro
ARP Materials
Brenntag Specialities
Cabot Corporation
Cancarb Limited
R.E. Carroll
Chardon Custom Polymers
Chemours
Chem Technologies, Ltd.
Çınar Kauçuk
Cri-Sil Silicones
Davis-Standard
DRP Industries
Eagle Elastomers
ECO USA
Emsodur
Harwick Standard
Kayton Industry Co., Ltd.
Kenrich Pertochemicals
LWB-Steinl
Polymer Solutions Group
Polymer Valley Chemicals, Inc.
Prism Worldwide
Pyropel, Inc.
Renkert Oil
Struktol Company of America
Tokai Carbon Cancarb Limited
Valex
Vanderbilt Chemicals
Wacker
Wynca USA
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MACHINERY AND EQUIPMENT

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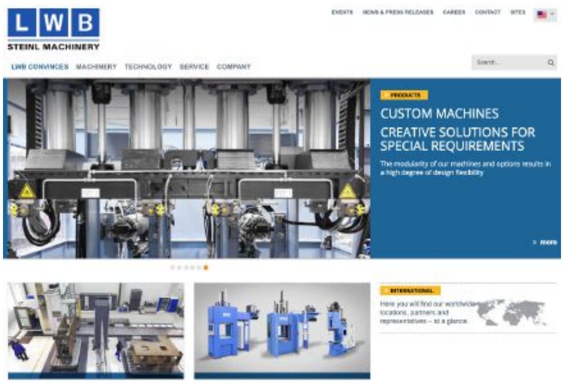


CUSTOM MACHINES

CREATIVE SOLUTIONS FOR SPECIAL REQUIREMENTS

The modularity of our machines and options results in a high degree of design flexibility

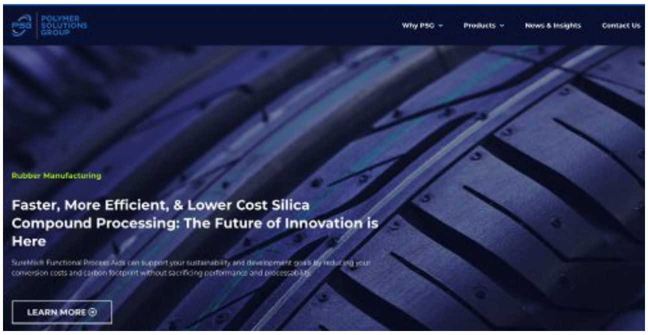
Here you will find our worldwide locations, partners and representatives – at a glance.

LWB-Steinl (www.lwb-steinl.com), with the production of over 400 machines annually for the elastomer processing industry, as well as a steadily growing customer base in the thermoplastic area, is a leading global supplier of rubber machinery. For more than 50 years, LWB-Steinl has grown to meet the needs of the rubber processing industry and understands its specific requirements.

The Steinl team has always been fascinated by the extraordinary material properties of elastomers and their control. This fascination is the basis for Steinl's focus on elastomer technology and the mechanical engineering for elastomer processing. It enables Steinl to understand the specific problems and requirements of elastomer processors and to build the right machines without compromise.

LWB Automation provides modular, flexible automation services. An experienced team accompanies customers from the concept to the implementation of individual solutions for the requirements of form-giving, assembly and follow-up processes. Customers receive turnkey production systems with extensive handling peripherals, including process technology, both in combination with vertical or horizontal presses and injection molding machines.

For decades, LWB has been providing new, important technical developments and innovative processes for the elastomer and thermoplastics industry. It was only logical to build up another area within the Steinl Group that covers the automation business area. With the expansion of its portfolio as a full service provider, LWB Automation customers benefit from a comprehensive service package. Customers receive not only the machine and process technology, but also complete automation solutions, including robot and handling systems from LWB. As an example, LWB-Steinl was able to satisfy the request of the German automotive supplier Reinz for fully automatic placement of up to 29 rubber seals on the sheet metal blanks of cylinder head gaskets by means of an injection molding cell.



Rubber Manufacturing

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Polymer Solutions Group (www.polymersolutionsgroup.com) strives to make its customers' products the best they can be. PSG nurtures a commitment to customer-centric innovation that demands deep knowledge of the markets served. By cultivating strong customer relationships, Polymer Solutions Group maintains insights into the chemistries, processes and market forces that drive its customers' success. Functioning as a team of teams, PSG innovates with an entrepreneurial edge that satisfies customers and fuels growth.

FlowSperse dispersions can help customers meet their performance, quality and environmental, social and governance (ESG) goals. PSG offers a broad range of morphology that can be tailored to customers' specific requirements. Polymer Solutions Group has implemented its CPS (controlled particle size) technology across its entire dispersion product line. FlowCal calcium oxide dispersions, paste products and polymer-bound products are all designed to take advantage of this process and provide customers with better performing and more consistent products. PSG technology for controlling particle size is essential for an effective and robust dispersion that yields exceptional rubber compound performance. When consistent dispersions that perform at high levels are needed, think of PSG's CPS technology utilized in the FlowSperse product line.

An anti-tack is more than a barrier coating or surface process aid. In fact, it may potentially impact the compound's processibility and the performance of the final part. Therefore, it should be selected as carefully as any other material in the formulation. The key to a superior anti-tack is coating efficiency: the dispersion produced must be stable, non-foaming, and non-settling. It needs to impart a thin, uniform and effective coating that dries fast, resists dusting and prevents compound sticking. Most importantly, it must not have any detrimental effects on the final part. Partnering with PSG will ensure that customers have selected the right anti-tack that allows them to efficiently produce their product.

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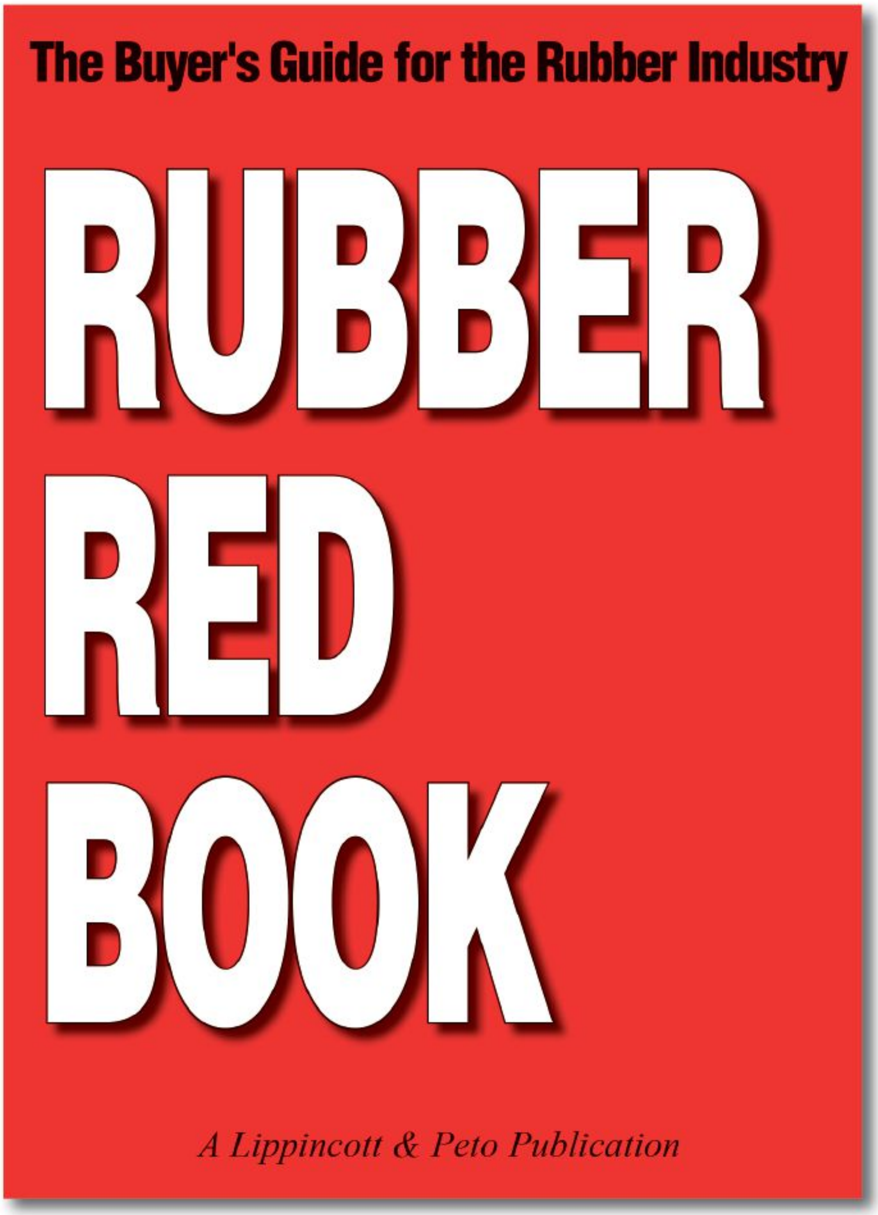

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People in the News

Barna named president of Yokohama NA


Jeff Barna
Yokohama NA


S. Takimoto
Yokohama Rubber


Stan Chandgie
Yokohama NA


Scott Lloyd
Vanderbilt Chemicals

Jeff Barna was promoted to president and chief executive officer of Yokohama Corporation of North America (YCNA), with expanded duties to support Yokohama Canada and Yokohama Mexico. **Shinichi Takimoto**, chairman and CEO of YCNA, was named head of the Japan Tire Business Division and the Original Equipment Tires Sales and Marketing Division of Yokohama Rubber in Japan. **Stan Chandgie** was named chief operating officer of YCNA , Yokohama Canada and Yokohama Mexico.

MANAGEMENT

Tansu IŞik was appointed chief executive officer of Continental Tire the Americas, succeeding **Jochen Etzel**, who is retiring. **IŞik** will also head Continental's Replacement Tires the Americas business area.

Yogesh Chauhan was named chief executive officer of Silcotech North America.

Patrick Fromal was appointed president of Shimadzu Scientific Instruments.

Apollo Tyres named **Rajeev Kumar Sinha** chief manufacturing officer.

SALES

Vanderbilt Chemicals, LLC, a manufacturer and distributor of rubber and plastics elastomers and chemicals, announced that **Scott Lloyd** has joined the company as a technical sales representative for the southeast/southwest region.

Matteo Spinola is joining Syncro Group as sales director.

LCY Group's Bowei Lee wins IISRP 2025 General Award

LCY Group Chairman **Bowei Lee** received the 2025 IISRP General Award from the International Institute of Synthetic Rubber Producers at the 65th IISRP Annual General Meeting held in Dublin, Ireland. As one of the highest honors in the synthetic rubber industry, the General Award recognizes individuals who have made outstanding contributions to global industry development, technological innovation and sustainable transformation. Lee has been a longtime champion of materials science innovation and the advancement of green technologies. Under his leadership, LCY Chemical has delivered significant breakthroughs in green materials, carbon neutrality and the circular economy, driving meaningful progress toward a more sustainable future for the industry.

Bowei said, "This recognition from the IISRP is a testament to LCY's commitment to innovation and sustainable development in synthetic rubber by our teams in Taiwan, China, the U.S. and Europe. The synthetic rubber industry is facing challenges such as changing market demands, tightening environmental regulations and carbon emissions management. In response, the industry must improve material performance to reduce environmental impact. LCY will continue to develop advanced materials and technologies and deepen collaboration across the industry to accelerate the transition to a greener future."

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