OCTOBER 2023

RubberWorld

135 years

THE TECHNICAL SERVICE MAGAZINE FOR THE RUBBER INDUSTRY VOLUME 269, NO. 1

RUBBER DIVISION MEETS IN CLEVELAND FOR INTERNATIONAL ELASTOMER CONFERENCE AND EXPO

International Elastomer Conference

Styrenic block copolymer solutions enhance sustainability and the circular economy

Transforming recycled plastics into high performance materials with styrenic TPEs

Inventing the RPA rubber process analyzer

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From the Editor

Jill Rohrer

IRSG releases industry outlook

The International Rubber Study Group (IRSG) has released the latest edition of its World Rubber Industry Outlook (WRIO). The strong recovery in advanced economies and emerging markets over the past three years, especially China and India, supported the world's rubber demand recovery in 2021 by 8.4% to 29.84 million metric tons (mmt), exceeding the pre-pandemic level. Total rubber demand contracted marginally in 2022 to 29.82 mmt, driven by downward pressure on the original equipment market causing a contraction in rubber demand. With the ease of supply chain issues and supply chain restructuring, global rubber demand is forecast to recover modestly to 2.2% in 2023.

Global natural rubber (NR) demand increased by 1.7% in 2022, reaching 14.31 mmt. NR demand is forecast to increase by 1.7% in 2023, driven by the tire sector growth in Asia Pacific and the Americas. World synthetic rubber (SR) consumption declined by 1.6% in 2022, primarily driven by a reduction in rubber usage in the tire sector. SR consumption is forecast to increase by 2.6% in 2023.

Global natural rubber production increased by 4.8%, reaching 14.47 mmt in 2022. NR production growth is estimated to slow down to 0.7% in 2023.

Cleveland hosts IEC and Expo

This October issue of *Rubber World* arrives to you at the 2023 International Elastomer Conference (IEC), including the Rubber Division's 204th Technical Meeting, Expo, Educational Symposium, Student Symposium, WORD Workshop, Get Involved Session, Career Fair, 25-Year Club Luncheon, Expo Theater Presentations, Awards Breakfast, and many other events taking place at the Huntington Convention Center in Cleveland, OH, October 16-19.

Be sure to pick up your copy of the *IEC Daily* each day. This tabloid-sized publication is filled with important news from the show, event schedules, special features and photos from the Expo floor. *Rubber World*'s *Pocket Spotlight* is a handy pocket-sized directory of all Expo exhibitors, and includes details on what the companies will be highlighting at their booths during the show.

Jill Rohrer

Take advantage of this excellent opportunity to learn about the latest rubber developments and industry news, and conduct business and socialize with valued customers. Please be sure to stop by the *Rubber World* booth (#629) to say hello. *Rubber World* wishes you much success at the IEC!

RubberWorld

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Business Briefs

Wacker expands silicone production

Wacker Chemie AG (www.wacker.com), Munich Germany, is expanding its specialty silicone manufacturing capacities in China at its Zhangjiagang site in Jiangsu Province. Construction has started on several new production lines where the globally operating chemical group will manufacture functional silicone fluids, silicone emulsions and silicone elastomer gels. Investments of some €150 million have been earmarked for the expansion project.

Acquisitions, expansions

Orion S.A. (www.orioncarbons.com), Luxembourg, a global specialty chemicals producer, is investing €12.8 million, including €6.4 million in funding from the German government and European Union, to further develop and demonstrate a climate neutral process for producing carbon black from alternative carbon sources. The technology is designed to improve Orion's yield and throughput in the production of carbon black using circular feedstocks, and thus potentially reduce the carbon footprint of the process by a significant amount. This could accelerate the shift to a circular economy and feed the growing demand for sustainable materials in the tire industry, according to Orion.

Dow (www.dow.com), Midland, MI, announced the start-up of a new MDI distillation and prepolymers facility at its world scale manufacturing site in Freeport, TX. This investment is said to optimize Dow's existing asset infrastructure and advance Dow's leading positions in attractive applications in automotive, construction, consumer and industrial markets. The Freeport MDI facility, which replaces Dow's North America capacity in La Porte, TX, will supply an additional 30% of product to Dow's customers. In coordination with the start-up of the MDI facility, Dow shut down its polyurethane assets at the La Porte site.

Generational Equity (www.genequityco.com), Dallas, TX, a mergers and acquisitions advisor to privately held businesses, announced the sale of **MS Rubber** to **TRG LLC**. Founded in 1963, and located in Jackson, MS, MS Rubber is an industrial supplier and fabricator of rubber products, including hydraulic hoses, fittings, belts, gaskets, rubber sheeting, expansion joints, plastic sheets and related products. The company is an authorized dealer of Danfoss Hydraulics products.

H.B. Fuller (www.hbfuller.com), Basel, Switzerland, said to be the largest pureplay adhesives company in the world, has acquired the business of U.K. based **Sanglier Limited**, said to be one of Europe's largest independently owned manufacturers and fillers of sprayable (aerosol and canister) industrical adhesives. The team of nearly 60 employees will operate within H.B. Fuller's existing Construction Adhesives global business unit.

Business Briefs

Hexpol collaborates with LabsCubed

Hexpol Compounding Americas (HCA) (www.hexpol.com), Barberton, OH, announced a collaboration with **LabsCubed**. Hexpol, said to be a leader in custom rubber compounding, and LabsCubed, said to be a dynamic and innovative automation company, have partnered to redefine the standards of rubber quality control and reiterate Hexpol's commitment to innovation and excellence, according to the firms. Recognizing the importance of precision and efficiency in rubber testing, HCA has made a strategic investment in LabsCubed's state-of-the-art automated tensile testing technology.

Contracts, licenses

Endurica (www.endurica.com), Findlay, OH, announced that University of Calgary students designed a non-pneumatic tire with Endurica software. The undergraduate student team at the University of Calgary in Alberta, Canada, was asked to develop a non-pneumatic tire for an off-road vehicle utilizing an in-wheel hub motor. Part of the project included simulating the tire's structural behavior with the **Ansys** finite element solver and determining the tire's fatigue life. Endurica provided the students with a software license and access to Endurica's online learning center. Students are said to have impressed the professors and project sponsors with their optimized design, which met the durability target of at least 100 million cycles.

Continental (www.continental-tires.com), Hanover, Germany, announced that **Alfa Romeo** is factory fitting its new Tonale compact SUV model with Continental's 17 and 18 inch EcoContact 6 premium tires. The tires are said to be designed for exceptionally energy efficient and noise optimized driving.

Balkrishna Industries (BKT) (www.bkt-tires.com), Mumbai, India, is sponsoring the World Curling Championships in Canada, as confirmed by **Curling Canada** and the **World Curling Federation**.

Henkel (www.henkel.com), Düsseldorf, Germany, a global provider of adhesives, sealants and functional coatings, announced its membership with **MedTech Europe**, the industry association representing the medical technology sector in Europe. This collaboration aims to foster innovation and promote sustainable development in the value chains supporting

Business Briefs

the medical technology industry. Henkel is said to have a long history of supporting the medical technology industry with its advanced adhesive and surface solutions.

Trelleborg Marine and Infrastructure (www.trelleborg.com), Trelleborg, Sweden, is partnering with **Daewoo Engineering & Construction**, based in South Korea, to deliver a comprehensive range of customized sealing systems for the Khor Al Zubair Immersed Tunnel project at Khor Al-Zubair Port in Basra, Iraq, said to be a major undertaking that stands as the largest immersed tunnel currently being constructed in the Middle East.

Scandinavian Enviro Systems (www.envirosystems.se), Gothenburg, Sweden, and **Siemens** have signed a memorandum of understanding (MoU) regarding a collaboration in support of the European expansion plan that Enviro announced earlier this year together with **Antin Infrastructure Partners**. Together with Antin Infrastructure Partners, and with the support of **Michelin**, Enviro has formed the world's first large scale tire recycling company, including a plan to establish recycling facilities in Europe by 2030 with a total annual recycling capacity of 1 million tons of end-of-life tires.

Lianda continues to sponsor IEC Technical Meeting

Lianda (www.liandacorp.com), Twinsburg, OH, a performance elastomers and specialty chemicals distributor, has been sponsoring Rubber Division, ACS, Technical Meetings at the International Elastomer Conference for ten years. IEC Technical Meetings include papers and presentations covering scientific research and technological developments relating to all aspects of rubber chemistry and rubber products.

Exchange of technical knowledge and ideas is said to be critical to promote innovation and keep the industry and academia at the forefront of technological development. Lianda is committed to supporting the industry, not only in the form of Technical Meeting sponsorship, but also through its technical support to its products, customers and principals.

Lianda maintains a very experienced technical staff and a 3,000 square foot, well equipped laboratory in its Twinsburg, OH, headquarters to perform formulation development, product quality testing, troubleshooting, and more. These capabilities are said to be critical to supporting its highly technical product lines.

Lianda's performance elastomer product line includes HNBR, FKM, fluorosilicone, silicone, chlorinated polyethylene (CPE), chlorosulfonated polyethylene (CSM), polychloroprene (CR) and ECO.

Lianda's specialty additives product lines include organic peroxides, FKM curatives, coagents (including metallic coagents), zinc sulfide, silane coupling agents, aramid fiber masterbatch, fumed and precipitated silica, and more.

Lianda's technical capabilities also help its customers in their attempts to diversify their supply base and minimize risk, and help its principals in their efforts to expand in the North American market.

Lianda is a minority and woman owned family business. It has maintained ISO-9001 accreditation since 2004. Visit Lianda at the IEC in booth 732, or at www.liandacorp.com

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Business Briefs

Continental uses rCB in its solid tires

Continental (www.continental.com), Hanover, Germany, is increasing activities to ensure a circular economy, adding recovered carbon black (rCB) to its newly produced Super Elastic solid tires at its plant in Korbach, Germany, reducing the use of fossil raw materials and CO_2 emissions. Solid tires such as Continental's SC20+ already contain around 60% renewable and recycled materials, thanks to their high natural rubber content. By 2050 at the latest, Continental aims to use 100% sustainable materials in its tire products. The rCB is supplied by **Pyrum Innovations**, one of Continental's partner companies. Pyrum breaks down end-of-life tires into their individual components in industrial furnaces using a special pyrolysis process. This allows valuable raw materials contained in end-of-life tires to be extracted and recycled. Solid tires have a high load capacity and are extremely stable, puncture proof, maintenance free and highly economical, according to the company. They are mainly used in material handling for forklift trucks, airport vehicles, heavy transport vehicles, sideloaders, platform trucks and other industrial vehicles.

CORPORATE, FINANCIAL NEWS

Continental announced that its innovative premium surface material for vehicle interiors, Benova Eco Protect, has been named a finalist in the 2023 PACE Awards. The product is said to mark an important milestone in product development, eliminating solvent based raw materials in the production by use of purely water based polymeric feedstock. The product is based on polyurethane as the premium polymeric matrix, with a multilayer construction coated on a basic textile.

Global Rubber Industries (GRI) (www.gritires.com), Colombo, Sri Lanka, is increasing its efforts in utilizing recycled carbon black (rCB) for compounding and its specialty tire production as the tire manufacturing industry shifts towards sustainable practices, products and eco-friendly solutions. GRI decided to substantially decrease the utilization of virgin carbon black and instead harness the power of rCB for the premium material handling tire Ultimate Green XT for forklifts, as well as the radial agriculture tires in the Green XLR Earth series.

Tokai Carbon CB Ltd. (www.tokaicarboncb.com), Fort Worth, TX, will raise prices on all carbon black grades in North America, effective November 1, or as contracts allow. The company will also roll all surcharges associated with its U.S. consent decree into its permanent pricing structure. This price increase is necessary to cover the increasing costs of carbon black production in the U.S.

Freudenberg Sealing Technologies (www.fst.com), Weinheim, Germany, announced that its commitment to achieving net zero emissions by 2045 or sooner is driving enor-


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Business Briefs

mous changes in how the company is managing its activities. Sites have re-energized their focus on system optimizations, a reduction in waste, electrification of machinery, the use of green electricity and installation of alternate energy systems. Recently, the company's material development experts joined the effort to eliminate CO_2 emissions by intensifying their research into sustainable material ingredients that could replace ingredients derived from fossil fuels. The sealing experts of the **Freudenberg Group** are currently analyzing a variety of sustainable substances that could replace the fossil fuel based ingredients in EPDM, NBR and FKM, all elastomers that are commonly used in industry applications that include batteries and fuel cells.

Birla Carbon (www.birlacarbon.com), Mumbai, India, released its 11th annual sustainability report, titled: Share The Future. The 2023 report highlights the company's commitment to achieving net zero carbon emissions by 2050 through substantial advancements in Continua sustainable carbonaceous material (SCM) and prioritizing the 4Rs strategy of research, reduce, replace and repurpose to lower greenhouse gas emissions. Birla has repurposed 72% of waste, reducing the amount of waste sent to landfills. The company has refinanced existing debts through a $750 million loan linked to sustainability performance. Upon completion of a partner's facility, 73,000 metric tons of Continua SCM will eliminate 228,000 metric tons of direct and indirect CO_2 emissions annually.

Quality registrations

Baker Industries (www.bakerindustriesinc.com), Macomb, MI, a **Lincoln Electric** company, and a supplier of tooling, prototyping, fabrication, additive manufacturing, assembly, finishing, quality inspection, and design and engineering services to OEM and Tier 1 manufacturers, has achieved ISO 14001 certification, an internationally recognized standard for enviromental management systems.

Cabot (www.cabotcorp.com), Boston, MA, has achieved International Sustainability and Carbon Certification (ISCC) Plus certification at six of its facilities. Cabot currently is said to have more ISCC Plus certified sites than any carbon black manufacturer, and has ambitions to expand certification throughout its global network. Sites currently certified include three reinforcing carbon facilities in Europe and the Americas, as well as two masterbatch and compounding facilities in Europe and the company's Europe, Middle East and Africa regional headquarters.

Stahl (www.stahl.com), Waalwijk, Netherlands, a provider of coating technologies for flexible substrates, has been awarded a Platinum rating by the sustainability agency **EcoVadis** for the second consecutive year.

Wallace Instruments (www.wallaceinstruments.com), Dorking, Surrey, U.K., a manufacturer and global supplier of rubber testing equipment, announced its **United Kingdom Accreditation Service** (UKAS) accreditation to ISO/IEC 17025 for the calibration of hardness testers. This recognition is said to set Wallace apart as the only U.K. provider to offer both Shore and IRHD accredited calibration services with extremely small uncertainties.

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Growth predicted for stretchable materials

With an impressive compound annual growth rate (CAGR) of 18.1% projected for stretchable conductive materials, the market should reach $3.7 billion by 2033, according to Future Market Insights.

Several key trends are driving this growth, including the increasing demand for stretchable conductive materials in wearable electronics, advancements in material science, the growth of soft robotics and the expansion of the Internet of Things (IoT).

Opportunities for growth in the stretchable conductive material industry include the growing demand for flexible electronics across various sectors; the focus on sustainable and eco-friendly materials; collaborations and partnerships for research and development; and emerging applications in sports and fashion.

There are also key hurdles to market growth, such as limited material performance, integration challenges, and regulatory and standardization barriers, that need to be addressed.

To capitalize on the opportunities, manufacturers and suppliers need to overcome the challenges and invest in research and development, partnerships, and sustainable solutions, according to the study.

The use of graphene fillers is a significant revenue generator in the stretchable conductive material market, with an exceptional growth rate of 18%. Graphene, known for its exceptional conductivity, enhances the conductivity of materials when used as fillers, allowing efficient transfer of electrical signals. It also improves flexibility, stretchability, durability and stability, making it highly desirable for various applications.

In terms of end users, the consumer electronics sector exhibits remarkable growth in the stretchable conductive material market. The sector is expected to maintain positive growth, with a projected CAGR of 17.9% from 2022 to the end of the forecast period, driven by increasing consumer preference for technologically advanced and user-friendly electronic devices.

In terms of regional analysis, the U.S. is a significant player in the stretchable conductive material market, projected to reach a market size of around $1.2 billion by 2033. The strong presence of the consumer electronics industry, technological advancements and increasing adoption of wearable devices drive the U.S. market.

The United Kingdom also holds a notable position in the market, with a 17.2% CAGR predicted by the end of the forecast period. The growing demand for wearable technology, advancements in the electronics industry, and investments in research and development contribute to the market's growth in the U.K.

China, as a global manufacturing hub with an emphasis on technological advancements, plays a significant role in the market. By 2033, the market size in China is projected to reach nearly $316.3 million, driven by its large population, flourishing electronics industry and growing demand for innovative products.

Carbon black market grows at 6% rate

Fact.MR states the global carbon black market size is estimated to be valued at $26.2 billion in 2023, and is expected to grow at a CAGR of 6% to reach $46.9 billion by the end of 2033.

The gross value added (GVA) of the global chemical sector is poised to be significantly influenced by the carbon black market. This influence primarily stems from its versatile application in various products, encompassing paints, coatings, packaging, plastics and printing inks.

Considering these factors, it is projected that the carbon black market will witness a revenue increase of 1.5 times by the year 2031, amounting to an approximate value of $30 billion at that juncture.

The revenue generating capacity of the carbon black market was also affected by the COVID-19 pandemic, leading to a year on year (YoY) decline. Nevertheless, the market is expected to stabilize by the end of 2021, with an estimated CAGR of around 6% over the subsequent decade.

The automotive sector significantly consumes carbon black, employing it in tire manufacturing, as well as in automotive coatings and plastics. The burgeoning global automobile market fuels the demand for carbon black.

Carbon black serves as a reinforcing agent in tire production, imparting strength, durability and resistance to wear and tear. With the escalating global demand for tires, there is a parallel rise in the demand for carbon black.

Carbon black contributes to the production of energy efficient tires, which enhance fuel efficiency and reduce carbon emissions. Given the escalating concerns over climate change and the imperative to mitigate greenhouse gas emissions, the demand for energy efficient tires is on the rise, consequently boosting the demand for carbon black.

In plastics and composite materials, carbon black functions as a filler and pigment in a variety of plastics and composite materials. As industries like automotive, construction and packaging exhibit increased demand for these materials, the need for carbon black follows suit.

Carbon black plays a vital role in the production of inks and coatings, offering color and stability. With mounting demand across various sectors, including packaging, printing and automotive, the demand for carbon black is on an upward trajectory, Fact.MR states.

According to the report, manufacturers are exploring sustainable and renewable sources of carbon black, including bio based and waste based variants. Customized specialty carbon black, tailored to specific performance requirements, is gaining traction in various sectors, such as automotive, plastics and coatings, according to Fact.MR.

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Nicolas Weibel, technology manager at Greene Tweed's Advanced Technology Group, which is said to be at the forefront of developing new materials to perform in the most demanding industries and applications, recently conducted a technical briefing, "Composite Components Boosting Performance in Rotating Equipment," at the Middle East Rotating Machinery Technology and Innovation Conference and Showcse. The briefing highlighted new and innovative composite components, such as Greene Tweed's latest composite impellers, that meet the demands of hydrogen compression. Unlike metallic impellers, which would explode before reaching the required speed for hydrogen compression, Greene Tweed's newly designed and patent pending composite impellers are engineered to spin with a top speed of more than 600 meters per second.

"At Greene Tweed, we are proud of our 160 years of continuous material science innovation," said Magen Buterbaugh, president and CEO of Greene Tweed. "We have been serving our customers in the Middle East for several years with our advanced Chemraz seals and thermoplastic composite wear- and abrasion-resistant components that ensure greater reliability, increased efficiency, and enable critical pump and compressor operations to push the boundaries of what is possible, even under the most extreme operating conditions."

Greene Tweed's custom engineered solutions are said to meet critical needs and deliver certainty for challenging pump and compressor operations in refineries, petrochemical plants, power generation plants and chemical processing plants. The advanced elastomer seals and thermoplastic composite wear- and abrasion-resistant components are said to last up to five times longer than metal, ceramic and rubber solutions for dramatically longer lifetimes. This durability results in safer operations, reduced downtime, and in turn, fewer maintenance requirements.

High performance products include WR 600, a carbon-fiber reinforced, PFA based composite featuring near universal chemical resistance and non-galling properties that facilitate extended periods of dry running during upset conditions. WR 600 tolerates rapid startup or shutdown without the risk of seizure, fracture or pump failure, according to Greene Tweed. Components made of WR 600 are said to run tighter clearances than traditional metallic materials, reducing recirculation and improving efficiency. This is said to result in substantial energy savings, extended service life and improved mean time between repairs. Greene Tweed composites solutions have been API 610 compliant for over two decades.

Greene Tweed's Arlon 4020 labyrinth seals are also available. Due to the custom engineered profile, with flexible teeth at optimal clearances, Arlon 4020 labyrinth seals are proven to provide long term compressor efficiency gains of 1% to 2%, according to the company.

Greene Tweed also supplies AR abrasion resistant thermoplastic composite bearings engineered to protect pump systems from sand, salt, scale and other solids. Chemraz o-rings and sealing solutions, said to be known for their exceptional resistance to extreme temperatures and aggressive chemicals, are also available from the company.

Greene Tweed applications engineers are said to work with customers to find the optimal elastomer and composite/thermoplastic solutions for the wear components of an industry's most demanding pump applications.

Greene Tweed is a global manufacturer of high performance thermoplastics, composites, seals and engineered components that are said to outperform and outlast in the world's harshest environments. For 160 years, Greene Tweed has served clients in the semiconductor, oil and gas, aerospace, defense, chemical processing, power generation and other sectors with a custom, collaborative approach that is said to deliver certainty for their crucial operations.

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Flexsys' critical role in supporting the tire industry for the long term

Tires are a critical safety component of every vehicle, with stringent performance requirements. Amidst a rapidly changing landscape marked by growth in electric vehicles, sustainability imperatives, deglobalization and emerging technologies, the tire industry's trajectory is intricately woven with the support of key suppliers. Sandip Tyagi, CEO of Flexsys, explores how the company is supporting tire manufacturers on their transformative journey, and working to curtail emerging industry-wide risks.

Sandip Tyagi is chief executive officer of Flexsys, a leading global producer of high quality rubber chemicals and solutions, including Crystex vulcanizing agents, Santoflex antidegradants and Duralink HTS post-vulcanization stabilizers. Flexsys operations span four continents, with eight manufacturing facilities and two technology centers.

Could you provide an overview of Flexsys' role in the tire sector?
Tyagi: Flexsys occupies a pivotal position as a global leader in tire additives. Our history of innovation paved the way for a diverse range of specialty rubber chemicals that not only enhanced tire safety and durability, but also streamlined tire manufacturing processes. Notably, in November 2021, Flexsys emerged as an independent entity dedicated to serving the tire industry. This move solidified our reputation as the world's premier pure-play tire additives supplier.

Could you shed light on the strategic themes that your customers prioritize, and how Flexsys addresses them?
Tyagi: In my interactions with customers, three predominant themes consistently take center stage: innovation, sustainability and security of supply. First, tire manufacturers are perpetually innovating to meet the needs of their customers, while ensuring high product performance and safety.


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Environmental sustainability is also a high priority item on the agenda of every major tire manufacturer. This extends beyond the final product, encompassing the raw materials sourced, including tire additives.

Finally, the reliability of the supply chain is non-negotiable. A disruption in the supply or quality of tire additives can halt manufacturing operations, causing significant financial losses.

It is essential to the tire industry that key suppliers deliver in all three of these areas, and Flexsys, as the global leader in the supply of specialty tire additives, has been and will continue to increase its investments into these three critical areas to make our customers successful in a rapidly changing world.

Indeed, recent events have underscored the importance of supply chain resilience. How is Flexsys addressing this pressing topic?
Tyagi: The events of the recent past, the pandemic, geopolitical tensions and escalating sanctions, have heightened the urgency of supply chain de-risking. This is particularly important for critical tire additives like insoluble sulfur and antidegradants, which lack functional alternatives.

Flexsys has taken decisive steps to build a customer-centric operational footprint uniquely tailored to the needs of our customers. Each of our eight world class manufacturing facilities is strategically positioned to be close to our customers. This geographical proximity, coupled with redundancy in our plant network, ensures the highest level of supply security. Our local-for-local supply approach, combined with locally sourced raw materials and local customer success teams, delivers unparalleled levels of customer service, supply reliability and agility.

What are some of Flexsys' most interesting recent innovations?
Tyagi: Since our transition to an independent company, Flexsys has been increasing its investments in research and development. One particularly promising avenue is the pursuit of a replacement for 6PPD, an antidegradant that has been used in tire manufacturing for decades.

Developing a replacement is a complex endeavor, as there are no known alternatives to date. The complexities lie in innovating a solution that not only matches the performance of 6PPD, but also adheres to stringent environmental and safety standards. To address this, Flexsys has positioned itself as the leader at the center of a collaborative ecosystem of multiple stakeholders focused on developing and testing innovative molecules. As soon as a suitable replacement to 6PPD is agreed upon and approved,

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the final step will be commercialization at an industrial scale. With our proven track record of innovation of next generation tire additives, we are confident that we will be successful in innovating a solution for the industry.

Sustainability is at the forefront of industry transformation. How is Flexsys aiding tire manufacturers in meeting this critical challenge?

Tyagi: As industry leaders, we are investing heavily to chart a sustainable path forward for ourselves and our downstream partners. Our aspirations are aligned with those of our customers, and we are striving to achieve net zero greenhouse gas emissions, 100% renewable electricity and the incorporation of 100% sustainable materials within our own supply chain by 2040.

Our efforts have earned us a Gold EcoVadis sustainability rating, placing us in the top 6% of global chemical manufacturers. Additionally, our commitment to the Science Based Targets Initiative (SBTI) underscores our determination to reduce greenhouse gas emissions in line with a 1.5°C pathway and help our customers do the same.

Flexsys is committed to transitioning to 100% sustainable materials by 2040, including the conversion of fossil based naphthenic process oil (NPO) to renewable bio oils for use in our insoluble sulfur products. This transition, while critical for sustainability, presents challenges due to the vital role of oil in dust suppression and dispersion performance. Defining what constitutes a sustainable bio oil remains a challenge, with concerns about land use, water use, pesticides and fertilizers. We already see different definitions of sustainability across key players in the industry, which makes it difficult to innovate quickly and at scale. We strongly support an industry-wide agreement to define sustainable solutions, ensuring a long term, environmentally responsible approach

In conclusion, could you offer a glimpse into the future of tire additives and Flexsys' role in shaping this evolution?

Tyagi: My perspective is that innovation and sustainability will be inseparable in the future, and that the deglobalization era will continue to amplify the need for supply chain security. Tire manufacturers will rely on forward-thinking, environmentally conscious and dependable suppliers to navigate these challenges, and we remain steadfast in our dedication to investing in superior solutions and nurturing robust partnerships. Together, we are forging a path toward a brighter, more sustainable future for the tire industry.

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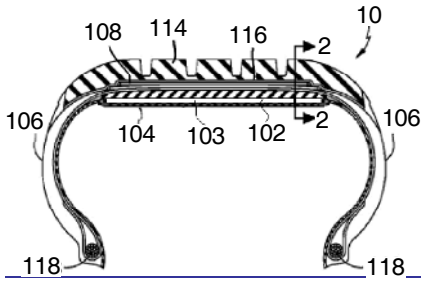
Patent News

Multilayer intrinsic sealants based on ionic butyl
U.S. patent: 11,738,606
Issued: August 23, 2023
Inventors: Ramendra Nath Majumdar and Wang Dapeng
Assigned: Triangle Tyre
Key statement: A tire with in-situ generated two or more intrinsic puncture sealant layers based on ionic butyl with two or more different viscosities comprising a supporting tire carcass having one or more layers of ply, an outer circumferential tread and a radially inner layer, a pair of beads, sidewalls extending radially inward from the axial outer edges of a tread portion to join the respective beads, a sealant comprising an outer layer of sealant and an inner layer of sealant, disposed radially inwardly from the radially inner layer of the tire carcass, wherein the outer layer of sealant and the inner layer of sealant have different viscosities, wherein the sealant provides self-sealing properties to the tire and wherein the inner layer of sealant is crosslinked to the outer layer of sealant with no barrier separating the inner and outer layers of sealant.



Method for producing nitrile group-containing copolymer rubber
U.S. patent: 11,692,051
Issued: July 4, 2023
Inventors: Atsuhiro Shiono and Tomoyuki Shibuya
Assigned: Zeon
Key statement: A method for producing a nitrile group-containing copolymer rubber including copolymerizing a monomer mixture containing an α,β-ethylenically unsaturated nitrile monomer and a conjugated diene monomer, in which the copolymer has a Mooney viscosity (ML1+4, 100°C) in a range of 30 to 60 at a time point when a polymerization conversion rate is 60%, the copolymerization is carried out until the polymerization conversion rate reaches 85% or more, and the obtained nitrile group-containing copolymer rubber has a Mooney viscosity (ML1+4, 100°C) of 85 to 150.

Anti-sticking agent composition for unvulcanized rubber, aqueous dis-

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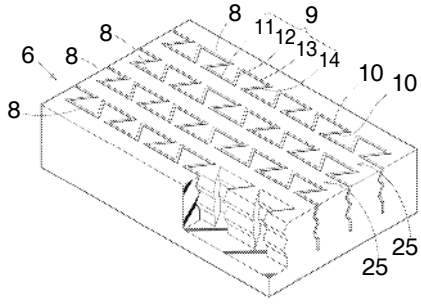
Patent News

persion liquid of anti-sticking agent composition for unvulcanized rubber and unvulcanized rubber
U.S. patent: 11,692,092
Issued: July 4, 2023
Inventors: Shiro Sehata, Kazuyuki Sakamoto and Takao Oka
Assigned: Lion Specialty Chemicals
Key statement: An anti-sticking agent composition for an unvulcanized rubber of the present disclosure includes the following components (A) to (C) and water is provided. The component (A) contains the following component (A1) and the following component (A2). The component (A) is water-soluble polymer, the component (B) is metallic soap, the component (C) is surfactant, the component is (A1) water-soluble polymer other than the component (A2) and the component (A2) is non-ionic cellulose ether.

Tire
U.S. patent: 11,691,459
Issued: July 4, 2023
Inventor: Kazuma Mori
Assigned: Sumitomo Rubber Industries
Key statement: A tire comprises a tread portion. The tread portion is provided with a sipe. The sipe comprises four sipe segments: a first sipe segment, a second sipe segment, a third sipe segment and a fourth sipe segment. At least one of the first sipe segment and the third sipe segment comprises an oscillated portion which extends in the radial direction of the tire, while oscillating in a lateral direction orthogonal to the length direction of the sipe in a cross section of the sipe orthogonal to the length direction. Each of the first sipe segment and the third sipe segment comprises the oscillated portion including an oscillating-start portion and the oscillating-start portion of the first sipe segment is inclined with respect to the tire radial direction in the same direction as the oscillating-start portion of the third sipe segment.



Rubber composition
U.S. patent: 11,692,088
Issued: July 4, 2023
Inventors: Kazumasa Matsuo, Natsuyo Kamimoto, Tatsuhiko Adachi, Toshihi-

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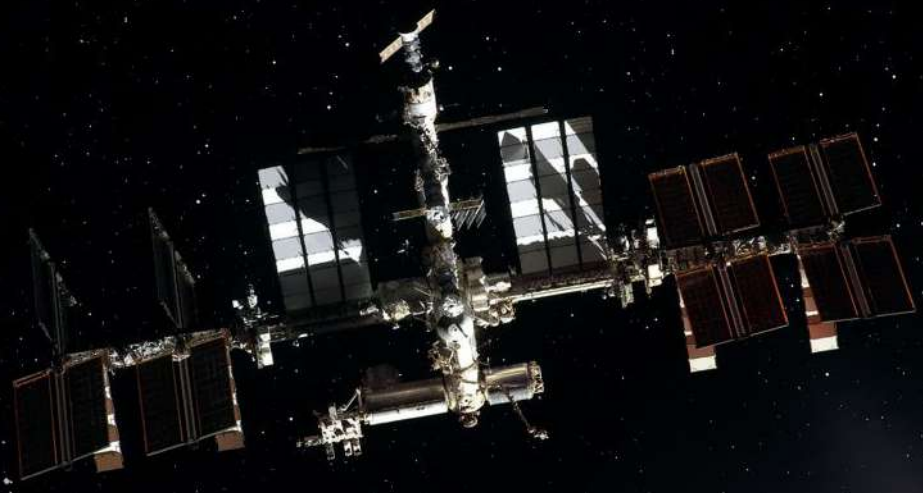

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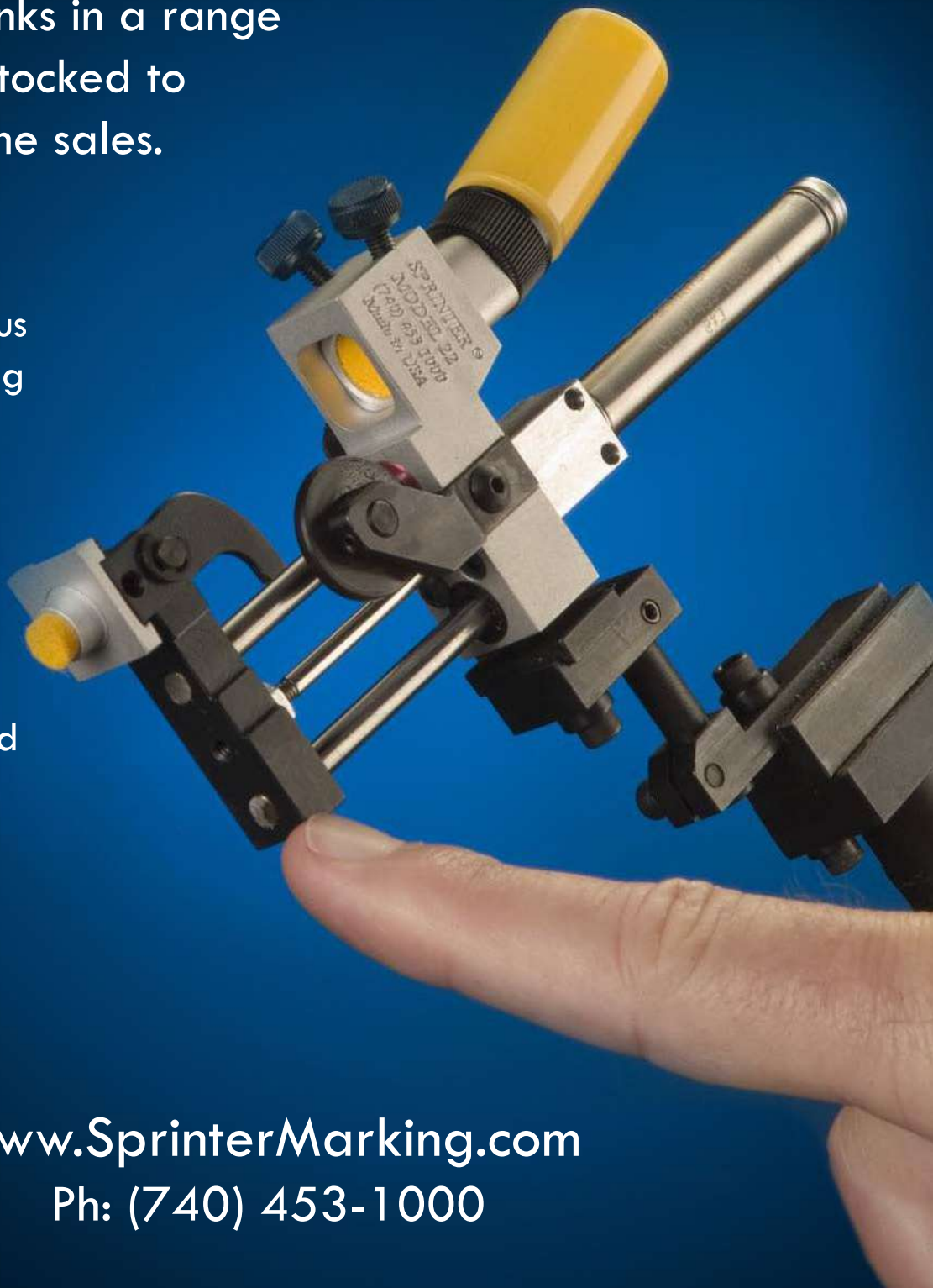

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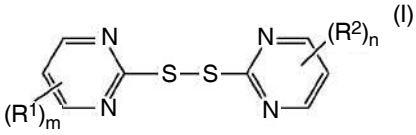
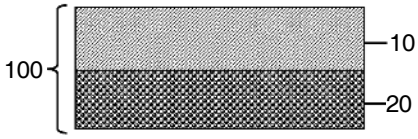
Patent News

ro Nobuoka and Takeshi Hara
Assigned: Sumitomo Chemical
Key statement: The present invention provides a rubber composition obtained by kneading a rubber component, a vulcanization accelerator, silica and a compound represented by the following formula (I):



wherein the groups are as defined in the description.

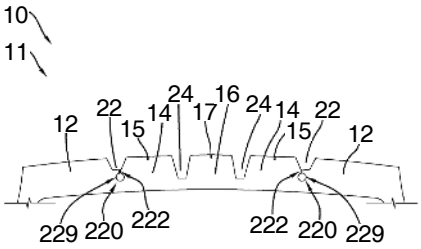
Composite with direct bonding between rubber and foam
U.S. patent: 11,691,395
Issued: July 4, 2023
Inventors: Zheng Zhang and Huaili Qin
Assigned: Dow Global Technologies
Key statement: This disclosure relates to a composite comprising (a) a rubber layer comprising a cured rubber and optionally a first copolymer having carboxyl groups or anhydride groups; and (b) a foam layer comprising a crosslinked ethylene vinyl acetate and optionally a second copolymer having carboxyl groups or glycidyl methacrylate groups; wherein the foam layer has at least one surface adhering to the rubber layer directly and provided that either the first copolymer or the second copolymer is present and the composite is free of glues or adhesive films in the interface between the rubber layer and the foam layer.



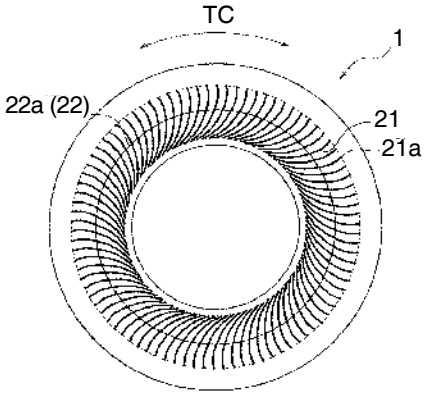
Stabilizer structure for a tread of a tire
U.S. patent: 11,697,312
Issued: July 11, 2023
Inventors: Ettore Passante Spaccapietra, Philippe Joseph Auguste Muller, Marco Nicolò Coccon and Lionel Jean-Marie Bortolet
Assigned: Goodyear Tire & Rubber
Key statement: A tread for a tire includes a first circumferential main groove, a second circumferential main groove, a third circumferential main groove and a fourth circumferential main groove. The fourth main groove has a stabilizing structure for increasing tread stiffness. The stabilizing structure has a circumferentially extending subgroove in a radially innermost bottom of the fourth circumferential main groove. The subgroove is axially offset a predeter-

Patent News

mined amount from a centerline of the fourth circumferential main groove.



Pneumatic tire
U.S. patent: 11,679,630
Issued: June 20, 2023
Inventor: Kazuo Shimomura
Assigned: Toyo Tire & Rubber
Key statement: A tire includes a tread portion, a sidewall portion and a bead portion. The bead portion includes a bead core that extends continuously in an annular shape in a tire circumferential direction and a bead filler disposed adjacent to the bead core and outside the bead core in a tire radial direction. Reinforcing cords are provided in the bead portion and the sidewall portion so as to be curved such that inclination angles of the reinforcing cords with respect to the tire circumferential direction gradually increase with nearness to an outside in the tire radial direction.



Sealant-containing tire and related processes
U.S. patent: 11,697,306
Issued: July 11, 2023
Inventors: Brian S. Alexander, Bradley S. Plotner, Ross W. Widenor, Jared J. Griebel and Kung-Ching Liao
Assigned: Bridgestone Americas Tire Operations
Key statement: Processes for producing a sealant layer-tire inner liner combination as well as a sealant layer-containing tire and related processes involving the sealant layer-containing tire are disclosed. The sealant layer is adhered to the tire inner liner, has a thickness of 2-8 mm and comprises 100 parts of at least one rubber, 90-500 phr of at least one tackifier, optionally one or more extenders, optionally at least one hydroscopic substance and a cure package.

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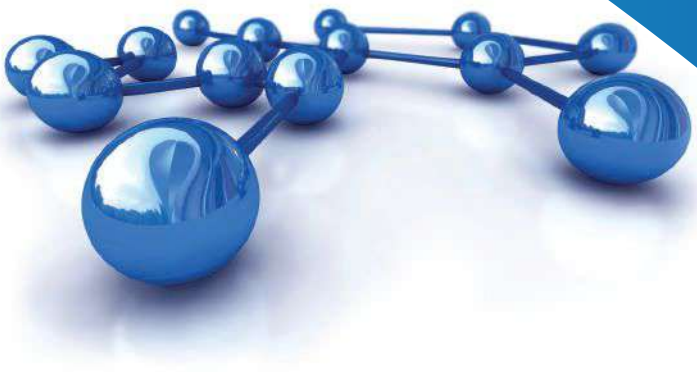

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Patent News

Rubber compositions with disaggregated carbon nanotubes
U.S. patent: 11,697,728
Issued: July 11, 2023
Inventors: Christopher Pappas and Christophe Chouvel
Assigned: Michelin
Key statement: Described are articles including treads and/or other tire components that are formed at least in part by rubber compositions having solid agglomerated material comprising disaggregated carbon nanotubes. Such rubber compositions include a diene rubber component and a solid agglomerated material comprising disaggregated carbon nanotubes that consist of a continuous network of carbon nanotubes that contains 1) voids and 2) aggregates of carbon nanotubes having a mean size d_{50} of less than 5 µm, the voids and the aggregates together in an amount that is less than 60% of a predetermined surface area, as determined by electron microscopy imagery analysis, the remainder being the disaggregated carbon nanotubes in the continuous network that do not comprise a clearly defined shape.

Tire for a motorcycle
U.S. patent: 11,697,305
Issued: July 11, 2023
Inventor: Kota Tomita
Assigned: Sumitomo Rubber
Key statement: Provided is a tire for a motorcycle having an improved turning stability on wet road surface, the tire comprises a tread composed of a rubber composition, which comes into contact with a road surface, wherein Hs being a rubber hardness and M300 being a tensile stress (MPa) at 300% elongation of the rubber composition of the tread satisfy Equations 1, 2 and 3:

$60 \leq Hs \leq 80$, Equation 1
$2 \leq M300 \leq 12$ and Equation 2
$(M300 - 2)/(Hs - 60) \leq 0.75$. Equation 3

Methods for treating inner liners, inner liners resulting therefrom and tires containing such inner liners
U.S. patent: 11,697,260
Issued: July 11, 2023
Inventors: Kung-Ching Liao, Jared J. Griebel, Brian S. Alexander, Bradley S. Plotner and Ross W. Widenor
Assigned: Bridgestone Americas Tire Operationa
Key statement: Methods for treating a cured inner liner as well as treated, cured inner liners resulting from such methods are disclosed. Also disclosed are tires containing the treated inner liners. The methods include treatment of the lower surface of inner liner surface with a rubber-containing liquid to produce a rubber-containing film thereupon.

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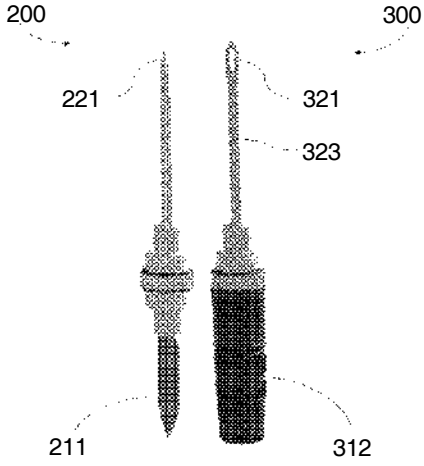
Patent News

Rubber composition and a rubber product
U.S. patent: 11,702,533
Issued: July 18, 2023
Inventors: Marc Weydert, Frida Nzulu, Arpan Datta Sarma, Pierre Verge and Daniel Schmidt
Assigned: Goodyear Tire & Rubber and Luxembourg Institute of Science and Technology
Key statement: The present invention is directed to a rubber composition comprising 100 phr of at least one diene based rubber, 30 phr to 250 phr of at least one filler and 1 phr to 40 phr of an epoxidized and aminated fatty acid ester, wherein the epoxidized and aminated fatty acid ester is obtained from the reaction of an epoxidized fatty acid ester with an aliphatic amine. Furthermore, the present invention is directed to a rubber product, such as a tire, comprising such a rubber composition.

Tire repair kit system and method
U.S. patent: 11,701,847
Issued: July 18, 2023
Inventor: Yongbo Jiang
Assigned: Rexpair Industry
Key statement: A method for repairing a tire is provided that includes: (a) providing a reamer, a knife, an insertion tool forming a receiving opening, a plugging strip and vulcanizing fluid; (b) inserting the reamer into a puncture hole of a tire to clear debris; (c) applying the vulcanizing fluid; (d) inserting the plugging strip into the insertion tool; (e) inserting the insertion tool with the plugging strip into the puncture hole to cause the plugging strip to fold into the puncture hole mixed with the vulcanizing fluid to bond the plugging strip and the tire; (f) removing the insertion tool from the puncture hole causing a middle portion of the plugging strip to fold internally forming a four-layer seal within the puncture hole; and (g) cutting the plugging strip from the insertion tool and the excess portions of the plugging strip with the knife.



Rubber composition and tire
U.S. patent: 11,701,921
Issued: July, 18, 2023
Inventors: Misa Aoki, Seiichi Tahara and Takuya Ogasawara
Assigned: Bridgestone
Key statement: Provided is a rubber composition that achieves both wet performance and low loss property while delivering excellent dry handling performance. A rubber composition comprises: a rubber component; and a styrene-alkylene block copolymer, wherein a total styrene content of the styrene-alkylene block copolymer is 30 mass % or more.

Modified conjugated diene based polymer and rubber composition including the same
U.S. patent: 11,702,485
Issued: July 18, 2023
Inventors: Kyung Chang Seo, Yu Jin Kim, Youk Reol Na and No Ma Kim
Assigned: LG Chem
Key statement: A modified conjugated diene based polymer and a rubber composition including the same are

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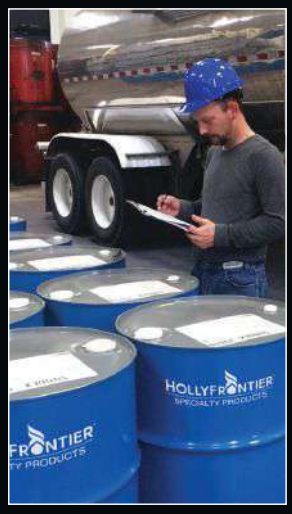

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disclosed herein. In some embodiments, the modified conjugated diene based polymer includes a modified monomer-derived functional group represented by Formula 1 and an aminoalkoxysilane based modifier-derived functional group at least one end thereof, wherein the polymer having a unimodal molecular weight distribution and a polydispersity index (PDI) of 1.0 or more to less than 1.7. The polymer has a narrow and unimodal molecular weight distribution and has excellent tensile properties and viscoelastic properties, while having excellent processability.

Rubber composition and tire
U.S. patent: 11,701,921
Issued: July, 18, 2023
Inventors: Misa Aoki, Seiichi Tahara and Takuya Ogasawara
Assigned: Bridgestone
Key statement: Provided is a rubber composition that achieves both wet performance and low loss property while delivering excellent dry handling performance. A rubber composition comprises: a rubber component; and a styrene-alkylene block copolymer, wherein a total styrene content of the styrene-alkylene block copolymer is 30 mass % or more.

Ultra-light graphene-rubber foam particle for soles and method for preparing same
U.S. patent: 11,702,524
Issued: July, 18, 2023
Inventors: Tianning Ding, Decai Ding and Yousi Ding
Key statement: An ultra-light graphene-rubber foam particle for soles is prepared from, by weight, 60-65 parts of natural rubber, 8-12 parts of isoprene rubber, 8-12 parts of butadiene rubber, 6-8 parts of styrene butadiene rubber, 0.8-1.0 parts of modified graphene, 0.08-0.12 parts of poly(N-vinylacetamide), 0.8-1.0 parts of silicone oil, 3.0-3.5 parts of inorganic nano-particles, 1.2-1.5 parts of activated zinc oxide, 0.8-1.0 parts of zinc stearate, 1.0-1.2 parts of stearic acid, 0.8-1.0 parts of crosslinking agents, 2.0-3.0 parts of flow promotors and 1.5-1.8 parts of foaming agents. According to the invention, the modified graphene is uniformly dispersed into the rubber materials, so that the ultra-light graphene-rubber foam particle has good thermal stability, wear resistance and tensile strength, the permanent compressive-deformation performance and thermal contraction resistance are improved, and the weight is reduced by over 50%.

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Styrenic block copolymer solutions enhance sustainability and the circular economy

by Aparajita Bhattacharya, Freddy Vervoort, Eduardo Goncalves and Yuliya Streen, Kraton

Kraton Corporation is the inventor of styrenic block copolymers (SBC) and has been a leading global producer of SBCs and sustainable pine chemical solutions for more than six decades. Kraton's block copolymer technology is based on anionic polymerization, a process that allows for well controlled and precise molecular structures which can be tailored to meet specific application requirements. This technology also ensures an extremely high degree of monomer conversion, ensuring minimal monomer residuals in the final polymer.

The architecture of Kraton SBCs comprises polystyrene end blocks that are covalently bonded to a rubbery midblock consisting of either butadiene, isoprene or mixtures of these components. Polystyrene blocks have a glass transition temperature (T_g) in the range of 85°C to 105°C, and form the hard phase. On the other hand, the rubbery midblocks have a much lower glass transition temperature that depends on the composition, but usually in the range of -80°C to -30°C, and form the soft phase. At room temperature, the incompatibility between the polystyrene and rubber midblocks causes the hard polystyrene blocks to separate and aggregate, forming hard domain structures that are distributed within a continuous soft rubber phase. These domains of polystyrene behave as physical crosslinking points, creating a rubber network that leads SBCs to have excellent elastic properties, flexibility and softness, along with high strength.

Kraton's SBCs have either an unsaturated rubber midblock (USBC) or a selectively hydrogenated midblock (HSBC). HSBC polymers have better resistance to high temperatures, improved mechanical properties due to stronger phase separation, can withstand higher shear forces, and have overall improved resistance to oxidative/ozone degradation and weathering. Both USBC and HSBC are used in blends with polypropylene, HDPE/LDPE/LLDPE, polystyrene and other styrene containing polymers, polycarbonate, polyurethanes and other engineering thermoplastics like polyamide and polyesters.

Kraton focuses on innovation that leads to sustainable solutions, such as enabling plasticizer-free polymers for the health and hygiene industry, allowing the use of natural fibers as fillers in polyolefin compounds, enhancing properties of bioplastics and allowing lightweighting of products, to name a few. In recent years, consumers, regulatory bodies and brand owners have placed tremendous emphasis on creating a circular economy within a tightly stipulated timeline, and mechanical recycling has stood out as one of the primary ways to achieve this goal. The three key challenges that the plastics industry is facing today in mechanical recycling are:

- Designing products with minimal materials to enable end-of-life recyclability, while meeting all property requirements of the application
- Improving the performance of products made with recycled content
- Enabling the reuse and recycling of mixed plastic wastes.

In 2020, Kraton introduced the CirKular+ product line, specifically designed for use with recycled plastics (PCR and PIR) and enabling the design of products for recyclability. CirKular+ additives have been approved for use with HDPE and polypropylene by the Association of Plastic Recyclers in North America, and by RecyClass in Europe. The CirKular+ product line comprises the compatibilization series and performance enhancement series, as shown in table 1. The products in the compatibilization series have functionalized rubber midblocks which impart midblock polarity, making these products highly compatible with both polar and non-polar plastics. C1010 (50% recycled) is a product that includes 50% of Kraton's post-industrial waste. The polymers C2000 and C3000, on the other hand, are not functionalized, but are highly compatible with non-polar plastics, primarily polyolefins and polystyrene. These polymers help in improving the mechanical properties and overall performance of polyolefinic compounds, with PCR as well as virgin resins.

In this article, data are presented that show comparisons between the performance of CirKular+ compatibilizers and polyolefinic compatibilizers that are alternatively used in this space.

Table 1 - Kraton's CirKular+ product line showing processing temperature and spectrum of compatibility with polar and non-polar plastics

CirKular+ series	CirKular+ grade	Maximum processing T°C	FDA clearance*	Melt flow 230°C/ 5 kg lg/ 10 minutes	Polyolefins: PP, HDPE, LDPE, MDPE, polyolefinic blends, mPE	PS, HIPS	EVA	EVOH, PVA	Wood fiber and cellulose	Polylactic acid	PET	Polyamides and nylons	ABS	PC
Compatibilization series	C1000	280°C	✓	22	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	C1010	280°C	✓	34	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	C1010 (50% recycled)	280°C		34	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Performance enhancement series	C2000	280°C	✓	24	✓	✓	✓	✓	✓					
	C3000	200°C	✓	11	✓	✓								

*Melt flow, 200°/5 kg lg/ 10 minutes

Table 2 - melt flow rate and structural details of polymers used to modify PCR polypropylene

Polymer	*MFR (230°C, 2.16 kg)*	*Structure*
Control r-PP	17.3	
C2000	11.0	*S-E/B-S*
C3000	11 (200°C/5 kg)	*S-B-S*
POE (EP-copolymer)	3.5	*16% C2 content*

Also highlighted are examples of commercially successful applications with CirKular+ products, with case studies and data to support the examples.

Experimental

Post-consumer recycled (PCR) polypropylene (r-PP) with a melt flow rate of 17.3 g/10 minutes at 230°C/2.16 kg was used as the control material. The r-PP was modified by compounding with C2000, C3000 or a POE (ethylene propylene copolymer) in a twin-screw extruder at 5% and 10% loading levels by weight. Details of the melt flow rate and polymer composition are shown in table 2.

The following physical properties were measured on the extruded compounds:

Melt flow rate (MFR)

Melt flow rate was measured according to ASTM D1238.

Mechanical properties

Mechanical properties were tested on polymer and compound specimens prepared by injection molding. The neat polymers were tested for tensile properties according to ASTM D412 for elastomeric materials, and the compounds were tested by ASTM D638 methods for plastics. The tests were conducted on an Instron 3366 that was fitted with a 1 kN load cell. Notched Izod impact strength of the compounds was measured using the Instron CEAST 9050 impact tester. A 4 ft.-lb. hammer was used, and impact strength was measured at room temperature (RT)

Figure 1 - stiffness-toughness balance of recycled PP compounds modified wiith CirKular+ C2000 and POE

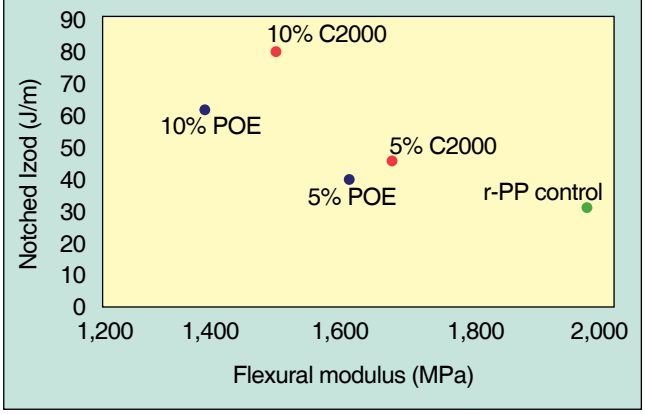
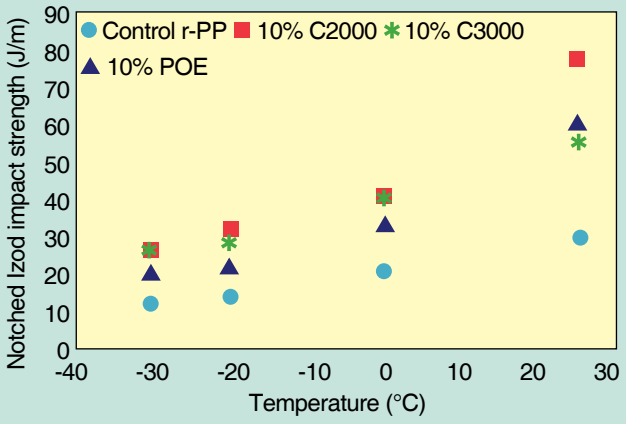


Figure 2 - notched Izod impact energy as a function of temperature for unmodified r-PP (control r-PP) r-PP modified with 10 wt.% of C2000, C3000 and EP-copolymer POE



and lower temperatures down to -30°C. Flexural modulus was tested according to ASTM D790 on an Instron 3366. Secant modulus at 1% strain was reported.

Results and discussion

Performance balance and formulation efficiency with CirKular+ performance enhancement additives

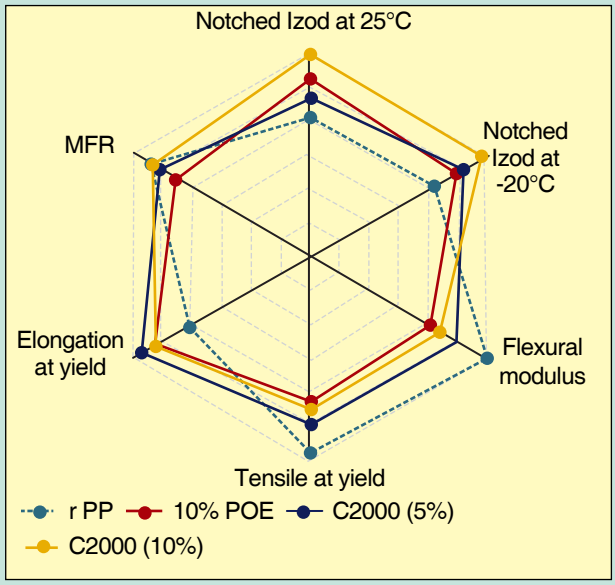
The stiffness-toughness balance of r-PP compounds modified with CirKular+ C2000 and POE is shown in figure 1. The r-PP control has high stiffness, but poor impact performance, as shown by the high flexural modulus and low RT notched Izod impact energy. Modifiers with high rubber content were used to increase impact strength; however, it was accompanied by a drop in stiffness of the compounds. It is seen that 5wt.% or 10 wt.% C2000 leads to a better balance of properties with a higher increase in impact energy, and is accompanied by a lower loss in stiffness as compared to the same loading levels of POE.

Stiffness is characterized by flexural modulus on the X-axis, and toughness has been shown as notched Izod impact energy on the Y-axis. These data also show that C2000 can be used at a lower amount than an EP-copolymer with r-PP, but can still lead to a higher impact strength, thus providing a better formulation efficiency.

Good impact strength at low temperatures is important in several rigid applications. Figure 2 shows the impact energy of the r-PP compounds with 10 wt.% of C2000, C3000 and POE at room temperature, 0°C, -10°C, -20°C and -30°C. C2000 and C3000 led to higher impact strength, especially at lower temperatures, compared to POE.

Figure 3 shows a spider chart comparing some of the other key properties of the unmodified r-PP and modified r-PP compounds for a rigid part application using an injection molding process. It can be seen that notched Izod impact strength at a low temperature of -20°C is similar between the 5 wt.% CirKular+ C2000 compound and the 10 wt.% POE compound, while MFR, elongation at yield, tensile strength at yield and flexural modulus were higher for the C2000 compound. This shows that

Figure 3 - spider chart comparing performance of unmodified recycled PP (r-PP) with compounds modified with CirKular+ C2000 at 5 wt.% and 10 wt.% loading levels and POE at 10 wt.%



a more efficient formulation can be prepared using CirKular+ C2000 modifier without compromising performance. Addition of 10 wt.% C2000 leads to further improvement in performance of the r-PP compound.

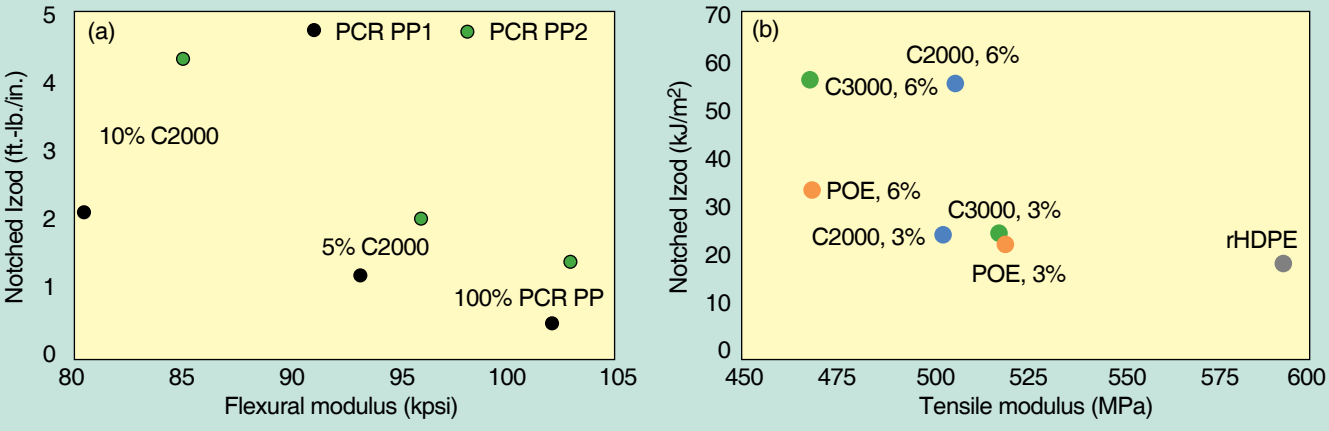
While the data above have been shown for compounds prepared in a twin-screw extruder, a similar trend is observed for injection molded articles prepared by dry blending of the CirKular+ additives with PCR polypropylene. Figure 4a shows improvement in impact strength achieved with 5 wt.% and 10 wt.% of C2000 dry blended with PCR PP from two different sources. The impact strength of the compound depends strongly on the quality of the PCR source itself. CirKular+ C3000 is more compatible with PCR HDPE. It can be seen from figure 4b that both C2000 and C3000 can provide improved impact strength when dry blended with PCR HDPE. The molecular architecture and processing temperatures of C3000 are aligned more closely with HDPE than with C2000. The ability to dry blend CirKular+ modifier into recycled streams allows one to use the modifier as a drop-in solution, thus eliminating the compounding step that could lead to potential system cost reduction.

Recycled plastic streams are usually contaminated with other components, with contamination ranging from 0.1% to 20%. Usually, the r-PP is contaminated with HDPE, and vice versa. But there may be recycled streams that are a combination of plastics with varying polarity; for example, PS/HDPE, r-PET/PE, ABS/PC/HIPS, and more. In most cases, the contaminant (minor component) is incompatible with the primary matrix (major component) and this acts as a defect, leading to a discontinuous morphology. A styrenic block copolymer has a midblock rubber molecular structure that makes it compatible with both polypropylene and polyethylene molecules, and acts as a compatibilizer for polyolefinic recycle streams, leading to a more continuous morphology. In the case of mixed plastic streams, a functionalized SBC polymer is used, where the polar functional group or polystyrene end block is compatible with the polar component, and the rubber main chain is compatible with the non-polar component.

Recyclability of CirKular+ additives

One of the aims when using SBC copolymers with virgin polyolefins or to modify recyclate streams is to design the products for recyclability. The compounds are thus expected to be subjected to multiple heat histories and high shear processing. Compounds of PCR PP with 6 wt.% of CirKular+ C2000 were evaluated in five passes through a twin-screw extruder. Unmodified PCR-PP was used as the control material. An antioxidant was added to the compound before each pass through the extruder to minimize further degradation of the PCR material.

Figure 4 - stiffness-toughness balance in (a) PCR-PP systems modified with C2000, as seen by notched Izod impact strength (y-axis) and flexural modulus (x-axis), and (b) PCR-HDPE systems modified with C2000 and C3000, as seen by notched Izod impact strength (y-axis) and tensile modulus (x-axis)



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- Intensive Mixers
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NEW RELIABLE 24” Lab Mill - dual drives/variable friction

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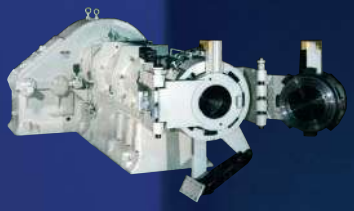

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NEW RELIABLE 36” Calender - roller bearings & variable speed

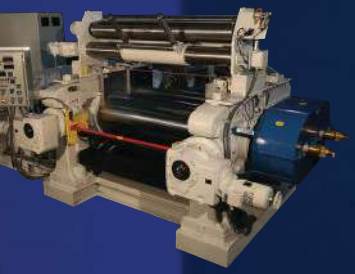
REBUILT 1200 ton Slab Side Press

NEW RELIABLE 36” Cushion Calender

BUILT Cracker Mill

NEW 16” x 42” Mill w/Overhead Blender

REBUILT Mixer

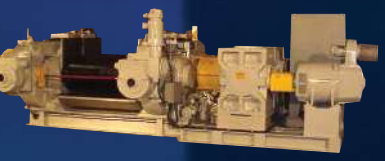


ILT 22” x 60” Variable Speed Mill rhead Mill Blender, drilled rolls & otorized roll nip adjustments

NEW 12” x 24” RELIABLE Two Roll Die Calender & Take-up System

NEW RELIABLE 84” Calender - roller bearings & drilled rolls

REBUILT 60” x 60” 2,000 ton Hydraulic Press



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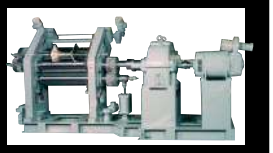


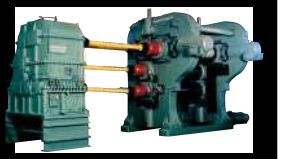

INVENTORY LIST

UNITIZED 2-ROLL MILLS

2 - 28" x 28" x 100"
3 - 26" x 26" x 100"
2 - 26" x 26" x 100" - Front Drilled Roll
1 - 26" x 26" x 100" - Drilled Rolls
1 - 28" x 28" x 84"
8 - 26" x 26" x 84"
1 - 26" x 26" x 84" - Dual Hydraulic Drives
1 - 26" x 26" x 84" - Hydraulic Roll Adj.
2 - 26" x 26" x 84" - Front Drilled Rolls
1 - 26" x 26" x 84" - Drilled Rolls
2 - Twin 26" x 26" x 84"- 400HP & 500 HP
1 - 24" x 24" x 84"
2 - 24" x 24" x 60"
1 - Twin 22" x 20"x 60" - 250 HP
12 - 22" x 22" x 60"
2 - 22" x 22" x 60" - Front Drilled Rolls
1 - 22" x 22" x 60" - Both Drilled Rolls
1 - 22" x 22" x 60" - **Roller Bearings**
1 - 22" x 22" x 60" - Hydraulic Roll Adj.
3 - 22" x 22" x 60" - Motorized Nip Adj.
4 - 22" x 22" x 60" - Heavy duty bearing journals
4 - 22" x 20" x 60"
4 - 22" x 20" x 60" - Heavy duty bearing journals
1 - 20" x 20" x 60" - Silicone
1 - 22" x 22" x 54" - Heavy duty
3 - 18" x 18" x 50"
3 - 18" x 18" x 48"
4 - 16" x 16" x 42"
4 - 16" x 16" x 40"
1 - 16" x 16" x 36"
1 - 16" x 16" x 32"
1 - 14" x 14" x 36"
3 - 14" x 14" x 30"
2 - 12" x 12" x 30"
1 - 10" x 10" x 26" - **Roller Bearings**
2 - 12" x 12" x 24"
2 - 10" x 10" x 24"
1 - 10" x 10" x 20"

Refiners/Crackers 2 ROLL MILLS

1 - 22" x 26" x 42"
1 - 32" x 20" x 38"
2 - 24" x 24" x 36"
3 - 22" x 22" x 36"
1 - 20" x 24" x 32"
2 - 19" x 24" x 30"
1 - 16" x 16" x 30"

Compact Cabinet Style Mills

1 - 14" x 14" x 36"- Both Drilled Rolls
2 - 14" x 14" x 30"
1 - 12" x 12" x 36"
1 - 12" x 12" x 30"
1 - 10" x 10" x 26" - Roller Bearings
2 - 12" x 12" x 24"
2 - 10" x 10" x 24"
1 - 10" x 10" x 20"
3 - 8" x 8" x 16"
2 - 8" x 8" x 16" - Var. Speed/Var. Friction
2 - 8" x 8" x 16" - Roller Bearings
16 - 6" x 6" x 12"/13"
3 - 6" x 6" x 13" - Var. Speed/Var. Friction
1 - 6" x 6" x 13" - Roller Bearings
2 - 4" x 4" x 8"
2 - 3" x 3" x 8"
2 - 3" x 3" x 8" - Var. Speed/Var. Friction

NEW "Cabinet Style" Mills up to 18" x 50"

NEW LAB MILLS

NEW - 3" x 8" various models
NEW - 6" x 13" various models
NEW - 8" x 16" up to 18" x 50" various models

INTERNAL MIXERS - Banbury® Type

1 - "Farrel" #F-370 - Unidrive Chamber Body, Base & Hopper
1 - "Farrel" #F-270 - Unidrive Chamber Body
1 - "Farrel" #11D - Unidrive Chamber Body
1 - "Farrel" #11D - Semi Unidrive
1 - "Farrel" #11D - Unidrive Body w/4 wing rotors
1 - "Farrel" #9 - Chamber Body - Drilled Sides
1 - "Farrel" #9 - Semi Unidrive Complete
2 - "Farrel" #9 - Conventional Chamber Body
1 - "Farrel" #F-80 - Unidrive Complete - 300 HP
1 - "Farrel" #F-80 - Unidrive Chamber Body & Hopper
1 - "Farrel" #3D - Unidrive Complete
1 - "Farrel" #3D - Unidrive Chamber Body & Hopper
1 - "Farrel" size No. #1D Mixer; 16.5 liter capacity/ 27 lbs. Semi-UniDrive with 150 HP DC/SCR variable speed motor, **EXCELLENT CONDITION**
2 - "Farrel" #1 - 16.5 liter Clam shell discharge Mixer - 100/50 HP Two speed motor
1 - "Farrel" #1 - 16.5 liter Replacement Chamber Body & Parts
1 - "Frances-Shaw" size K1 Mixer - intermeshing rotors
2 - "Bolling" "#OM" Lab Mixers - one w/50 HP motor & one w/40 HP motor
1 - "Farrel" "#00C" 4.3 liter variable speed motor
1 - "Farrel" "#00" 4.3 liter variable speed motor **EXCELLENT CONDITION**
1 - **"RELIABLE"** Model R-260 Lab Mixer, 4.3 liter 50 HP variable speed **EXCELLENT CONDITION**
1 - "Bolling" "#00" Lab Mixer - w/30 HP motor
1 - "Buzuluk" Lab Mixer - "BR1600" - 1.6 liter - **Drop Door** - UniDrive/variable speed motor
3 - "Farrel" "#BR" - 1.6 liter - variable speed motor w/new controls
1 - **"RELIABLE"** "Model R-100" - 1.6 liter - variable speed motor
1 - "Farrel" "#Midget" - .41 liter - variable speed motor w/new controls
1 - "Farrel" "#B"-Replacement Chamber Body & Hopper
1 - "Farrel" "#BR" - Replacement Chamber Body & Hopper
1 - "Farrel" "#Midget" - Replacement Chamber Body & Hopper
2 - "Lufkin" F-270/D-890 Unidrive Gear Reducers
1 - "Farrel" 3D Unidrive Gear Reducer
1 set - Spare/replacement Size #270 "Farrel" 2-wing mixer rotors
1 set - Spare/replacement Size #11D "Farrel" 4-wing mixer rotors
1 set - Spare/replacement Size #9FCM "Farrel" mixer rotors - Style #15
2 sets - Spare/replacement Size #9 "Farrel" rotors

INTERNAL MIXERS - Kneader Type

1 - "Kneader Machinery" 75 Liter - Model KD - 75 - 150 Kneader Mixer/with 150 HP motor & PLC controls **(NEW in 2004 - EXCELLENT/NEW CONDITION)**
1 - "Kneader Machinery" 55 Liter - Kneader Mixer/complete w/200 HP motor & PLC controls - **(NEW in 2005 - EXCELLENT/NEW CONDITION)**

INTERNAL MIXERS - Kneader Type (Continued)

2 - "Moriyama" 55 Liter - Type DX-55-75 Kneader Mixer/ complete w/75 HP motors & controls
2 - "TMP" 55 Liter - Kneader Mixers - one complete & one with mixer chamber only
1 - "TMP" 35 Liter - Kneader Mixer w/125 HP w/variable speed motor **(NEW in 1994)**
1 - "B-P" Sigma Blade Mixer - Pilot Production/silicone
1 - "B-P" Sigma Blade Mixer - Lab size/silicone

EXTRUDERS/STRAINERS

1 - "Farrel" 15" w/Pneumatic Stuffer
2 - "Farrel" 15"x12" w/Pneumatic Stuffer
2 - "Davis Standard" 3 1/2" Extruders w/Power Roller Feed
1 - "Royle" 10" Hot Feed
1 - "NRM" 8" Hot Feed Strainer
3 - "NRM" 6" Hot Feed
2 - "Royle" 6" Hot Feed
1 - "NRM" 4 1/2" Cold Feed w/Power Roller Feed - 125 HP
1 - "NRM" 4 1/2" Cold Feed 17:1 L/D w/Power Roller Feed - **EXCELLENT CONDITION**
1 - "NRM" 3 1/2" Cold Feed w/Power Roller Feed
1 - "NRM" 1 1/2" Cold Feed
1 - "Maag" 2 1/2" Pin Barrel Extruder with Gear Pump **EXCELLENT CONDITION**
1 - "Royle" 2" Hot Feed
1 - "Barwell" Model "Midi" Preformer - ram type

CALENDERS

1 - 26" x 100"- 2 Roll
1 - 24" x 84"- 3 Roll
1 - 24" x 84"- 2 Roll
1 - 28" x 82"- 2 Roll **EXCELLENT COND.**
1 - 28" x 78"- 4 Roll, "Z" (4) Drilled Rolls/Ind. Drives to suit
1 - 26" x 78"- 3 Roll, Even Speed & Friction Gears to suit
1 - 24" x 66"- 3 Roll, Even Speed & Friction Gears
1 - 24" x 60"- 2 Roll, Variable Speed & Variable Friction
1 - 22" x 60"- 3 Roll, Even Speed & Friction Gears
1 - 18" x 54"- 2 Roll - **EXCELLENT CONDITION**
1 - 18" x 48"- 2 Roll
1 - 16" x 48"- 2 Roll
1 - 20" x 42"- 2 Roll - **Roller Bearings**
1 - 18" x 36"- 3 Roll
1 - 12" x 28"- 3 Roll Incl. Offset **EXCELLENT CONDITION**
1 - 10" x 20"- 3 Roll
1 - 8" x 16"- 4 Roll "Z"
1 - 8" x 16"- 3 Roll
3 - 6" x 13/12"- 3 Roll
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1 - 3" x 8"- 2 Roll - **EXCELLENT/NEW CONDITION**

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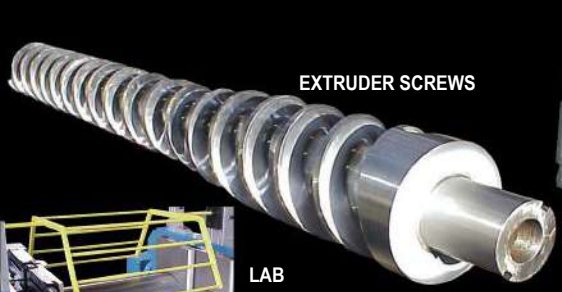

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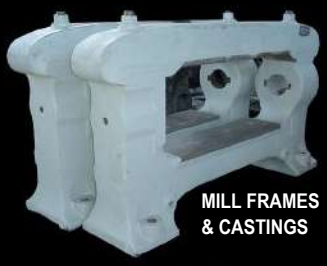

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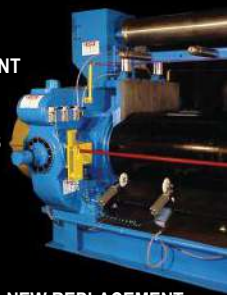

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SIZE	RAM	DAYLIGHT	TYPE
3 - 60"x60"	42" dia	64"	Slab Side
1 - 60"x40"	42" dia	55"	Slab Side
4 - 48"x48"	36" dia	48"	Slab Side
1 - 48"x48"	36" dia	36"	Slab Side
1 - 48"x48"	36" dia	36"	Post
2 - 42"x42"	30" dia	40"	Slab Side
1 - 40"x72"	28" dia	34"	Post
3 - 40"x40"	30" dia	30"	Post
1 - 38"x38"	30" dia	35"	Post
1 - 36"x36"	30" dia	42"	Post
3 - 36"x36"	30" dia	30"	Post
1 - 36"x36"	22" dia	43"	Post
1 - 36"x36"	24" dia	30"	Slab Side
1 - 36"x36"	20" dia	48"	Slab Side
1 - 36"x36"	18" dia	55"	Post
1 - 34"x34"	24" dia	43"	Slab Side
1 - 34"x34"	24" dia	20"	Post
1 - 34"x34"	20" dia	30"	Post
1 - 34"x34"	20" dia	42"	Post
1 - 32"x42"	16" dia	28"	Post
3 - 32"x32"	24" dia	30"	Slab Side
1 - 32"x32"	24" dia	28"	Slab Side
2 - 32"x32"	24" dia	20"	Slab Side
3 - 32"x32"	24" dia	32"	Slab Side
2 - 32"x32"	24" dia	32"	Slab Side
1 - 32"x32"	24" dia	19"	Slab Side
2 - 32"x32"	20" dia	42"	Post
1 - 32"x32"	20" dia	27"	Post
3 - 32"x32"	16" dia	37"	Post
1 - 32"x32"	12" dia	26"	"C" Frame
1 - 30"x60"	(2)12" dia	20"	"C" Frame
1 - 30"x48"	22" dia	25"	Post
1 - 30"x30"	24" dia	34"	Post
1 - 30"x30"	20" dia	22"	Slab Side
2 - 30"x30"	24" dia	24"	Slab Side
1 - 30"x30"	22" dia	24"	Slab Side
2 - 30"x30"	22" dia	24"	Slab Side
1 - 30"x30"	16" dia	32"	Post
2 - 30"x24"	18" dia	40"	Post
2 - 28"x36"	12" dia	32"	Post
2 - 28"x28"	22" dia	22"	Post
3 - 28"x28"	18" dia	44"	Post
4 - 26"x26"	20" dia	20"	Post
1 - 24"x156"	(4)14" dia	30"	Post
4 - 24"x24"	20" dia	20"	Post
1 - 24"x24"	18" dia	36"	Slab Side
1 - 24"x24"	18" dia	22"	Post
1 - 24"x24"	16" dia	34"	Slab Side
2 - 24"x24"	16" dia	32"	Post
2 - 24"x24"	14" dia	20"	Post
6 - 24"x24"	14" dia	14"	Post
1 - 24"x24"	12" dia	30"	"C" Frame
3 - 22"x22"	14" dia	14"	Post
1 - 20"x20"	14" dia	48"	Post
3 - 20"x20"	12" dia	22"	Post
3 - 20"x20"	10" dia	18"	Post
3 - 18"x18"	9" dia	9"	Post

1 - 36"x36" Self Cont. Motorized Press
1 - 32"x38" Self Cont. Motorized Press
1 - 30"x30" Self Cont. Motorized Press
1 - 24"x24" Self Cont. Motorized Lab Press
6 - 18"x18" Self Cont. Motorized Lab Presses
2 - 16"x16" Self Cont. Motorized Lab Presses
1 - 15"x15" Self Cont. Motorized Lab Press
3 - 12"x12" Self Cont. Motorized Lab Presses
4 - 10"x10" Self Cont. Motorized Lab Presses
5 - 18"x12" Benchtop Hand Pump Lab Press
5 - 18"x18" - 12"x12" Benchtop Hand Pump Lab Presses
1 - 12"x 12" Benchtop Hand Pump Lab Press

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INVENTORY HIGHLIGHTS

MIXING LINE:

1 - "Kneader Machinery" 55 Liter - Model KD-55-200AC Kneader Mixer w/200 HP variable speed motor & PLC controls - **(NEW in 2005)** - **EXCELLENT CONDITION**
1 - 18" x 48" **"RELIABLE"** Modern Two Roll Mill, direct driven, unitized base w/100 HP motor **(Built to suit)**
1 - 6" x 13" "Bolling" Two Roll Variable Speed Lab Mill - silicone features - **Excellent Condition - Quick Delivery**
3 - 18" x 18" Self contained Motorized Presses, 75 ton, with **NEW** electric heated platens; all **NEW** controls
1 - 18" x 12" "PHI" Self-Contained Motorized Transfer Press, 50/10 ton, with electric heated platens; all controls - **Very Good Condition**
1 - 22" x 60" "Nippon" Two Roll Mill with Drilled Rolls, Variable Speed/Variable Friction, dual motors, Anti-friction/Roller Bearings, Motorized Roll Nip Adjustments; **many extras - Very Good Condition**
1 - 16" x 42" "Kobe" Mill, unitized design, 60 HP motor
1 - 8" x 16" **"RELIABLE"** Two Roll Lab Mill - Cabinet Style, 15 HP motor & controls
1 - **"RELIABLE"** Model R-100 Lab Mixer - 1.6 liter w/variable speed motor & controls
1 - "KSBI - Kobelco Stewart-Bolling" size "00" Lab Mixer - 1.6 liter w/30 HP variable speed motor & controls. (New in 1990) **EXCELLENT CONDITION**
1 - 22" x 60" "Eemco" Mill, direct driven unitized base, compact design w/150 HP motor, **EXCELLENT CONDITION**
1 - 26" x 84" "Farrel" Rubber Mill, both **Drilled Rolls**, direct driven, unitized base 250 HP drive train
1 - 26" x 100" "Eemco" Mill, direct driven, unitized base "Lufkin" gear reducer, 300 HP variable speeds
1 - "Kneader Machinery" 75 Liter - Model KD-75-250 Kneader Mixer w/200 HP motor
1 - 6" x 13" **"RELIABLE"** Two Roll Lab Mill 7 1/2 HP; Rebuilt - **QUICK DELIVERY**
1 - 22" x 60" "Farrel" Two Roll Plastics Mill, low profile mill frames, direct driven, "Alten" gear reducer, unitized base variable speed motor. **EXCELLENT CONDITION**
1 - 26" x 84" "Bolling" Two Roll Mill, low profile mill frames, direct driven, "Lufkin" gear reducer, unitized base 200 HP motor.
1 - 24" x 24" "Wabash" Self-Contained Hydraulic Press; 200 ton with electric heated platens. **EXCELLENT CONDITION**
1 - 28" x 100" "Farrel" Mill, direct driven, unitized base, built to suit
2 - 22" x 60" "Comerio" Mills **w/motorized roll adjustments,** unitized design; **compact footprint**

INVENTORY HIGHLIGHTS (Cont.)

1 - 26" x 84" "Farrel" Rubber Mill - Dual "Hagglunds" hydraulic drives, hydraulic roll nips, variable speed/ variable friction. **Rebuilt Condition with one year warranty. IMMEDIATE DELIVERY**
1 - "Farrel" size "BR" Lab Mixer w/variable speed motor & NEW controls
1 - 30" x 40" "Southwark" Four Post Press, 18" dia. ram, 20" daylight w/new electric platens & self-contained hydraulics
1 - **Twin** 32" x 32" "French Oil Mill" Slab Side Hydraulic Press System; 750 ton each with a self-contained common hydraulic pump system
2 - 12" x 12" "PHI" C-Frame Design, Benchtop Press; 35 ton w/electric heated platens
1 - **"RELIABLE"** 28" wide Self-Contained Hydraulic Guillotine Style Bale Cutter - **QUICK DELIVERY**
1 - 6" x 13" "KSBI" "Cabinet Style" Lab Mill - Variable Speed; **(NEW in 2006) - UNUSED / EXCELLENT CONDITION!!**
1 - 22" x 60" "Farrel" Mill direct driven unitized design, "Horsburgh & Scott" gear reducers; 150 HP **Excellent Condition - Quick Delivery**
3 - 26" x 26" **"RELIABLE"** Four Post Hydraulic Presses; 470 ton with electric heated platens
1 - 4" x 8" "CW Brabender" Prep Mill - **VERY GOOD CONDITION**
1 - 22" x 60" "Bolling" Mill direct driven unitized base 150 HP motor, both Drilled Rolls, **Anti-Friction/ Roller Bearings, Hydraulic Roll Nip Adjustments, GOVERNMENT SURPLUS/ EXCELLENT CONDITION**
1 - 12" x 12" "Wabash" Self-Contained Hydraulic Press; 30 tons with electric heated platens
1 - 18" x 54" **"RELIABLE"** Two Roll Vertical Calender - unitized design style, 75 HP variable speed motor & controls. **EXCELLENT CONDITION**
1 - "Maag" 2 1/2" Pin Barrel Extruder with **Gear Pump. EXCELLENT CONDITION**

MISCELLANEOUS

1 - 12 cubic ft. Ribbon Blender - Stainless Steel for Dry blends; good condition.
1 - "USM" Die Cutter/Clicker Press
1 - 84" Mill Batch Divider
1 - "Cumberland" Granulator, 8" x 12" opening; 4Kw/460 volt - **NEW CONDITION**
1 - 16 cubic ft. Ribbon Blender - Stainless Steel for Dry blends; good condition.
1 set - Spare/replacement size #11D "Farrel" 4-wing mixer rotors
1 set - Spare/replacement size #270 "Farrel" 2-wing mixer rotors
1 - 84" Overhead Strip Blender - non reciprocating type
2 - 60" & 84" "ASM" Overhead Mill Blenders, reciprocating type
1 - Batch Plow Assembly for 60" Plastics Mill - pneu. operated
1 set - **NEW** size "BR" Lab mixer rotors

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Figure 5 - unmodified PCR-PP and PCR-PP modified with 6 wt.% C2000 over five cycles of twin-screw extrusion; (a) notched Izod impact strength as a function of extrusion cycle, (b) flexural modulus as a function of extrusion cycle

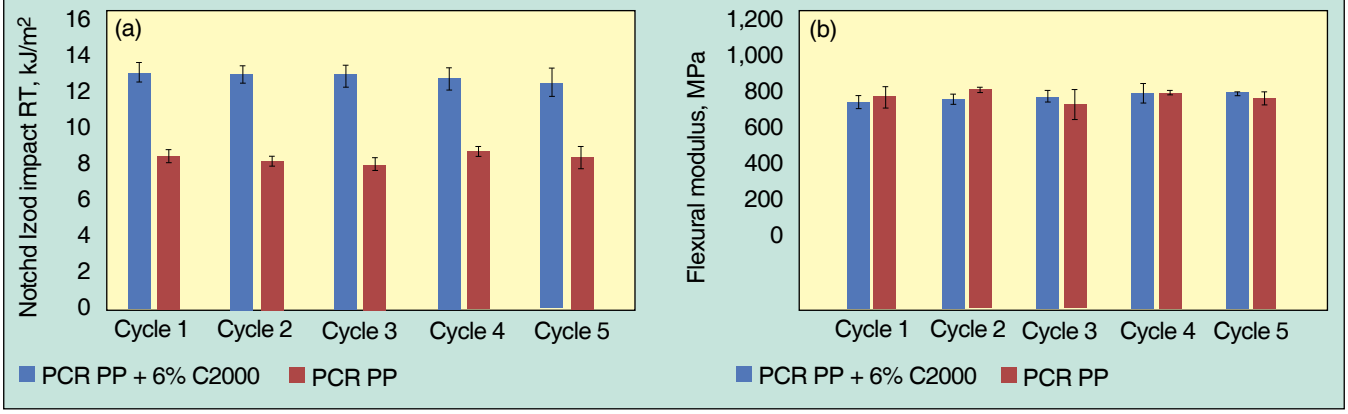
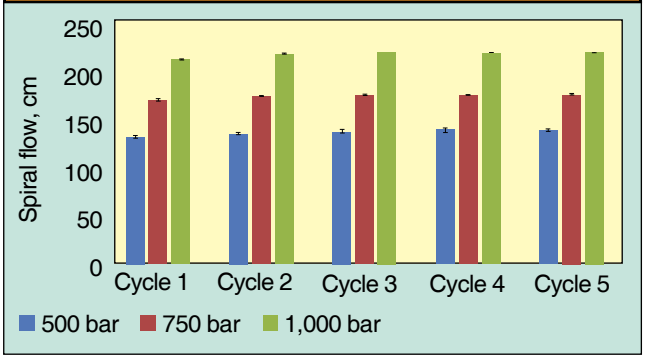


Figure 6 - spiral flow length of 6 wt.% C2000 + r-PP compounds after each cycle through a twin-screw extruder



Data on notched Izod impact strength and flexural modulus tested after each extrusion cycle are shown in figures 5a and 5b. The impact strength of the C2000 modified PCR PP is higher than for the unmodified material, and the improvement is retained to the same magnitude in each cycle. It can also be seen that the flexural modulus of the modified compound is similar to that of the unmodified PCR PP, and remains unaffected up to five cycles of passing through the twin-screw extrusion process.

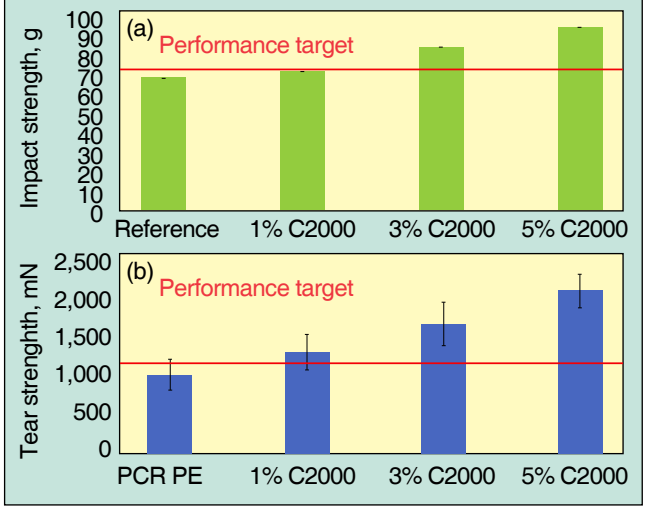
The flow behavior of the compounds in each case was assessed by spiral flow measurements. Figure 6 shows spiral flow data at three pressures of 500, 750 and 1,000 bar. Flow length at each pressure was consistent after each cycle.

Use of CirKular+ compatibilizers in practical applications

CirKular+ C2000 has been successfully used in a flexible film application that was aimed at making large waste bags by a blown film process, and required improvement in impact and tear strength, while maximizing recycled PE content in the production. The recycled HDPE was modified with C2000 at loading levels of 1, 3 and 5 wt.%. Impact strength was characterized by drop dart impact tests, and the data are shown in figure 7a.

Figure 7b shows tear strength as a function of the loading level of C2000. Unmodified PCR was used as a benchmark to

Figure 7 - performance improvement of PCR PE modified with 1-5 wt.% of C2000 compared to unmodified PCR material; (a) impact strength measured by drop dart impact tests, (b) tear strength



gauge improvement. The red line in figures 7 a and 7b shows the target set by the end user. Both impact strength and tear strength were increased, even at the lowest addition level of 1 wt.%. At 3 wt.%, the compounds exceeded the desired target property set. The impact and tear performance can be further enhanced by the addition of 5 wt.% of C2000. By using 3 wt.% of C2000, the incorporation of PCR content could be stretched to as high as 97% without adversely affecting processability in the blown film operation.

CirKular+ compatibilizers have also been used in rigid applications; for example, large trash containers where the manufacturer's aim was to incorporate recycled content (PCR HDPE) in an injection molding process. The parts needed to meet high impact strength requirements and have a balanced stiffness-toughness profile. It was found that C2000 or C3000 could be dry blended into PCR HDPE at a 3 wt.% loading level to meet

Table 3 - property set showing stiffness-toughness balance of unmodified recycled polystyrene stream and compounds with recycled polystyrene containing 5 wt.% to 10 wt.% of CirKular+ C3000

	Charpy nocched, 23°C, kJ/m²	*Tensile modulus, MPa*	*Elongation at break, %*	*Tensile at yield, MPa*
Recycled polystyrene >95% sorted WEEE stream	4.0	2,200	20	21
+ 5% CirKular+ C3000	7.0	1,900	30	21
+ 7.5% CirKular+ C3000	9.0	1,800	40	20
+ 10% CirKular+ C3000	9.5	1,700	50	19

the property requirements. This also allowed for the blend to be injection molded with the same mold, without the need for mold design modifications.

As mentioned previously, SBC materials are highly effective in compatibilization of waste streams containing recycled polystyrene (PS). The recycled PS stream was obtained from a WEEE (waste from electrical and electronic equipment) recycler who sorted the waste to get 95% polystyrene. Table 3 shows the notched Charpy impact strength and tensile properties of the unmodified recycled PS compared to compounds of recycled PS with C3000 at varying loading levels. At 5 wt.% C3000, the impact strength at room temperature was almost double, with minimal effect on other properties like tensile strength at yield and ultimate elongation. There was a slight reduction in tensile modulus.

CirKular+ additives can also improve the performance of recycled WEEE streams containing ABS. This was done by a toy manufacturer to replace virgin ABS with recycled content to be compliant with the EU Green Deal. The addition of CirKular+ to recycled ABS at a low loading level was found to improve impact strength up to 10 kJ/m².

In addition to the examples highlighted in this section, Kraton's CirKular+ additives have also found uses with natural fiber compounds, where the natural fiber can be a wood fiber or hemp based material. They have also been found to improve the performance of bioplastics like polylactic acid (PLA). In these applications, the functionalized SBC polymers, and in some cases a combination of functionalized SBC with C2000 or C3000, have been found to provide the best balance between impact and tensile properties and aesthetics.

Conclusions

There is a significant effort in the industry towards better sorting of PCR materials to make waste streams cleaner and easier to upcycle. There is also a push in the plastics industry to move towards more mono-material formulation approaches. CirKular+ additives, due to their molecular architecture, provide the alternative approach of enabling compatibilization and property enhancement in mechanical recycling processes. They can potentially be used with a wide range of recycled systems with varying levels of contamination. These materials can be either compounded or dry blended with recycled materials. Addition of CirKular+ can also improve the processability of PCR streams.

Through data and commercial examples, the ability of CirKular+ additives in enabling product design recyclability, maximizing recycled content, improving PCR performance and improving the reusability of recycled streams that are contaminated or contain a mixture of multiple plastics has been demonstrated.

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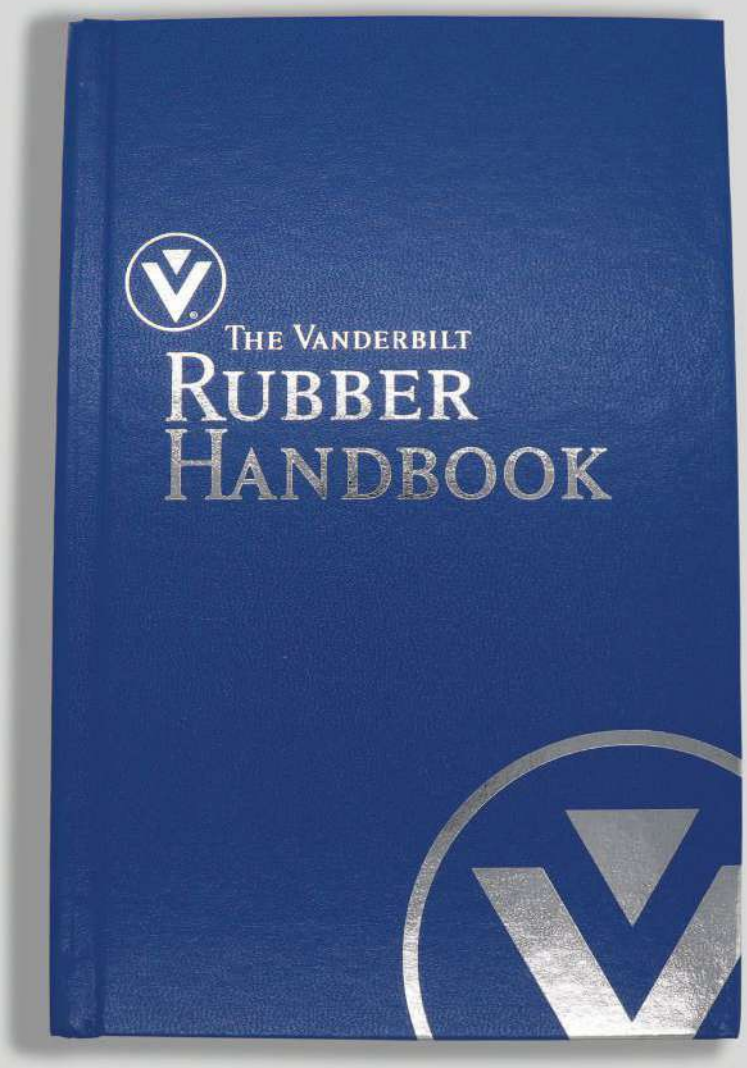

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Transforming recycled plastics into high performance materials with styrenic thermoplastic elastomers

by Luis Rodríguez-Guadarrama, Beatriz Lastra-Barreira and Juan Marcos-Yubero, Dynasol Group

The world is facing an unprecedented crisis in plastic waste management. The widespread use of plastics in modern society has resulted in a deluge of discarded plastic materials, much of which ends up in landfills, oceans and other environments. This has serious consequences for both human health and the environment, as plastics take a long time to degrade, and can leach harmful chemicals into soil and water. To mitigate this crisis, it is essential to develop sustainable solutions for plastic waste management that prioritize reuse, recycling and minimization to promote the circular economy. In response to the pressing issue of plastic waste, the European Union's Plastics Strategy aims to create a more sustainable future by making all plastic packaging recyclable or reusable by 2030 (refs. 1 and 2).

Mechanical recycling is one such solution that has gained significant attention in recent years. Mechanical recycling involves breaking down post-consumer plastic materials into smaller particles, and then melting them down to reuse them. This process offers several benefits over traditional recycling methods, including higher quality output materials, lower energy consumption and reduced greenhouse gas emissions. However, mechanical recycling also faces several challenges, including limitations in the types of plastics that can be recycled, and the difficulty of achieving high quality outputs. Melting operations like extrusion can affect plastics' thermal and mechanical properties (refs. 1-4).

The amount of plastic waste from electrical and electronic equipment (WEEE) has been increasing due to the growing production of electronics and appliances worldwide. This has raised concerns about environmental protection and the depletion of raw material resources. As a result, there are regulations in place to reduce the generation of waste and conserve energy. However, recovering WEEE plastics is challenging because they contain a variety of materials. Of these, polystyrene (PS), acrylonitrile butadiene styrene copolymer (ABS) and high impact polystyrene (HIPS) makes up approximately 80% of the total amount of WEEE plastics (refs. 2 and 3).

Mechanical recycling of polystyrene (rPS) and acrylonitrile butadiene styrene copolymer (rABS) waste has become increasingly popular in recent years due to its ability to produce high quality materials based on upcycled plastics that can be used in a wide range of applications. However, one of the main challenges faced by mechanical recycling manufacturers is finding a suitable binder material that can improve the physical and mechanical properties of rPS and rABS (refs. 1 and 5).

Thermoplastic elastomers (TPE) combine elastomeric flexibility and thermoplastic moldability for superior service performance and efficient manufacturing. Providing rubber-like properties and streamlined processing, TPE offers enhanced durability and resilience. Styrenic thermoplastic elastomers (TPE-S) are synthetic copolymers based on styrene and butadiene monomers. TPE-S possesses a singular structure, resulting in a wide range of properties and applications. This unique structure allows TPE-S to exhibit diverse performance characteristics, making it a highly versatile material for several applications. The most common TPE-S materials include styrene butadiene styrene (SBS) and styrene ethylene/butylene styrene (SEBS) block copolymers (ref. 6).

In this article, the use of styrenic thermoplastic elastomers (TPE-S) as modifiers of recycled polystyrene and acrylonitrile butadiene styrene copolymer (ABS) is investigated. TPE-S products were used because of their ability to enhance the impact resistance of recycled plastics, making them suitable for applications where impact resistance is a critical property.

Experimental section

Materials

The recycled polystyrene (rPS) and acrylonitrile butadiene styrene (rABS) were commercially available grades manufactured by Eslava and Alser Plásticos, S.A., respectively. According to the ASTM D1238 procedure, the melt flow index of rPS was 6.8 g/10 minutes at 190°C and 5 kg, and the melt flow index of rABS was 27 g/10 minutes at 230°C and 10 kg.

The styrenic thermoplastic elastomers used were: Calprene 700 (C-700) and Calprene H6110 (C-H6110), both manufactured by Dynasol. The copolymer structure, styrene content and viscosity in toluene (TSV) at a concentration of 20% by weight are reported in table 1.

Preparation of rPS or rABS/TPE-S blends

The rPS or rABS and TPE-S were physically mixed and then extruded in a twin-screw extruder after barrel melt mixing, in which a temperature profile of 195°C, 200°C, 205°C and 210°C was applied throughout the barrel from the feeding zone to the die with a screw rate of 105 rpm. The TPE-S concentrations in the blends were between 1 wt.% and 10 wt.%.

Blends characterization

The melt flow index (MFI) was measured using an Instron Ceast Model 7023 melt flow indexer according to ASTM D1238. The MFIs were measured at constant temperature and load. The re-

Table 1 - properties of styrenic thermoplastic elastomers

	Structure	*Styrene content*	*TSV at 20% (cP)*
C-700	SBS	30	470
C-H6110	SEBS	30	451

sults obtained were the average of five measurements.

The flexural modulus was determined using an MTS Model 642.01 coupled to a dynamometer MTS Model Alliance RT/5 according to ASTM D790. At least five samples were tested for flexural modulus measurements. The Izod impact strength of notched specimens was determined in a CEAST Model 9050 impact machine according to ASTM D256. Izod impact strength was determined at 23°C, 0°C and -20°C.

Rheological properties of the recycled plastic/TPE-S blends were measured using a TA Instruments DHR-2 rheometer. Measurements have been carried out on test specimens with dimensions of 30 x 13 x 1 mm^3 in torsion mode using torsion rectangular geometry. The temperature sweep tests were carried out between 20°C and 120°C at a frequency of 1.0 Hz and 0.01% strain amplitude. The heating rate used was 3°C/minute, and the elastic modulus (G') of the blends was measured at different temperatures.

The fracture surfaces of the blends were examined using the Zeiss Sigma 500 electron microscope with field emission scanning mode (SEM). Before analyzing, the samples were cryogenically fractured using a Leica microtome and a diamond knife in a liquid nitrogen environment. Finally, a gold-palladium layer with a thickness of 20 nm was spattered on the cross-section of the samples. The electron microscope provided high resolution images of the fracture surfaces, allowing researchers to observe the detailed morphology of the crack surfaces of the blends.

Results and discussion

Recycled polystyrene (rPS)

Melt flow index (MFI) provides an indicator of the processability of a wide variety of plastics, and so it is important to retain the MFI values of plastics when they are recycled. The melt flow index (MFI) of rPS/C-700 blends measured at 190°C and 5 kg is shown in figure 1. In this composite range, a slight increase in MFI was observed with increasing C-700 content. This effect was especially perceivable at C-700 concentrations above 5 wt.%. The addition of C-700 to rPS will increase its MFI slightly, but the blend will have good processibility.

Figure 1 - melt flow index of rPS/C-700 blends at 190°C and 5 kg

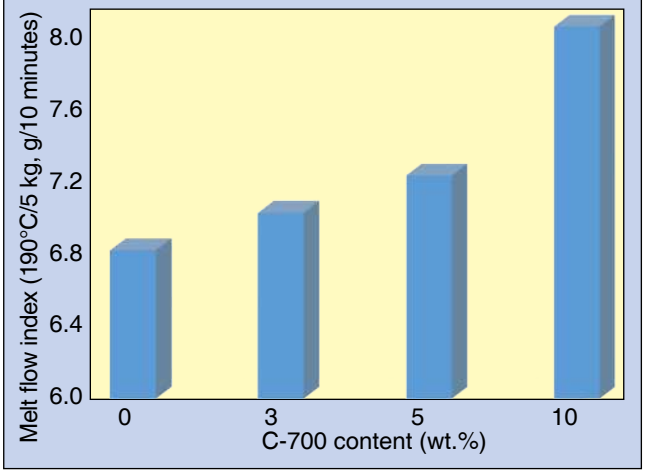
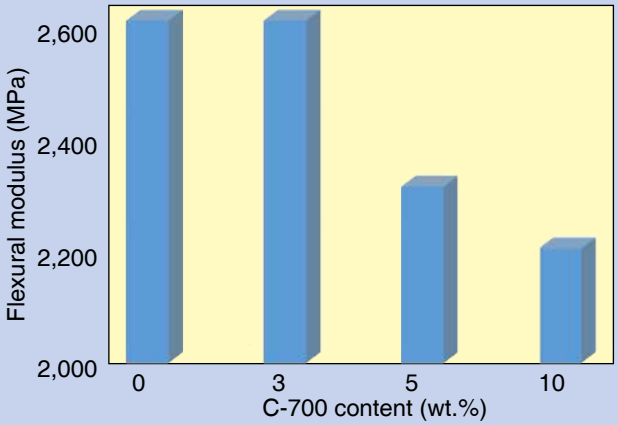


Figure 2 - flexural modulus of rPS/C-700 blends



A high flexural modulus usually defines a material which is stiffer with high hardness, whereas low flexural modulus is most often seen in very flexible, softer materials. The stiffness of recycled rPS/C-700 blends is assessed in terms of their flexural modulus. The variation of the flexural modulus with respect to C-700 content is shown in figure 2. The flexural modulus was found to slightly decrease (less than 15%) with increasing C-700 concentration in comparison to rPS.

The Izod impact strength at 23°C, 0°C and -20°C of rPS/C-700 blends as a function of C-700 content is shown in figure 3. Despite the temperature, it is noticeable that the impact strength of the blends increases significantly when the concentration of C-700 is increased. This indicates that C-700 promoted interfacial interactions with the rPS matrix, strengthening the system interface. Consequently, there was an incremental increase in the energy dissipation level and impact strength. This implies that the rPS/C-700 composite displays improved resistance to deformation and fracturing under sudden loads, such as those experienced during a crash.

The arrangements and structures of the rPS/C-700 blends

Figure 3 - Izod impact strength of rPS/C-700 blends at different temperatures (23°C, 0°C and -20°C)

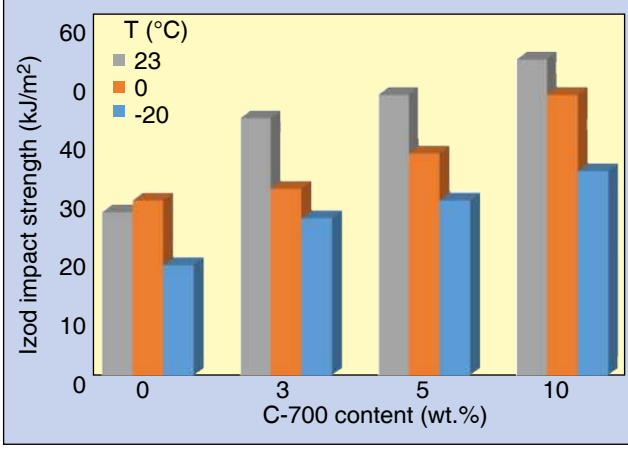
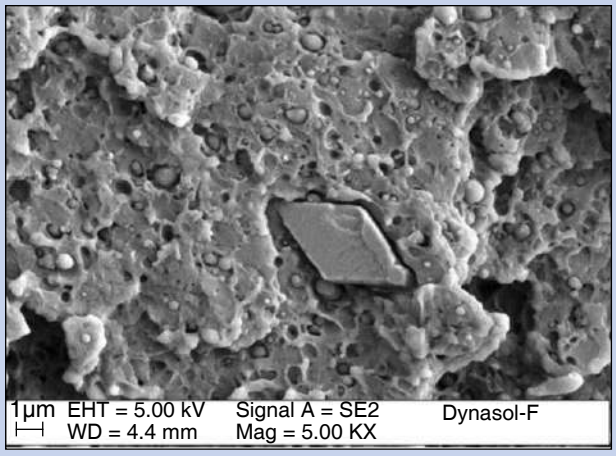


Figure 4 - cross section SEM image of a 5% C-700/rPS blend



play a crucial role in determining their mechanical properties. Hence, scanning electron microscopy (SEM) was conducted to assess the changes in the blends' morphology due to the presence of C-700. Figure 4 shows the SEM micrographs of a 5% C-700 blend, where the presence of droplets is attributed to the presence of C-700 in the matrix. When the concentration of C-700 was increased, the droplets became more concentrated and visible.

The elastic modulus of a material indicates its resistance to deformation when subjected to external forces, which is also known as its stiffness. As demonstrated by figure 5, the elastic modulus of the 5% C-700 blend exhibited a consistent trend similar to that observed in pure rPS. These findings indicate that the addition of C-700 to rPS did not significantly alter the elastic properties of the blended materials.

Recycled acrylonitrile styrene butadiene copolymer (rABS)

Based on the data presented in figure 6, it becomes evident that the melt flow index (MFI) of rABS increases as the concentration of C-H6110 increases. In conclusion, the experimental results show that the addition of C-H6110 to rABS can improve its processability. Specifically, there is a significant increase (a factor of two) in MFI when C-H6110 content was 10 wt.%. This suggests that adding C-H6110 to ABS can improve its processability by increasing its melt flow viscosity.

Figure 5 - elastic modulus of rPS and a 5% C-700 blend as a function of temperature

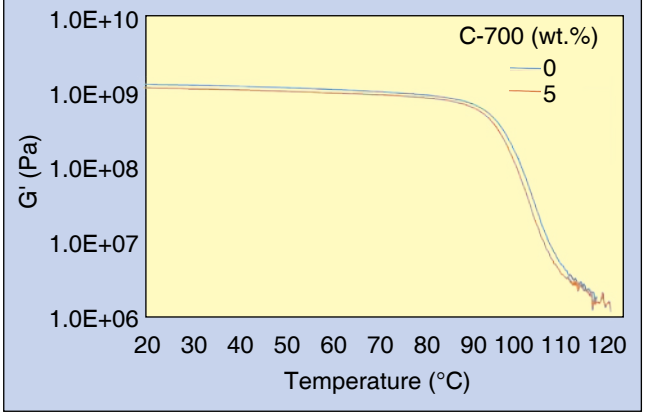
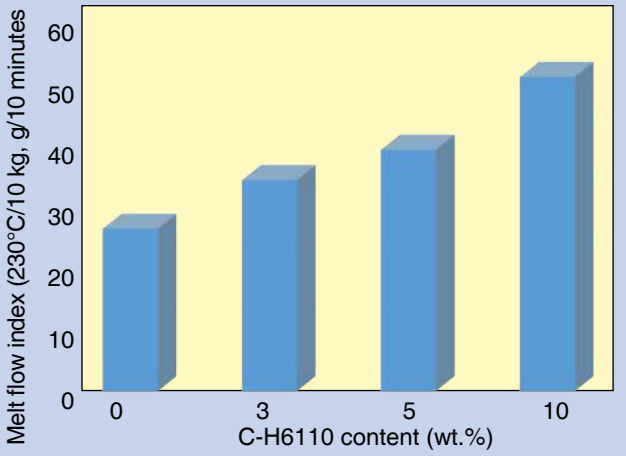


Figure 6 - melt flow index of rABS/C-H6110 blends at 230°C and 10 kg

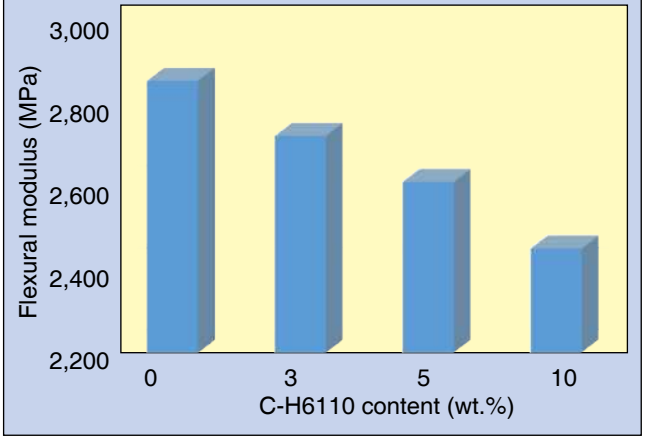


The stiffness of the rABS/C-H6110 blend is assessed using its flexural modulus. In figure 7, the variation of the flexural modulus with C-H6110 concentration is shown. The flexural strength was found to slightly decrease (less than 15%) with an increase in C-H6110 concentration. The decrease in the flexural modulus was most evident at a C-H6110 concentration of 10 wt.%.

In figure 8, the Izod impact strength at 23°C, 0°C and -20°C is shown as a function of C-H6110 content. Low C-H6110 concentrations, such as 5 wt.%, resulted in minimal impact behavior changes in the blend. The improvement in impact strength was more pronounced at 23°C. Note that the improvement in impact strength could be achieved using small concentrations of C-H6110 (lower than 5%). It is likely that the improvement in impact strength is a result of the interactions between the rABS matrix and C-H6110 at the interface.

As seen in figure 9, the scanning electron microscope (SEM) images of a 5% C-H6110 blend demonstrate the presence of

Figure 7 - flexural modulus of rABS/C-H6110 blends



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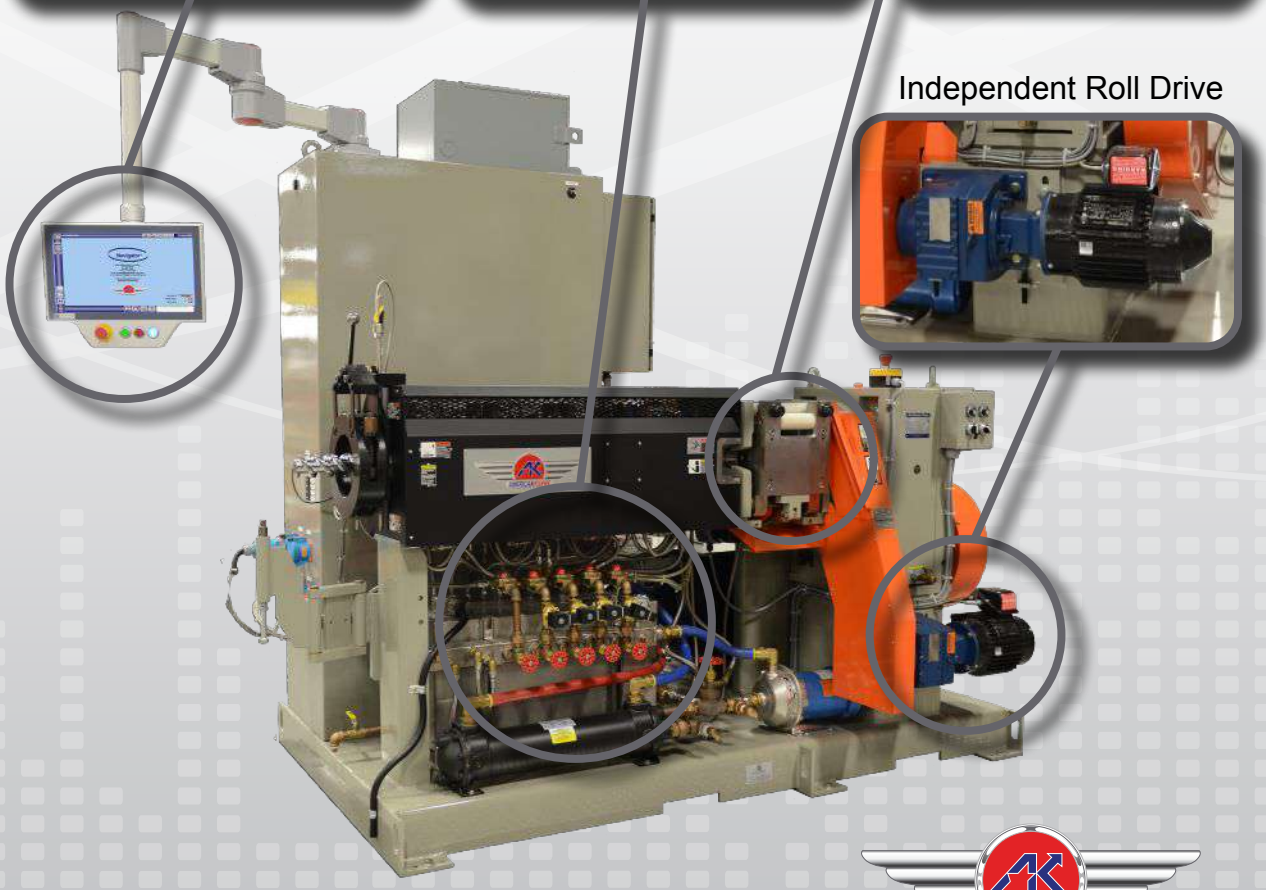

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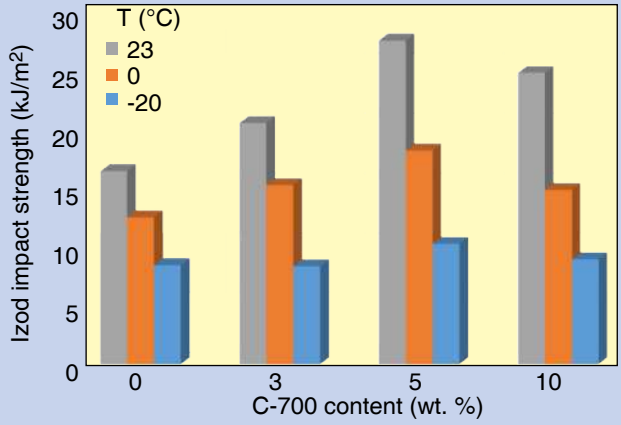
Figure 8 - Izod impact strength of rABS/C-H6110 blends at different temperatures (23°C, 0°C and -20°C)



droplets within the rABS matrix. These droplets become more prominent as the concentration of C-H6110 increases.

As shown in figure 10, the elastic modulus of the rABS/C-H6110 blends with different weights (5 wt.% and 10 wt.%) exhibits a similar trend as that observed for pure rABS. The elastic modulus of a material represents its rigidity, while the loss modulus directly characterizes the relaxation behaviors. These results suggest that the introduction of C-H6110 into the rABS matrix does not significantly affect the elastic modulus of the blended materials.

Conclusions

The structure-composition-property relationships of blends of recycled polystyrene (rPS) and acrylonitrile styrene butadiene copolymer (rABS) with styrenic thermoplastic elastomers were investigated. The effect of Calprene 700 on the properties of rPS was investigated. The results showed that the addition of Calprene 700 to rPS increased its melt flow index and its impact strength, and had a moderate effect on its flexural modulus. Furthermore, the study found that Calprene H6110 provided an excellent balance in the properties of rABS, resulting in improved impact strength materials. This suggests that Calprene H6110 could be a suitable additive to improve the impact strength of rABS.

In conclusion, styrenic thermoplastic elastomers (TPE-S) can improve the impact resistance of mechanically recycled plastics such as polystyrene and acrylonitrile styrene butadiene copolymer. As a result, these materials become more resistant to scratches, dents and other forms of damage, making them even more suitable for a wider range of uses. TPE-S can improve the processability of mechanically recycled PS and ABS, making it easier to melt blend and formulate the desired product. These findings have the potential to contribute to the development of more sustainable and environmentally friendly materials derived from mechanical recycled plastics.

Figure 9 - cross section SEM image of a 5% C-H6110/rABS blend

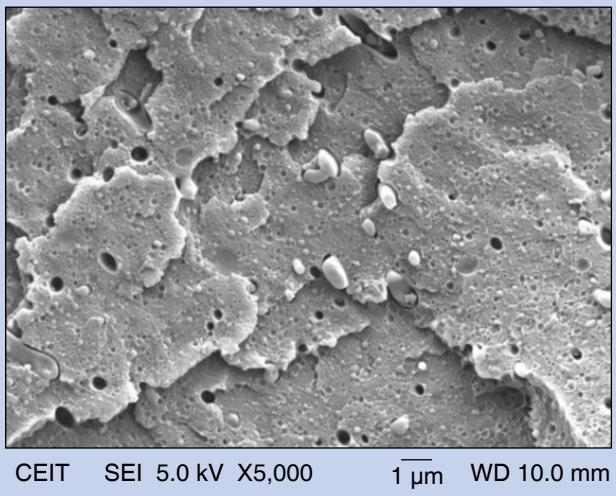
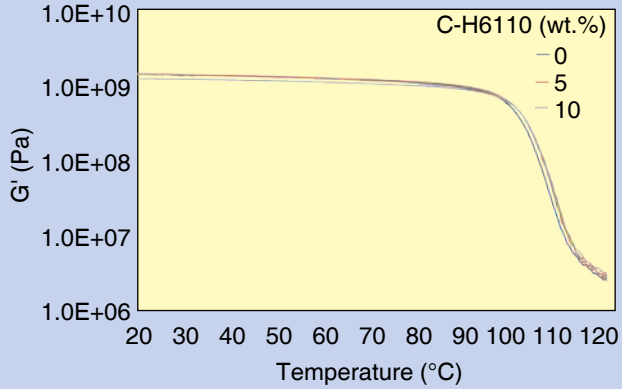


Figure 10 - elastic modulus of rABS/C-H6110 blends as a function of temperature



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Inventing the RPA rubber process analyzer

by Jeff Russell, Alpha Technologies

The rubber process analyzer (RPA) (figures 1 and 2) has had a rather complicated history. It began as a research and development project at Monsanto Instruments & Equipment, a division of Monsanto Rubber Chemicals, to build on the success of its invention of the moving die rheometer (MDR). However, like the invention of the MDR before it, the RPA took a series of zigs and zags before becoming a successful and valuable instrument for the rubber industry. That should not be surprising. In any research and development project, the path is not usually straight. Sometimes one stumbles off the path and ends up in a ditch. (Or maybe one stumbles into what they think is a ditch, only to discover a secret underground passageway that gets one closer to where they are going.)

To really put the invention of the RPA into perspective, it is necessary to understand the two generations of instruments that came before it, and how moments of alternating successes and failures, sort of like sine waves, finally resulted in a reliable, repeatable, reproducible resource for rubber and polymer manufacturers.

How the oscillating disc rheometer changed the rubber industry

The rubber industry is not keen on making changes. The patent for the Banbury mixer was awarded in 1916, and it is still in use today with a minimum of modifications and new features. The Mooney viscometer arrived in the 1930s and is still found in rubber factories worldwide. The Mooney viscometer provided data on the onset of vulcanization (scorch) and a crude indication of average molecular weight; but one could not really see the ultimate state of cure.

It was not until the 1960s and 1970s that scientific instrument companies began developing and commercializing rubber cure testing methods using die systems. B.F. Goodrich introduced an instrument with a cone configuration. Goettfert, in Germany, developed an unsealed rotorless die method, but with limited success in providing cure test data. But it was Monsanto Instruments & Equipment that provided a major breakthrough in cure technology with the invention of the oscillating disc rheometer (ODR). The patented ODR system, known as the R100, had the only sealed and pressurized sample chamber, which is important for the collection of good, repeatable data. It quickly became the industry standard around the world.

The instrument fits on a tabletop or counter in a laboratory. The data collection method was a flatbed chart recorder. The ODR was operated at 1, 3 or 5 degrees of arc; although statistical analysis showed that 1 degree provided the best signal-to-noise sensitivity, and produced the best data.

Henry Pawlowski, rheology fellow at Alpha Technologies (formerly Monsanto Instruments & Equipment), recalled: "The big breakthrough that the ODR brought to the rubber industry was that it was actually three tests in one. Other instruments tended to provide data for one item and only one item. But the ODR could provide three pieces of data that the rubber industry wanted. They got processing information: the properties of the material before cure, including an estimate of the molding time required. One could get cure data: How fast does it cure? And one would get a maximum property state of the material: What are the final properties going to look like?"

Figure 1 - rubber process analyzer (RPA)

Figure 2 - Alpha Technologies RPA 2000 series instrument

The ODR provided tasks that were otherwise difficult to do. And suddenly, companies would test every single batch, because it was a relatively fast test to do for quality control purposes. It was also popular for evaluating new compound formulations in the research and development laboratory.

There were, of course, problems and limitations of the ODR. The rotor was unheated, so tests were not under true isothermal conditions. Seal and bearing friction added signal to the measurements that did not come from the rubber sample. Changing test temperature could take up to an hour. And removing the embedded rubber sample from the rotor was difficult; often requiring removing the rotor from the machine to be able to pry the sample off.

Still, even a flawed instrument can be worth using if it has reasonably good sensitivity and good repeatability. The ODR became the workhorse curemeter for the industry.

One step forward, two steps back: The invention of the moving die rheometer

Meanwhile, the discussion at Monsanto Instruments & Equipment was whether or not to develop the next generation curemeter. Would the new curemeter cannibalize sales from the ODR? How would customers react to a new instrument that shifted the data, even if the data were more accurate? With the ODR already established, why would anyone bother to buy a different curemeter? In the end, the decision was made to proceed on the basis of: "If we do not do it, somebody else will."

And so, the project went forward to create a moving die rheometer (figure 3), to be known as the Classic MDR. It produced a number of breakthroughs in design and engineering. Probably the most challenging and complicated issue to resolve was the design of the upper seal. Another critical issue that was solved was how to calibrate torque. But as Pawlowski remembered: "I spent five years trying to help the engineers develop the MDR. And when we were done, and introduced it, it was a dismal failure."

Figure 3 - Premier MDR from Alpha Technologies

One of the problems was the "fenced" die that had been patented by Monsanto Instruments & Equipment, with rings on the upper and lower dies that were engineered to intermesh. "The thinking was that the design created more signal," recalled Pawlowski. "In addition, the rotor was eliminated, and all elements were heated. It was only later, as we got smarter, that we discovered the fences did not have uniform temperatures, so it was not a true isothermal cure test. What is more, the fences were a great place for slippage to start. But it was our patent, and we were going to make the most of it."

There were about six Classic MDRs (moving die rheometers) sold. One customer in Germany bought two and immediately had trouble getting good reproducibility between the instruments. Pawlowski was dispatched to the customer's factory, and spent three weeks in Cologne running tests. He saw the problems and began working on a different die system.

One of the rubber compounds that was used to evaluate the instrument had a bonding agent in it. And if one ran enough tests, eventually it would bond itself to the fenced dies. Pawlowski's concept was to simplify the die set completely, using a biconical design with no grooves or bits or fences in the center.

At that time, Monsanto Instruments & Equipment manufactured all its components in-house. They had a mechanical engineer, Les Randall, who was also a machinist. Whenever Pawlowski or another engineer would say, "Hey, I want to try this out," Randall would look at it, make some quick drawings, and in a day or so it would be ready for testing. As a result, the design team could accelerate its progress.

Once the simpler design was incorporated, the MDR started looking more like the MDR of today. Issues involving the seals and the torque calibration spring were resolved.

Jeff Ward had joined Monsanto in the mid-1980s as a field service engineer, just as the Classic MDR was introduced. He saw the problems it was causing in the field and contributed that knowledge to the team, developing what was to become the Series 2000 MDR.

"When we came out with the Series 2000, the MDR was revolutionary. Nobody saw it coming," said Ward. "We had to convince customers to go from an R100 to our new MDR, but the data were totally different. We had to inform them: 'Hey, this is the future.'"

Tire companies saw that correlating the data on the MDR 2000 with the R100 would take running the same rubber on both machines. In six months or less, they would have their new specifications. "And once they finished that correlation," recalled Ward, "they were off and running."

The invention of the RPA

"The MDR gives you a high resolution photograph of your

compound. The RPA gives you the movie," says Rick Hanzlik. an applications engineer at Alpha Technologies.

In 1975, because of oil price surges and shortages, Congress created the Corporate Average Fuel Economy (CAFE) standards. The car companies first began working on the obvious: reducing weight and improving motor efficiency. But along the way, they discovered that the rolling resistance of a car's tires made a big difference on fuel mileage. Their focus turned to tire manufacturers.

The car companies informed tire companies that they were going to establish a specification for rolling resistance. And, by the way, "If you fail to meet it, we will be forced to reject your tires." The problem was how to determine the rolling resistance of a tire before building the tire.

Goodyear tackled the problem using the Rheometrics System IV, a dynamic mechanical analyzer, to determine correlations to rolling resistance. However, System IV was expensive and required a highly trained technician to run the tests. It was not a good solution for the production floor.

Goodyear had been an early adopter of the MDR 2000. Now they began working with Monsanto Instruments & Equipment on the development of a new instrument: a rubber process analyzer, or RPA.

"The very first designs for the RPA had a lot of issues where the concept did not play well with reality," recalled Ward. "It was a very interesting, very complicated design. The die assembly had little fins that stuck out. It was revolutionary as far as anything we had seen before. But we learned a lot from that. It was the stepping stone to get where we needed to go."

The design took an MDR 2000 and changed the motor to allow it to operate at different speeds. The new instrument was named the MDR-P; the P stood for processability. One could change the frequency of oscillation, but could not change the strain.

This device was sent to Goodyear, which spent a year doing evaluations and tests. When Goodyear was done, it presented its conclusions: "We cannot have an instrument that just varies frequency. We must have the ability to vary strain, as well." And Monsanto Instruments & Equipment's design and engineering teams went to work to meet Goodyear's expectations.

"Frequency is easy; there are a lot of motors that can run at different speeds and change the frequency of oscillation," noted Pawlowski. "But changing the strain was more complicated. The first effort to make the RPA with strain variability utilized a little motorized eccentric. But after it was finished, we determined it was a horrible design because of the slop (hysteresis) in the system. It was something you would really notice when you went to low strains. The percent error was very high, so you did not get repeatable data; you did not get reproducible data; you were in a lot of trouble."

It was decided that changing to a direct drive motor was the best solution. The engineers found a motor made for robotics that had 500,000 points of resolution per 360 degrees of arc, allowing the motor to move at angles as small as 0.05 degrees (0.7%).

The computer that would operate the RPA was a critical element in getting it to work. The original operating system that was used was developed by IBM and known as OS/2. When the test was done, the software would produce data files that were compatible with Microsoft Excel; one file for each subtest, which were then analyzed using Excel Macros. Results could be read on the latest dot matrix printer.

Version 1 of the software provided isothermal cure, frequency sweeps and strain sweeps; however, the number of raw data points was limited to about 250 data rows in Excel. Version 2 introduced a variable temperature analysis (VTA) subtest that allowed non-isothermal cures. Version 3 introduced the stress relaxation subtest.

John Dick joined Alpha Technologies just as the RPA went into beta testing. "The die design of the RPA was virtually identical to the die design of the MDR," he recalled. "The difference between them was frequency, strain and temperature. You could change the temperature more quickly with the RPA than you could with the MDR, especially cooling down, because you had forced air cooling. The RPA had a direct drive system that oscillates back and forth sinusoidally and could change strain very quickly, so you could start from low strain and work your way up. The frequency was always 100 cycles per minute for the MDR, which was a carry-over from the ODR. But with the RPA, we could vary the frequency to be what we wanted."

With the successful implementation of strain sweeps, along with breakthroughs made during the development of the MDR 2000, such as biconical die design, die gap adjustment, better temperature accuracy and recovery, high performance seals and the first sample automation system, Monsanto Instruments & Equipment sent five beta versions of the RPA to customers for their evaluation.

"Goodyear really fast-tracked the development of the RPA," noted Pawlowski. "They knew how it had to function and they knew what the results should look like."

"Monsanto Instruments & Equipment rheologists ran comparisons with scientific rheometers like the System IV, and found that the correlations were incredibly good. Comparisons were also made to data for stress relaxation of uncured materials on a Mooney viscometer. The RPA produced good data that correlated well with the Mooney. The big idea was that the RPA could be a dynamic tester that could be used in a production environment and produce data close to what a scientific rheometer would produce," said Pawlowski.

During 1991 and 1992, engineers continued to come up with solutions to problems in the RPA's design. The seals used in the MDR were also put into the RPA, but were utterly destroyed in a short period of time, especially at high frequencies and high strains. A new, stronger polymer was incorporated into the design. The need for cooling was obvious when trying to reduce the temperature during a test with closed dies. A series of experiments was conducted that resulted in a straightforward design that rapidly brought the air into the cooling area and allowed it to exit.

Monsanto's automation system using film, which was first developed for the R100, provided easy sample removal, but produced more slippage. Different films were investigated until the team found a nylon film that provided resistance to slippage

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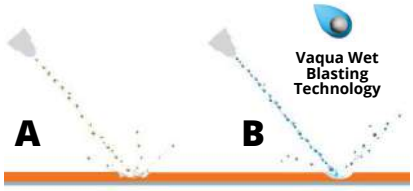

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similar to no film. Further work was done at the request of Bridgestone to provide an alternate film that would still give good data performance, even up to 100% strain.

One more formidable challenge remained

Previously, scientific rheology instruments such as the System IV used an open cavity system. But when one went to high strains, the sample would start falling apart, because it was not constrained. When that happens, the signal coming from the rheometer becomes very noisy. This noise is referred to as edge effects: On the inside, one can get great flow and movement; but on the outside, it is not good data.

"One of the things that the RPA introduced was a system that eliminates or significantly reduces edge effects," said Pawlowski. "Because when you have everything sealed up, when the lower die moves, the sample cannot go anywhere. And when you run the high strains, you get what is known as a square wave, and you can do a Fourier transform to that signal and the harmonics tell you something about the molecular nature of the material."

"The RPA brought us into the realm of science, rather than the realm of tradecraft. Tradecraft is when you cannot put numbers on things, so you have subjective words to describe things, whether it is a 'smooth' extrusion or 'seems a little tacky today,'" said Dick. "While the MDR moved us down that path because it allows us to see the ultimate state of cure, the RPA can go much further. We can tell you how this material is going to process. We can tell you of the excessive die swell in extrusion operations, and if you are you going to have non-fills in a certain mold filling operation. All this can be determined from the tests we have now, which were not available by measuring with crude instruments such as the Mooney."

"We were able to simulate everything that rubber goes through in a production line; mixing through extruding or putting it into a mold," said Ward. And that was the key, that is why they called it the processability tester. The RPA was able to check the process from the mixing end all the way through to the molding into the final product, and was able to cool it back down and test it at whatever temperature the rubber was going to operate. All of that had never been done before," Ward added.

By 1992, the RPA 2000 was finally ready for prime time.

Development of tests and standards

Alpha's RPA was hailed as a "Ferrari" of an instrument when it was introduced. It gained rapid acceptance for its ability to test a compound before, during and after cure. But there was still work to be done, including development of tests and standards to guide customers in the use of this innovative technology.

And while Pawlowski was the pit crew engineer behind building it, Dick became the driver. Over the last 30 years, Dick has continually developed tests and correlations that help rubber and polymer manufacturers get more value out of their materials.

"The challenge was: the RPA gives you a lot of information, but does it give you knowledge?" noted Dick. "I was trying to convert the information into knowledge that rubber technologists could use in solving a variety of problems."

"In a factory setting, you must make fast decisions. If something is going wrong, you want to know about it and understand what the corrective action would be. So, I worked a lot in those sorts of situations, trying to allow customers to interpret what the RPA was telling them and take corrective action," Dick said. "Since then, I've documented several ASTM (American Society for Testing and Materials) standard methods using the RPA. They deal with processability; they deal with measuring cured physical properties, and what sort of correlation you can get with traditional tests. Some of these tests are short: It only takes about four minutes to run the whole thing. But that is what you want in a factory; you want something quick and to the point."

Between 1992 and the introduction of the Premier RPA in 2018, the instrument underwent continuous improvement and innovation. "Comparing what we can do today with the RPA is light years ahead of what we could do in 1991," said Dick.

"We put a better motor in our Ferrari," recalled Pawlowski. "The original motor of the RPA was able to do 500,000 counts in 90 degrees. The new motors can do 1,000,000. And there is a concept called oversampling, and that allows you to get to lower signal levels. What that means is that instead of using 16 data points like an MDR, or even 120 like the original RPA, now you can use over 1,024 data points and get to an even lower signal level."

"We learned how to improve our signal-to-noise ratio on very low strain testing," said Dick. "That is critical because of all the silicas being used today. In the old days, we hardly used any silica because it was hard to mix. But Michelin received a patent that if you used a heavy load of silica and got it effectively dispersed, then you got better rolling resistance. That is why we are doing sub-ambient now, because it is the only way to determine silica silanization. We are the only ones I know who make an RPA that can go that low in temperature, and accurately measure tangent delta at 0°C."

The old OS/2 platform gave way to Windows and its successive generations before being ported over to Eclipse software developed in the Netherlands. Eclipse was bought by Alpha Technologies in 1999, and a team of software engineers relocated to Akron, Ohio, to develop Alpha's Enterprise platform. "One of the things we started doing was replacing the

Figure 4 - Alpha Technologies RPA+ with sub-zero technology

Windows software that originally went with the RPA," said Peter Boogaard, software engineering manager, Alpha Technologies, since 1986. "The design of Enterprise was to have a computer to talk to the instrument through a program called Workbench. And then we had a management program that defined the tests, defined the materials and defined the specifications. And we developed a web application that we call the Online Manager."

Innovating for the future

The ability to measure at such a low strain so accurately was a great breakthrough for the RPA. But other improvements, such as precision dynamic modulus (PDM), were developed and added to the Premier RPA. Sub-Zero technology (figure 4) is providing greater insight into performance characteristics like traction in wet and icy conditions.

Alpha has continued to expand the knowledge base of RPA tests and correlations through its work on ASTM and other global standards committees. "But one thing I observed was that when you create something that has never been available in the world before, as companies run tests and collect data and make all sorts of discoveries, the more discoveries they make, the less they tell you," said Pawlowski.

"That is why I wrote so many books and documented so many standards," said Dick. "I'm trying to share the science of it. On the other hand, a standard tends to make a technology permanent."

After 30 years, the RPA is a proven technology for the rubber and polymer industries. After passing down knowledge and industry know-how to the next generation, even at Alpha Technologies there comes a time when the original scientists and engineers must pass the torch to the next generation. That is seen in Alpha's applications and product management department. Now that Henry Pawlowski and John Dick have gone on to retire and consult, Richard Hanzlik and the Alpha Technologies applications team have taken the teachings and experiences from the last 30 years, applied them and adapted them to the next generation of challenges from the rubber and polymer world.

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Endurica holds training on fatigue testing

Endurica, LLC, a provider of software, materials characterization services, consulting, testing instruments and training to help companies meet rubber durability targets during product design, is offering online fatigue testing analysis training.

Characterizing Elastomer Fatigue Behavior for Analysis and Engineering will be held November 6-10. This course provides a thorough explanation of the essential principles and practices of material characterization for fatigue life prediction, and strategies and procedures for planning effective fatigue test programs, as well as making effective use of crack nucleation and fracture mechanics tools.

Lectures will allow attendees to thoroughly understand the science behind Endurica's workflow and software solutions, and demonstrations from the Axle Products testing laboratory will fully illustrate the complete material characterization process.

Course objectives include: know the physics and factors that govern the fatigue behavior of rubber; use accurate models and efficient procedures to characterize fatigue behavior; take advantage of test strategies that minimize risk and maximize productivity; use crack nucleation and fracture mechanics approaches effectively; use characterization to inform accurate fatigue calculations; and use characterization to diagnose and solve development issues.

The course instructor is Will Mars, an internationally acclaimed authority on the topic of damage mechanics in elastomers. The course fee is $1,995. Details are available at www.endurica.com.

Application of Rubber Fatigue Analysis with Endurica Software will be held December 4-7. This course will instruct how to wield Endurica software to virtually evaluate fatigue performance and solve design issues at the concept stage. This workshop features live lectures and exercises focused on Edurica's workflow and software solutions.

Course objectives include: review three famous cases involving elastomer failure and the issues at stake in fatigue analysis; understand the key ingredients of successful fatigue analysis for rubber; be able to select and specify material models that accurately describe elastomer stress-strain and fatigue behavior; understand principles needed for accurate fatigue analysis, including critical plane analysis, rainflow counting and damage accumulation; set up a finite element model to ensure accurate fatigue analysis; and use Endurica software to solve durability issues involving multiaxial, variable amplitude loading.

The course instructor is Will Mars. The course fee is $1,595. Details are available at www.endurica.com.

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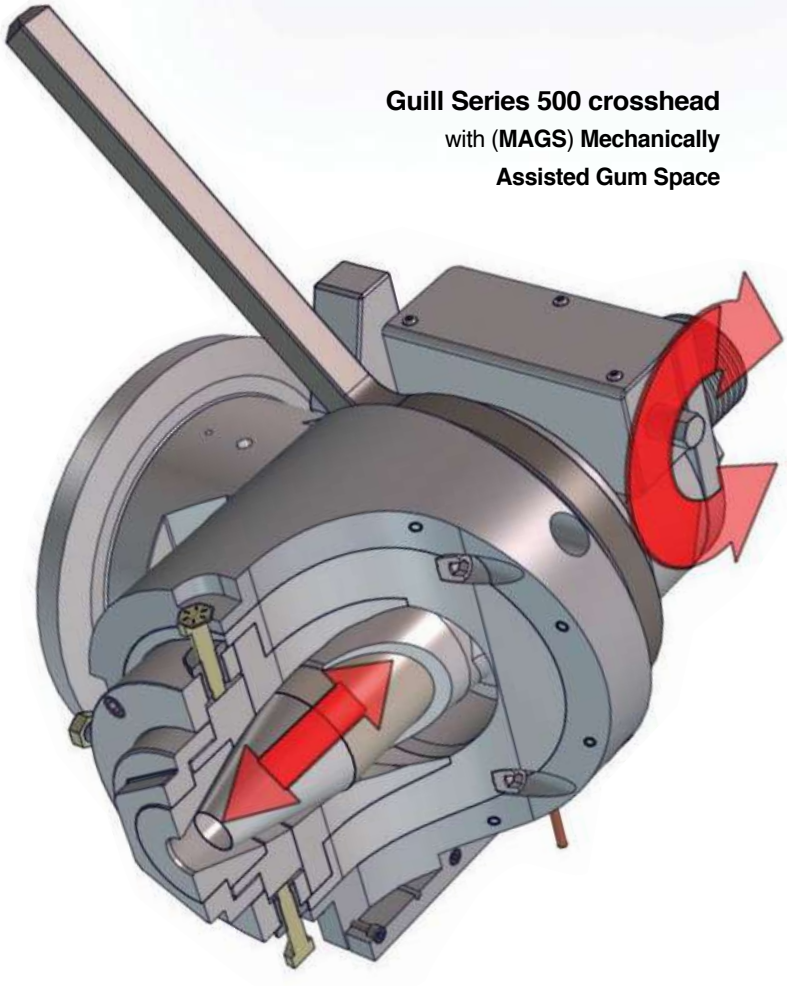

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Meetings

Smithers organizes silicone, TPE summits

The Silicone Elastomers World Summit and Thermoplastic Elastomers World Summit, organized by Smithers, will be held November 28-29 in Amsterdam, Netherlands.

Silicone Elastomers World Summit and Thermoplastic Elastomers World Summit bring together manufacturers, processors, end users, designers and researchers for a summit style technical discussion of silicone and TPE elastomer materials, global markets, processing advancements and novel applications. Industrial and academic research staff and the customer users of silicone and TPE elastomers will explore the emerging applications, manufacturing techniques, processing improvements and testing advances that are moving this growing industry forward.

Delegates at the silicone elastomers and TPE elastomers summits will be able to expand their business opportunities and network with industry leading professionals; learn what is happening with the silicone and TPE elastomers industry; receive updates on the latest policy issues; hear from high level speakers offering key insights and advice; and source new products and discover the latest innovations.

Smithers is said to have established a strong tradition of delivering market leading conferences for both the silicone elastomer and thermoplastic elastomer industries. Further information is available at www.smithers.com.

Rubber Group News

The **Detroit Rubber Group** will hold its fall technical meeting November 8 at Freudenberg-NOK Sealing Technologies in Plymouth, MI. Presentations will include: "Rubber for Mars: Optimization of BR/VMQ compounds," Rafal Anyszka, University of Twente; "Revolutionizing rubber development: The power of automation and AI," Khaled Boqaileh, LabsCubed; "Case studies in failure analysis of rubber and plastics," Jason T. Poulton, Akron Rubber Development Laboratory; "Rubber circular economy: Reusing waste at the generation site," Ben Chouchaoui, Windsor Industrial Development Laboratory; "Thermal barriers for E-mobility," Michael Blake, Freudenberg-NOK Sealing Technologies; "Cellular rubber extrusion," Richard Strong, Elastomeric Consulting Services, LLC; "Understanding rubber through simulations," Ken Cheng, Moldex3D North America; and "Biodegradable, sustainable guayule based materials for novel applications," Sriloy Key, Ohio State University. Details are available at www.rubber.org/detroit-rubber-group.

The **Mexico Rubber Group** will hold the course, Design, Development and Production of Rubber Compounds, instructed by Luis Mayorga, November 23 at the Rubber Chamber Auditorium in Mexico City, Mexico. Details are available at www.rubber.org/mexico-rubber-group.

Calendar

Rubber Division
American Chemical Society

Future Meetings/ Expos

2023
Cleveland **October 16-19**

2024
Pittsburgh **September 9-12**

www.rubber.org

Rubber Division, ACS, International Elastomer Conference, Huntington Convention Center, Cleveland, OH, www.rubber.org - October 16-19.
Association of Modified Asphalt Producers, 2023 Annual Conference and Workshop, Hyatt Regency Riverfront, Jacksonville, FL, info@modifiedasphalt.org - October 17-19.
Mexico Rubber Group, How to Improve Rubber Compounds, Part III course, Rubber Chamber Auditorium, Mexico City, Mexico - www.rubber.org/mexico-rubber-group - October 19.
JEC Group, JEC Forum DAH, Salzburg, Austria, www.jeccomposites.com - October 24-25.
University of Akron, Akron Polymer Training Services, Sponge Rubber 101, www.uakron.edu/apts/ - October 25.

November

Rubber Division, ACS, Elastomers for Selective Gas Separation, Including Carbon Capture webinar, www.rubber.org/training - November 1.
Rubber Division, ACS, Sponge Rubber 101 online course, www.rubber.org/training - November 2.
University of Akron, Akron Polymer Training Services, Rubber Compounding and Process Troubleshooting course, www.uakron.edu/apts/ - November 3.
Endurica, Characterizing Elastomer Fatigue Behavior for Analysis and Engineering workshop, www.endurica.com - November 6-10.
University of Akron, Akron Polymer Training Services, Understanding Raw Materials, the Building Blocks of Rubber Compounding course, www.uakron.edu/apts/ - November 7.
University of Akron, Akron Polymer Training Services, Structure/Property Relationships in Polyurethanes course, www.uakron.edu/apts/ - November 7-8.
Detroit Rubber Group, Fall Technical Meeting, Freudenberg-NOK Sealing Technologies, Plymouth, MI, www.rubber.org/detroit-rubber-group-inc - November 8.
University of Akron, Akron Polymer Training Services, Rubber Compounding for Performance course, www.uakron.edu/apts/ - November 8-9.
University of Akron, Akron Polymer Training Services, Elastomer Molding Technology course, www.uakron.edu/apts/ - November 8-10.
Rubber Division, ACS, Career Catalyst Webinar: Using LinkedIn to Increase Your Visibility in the Job Search, www.rubber.org/training - November 9.
University of Akron, Akron Polymer Training Services, Solving Problems in Rubber Compounding, Processing course, www.uakron.edu/apts/ - November 10.
University of Akron, Akron Polymer Training Services, Polymer Compounding, Formulating and Testing of Plastics, Rubber, Adhesives and Coatings course, www.uakron.edu/apts/ - November 14-16.
Rubber Division, ACS, Advanced Rubber Compounding and Testing course, Akron Rubber Development Laboratory, Barberton, OH, www.rubber.org/training/ - November 14-17.
University of Houston, Elastomers: Behavior and Failure in Critical Environments online course, https://uh.edu/uh-energy/elastomers-behavior-failure-critical-environments/ - November 15-16, 29-30.
TechnoBiz, Middle East Rubber & Tire Expo 2023, Sharjah Expo Center, Sharjah, United Arab Emirates, https://expo.technobiz.org - November 21-22.
Mexico Rubber Group, Design, Development and Production of Rubber Compounds course, Rubber Chamber Auditorium, Mexico City, Mexico - www.rubber.org/mexico-rubber-group - November 23.
University of Akron, Akron Polymer Training Services, Essentials of Rubber Science and Technology course, www.uakron.edu/apts/ - November 28.
Nova Institute, Advanced Recycling Conference 2023, Cologne, Germany, www.nova-institut.de - November 28-29.
Offshore Energy, Offshore Energy Exhibition & Conference 2023, Amsterdam, Netherlands, www.offshore-energy.biz - November 28-29.
Smithers, Silicone Elastomers World Summit, Amsterdam, Netherlands, www.smithers.com - November 28-29.
Smithers, Thermoplastic Elastomers World Summit, Amsterdam, Netherlands, www.smithers.com - November 28-29.
International Plastic Fair Association, IPF (International Plastic Fair) Japan 2023, Makuhari Messe, Tokyo, Japan, www.ipfjapan.jp - November 28 - December 2.
Leistritz Extrusion Technology, Twin Screw Workshop, Hyatt House Hotel, Branchburg, NJ, May Zaw (mzaw@leistritz-extrusion.com) - November 29-30.

December

Endurica, Application of Rubber Fatigue Analysis with Endurica Software workshop, www.endurica.com - December 4-7.
Rubber Division, ACS, Introduction to Continuous Vulcanization online course, www.rubber.org/training - December 6.
Messe Dusseldorf North America, ArabPlast, 16th International Trade Show for Plastics, Petrochemicals, Packaging and Rubber Industry, Dubai World Trade Center, Dubai, United Arab Emirates, www.mdna.com - December 13-15.
Rubber Division, ACS, Career Catalyst Webinar: Know Your Worth; Negotiating Salary and Benefits in a Job, www.rubber.org/training/ - December 14.
University of Akron, Akron Polymer Training Services, Essentials of Rubber Science and Technology course, www.uakron.edu/apts/ - December 19.

January

Active Communications International, Future of Polyolefins 2024 conference, Antwerp, Belgium, https://www.wplgroup.com/aci/event/polyolefins-conference - January 17-18.
Ohio Rubber Group, winter technical meeting, Hilton Garden Inn, Twinsburg, OH, www.ohiorubbergroup.org - January 23.
TechnoBiz, Latex Conference 2024, Prince Songkla University, Pattani, Thailand, https://conference.technobiz.org - January 30-31.
ACI Events, Future of Chemical Recycling Europe 2024, Rotterdam, Netherlands, https://www.wplgroup.com/aci/event/future-of-chemical-recycling - January 31 - February 1.

March

Active Communications International, European Biopolymer Summit, Ghent, Belgium, https://www.wplgroup.com/aci/event/european-biopolymer-summit - March 26-27.

April

TechnoBiz, Rubber Compound Conference, Century Park Hotel, Bangkok, Thailand, https://conference.technobiz.org - April 22-23.
TechnoBiz, Rubber Molding Conference, Century Park Hotel, Bangkok, Thailand, https://conference.technobiz.org - April 24-25.

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Thermoplastic vulcanizates with recyclate

Sarlink thermoplastic vulcanizates (TPVs) are said to be the premier choice for automotive applications requiring superior elasticity and long term performance as a recyclable, light weight alternative to EPDM rubber. Sarlink RX 3100B was developed to help automotive brands achieve sustainability targets by incorporating up to 40% post-industrial recyclate, depending on the hardness. These multi-purpose TPVs are suitable for injection molding, extrusion, overmolding and co-extrusion with polypropylene or other thermoplastic elastomers (TPEs), according to the company. For these high durometer grades, applications include the backbone or carrier for extruded seals, like in glass run channels, or boots, bellows and other under hood components.

The two grades, an 84 durometer A and 94 durometer A, are based on the existing Sarlink 3100 Series technology, but contain 25% and 40% recycled content, respectively. The materials are said to process and perform similarly to their virgin counterparts, yet offer sustainability benefits such as reduced dependency on virgin petroleum based plastic, which is said to be ideal for OEMs looking to reach aggressive targets around the use of sustainable material content in vehicles. Sarlink RX 3100B TPVs are pre-colored black and can still be recycled in process or at the end of the product's life cycle.

The use of PIR content, versus post-consumer recycled (PCR) content derived from household waste, is said to provide for a more controlled and consistent raw material stream that can be used in extrusion grade TPVs without issue. The firm treats recycled feedstocks like prime raw materials, and they are subject to the same quality assurance testing and must meet relevant specifications for use. (*Teknor Apex*)

www.teknorapex.com

Thermoplastic elastomers

This material science company from Taiwan provides a thermoplastic elastomer portfolio that demonstrate how it accelerates material science innovation for a sustainable future. With manufacturing bases in Taiwan, China and the U.S., as well as a wide distribution network of warehousing facilities across Europe, the firm is said to join with customers around the world to create best-in-class material solutions with its in-depth knowledge of material functionality, a proprietary hydrogenation process, customized quality products and trusted local service support. The company's state-of-the-art toughening modifier is said to exhibit improved physical properties in strong plasticity, abrasion resistance, durability and good modification capability. This low-medium molecular weight SEBS takes only 5% of total feedstock, while providing an increase in energy efficiency of 30% and production capacity by 20%, as well as saving on production costs for customers, according to the company. In addition to impact modifiers, the firm also offers its eco-friendly BSA (bio-based succinic acid). Compared with petro-based items, this bio solution is said to cut down on scope I emissions and reduces scope II emissions by 68%. (*LCY Chemical*)

www.lcygroup.com

PU/silicone adhesion

Polyurethane and silicone adhesion is said to have been achieved with two complementary materials, though they are theoretically incompatible. In its approach, the company is said to come close to a composite material composed of two materials with differing natures. Combined, the composite material is said to obtain more performance technical properties by combining each of the respective properties of the initial materials. (*Exsto Group*)

www.exsto.com

Sustainable solutions

Estane EV thermoplastic polyurethane (TPU) was developed to meet the growing sustainability requirements of selected markets with innovative polymers that have up to 50% lower carbon footprint, and deliver high performance attributes (like high mechanical and hydrolysis resistance) to the end product. Estane EV TPUs are plasticizer-free, non-halogenated flame retardant materials that enable the high performance of electric vehicle charging cables, according to the company. Sustainable solutions include the recent development of a biomass balanced polymer solution: Estane RNW specialty TPU with the same performance as Estane TPU resin, but with total or partial bio carbon attribution. This portfolio will further support sustainability in industries such as mobility, according to the company. In the pursuit of sustainability and premium quality, the firm has developed the Estane EV TPU product range, said to offer material performance, aesthetics and ease of use. (*Lubrizol*)

www.lubrizol.com

Liquid TPU for footwear

A liquid thermoplastic polyurethane (LTPU) has been developed that enables the rapid manufacture of high performing midsoles, and is said to be aligned with the circularity ambitions of brands manufacturing sports and athleisure footwear. Easier to use than expanded forms of TPU, which require complex procedures such as supercritical foaming and steam chest molding, the Smartlite O LTPU system can be processed in a single step that uses significantly less water and energy, and generates less waste and carbon emissions, according to the company. The Smartlite O LTPU system can also be converted and repurposed into new materials, either in its post-industrial or post-consumer form. (*Huntsman*)

www.huntsman.com

Thermoplastic elastomer

Monprene S3 CP-15170 BLK is an eco-conscious thermoplastic elastomer (TPE) made with 35% sustainable content that includes UBQ and post-consumer recycled material. UBQ is a sustainable plastic substitute converted entirely from organic and unrecyclable waste. Biobased and highly recyclable, UBQ is said to offer a climate-positive solution towards a circular economy. By replacing oil based raw materials with UBQ in TPE formulations, this company is said to be helping to address the global waste crisis, preserving finite natural resources and reducing the carbon footprint of end products which utilize its TPE. This Monprene TPE is initially available in 70 durometer A and is colored black. It performs and processes comparable to its standard TPE offset. The durometer and amount of sustainable content can be customized based on end use requirements. This high flow TPE is designed specifically for injection molding or overmolding onto PP, and is said to be ideal for consumer product applications requiring flexibility, such as hand and power tools, consumer electronics and appliances that include soft touch components for anti-slip, comfort grip and improved ergonomics. (*Teknor Apex*)

www.teknorapex.com

TPE derived from EL tires

This clean technology company announced the commercial availability of Ancora C-1000 thermoplastic elastomer (TPE). Based on the firm's patented technology, Ancora C-1000 contains 50% post-consumer recycle content derived from end-of-life tires, while maintaining the look, feel and processing of a typical petrochemically derived TPE. Ancora TPEs are said to be a new class of TPE compounds utilizing polymers derived from end-of-life tires manufactured with the company's patented Prism process. This process uses tire rubber as the primary feedstock in the production of polymer intermediates called PTR. These intermediate polymers are then compounded into injection moldable TPE pellets at the firm's Rochester, NY area facility. The first compound in the series, Ancora C-1000 is said to be suitable for use in a broad range of applications, such as automotive all-weather mats, weather stripping, footwear, and more. This Ancora compound is available in black and has a durometer A of 80. Ancora C-1000 is 99% domestically sourced, meeting IIJA Buy America requirements. Compared to virgin synthetic rubber compounds, the base polymer has an approximately 86% lower carbon footprint. (*Prism Worldwide*)

www.prismww.com

Recycled TPE materials

This global TPE manufacturer of custom solutions for a variety of industries offers Thermolast R RC/PCR/AP and RC/FC/PCR/AP sustainable TPE compounds for universal industrial and consumer applications targeted specifically for the industrial sector in the Asia-Pacific market. The company is said to be raising sustainability awareness with a mature alternative through its Asia Pacific targeted RC/PCR/AP and RC/FC/PCR/AP series. The Thermolast R RC/PCR/AP series is adaptable to universal industrial applications thanks to its non-sticky surface and comfortable grip, among many other advantages. according to the company. The RC/PCR/AP series includes compounds with 25% to 48% post-consumer recycled content (harness dependent) for a wide range of applications requiring adhesion to PP in multi-component parts or single component parts. The RoHS compliant RC/PCR/AP series has a hardness range of 50-90 durometer A. With good mechanical properties and flowability, the series is said to be ideal for tool handles (hand and power tools) and grip applications, as well as grommets, functional and design elements, connectors, cable clips, and electric and electronic components. (*Kraiburg TPE*)

www.kraiburg-tpe.com

Green polyols for PUs

This global chemical sales and marketing specialist announced the launch of its innovative product lines of green polyols, said to mark a significant milestone in the advancement of bio-based technology within the high performance segment of the polyurethane elastomers industry. These green polyols are said to pave the way for integrating bio based solutions into the polyurethane elastomers sector. These new generation polyols are said to offer exceptional hydrolytic stability in wet environments, low temperature flexibility, outstanding toughness, wear and abrasion resistance, flex fatigue life, durability, resiliency and elastic recovery. They are said to seamlessly complement the company's existing product lines of high performance and general purpose polyols derived from petrochemical sources. These green polyols are said to offer outstanding performance attributes and contribute to a more environmentally conscious future, according to the company. This firm, in close collaboration with its partners, including Chanda Chemical, Daicel, Dairen Chemical, SK Chemicals and SK Pucore, is said to offer the most extensive portfolio of aliphatic polyols in the polyurethane industry. (*Gantrade*)

www.gantrade.com

Ester based TPU grade

This specialty materials solutions provider launched a transparent thermoplastic elastomer (TPE) grade for footwear applications. The Apilon 52 XB-75A Cristallo is the company's first ester-based transparent thermoplastic polyurethane (TPU), and is said to be an important addition to the company's growing portfolio of solutions for fashion and footwear. The Apilon 52 XB-75A Cristallo grade is said to fill a unique need in the footwear industry by delivering transparent TPU for outsoles and shoe parts, while also offering excellent processability and fast cycle times using injection molding technology. This grade also is said to deliver high weatherability, color consistency and superior mechanical performance when compared to more traditional ether based TPU, according to the company. Apilon 52 XB-75A Cristallo is said to join a robust portfolio of solutions for the footwear market, which also includes a broad array of bio based and recycled content containing resins to support the industry's sustainability efforts. The company's thermoplastic product portfolio is said to provide a combination of durability, softness, flexibility and high quality, all while allowing for more efficient processing. (*Trinseo*)

www.trinseo.com

Medical mass balance TPEs

Medical TPEs are available with bio-attributed content according to the mass balance principle, adding to the company's growing portfolio of materials that enable a shift away from fossil feedstocks. Mass balance is said to allow for a gradual increase of the bio-circular share using existing infrastructure with the target to reduce the use of fossil resources step by step. It is an approach to account for materials entering and leaving a system. The bio-circular feedstock is added at the beginning of the process, traced through intermediate transformations, and allocated to the end product. As both bio-circular and fossil feedstocks are mixed, it is not possible to guarantee a specific concentration in the final product. This is comparable to "green" electricity, where consumers cannot be sure the electricity they use has come directly from renewable sources, but the overall share of green electricity in the grid rises in step with demand. The company is said to have identified mass balance as a good option for medical customers, as the resulting TPE material is a drop-in solution with identical properties. Monomers from renewable sources, but with the same quality and purity as those of fossil origin, are used to make bio-circular polymers. (*Hexpol TPE*)

www.hexpoltpe.com

Patented sealing solution

In appliances used for water purification and carbonated water, the valve of a carbon dioxide cartridge and the pressure reducing valve on the device itself must be joined with a secure seal, according to the company. The firm has developed a patented, high performance polyurethane seal for a customer that has a specific geometry that not only accommodates different valve dimensions on the various gas cartridges, but also offers high impermeability under long lasting pressure. The company's high performance polyurethane, 93 AU V167, is said to be resilient and has excellent tensile strength, in addition to high elongation at break. It is said to be very elastic, wear resistant, and is approved for food contact pursuant to European Union Regulation 10/2011. It also complies with FDA requirements and 3-A sanitary standards. The company supplied the first CNC machined prototypes and then took over the production of two preliminary series, each with about 1,000 CNC machined seals. (*Freudenberg Sealing Technologies*)

www.fst.com

Bio based polyurethane

The Acoustiflex VEF BIO system is said to be a pioneering bio based viscoelastic foam technology for molded acoustic applications in the automotive industry that contains up to 20% bio based content derived from vegetable oils. This solution can lower the carbon footprint of automotive carpet back foaming by up to 25% compared to the firm's existing systems for this application, according to the company. The technology can also be used for dash and wheel arch insulation. The Acoustiflex VEF BIO system is said to address rising demand for material technologies that can help automotive manufacturers lower their carbon footprint; but are still said to be high performing. Through careful formulation, the company is said to have integrated bio based content into its Acoustiflex VEF BIO system with zero impact on any of the acoustic or mechanical characteristics that automotive component manufacturers and OEMs seek to achieve. The Acoustiflex VEF BIO system is said to incorporate bio based content into the mix to deliver a lower carbon acoustic solution that does not compromise emission or odor requirements, and is said to be far better for vehicle brands and their partners and customers, but also the planet. (*Huntsman*)

www.huntsman.com

TPU solution for printing

Estane 3D TPU M88A thermoplastic polyurethane (TPU) is offered by the company under a selective availability program. This grade is exclusively designed and certified for HP's Jet Fusion 5200 series, a 3D printing solution said to be ideal for production applications. Estane 3D M88A is a flexible and highly durable material suited for production parts and the printing of complex geometries and lattice structures. As a certified HP materials partner, Estane 3D TPU M88A has been developed in close collaboration with HP. Estane 3D TPU M88A is a soft, flexible polymer said to have excellent processing and unpacking properties for HP's industrial grade Jet Fusion 5200 printers employing powder bed fusion technology. It has gone through extensive development and testing at several facilities. The availability of Estane 3D TPU M88A is said to allow additive manufacturing companies to effectively target a variety of final parts, taking advantage of the benefits of HP's advanced 3D printing technology. The material is said to be enabling much faster printing time, 45% less than the company's current TPU. Applications are said to be easily unpacked at room temperature, allowing for free schedule production runs. (*Lubrizol*)

www.lubrizol.com

Thermoplastic elastomer

Monprene RX CP-15100 is a high performance thermoplastic elastomer compound containing 25% to 35% recycled content. Trusted by major consumer brand owners and processors alike, Monprene thermoplastic elastomers (TPEs) allow designers more flexibility, according to the company. The Monprene RX CP-15100 series is said to help brands achieve their sustainability goals. The Monprene RX CP-15100 series, formulated with PCR (post consumer recycled) content, promotes a circular economy, while decreasing reliance on virgin fossil based resources and energy, according to the company. This offering is said to allow brands to meet consumer and regulatory demands for recycled content within their products. These TPEs are available globally and manufactured around the world with materials procured to exacting specifications, turning local waste into a resource. Unlike competitive TPEs with recycled content, available in black only, these materials are delivered in a consistent light, natural color, similar to their prime offsets, according to the firm. The company partners with UBQ Materials, climate technology developer of advanced materials made from unsorted household waste. (*Teknor Apex*)

www.teknorapex.com

Hydraulic drive motors

The smallest of the company's hydraulic motors from Bosch Rexroth has been transformed: The Atom takes over from the existing CAb, supplying not only more revolutions per minute, but also far more power than motors of similar size, according to the company. The result is said to be a tiny, power-dense package ideal for mobile and recycling applications. The Atom is said to be a powerhouse in miniature, with a maximum torque of up to 13.6 kNm and an outer diameter of only 350 mm. It has a maximum speed up to 400 rpm, depending on frame size. All sizes allow maximum pressure up to and including its maximum speed, meaning an output power of up to 394 kW, with a motor weight of 52 to 102 kg. The compact and lightweight motor fits easily on a winch, for example. Its peak pressure of up to 420 bar allows it to deal easily with shock loads. according to the company. That is said to open the door to smaller shredders and other machines in tough and unpredictable applications. The Atom is said to be rugged and robust, like the company's larger motors, which makes it just as dependable as it is versatile, according to the firm. (*Hägglunds*)

www.hagglunds.com

Material handling systems

Materials handling technologies for mixing rooms, along with new concepts for sustainable remanufacturing are offered by the company. This solution provider focuses on specialist handling of conventional materials, as well as high quality recyclates and new sustainable materials, contributing to a circular economy. The firm is said to be well known and respected for its process know-how and supply of solutions for silo storage, pneumatic conveying, weighing and feeding of powders, chemicals, solids and liquids, all carefully managed by its automation packages. However, the company is said to not only be constantly developing in this field of expertise; tire recycling is now an essential and expanding part of the firm's plant engineering business, as the industry is facing growing challenges. Modern tire production needs to embrace new targets in sustainability, accuracy, reliability and quality through precision materials handling, according to the company. Additionally, new sustainable materials and return of recovered raw materials to the production cycle are said to be key. This company is said to meet these needs by supplying solutions for the tire mixing room, recycling technology and recovery plants for end-of-life tires. The firm is said to be a reliable provider of mixing room solutions and a potential partner for solutions to produce recyclates, such as devulcanized rubber, fiber reinforced stabilizers, recycled and cleaned carbon black (rCB) and recycled oils. These sustainable materials are produced using several advanced processes (e.g., sorting, separation, shredding, granulating, devulcanization and water jet technologies. (*Zeppelin Systems*)

www.zeppelin-systems.com

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Virtual durability testing

Ford Motor Company provided this firm with recordings of all of the track events in its durability qualification schedule for a motor mount. The recordings represent the full warranted life for the subject vehicle program. Ford asked this company to simulate this history and predict expected fatigue performance. The recording comprised three channels (x, y and z load inputs) of history over 15 million time steps; an analysis scope that had never previously been possible. The launch of multithreading capabilities in the company's EIE road loads interpolation solver and in the company's CL fatigue life solver enables the calculation, which can now be distributed across multiple CPUs with excellent scaling performance (i.e., using 10 CPUs speeds execution by 10 times), according to the company. The full, warranted life of the vehicle was computed in 33 hours on a 32-core engineering workstation; said to be a new record, and now within the reach of many rubber part developers. This company provides software, materials characterization services, consulting, testing instruments and training to help companies meet rubber durability targets during product design. Solutions put engineers in control of rubber durability issues. (*Endurica*)

www.endurica.com

Long range extensometer

This company recently developed a long range extensometer which is used to calculate elongation based on the overall distance moved. This easy to use, practical fixture provides a long travel distance, critical for rubber and elastomer applications, according to the company. The long range extensometer pictured is the MMS-EXT-1100M on the company's Force MMS-5000-L3 material testing system, designed for stress-strain testing for samples up to 5,000 newtons (1,100 pounds) and up to 1,100 mm (43 inches) in total travel length. This company provides optical comparators, digital comparators, vision systems, video inspection, force and material test systems, custom solutions and special gages. Services include application analysis, system specification, installation and training, as well as post-installation field services. (*L.S. Starrett*)

www.starrettmetrology.com

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At PTE, we take immense pride in being a leading rubber compounding mixing company, dedicated to delivering exceptional quality and innovation in the rubber industry.

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Our commitment to quality is unwavering. Every batch of rubber compound undergoes rigorous quality control checks to guarantee that it meets or exceeds industry standards.

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To assist in product development, we offer prototyping services and access to our testing facilities for comprehensive analysis and performance evaluations.

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Our team of experienced engineers and technicians is always ready to provide technical assistance, answer questions, and help you find the right rubber solution for your project.

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Our rubber compounds are widely used in automotive components such as seals, gaskets, hoses, and vibration isolators.

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The drinking water compounds that are produced by PTE comply with and are certified according to the requirements of the European standards in Germany (Elastomer Guideline), Great Britain (WRAS) and France (ACS).

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Tensile and tear machine

Upgrades have been made to the company's CubeOne automated tensile and tear machine, designed exclusively for the rubber industry. The CubeOne has already revolutionized testing in major rubber companies, and these enhancements take its capabilities to a new level, according to the company. A standout feature is said to be the revolutionary auto thickness system. This compact, highly accurate addition transforms testing procedures. With CubeOne's auto thickness, technicians are said to save time, while ensuring unmatched consistency in tests. Manual thickness measurements are a thing of the past. This is said to boost efficiency, reduce errors and provide a competitive edge. A cutting edge temperature control system is also available from the company. It is said to maintain consistent ambient temperatures for every test. Temperature fluctuations often impact test results. This system is said to eradicate inconsistencies caused by environmental factors, providing precise, consistent data, according to the company. (*LabsCubed*)

www.labscubed.com

Handheld durometers

All models of the company's durometers, both digital and analog, are designed for handheld applications or to be used in conjunction with the firm's handheld durometer stand. Rubber testing instruments for measuring compression, hardness, plasticity and viscosity are available from the company. The firm's handheld durometers are said to provide lower cost alternatives for accurate and repeatable hardness testing results in accordance with the relevant ISO and ASTM standards. The versatile stand easily adapts to support the full range of durometers (including Shore A, Shore D and Shore OO), and ensures maintained force and perpendicularity during tests, according to the company. The easy height and weight adjustment is said to make it simple to measure non-standard products. Key features include the analog durometer's non-reflective 360° dial face, precise 1/2 point accuracy and the digital model's direct PC connectivity, fast data transfers and power saving auto-off function. This range of handheld durometers is said to be affordable. (*Wallace Instruments*)

www.wallaceinstruments.com

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Electronic durometers

This global manufacturer of precision measuring tools and gages, metrology systems and more offers its 3805 electronic durometer series for the hardness testing of rubber, plastics and other materials. The handheld hardness testers are crafted and engineered to perform at the highest level of accuracy, according to the company. An ergonomic, lightweight design with a large LED digital readout assists users in taking precise and consistent hardness measurements. The company's 3805 electronic durometers feature a measuring range of 0-100 HSA (0-100 HSD) and a resolution of 0.5 H. The Model 3805B features a durometer A scale which is said to be ideal for testing rubbers, such as the soft vulcanized types found in tires, natural nitrile elastomeric materials, and wax, felt, leather and additional materials that normally yield under fingernail pressure. The Model 3805D features a durometer D scale which is used for testing hard rubber, harder grade plastics and a variety of other materials that do not normally indent under fingernail pressure. The company is said to be a leading global manufacturer of precision measuring tools and gages, optical comparators and vision systems, and force and hardness testing solutions. (*L.S. Starrett*)

www.starrett.com

Automated tensile tester

The CubeTen is an automated tensile machine inspired by the company's CubeOne for rubber testing, CubeTen unlocks its key features for plastics. Like CubeOne, CubeTen is intuitive, affordable and technician-friendly, offering efficiency and ease of use, according to the company. CubeTen is said to have received an overwhelming response, with companies praising its intuitive design and user-friendly interface. Early pre-sales numbers are said to have exceeded expectations. CubeTen extends the company's commitment to a broader audience in the plastics sector, empowering companies to streamline testing processes, enhance efficiency and improve product quality, according to the firm. Designed to address plastics industry challenges, CubeTen is said to be intuitive, affordable and time-saving. It is said to level the playing field for companies of all sizes, allowing them to focus on creating exceptional products. The company's goal is said to be engineering and designing equipment that enables clients to keep their customers happy. To achieve this, the firm has created the Cube family, automated tensile testers that help polymer testing laboratoriess increase accuracy, consistency and speed of testing. (*LabsCubed*)

www.labscubed.com

Synthetic elastomers

This authorized distributor of several specialty synthetic elastomers provides nitrile rubber from Dynasol, as well as fluoroelastomers. The firm offers a wide range of high performance FKM elastomers in a range of fluorine contents from 64% to 70% and Mooney viscosity from 25 to +100. Depending on type, these are said to have varying degrees of excellent high temperature, oil and chemical resistance. These products are available as cure incorporated copolymers and terpolymers, bis-phenol cure, and also peroxide cure grades. In addition, the company also offers gums and FKM curatives. Nitrile rubber (NBR) products are offered with a range of ACN contents from 19% to 40% and Mooney viscosity from 20 to 110. They are used for oil and fuel resistant rubber applications and plastics (PVC and ABS) modification. Nitrile rubber (NBR) is used to make fuel and oil handling hoses, seals, o-rings and grommets. They are also used to produce molded goods, footwear, adhesives, sealants, sponges, expanded foams and floor mats. The company is said to be a reliable distributor and re-packager dedicated to maintaining quality at all levels of its organization. (*R.E. Carroll*)

www.recarroll.com

FFKM fluoroelastomers

Two grades have been added to the company's line of perfluoroelastomers. Aflas FFKM PM-5000 and FFKM PM-5500 perfluorinated elastomers are said to be ideal for semiconductor plasma process applications because of their high temperature durability beyond 300°C and excellent resistance to O_2 and NF_3 plasma. They also have a high molecular weight that enables greater hardness without using fillers, which can create unwanted particles, according to the manufacturer. These nitrile curable grades build on the high performance properties of other Aflas FFKMs. This means they also provide excellent chemical resistance and electrical insulation, according to the company. These qualities are said to make them suitable for fabricating components that perform in aggressive and sensitive environments. PM-5000 offers lower compression set and adhesive force, whereas PM-5500 has a higher molecular weight and hardness, which is achieved without the use of fillers. This company is a global subsidiary of a multinational corporation said to be one of the world's largest manufacturers of glass, electronic displays and chemical products. (*AGC Chemicals Americas*)

www.agcchem.com

Rubber-to-metal bonding

Fluon+ flexible AR melt processable compounds are based on a modified ETFE copolymer and a unique fluoroelastomer. These grades maintain many of the desirable properties of ETFE, like excellent heat and chemical resistance, but are more flexible than other fluoropolymers, according to the company. These materials are used in many applications, including wire and cable, films and sheets, tubing and pipe, and electronic components. Fluon+ flexible AR melt processable compounds are said to be ideal alternatives to THV in formulations because they are resistant to fuels and chemicals, exhibit toughness and flexibility, and have a wide service temperature range. These customizable compounds are readily available as a highly suitable replacement for THV. The company also offers Aflas fluoroelastomer grades that are said to be proven to improve the performance of parts and components that need to perform reliably in the harshest environments. Aflas 400E and 600X FEPM fluoroelastomer grades are designed for multilayer hose constructions and other critical parts used in high pressure, high temperature environments. They are resistant to NOx, SOx, engine oils and other aggressive fluids. (*AGC Chemicals Americas*)

www.agcchem.com

Sustainable polymers

This company is said to be committed to building on its legacy of compounding expertise and environmental awareness by establishing itself as a market leader in scalable and sustainable materials solutions. Responding to market demands for sustainable compounds, the company is relaunching its Terraloy brand to build up a portfolio of products that will meet the challenges of today's rapidly changing industry. The portfolio will include polymers, additives and fillers covering a broad range of sustainable attributes such as recycled, bioderived and biodegradable content. It will include credible products with verifiable carbon footprint and LCA data. In 2015, the company received two awards for the Terraloy technology: the Innovation in Bioplastics Award from SPI: The Plastics Industry Trade Association; and the Bioproduct Innovation of the Year Award from Ohio State University's OBIC Bioproducts Innovation Center. It was this same year that the United Nations created its Sustainable Development Goals (SDGs). These goals, supported by the firm's initiatives, promote a global partnership to improve health and education, reduce inequality and stimulate economic growth, all while addressing climate change. (*Teknor Apex*)

www.teknorapex.com

Two-component epoxy

The epoxy EP21LVFL is said to combine good flexibility with a solid strength profile. It is curable at room temperature with a long working life of 120-160 minutes at 75°F for a 100 gram batch, and features a flowable initial mixed viscosity of 10,000-14,000 cps. This epoxy generates low exotherm, making it suitable not only for bonding and coating, but also for sealing and potting applications. EP21LVFL is said to be especially useful in bonding substrates with different coefficients of expansion, such as metals, composites, glass, ceramics, rubbers and plastics. It has a high elongation of 120% to 150%, a low tensile modulus of 1,500-2,500 psi and a durometer D hardness of 40-50. The product is said to offer excellent electrical insulation properties with a volume resistivity exceeding 1,015 ohm-cm and a dielectric constant of 2.95 at 60 Hz. EP21LVFL has a tensile strength of 1,200-1,400 psi and a lap shear strength measuring 900-1,100 psi, which is impressive for a flexible product, according to the company. The system is said to be capable of withstanding rigorous thermal cycling, vibration, mechanical stress and shock. This two-part epoxy offers a non-critical one to two mix ratio, by weight or volume. (*Master Bond*)

www.masterbond.com

Durable fluoroelastomers

Viton fluoroelastomers are said to deliver peak performance in harsh environments. With a shift toward renewable energy policies in countries around the world, there is said to be a growing emphasis on sustainable transportation options, including electrified vehicles. As automotive original equipment manufacturers (OEMs) are working hard to remove barriers to the adoption of EVs by the public, greater focus is being placed on improving the battery systems necessary to power these vehicles. In order to increase energy efficiency and increase driving range, some manufacturers are said to be switching to higher voltage systems. As a result, the use of larger diameter power cables in fully hybrid and battery electric vehicles is increasing significantly, according to the company. This change is said to be creating the need for high performance materials to be used in the manufacture of power cables that connect the battery, motor and inverter, in order to guarantee both performance and safety of vehicle operation. It is said to be critical that these materials have the right combination of electrical insulation properties, and temperature and chemical resistance. High quality Viton fluoroelastomers are said to extend component life. (*Chemours*)

www.chemours.com

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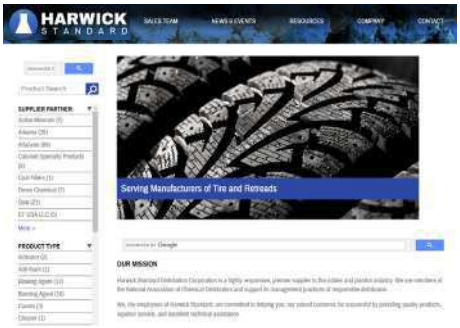

Harwick Standard Distribution Corporation (www.harwick.com) is a premier supplier of superior raw materials for industries specializing in rubber, plastics and other polymer related fields. Harwick provides an expansive and specialized product base which is able to address any customer's most challenging requirements. Harwick's commitment to helping its customers achieve optimum results in all of their applications has afforded the firm the reputation as a responsive, unique and valuable resource.

Servicing the rubber, thermoplastics and other polymer related industries for more than 85 years, Harwick Standard is a management owned and operated sales, marketing and technical support organization headquartered in Akron, Ohio. Harwick Standard is ISO 9001-2015 registered, and operates a nationwide distribution network aupplying products from more than 30 blue chip manufacturers. Harwick Standard is a proud member of the National Association of Chemical Distributors (NACD) and practices the NACD's Responsible Distribution.

General products available from Harwick Standard include: accelerators, auto-foams, antioxidants/antiozonants, anti-scorch agents, bleaching and disproportionation agents, blowing agents, bonding agents, casein, chemical dispersions, cleaners, coagents, coupling agents, desiccants, dry liquid concentrates, fatty acids, fillers, flame retardants, lubricants, magnesium oxides, metallic stearates, multifunctional additives, peroxides, pigments, plasticizers, polymers/elastomers, process oils, PVC/thermoplastics additives, reodorants, resins, rubber chemical dispersions, rubber to substrate bonding agents, sulfur, vulcanized vegetable oils and zinc oxide.

Polymers and elastomers provided by Harwick Standard include: BR, liquid butyl rubber, pre-crosslinked butyl pellets, liquid polyisoprene, CPE (chlorinated polyethylene), CR (polychloroprene), EPR, EPDM, EVM, NBR, XNBR, NBR powder, HNBR, FKM, NR and SBR.

Safety Data Sheets (SDS) are available for all products, along with product literature for select product lines.

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Doss' Italian roots have grown into a multinational presence, with corporate headquarters in the United States and Asia, enhancing its ability to meet the requirements of various industrial sectors across the world.

With worldwide installations exceeding 1,000 machines, Doss' advanced systems play a crucial role in maintaining and enhancing the high quality standards of various industries, such as pharmaceutical, automotive, oil and gas, and others. Doss' state-of-the-art algorithms use high resolution images and the Multishot system to optimize analysis accuracy.

Manual sorting processes can be arduous and costly, accounting for up to 60% of a company's expenses, including labor and lost opportunities (estimated by the American Society for Quality). Furthermore, the risks associated with human eye inspection in detecting defects can lead to substantial liabilities and erode customer confidence. Automated visual inspection, on the other hand, is not only fast and accurate, but also cost-effective, enhancing a team's ability to focus on driving business growth.

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Struktol Company of America (www.struktol.com) is a member of the Schill+Seilacher group, with global representation in over 100 countries. Struktol's approach to the rubber and plastic additives business is by no means typical or ordinary. Chemistry is at the heart of everything Struktol does. Providing intelligent additive solutions, Struktol products are designed to meet the challenges and exacting demands of its customers. Struktol's technical specialists, research and development chemists and compound laboratory are dedicated to creating innovative solutions for the ever-changing polymer industry; solutions that keep customers ahead of their competition with increased productivity, better quality parts and lower overall cost. In addition to premium product performance, Struktol's customer service initiatives have become the industry benchmark.

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Struktol silica dispersants provide faster processing of high performance silica compounds. The use of processing additives in compounding containing high dispersity silica/silane coupler and high levels of natural rubber can provide a variety of processing and physical property benefits, including reduced viscosity for improved processing, increased cure state, improved scorch safety, better modulus and tensile, a significant decrease in Payne effect, reduced abrasion loss, and more.

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People in the News

Teknor Apex names Donald Wiseman CEO

Donald Wiseman was named chief executive officer of Teknor Apex. He replaces **Jonathan Fain**, who is stepping aside as CEO after 51 years with the company. Fain will remain a stakeholder and continue serving Teknor Apex as chairman of the board.

Management

Luca Pini has joined Global Rubber Industries (GRI) as the company's original equipment manufacturer (OEM) lead in Europe.

Olivier de Linares was appointed PLA production plant director in Rayong, Thailand, for TotalEnergies Corbion. He will oversee the firm's safe operations, product quality and reliable supply.

Donald Wiseman
Teknor Apex

Jonathan Fain
Teknor Apex

Technical

Edwin Goudswaard was appointed head of research and development at Continental Tires. He succeeds **Boris Mergell**, who took over as head of the User Experience business area at Continental Automotive.

Luca Pini
GRI

Edwin Goudswaard
Continental Tires

Ceat appointed **Renji Issac** senior vice president, research and development and technology, in India. Issac succeeds **Peter Becker**, who previously held the position.

Trent Maynard was promoted to director of product and engineering for Global Shop Solutions, a provider of enterprise resource planning (ERP) software.

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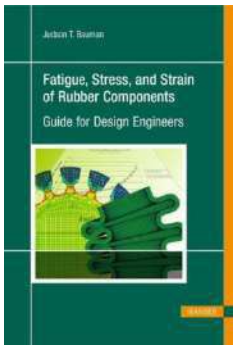

Fatigue, Stress, and Strain of Rubber Components

This book covers the fatigue testing of specimens, curve fi tting of equations to the test data, and theuse of such equations in life prediction. Earlier chapters are background in the nature of rubber, historyof its usage, brief mention of types of rubber and manufacturing methods. Stress-strain testing andbehavior is covered to the extent relevant to fatigue analysis. Also, the text covers the application offi nite element analysis to components to determine high stress points that are vulnerable to fatigue-failure. It is a very useful reference for practicing engineers charged with the responsibility to designstructural rubber components where fatigue life is a concern.

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