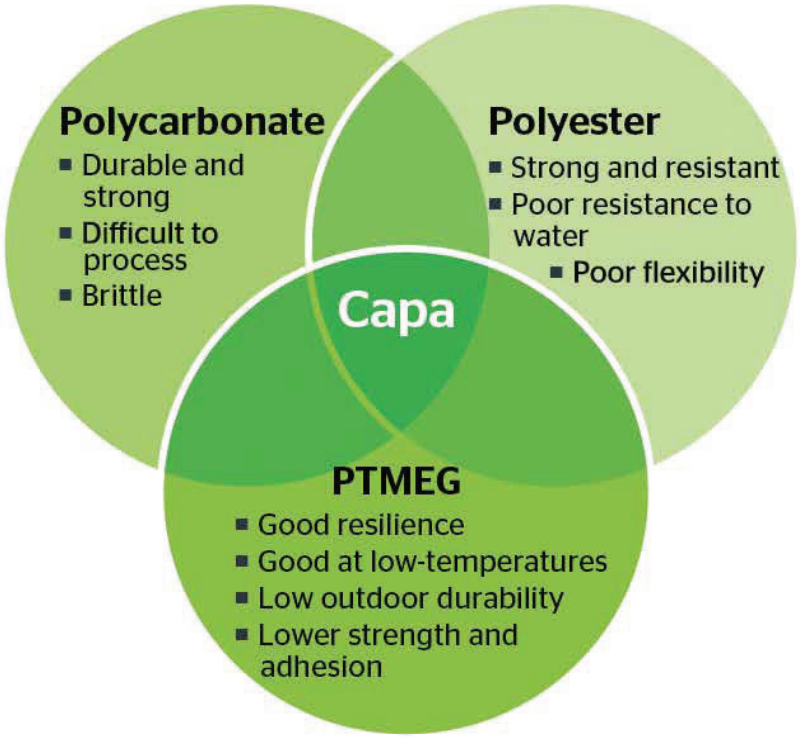
Capa adds value particularly where polycarbonate, polyesters and PTMEG fall short.



Capa polycaprolactones for soft thermoplastic polyurethanes

Thermoplastic polyurethane (TPU) elastomers, a unique type of plastic that bridges the gap between plastics and rubbers, are an integral part of industrial and consumer products where high performance and durability are key. For more than 60 years, this technology has been considered an ideal polymer for use in a wide variety of segments, including specialty molded parts, film and sheet, footwear, adhesives, compounding and more. According to a recent industry market report, the global TPU market was estimated to be worth USD 3.8 billion in 2021 and could reach USD 5.1 billion by 2026.* This significant growth is mainly due to the expansion of end-use industries, as TPUs are broadly utilized in automotive, construction, aerospace and medical industries for various applications due to unique performance properties such as elasticity, durability and resistance.

By Scott Phillips

Key TPU technology trends and developments

The continuing and growing consumer trends seen in electronics, appliances and automotive interiors have given rise to the demand for products that are not only functional and durable but also comfortable and aesthetically appealing during use and wear. The significant challenge of TPU technology exists in producing materials that are formulated to be soft and stay soft over the course of their useful lifetime. Traditional TPUs inevitably harden over time, leading to cracking and product failures. These factors have led to the development of a technology that provides a viable alternative to standard TPU grades offering part manufacturers the ability to be even more competitive in premium applications such as in wearable technology and car interiors, where soft touch and durability are key.

In efforts to target this specific industry gap, specialty chemical supplier Ingevity developed the Capa S series for soft polyurethane (PU) applications. Derived from its Capa caprolactone chemistry, this proprietary technology not only allows production of soft TPUs using standard manufacturing techniques but yields low-durometer end parts (30-60 Shore A) that maintain this value during their functional lifetime. All while avoiding the use of plasticizers.

A more sustainable, high-performing alternative to plasticized TPUs

Ingevity's Capa S series is an innovative and sustainable new polyol product line that extends the scope of TPU technology. The series is designed to inhibit traditional cold hardening, resulting in end products that are soft yet durable and enable TPU producers to challenge more expensive, less environmentally friendly materials such as fluoroelastomers and siloxanes. The flexibility of polycaprolactone chemical technology allowed Ingevity to design polyol intermediates specifically to address the challenge of cold hardening, giving customers the opportunity to offer products that are not only soft, but remain soft and can compete with alternative materials. The key to the versatility of TPUs lies in its highly customizable hardness, and Capa S helps achieve that like never before.

Prior to the development of Ingevity's Capa S portfolio, no existing products were manufactured on a commercial scale that have been proven to successfully address this soft TPU technology gap. With Capa S polyols, customers can now produce soft TPUs that can be used in applications including wearable devices – such as smart watches and fitness and GPS trackers – and automobile dashboards, seating and door panels, which are repeatedly exposed to heat, cold, moisture and ultraviolet rays. This new portfolio helps maintain softness and minimize cracking during a product's functional lifetime, simplifies formulations and lowers production costs.

Capa S allows more streamlined manufacturing of thermoplastic parts for use in applications that could only formerly achieve desired flexibility and longevity with thermoset plastics, namely fluoroelastomers and silicone elastomers, or by using TPUs with traditional phthalate plasticizers. The Capa S alternative allows part manufacturers to be more responsive to industry demands for phthalate-free products due to chemical and toxicity concerns, while also enabling high-performing end-use products.

Capa polyols in PU elastomers

To better understand the Capa S technology, it's helpful to recognize the unique benefits this molecule provides. Ingevity's caprolactone derivative technologies are made possible through a unique ring opening polymerization process, whereby caprolactone monomer can be derivatized into proprietary, value-added polyols and thermoplastics. Capa enables high-performing products that are often:

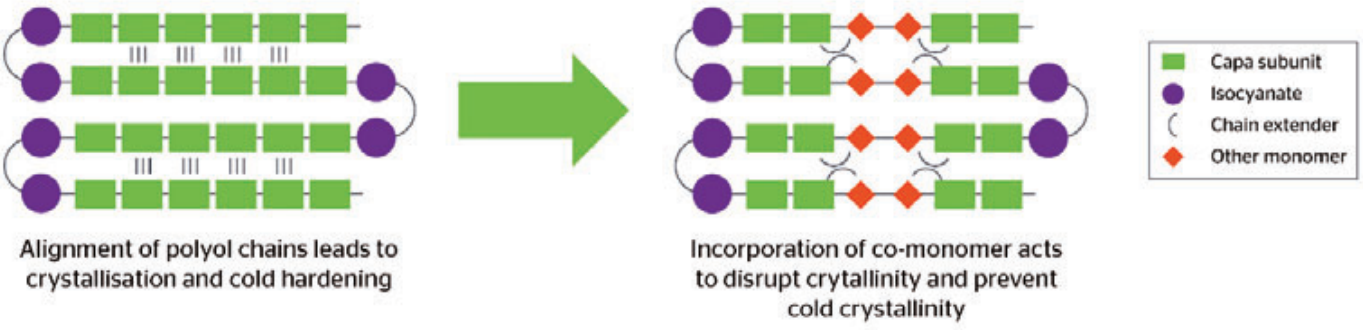
- More resilient
- More durable
- More resistant to water, chemicals and weather
- Biodegradable
- Food-contact approved

Capa enhances the ability of PU elastomers to withstand the effects of temperature, moisture and mechanical stresses, prolonging the lifetime of end parts. High-quality PU articles – such as seals, gaskets and O-rings – can be produced that can endure harsh environmental conditions and maintain optimal performance. The added strength, flexibility and durability Capa provides also benefits PU products where there can be no compromise on processing ease, performance and durability.

Specialty polyols designed to keep TPUs soft

Capa S 22X and Capa S 23Y were developed through rational polyol design. Polyols used in conventional polyurethane formulations are typically semi-crystalline, giving materials with robust mechanical properties that are durable in the face of environmental stresses. This has the drawback that when softer materials are prepared, the polyol component can further crystallize, leading to hardening of the material over time, making it difficult to maintain soft properties. The Capa S series is intended to be less crystalline than conventional polyols, but without being completely amorphous, ultimately maintaining the best features of TPUs in addition to softness (fig. 1).

Fig. 1: Rational design of the Capa S series polyols.



Conventional polyether and polyester polyols - including Capa homopolymers - are not suitable in soft TPU formulations with a low isocyanate content due to the post-manufacture crystallization of the soft segment, also known as cold hardening. Ingevity tuned the crystallinity of the Capa polyol so that cold hardening of the polyurethane soft segment is prevented while maintaining the performance, mechanical and processing properties to be expected of a Capa polyol (fig. 2, tab. 1).

Fig. 2: A representation of the molecular structure of the Capa S series

Base polyol	Capa 2201A	Capa S 22X		Capa S 23Y	Silicone elastomer	Fluoro-elastomer	TPO & TPV	SBC
Hardness (Shore A)	69	61	50	60	70	63	65	60
Tensile strength (MPa)	22.5	24.9	20.4	14.3	7.8	15.7	6.0	6.0
Tear strength (kN/m)	54	43	37	36	44	24	30	22

Tab 1: Ingevity's current Capa S product offerings

Balancing soft touch and durability

The Capa S series are formulated to give soft thermoplastic polyurethanes (30-70 Shore A) that remain soft over their functional lifetime. It has been demonstrated that such formulations remain soft for at least six months under ambient conditions and in accelerated (low temperature) testing (fig. 3, tab. 2). This is compared to polyurethanes based on more crystalline polyols such as Capa 2201A

Tab 2: Formulation for 60 Shore A polyurethane elastomers

Target hardness	60 Shore A
Polyol molecular weight (g/mol)	2000
Polyol (parts)	100
MDI (parts)	27.7
BDO (parts)	5.2
Isocyanate index	103

The soft properties are accompanied with the mechanical properties that would be anticipated from high performance polyurethane materials. This allows access to materials with the optimal balance of softness, mechanical strength and durability. Soft TPUs based on the Capa S series can give productivity and/or costs benefits versus silicone elastomers and fluoroelastomers whilst being a more mechanically robust alternative to TPO/TPV and SBC (tab. 3).

Tab 3: Mechanical properties of PU prepared using the Capa S series versus other commercially available soft materials.

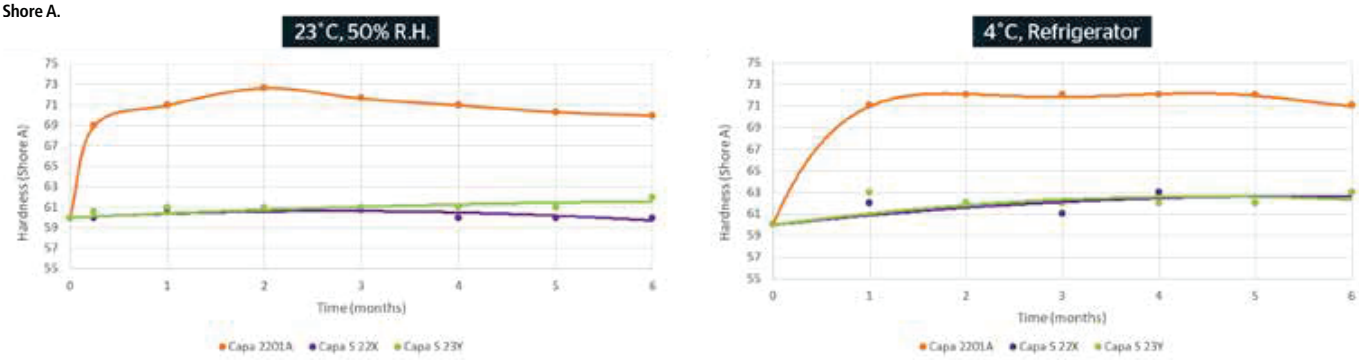
Product	Appearance	Functionality	Molecular weight (g/mol)	OH value (mg KOH/g)	Acid value (mg KOH/g)	Melting point (°C)	Viscosity @ 25°C (mPa·s)	Viscosity @ 60°C (mPa·s)
Capa S 22X	Waxy solid	2.0	2000	56.0	<0.05	15-35	Solid	107 (80°C)
Capa S 23Y	Waxy solid	2.0	3000	37.5	<0.05	30-40	Solid	124 (80°C)

Processing ease

A key advantage of TPU technology is the ability to produce high performance materials continuously (via reactive extrusion) that are melt-processable, giving a wide array of possible end products. There are thus cost, productivity and processing benefits of TPU technology over competitive (often thermoset) materials. The availability of polyols that allow the production of soft TPUs extends the range of potential end-use products beyond what has previously been possible.

Ingevity has shown that it is possible to process TPUs made from the Capa S series in a similar manner to conventional TPUs. The reduced crystallinity of these polyols leads to a slightly increased cycle time when TPUs are injection moulded but it is believed that even if productivity in this process is reduced compared to conventional TPUs, it still offers distinct processing and cost advantages to the downstream users over competitive materials. It is also highly likely that any cycle times issues can be overcome by optimization of the polyurethane formulation.

Fig. 3: Hardness development in polyurethanes (MDI/BDO/polyol) based on Capa S 22X and Capa S 23Y versus a Capa 2201A benchmark. All formulated to give an initial hardness of 60 Shore A.



Market impact of soft TPU technology

Consumers' ongoing and increasing interest in functional, long-lasting products that are also comfortable and aesthetically appealing during use and wear means formulators must also continually innovate and respond to these demands. The Capa S series will have a profound impact on materials for consumer products by widening the use of TPUs (a low cost, sustainable material produced with high throughput) to softer materials, inaccessible with current technologies. This will mean material replacement of more expensive, hard-to-produce thermoset materials such as fluoroelastomers and silicone elastomers, with products that are just as soft but with added durability. Capa S also offers a more sustainable alternative to current materials – a thermoplastic that can be chemical recycled at the end of its lifetime.

Ingevity launched its new Capa S polyol technology for soft thermoplastic polyurethane applications in November of 2020. The Capa S portfolio is designed for use in wearable devices and automobile interiors that are repeatedly exposed to heat, cold, moisture and ultraviolet rays. This new portfolio helps maintain softness and minimize cracking during a product's functional lifetime, simplifies formulations and lowers production costs. Capa S technology is an alternative that allows part manufacturers to be more responsive to industry demands for phthalate-free products due to chemical and toxicity concerns, while also enabling high-performing, end-use products.

*Thermoplastic Polyurethane (TPU) Market - Global Industry Analysis, Size, Share, Growth, Trends, and Forecasts 2019 – 2027. Transparency Market Research

About Ingevity's Engineered Polymers business

Ingevity's Engineered Polymers business is a leader in caprolactone technology and innovation, with a 40-year history of improving performance in a wide variety of end-use products. Ingevity supplies Capa products into multiple markets, helping formulator and applicator customers make tougher, more durable, flexible and even biodegradable products. The caprolactone derivative technologies are made possible through a unique ring opening polymerization process, whereby caprolactone monomer can be derivatized into proprietary, value-added polyols and thermoplastics. The Capa portfolio is comprised of three product families:

- Monomers: Main building block for internal and customer use
- Polyols: Range of polymers used in polyurethane coatings, adhesives, sealants and elastomers (CASE)
- Thermoplastics: Specialty polyester thermoplastics used in bioplastics, medical and adhesive applications

Capa products are developed for a diverse set of applications such as PU materials, adhesives and sealants, coatings, polymer additives and bioplastics that are used for end markets such as industrial equipment, automotive, footwear, consumer packaging, electronic and medical devices, and furniture.

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All figures and tables, unless otherwise stated, have been kindly provided by the author.

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