Fiberglass pultrusion profiles for window applications:

A more sustainable and innovative solution with polyurethane resins

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Introduction

Windows are essential elements of buildings that provide natural light, ventilation, and aesthetic appeal. However, windows also account for a significant amount of heat loss and gain, affecting the energy efficiency and comfort of buildings. Therefore, there is a growing demand for high-performance windows that can reduce energy consumption, improve thermal and acoustic insulation, and enhance durability and design flexibility.

Traditionally, window frames have been made of materials such as wood, aluminum, steel, and PVC, each with its own advantages and disadvantages. However, none of these materials can inherently offer the optimal combination of mechanical, thermal, and environmental properties that are required for modern windows. This is where composite materials, especially pultruded profiles, can provide a superior alternative.

Pultrusion is a continuous and automated process that produces composite profiles with a constant cross-section and high fiber content. Pultrusion can use various types of resins and fibers to create profiles with different characteristics and applications. Among the resin systems available, polyurethane (PU) stands out as a versatile and high-performance option that can deliver exceptional pultrusion results.

This white paper aims to provide an overview of the benefits of using PU resins for pultrusion, especially for window applications. It will also present a case study of a project realizing a PU pultrusion window profile based on an existing PVC window profile design.

Trends in the window market and need for new materials

The global window market is expected to experience significant growth, driven by increasing demand for energy-efficient buildings and the rise of urbanization. According to a report by Lucintel, the global door and window market is projected to grow at a compound annual growth rate (CAGR) of over 4% from 2024 to 2030, driven by increasing demand for energy-efficient building solutions and advancements in window technologies. In particular, the European market is expanding rapidly, with a growing focus on sustainability and environmental regulations. This trend is influenced by the stringent energy efficiency standards set by the European Union, which aim to reduce carbon emissions and promote the construction of energy-saving buildings, for example as set forth in the Energy Performance of Buildings Directive (EU/2024/1275), the European Green Deal or the Energy Efficiency Directive (EU/2023/1791). As a result, there is a rising demand for innovative materials that not only fulfill these regulations but also offer superior performance and design versatility. This makes the window market highly attractive for materials that can deliver on these fronts, such as pultruded polyurethane profiles for window frames.

However, the window market also faces several challenges, such as high initial and maintenance costs, the environmental impact of materials, and regulatory compliance with building codes and standards. Moreover, the window market is highly competitive and fragmented, with many players offering similar products and services. Therefore, window manufacturers and designers need to differentiate themselves by offering innovative and sustainable solutions that can meet the evolving needs and expectations of customers (Fig. 1).

One of the ways to achieve this differentiation is to use new materials that can offer superior performance and functionality, while also reducing the environmental footprint and lifecycle costs of windows. Composite materials, especially pultruded profiles, are emerging as a promising option that can address these challenges and create new opportunities for the window market.

Fig. 1 Modern window solutions need to offer superior performance, improved sustainability and design variability (Profine GmbH)

Composite profiles as an innovative material solution

Composite materials are composed of two or more different materials that are combined to create a new material with enhanced properties and characteristics. The main components of composite materials are the matrix, which binds the materials together, and the reinforcement, which provides strength and stiffness. Composite materials can be tailored to achieve a specific performance and functionality by varying the type, amount, and orientation of the matrix and the reinforcement. Pultruded composite profiles have a constant cross-section and are produced by a continuous process. Pultrusion is a cost-effective and efficient process that involves pulling continuous fibers through a resin bath or injection box and then through a heated die, where the resin cures and the profile is formed. Pultrusion can produce profiles with various shapes and sizes, such as rods, tubes, channels, angles, and complex geometries.

For window applications, composite profiles have several advantages over conventional materials such as wood, aluminum, steel, and PVC. Some of these advantages are:

High strength-to-weight ratio

Composite profiles are lighter than steel and aluminum, but still have very high strength and stiffness. This reduces the structural load caused by the weight of the window and allows for larger window sizes and slimmer designs.

Low thermal conductivity

PU composite profiles have lower thermal conductivity than steel and aluminum and offer inherent thermal insulation. This means they can offer better energy efficiency without additional complexity from dedicated insulation materials, such as plastic thermal barriers like those frequently used in aluminum windows. This effectively reduces the risk of condensation and thermal bridging, which can cause moisture and mold problems.

Low coefficient of thermal expansion

PU composite profiles have similar or lower coefficient of thermal expansion than glass used for the window and cement used for the walls, which means they have better dimensional stability and less deformation due to temperature changes compared to thermoplastic or metallic window frame materials. This adds to improved air and sound insulation, smoother mechanical operation, and an overall improved user experience.

Durability

PU composite profiles are resistant to corrosion, weathering, and, when coated properly, UV radiation, which means they offer good durability and low maintenance costs, especially when compared to wooden windows.

Design flexibility

Composite profiles can be produced with various shapes, sizes, and colors, which means they offer competitive design options and customization for windows. Further, they can be easily cut, drilled, and glued, which guarantees efficient fabrication and installation of composite windows.

Pultrusion with polyurethane: brief process overview and profile properties

Polyurethane (PU) is a type of polymer that is formed by the reaction of a polyisocyanate and a polyol. PU can have various properties and characteristics depending on the type and ratio of the reactants, the additives, and the curing conditions. Such polyurethane systems for pultrusion are provided by Covestro.

With Baydur® PUL, we have developed a two-component thermoset PU resin system that is highly suited for the pultrusion process. Baydur® PUL resins have several advantages over other resin systems, such as epoxy, unsaturated polyester, and vinyl ester. Some of these advantages are:

Low viscosity

Baydur® PUL typically has a very low viscosity, which means it can impregnate the fibers quickly and evenly, resulting in good fiber wet-out and resin distribution. PU impregnates the fibers in a closed injection box, which protects the materials from environmental conditions, increases reproducibility and reduces the resin consumption and the waste generation.

High reactivity

Baydur® PUL has higher reactivity than other resins, which means it can cure faster, resulting in higher line speeds. This also reduces emissions and the influence of the environment on the curing process. In combination with fast fiber impregnation, Baydur® PUL systems enable high productivity in the pultrusion process.

Smooth processing

Baydur® PUL systems are easy to handle and enable stable and trouble-free operation with minimum scrap.

Good mechanical properties

Baydur® PUL has outstanding mechanical properties, such as tensile strength, flexural strength, flexural modulus, and impact resistance, which means it can produce profiles with high performance and functionality. Baydur® PUL can also be tailored to achieve specific properties by varying the type and ratio of the reactants and the additives.

Pultrusion with PU involves the following steps (Fig. 2):

1. The fibers, usually glass or carbon, are pulled from creels and guided through a tensioning and preforming device.
2. The fibers are then passed through an injection box, where they are impregnated with the PU resin system. This consists of an isocyanate, a polyol and typically an internal mold release agent, as well as other optional additives, such as flame retardants or mineral fillers.
3. The impregnated fibers are then passed through a heated die, where the PU resin system cures and the profile is formed. The die temperature and length are adjusted according to the resin reactivity and the line speed.
4. The cured profile is then pulled by a puller device, which controls the line speed and the tension of the profile.
5. The profile is then cut by a saw device, according to the desired length and quality.
6. The profile is then cooled, inspected, and packaged for delivery.

Figure 3 shows a polyurethane pultrusion line with its typical components and Table 1 lists the required equipment and process characteristics.

Technical processing information

Watch our video

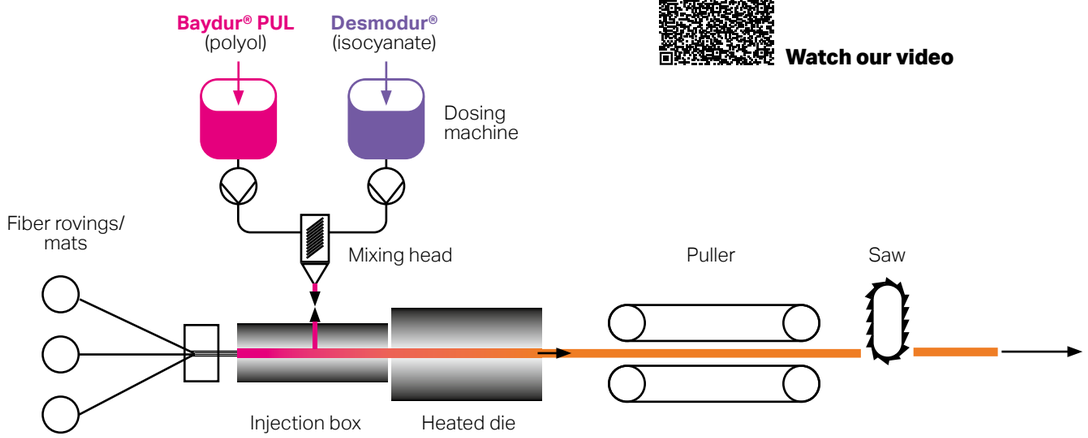

Fig. 2 The polyurethane pultrusion process

Fig. 3 Polyurethane pultrusion line (KraussMaffei Technologies GmbH)

Equipment and Process Characteristics of Polyurethane Pultrusion	
Key Equipment Components	• Fiber feed system • 2K dosing and mixing machine • Closed injection box (for highly reactive resin systems like PU) • Heated die for shaping and curing (1-meter-long with 3-6 heating zones up to 230 °C) • Pulling mechanism (alternating grippers or caterpillar puller) • Cutting saw for profile sizing
Fiber Reinforcement	• Primarily uses glass fibers (over 90% of cases) • Typically unidirectional (UD) rovings • Can incorporate additional textile reinforcements (mats, fabrics) for increased transverse properties
Production Speed (fully optimized process)	• Typical speeds up to 2-3 m/min with 3 mm wall thickness of the pultrudate (depending on profile complexity) • PU systems can potentially double the speed compared to other resins
Advantages of the Pultrusion Process	• Automatable process • Low labor input • Minimal material waste • Suitable for large-scale production of FRP components

Table 1

Value of using polyurethane systems: excellent mechanical properties and efficient production

Using Baydur® PUL polyurethane systems from Covestro for pultrusion offers a unique value proposition for window applications, as it combines excellent mechanical properties and efficient production (Fig. 4 & 5). This value is generated for the customer by the following aspects:

Baydur® PUL …

… pultrusion profiles have high strength-to-weight ratio, low thermal conductivity, a low coefficient of thermal expansion, corrosion resistance, and design flexibility; in sum, these properties make them superior to other materials for window applications.

… pultrusion profiles can reduce wall thickness and fiber content compared to other resin systems, such as unsaturated polyester or vinyl ester, while maintaining or improving mechanical performance, which can lower material and production costs.

… allows for increased line speeds, while reducing resin consumption and waste generation, which can improve productivity and the environmental impact.

… pultrusion profiles can enable the production of complex and customized profiles, which can create new market opportunities and differentiation for window manufacturers and designers.

The value of our Baydur® PUL resin system for pultruded window frames can be demonstrated by a case study of a project that realized a PU pultrusion window profile based on an existing PVC window profile design. The project was a collaboration between Covestro Deutschland AG, Leverkusen, a leading supplier of PU resins, KraussMaffei Technologies GmbH, Munich, a leading supplier of pultrusion equipment, and Profine GmbH, Pirmasens, a leading supplier of window systems.

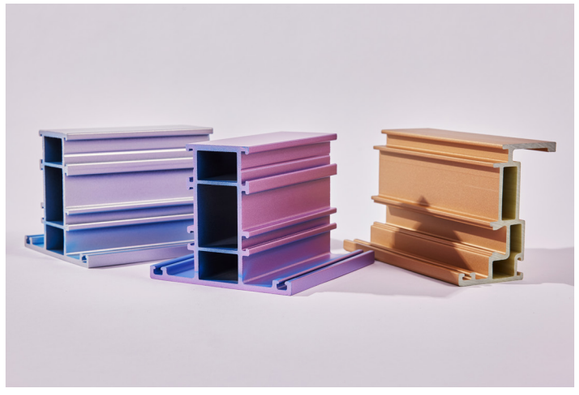

Fig. 4 Pultruded window profiles based on Baydur® PUL raw materials from Covestro

Fig. 5 Pultruded window profile based on Baydur® PUL raw materials from Covestro

Replacing a PVC profile with a fiberglass pultrusion – a case study by Covestro, KraussMaffei, and Profine

The Profine case study was a project that aimed to replace a steel-reinforced PVC window profile with a pultrusion profile made from Baydur® PUL PU resin, while maintaining or improving the mechanical and thermal performance. The project involved the following steps:

1. The original window profile design, which is a face plate profile that covers the overlap between the two sashes of a double sash window, was provided by Profine. The original PVC profile has a complex geometry and is reinforced with a steel profile to reach the required mechanical stiffness.
2. The PVC window profile design was converted into a PU pultrusion profile design, which involved reducing profile complexity while maintaining all functional areas, adjusting the wall thicknesses, eliminating the steel reinforcement, and optimizing the fiber distribution (Fig. 6).

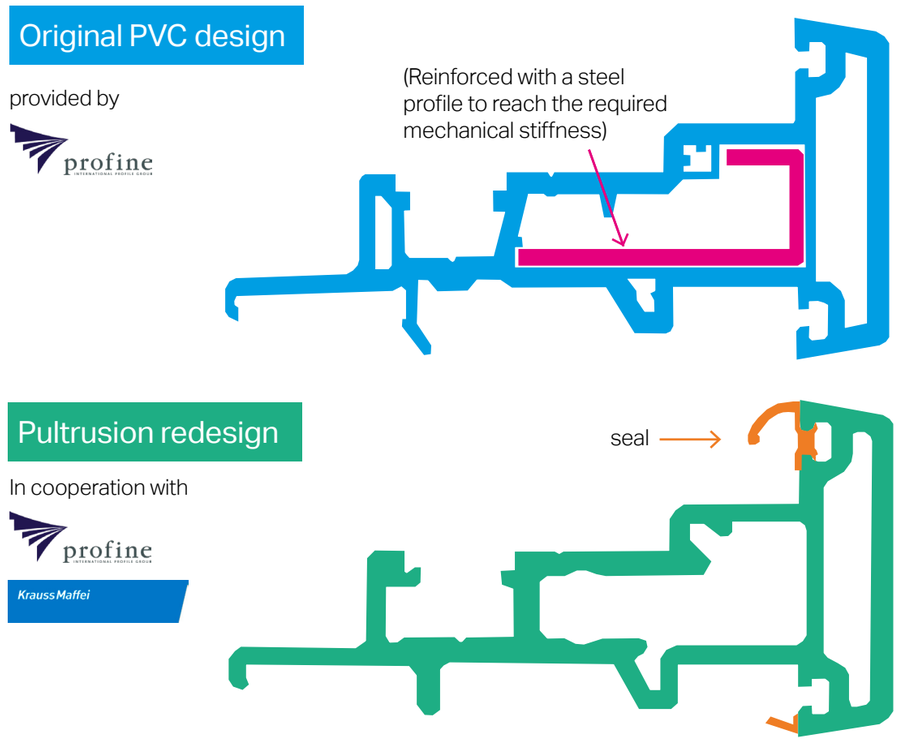

Fig. 6 Comparison of the original PVC window profile design and the pultrusion redesign

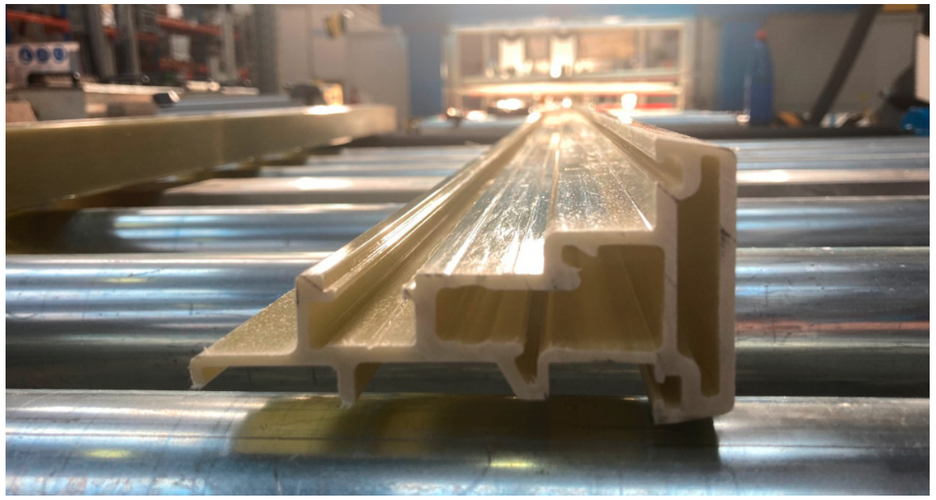

Fig. 7 Prototype of the pultruded window profile based on Baydur® PUL

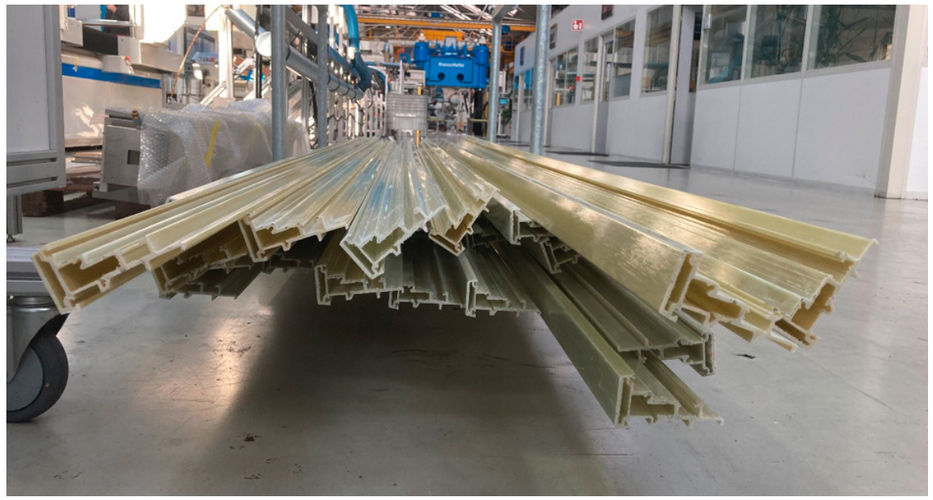

Fig. 8 Prototypes of the pultruded window profile based on Baydur® PUL

3. The PU pultrusion profile design was validated by KraussMaffei, which involved producing the profile using standard PU-specific pultrusion equipment. The produced pultrusion profiles are shown in Figures 7 & 8. The equipment consisted of a dosing machine, a mixing head, an injection box, a heated die, a puller, and a saw. The profile was produced with unidirectional glass fibers with 2.400 and 4.800 tex.

4. The PU pultrusion profile performance was evaluated and compared with the PVC window profile by Profine, which involved calculating the stiffness and the thermal conductivity, as well as evaluating dimensional accuracy (Fig. 9). The results showed that the PU pultruded profile had a seven times higher stiffness in the wind load direction compared to PVC/steel, without any sacrifice in thermal conductivity. This means a pultrusion based window could carry significantly more load or, when focusing on optimizing the overall window design with regards to the pultrusion performance, enable a slimmer design at improved thermal conductivity.

Summary of the case study:

The Profine case study showed that PU pultrusion can offer an innovative solution for window applications, as it can replace conventional materials with superior performance and functionality. The project also demonstrated the successful collaboration and open innovation between Covestro, KraussMaffei, and Profine, which combined their chemistry, technology, process, and market expertise and know-how.

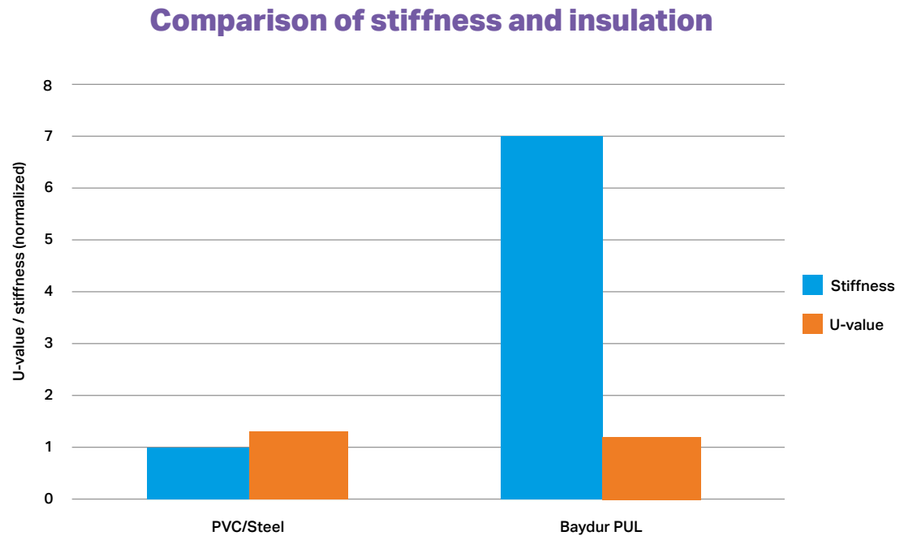

Fig. 9 Comparison of stiffness and insulation performance for the PVC/steel and the pultruded window profiles

How to make a window out of composite profiles: painting, cutting, gluing solutions

Making a window out of composite profiles involves several steps, such as painting, cutting, and gluing, which are similar to those used for other materials, but may require some modifications or adaptations. Some of these steps are:

Painting

Composite profiles can be painted with various types of paints, such as water-based, solvent-based, or powder coatings, depending on the desired color, finish, and durability. However, some paints may require a primer or a surface treatment to improve the adhesion and the appearance of the paint.

Cutting

Composite profiles can be cut with various types of saws, such as circular, band, or miter saws, depending on the shape, size, and accuracy of the cut. However, some saws may require special blades, cooling systems, or dust extraction systems to prevent overheating, chipping, or dust generation. Alternatively, composite profiles can be produced with precise lengths, which can reduce the need for cutting.

Gluing

Composite profiles can be glued with various types of adhesives, such as polyurethane, epoxy, or acrylic, depending on the strength, flexibility, and durability of the bond. However, some adhesives may require a surface preparation, a curing agent, or a curing process to achieve the optimal bond. Alternatively, composite profiles can be joined with mechanical fasteners, such as screws, bolts, or rivets, which can simplify the assembly process.

Making a window out of composite profiles can offer several benefits, such as improving the quality and consistency of the window and enhancing the design and customization options. However, making a window out of composite profiles may also require some technical knowledge and skills, as well as some specific equipment and tools, which may vary depending on the type and quality of the composite profiles. Therefore, it is advisable to consult with the resin supplier or composite profile producer before making a window out of composite profiles.

Added value: sustainability & recycling options for composite profiles based on Baydur® PUL

By using Baydur® PUL resins in pultrusion, we can take an important first step toward sustainability and recycling. While current recycling options for thermoset composites often focus on solutions such as using the composites as additives or fuel for cement kilns, these represent only the beginning. In line with Covestro's vision of becoming fully circular, we are also actively exploring other innovative approaches, to tackle both end-of-life solutions and reducing the carbon footprint of composite parts. Feasibility studies in this area and others are already underway. This aligns with our broader goal of contributing to a circular and climate-neutral economy by closing material and carbon loops and reducing our reliance on fossil resources through the use of alternative raw materials, renewable energy, and advanced recycling technologies:

Alternative raw materials

PU materials can generally be produced with alternative feedstocks, such as bio-based or waste-based materials, which can reduce the carbon footprint and the environmental impact of the resins. For example, Covestro offers ISCC PLUS certified circular MDI and PET via mass balance, which are PU resins that have been attributed to feedstock originating from bio-mass, bio-waste and -residues.

Renewable energy

PU materials can generally be produced with renewable energy, such as wind, solar, or hydro power, which can reduce the greenhouse gas emissions and the energy consumption of the production process. For example, Covestro is committed to sourcing 100% of its electricity from renewable sources by 2035, and to becoming climate neutral by 2050.

Innovative recycling

PU resins can be recycled with known technologies, such as chemolysis, solvolysis, or pyrolysis, which can recover the valuable materials and energy from the PU resins and the composite profiles. For example, Covestro is conducting research and development activities on various recycling options for thermoset PU resins, such as smart pyrolysis, which can separate the fibers from the PU matrix and selectively decompose the PU resins into residues that can be reused in chemical processes, e.g. to produce new circular materials.

Summary & contact details

In summary, this white paper has presented the following main aspects:

- Windows are essential elements of buildings that require high-performance materials that can reduce energy consumption, improve thermal and acoustic insulation, and enhance durability and design flexibility.
- Composite profiles, especially pultruded polyurethane profiles, are emerging as a superior alternative to conventional materials, such as wood, aluminum, steel, and PVC, for window applications, as they offer a high strength-to-weight ratio, low thermal conductivity, a low coefficient of thermal expansion, corrosion resistance, and design flexibility.
- Baydur® PUL polyurethane (PU) resins are a versatile and high-performance option for pultrusion, as they offer low viscosity, high reactivity, and good mechanical properties, which enable high productivity, efficient material usage, and complex profile production.
- The Profine case study showed that PU pultrusion can replace a steel-reinforced PVC window profile with a PU pultruded profile, while maintaining or improving the mechanical and thermal performance. The project also demonstrated the successful, complete value-chain collaboration and open innovation between Covestro, KraussMaffei, and Profine.
- Making a window out of composite profiles involves several steps, such as painting, cutting, and gluing, which are similar to those used for conventional materials, but may require some modifications or adaptations. Making a window out of composite profiles can offer several benefits, such as improving the quality and consistency of the window and enhancing the design and customization options.
- Using Baydur® PUL resins for pultrusion can also offer added value in terms of sustainability and recycling, as PU resins can contribute to the circular and climate neutral economy vision, by using alternative raw materials, renewable energy, and innovative recycling technologies.

If you are interested in learning more about PU pultrusion for window applications, or if you have any questions or feedback, please feel free to contact us. We are looking forward to hearing from you and to exploring the potential of PU pultrusion for your projects.

Find out more

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