FORWARD AM
Innovating Additive Manufacturing

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Automotive – Ultrasint® TPU for Car Interior Applications

Executive Summary

The mindset "think additive" summarizes how the use of Additive Manufacturing (AM) technology unlocks the potential for novel part geometries and revolutionary designs compared to traditional manufacturing technologies. For the automotive industry, it means completely new application concepts, lighter parts as well as time and cost savings for the product development. According to the Wohler's Report 2020 (1), the automotive industry is leading the charge of 3D printing, accounting for 16 percent of all AM expenditures.

Therefore, this whitepaper provides an introduction of AM application of thermoplastic polyurethane for car interior. First, the essential requirements of automotive applications are discussed, and the benefits of 3D printing technologies are illustrated in various use cases. Afterwards, selected test results and certifications used to achieve the requirements of materials in car interiors are introduced. Beyond printing, the benefits of using simulation and post-processing are explained.

In this whitepaper:

- Requirements and benefits of Additive Manufacturing for automotive interiors
- Thermoplastic Polyurethane (TPU) powders for automotive interiors
- Automotive interior applications – Use cases
- Ultrasint® TPU powders – Certifications and testing performance
- Ultrasim® to take part performance to the next level
- TPU Post-Processing for a groundbreaking finish

Requirements and Benefits of Additive Manufacturing for Automotive Interiors

The interior of a vehicle provides automotive OEMs and suppliers with a perfect opportunity for value-added product differentiation. It is essentially a cockpit with safety, seating, entertainment, and communication features that need to exist in a visually harmonious layout.

Designers are challenged to create a space that considers comfort, aesthetics, noise insulation, and durability all within a relatively small space and with weight limitations. Additive Manufacturing plays a big role in enabling vendors to deliver all these elements. With a combination of high-performance materials and innovative processes, modern automotive interior designs can be created. AM can help manufacturers achieve the following performance considerations for automotive interiors:

- Lighter weight structures
- Increased comfort and functionality like climate control within interior
- Individualization – meeting specific driver requirements
- Unique design to stand out (e.g. fleet branding)

In addition, our testing and experience have shown that our Ultrasint® materials and post-processing solutions can also fulfill other aspects which are usually required for automotive, like:

- Outstanding surface quality
- Good abrasion and scratch resistance
- High longterm durability
- Minimal volatile organic compound (VOC) emissions
- UV stability
- Heat stability

Thermoplastic Polyurethane (TPU) Powders for Automotive Interiors

Automotive engineers and designers have long relied on polymers to simultaneously save cost, reduce weight, and enhance aesthetics all while delivering the required performance characteristics. TPU has traditionally been used a lot in car interior applications. It is very good in long-term stability and durability as well as in outstanding haptics and pleasant touch.

TPU powders from Forward AM's Ultrasint® portfolio have been perfectly adapted to create a variety of innovative design patterns using the AM processes of Multi Jet Fusion (MJF) as well as Selective Laser Sintering (SLS):

Ultrasint® TPU01 is a multi-purpose TPU powder designed explicitly for Hewlett Packard's (HP's) 5200 series Multi Jet Fusion printers. Ultrasint® TPU01 offers strong, flexible, and durable part performance, combined with excellent surface quality and level of detail. The material is extremely easy to print, has very high process stability, and one of the highest throughputs for flexible materials in the 3D printing market. These unique characteristics make it a perfect fit for serial production with HP Multi Jet Fusion printers and applications that support lattice structures.

Ultrasint® TPU 88A is a TPU powder designed to be very easy and stable to process on any Powder Bed Fusion equipment. Parts printed with Ultrasint® TPU 88A offer strong, flexible, and durable performance, combined with excellent surface quality and level of detail. Parts have a stable white color, allowing easy finishing through dyeing and chemical etching.

Automotive Interior Applications – Use Cases

Image 1: The interior of a vehicle provides the perfect opportunity for value-added AM product differentiation (Source: Adobe Stock).

Automotive seating and related components (such as headrests, armrests, and consoles) play a critical role in the comfort of the driver and occupants and they provide safety features and even influence the driver's handling of the car. Using AM for seat components has distinct advantages over traditional manufacturing. One of the biggest benefits is design freedom with innovative structures like lattices.

3D printing processes like Multi Jet Fusion (MJF) using TPU powders along with BASF's specialized simulation software Ultrasim® allow engineers to unlock the capabilities of lattice structures to significantly enhance the performance potential of their designs. How simulation contributes to finding the perfect lattice type is shared in the section "Ultrasim® to take part performance to the next level".

Seating components that use traditional foam are restricted to one consistent level of density or hardness in a structure, but with AM it's possible to print, for example, a seat as a single-component design with variable levels of hardness – individual sections can be constructed with a specific function, like perfect cushioning or superior support with increased structural stiffness so that the back and lumbar are perfectly supported.

Use Cases: 3D Printed Headrest and Seat printed using MJF and TPU

Below are two seat components showing the use of TPU for end-use applications in automotive interiors (left) semi-personalized seating, (right) headrest concept. The challenge in both cases was to achieve a lightweight and open design, allowing passive climate control and, most importantly, superior comfort at all time through novel cushioning function design.

The solution was a set of reduced-weight thin lattice structures offering equivalent hardness compared to traditional foams with equal performance characteristics for each comfort area of the seat and significantly reduced lead times in Product Development as well as in Manufacturing Operations because unlike conventional molding methods no casts or forms are needed and the number of parts in the assembly and their complexity are significantly reduced.

Image 2: Seat frame printed by HP, Seat lattices printed by Oechsler AG, Post-Processing by Forward AM

Grey lattices = Ultrasint® TPU01, MJF printed + sandblasted
Black lattices = Ultrasint® TPU01, MJF printed + chemically vapor smoothed
Blue lattices = Ultrasint® TPU01, MJF printed + chemically vapor smoothed + coated with Ultracur3D® Coat F
Grey seat frame: HP HR PA12, MJF printed + graphite blasted

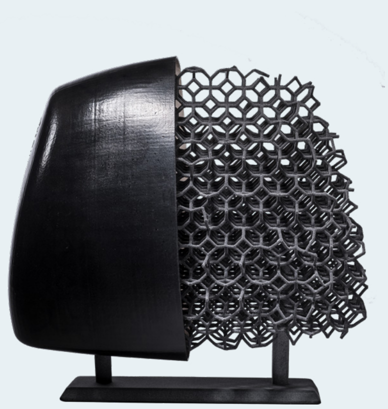


Image 3: Headrest developed by Forward AM

Frame = Ultrasint® TPU01, MJF printed + chemically vapor smoothed
Lattices = Ultrasint® TPU01, MJF printed + dry ice blasted

The impact of post-processing treatments can be seen by looking closely at the pictured seat. The application shows the results of three different post-processing methods: simple sandblasting, vapor smoothing, and a coating of Ultracur3D® – more information on this topic is shared below in the section called ‘TPU Post-Processing for a groundbreaking finish’. These use cases demonstrate how a component can be dramatically improved with a smart redesign that replaces the foam with a lattice structure that can be tuned to specific comfort and safety specifications, allowing to tune the hardness even of one single part or small segment.

Ultrasint® TPU Powders – Certification and Testing Performance

As highlighted in the introduction, there are a variety of certifications and tests that go along with automotive interior requirements.

The TPU powders from Forward AM’s Ultrasint® portfolio have been tested extensively to ensure that the produced parts can meet these standards. The analysis conducted includes:

- UV resistance
- Heat stability
- Volatile compounds
- Fatigue tests

In terms of certification, Ultrasint® TPU powders contain regulatory documents for Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), End-of-Life Vehicle (ELV), Global Automotive Declarable Substance List (GADSL) and are listed in the International Material Data System (IMDS) for automotive industry. These and further certifications are available upon request.

UV Resistance

Durability is a key feature for the components used in the interior of a vehicle. The materials used in this space must be put through a variety of severe tests to ensure that they can withstand years of exposure to the elements.

Accelerated weathering simulates the anticipated environmental conditions to indicate how well the material will perform when exposed to elements such as sunlight, moisture, and humidity. Worst conditions are used to accelerate effect which may be observed on long term. The following table summarizes the two testing conditions that have been investigated:

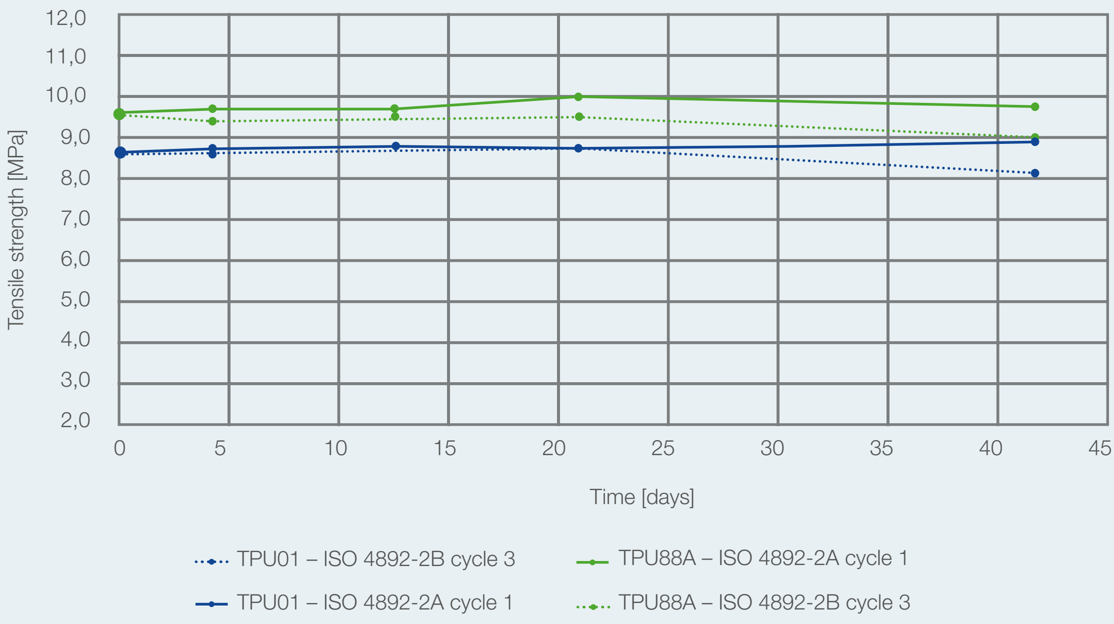
Table 1: Ultrasint® TPU01 and Ultrasint TPU 88A – Test conditions for UV resistance (Source: Forward AM).

	Example	UV exposure	Exposure period	Chamber temperature	Black-standard temperature	Relative humidity
ISO 4892-2A Cycle 1	Outdoor conditions	Daylight filters	102 min dry 18 min water spray	38 ± 3 °C	65 ± 3 °C	50 ± 10 %
ISO 4892-2B Cycle 3	Car dashboard	Window glass filters	Continuously dry	65 ± 3 °C	100 ± 3 °C	20 ± 10 %

Results: The tensile strength as well as the elongation at break demonstrate a stable behavior under accelerated weather condition ISO 4892-2A Cycle 1. For ISO 4892-2B Cycle 3 only after long times a slight decrease in the elongation at break can be recognized, but overall, the elongation is at sufficient level for car interior applications. For both test conditions the tested material possesses a good color fastness over the time of 1000h.

The test results below reflect the durability of Ultrasint® TPU01 powders and Ultrasint® TPU 88A powders and their suitability for use in automotive interiors.

Table 2: Tensile strength and elongation at break for Ultrasint® TPU01 and Ultrasint® TPU 88A under UV exposure from 0h to 1000h (Source: Forward AM).



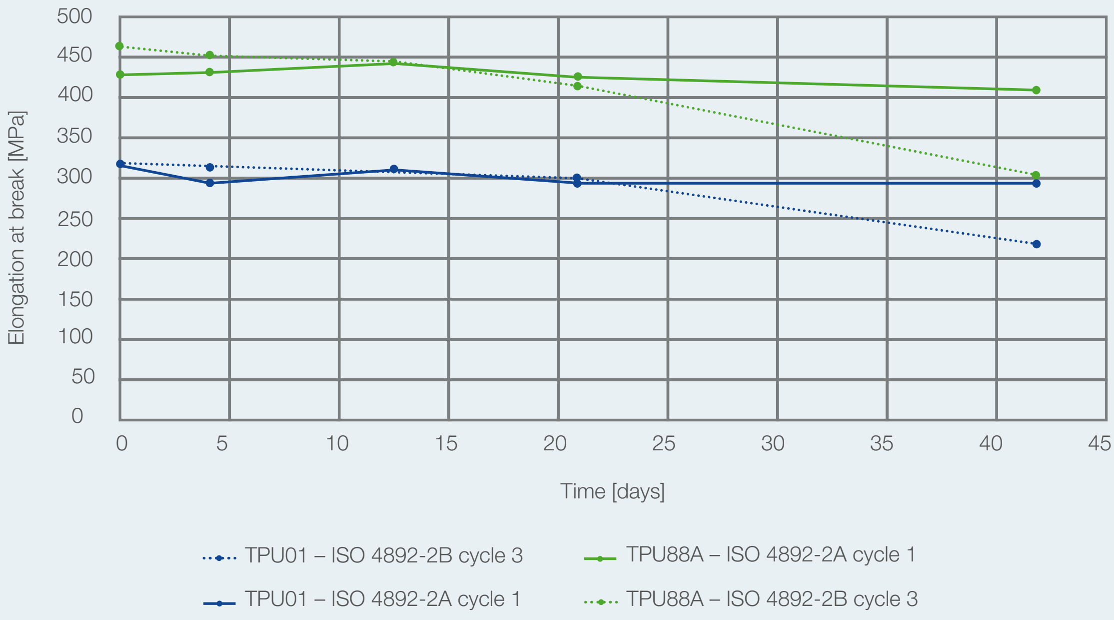


Image 4: Colour fastness of sandblasted Ultrasint® TPU01 samples from 0h to 1000h (Source: Forward AM).

Heat Stability Tests

Heat stability tests are of central importance for materials in car interiors and aim to determine the burn resistance capabilities of materials under standardized conditions.

The following table shows the results for Ultrasint® TPU01 plates (356x102mm), tested according to FMVSS 302. All samples passed the heat stability tests with lower burning rates than 100mm/min. In principle, these test results have to be performed on the final part geometry as the burning is geometry-dependent. As a reference case a one-millimeter plate has been used.

Table 3: Ultrasint® TPU01 – Results for heat stability tests according to FMVSS 302 (Source: Forward AM).

Norm	Orientation	Thickness	Max. burning rate (limits ≤ 100 mm/min)
FMVSS 302	XY	1.16 mm	passed
FMVSS 302	Z	1.32 mm	passed

Volatile compounds

Although many people expect and even appreciate a ‘new car smell’ when seated in a car, it is necessary to ensure that the air quality inside the vehicle does not pose any potential health risks for individuals.

Therefore, stringent tests that gauge the emissions of volatile/semi-volatile substances and odors need to be conducted on the products and materials that are used in the interior of an automobile.

The table below displays the results of analysis conducted on interior parts produced from Ultrasint® TPU01. The test specimens have been sandblasted and further processed after printing. Details and further data are available upon request.

Table 4: Ultrasint® TPU01 – Results of VDA tests (Source: Forward AM).

	VDA 270 (smell)	VDA 275 (formaldehyde)	VDA 276 ($1 m^3$ room test)	VDA 278 – VOC (volatile organic compounds)	VDA 278 – FOG (condensable substances)	DIN 75201B (condensable substances)
Sandblasted	< 3	< 0.3 mg/kg	Data available on request	690–1032 ppm	461–532 ppm	5.9 mg
Sandblasted + processing				< 100 ppm	< 200 ppm	0.1 mg
Chemically smoothed + colored Ultracur3D® coating + processing	2.7			<100 ppm	< 200 ppm	0.8 mg

Fatigue Tests – Dynamic/Long-term tests

Fatigue testing employs cyclic loading to predict the life of parts and materials under fluctuating loads. This is important for automotive interior components, as parts such as seats and headrests are subjected to cyclic stress over long periods of time.

To investigate the cyclic loading capacity of the materials, Rossflex tests were carried out on plates as well as on lattice parts at room temperature and at -10°C ambient temperature. The following images 5 and 6 and table 5 show the results of the Rossflex tests.

Table 5: Ultrasint® TPU01 and TPU 88A – Cycle mechanical test results (Source: Forward AM).

	After 100k cycles	
	Ultrasint® TPU01	Ultrasint® TPU 88A
Plate, 23°C, 2mm incision	no cut growth	no cut growth
Plate, –10°C, 2mm incision	no cut growth	no cut growth
Lattice, 23°C, no incision	no broken connections	not investigated

Initial state | After 100 k cycles at 23 °C | After 100 k cycles at –10 °C

Image 5: Rossflex test on Ultrasint® TPU 88A samples – No cut growth after 100.000 cycles (Source: Forward AM).

Initial state | After 100 k cycles at 23 °C | After 100 k cycles at –10 °C

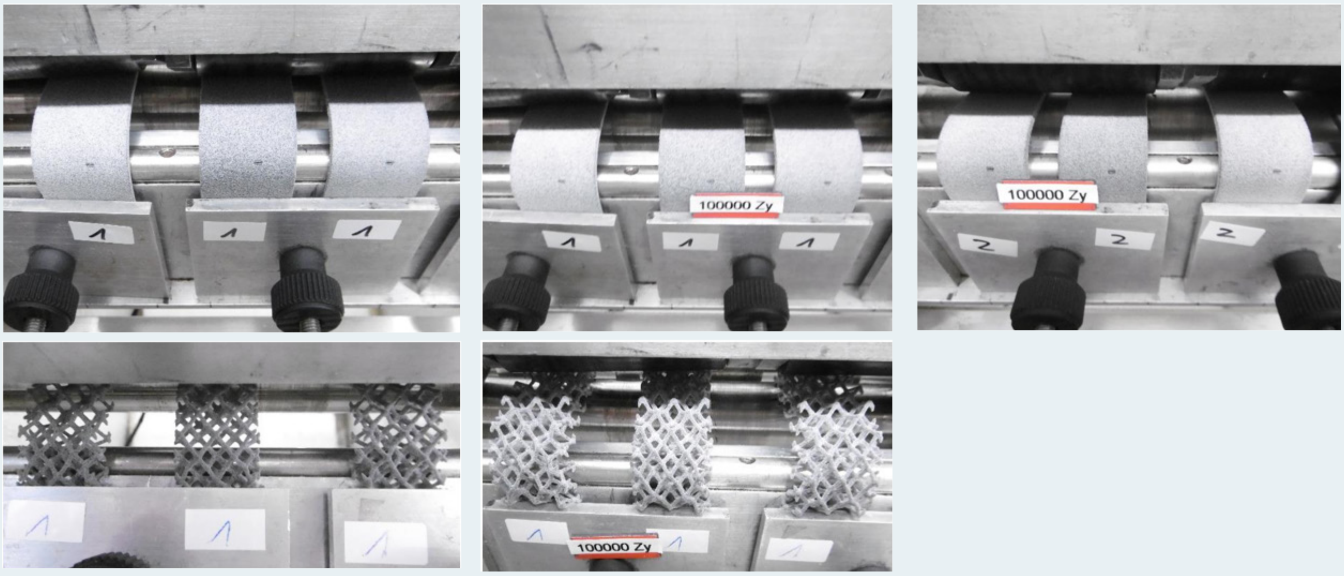


Image 6: Rossflex test on Ultrasint® TPU01 samples – No cut growth after 100.000 cycles (Source: Forward AM).

Ultrasim® to Take Part Performance to the Next Level

To realize the benefits of 3D printing for automotive interior applications, simulation plays a crucial role in the product development process. It is key in producing functional designs in development of lightweight geometries with lattices to meet the mechanical requirements of the components.

These requirements on light weight application are mostly defined by a desired force-deflection curve, which is usually very nonlinear and based on large deformations. It is mostly based on experience coming from impact or resilience tests of real parts.

Instead of a trial-and-error approach to find the right lattice by many printing iterations, simulation methods coupled with optimization tools can be used to identify the best lattice structure by automatically varying the underlying unit cell in its topology and geometry parameters. BASF has developed specific methods based on advanced automatic geometry creation and mathematical optimization techniques which allow an automatic, intelligent search for the best lattice geometry fulfilling mechanical requirements.

Besides the geometry of the lattice, the right material model is crucial for simulation success of nonlinear lattice behavior. Especially TPU shows a complicated viscoelastic-plastic behavior (strain rate influence, Mullins effect etc.), which tends to make modelling challenging. Ultrasim® contains material models for these classes of materials. Together with nonlinear analyses containing frictional contact and large deformations it allows the identification of the right lattice for the requirement of car interior applications.

In addition to cyclic loads also impact loads are covered by the Ultrasim® approach. In those cases the automated workflow allows a fast comparison between different unit cells and an optimization of geometry dimensions without printing hundreds of specimen.

The following image 7 illustrates the course of different force/discplacement curves for the identification of lattices for corresponding applications.

Find the Right Lattice Design for Your Application

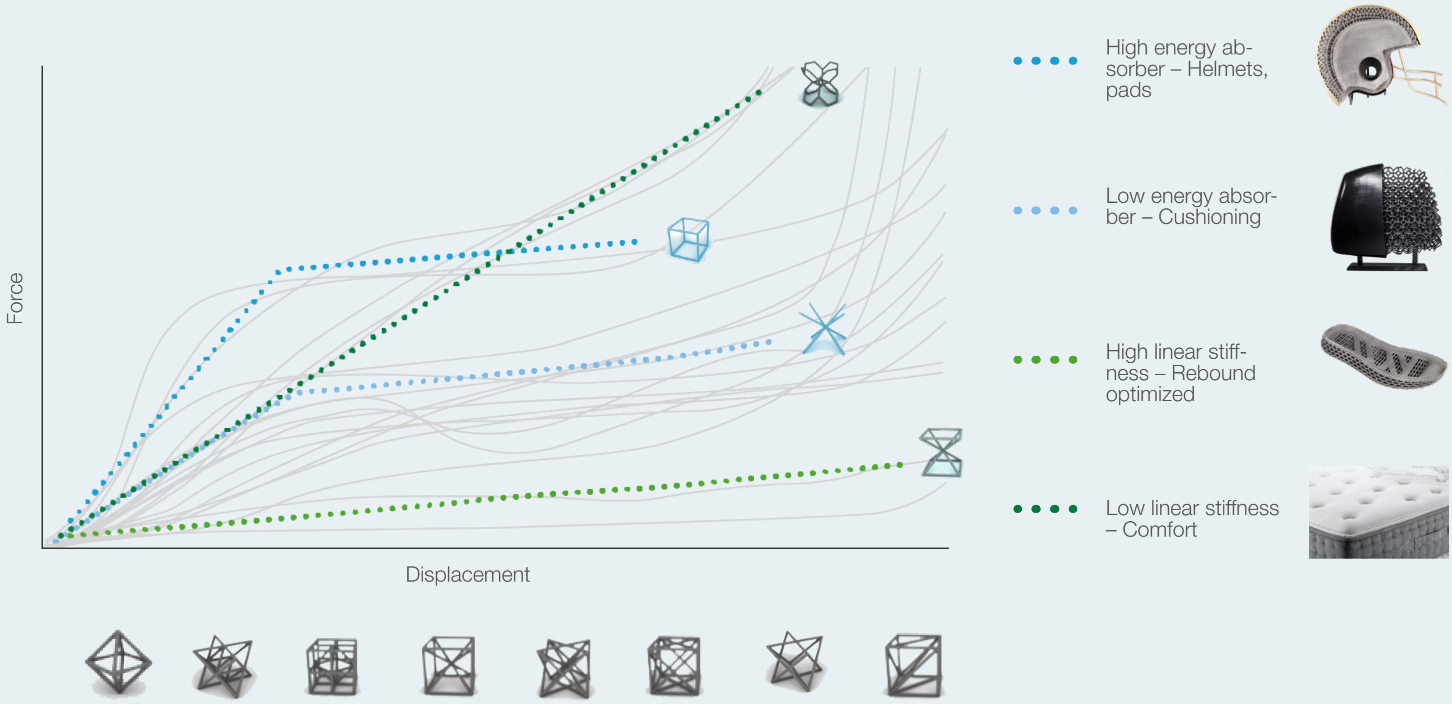


Image 7: Force/Deflection curve for different application to identify the right lattice (Source: Forward AM).

TPU Post-Processing for a Groundbreaking Finish

Post-processing offers a wealth of possibilities to enhance the appeal, durability, and overall quality of the 3D printed automotive interior component.

It can also include applying the right coating, like Ultracur3D® Coat F to improve properties like abrasion resistance, UV protection, dirt repellency, as well as giving your automotive interior components the desired color finish. The Ultracur3D® Coat F was specifically developed together with BASF Coatings to meet the need for a highly flexible coating solution for flexible printed parts like seating components for automotive customers.

In close cooperation with BASF Coatings further colors can be matched based on specific color codes or sample parts upon request. It is possible to apply the coating with a dip or spray coating process, to ensure flexibility in the manufacturing setup and adjust the process to the geometry of the application.

Forward AM can support in the following post-processing areas, which are relevant for automotive interior applications:

- Surface smoothing
- Coating solutions
- Dyeing

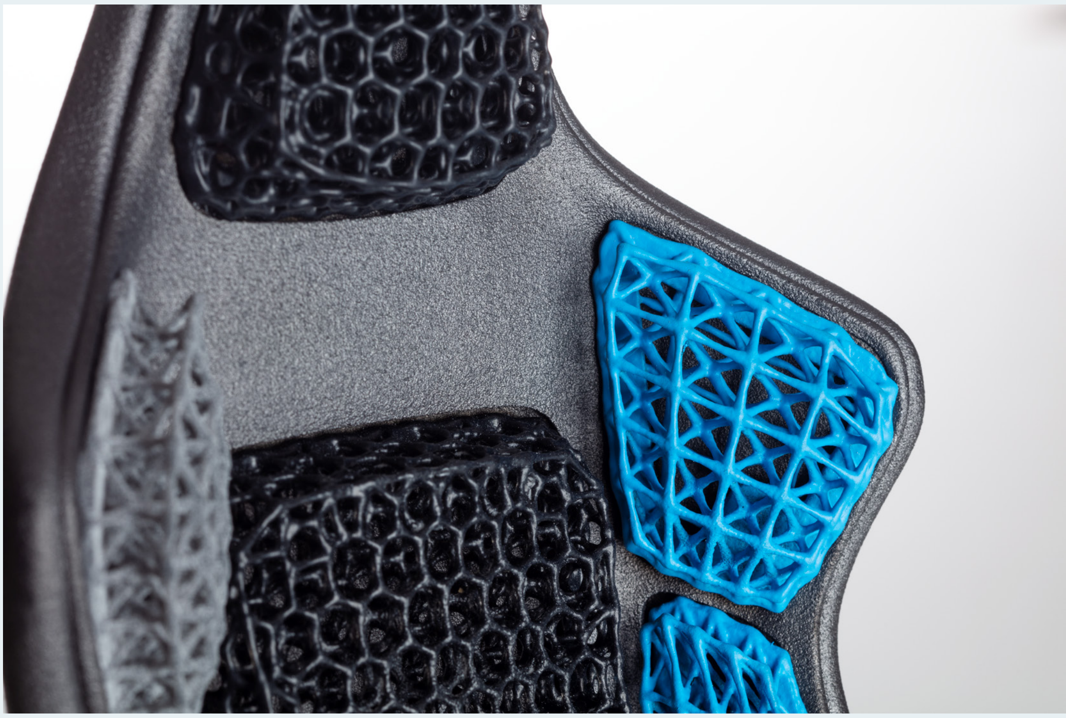


Image 8: Seat frame printed by HP, Seat lattices printed by Oechsler AG, Post-Processing by Forward AM (Source: Forward AM).

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Conclusion

This whitepaper highlights the requirements and benefits of using TPU for automotive interior. The TPU powders of the Ultrasint® portfolio have been tested extensively to ensure the produced parts can meet these standards.

Beyond material selection, Forward AM offers the possibility of a holistic solution of the product development process in order to develop functional components optimized for lightweight construction through engineering services such as simulations and to optimize the surface finish through post-processing solutions.

References

1 Wohlers Associates, Inc.: 3D Printing and Additive Manufacturing.
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