3D PRINTING SOLUTIONS
BY ARKEMA

White paper

Expanding industrial applications of additive manufacturing with advanced material solutions

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Introduction

Additive manufacturing or 3D printing has made its way out of the prototyping phase and is actively disrupting the way businesses design, create and market their ideas and products. Turnaround time is quicker, parts are lighter and more resilient, and entire supply chains are streamlined as a result of major leaps forward in the development of additive manufacturing technology (equipment, software, post processing) and especially, the high-performance materials used in 3D printing.

"Entire supply chains are streamlined as a result of major leaps forward in additive manufacturing technology and high-performance materials."

While brimming with possibilities, the full potential of additive manufacturing is still relatively untapped – for now. "Quicker, cheaper and better" may be universal goals in production, but it's imperative that the differences and advantages of additive manufacturing vis-à-vis conventional manufacturing be understood as the technology continues to evolve, and that the potential be harnessed to better anticipate the possible challenges of applying it to conventional manufacturing processes.

Additive manufacturing: why is it revolutionary for industries

When additive manufacturing debuted more than two decades ago, it represented a solution for rapid prototyping. Since then, the evolution of additive manufacturing experienced a highly dynamic growth with new 3D printing platforms and new printing technologies. This way, 3D printing's capacity expanded to manufacture highly functional pieces on an industrial scale. Additive manufacturing is already changing the way we think about a product, from conceiving the idea all the way through manufacturing and distribution. The impact of additive manufacturing goes beyond manufacturing and printing – it implies potential shifts in entire value chains and business models.

Another significant advantage of 3D printing is the ability to produce is mass customization. Unlike conventional manufacturing technologies, additive manufacturing does not face constraints of minimum batch production, tools or mold change. Additive manufacturing involves a simpler process of printing and it does not require a changeover between tailor-made pieces. Therefore, 3D printing has high potential in mass customization: it is possible to make tailor-made pieces at the low unit cost.

Integrating additive manufacturing allows industrial businesses to rethink issues like logistics, serial production, mass customization and / or building entirely new business models based on 3D printing technologies.

Besides just overhauling business models and considering potential partnerships with specialists in the additive manufacturing game, integrating 3D printing allows industrial businesses to rethink issues like localization of production and possibilities of merging it with conventional manufacturing technologies.

Conventional and digital manufacturing: bridging the gap

The high-performance materials for 3D printing are evolving in tandem with advancement of additive-manufacturing technology. Arkema's research and development in additive manufacturing is rooted in the understanding of the past practices and bridging the gap between traditional and emerging technologies. Despite dynamic development, the 3D printing sector is still seeking to associate two very different spheres: printer manufacturers who are overcoming to industrial manufacturing constraints and industries are still in the process of discovering the digital world and its players, limits and opportunities. This is where the material manufacturer can – and should – act as the facilitator.

"Understanding and building on past practices is critical to bridging the gap between traditional and emerging technologies."

As a result of years spent co-developing 3D printing specific material solutions with machine manufacturers while simultaneously developing end-user application solutions for traditional production processes, material manufacturers like Arkema have a deep knowledge of the constraints of both spheres. When the race for application development is in full swing, material producers can play an important role and ensure that all parties work together to gain comprehensive additive-manufacturing value.

Materials at the heart of innovation: high-performance thermoplastics and UV curable resins

Sophisticated polymers like the extensive **3D Printing Solutions by Arkema** range were conceived for use across all major additive-manufacturing processes, including UV curing, powder-bed fusion and filament extrusion. Arkema's flagship 3D printing materials include Rilsan® PA11, Kepstan® PEKK and N3xtDimension® liquid resins for UV curable 3D printing. All three offers design tailored solutions through easily processed materials delivering superior performance.

Rilsan® PA11
bio-based and high performance

Rilsan® PA11 is fast becoming one of the key materials for additive manufacturing thanks to excellent powder-bed fusion processing characteristics and unrivalled mechanical properties. Parts made with high-performance bio-based Rilsan® PA11 fine powders display superior resilience and longevity, making it the favored choice for the creation of final-production parts by additive manufacturing.

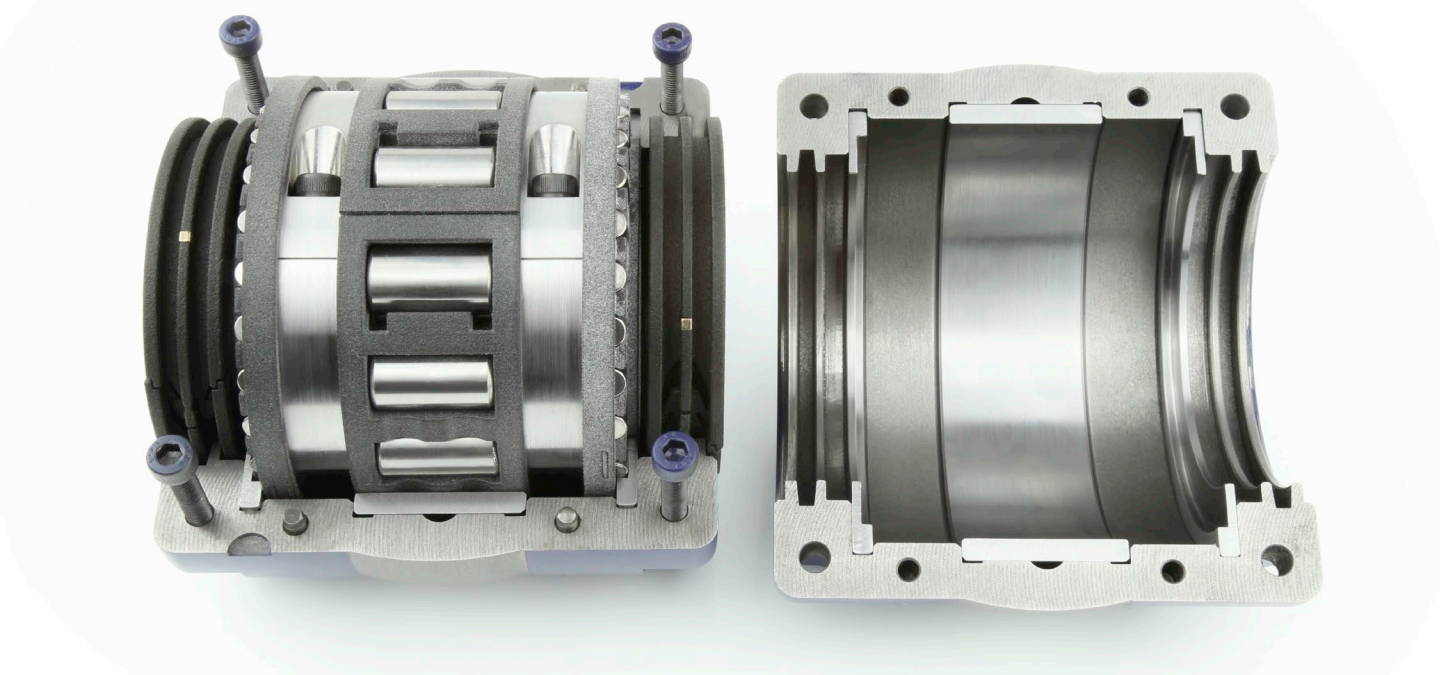
"PA11 is trusted to perform in some of the most extreme environments and is often specified to address the most demanding needs from additively manufactured parts."

Rilsan® PA11 powders are also known as PA11 or Nylon 11. This 100% bio-based polyamide polymer offers users new possibilities in the creation of custom-made products with complex geometric shapes. The difference in chemical make-up between PA11 and petroleum-based PA12 is one carbon atom in the polymer backbone, but that single carbon atom makes a tremendous difference in how the polymer arranges itself to form three-dimensional objects. Since it has a unique crystalline morphology, PA11 is trusted to perform in some of the most extreme environments and is often specified to address the most demanding needs from additively manufactured parts. Concerns that the strength of the 3D printed part in the plane of the layers is typically much weaker than in the XY plane are effectively resolved by PA11's superior mechanical properties and isotropic performance. PA11 also has excellent ductility, which means that parts can be designed with thinner walls, resulting in lighter, lower-cost products, reduced waste and faster production times.

MACHINERY : IMPROVED DESIGN AND EASE OF USE WITH RILSAN® PA11

One of the key advantages of additive-manufacturing technologies is the ability to print a single mechanical part complete with all integrated features. Bowman International's unique triple labyrinth cage for split bearings is produced with **Rilsan® PA11**, the only material that has enough ductility and fatigue resistance to withstand the cage's click-fit system. The bearing is an important component in any mechanical component applied in power generation, manufacturing and aerospace. Bowman's bearing cage is very easy to fit onto rollers thanks to its unique design without joints or spring plates. This revolutionary design will ease maintenance work by simplifying the mounting without any tools. Considering **PA11**'s properties and durability, the labyrinth cage is a superior alternative to conventional bearing cages.

« A key advantage of additive manufacturing is the ability to print a single mechanical part complete with all integrated features. »



Courtesy of Bowman International 2019

PROTECTIVE HEAD GEAR : CUSTOM DESIGN AND INCREASED SAFETY WITH BIO-BASED RILSAN® PA11

Courtesy of HEXR 2019

The custom-made **HEXR helmet** is the world's first 3D printed bicycle helmet crafted to the rider's head shape. Not only does this ensure a tailored, comfortable fit, but the honeycomb core is proven to be 26% safer than traditional foam helmets. Due to its low density, **Rilsan® PA11** offers lightness and maximum comfort, while better flexibility, ductility delivers impact resistance and increased safety. The ability to 3D print **PA11** has now made it possible to create an unprecedented improvement in the safety performance of such equipment.

Kepstan® PEKK ultra high-performance polymers

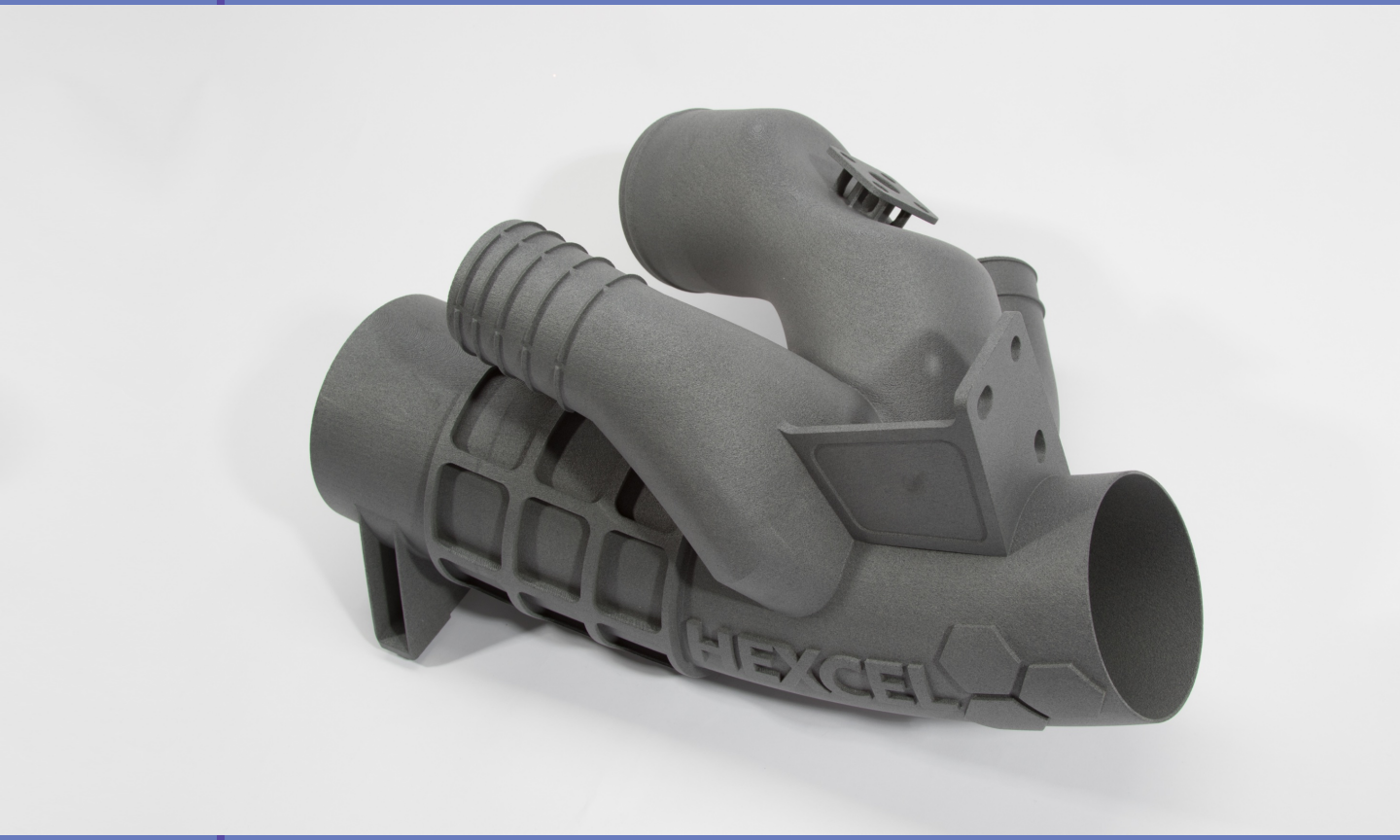
In addition to Rilsan® PA11, Kepstan® PEKK is another flagship material in Arkema's portfolio of high-performance thermoplastics for powder-bed fusion. Kepstan® PEKK has a unique combination of strength, toughness, low flammability and easy processing make it the ideal material for the most demanding applications. Because of its strength and toughness Kepstan® PEKK is particularly well suited as a replacement for metal, due to its excellent performance at extremely high temperatures and inherent flame resistance. Already a material of choice for additive manufacturing in the aerospace industry, Kepstan® PEKK's unique properties make it the ideal high-performance polymer for either Fused Filament Fabrication (FFF) or Laser Sintering (LS) processes.

"The ability to control the melt temperature, crystallinity and crystallization rate enables Kepstan® PEKK to be processed in ways that are difficult or impossible with many similar polymers such as PEEK ."

Kepstan® PEKK has an additional ketone group replacing one ether group in the backbone. This single modification differentiates it from PEEK, a structurally similar semi-crystalline material suited to traditional manufacturing processes. In Kepstan® PEKK, this ketone group makes for a stiffer bond than the ether linkage, increasing the material's glass transition temperature (or Tg, the temperature where the polymer first begins to soften.) One of these ketone bonds can either be in the para (straight) or meta (kinked) position. This modification also allows for more precise control of melt temperature, crystallinity and crystallization rate. "This control enables Kepstan® PEKK to be processed in ways that are difficult or impossible with many similar polymers such as PEEK," explains Roderick Reber, one of Arkema's technical engineers. Besides higher Tg, Kepstan® PEKK also offers users higher compression strength, improved barrier performance and better wear and friction properties. Kepstan® PEKK can be further tailored to suit specific needs with molecular weight control or the addition of carefully selected additives such as glass fibers, carbon fibers or carbon nanotubes. Lightweight, strong, and resistant to the most aggressive chemicals, it can be used to replace metal components in highly demanding environments to reduce weight.

AEROSPACE : REPLACING METAL WITH KEPSTAN® PEKK

The use of carbon-fiber 3D printed parts in aerospace and automotive applications has become commonplace as a replacement for metal thanks to their superior lightness and chemical- and heat-resistant qualities. A single-piece component can be designed to replace a large assembly of several components. Hexcel's **HexPEKK™** parts, printed with Kepstan® PEKK and carbon fiber, simplify the complex duct system by printing built-in features directly into the structure. These pieces allow a reduction in time and cost of assembling different components by printing the entire part three dimensionally. Additionally, because of its high-temperature endurance and mechanical and chemical resistance, it can replace magnesium or aluminium in traditional parts.



Courtesy of Hexcel Corporation 2019

N3xtDimension® engineered resins

"Each application of photocurable additive manufacturing requires a delicate balance of properties through through a unique composition of ingredients."

The N3xtDimension® brand is another leader in the **3D Printing Solutions by Arkema**. These advanced liquid resins are engineered to be tougher, water soluble, or castable, more flexible, have higher temperature resistance and are designed for Stereolithography (SLA), Digital Light Processing (DLP), Binder Jetting (BJ) or Multi-jet Printing (MJP) systems to name a few.

N3xtDimension® engineered resins are tailor made materials, designed to withstand mass production challenges. Their key advantage comes when customization begins at material's level, for responding to any specific end-consumer requirements. Each application of photocurable additive manufacturing requires a delicate balance of properties through a unique composition of ingredients such as liquid resins, additives and photoinitiators; empowered by a strong technical expertise, advanced material research and deep collaboration with market leaders. With N3xtDimension® resins, custom material solutions are developed to offer exceptional freedom of performance design enabling the success for customers and partners in numerous markets including medical, dental, automotive or consumer goods.

ATHLETIC FOOTWEAR : UV CURABLE SOLUTIONS FOR FREEDOM OF PERFORMANCE DESIGN

The athletic footwear industry is highly demanding in terms of performance, comfort and creative design. A digital manufacturing company Carbon® is revolutionizing footwear manufacturing by combining 3D printing technologies with innovative material science. Lattice structure printed with **N3xtDimension®** engineered resins is a unique foam-like lightweight structure delivering high performance adapted for shock and stress absorption. **N3xtDimension®** resin's unique mechanical properties offer improved performance, quicker, more simplified production and unprecedented geometric design possibilities. The printed parts crafted with **N3xtDimension®** engineered resins are exceptional from a functional point of view due to increased elasticity, tear resistance and resilience.

Courtesy of Carbon® 2019

DENTISTRY : REDUCED TIME AND SIMPLE WORKFLOW WITH 3D PRINTED LIQUID RESINS

The dental industry is one of the earliest adopters of 3D printing technologies, benefiting from mass customization and on-demand production. Dentca's production of dentures has simplified its processes by implementing digital workflow. The benefits include improved time to market, increased precision, reduced delivery delays, and improved customer satisfaction. Sartomer's UV curable **N3xtDimension®** engineered resins and tailored solutions, which make up a part of Dentca's 3D printed denture, deliver exceptional freedom of performance design to the denture-manufacturing process. Dentca's 100% 3D printed denture is the first of its kind and the first to become FDA-approved within the dental industry.

Courtesy of Dentca 2019

Faster, stronger and more sustainable

Besides leaner economics and quicker turnaround times, additive manufacturing is increasingly favored for its positive impact on the environment. Instead of producing parts in a centrally located plant and shipping them on high-emission container vessels and trucks, organizations are looking to digitalize their production networks with additive manufacturing: producing only what is required, where and when needed.

Companies are also demanding cleaner, more sustainable materials. Rilsan® PA11, Arkema's 100% bio-based polymer made from castor oil, is an excellent example of how the company continues to innovate and progress while keeping its carbon footprint as small as possible and meeting corporate social-responsibility goals.

Since 2016, Arkema is a founding member of Pragati Initiative in India's Gujarat region where 70% of the world's castor-bean supply is produced. The initiative encourages sustainable castor-crop production, as well as intensive farmer engagement that led to a 55% increase in yield compared to the 2016 baseline.

Democratizing additive manufacturing and the value of partnership

When considering integrating or making the transition to additive manufacturing, key decision-makers should have a clear understanding of the advantages and drawbacks of both injection molding and 3D printing. It is relatively easy to find information on processing industrial-grade materials by injection molding, but expertise in processing 3D printed materials is still lacking.

Arkema understands the need for this kind of cooperation between multiple actors, particularly in cases where users require detailed data sheets to ensure that the material, the printing technology and the performance of the printed part match the needs of a specific industrial application. Arkema's relationship with Finnish printer manufacturer and high-performance polymer specialist miniFactory perfectly illustrates this: impressed by Kepstan® PEKK, miniFactory felt that it would be suited to their aerospace clients for whom qualities like strength, toughness, high-use temperature and easy processing were essential for optimal performance in extreme conditions. However, the decision to opt for Kepstan® PEKK 3D printed parts (as opposed to molded parts) would have to be based on a complete material data sheet summarizing performance and technical characteristics in a spectrum of circumstances, particularly those experienced in the Earth's orbit.

"The Centers of Excellence are innovative hubs where engineers can develop custom resins and work together to solve material challenges in the 3D printing industry."

Arkema maintained an ongoing exchange for over a year to assess Kepstan® PEKK properties in real applications and eventually generate a relevant datasheet. The process was a long and difficult one, explains Olli Pihlajamäki, sales and marketing director at miniFactory: "Producing one data sheet for end-use applications implies tests for all ranges of a material with a hundred printers from other manufacturers with different set-ups, descriptions of the mechanical properties and the best combinations regarding mechanical strength and printing quality."

During this on-going assessment, many questions emerged, particularly about the performance of Kepstan® PEKK in extreme conditions such as cold and radiated interstellar medium. Committed to its responsibility in this collective endeavour, Arkema dedicated its engineers to conducting full tests on specific topics such as vacuum outgassing and isotropic properties. Arkema has since planned to look into Kepstan® PEKK's low-temperature properties.

There is a one obvious trend in 3D printing: understanding the value of partnership and co-development to produce more data and propel additive manufacturing towards the industrial mainstream. Like the case with miniFactory, Arkema's is committed to multiple partnerships and joint-development projects with machine manufacturers, software editors or end users.

Arkema's Centers of Excellence represent beacons of this kind of cooperation. The three centers constitute an international R&D network dedicated to the development of new 3D printing applications with advanced materials. The center in France is focused on powder bed fusion while the two United States centers concentrate on UV curable resins and filament extrusion respectively.

All three Centers of Excellence are equipped with labs, printers and facilities to research and test specific materials, but beyond mere testing sites, the centers are innovation hubs for building customer partnerships and initiating work on joint projects. Equipment manufacturers and end-users can house equipment and/or personnel to partner with Arkema's technical engineers to develop custom resins for their own application needs and work together to solve unmet material challenges in the 3D printing industry.

Beyond just printing

Additive manufacturing is generating undercurrents of excitement throughout the industrial supply chain. The possibilities seem endless in terms of what it could mean for a business, from customization, freedom of complex shape design, faster product development cycles, personalisation, reusability, reduced costs and production time, as well as smaller carbon footprint. Of course, continuous innovation and the expanding potential of applications is strong and inspiring, but this high-speed and ever-accelerating innovation also breeds uncertainty about venturing into what must feel like unchartered terrain. For many, making the transition with a shift in mindset followed by an overhaul of an entire production process and the equipment associated with it is too daunting a prospect.

This reluctance is understandable, and over time, the onus will be on material producers, machine manufacturers and final customers to continue collaborating to produce, gather and share data to 1. reassure the greater industrial-production community and 2. develop real state-of-the-art technology. Already the results of 3D printed parts and products versus those made through conventional methods are undeniable, and the rapid fine-tuning of the technology and materials will only continue its course. This is not to say that traditional manufacturing no longer has its place, but rather that understanding both worlds and finding ways to move forward together is best for a seamless ushering-in of 3D printing as a reality for the entire industry.

Learn more at 3D-arkema.com.

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ARKEMA
INNOVATIVE CHEMISTRY

Headquarters: Arkema France
420, rue d'Estienne d'Orves
92705 Colombes Cedex – France
Phone: +33 (0)1 49 00 80 80
Fax: +33 (0)1 49 00 83 96
arkema.com

3D-arkema.com