



CASE STUDY

Single-Piece Bike Frames Cast in Aluminum with 3D Printed Molds

ExOne binder jetting at Liberty Pattern combines with Foundry Casting Systems' pressurized solidification process to produce a more confidence-inspiring ride without welds



“3D printing enables people to explore casting. They might have been shunned away because of the tooling costs or because of the iteration costs in the past. Binder jetting opens that door.”

Charlie Murray, Co-Founder of Foundry Casting Systems & Heavy Bikes

Most people don't think of the foundry industry when “garage startups” come to mind. The centuries-old process of metalcasting has rarely been synonymous with rapid innovation or cutting-edge technology. It's not immune to disruption, however, as one “serial entrepreneur” is out to prove.

Charlie Murray works his day job in industrial controls and automation, serving several foundry customers. He understands the value of repeatability in manufacturing. “Automation comes with repeatable events and capabilities,” he said. Supporting his foundry customers, he noticed that inconsistencies in the process environment often led to phenomena like porosity, shrinkage porosity, and inclusions in metal that were detrimental to casting quality and foundry profitability.

“Instead of CNCing and making a bunch of chips out of billet aluminum, can we be more effective with casting and still get the best material properties?,” Murray wondered. Researching the effects of pressurized solidification on molten metal with some of his foundry contacts, the team set out to prove that a casting could be as good as billet feedstock.

Foundry Casting Systems (FCS) was born and today the company provides a method of hardware and controls that optimize the environment where the phase change occurs to amplify the mass feeding. Its Pascal Process for the pressurized solidification of sandcastings pumps inert gas into the mold to create positive pressure that ensures a properly filled part with enhanced mechanical properties and repeatable results.

Murray, Co-Founder of FCS, explains the concept of a 12-inch (304 mm) riser at atmosphere acting, as one would expect, like a 12-inch riser. He notes the corresponding amount of head pressure and the mass feeding rate. In the FCS machine, the increased pressure increases the mass feeding rate up to 70 feet (21.3 m) on a one-foot riser, providing the equivalent head pressure of a 70-foot riser.

CUSTOMER COLLABORATION

Heavy Bikes
Foundry Casting Systems
Liberty Pattern
Craft Pattern & Mold
Denison Industries

INDUSTRY

Consumer products, sporting goods

APPLICATIONS

Single-piece cast bike frame

3D PRINTER

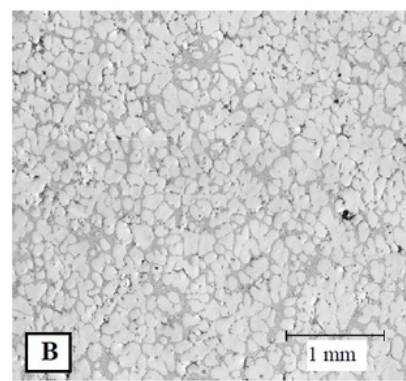
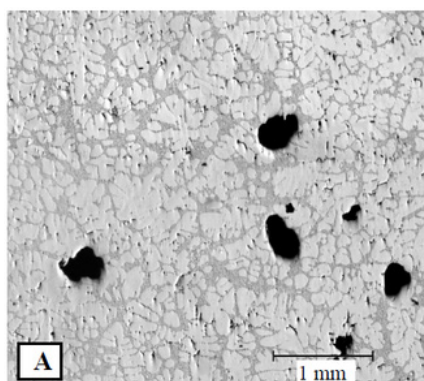
ExOne S-Max®
with silica sand and furan binder

ALLOYS CAST

A356 aluminum

WEBSITES

www.heavybikes.net
www.fcs-apc.com
www.libertypattern.com
www.craftpattern.com
www.denisonindustries.com



Left, micrograph without Foundry Casting Systems technology, and right, with FCS technology. FCS combines process and hardware to control and optimize the environment where the phase change occurs for consistently high casting quality.

Needing a functional part to display these capabilities, but not wanting to get into intellectual property debates between foundries and their customers, he reached back to what he knows best, bicycles.

Murray has participated in every discipline of competitive cycling, from the track and road races to triathlons and mountain biking. Comparing the thin cross sections and constant desire to chase weight, Murray says the closest thing to an aerospace part, what many use as a benchmark for top-quality and innovative designs, is a bicycle.



He explained, “The bike enabled us to physically tell the story of the Foundry Casting System Pascal Process and show it off, and that’s why we first built the bike.”

Born to tell a story, developed with binder jet 3D printing

With a prototype system for the pressurized casting process, Murray reached out to the experts at the University of Northern Iowa (UNI). In early 2021, the FCS team tested the technology working at the Metal Casting & Foundry 4.0 Centers at UNI.

It was during this collaboration that Murray was first introduced to binder

jetting technology. The UNI Additive Manufacturing Center installed an ExOne S-Max system in 2013 with the objective to advance adoption of additive technologies in metalcasting. Today, the center continues to promote and expand binder jetting applications with additional materials and ever-advanced designs.

As Murray witnessed the S-Max in action, he quickly recognized the benefits of the technology and admitted, “Seeing sand 3D printed molds and cores for the first time got my mind spinning.”

Partnering with UNI also provided the FCS team with access to simulation programs that could, for example, identify the best riser shape for a mold. Murray remembered, “We learned with 3D printing we don’t have to use traditional risers and that spheres were the best shape with the highest modulus. So, it was an obvious question of why we were using cylinders if spheres were the best riser shape?”

Knowing the advanced design capabilities unlocked by 3D printing sand molds and cores, Murray returned to the bike design to explore the limits of thin-walled castings for a single piece bike frame. Binder jetting technology also eliminated the need for expensive and time-consuming tooling production, enabling him to quickly test and iterate designs.

In 2022, Murray visited CastExpo to connect with the foundry industry, promote Foundry Casting Systems’ technology, and introduce his new company, Heavy Bikes. There, he met the Liberty Pattern team and began discussing the complex shape of his bike frame.



Above, the first Heavy Bikes prototype frame hits the trails. Below, Murray rides the latest generation of Heavy Bikes.

The pattern shop operates a fleet of five S-Max 3D printers, servicing aerospace customers and others with complex sandcasting molds and cores. Because Liberty Pattern could produce a complete casting package without any hard tooling, it was feasible to cost-effectively develop the Heavy Bikes product idea.

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Casting a bike for people on the margins

In an industry always chasing weight reductions, Murray recognizes the irony in naming his company Heavy Bikes. Admitting that a bike cast in solid metal would be “heavy” in comparison to traditional models made from hollow, extruded tubes that are cut to length and welded together, he leaned into the idea and named the company Heavy Bikes. He emphasized, “It’s not a bike for everyone. It is a bike for the people on the margins.”

The custom design allows riders to get a bicycle fitted to their needs, while the solid frame provides a different kind of ride, often one with more confidence.

Murray gave the example of former heavyweight athletes that may look to biking as an option to stay active, but who can quickly run into the limits of traditional options.

“If you read the fine print, many mountain bikes are only good to 300 lbs (136 kg). A riding friend of mine who weighs 280 lbs (127 kg) works in welding. He pointed to a weld in the head tube right behind the handlebar of his mountain bike and knew that was the weak point in the frame. He didn’t have the confidence to jump because he knew it would break at that spot. Football linemen break bikes all the time. We knew a solid bike with no welds would inspire more confidence, so it was an opportunity.”

It became the goal of Heavy Bikes to offer a more confidence inspiring ride to a wider audience, as well as to build bikes for more challenging requirements, faster. With the motto “No welds, no worries,” Murray pushed to have a bike without the failure points of traditional, hollow tube bicycles.



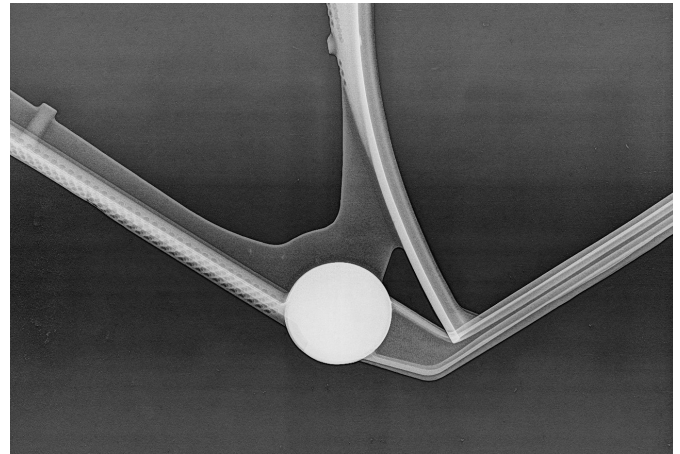
Because the Pascal Process results in higher-density, less porous parts than traditional aluminum casting, Murray explained how this boosts the metal’s tensile strength. That means the bike frame can incorporate thinner, lighter walls that are just as strong as those

A fleet of five ExOne S-Max sand binder jetting systems at Liberty Pattern in New Liberty, Iowa, allow the company to produce foundry molds and cores with flexibility, even for low-volume projects.

of traditional aluminum frames while providing the rider with a new sense of momentum and a connected feel unique to Heavy Bikes. “There’s more continuity and more direct power delivery of the energy that you put into the bike,” he said.

The mold package to cast each custom design is 3D printed from a digital file on an S-Max binder jetting system. Every bike frame is run through Finite Element Analysis (FEA) models and virtual simulated riding. Combined with several hours of solidification simulation to optimize gating with the team at Liberty Pattern, Murray said, “We got the mold 98.6% perfect in one shot. You can’t do that with any other tooling process.”

Avid cyclists themselves, the team at Liberty Pattern was excited to work on a project without NDAs they could share with friends and family. Specializing in aluminum and magnesium aerospace castings, the team often sees exciting designs they’re not allowed to discuss openly.



Top left: The 3D printed sand mold from Liberty Pattern is prepped for casting. Top right: The FCS Pascal Process utilized to cast the prototype at Craft Pattern and Mold. Bottom left: The prototype casting ready for post-processing. Bottom right: Next-generation Heavy Bikes are cast at Denison Industries and x-rayed by the foundry to verify the solidity of the aluminum frame.

“We learn from what we see,” said Steve Slininger, President of Liberty Pattern. “We applied the best aerospace-type gating to the bike frame package all to fit within the dimensions of the pressurized solidification system.” He also consulted on the project with his customers – aerospace engineers he meets with regularly who are happy to review cool projects and share ideas.

The initial Heavy Bikes Hypocrite prototype was cast at Craft Pattern and Mold of Montrose, Minnesota. Using Foundry Casting Systems’ Pascal Process, an inert gas is pumped into the 3D printed mold creating a positive pressure of 150 psi (10 bar). That pressure forces the molten A356 aluminum into all the narrow passages and intricate features of the frame while eliminating porosity.

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A year later, Murray provided his friend with a solid-frame bike to test. While custom bicycles on the market today come with long lead times – between eight and 16 months – he thinks the immediacy is missing from the industry. “I think you should get a bike within weeks. We’ve iterated the tool eight times since that prototype in 2022,” he emphasized. “That wouldn’t be possible in 1990. But today you can and I’m only able to do that because of the digital tooling capability that ExOne has brought to market.”

The fast turnaround of binder jetting was needed in 2023 when Murray broke a test bike at a race in mid-October. The team was quickly able to modify the design and print tooling at Liberty Pattern for a new casting within a week. The new bike with design optimizations (pictured opposite) was ready for the next race on December 1st.

Denison Industries in Texas pours the latest generations of Heavy Bikes, providing x-ray analysis to verify the aluminum castings’ solidity using the FCS Pascal Process. Through iterations enabled with easy adjustments to the digital printing files, the latest frames poured in September 2024 were reduced in mass about 1.1 lbs (486 g) compared to the previous generation.



Digital manufacturing allows custom design features like logos and dimpling to be added to each bike with ease.

Functional performance and three-dimensional art

Murray has a list of potential customers looking to get their own Heavy Bikes and says the product development cycle is probably one design away from a bicycle he can offer on the open market. “Somewhere you iterate to the point where you’re proud of the product and confident of taking someone’s money.”

Producing the bike without hard tooling, Murray was able to quickly improve the bike as it’s been tested. The second iteration of the bike redesigned the chain stay, increased the strength of the rear brake mount, increased clearance for the crank arm, and added embossed points for mounting bottle holders. All changes were made in the digital design and printed in sand on the S-Max without expensive or time consuming changes to hard tooling.

Incorporating additive manufacturing into production not only enables fast iterations and deliveries, but also opens new possibilities for design. On the practical side, the outer diameter of mold itself is curved into a cylindrical shape to fit into FCS platform – a simple adjustment in digital production not easily made with traditional tooling. Additional features can also be added to designs, for example, molding a section of mud guard onto the frame.

Murray also emphasized the ability to expand access to the sport with customized bikes. “People want to ride but can’t because they have irregular body types. They can’t get a bike to fit a torso that’s different or one that makes adjustments for someone who may have lost a limb. We can update a digital design and then produce it the same as any of our other bikes without added tooling costs.”

The design freedom of 3D printing also means the surface customization possibilities for each bike are endless. From dimpling like a golf ball to bird feather designs, the bike tube can be customized for each rider. “It would be incredibly tedious and expensive to get those designs into traditional tooling,” he said. “But we know we can make it with binder jetting machines.”

As a solid casting, each bike can be finished as much or as little as the customer wants. Traditional tube bikes are “made to be painted” to cover the welds and raw shapes, Murray points out. Heavy Bikes can be painted, anodized, clear coated, or left raw because there are no welds to hide.

And because aluminum has a ride life of about 4,000 miles (6,400 km), Murray hopes the Heavy Bikes customer enjoys looking at his creation as much as riding it. “When you reach the 4,000 mile mark, and I hope everyone does on Heavy Bikes, then I hope you’re just as excited to hang it on your wall,” he said. “Heavy Bikes is three-dimensional art, and ExOne digital tooling enables that.”



Heavy Bikes The Hypocrite

Casting mold features:

- 2,200+ lbs (998 kg) of sand
- 42 x 34 x 16 in (1,067 x 864 x 406 mm)
- Two cores; one the size of a flattened basketball for the rear triangle and one the size of a tennis ball on an interspace inside of the first
- Curved outer mold shape to accommodate Foundry Casting Systems Pascal Process

Bicycle features:

- Measurements by Bike Fit Guru
- 3D printed sandcasting mold from Liberty Pattern
- Metallurgy: Aluminum A356 cast at Denison with T6 heat treatment
- Cranks: 2XR by Appleman Bicycles
- Wheels: Emporia GC3 Pro by HED
- Drivetrain: SRAM XX Eagle transmission with eTap RED shifters & calipers with 6.3 in (160 mm) rotors

Heavy Bikes are ISO 4210:2015 compliant custom one-of-one cast aluminum gravel bikes for any size of rider. The build process starts with a custom bike fit which drives the 3D printed sand mold design. Molds are filled with molten A356 aluminum with Foundry Casting Systems’ Pressurized Solidification process to ensure a properly filled mold and superior mechanical properties. After casting, molds are broken with a sledgehammer before heat treatment and machining of all interface and art surfaces to complete the process.

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ABOUT HEAVY BIKES

Heavy Bikes produces custom one-of-one cast aluminum bikes via pressure solidification from Foundry Casting Systems’s Pascal Process. The sturdy single-piece gravel bikes eliminate the failure points of traditional, hollow tubular bikes. ISO certified and completely custom, Heavy Bikes are engineered for sizeable adventures - no welds, no problems.

ABOUT FOUNDRY CASTING SYSTEMS

Foundry Casting Systems is a custom equipment manufacturer of automated pressure casting solutions for sandcastings. FCS’ solutions provide an optimized solidification environment that virtually eliminates porosity, improving mechanical properties and reducing scrap castings. “Crush hope, cast with certainty.”

ABOUT LIBERTY PATTERN

Liberty Pattern Co. is a “Full-Service Patternmaking Company” which provides the foundry industry with quality products, on time deliveries and customer satisfaction at competitive prices. This is accomplished by providing quality patterns and customer services that is second to none. Our vision is to be the global leader that provides quality pattern tooling, fixtures, and machining services by empowering and equipping our employees to be the best in the industry.

ABOUT CRAFT PATTERN & MOLD

Craft Pattern & Mold is an industry leading manufacturer of prototype plastic and metal parts, as well as production tooling, for a variety of commercial and industrial applications. The team has delivered cost effective, precision prototype casting, machining, and tooling solutions to customers for over 40 years. Craft pattern offers quick turn, customized prototyping of metal and plastic parts using a variety of industrial grade materials and robust manufacturing processes.

ABOUT DENISON INDUSTRIES

Denison Industries delivers quality machined aluminum castings and complex components backed by a versatile range of sandcasting foundry services. Its AS 9100 D & ISO 9001:2015 certified facility is outfitted with a repertoire of the industry’s most high-tech machining, molding, and casting equipment. Cutting-edge production technology combined with the skills of innovative craftsmen have enabled Denison Industries to provide the world’s most advanced industries with a complete range of premium American manufacturing solutions since 1971.

ABOUT EXONE

ExOne is now part of Desktop Metal’s group of #TeamDM brands, which exist to make Additive Manufacturing 2.0 a reality so we can unlock the vast benefits of 3D printing at meaningful production volumes. Our 3D printing systems quickly transform powder materials – including metals, ceramics, composites and sand – into precision parts, metalcasting molds and cores, and innovative tooling solutions. Industrial customers use our technology to save time and money, reduce waste, improve their manufacturing flexibility, and deliver designs and products that were once impossible. As home to the world’s leading team of sand binder jetting experts, ExOne also provides specialized 3D printing services, engineering, and design consulting.

