GF Machining Solutions

Additive Manufacturing

Tire mold manufacturing gains traction through hybrid workflow

Introduction

Today's powertrain developments fast-track innovation in multiple directions, as new engine designs, fuels and other technologies seek to blend power, efficiency and economy. Throughout all these diverse power choices, the rubber continues to hit the road, prompting tire manufacturers to pursue maximum life, safety, ride comfort and energy efficiency through advances in production technology and tread designs.

Complete tire mold segment in Maraging Steel printed with the DMP Flex 350

Patterns of ribs, sipes, blocks, and other molded elements determine wear characteristics, bad-weather performance, noise behavior, roadholding traction and energy consumption.

Traditionally, tire-mold manufacturing has used subtractive machining to produce metal segments. As tread designs become more complex, they also become too expensive for conventional milling to produce. Electrical Discharge Machining (EDM) can machine small details, but this process requires the manufacture and application of multiple graphite electrodes.

More recently, additive machining (3D printing or AM) also can create complex mold geometries, but the process has been relatively slow and costly.

To accelerate tire mold production,

GF Machining Solutions has innovated a cost-effective hybrid manufacturing approach that applies additive and subtractive machining where each is most effective and efficient. This breakthrough process produces highly sophisticated tread designs, along with significant savings in manufacturing time and cost to secure volume production.

Challenges

Manufacturers mold tires from a mixture of natural and synthetic rubber, carbon black, oil, reinforcing materials and a variety of other substances. A tire mold includes matching curved metal segments that form the tire's outer circumference. The interior of the mold segments, machined with reverse versions of ribs, sipes and contours, forms the details of the tread surface. Rubber stock wraps over the tire's belts, body plies and bead components. In the mold, pressure, heat, sulfur and other chemicals cure and vulcanize the materials in a polymerization reaction that crosslinks rubber monomers to produce flexibility and strength.

Tire designers use computer simulations of tread features to produce desired braking, handling, wear and safety performance. Tradeoffs abound: a design that limits tire noise may shorten tire life, or an open tread that performs well in wet weather may prove less effective in dry braking.

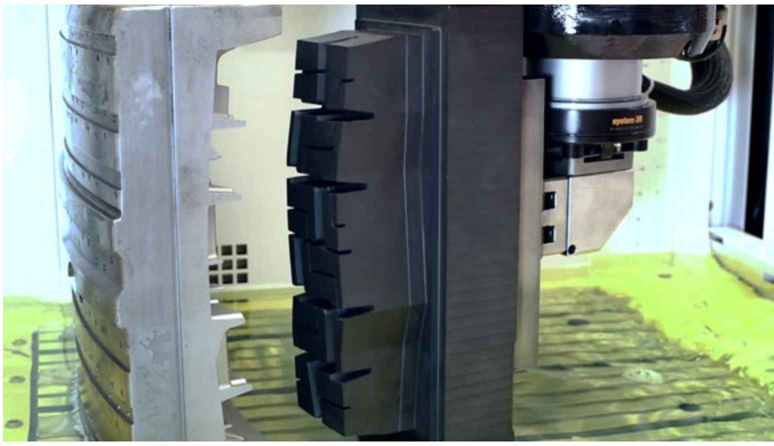
With evolution of new mobility driving " NEV's" (new Energy vehicles"), the tire play a major role, not limited to Noise, Mileage and safety. Advanced 3D sipes & serrated grooves designs enable to handle tough terrains and climatic conditions. Mold makers face difficulty to machine sharp features and to avoid manual labors that are hugely inconsistent.

Once the tread design is complete, traditional tire-mold manufacturing begins with creation of CAD/CAM files that represent surface features. In many cases, these files guide a 5-axis CNC machining center to mill an epoxy resin block into a positive version of a mold segment. A rubber casting from the epoxy block becomes the basis for a metal casting of the segment. Milling, drilling, polishing and die-sinking EDM then machine ribs, sipes and other details, such as logos and product information, into the interior of the mold segment.

Epoxy resin block
and milled segment

High tooling costs rule out an approach that uses only milling and EDM to machine the mold directly from a solid block of metal.

Tire mold segment
after die-sinking
erosion process

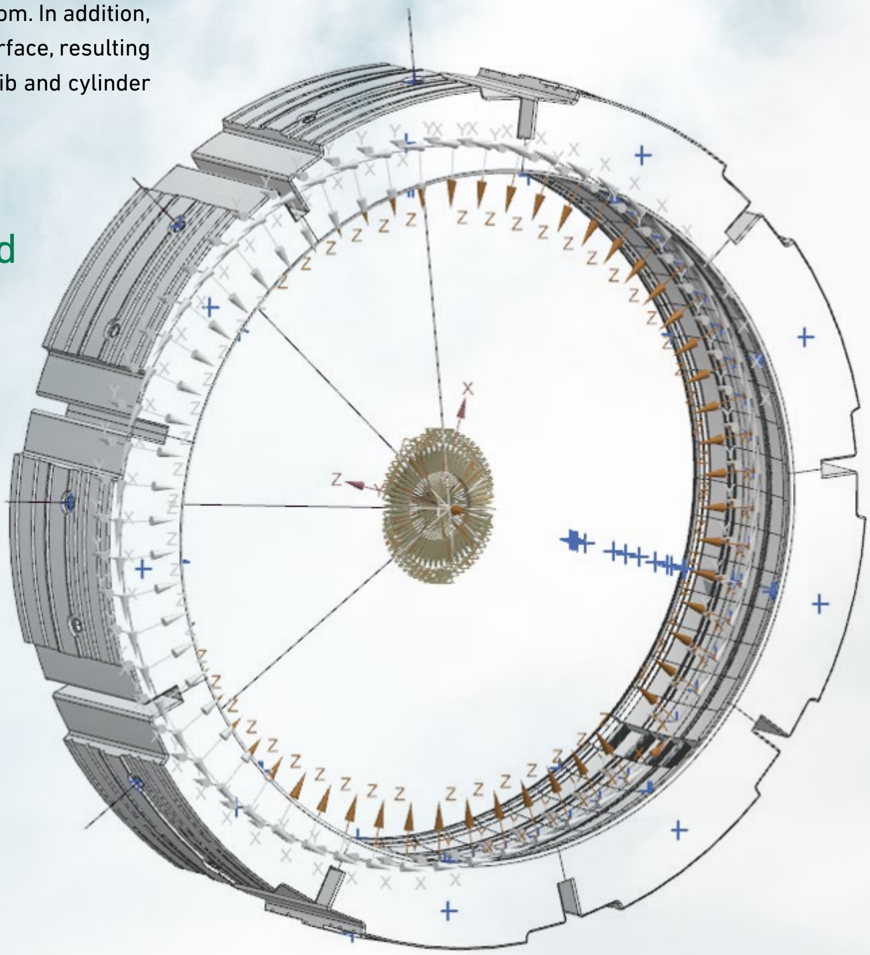


The EDM process requires multiple sets of graphite electrodes for each segment, and may need special positioning heads so the EDM electrodes can access complex geometries. In some cases, small metal inserts that represent sipes in the tread pattern must be machined separately and integrated into the segment manually.

As tire technology grows in sophistication, tread features become more intricate and mold-production time increases. The traditional approach can take six months, or even longer if the sipes and ribs contain large amounts of small details. Some complex, asymmetric rib/sipe patterns are difficult if not impossible to create through either milling or EDM.

As an example. a complete tire mold for a 295/75 R22.5 light-truck tire typically contains nine segments with dimensions of 320 mm x 160 mm x 80 mm each and is a prime example of a complex tread design. Narrow rib elements measure 0.4 mm wide, with a 0.9 mm radius at the bottom. In addition, the ribs tilt at a 10° angle relative to the tire surface, resulting in a conical arrangement that requires each rib and cylinder to be machined at a matching angle.

Rendering of an entire tire mold



To produce the entire mold the conventional way, a manufacturer must machine more than 7,680[a] cavities with small, long tools. Through subtractive machining alone, the rib cavities would require 400 work hours, aside from other milling operations.

Realize secured production of complex tire molds

To perform the required undercut from the cylinder to the ribs and generate sharp inner edge features through EDM requires more than 128 sets of graphite electrodes for each segment and more than 2,500 individual electrodes for the entire tire mold. Special heads position the electrodes to access complex sipe geometries. To create the cavities through die-sinking EDM would consume more than 1,280 work hours—in addition to machining the graphite EDM electrodes and checking them via CMM.

The length and complexity of machining cycles can introduce instability in the manufacturing process, but precision and repeatability remain essential even through hundreds of tool changes. To control noise and rolling resistance, the entire finished mold must feature total indicator runout (TIR) below 0.1 mm.

Additive manufacturing (AM) offers an alternative to complex milling and EDM operations. By building up layers only tens of microns thick, AM can produce small features and undercuts that would be difficult or impossible to achieve with milling and/or EDM, including complex sipes and other details.

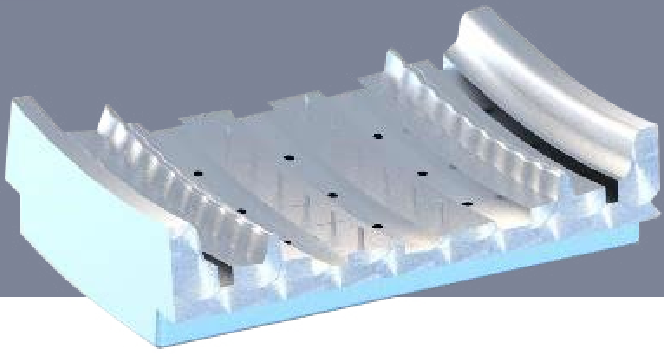
A very important final factor that plays a decisive role here is that with the AM process, the process costs per print series are always the same, regardless of whether low or high quantities, whether difficult or simple parts.

a: the number varies based on Tire design.

Solutions

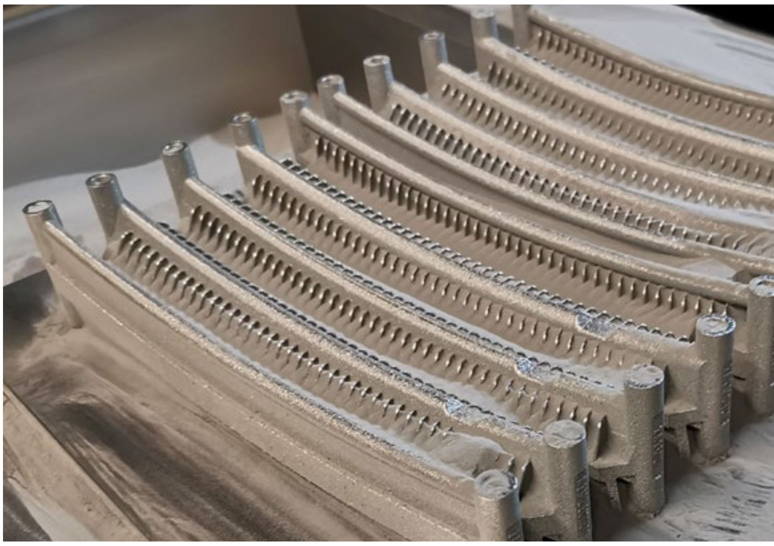
GF Machining Solutions’ breakthrough hybrid manufacturing process addresses the constraints of traditional tire mold making and can reduce mold-segment lead times to below six weeks.

Like traditional mold making, the hybrid process uses CAD/CAM programming and 5-axis machining to produce the mold segment. For this phase of the process, CNC milling on a GF Machining Solutions MILL P 500 U machining center is fast, accurate and repeatable. The same machine also mills the corresponding fitting cavities in the segment to accommodate AM sipe/rib inserts.



Base of the mold segment milled with the MILL P 500 U

Ribs inserts with sipes after building process with the DMP Flex 350



Separately, the hybrid process uses AM to produce fine, complex detail on sipe/rib inserts that slide into the mold segment. A GF Machining Solutions DMP (Direct Metal Printing) Flex 350 metal AM manufacturing system produces the inserts in LaserForm® Maraging Steel or corrosion-resistant Böhler M789 steel. The machine's fast bi-directional material deposition and a consistently low oxygen environment—fewer than 25 parts per million—produces highly dense parts with excellent microstructures and stable mechanical properties. The DMP Flex 350 builds these parts on System 3R tooling, which provides a precision reference system for ultimate repeatability throughout multiple process steps.

This new method requires specific CAD/CAM files created to fit the AM workflow, build the inserts and prepare them for insertion into the main segment body. GF Machining Solutions 3DXpert all-in-one integrated software handles the entire AM workflow, from data import and part-structure optimization to simulation and arrangement of build and programming post-processing operations.

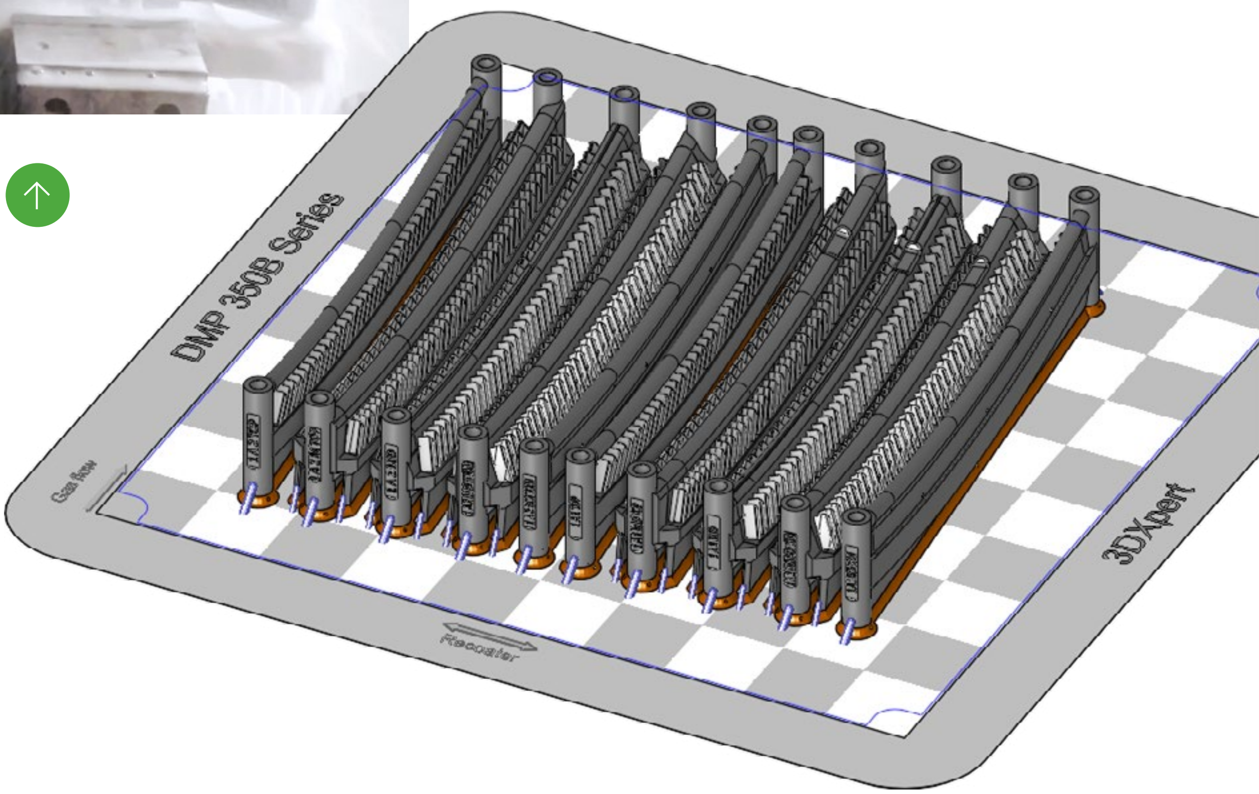
Manufacturing workflow

In order to integrate each of the printed elements precisely into the corresponding cavities in the mold segments, a unique identification number of the component is the two extremity clamping cylinders. Such two cylinders with a reference diameter and M6 mounting holes, were added in the purpose of a single setup for an accurate part orientation and rework. These cylinders are then removed during the rework.

After the AM operations and part separation on the CUT AM 500 machine, each printed insert is transported to a Mikron MILL S 400 U machining center. This machine mills the side fit and the curved underside, drills the M5 threads to secure the insert in the segment, and mills each individual element to its appropriate length. In the process, the two extremity cylinders are cut off.

MILL S 400 U was used for post-processing steps

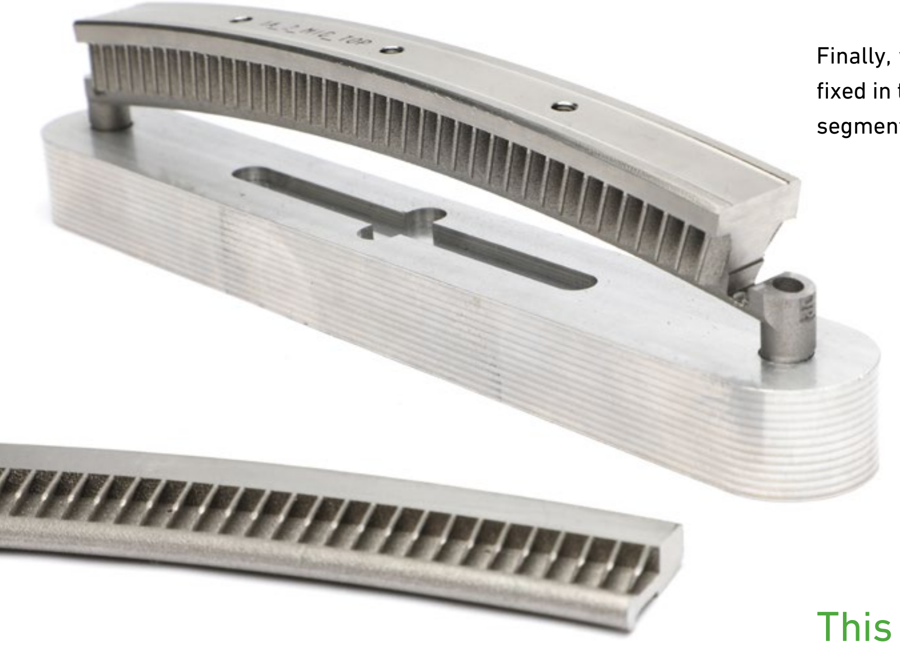
3D printed ribs milled with MILL S 400 U



However, prior to this post-print rework, the entire build platform and components are heat heat treated for stress relief and final mechanical properties. Only then are they separated from the support structure using a GF Machining Solutions CUT AM 500 horizontal wire EDM machine, which is a fast, precise, affordable and automatable alternative to standard EDM machines or a band saw.

Finally, when all the machined and reworked elements are fixed in the segments by means of the M5 screws, the whole segment is sandblasted to obtain a uniform surface.

Unique identification, helps to manage MRO activities post production effectively.



3D printed ribs on dedicated tooling after post-process

This innovative hybrid process saves time and power resources, cuts lead times to six weeks or less, cut down on manufactu-ring costs and reduces power consumption by more than 60%.

In this case, AM printing of the sipe/rib segment consumed 325 minutes at 30-60µm per layer. Post processing included 90 minutes for a base segment milling, 22 minutes wire EDM and 12 minutes milling for each insert.

Final assembly of milled segment with 3d printed ribs with sipes

Traditional process

- **CAD/CAM design**
- **Positive segment machining**
- **Rubber casting**
- **Metal casting**
- **Metal segment machining**
- **Integration of sipes**
- **Metrology**

Leadtime = ~ 6 months

GF Machining Solutions' process

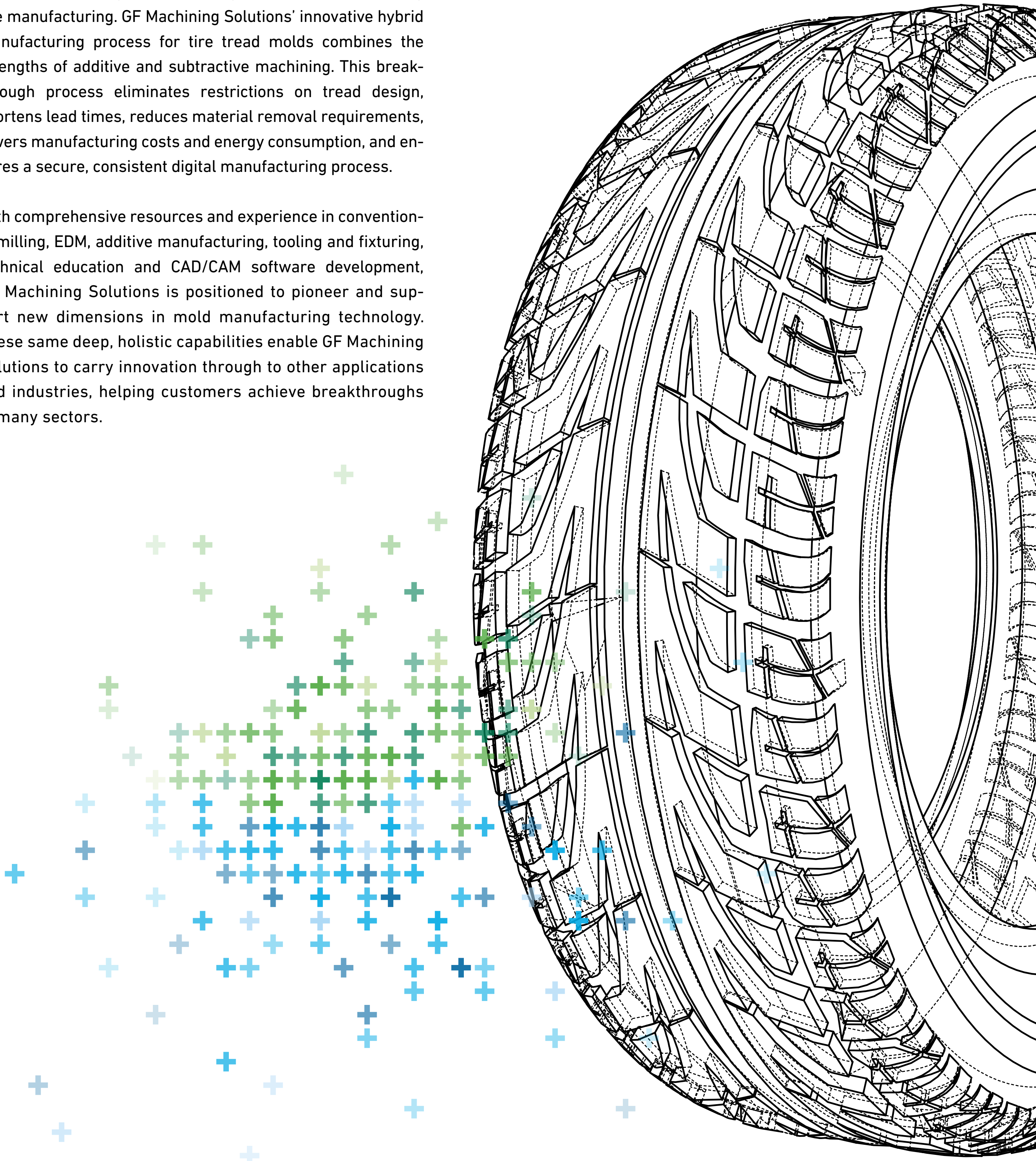
- **CAD/CAM design**
- **Manufacturing of mold segment with slots**
  - 5 axis machining on MILL P 500 U
- **Manufacturing of sipes inserts**
  - 3D metal printing on DMP Flex 350
  - Ageing by heat treatment
  - Post-processing on MILL S 400 U
  - Cleaning and assembly
- **Metrology**
  - Inspection and quality control

Leadtime = ~ 6 weeks

Conclusion

To gain maximum benefits from new powertrain initiatives demands new thinking and processing on many fronts, including tire manufacturing. GF Machining Solutions' innovative hybrid manufacturing process for tire tread molds combines the strengths of additive and subtractive machining. This breakthrough process eliminates restrictions on tread design, shortens lead times, reduces material removal requirements, lowers manufacturing costs and energy consumption, and ensures a secure, consistent digital manufacturing process.

With comprehensive resources and experience in conventional milling, EDM, additive manufacturing, tooling and fixturing, technical education and CAD/CAM software development, GF Machining Solutions is positioned to pioneer and support new dimensions in mold manufacturing technology. These same deep, holistic capabilities enable GF Machining Solutions to carry innovation through to other applications and industries, helping customers achieve breakthroughs in many sectors.



Appendix: Case study: Hybrid tire mold

Hybrid tire mold

Technology	DMP Flex 350 MILL P 500 U MILL S 400 U CUT AM 500 System 3R Tooling for AM
Market Segment	Automotive
Material	LaserForm® Maraging or Certified Böhler M789 (insert) Aluminium (base segment)
Build Time	325min per insert
Layer Thickness	30 and 60 µm
Machining time	90min per segment (MILL P 500 U) 22min per insert (CUT AM 500) 12 or 25min per insert (MILL S 400 U)

Key challenges

+ Process feasibility of small ribs and sipes at low cost regardless the complexity
+ Reduce drastically the manufacturing time by more than 60%
+ Improve the metal AM workflow with an upstream and downstream integration

Your contact

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