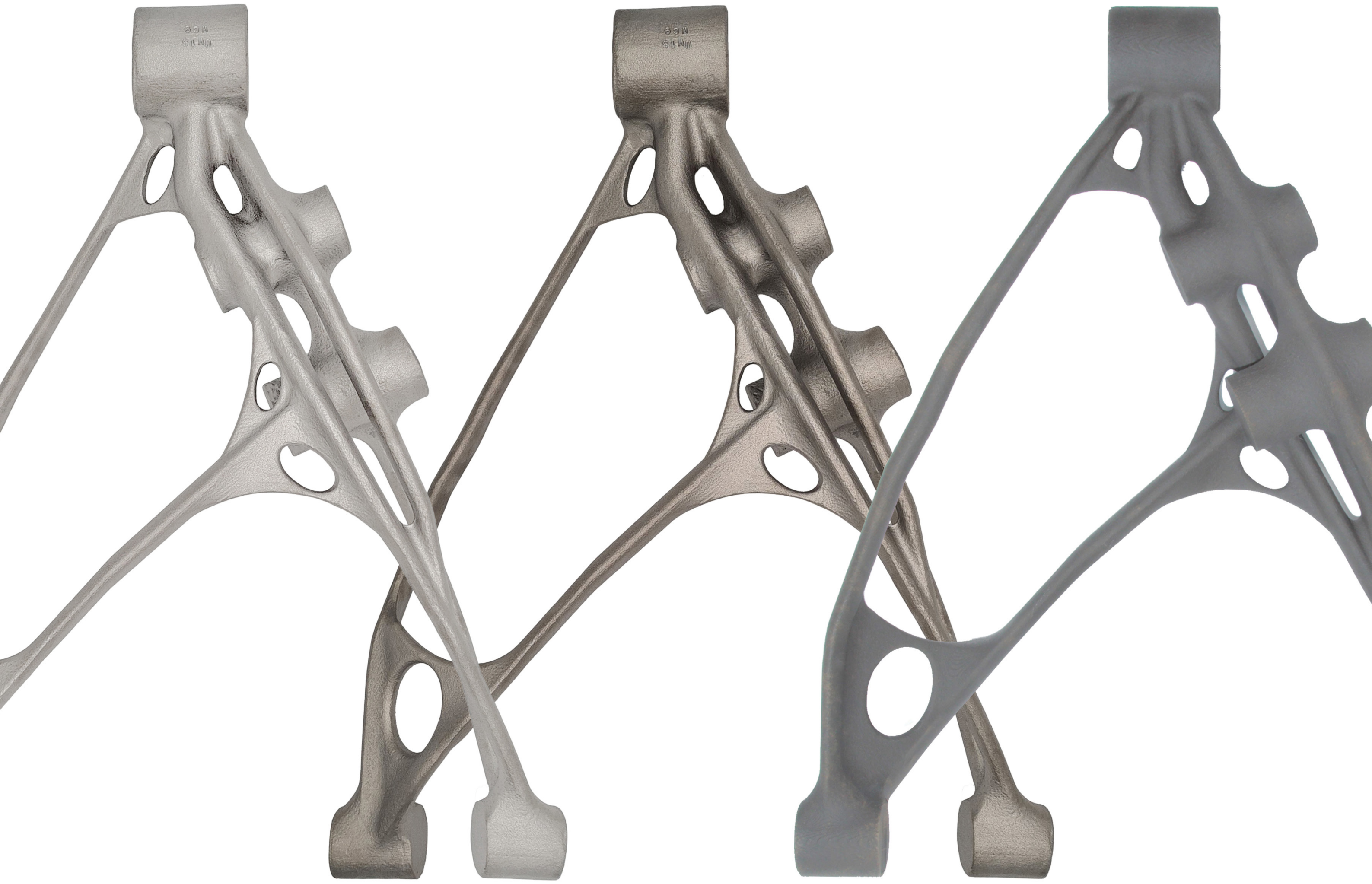
PROVING THE CONCEPT OF

ADDITIVE CASTING®



WHITE PAPER

VOL 2 - LARGE SUSPENSION ARM

ENABLE
PRINT. CAST. DELIVER.

FEBRUARY 2022

ABOUT THIS PAPER

Enable Manufacturing was awarded an Innovate UK grant towards the end of 2020 to investigate a novel manufacturing method known as Additive Casting®.

The aim of this project was to challenge the Additive Casting technology to manufacture a number of parts in a range of sizes, metals, and quantities.

This project would therefore prove the viability of Additive Casting across a spectrum of potential applications and markets.

Four component types were identified across various industries, ranging in size, material, and application, that would adequately demonstrate the breadth of the Additive Casting process.

This white paper will focus on the second of the four components - a large suspension arm for automotive applications - and will summarise what was done, and what was accomplished.

CONTENT

ABOUT ADDITIVE CASTING®

PROCESS OUTLINE

- *CAD file preparation*
- *3D printing*
- *Metal casting*
- *Quality control*
- *Shipping*

Additive Casting is a bit of the old, and a bit of the new. It combines the best parts of new technology (Additive Manufacturing), and old technology (Traditional Metal Casting) and effectively brings together the best of both worlds, to provide metal parts faster, and more cost-effectively than before.

Additive Casting® is not a single process. Rather it is a family of numerous processes that can be combined to deliver a metal part through the combination of Additive and Traditional Manufacturing processes. At its core however, it can be summarized as follows:

A process of 3D printing the moulds or patterns for metal part production and combining this with traditional metal casting processes to deliver metal parts without the often expensive initial start-up costs synonymous with casting. The result is a metal part that can be made faster, cheaper and more complex.

The Additive Manufacturing (AM) of metal components is currently limited by a range of materials, small sized components, and the high cost of manufacturing. Additive Manufacturing must provide significant added value to these components to justify the costs of manufacture, which is why the uptake is often limited to ultra-high-value components in low volumes.

In contrast, traditional metal casting has no limitations on the range of materials or sizes available to components, but the cost to produce a low volume of parts can be prohibitively high, and these costs rapidly scale as the complexity of the part increases. This creates a barrier against the organic light-weighting designs that are found with AM produced components, simply because the cost to manufacture the component outweighs the benefit that optimisation provides.

Combining the best of both of these processes, means we can cast metal parts faster and cheaper, with many of the design benefits available to the AM sector.

In this project, we produce components using 3 key Additive Casting processes, including:

SAND ADDITIVE CASTING

- L — *Large parts*
- *Scalable for production*
- *Average complexity*

INVESTMENT ADDITIVE CASTING

- M — *Fine detail*
- *Scalable for production*
- *Complex parts*

VACUUM ADDITIVE CASTING

- S — *Ultra fine detail*
- *Scalable for production*
- *Highly complex parts*

This paper will focus on a **large suspension arm**, manufactured with the **Sand Additive Casting** process.

Throughout this white paper series, we will outline the variations in each of these processes and the factors that influenced the designs of the components manufactured, followed by an analysis of each part and a comparison with alternative manufacturing methods.

LARGE SUSPENSION ARM

The large suspension arm is an automotive component that forms part of the suspension gear of a car. This part was chosen due to its size, which would be costly and time consuming to produce at volume with Metal Additive Manufacturing (AM).

Currently, only relatively small, and complex parts are optimised due to the available sizes of AM printers. With Additive Casting, any component size is possible, and can enjoy significant light weighting benefits with the right optimisation methods.

While this part was produced as a steel and aluminum sand casting, it was also manufactured in magnesium, which is seen as the ultimate material in light weighting. Steel is a standard material for automotive suspension components. As vehicle weight has become an increasingly important factor in car performance, more manufacturers are opting for aluminum - but what comes after that? Magnesium.

Magnesium is not used in the Metal AM industry due to its volatility under heat. It must be cast under special conditions, which becomes possible with Additive Casting, and can result in a part with tremendous weight savings capabilities.

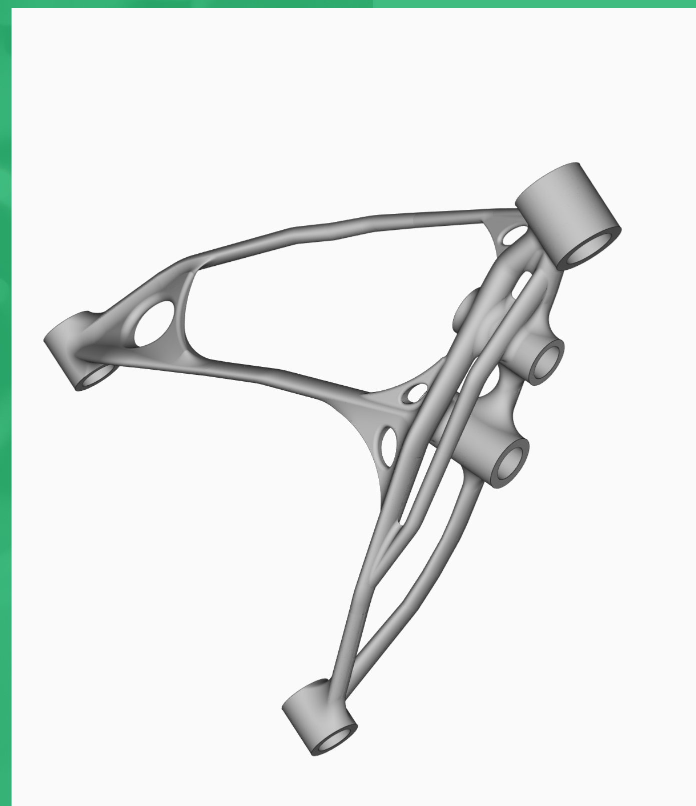
LARGE SUSPENSION ARM SPECIFICATION

Size: 504 x 402 x 104 mm
Process: Sand Additive Casting
Material: Steel ASME SA217-17 WC9, aluminum LM25-TF and magnesium L128

SUSPENSION ARM DESIGN

A suspension arm is a structural component, and in a car, must be capable of supporting high loads without failure. This component's original design was developed for fabrication using T45 sheet metal, which presented few opportunities for light-weighting design optimisation.

The initial design was run through an FEA software package, modelling the hard-point locations and testing against 12 different loading cases that simulated real-world loading situations. Optimisation software then removed excess material from the regions of the part's volume that were not vital to its mechanical performance. This method isn't fool proof, and multiple iterations of this component were examined before arriving at a final design.



The initial design weighed 13.14kg and the final design weighed 7.17kg (steel), delivering 5.97kg savings in weight. Depending on the suspension setup of the vehicle, it could have 2 or 4 lower control arms. Meaning, in a standard vehicle, this new design can yield a total weight reduction of 12kg.

In magnesium, the weight saving impact was more pronounced, due to the significantly lower density of the material compared to steel. The final part weighed 1.66kg (a reduction of 1.38kg if the original design was cast in magnesium), which represents a significant improvement to fuel economy in a vehicle.

An aluminium version was also produced, to emphasize the variation in weight between the difference materials. Weighing in at 3.3kg, it is approximately double the weight of the magnesium part and more than half the weight of the steel variant. While heavier than the magnesium component, the weight savings compared to the steel variant will result in significant improvements to fuel consumption.

PRODUCTION PROCESS

Production of this component was much more technically complex than the pens, covered in VOL 1 of this series of white papers. Due to its size, the Sand Additive Casting process was required. This requires the production of a sand mould, which is a negative representation of the part to be cast.

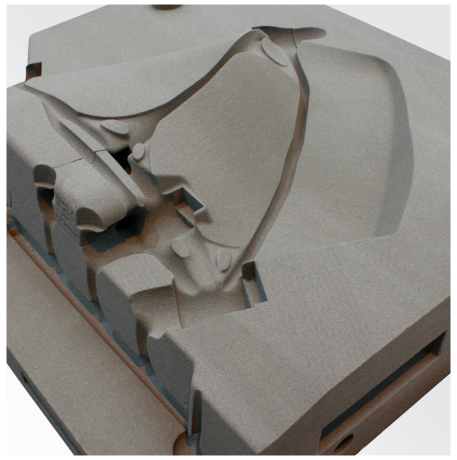
The design of a sand mould (often referred to as a mould pack) requires the design of several components: A cope (the top half of the mould pack), a drag (the bottom half), and cores (additional inserts within the mould pack). Designing a mould pack requires knowledge of the metal being poured (different metals require different runner systems and different grades of sand), and an understanding of how the mould should be assembled (each component is printed separately and assembled prior to casting).

On the 3D printing side, some consideration is required to enable line of sight to all internal surfaces (no enclosed cavities) to ensure any loose sand can be removed after printing (can result in casting defects if not cleaned properly).

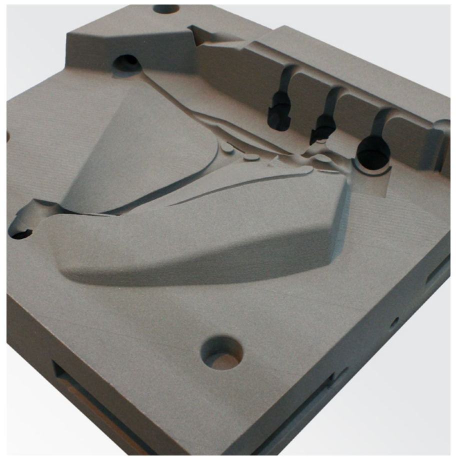
The advantage of 3D printing the mould pack, however, is that mould components do not require the same design considerations as traditionally tooled sand moulds, such as draft angles; and printed moulds can incorporate under/overhangs, which would traditionally be separated into an additional core. This enables the simplification of mould pack designs, which can reduce some of the complications that can arise with very complex moulds that contain a high number of cores.

In traditional sand casting, the runner systems that the molten metal flows through are often added to the mould components after that have been formed.

Mould pack -cope



Mould pack -drag



Mould pack -cores

> ***"The advantage of 3D printing the mould pack is that mould components do not require the same design considerations as traditionally tooled sand moulds, such as draft angles; and printed moulds can incorporate under/overhangs, which would traditionally be separated into an additional core.***
>
> *Jonathan Wright, Technical Manager*

PRODUCTION PROCESS

Depending on the complexity of the part, this can be a time-consuming process and enables a degree of human error. With Additive Casting, the runner systems can be incorporated into the printed mould pack, reducing the human error element, ensuring a lower labour content, and enabling the use of more complex runner systems.

Chillers and filters are additional components used within the sand casting process and, while these components cannot be printed into the mould packs, the cut-outs of these components will be inserted into the design.

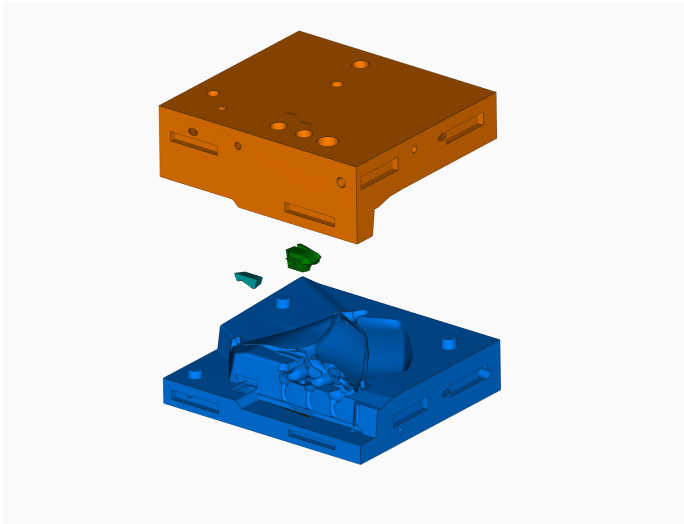
When producing this component in steel and magnesium, two completely different mould pack designs were realised, which highlights the different melt flow properties of the materials they were cast in.

Both mould pack designs were printed in sand and cleaned down to remove any traces of loose sand. With the magnesium sand mould, the inhibitor used with magnesium sand castings was mixed in with the sand prior to printing, which ensured a uniform coverage. With the steel sand mould, a specialist grade of sand was substituted for the core material. This sand has greater refractory properties, making it ideal for use with high-temperature alloys.

At the foundry, the sand moulds were assembled and sealed under heavy weights. High pressures can be experienced during the pouring of the metal, which can lift or shift mould components, leading to inaccurate castings. Once the metal had been sufficiently heated, they were poured into the moulds and allowed to cool before being broken out and finished with a series of shot-blasting and fettling. Lastly, both sets of parts underwent additional machining operations to produce a finished component.

The casting process for both steel, magnesium, and aluminium components are largely the same, and all components underwent similar methods. Magnesium, however, is a highly reactive material and must be cast within a vacuum chamber to prevent an explosive reaction which can pose deadly. This is not a problem for a foundry equipped to handle magnesium castings.
Due to using existing casting methods for this component, the steel variant was manufactured in accordance with BS EN 10204 3.1 (a European standard for inspection procedures) and ASTM A802 (acceptance criteria for the surfaces of steel castings).

Mould pack - exploded



PRODUCTION PROCESS - FINAL PARTS

Aluminium - 3.3kg

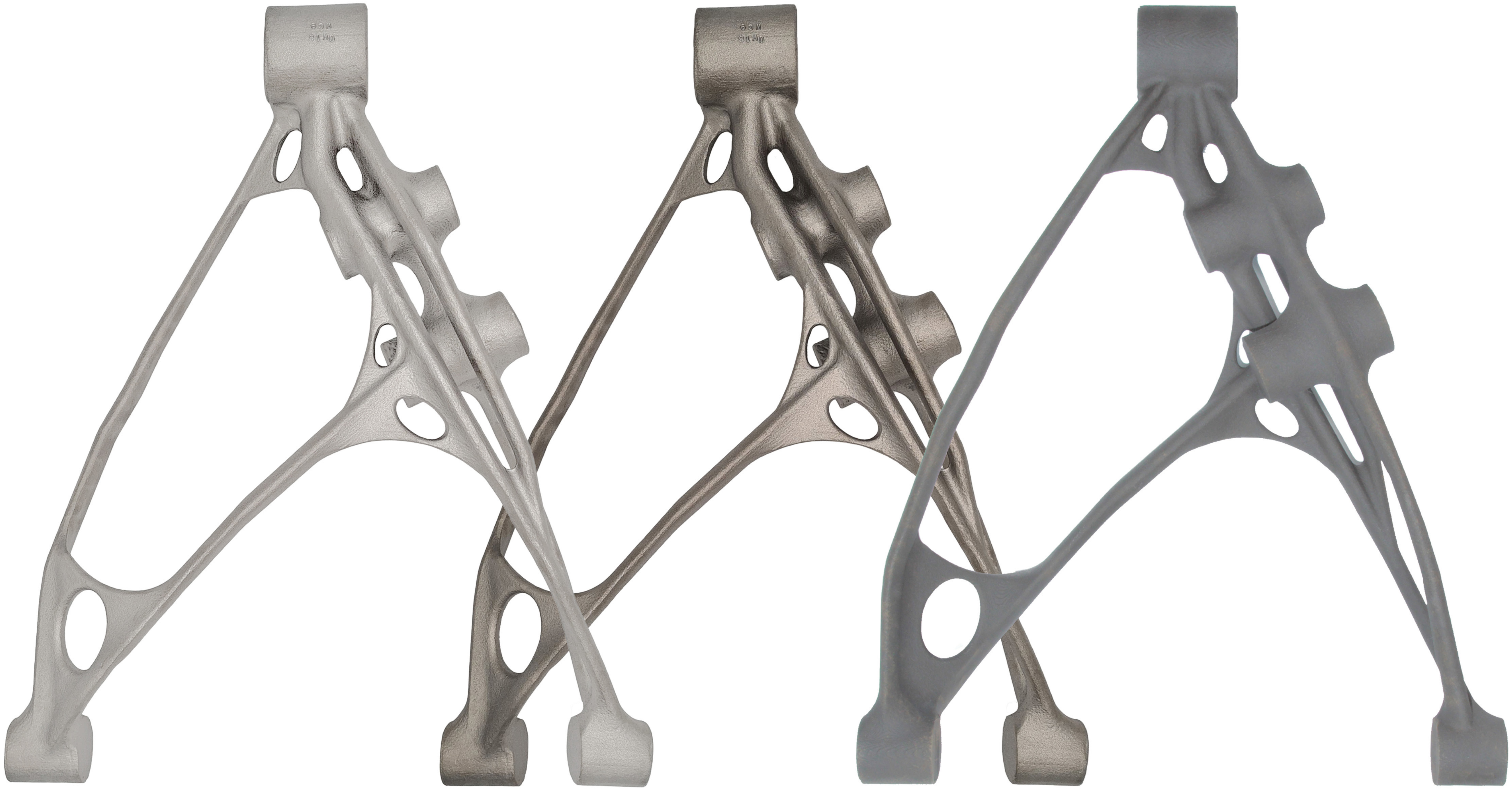
Standard manufacturing material with good properties.

Steel - 7.17kg

Twice as strong as Aluminium and Magnesium thanks to the wide choice of different grades and heat treatment options.

Magnesium - 1.66kg

Ultra light with a similar strength to Aluminium.

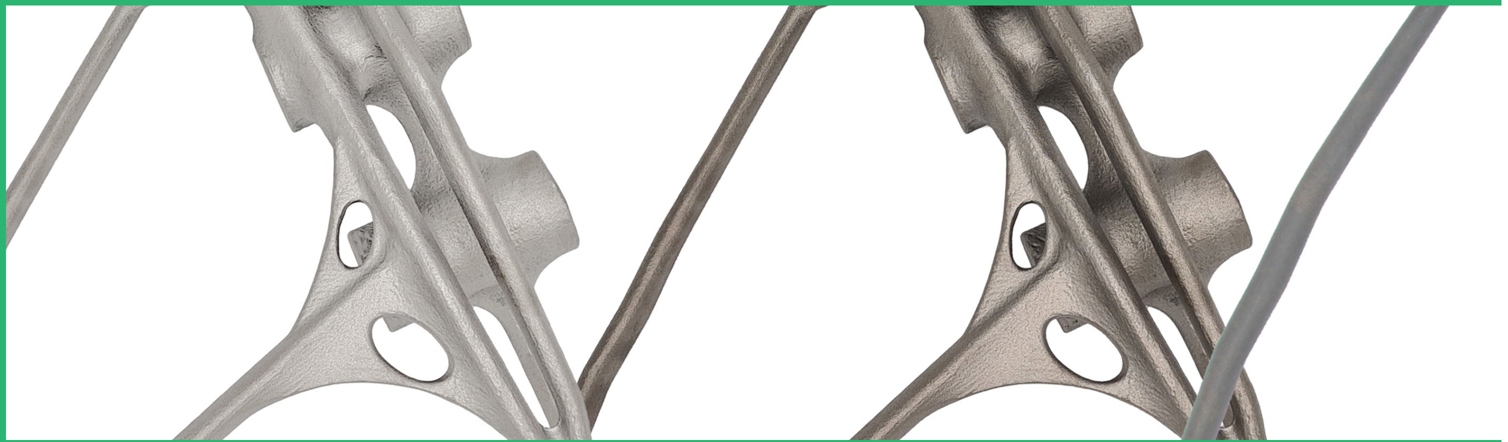


PRODUCTION PROCESS

ADDITIVE MANUFACTURING ALTERNATIVES

There are very few AM printers and processes with a build bed large enough to accommodate this component. While it would be possible to fit this part within GE Additive's X Line 2000R printer, which has a build volume of 800 x 400 x 500 mm, or within the build volume of many WAAM printers, ordering parts (and even quoting) on these printers proved difficult, with suppliers declining to quote.

While it may be possible to manufacture the steel variant of this component through metal additive manufacturing, producing the magnesium variant would not be possible through AM without Additive Casting. Magnesium powder bed fusion has only been trialled in a small number of studies, and the printers capable of using this material are not well suited for parts as large as this. The production of industrial scale magnesium components through additive manufacturing is still many years away.



THE COST

Both the steel and magnesium variants of this design were compared against alternative manufacturing processes; however, a cost for direct metal laser sintered (or other metal-based AM process) could not be obtained for this component.

In contrast to the Investment Additive Casting manufactured Rocker Arm and Bracket, both LCA's were manufactured using a Sand Additive Casting process, which uses a binder jet printed sand mould instead of an investment casting pattern. In traditional sand casting, this sand mould must be created through the use of patterns (a positive impression of the part to be made, often made from wood, metal, or plastics). These patterns can be manufactured in a variety of manners, but the most accurate methods for industrial sand casting use CNC machines (wood for short batch runs or metal for higher volumes). There are some design considerations to keep in mind when creating traditional patterns, such as draft angles (enable the pattern to be removed from the sand mould without damage) and overhangs (such features prevent the pattern being removed without damage). This can result in more complex sand mould and pattern design, containing more components than an Additive Casting version. Complex sand castings require the use of sand cores, which require a special moulding box, and often feature many curved surfaces. Each additional core requires a new pattern, which can drive up the initial cost of traditional sand casting.

However, sand casting on its own is a relatively cost-effective manufacturing process; and as volume grows, the influence of the start-up cost on the unit price rapidly diminishes. This is evident in the below tables, which compare the unit cost between Additive Casting of the LCA in both steel and magnesium, and traditional sand casting.

The cost for a one-off can be prohibitively expensive for both materials, which can be detrimental towards the development of new or improved components, especially in the prototyping stages of more complex designs.

In these stages, alternative metal AM processes, such as DMLS, metal binder jetting, or WAAM, can also prove fairly cost-prohibitive, and the final component may not behave as intended due to the different manufacturing processes used (DMLS, BJ, and WAAM use a layer-based printing approach which can produce anisotropic mechanical properties).

Qty	Additive Casting	DMLS	Traditional
1	£3,201.80	N/A	£9,880.24
5	£3,094.01	N/A	£2,934.13
10	£3,082.04	N/A	£2,065.87
25	£2,974.25	N/A	£1,544.91
50	£2,938.32	N/A	£1,371.26
100	£2,920.36	N/A	£1,284.43

Cost-Comparison for Steel Casting (unit pricing)

Qty	Additive Casting	DMLS	Traditional
1	£3,994.61	N/A	£12,275.45
5	£3,347.90	N/A	£3,652.69
10	£3,258.08	N/A	£2,574.85
25	£3,146.71	N/A	£1,928.14
50	£3,128.74	N/A	£1,712.57
100	£3,126.95	N/A	£1,604.79

Cost-Comparison for Magnesium Casting (unit pricing)

CONCLUSION

The large lower suspension arm (LCA) component was identified as a suitable component to explore the Sand Additive Casting process and was subsequently optimised to introduce light-weighting features to a component which was initially designed for manufacture from sheet metal. The design was optimised for the Additive Casting process and light-weighting applications before the design was converted into a sand mould and 3D printed using a binder jetting approach. The sand mould components were assembled at a foundry and cast in both steel, aluminum and magnesium. Following casting and cool-down, the components are broken out of their sand moulds, fettled, and shot-blasted to remove any remaining debris from the casting process before final inspection.

A cost analysis comparing the Additive Casting and traditional sand casting processes was compiled, which showed a stark difference in the initial costs for both processes, due to the high cost of the traditional tooling. These costs become manageable as volumes scale, but only once the design has been finalised, which presents an issue for prototypes or small-volume batches. Costs for a metal AM alternative could not be obtained for these components.

In contrast to the cost, the manufacturing lead time for the traditional tooling was approximately 3-4 weeks. Meanwhile, the 3D printed sand mould could be manufactured within a week.

Sand Additive Casting can be a viable manufacturing process for large metal components in low volumes or

requiring a level of complexity that would be cost-prohibitive of traditional manufacturing methods (an early version of the LCA design featured a multitude of hollow sections running throughout the legs of the part, the cores, for which would have been exceptionally difficult to manufacture patterns for).

There are further opportunities for optimising the design, such as hollow sections, which would add complexity to the design and would in turn add additional cost to traditional tooling - but not to Additive Casting. Therefore complexity is an important factor for whether Additive Casting is cost effective in higher volumes.

Whether or not it is cost effective in volume, it is clearly a valuable prototyping tool that is fast, cost effective and truly representative of a production part.

This process can also be suitable for weight-sensitive components that must reduce weight where necessary; for example, by removing all draft angles from the part entirely, which has been shown to save 5% on most components without any effect on the part performance. With traditional sand casting, this can only be accomplished through extensive post-casting machining operations.

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