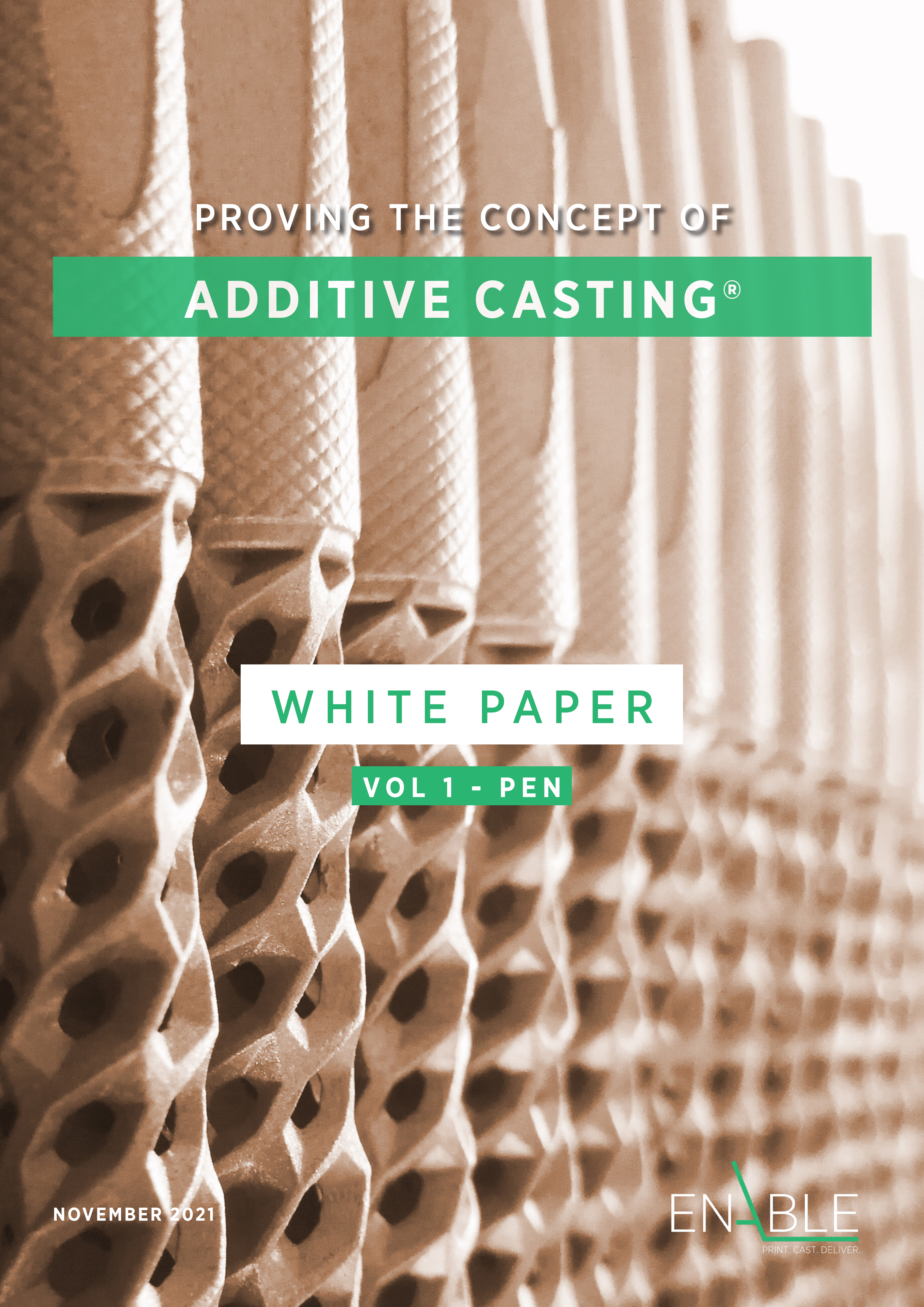

PROVING THE CONCEPT OF

ADDITIVE CASTING®

WHITE PAPER

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ENABLE

PRINT. CAST. DELIVER.

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 first of the four components - a COVID-safe pen - and will summarise what was done, and what was accomplished.

CONTENT

PROCESS OUTLINE

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

ABOUT ADDITIVE CASTING®

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	INVESTMENT ADDITIVE CASTING	VACUUM ADDITIVE CASTING
L — ***Large parts***	M — ***Fine detail***	S — ***Ultra fine detail***
Scalable for production	***Scalable for production***	***Scalable for production***
Average complexity	***Complex parts***	***Highly complex parts***

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.

This paper will focus on a **COVID-safe pen**, manufactured with the **Vacuum Additive Casting** process.

THE COVID-SAFE PEN

This limited edition COVID-safe pen is made from a sterile material that kills viruses on the pen's surface within 10 minutes. As a component, it was one that could be produced at a large enough volume to demonstrate the scalability of Additive Casting.

This component was also chosen as one that could demonstrate the capabilities of the Vacuum Additive Casting process, a process ideal for small and intricate components with high levels of detail and complexity, and wall thicknesses down to 1mm.

There are many different kinds of ball-point pens on the market, many utilising a wide range of manufacturing methods. Some of these pens are low-cost and produced in ultra-high volumes, while others fetch a higher price and are produced in limited quantities. These higher value pens are often made of machined metal with a polished finish, requiring significant investment in tooling and labour content to produce.

Additive Casting® is another potential solution for these types of products. Ball-point pens are often highly customised, sometimes featuring branding, unique patterns and textures, etc. Each of these features requires an additional manufacturing process. Additive Casting can be used to bring mass customisation to cast metal products, and can provide a greater degree of flexibility to designers.

This ball-point pen was also produced in Silicon Brass, due to its proven antimicrobial properties.

BALL-POINT PEN SPECIFICATION

Size: 119 x 14 x 11 mm
Process: Vacuum Additive Casting
Material: Silicon Brass

"To produce this component, we utilised Vacuum Additive Casting, an offshoot version of investment casting that draws molten metal into the mould under a vacuum. This enables the production of components with wall thicknesses down to 1mm.

— Jonathan Wright, Technical Manager

PEN DESIGN

Following the typical process of scaling a design to volume, several concepts were initially produced in prototype batch quantities to evaluate the design parameters and identify which features would perform best with the process. This enabled us to understand the specific design requirements of the process when used in combination with Additive Manufacturing. E.g., Wall thickness limitations, minimum and maximum corner radii, under/over hangs, and general part complexity.

Each of the designs also featured some levels of optimisation, with some featuring organic curvature and others featuring unique texturing, that would be difficult to achieve through conventional methods without an expensive investment in tooling and much longer manufacturing times for the prototyping stages.

To further emphasize the capabilities of the process, all designs shared one key criteria: minimizing the number of additional non-cast metal components. The only non-cast components in the pens were the ink cartridge and the spring.

The mechanism responsible for linking the cap and pen body together, as well as enabling control over the write/retract positions was designed and cast directly into the bodies of the pens.

THE DESIGNS WENT THROUGH 3 KEY BATCHES:

First, an initial prototyping stage to trial 5 drastically different designs against one another.

Second, using a shortlisted selection of 3 designs, a larger trial testing 48 different variations in a single batch was run in less than 4 weeks time, which sought to identify design specifications for several key features shared between the pens and the impact of their combination with one another.

Third, volume production of 300 pens using an ideal set of design parameters identified in the second batch.

> *"The ability to test as many as 48 design variations in a single batch in as little as 4 weeks time can have a huge impact on an organisation's ability to innovate at unprecedented speed.*
>
> *Jonathan Wright, Technical Manager*

PRODUCTION PROCESS

The first batch focused on casting one off prototypes for a range of 5 unique designs. Each design varied in complexity but with overall consistent dimensions. One of each of these designs (pen body and cap) were 3D printed as part of the Additive Casting process.

The 3D printed pens were used as a pattern in our Vacuum Additive Casting process. This process was particulary suitable as it allowed us to connect multiple different pen patterns to a single casting tree to be cast in a single shot, increasing productivity and reducing waste.

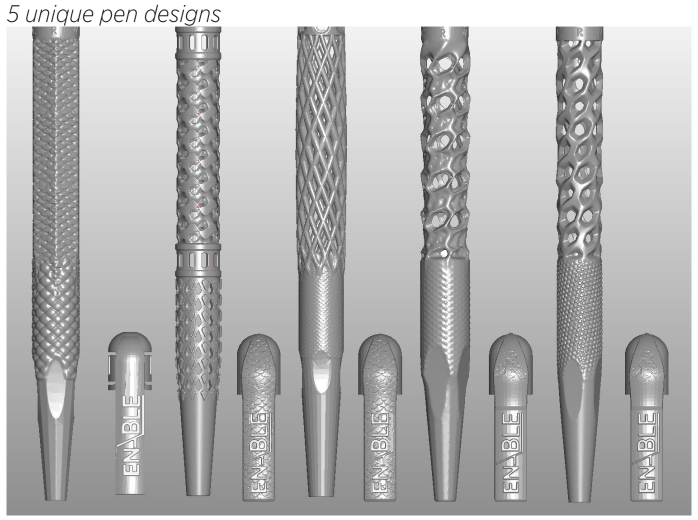
Thanks to the influence of the vacuum, the suction pulls high fluidity metals into tight, narrow cavities with a significantly lower risk of casting defects that can usually arise with narrow wall thickness castings.

After casting the pens were seperated from the tree. A small amount of cleanup was required to remove connection sprues and provide the required surface finish for an aesthetic part.

The quick turn around time of the Additive Casting process allowed us to iterate our design, to implement some new ideas and to make several improvements to our pen between the 1st batch and the 2nd batch.

With the second batch, only the 3 best performing designs from the first batch were shortlisted. Several design limitations were identified even with these best performing designs, which required further testing. Thanks to the mass customisation capabilities of Additive Casting, we were able to condense all necessary testing into a single batch.

5 unique pen designs



One-off prototypes from batch 1

The batch comprised 48 unique pens and 16 unique caps. Of the 48 pen designs, there were

- 3 major body designs
- 4 unique features were identified in the mechanism, cap, and pen nib, and 2 variations for each were determined. Each variation was then combined with all other variations to create 16 unique combinations, which were then paired with a different overarching pen design.
- The result of this was a detailed test that enabled 3 samples of each combination across all the parts within the batch, and would be able to quickly identify which combination would produce the highest throughput for volume production.

The second batch was printed in a finer resolution to the first batch to clearly show the level of detail capable of the casting process. The higher volume with this batch also allowed us to optimise the printing process for mass production, reducing wasted materials, labour and scrap rates. To aid in the tree assembly process, portions of the runner system were printed onto the ends of the pens and caps, which allowed them to be mounted quickly and with minimal risk of damage. The remainder of the casting process for this batch is the same as with the first.

The results of the second batch revealed the ideal combination of features to produce the highest throughput when moving to volume production. This design was then taken onboard and finalised before being printed in a higher volume.

To aid in the casting process, portions of the runner system were again implemented to the design prior to printing, with a few modifications thanks to feedback obtained during the second batch. While multiple investment trees were required for the full volume of pens, the high-throughput capabilities of the casting process allowed us to cast all the pens simultaneously. The post-production side of this batch took the longest however, as each pen (cap and body) required manual removal from the tree and additional finishing work to remove the runner system and properly clean. All of these components were then polished and assembled using pre-bought ink cartridges and springs to produce the final product.

Final product from batch 2

THE COST

A cost analysis for this component was performed to examine the variations in cost between Additive Casting®, DMLS, and traditional manufacture. Costs for Additive Casting® were understood through the course of this project, whilst costs for DMLS were obtained through several suppliers for metal additive parts and averaged. The final design of this component used for serial production could not be produced through traditional tooling, so these costs are not included.

It should be noted that the column for DMLS costs have been averaged across all the prices obtained for this component. The prices shown also reflect the cost for the assembly (cap and body), including post-production polishing, and the accompanying not cast or additively manufactured components (spring and ink cartridge). It should also be noted that the particular grade of brass used for this component (Silicon Brass) is not currently used in DMLS. Instead, prices for steel, aluminium, and bronze have been obtained and averaged, resulting in a non-material specific cost overview for manufacturing this component with DMLS.

Qty	Additive Casting	DMLS	Traditional
1	£223.95	£209.19	N/A
5	£70.66	£151.38	N/A
10	£50.30	£142.33	N/A
25	£35.63	£135.36	N/A
50	£33.23	£130.76	N/A
100	£31.44	£111.09	N/A
200	£30.66	£110.61	N/A
300	£29.62	£110.21	N/A

The table above shows that DMLS is an ideal candidate for manufacturing this component as a one-off. However, the cost to produce subsequent quantities remains high, whilst Additive Casting® drops substantially.

CONCLUSION

The serial production of this consumer product was designed and iterated over 2 rounds of prototyping. Utilising the unique capabilities of the Vacuum Additive Casting process to trial 5 drastically unique designs in the first batch, and 48 unique variants in the second batch, in order to identify a set of designs and features that would perform best for volume production.

The production process also identified a unique method of operating the mechanism cast in-place within the component without additional equipment, keeping the number of non-Additive Cast components to a minimum (only requiring an additional ink cartridge and spring).

A cost analysis revealed that a DMLS variant could be manufactured cheaper than through Additive Casting for a one off; however, it should be noted that the particular grade of metal used for this component (Silicon Brass) is not currently used in metal Additive Manufacturing, so some concessions would need to be made. As volume scales however, the cost to Additive Cast the serial production component dropped substantially, demonstrating the ability of the process to utilise economies of scale when producing at volume.

The manufacture of this component has demonstrated the usefulness of Additive Casting in the development and prototyping of a new consumer product that must utilise Additive Manufacturing in some form and has demonstrated the ability to rapidly prototype many different variations simultaneously. New products developed and prototyped using Additive Casting® can also be scaled up to volume production whilst utilising economies of scale to keep production costs manageable.

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