

TR501949

# Using Fusion 360 and metal AM to optimize automotive mold cooling solutions

Jack Holmes  
Autodesk

Joe Pike  
Impression Technologies

## Learning Objectives

- Discover the benefits of using additive manufacturing for the design-and-make process of more-sustainable mold tools.
- Compare the design approaches required for several manufacturing technologies, and the advantages of each.
- Assess the trade-offs of various additive manufacturing techniques when applied to the components you design and make today.
- Learn about applying the full design-to-make process using advanced design methods, simulation, and metal additive technologies.

## Description

This industrial case study will cover a recent design-and-make collaboration between Autodesk and Impression Technologies (ITL), an industry-leading, automotive, hot-forming solutions provider. Together we'll present a comparison of several mold designs across a range of design approaches and manufacturing technologies. We'll demonstrate how optimizing design for additive manufacturing can be maximized to achieve more-efficient production times and material usage, improved part quality, and reduced part cost and energy consumption. During the project, experts from Autodesk and ITL collaborated via Autodesk CFD software and the Autodesk Fusion 360 platform. We used simulation and several design methodologies, including conformal cooling and the application of lattice structures via the Autodesk Fusion 360 Product Design extension. The project culminated in the tooling production using Autodesk's Birmingham Technology Centre metal additive manufacturing systems, and testing and validation at ITL's research facility.

## Speakers

Jack Holmes:

- Technology Consultant at Autodesk, working with customers and partners across all industries to innovate on solutions
- Focus on Fusion 360 manufacturing, including subtractive, additive and machine tool connections
- [jack.holmes@autodesk.com](mailto:jack.holmes@autodesk.com)



Joe Pike:

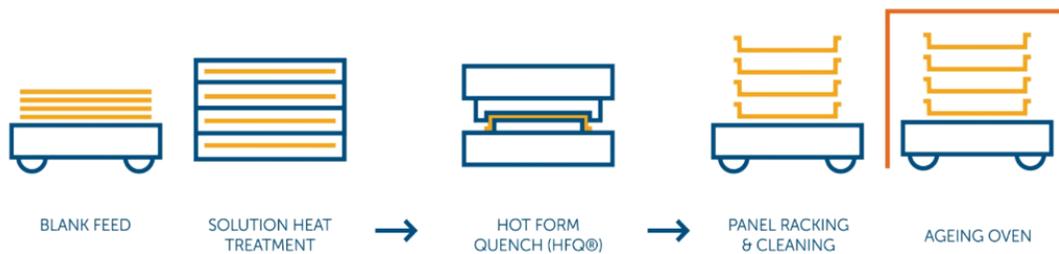
- Programme manager at Impression Technologies with experience across various automotive sectors for OEM's including Ford, Jaguar Land Rover, Bentley & McLaren.
- Lover of anything motorsport related and an avid part time field hockey player
- [J.pike@impression-technologies.com](mailto:J.pike@impression-technologies.com)



## ITL and Technology

Impression Technologies (ITL) was incorporated in 2012, and is now a global supplier of pressed body panels to the automotive industry. They have developed a process called Hot Form Quench (HFQ) to press aluminium blanks using cooled tools. HFQ is a proven scalable process similar to that of press-hardened steel.

How it works:



Typically 5-10s cycle time from sheet entering press to form & quench

ITL'S HFQ PROCESS

The benefits of HFQ are:

- > 20% reduction in part cost & tooling is typical
- 20 - 50% weight saving using UHS Al alloys
- Dimensional conformance first time
- Improved crash properties
- Lower assembly & tooling costs
- Uses standard alloys (6xxx & 7xxx) & potentially recycled

During the HFQ process uniformity of temperature distribution across the tooling surface is key in ensuring an even quench rate. By maintaining high cooling rates ITL are able to provide parts with substantially better material properties when compared to other technologies.

- ✓ Integration of front Header connection, not possible with cold forming
- ✓ Minimum bond flange width, for improved occupant vision
- ✓ Deep draw capability, not possible with cold forming
- ✓ Extremely tight internal bend radii, not possible with cold forming

Utilisation of high strength aluminium to reduce weight - circa 20% versus lower strength cold form grades ✓

Formed in a single HFQ draw operation to minimise investment ✓

Negligible springback ✓

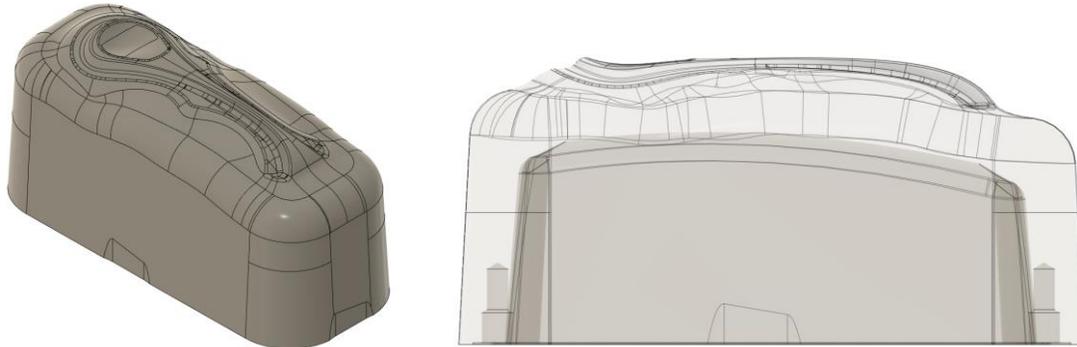
APPLIED BENEFITS OF HFQ TECHNOLOGY VERSUS COLD FORMING

### The Challenge & Opportunity

Within many industries, including automotive supply, speed and precision is the priority. To act as fast or faster than your customer puts you in a completely different place of opportunity. However, limitations in current tooling manufacture methods mean that cooled tooling can create additional timing when producing tools for manufacture. By utilising new methodologies, we can reduce tooling manufacture times as well as incorporate optimal cooling designs. HFQ has a few specific requirements, mainly to achieve high precision tooling with cooled internals and a necessity for high grade materials. The future holds many benefits for HFQ when we discuss additive manufacturing technologies and their possibilities. Autodesk are able to visualise, support in design and build our tooling. By utilising software such as Autodesk CFD and Fusion 360, we have been able to prove out our theory that future tooling manufacturing methods are suitable to HFQ. This enables us to provide faster lead times for accurate tooling with advanced cooling features. This ability will allow HFQ to be at the forefront of fast prototype vehicle structures that provide like for like capabilities compared to their production intent counterparts.

### Project Aim

The aim of the joint project between Autodesk and ITL was to investigate alternative methods for designing and manufacturing a cooled punch tool, researching best practices to be able to apply to industry applications, mainly in the automotive field in which ITL currently operates. The case study used the “bottle-opener” mould, a standard test part used at ITL, which was selected as a suitable initial component to focus on due to its smaller size and relatively simple surface geometry, as well as already having the required testing equipment in place. For simplicity, the case study focused only on the bottom half of the die.

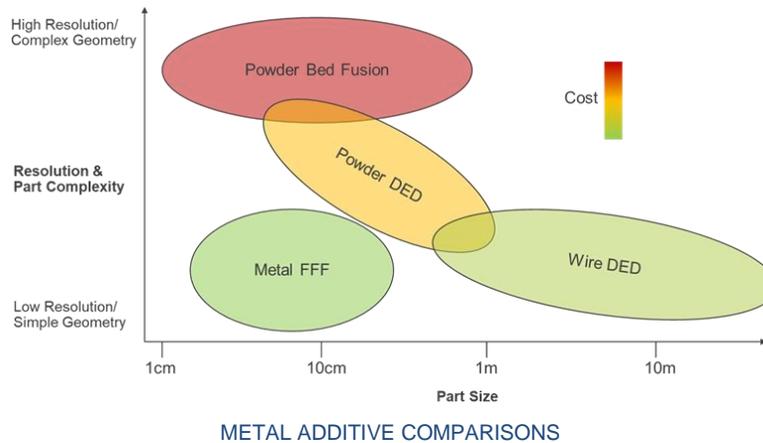


ORIGINAL BOTTLE-OPENER TOOL

This tool is used to press aluminium blanks into the form of the tool's top surface, the bottle-opener shape. These blanks require heating before being pressed in order to be shaped without causing damage to them, and must then cool again before they can be removed from the tool. To achieve this the original design is flood cooled by flushing water into a central cavity on the die component, seen above. As the directional flow of the cooling fluid is not controlled this leads to non-conformal cooling across the tool and therefore blank surfaces, which produces non-optimal material properties in the finished pressed part. It also then requires a longer pressing time in the mould than could be necessary, because the heat is not removed as rapidly as it could be, resulting in a higher energy consumption across the process. The desired outcome of the design and manufacturing investigations was to improve this tool design by using internal structures to achieve conformal cooling across the die surface, and in-turn the pressed blank, leading to improved material properties in the finished component as well as reduced time and therefore energy required for the process. An added benefit of including the internal structures and therefore partly hollowing-out the component was also thought to be reduced material usage, aiding in the sustainability improvements of the design.

### Manufacturing Methods

Two alternative manufacturing methods were identified which would allow for the production of these internal cooling structures which cannot be achieved with the more traditional method of CNC milling, which is currently utilised for ITL's die production. Both methods are based on metal additive processes. The first of these was Wire Directed Energy Deposition (DED), which uses a wire fed system heated by lasers to bond layers of deposited metal together to build up a part, similar to how common desktop plastic 3D printers operate. The second method was Powder Bed Fusion (PBF), whereby a bed of metal powder is sintered together using a laser to build up a component layer by layer. Both methods provide their own constraints and advantages, the graph below displays how they relate to each other along with two other metal additive technologies:



The main differences between the two are:

- Wire DED is lower cost, both for material and hardware
- Larger parts possible with Wire DED
- Material storage easier for DED
- Multi material builds easier with DED
- DED can build directly onto existing parts, and be used for repair work
- PBF has a higher resolution possible, meaning more complex geometry built
- PBF gives better surface finish, meaning less machine finishing required
- PBF gives better geometrical accuracy
- PBF generally has reduced distortion

To learn more about these processes you can use these resources:

- <https://www.hubs.com/knowledge-base/3d-printing/>
- [Additive Manufacturing: Understanding and Applying Key Design Considerations](#)
- [Learning Advanced Additive Manufacturing Workflows Within Fusion 360](#)
- [How to Redesign Parts for Metal 3D Printing](#)
- [Closing the Hybrid Manufacturing Loop with Fusion 360](#)
- [On-Demand, High-Rate Additive Manufacturing for Ship/Maritime Repair](#)

Because of these differences between the two selected methods, different design techniques are better suited for each. Another aim of the project was to apply different design techniques to each manufacturing method to highlight the distinctions in the process, assessing the trade-offs and associated advantages for each, and how these affect the success of the end component.

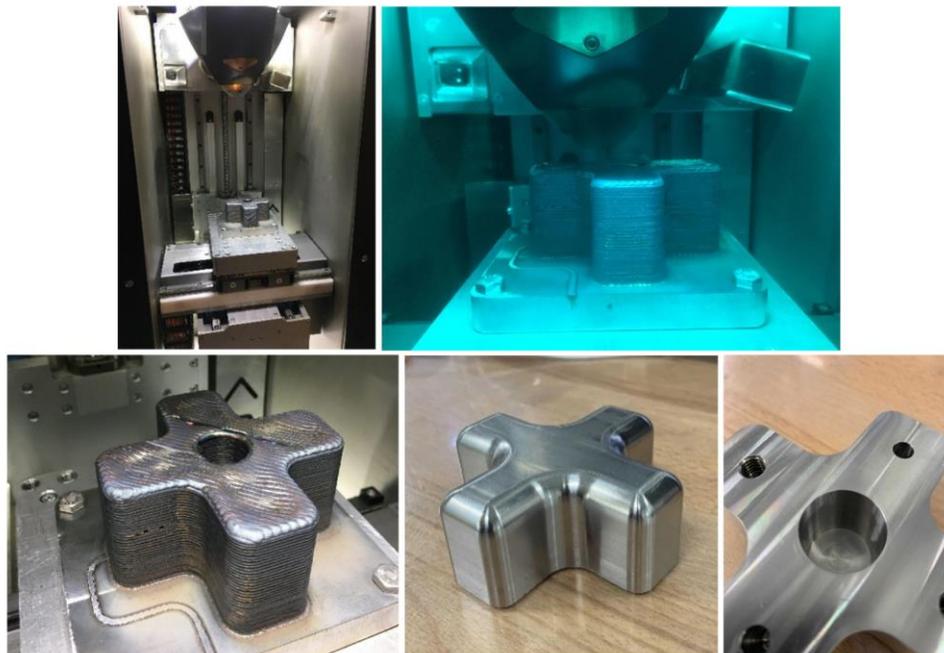
For the DED process it was decided that the design focus would be on using internal channels to aim to achieve conformal cooling, as this level of complexity was thought to be suitable for the technology, because these channels would not require too high a resolution. For the PBF component the design process was to use an internal lattice structure, a more complex design better achievable with this technology. For both end components, the cooling fluid would be pumped through these internal features with the aim of removing heat more consistently from the tool surface, so designing the features to achieve a suitable flow for this was key.

It is important to emphasise that although the case study was for a specific design with a particular industry focus, the findings and process could be applied to a variety of applications to help achieve the same production improvements. The aim was that these would also include an increased level of sustainability for the process, via the reduced material usage and power needed for each part achieved by a reduced pressing cycle time.

## Initial Testing

Before starting work on the main bottle-opener component, a test workflow was completed to ensure that the necessary material properties could be achieved using the DED process. The dies used by ITL are generally made from tool grade steel H13, however at the time of this test only Stainless Steel 316 was set up on the DED equipment available, so it was key to know how this performed. For this test workflow a simpler design was used, which was the cross-pattern part seen below, another standard test part of ITL, only non-cooled. The aim was to manufacture a like-for-like component of the original, without any of the design optimisation processes. This was manufactured using a Meltio M450 machine for the additive build, and a DMG 60 Evo milling machine to remove the excess material deposited, both located at Autodesk's Birmingham Technology Centre. From this workflow various lessons were also learnt to help with the end process on the bottle-opener component. These included defining the correct build parameters to use on the Meltio machine for the additive stage, and best practices for preparing the builds on here, such as the amount of extra material to add to the model to ensure full clean-up to finished form in the subtractive stages. From this test workflow these values were determined to be:

- 3mm excess stock on the top surface
- 2mm excess stock on the side walls
- 5mm excess stock on bottom of part, to account for removal from build plate



CROSS-PATTERN BUILD

The end component was then tested at ITL's research centre on their smaller press, and used to press multiple heated aluminium blanks. The results from this showed that the material performed as well as standard tooling, coping well over multiple hits and blanks, and therefore was suitable to continue to be used for this research and development stage.

## CFD Simulations

The initial stage of working on the bottle-opener tool consisted of a series of simulations, utilising Autodesk CFD software. This software can be used to simulate heat transfers over time in a defined setup, therefore it could be used in this case to firstly assess how the original design performed in regard to providing conformal cooling in the current pressing process, and from these findings how it might be improved. This gave the team a better understanding of the operation of the tool, and how and where to apply the design changes. Following this, the same simulation constraints were then used to assess how these various design iterations performed, to give an indication if the desired improvements were being achieved and help lead to further iterations. Using this method, the best design from those available could be selected to be taken forward to the manufacturing stage.

In order to get reliable results from the simulations it was key to have as accurate inputs as possible. ITL had data available related to how the component would be used in operation. This included the heat transfer coefficient at various temperatures and pressures which the die would be subjected to during the forming process (seen below), the initial blank temperature (500 degrees Celsius) and the cooling fluid temperature (21 degrees Celsius).

	Contact pressure (MPa)		
Die temperature (°C)	5	10	20
25	3112	3263	3560
100	2866	3034	3210
200	2468	2656	2890
300	1995	2112	2360
400	1563	1736	1863

HEAT TRANSFER COEFFICIENT DATA

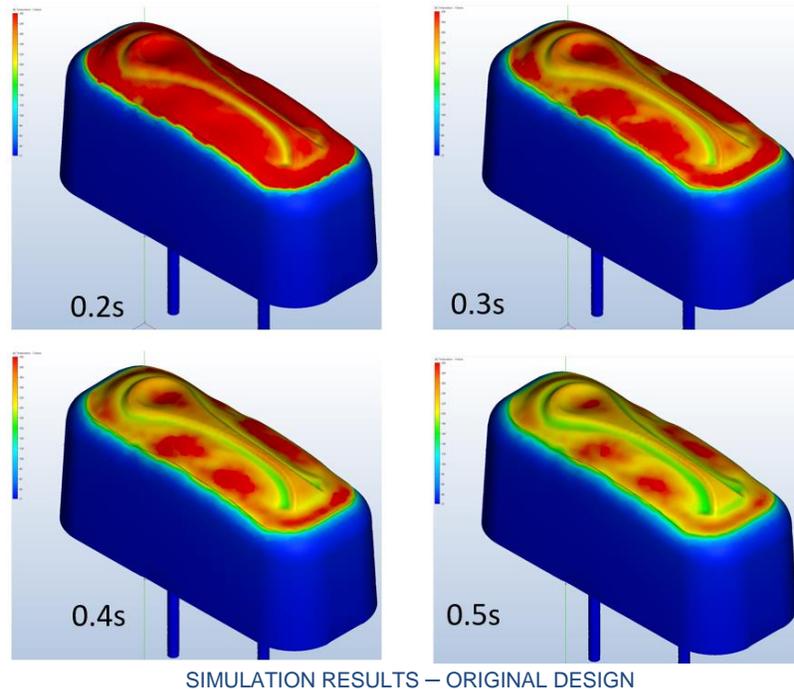
With these in place a template model for the simulations was created, which could then be applied to the various designs to ensure they were all under the same conditions. For each design two scenarios were simulated, each consisting of two sets of simulations ran.

The first scenario was for when cooling flow has been established throughout the mould and the very first blank is stamped. The first simulation for this was a steady state flow analysis to reach convergence, which was then followed by the second simulation to include heat transfer from the initial blank temperature of 500 degrees Celsius.

The second scenario was for when multiple blanks have been stamped and the mould has reached a steady state temperature. The first simulation for this was a steady state including heat transfer using a constant average power input from the tool surface, which was run until convergence. This was then followed by the second simulation which stopped the average power

input and instead set the initial temperature of the blank to 500 degrees. The conditions at the end of this simulation were then what the tool would be under in full production, so the results of these were the most useful to look at.

The results for these end conditions of the original design can be seen below:



These results are most easily interpreted by looking at the colour gradient differences across the surfaces, which indicate any non-conformal cooling. It can be seen from this that the original design does produce non-conformal cooling, as there are obvious differences in the colour gradient. For example, by looking at the centre of the bottle opener shape it is displayed as consistently much hotter than the other key surfaces, seen by the remaining red patch in the images. This indicates a higher temperature than the surfaces surrounding it, especially as the time increases. As a key area of the die this is something which was a focus to address. A similar pattern can be seen in the surrounding areas of the top surface, shown by other red patches remaining. Although these surrounding areas are less crucial, an optimal design would still remove these inconsistencies and one colour gradient would be seen across the entire top surface. These simulation results therefore gave a good indication of the areas needing more controlled cooling, which guided the team when making the design edits.

## Design Iterations

As discussed previously, two different designs were planned to be created, one better suited to DED technology and one to Powder Bed Fusion. The initial CFD simulation results helped to guide these design changes. All design work was completed using Autodesk Fusion 360.

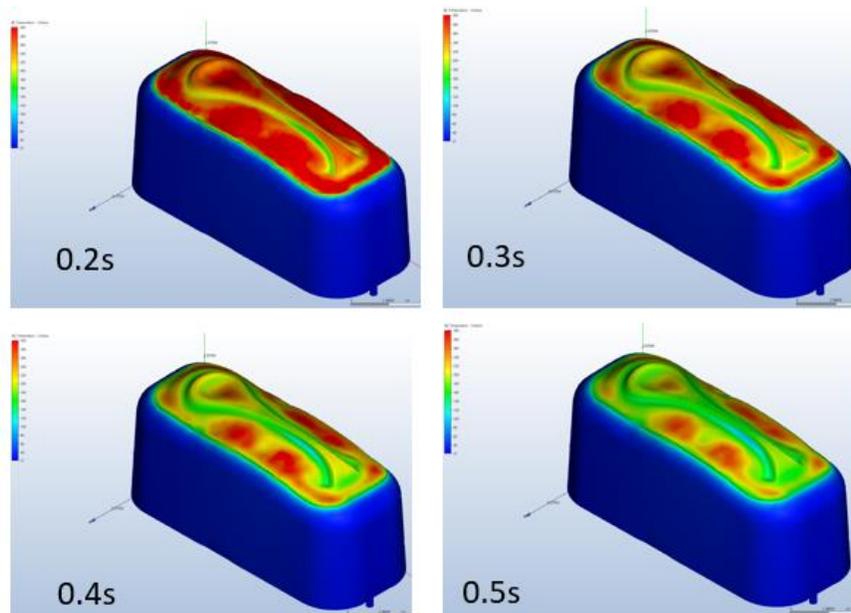
## DED Designs

Looking at the DED design first, an initial version of the conformal cooling channels was modelled, with a central channel following the shape of the “bottle-opener” main surfaces.



DED DESIGN 1

This was then run through the same CFD simulation process used for the original design, to check for improvements. The end results for this are shown below:



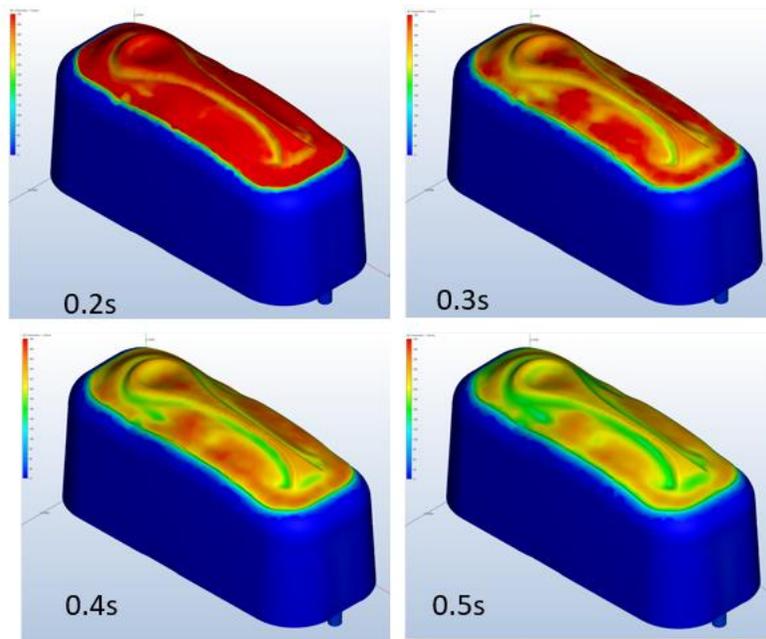
SIMULATION RESULTS – DED DESIGN 1

It can be seen from these results that this design iteration would perform slightly better than the original in certain areas. Across the main surfaces of the bottle-opener geometry itself the heat transfer is more consistent, shown by less of a gradient change displayed (mostly all in green). However, the centre of this area still showed a difference in gradient, with a similar red patch seen as in the previous simulation, and there is still a variation seen across the rest of the surface.

To aim to distribute the heat better still another iteration of the design was modelled. This time a cooling channel consisting of five branches, one central and two more either side, was used. By spreading the channels across the width of the tool the theory was that this would remove heat from a larger area and therefore provide more conformal cooling. A CFD simulation was run again on this design:



DED DESIGN 2

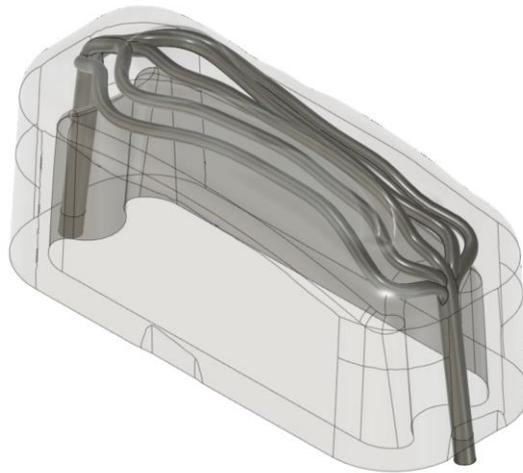


SIMULATION RESULTS – DED DESIGN 2

These results show a much more uniform distribution of the heat than seen in the previous designs. Looking at the final image, there is more of a consistent gradient over the entirety of the top tool surface, and the patch within the centre of the main pressing surfaces is much less present. This would provide an environment much closer to conformal cooling. Looking at the 0.5 seconds image, as the colours displayed are further towards the lower end of the scale (more

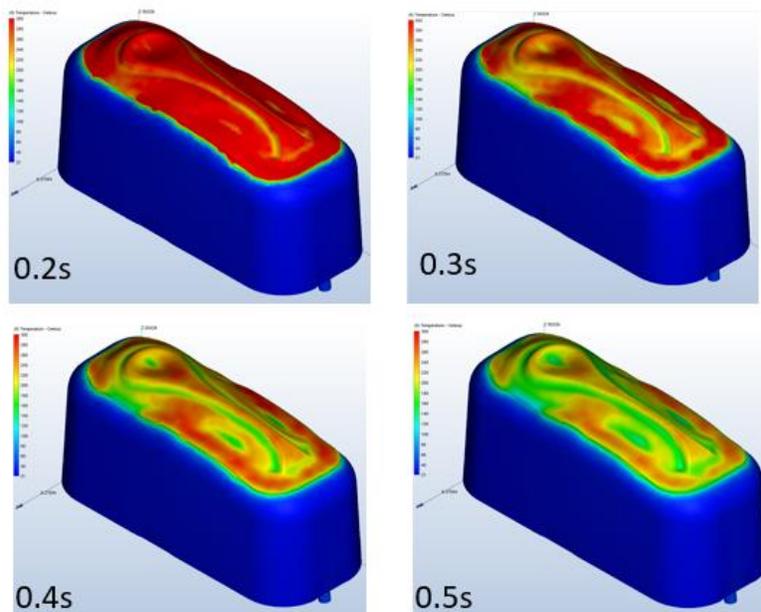
towards yellow and green than red), it also indicates that the tool surface would be cooler at this point in time when compared to the previous designs. This means that not only would cooling occur more evenly, but also at a faster rate which is another desired effect.

Another iteration to aim to improve the design further was then created. This involved a mixture of the two previous iterations – multiple channels spread out across the width of the part, with the central channels following the main geometry of the tool, and one channel directly through the centre:



DED DESIGN 3

Again a CFD simulation was run to compare:



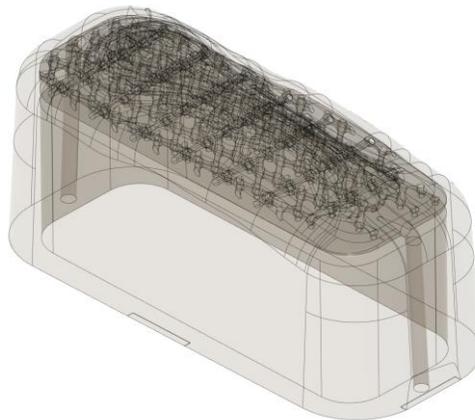
SIMULATION RESULTS – DED DESIGN 3

These results show that this iteration would actually perform worse than the previous, as displayed by the patchier gradient of colours. This was most likely due to the non-uniform distribution of the channels themselves, with some following the geometry of the upper surfaces and others following a more general path.

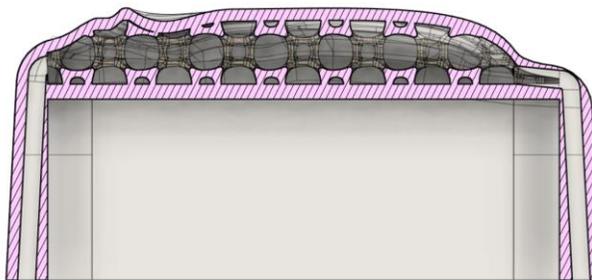
At this stage, with limited time available for the project a decision had to be made on which design to carry forward. With more time the iterative process of design change and simulation would have been continued, and likely a further optimised design could have been found, but it was deemed enough progress was shown for this initial stage. Therefore, DED design 2 with the five channels was selected, as this provided the best results from the simulations in terms of producing conformal cooling across the tool surface.

### Lattice Design

Following the conclusion of the DED design, the powder bed fusion design which would utilise an internal latticed structure was worked on. For the initial version of this an Autodesk research technology, Alpha Centauri was used, an in-development tool for turning solid models into a lattice. A cavity was modelled below the surface of the tool and this used as the space for the lattice. This initial design is shown below:

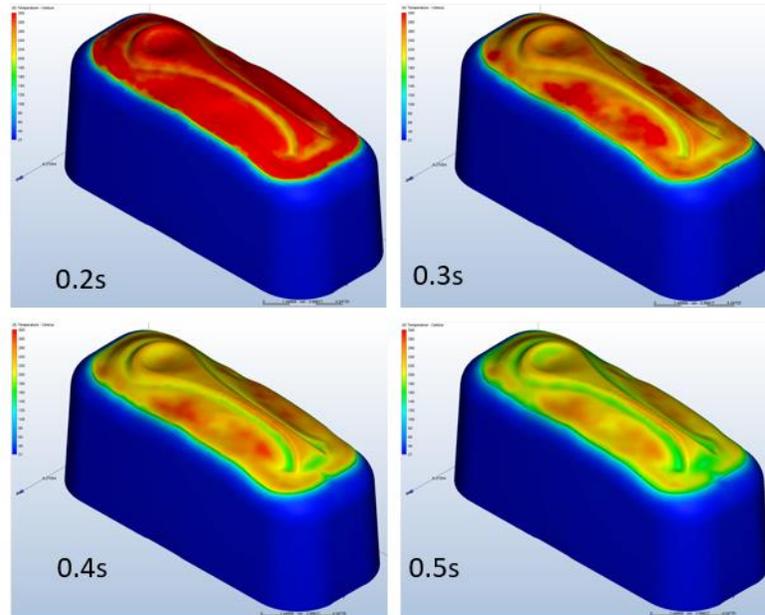


LATTICE DESIGN – FULL VIEW



LATTICE DESIGN – SECTION VIEW

Like with the other design iterations this was then passed through the CFD simulation setup:



SIMULATION RESULTS – LATTICE DESIGN

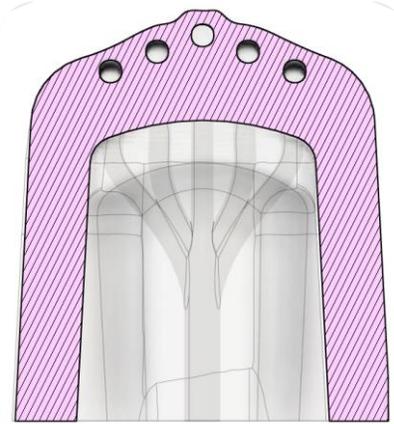
It can be seen that this lattice structure is fairly effective in producing conformal cooling, displayed by a relatively uniform colour gradient across the surface. The key pressing surfaces are quite consistent, and the red patch displayed in the original design is not present, showing a definite improvement.

Due to the fact that the exact lattice design used, i.e. size and orientation, would need to be adjusted for manufacturability reasons anyway, and because the simulation results had shown that a lattice across the surface was of a benefit, no further iterations of this design were created at this point.

## Manufacturing of DED Designs

### Build Preparation

Before the selected design for the DED process could be taken through to the manufacturing stage some design changes were needed to make it more suitable for the process. The main concern of using the existing design up to that point was the amount of internal overhanging surfaces within the cooling channels. With almost all additive processes, surfaces which are not built on top of the material below or out at a shallow angle will need supporting with material that is removed after the build and is not part of the final component. The issue in this case is that the majority of these surfaces were located within the internal channels, which would not be accessible to any tool to then remove supporting material. This can be seen in the cross-section of the design below which shows the circular profile of the channels, the top of which contain overhanging regions due to no material supporting them underneath.



CROSS-SECTION SHOWING OVERHANGING CHANNELS

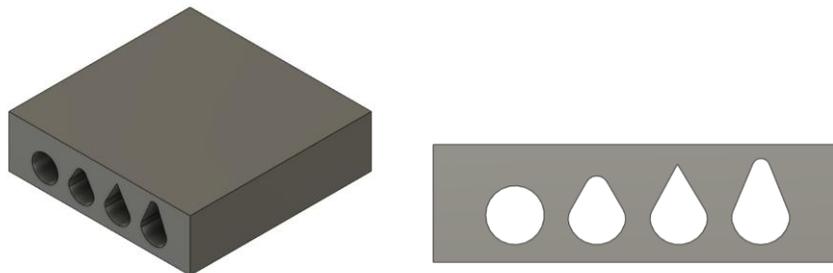
To get around this issue the plan was to edit the geometry of the channels, from a cylindrical surface used in the initial designs to a “teardrop” shape, which tapers towards a point at the highest position of the geometry to remove the worst of the overhanging surfaces.

To help find the best geometry to use for these edits some physical test pieces were run on a DED capable machine at the Autodesk Birmingham Technology Centre. The images below show the geometry modelled in Fusion 360 versus the results from the DED build.

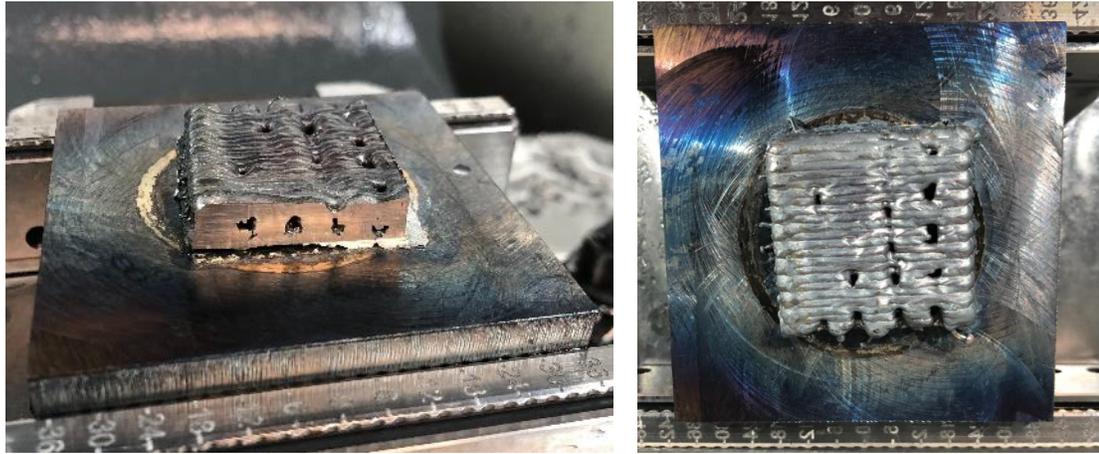
### Test Piece 1:

From left to right the channel profile geometries are:

- 5mm radius circle
- 5mm, 60 degree overhang to radius
- 5mm, 60 degree overhang to point
- 5mm radius, 45 degree overhang tear drop to radius



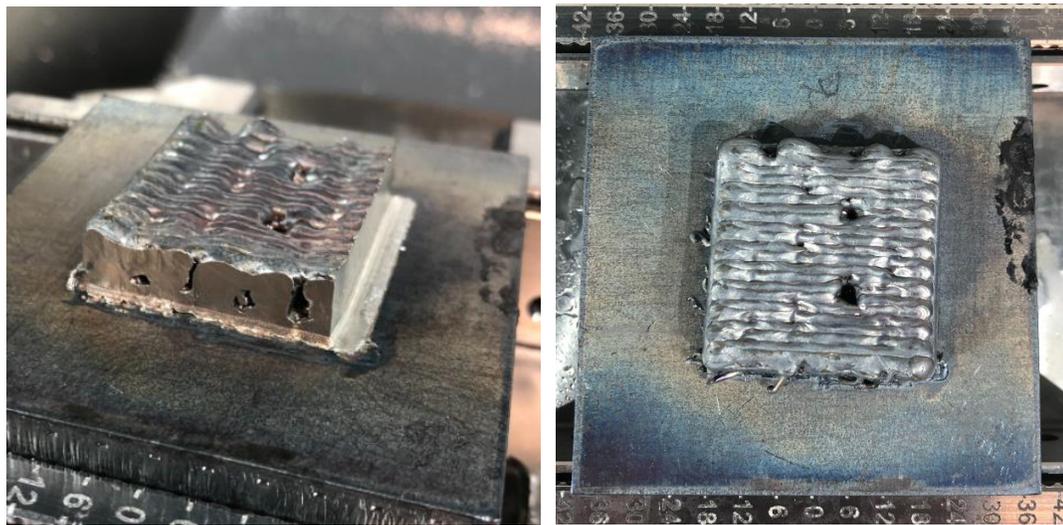
TEST PIECE 1 CAD MODEL



TEST PIECE 1 BUILD RESULTS

### Test Piece 2:

Geometries are the same as Test Piece 1, only difference is “Perimeter” setting was used for toolpath options within Fusion 360.

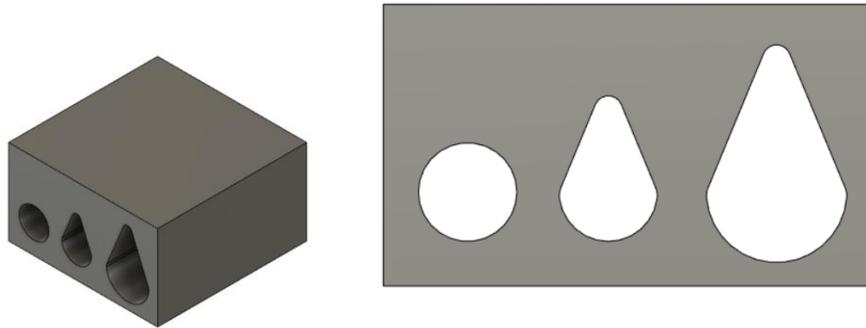


TEST PIECE 2 BUILD RESULTS

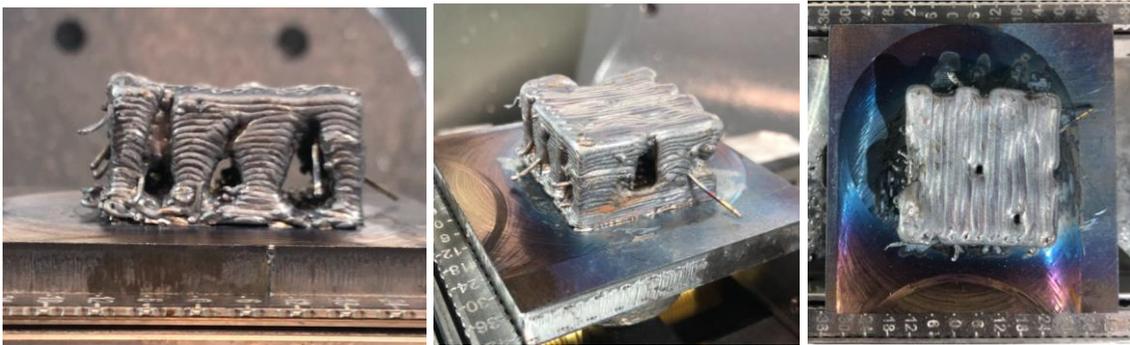
### Test Piece 3:

From left to right the channel profile geometries are:

- 7mm radius
- 7mm radius, 45 degree overhang to 1mm radius
- 10mm radius, 45 degree overhang tear drop to 1mm radius



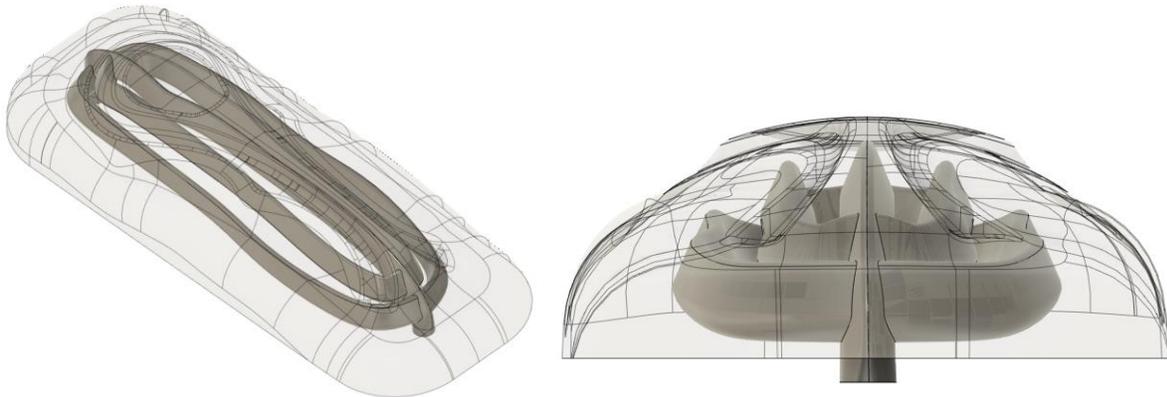
TEST PIECE 3 CAD MODEL



TEST PIECE 3 BUILD RESULTS

As can be seen there were high levels of deformation in most of the geometry types built, and porosities in the material on the top surface where material had dropped below, because there was not a solid enough surface below to deposit onto. This led to some of the channels being sealed over, especially the 5mm radius channels of various geometry types and the 7mm circular channel. This sealing over would make them non-functional for the punch tools intended applied use, as the cooling fluid could not flow through sufficiently. It was also found that the 45 degree tear drop shape built better than the 60 degree shape, as would be expected with less of an overhang angle. The 7mm and 10mm tear drop shapes built the best, being the only geometries to have a clear channel through. The 10mm was the most clear, but did have issues with the side wall build creating a porosity, as can be seen in the image above.

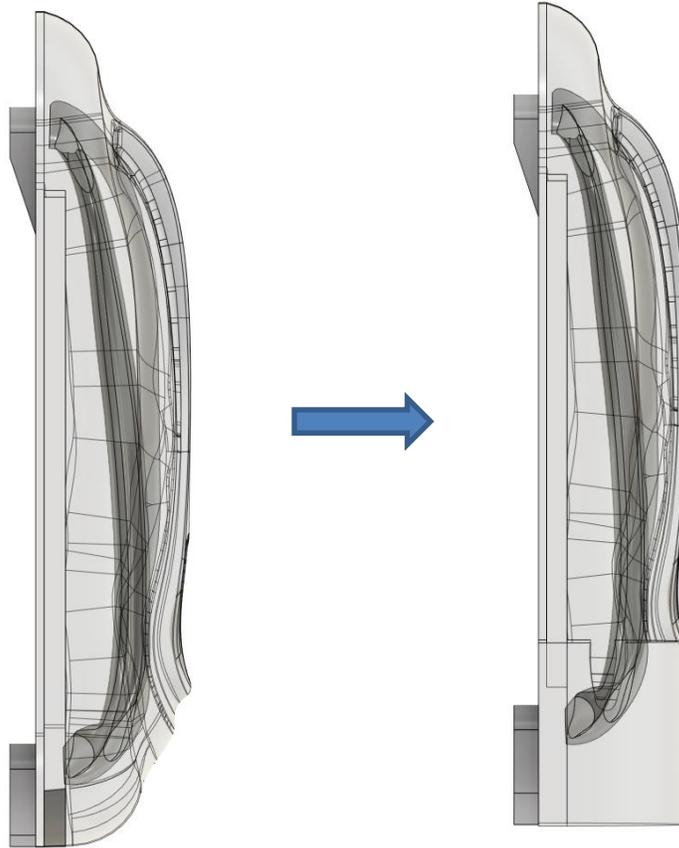
It was decided to use a 7mm tear drop shape with 45 degree overhang angle for the final design, as this produced the second best results behind the 10mm version, but was of a more appropriate size to be used within the bottle-opener design to still be able to place the channels close to the top surface. The model was edited in Fusion 360 to use this geometry for the cooling channels in the sections with an overhang.



#### DED DESIGN EDITS

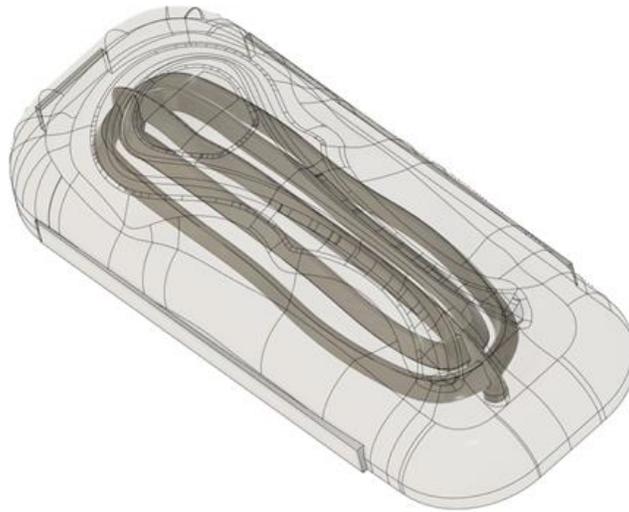
Further design edits were made to prepare it for manufacturing. As can be seen in the images above, the part was split into two to only build the top section. This was to firstly make the manufacturing of the build a quicker process, as it would vastly reduce the time taken to build as well as carry out the post-build subtractive finishing by machine tool. It was also seen as a method for using less material for the end tool, as only these surfaces at the top of the part were key, so a more cost-effective piece could be used for the lower section. When used in full production this would also mean if the punch tool became worn or damaged, rather than replacing the entire tool only this top section would need replacing. This would again reduce the material usage at this stage, as well as mean a new tool could be available quicker by simply building on demand when needed, without a lengthy lead time associated with larger parts or other manufacturing methods.

The model was also edited to prepare it to be built in two alternative orientations. These were; in the horizontal orientation with the large flat surface connected directly onto the build plate, and in a vertical position with the part built up from one end. The reasoning for this was to test which orientation would build best. Both options had their own advantages and disadvantages, the horizontal version would have more overhanging sections within the channels due to them running along the length of the part but would be better supported on the base, and the vertical version less supported but also with less internal overhangs as most of the channels would run vertically up the part. The differences modelled for the two versions accounted for the different locations of these overhanging sections, adding the “tear-drop” shape where needed for each.



#### VERTICAL BUILD DESIGN EDITS

Finally, for both versions excess material was added to the models to overbuild the size of them, to ensure that enough would be deposited to machine back to the final form for a full “clean-up”, meaning no un-machined deposited material would remain. Both models also had extra strips of material added to give a flat edge on each side and at one end, which would be used to clamp the deposited part for the subtractive machining stages. Following this, the vertical orientation model also had extra material added towards the bottom of the part where material would be deposited directly onto the build plate, to remove the external overhangs in this region, which can be seen in the images above.



EXCESS MATERIAL AND STRIPS ADDED TO MODEL

With these edits the models were then ready to be programmed, using Fusion 360 to create the DED toolpaths. These used the perimeter setting and other build parameters found to work best from the test piece stage outlined earlier.

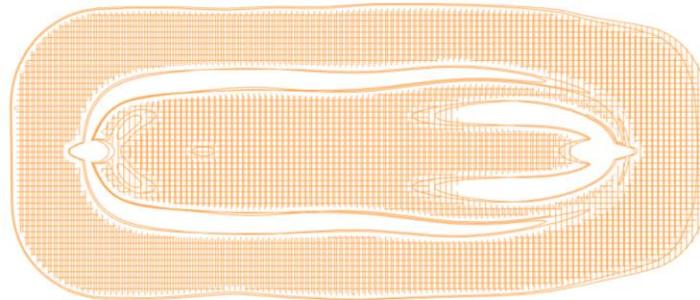
Due to the size of the part and the orientations, the two design versions were built on two different machines. The horizontal build was done on a Haas UMC-1000 Hybrid machine, utilising a Meltio additive head attached, whereas the vertical build was done on a stand-alone Meltio M450. This was because the part in the horizontal orientation would be too wide for the build plate of the M450, and the Haas had a larger build area. It also had the advantage that as it is a hybrid machine the subtractive machining stages can be carried out in-situ, using the same setup as the additive build. However, this is more of a development machine and therefore not quite as reliable in the build quality and consistency compared to the M450.

### **Build of Horizontal Design**

The horizontal setup build on the Haas was carried out first. This build had a lot of issues, as can be seen in the images below. There were very high levels of porosity present, caused mainly by the large amount of overhanging sections along the channels within the design, which ran the majority of its length. This increased the likelihood of the build failing in these areas, which clearly has occurred. These porosities were also caused partly by the amount of stops and starts of the tool with short moves required to pass over the channel geometries, which in places led to the material dropping into the cavity or not depositing correctly once starting again on the other side. An image of the DED toolpath is shown below displaying the cavities for the channels at which these issues occurred.

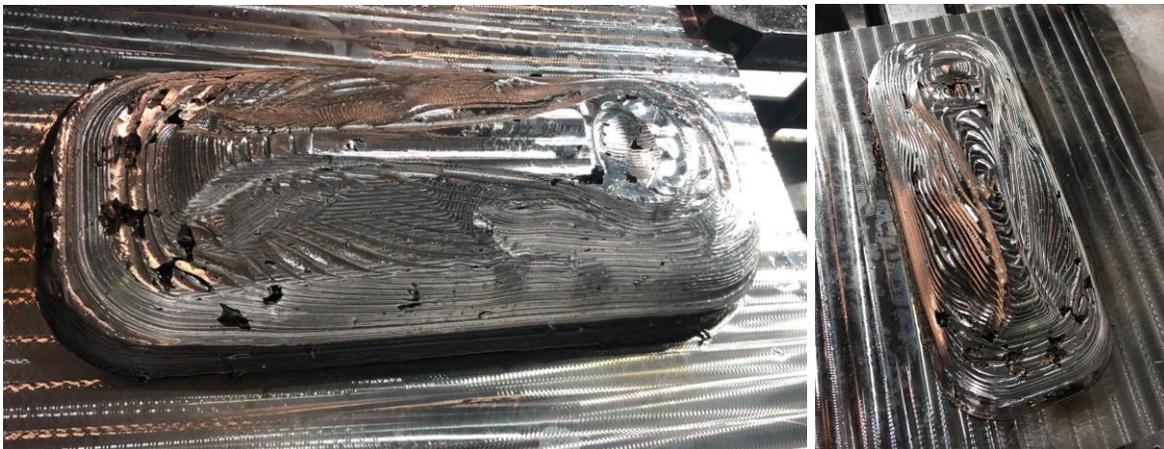


HORIZONTAL BUILD



DED TOOLPATH

At points the build was stopped, the material machined back by a couple of layers, and then the build restarted from that height to try to resolve the porosity issues, but it was found there were too many to fully avoid. The finished build was partly machined back to check if the porosities were just on the outer surface of the deposit or went down to the finished part, which generally they did, also seen in the images below.



MACHINED DEPOSIT SHOWING POROSITIES

This was a good test of whether this technology combined with the design method and orientation used was suitable to manufacture this part. Due to the large levels of porosity, any cooling fluid flowing through the tool would not stay internal and instead would exit out of the holes at the surfaces, meaning the part would not be suitable for its intended application. Therefore, it was concluded with the current setup the process was not suitable. Although the part was not a success it was still very useful for the project team to know what does and doesn't work best, and being able to exclude this process for the time being is an outcome in itself. With further design edits and process changes it could be possible to build a similar design in this way, but currently with the time available these further tests have not been completed.

### Build of Vertical Design

The vertical build was then run, which provided much better results. As seen in the images below, the surface finish was a lot better than the previous build, with much fewer porosities. This showed that having less areas with internal overhangs greatly helped the build. There were however some small patches of porosity present, but these only seemed to occur on the outer surface and not penetrate through to the area of the tool's final form.



VERTICAL BUILD RESULT

On the back surface especially, there was a lot of excess wire protruding from the part. This is caused by the wire falling off the part at the perimeter when it does not get properly melted by the lasers. This indicates that the build conditions were perhaps not optimal, and the material not deposited exactly as it should, which could have led to some of the porosities seen. Overall it did not seem to affect the build quality much though. Finally, it can be seen that about halfway up the build that it shifted over slightly to one side. It could not be determined what had caused this, but could have been linked to these small deposition issues. Either way this shift was relatively small so it was hoped that it would not affect the internal channels and the outer surfaces could still “clean-up” in the subtractive stage.

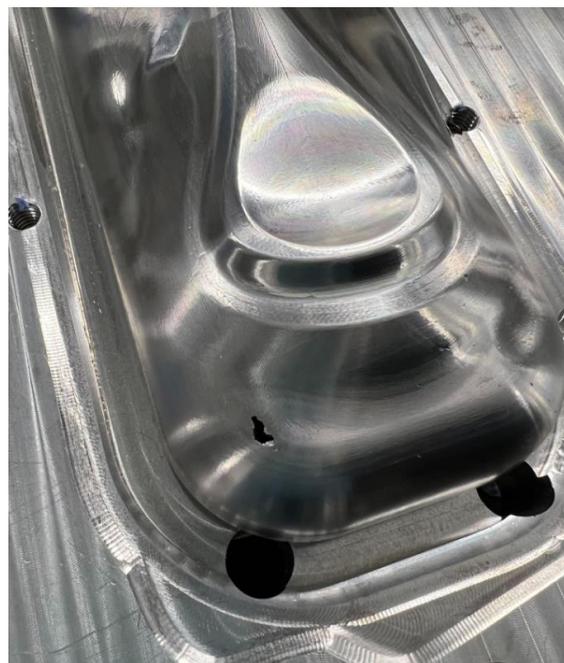
The final point to note about the build is the layering effect seen in the build direction, as part of the nature of the build process. ITL stated this was actually of a benefit to them, as even after the subtractive machining stage these layers would remain on the microscopic level, which aids with trapping the lubrication on the tool during its end use. This deposit was then moved forward to this next stage of subtractive processes, which unlike the horizontal build needed to be carried

out on a different machine. This did mean that more time was needed to set up the part on this separate machine, which was a drawback of not using the hybrid machine.

Once this work had been completed however the end result was much better than the previous build, the finished part can be seen below. This time the part cleaned up very well producing a great finished surface. It was not a perfect deposit as there was one area of porosity present, seen on one of the corners, but this was only at the surface level and not on the key pressing surfaces so not too critical.



MACHINED VERTICAL BUILD



POROSITY IN BUILD

This build was a clear improvement over the horizontal version, proving that it was possible to get a successful end part produced using the cooling channels design technique in combination with the DED manufacturing technology, but setting these up in the correct way was crucial.

The finished part was then passed over to ITL for testing at their laboratory.

## Latticed Design

### Design Edits

The alternative design being investigated utilised the internal lattice structure, to be manufactured with Powder Bed Fusion. This also required some design edits to prepare it for manufacture. The first thing that was done, like the DED design, was to split the model and only look at building the top section consisting of the actual pressing surfaces. Doing this had the aim of providing the same advantages, namely a reduced build time, reduced material usage, and removing the need to replace the full tool in production. The model was split at the same height as the DED design, and the inlet and outlet points for the cooling fluid placed in the same positions, so that the same lower section could be used for both parts during testing. Again this reduced the necessary material usage throughout the process.

The internal cavity to be converted to the lattice structure was then remodeled for this upper section, as the geometry varied slightly from that in the full part. With this in place the lattice could be created. Some modifications were needed to this from the design used for the CFD simulations, to create a lattice better suited to the manufacturing process. The original contained many overhanging sections due to the type of lattice used, which would likely cause the build to fail. Instead, a lattice was needed that could be self-supporting. This time the Volumetric Lattice tool, part of the Product Design Extension available within Fusion 360, was used to create the lattice. This was because the lattice options given with this tool are better suited for additive processes.

Several lattice options were created using the tool to find one that seemed best suited for the manufacturing process, in terms of its size, orientation and location, to be able to support itself and the surfaces above it. The lattice shown below, displayed within the punch tool, was the option selected. This was due to the "X" like shape meaning it could support itself as the part was built, its size making it suitable for the process and to allow the cooling fluid to flow through, and its position within the cavity so that it provided support to a good amount of the surfaces above.

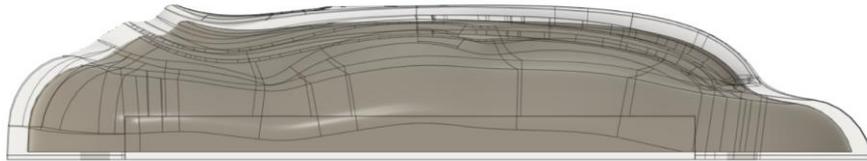


FINAL LATTICE DESIGN - SIDE VIEW



*FINAL LATTICE DESIGN – FULL VIEW*

Similar to the DED design, excess material was added to the model to ensure clean-up in the post-build subtractive stage. Not as much material was needed for the powder bed process due to the higher resolution and reduced distortion achieved, which also helped with reduced material usage for the process. Finally, flat edges were added to each side to help clamp the part during subtractive machining.



*PBF READY DESIGN – EXCESS MATERIAL MODEL*



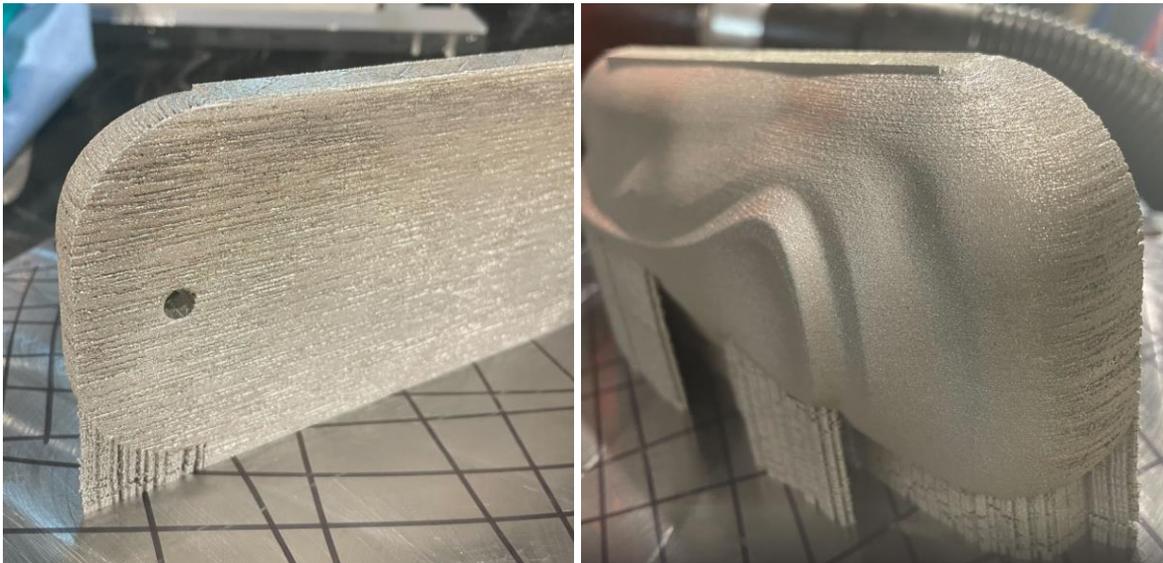
*PBF READY DESIGN – SIDE STRIPS*

With this the final design was ready to be set up for the build. To do this Fusion 360 was again used to create the toolpath and the external supporting structures. The output from Fusion 360 was then ran on a PBF Mazak machine at Autodesk's Boston Technology Center. The build was an overall success, the results of which can be seen below.



PBF BUILD RESULT

There were some small issues with the build quality, where some areas of the powder had not sintered together correctly, seen in the images below. This was thought to be due to a slight misalignment of the lasers on the machine. The issue only occurred in certain places so it was not thought that it would affect the end part too badly, and it was hoped it would still machine without problems. This was the reason for adding the excess material on.



SINTERING ISSUES

This deposit was then removed from the build plate and moved to another machine to carry out the subtractive machining stages. Similar to the vertical DED build some work was needed to locate the part and set it up ready on the machine. The full process was then completed successfully, producing the finished part.



PBF FINISHED PART

The end part was a great result. The deposit machined very well, producing a nicely finished surface with no porosities or other issues present at all. In this way the process was more successful than the DED build. This end part also proved that the combination of the lattice design technique and PBF manufacturing technology was a viable option for creating these kinds of tools. The finished part was then handed over to ITL for testing.

## Conclusions

The project is currently up to the point explained so far, with the two alternative designs manufactured and awaiting testing with ITL. Unfortunately without the full testing results it is difficult to say exactly how well each has worked, but there are certainly some findings and conclusions from the work carried out so far. We have learnt a few lessons of what has worked best for the investigated application.

Going through the CFD simulation steps at the start seemed to work well, as it gave us a good idea of how to edit the design to achieve the end result, rather than simply going ahead with a design we thought would work best, manufacturing this and then discovering it did not give the improvements we hoped for. However without the testing we cannot know how well the reality matches up with the simulations and our expectations of the designs.

The DED manufacturing stage proved much less successful with the horizontal version of the part compared to the vertical build. This was due mainly to the amount of overhangs in the channels with that orientation causing the build to fail. We found from this that when planning to manufacture a part like that using DED the setup is very important, and the orientation should be thought about carefully to avoid overhangs as much as possible.

One reason many of these channels failed is because their design was most likely not optimized as much as possible. If we had more time we would have carried out more tests beforehand to try to find a channel design which would stand a much better chance of building successfully. A lesson from that would be to invest more time in initial testing stages to find what works best before going to manufacture the end part.

Although the vertical build was more successful it still was not perfect, as there was the noticeable porosity present on the finished surface. How much this affects the end result will need to be determined during the testing at ITL. Apart from that issue we have shown however that it is possible to get a working result using this method, and as seen earlier Wire DED is a more accessible solution in order to achieve this result.

At the same time we also proved that the Powder Bed Fusion technology is another suitable solution, as we were able to get out a working result using this, and one which was actually better in terms of surface finish. Again we saw earlier that PBF is a less accessible solution, but it could be that the benefits provided make it worth the extra cost. The testing results will again be required to help with this decision, but simply from the surface finish achieved on the two end parts it would appear that PBF would be the preferred technology.

## Next Steps

As mentioned, the key next step is first certainly to test the finished parts at ITL's site, to see how well they perform. Depending on the results we may iterate the designs again and remanufacture if needed. If this was to happen we would use the lessons learnt from the work carried out so far to try to avoid the same issues.

From Autodesk's perspective we will also continue carrying out tests to find the best process for creating the overhanging geometry with the DED technology. More test pieces will be built to aim to optimise on these, and possibly incorporate this design into the bottle-opener to achieve a more successful DED build.

For the lattice design manufactured we went with what seemed the most suitable, as we could not run a complete CFD simulation on this due to issues with the amount of triangles in the mesh. Next steps to aim to improve this are to carry out tests in the software to find the best lattice structures to use for heat transfer, and from these which are the best suited to powder bed manufacture, and therefore which would be the best to use in this design or a similar application. Again depending on what is found in the testing stage, both of the physical part and this software based testing, we may edit the design and create another to improve upon it.

For ITL the testing will first consist of pressing aluminium blanks using the two tools, then laser cutting these into shape and running tensile tests on the material to allow the ITL technical team to quantify the difference and advancement in final material properties. With this information they will be able to compare each process versus the benefits given. Following this they will have a better understanding of which of these techniques they would want to implement into full industry applications. When it comes to working on these, during this project we have proven that the theory works on a small scale, but hardware developments may first be needed to allow for use on the scale needed for ITL's production components, both in terms of size and cost. While they wait for these they are confident that prototype projects will be in a position to have significant timing reductions whilst maintaining critical material characteristics, to allow HFQ to be delivered within prototype timing to production standards.