Conformal Cooling and Heating Channels using Laser Sintered Tools

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1 Abstract

The EOS Direct Metal Laser Sintering (DMLS) and DTM Rapid Steel 2 processes may be used to create tools incorporating conformal channels behind the tool surface through which fluids may be passed. To date, a significant amount of work has been carried out to investigate the efficiency of using conformal channels to cool tools.

This work suggests the use of conformal channels to both cool and heat a single tool. This may appear self-defeating at first but the selective nature by which conformal channels may make this a worthwhile means of generating hitherto unavailable thermal conditions within a tool. Such conditions may then allow the successful production of geometries which had previously been impossible to mould.

2 Background

2.1 Conformal Cooling Channels

The subject of conformal cooling channels has been a focal point for a large amount of research and published case studies in the field of Rapid Tooling.
In terms of pure research, a number of academic institutions have published results from practical experiments and modelling work.
Research at the University of Lowell (USA) investigated the positions of cooling channels in terms of their distance from the tool surface using stereolithography (SL) tools for injection moulding. The cross sectional shape and features designed to induce turbulent flow were also assessed. This research showed that the use of conformal cooling channels in SL tools could reduce temperatures by 170 deg F (77 deg C) (Janczyk et al 1997). Further research at De Montfort University (UK) has suggested that the low thermal conductivity renders conformal cooling channels redundant in SL tools (Colomer 1998 and Hopkinson 1999).
Work performed at MIT showed that infiltrated steel tools produced with conformal cooling channels using the 3D Printing process resulted in cycle time reductions up to 15%. The same body of research showed that reductions in part shrinkage of 37% could be achieved with these tools using a standard cycle time (Sachs et al 1997).
Further research from MIT investigated modelling the expected performance of conformal cooling channels and produced a systematic method to aid the design of cooling channels (Xu et al 1998).
The ExpressTool^{TM} process was shown to reduce cycle times by 40% when using conformal cooling channels in electroformed tools (Macdonald 1998)

2.2 Conformal Heating Channels

Despite the widespread work on conformal cooling channels there appears to be little reported work regarding the use of conformal channels to heat a tool. Work at Leeds University (UK) has shown how conformal heating channels can be used to improve processing conditions in the moulding of elastomer compounds (Delgarno et al 2000). It seems logical that the use of conformal heating channels could be used successfully in other manufacturing processes which rely on thermal curing such as compression moulding and reaction injection moulding.

2.3 Layer Manufacturing Technology used in this research

The DMLS bronze process uses a laser to directly sinter metal particles layer by layer and the layer manufactured part is subsequently infiltrated with epoxy resin. This process has the significant advantage over processes such as Rapid Steel 2 in that no furnace operation for polymer burnout, sintering and infiltration is required. The DMLS process does however require higher temperatures during the laser sintering stage.

A consequence of the differences between DMLS bronze and Rapid Steel 2 may be thought of as a “law of conservation of difficulty” issue; Rapid Steel 2 requires careful processing and thought in the post laser sintering stages whereas with DMLS bronze it is the laser sintering stage itself which requires the closest attention.

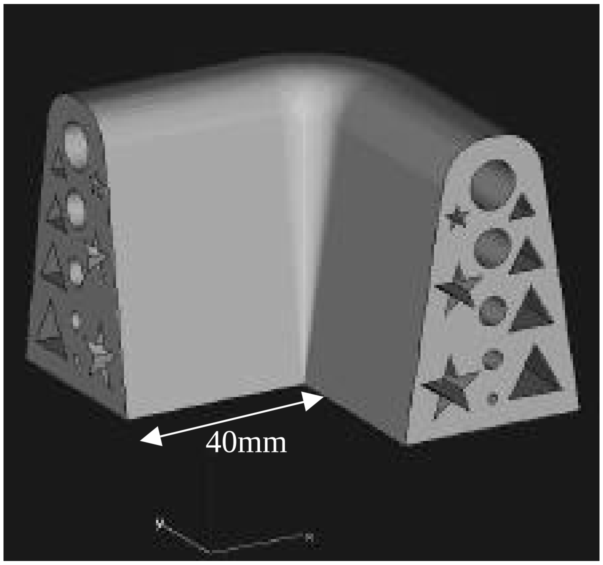
3 Methodology

The aim of this programme of research is to investigate the possibility of using the DMLS bronze process to manufacture tools with heating and cooling channels and then to assess the performance of the tools. The first task is therefor to assess the types of geometries which can be built; having established the geometries which may be made it will then be possible to build tools and assess their performance. For comparison, test parts were built using DTM’s Rapid Steel 2 process.

3.1 Design of conformal heating and cooling channels

Figure 1 shows the STL file for a test part to assess the manufacturability of conformal channels of different cross sectional shapes and sizes. The reason for building channels of different sizes was to assess the minimum size of feature which could be conformally cooled. The different cross sectional shapes were built as these would offer increased surface area for heat transfer (especially in the case of the star shaped channels) and easier manufacturabilty (in the case of the triangular shaped channels).

Figure 2 shows the STL file for a test part to assess how easily loose powder could be removed from the layer manufactured model after laser sintering. In this part, longer channels with two right angled bends were used and again different cross sectional areas were included.



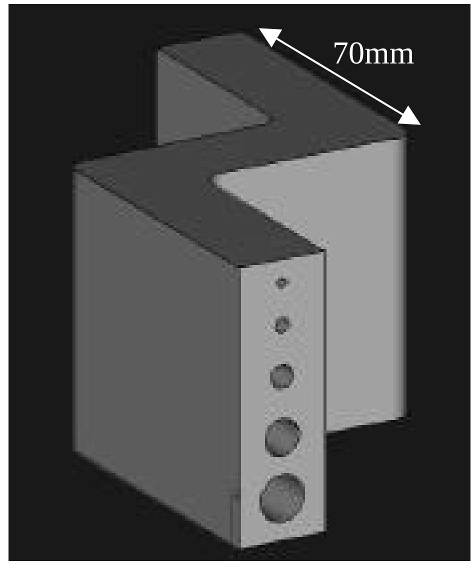


Figure 1. STL file for part to assess different cross sectional shapes and areas

Figure2. STL file for part to assess longer channels

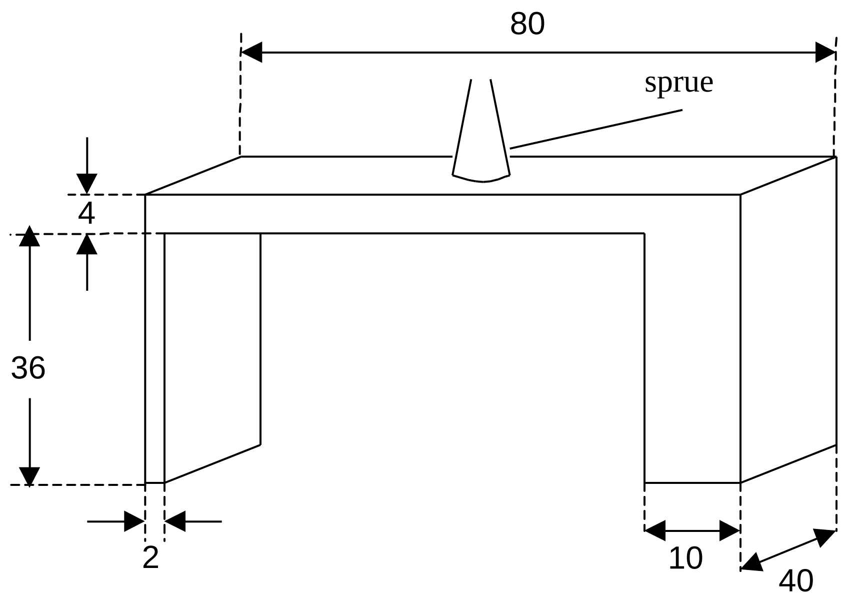
3.2 Assess improvements in moulding quality

Figure 3 shows the design of the initial test moulding which was intended to assess how a tool with different wall thickness performs. The test tool was intended to assess firstly how the thinner wall section could be filled during injection and then to see how effective packing pressure could be applied – especially in the thick walled section which would be likely to show sink marks due to in-mould shrinkage. Finally, the test tool was intended to see how the variable wall thickness, with varying cooling rates, would be affected by warpage.

4 Initial Results

4.1 Manufacture of Conformal Channels

Figure 4 shows the conformal channel test parts built using DMLS bronze with different channels lengths, cross sectional areas and cross sectional shapes. The two smallest diameter (2mm and 4mm) channels remained blocked with un-sintered powder after laser sintering. In the larger channels the loose powder was easily blown away with compressed air; these parts were not infiltrated with epoxy resin.
The star shaped and triangular channels showed some crack propagation at sharp corners however these could probably be sealed with epoxy infiltration. The star shaped channels showed considerable delamination on downfacing surfaces suggesting the need for redesign, possibly using supports.



All dimensions in mm

Figure 3. Initial Test Moulding Design

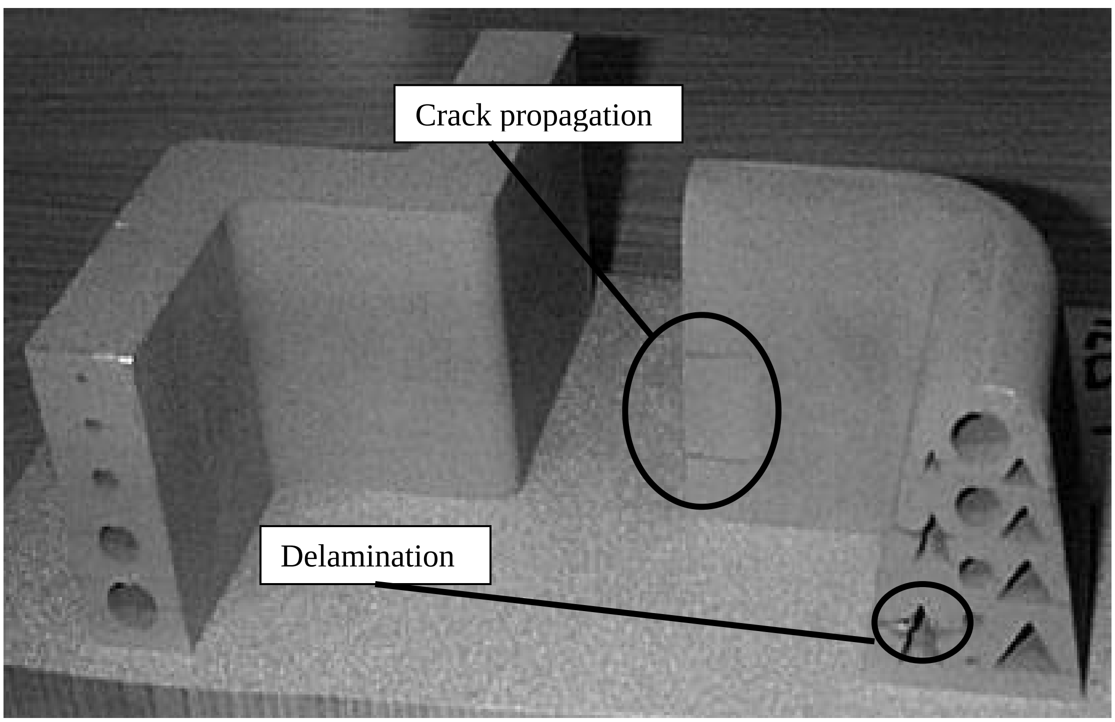


Figure 4. Conformal channel test parts built by DMLS after loose powder removal

Figure 5 shows the conformal channel test parts built using Rapid Steel 2. The test part with the long channels shows a hole where the green part broke while compressed air was used to clear loose powder in the 8mm diameter channel. Only the largest (10 mm diameter) hole remained unblocked. The different shaped cooling channels were built with no major difficulty although again, only the larger channels could be cleared of their loose powder.

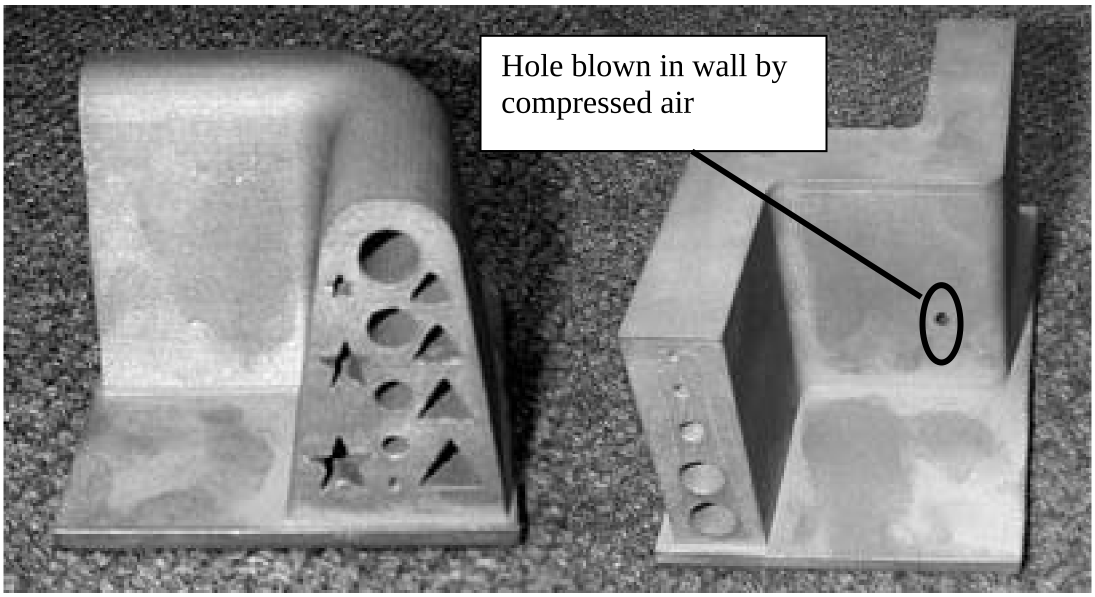


Figure 5. Conformal channel test parts built by Rapid Steel 2 after loose powder removal.

4.2 Manufacture of a test tool

Figure 6 shows a sectioned picture of the STL file for the test tool core. The core includes two 10mm diameter conformal channels intended for cooling fluid around the 10mm thick wall and two conformal channels intended for heating fluid around the 2mm thick wall.

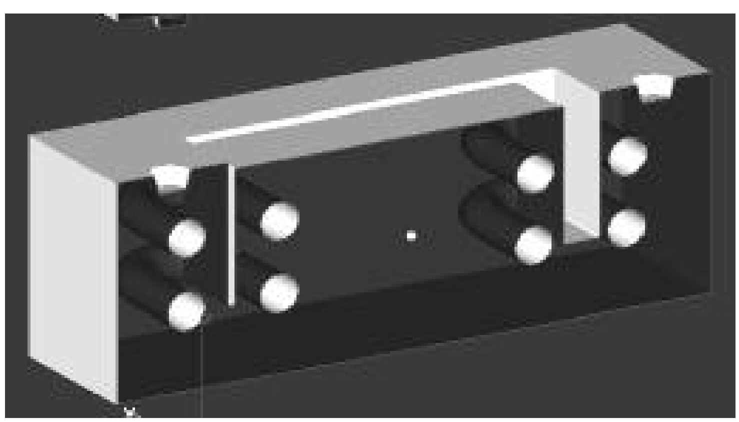


Figure 6. Cross sectional picture of the STL file for the test tool core

Figure 7 shows the core and cavity halves of the DMLS tool used to mould the test parts after it had come off the laser sintering machine and prior to infiltration with epoxy resin. This was the only tool used as a Rapid Steel 2 version was not built

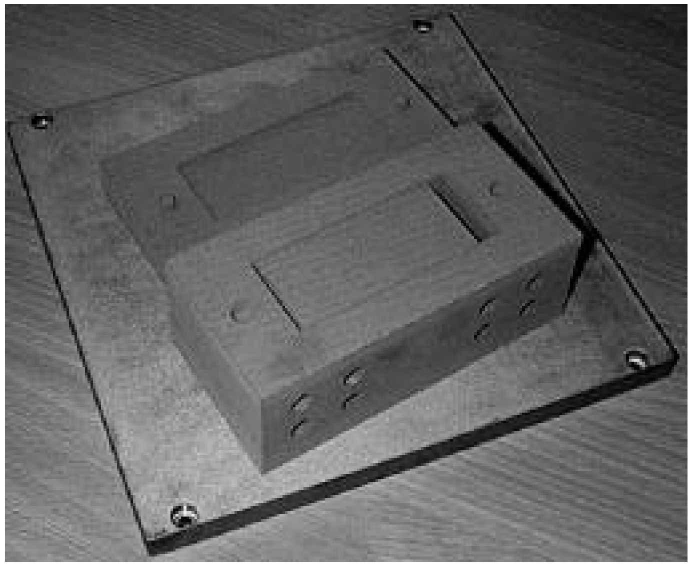


Figure 7. The test tool core and cavity

4.3 Moulding trials with the test tool

After machining to allow for a sprue bush and fixing to a bolster, the DMLS tool was infiltrated with epoxy resin to seal its surfaces. The tool was then mounted on a 60 ton Battenfeld injection moulding machine and injected with polypropylene. Figure 8 shows a short shot with the thin section filling less readily that the thick section. The short shot, which had no follow up pressure applied was also subject to more warpage.

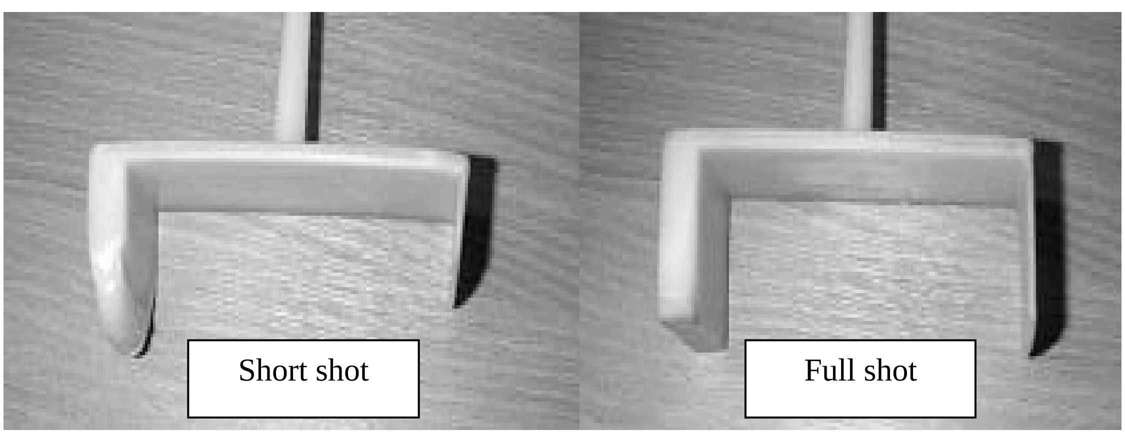


Figure 8. A short and full shot from the test tool

The conformal channels were not connected to heating or cooling fluids however thermocouples were located on two of the surfaces of the conformal channels. One thermocouple was used to measure the surface temperature inside the cooling channel next to the thick moulding wall section and one used next to the thin moulding wall section. These thermocouples were intended to monitor the amount of heat generated at the surfaces of the channels from the two different wall sections. Parts were injected at temperatures of 170 degrees C and 270 degrees C to assess how this affected the heat generated at the edges of the conformal channels. Figure 9 shows the temperature rises after injection of the melt in the two channels using the two different injection temperatures.

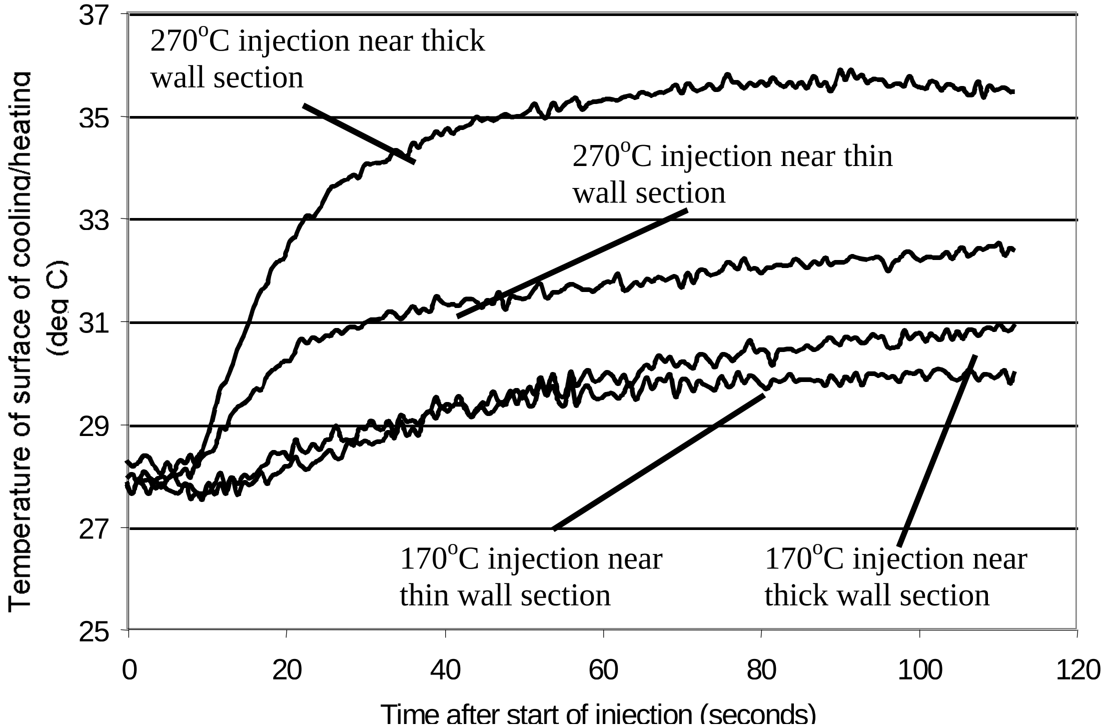


Figure 9. Surface temperature readings from the inside of the conformal channels

Figure 9 shows that higher temperatures were recorded when injecting with a hotter melt as expected. Higher temperatures were recorded close to the thick wall section than the thin wall section as the thick section had more heat to dissipate. The actual rises in temperature however appear quite low when compared with previous work (Hopkinson, 1999); this may be due to the fact that the thermocouples were pressed against rather than embedded into the surface of the channels. Also, the effect of epoxy infiltration may result in the tools having a low thermal conductivity but a high specific heat. If the tools have a low thermal conductivity and high specific heat it may be difficult to achieve desired temperatures inside them however it should be relatively easy to maintain temperatures without too much fluctuation.

5 Conclusions and further work

The EOS DMLS bronze process may be used to build injection moulding tools with conformal heating/cooling channels with some restriction on their geometry. In particular horizontal unsupported downfacing edges are susceptible to delamination and sharp corners can lead to crack propagation. Circular channels may be built and other shapes such as triangular and possibly fractals may be built to achieve different levels of heat transfer.The tools may be used for injection moulding however they must be sealed as they are porous after sintering.

The slow thermal response measured in the heating/cooling channels suggests that a large amount of energy may be required to achieve desired temperatures throughout the tool; however, if achieved, these temperatures should be relatively easy to maintain. The next step to assess the thermal control will be to run tools with thermocouples embedded within the tool and then to run the tools with heating and cooling applied.

The test moulding was produced relatively easily so further designs, perhaps with thinner sections, should be built to assess mould filling, the efficacy of packing pressure and warpage due to variable wall thickness.

6 References

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