

# PRODUCTION TOOLING FOR POLYMER COMPONENTS VIA THE DTM RAPIDSTEEL PROCESS

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## **Abstract**

This paper reports the results of a study examining the potential of layer manufacturing processes to deliver production tooling for polymer manufacture, with the DTM RapidSteel process used to provide the tooling. Four main areas were addressed during the study: wear, mechanical strength, accuracy, and productivity, with each area examined through analytical studies and industrial trials. An overview of the results from both the analytical and in company experimental studies are presented.

## **1. Introduction**

The use of layer manufacture technologies to generate prototype tooling for polymer manufacturing processes is now established as an appropriate and effective method of generating product and process information in product development. Production tooling represents a further challenge for layer manufacturing technologies, and the work reported in this paper is part of an industrially supported study to examine the scope for production tooling for polymer processing to be generated using layer manufacture, with the specific layer manufacture technology used the DTM RapidSteel process. Four main areas will be considered: accuracy, strength, productivity and wear.

## **2. Accuracy**

The studies related to accuracy have considered bulk accuracy and surface finish, and the accuracy and manufacturability of features.

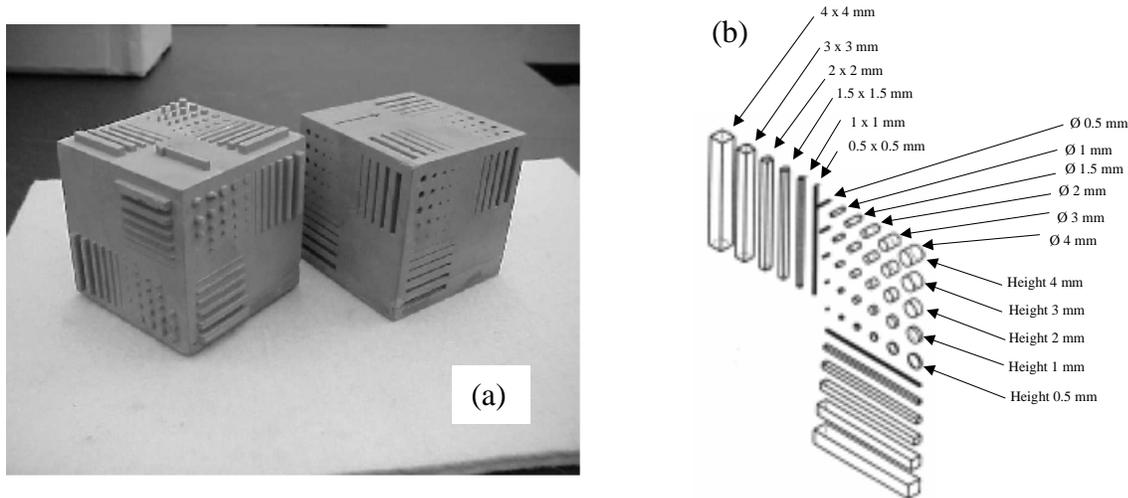
### **2.1 Bulk Accuracy and Surface Finish**

The bulk accuracy of tools has been assessed through the manufacture and measurement of a range of components and tools. Initial studies with the RapidSteel 1 material showed this material to be generally accurate to within  $\pm 0.2$  mm in the horizontal plane of build, but, as a result of differential shrinkage and vertical consolidation in the resin infiltration/drying phase, to be much less accurate with regard to the height of components, which could be millimetres out. With RapidSteel 2 this problem has been overcome and components will generally be accurate to within  $\pm 0.2$  mm in all directions, with large flat horizontal faces the most common exception to this rule. The surface roughness of RapidSteel 2 components after infiltration is typically in the range 6-10  $\mu\text{m}$   $R_a$ .

### **2.2 Feature Manufacturability**

The ability of the RapidSteel process to generate features was of interest from two points of view. Many mould tools incorporate small positive and negative features and the degree to which these could be formed with the RapidSteel process was clearly of interest. In addition the ability of layer manufacture processes to generate conformal channels in tools was of interest with regard to productivity (see section 4), so the limitations on channel geometry needed to be understood before conformal channels could be designed into tools.

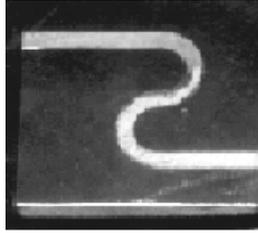
Figure 1 shows the test blocks which were used to characterise the ability of the process to manufacture small positive and negative features. A family of features, made up of a number of bars and cylinders, and shown in Figure 1(b), was defined and applied to a 80 mm cubic block. The feature set was the same for the positive and negative feature blocks, and an example of each is shown in Figure 1(a). The manufactured blocks were then measured to determine what features the process was capable of manufacturing to within the  $\pm 0.2$  mm range identified above as the bulk accuracy figure.



**Figure 1 - Test Blocks to Assess Small Feature Accuracy**

For RapidSteel 1 the conclusion from this study was that any feature with a dimension less than 4 mm would not generally be accurate to within  $\pm 0.2$  mm. For RapidSteel 2 the conclusion was that any feature with a dimension less than 2 mm would not generally be accurate to within  $\pm 0.2$  mm.

Figure 2 shows one of a number of test blocks which were manufactured to assess the extent to which channels in the tools could be manufactured. Blocks were manufactured to assess the diameter, length and complexity of channels which could be manufactured. For RapidSteel 1 the conclusion drawn from working with the blocks was that the minimum practical size of cooling channel which could be manufactured was of 5 mm diameter, however, the recommended size of cooling channel (for relatively easy powder removal) was 8 mm. In general the complexity and length of the channels which could be created was limited by poor powder flow characteristics. For RapidSteel 2 the same limitations in terms of diameter were found (5 mm minimum, 8 mm recommended), but the improved flow characteristics of this powder meant that the complexity of channels which could be manufactured increased markedly. To date we have found no limit in terms of the complexity which can be manufactured, given an 8 mm channel diameter. An important factor to be taken into consideration when considering the manufacture of channels is the part weight. Clearing powder from channels is much easier where the green part is of a weight which allows it to be manipulated by hand, and can become difficult when the weight of a component exceeds that which can be lifted by one person.



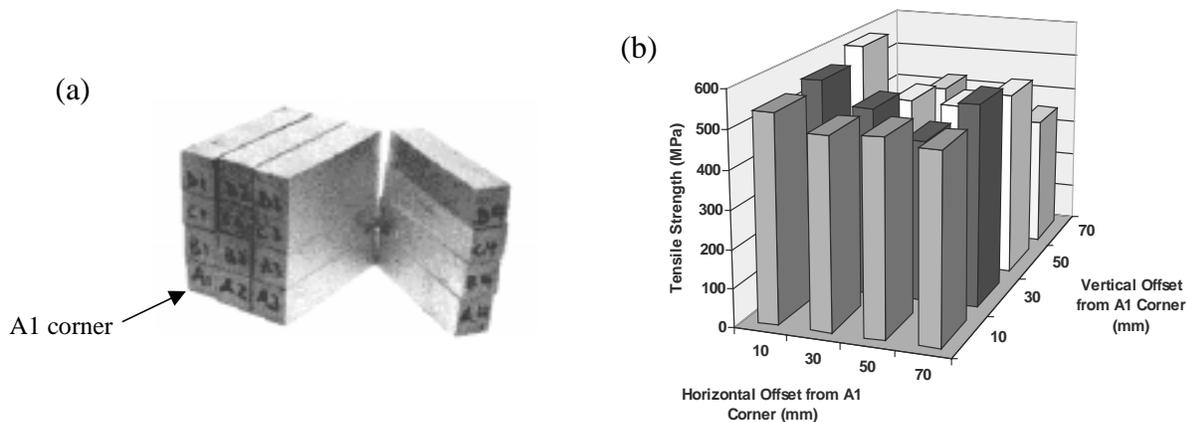
**Figure 2 - Sectioned  
"S" Channel Test Part**

### **3. Strength**

Strength was of interest from two points of view; the strength of the RapidSteel material itself, and the extent to which the strength of mould tools would be undermined through the use of conformal cooling channels.

#### **3.1 RapidSteel 2 Material Properties**

We have previously reported [1] on variations in the tensile strength of samples cut from RapidSteel 1 blocks, which showed that, the further away from the point of infiltration within a block a piece of material was, the lower its tensile strength would be, with the tensile strength varying from 500 MN/m<sup>2</sup> to 180 MN/m<sup>2</sup> within an 80 mm cubic block. This effect was believed to arise as a result of microporosity within the block. Figure 3 shows the results of a similar test carried out with the RapidSteel 2 material. The samples cut from the 80 mm cubic block shown in Figure 3(a) were subsequently machined to cylindrical dumbbells for tensile testing, and gave the strength results shown in Figure 3(b). The tensile strength results show little variation in the horizontal plane, but there is still some reduction in strength evident with an increase in height in the block. The relatively even results in the horizontal plane are thought to be a result of infiltrating from all round with RapidSteel 2, rather than from one point with RapidSteel 1. Taking this into account the results broadly echo those from the study with RapidSteel 1, with the strength reducing with distance from infiltration point, but infiltrating from all around components clearly restricts the effect in the horizontal plane.



**Figure 3 - Variation of Tensile Strength through a block of RapidSteel 2 Material**

#### **3.2 Mould Tool Strength**

The effect of positioning channels close to one another within a mould tool was investigated using finite element analysis. An idealised tool geometry with a range of cooling channel configurations was modelled to assess whether or not any significant stress concentrations arose

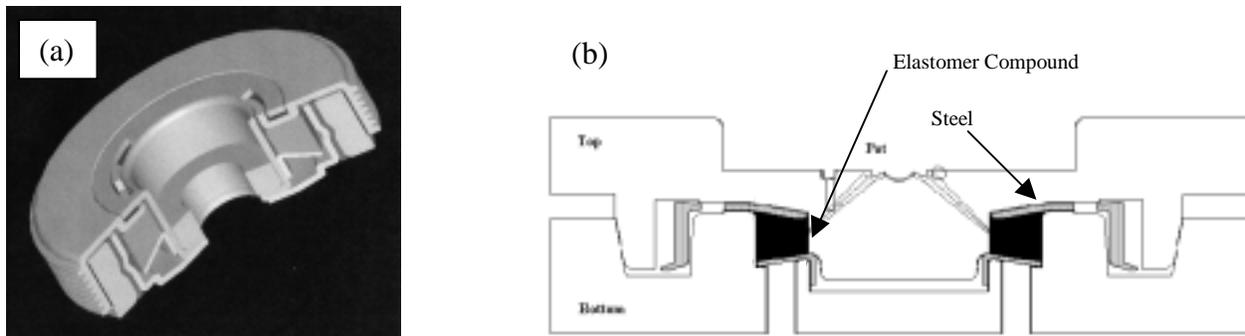
as a result. Given that mould tools must have channels the aim of this piece of work was to ensure that conformal cooling/heating channels (which follow the tool surface), would not give rise to greater stress concentrations than necessary. The conclusion from this piece of work for circular channels was that as long as channels were separated from adjacent channels by at least a channel diameter, and were at least a diameter from the tool surface, then no additional stress concentrations would occur.

#### **4. Productivity**

A major element of the research programme was an examination of the productivity benefits which could be gained through the use of conformal heating/cooling channels in polymer moulds. This was investigated through three case studies, one elastomer compound transfer mould tool and two plastic injection moulding tools.

##### **4.1 Transfer Mould Tool - Damper Pulley**

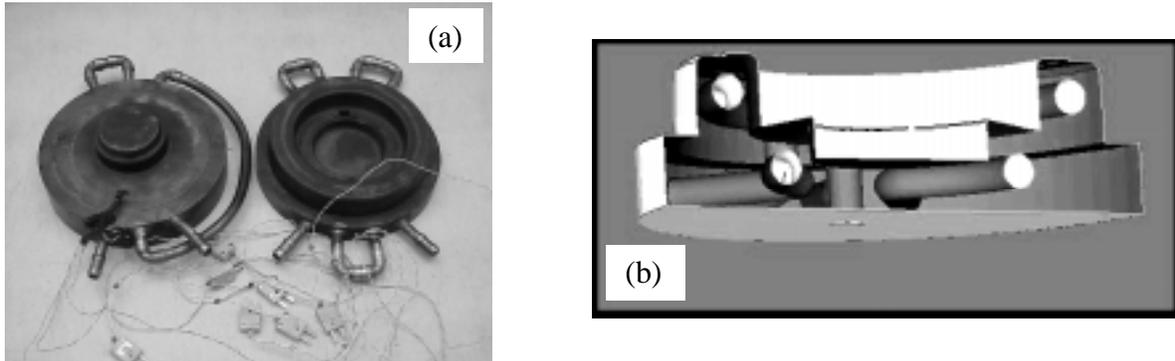
The transfer mould tool case study was based around the manufacture of part of an isolation pulley, shown in Figure 4(a), with a cross section of the tool and the moulded component shown in Figure 4(b). This component is manufactured for Peugeot by Simpsons International (UK) Ltd.



**Figure 4 - (a) Isolation Pulley, and (b) Transfer Tool and Moulded Component**

In conventional transfer moulding the heat to cure the elastomer compound is normally provided through electrical platens above and below the tool, and using this heating method the cycle time to manufacture a component was 25 mins. Figure 5 shows a redesigned mould to provide heat to the elastomer compound through recirculating oil through conformal heating channels. The re-designed tool was reduced in size and was manufactured in RapidSteel 1. To meet the accuracy needs of the application additional material was added to all mating and moulding surfaces on the 3D solid model and the tool was machined back afterwards. The tool as manufactured contained some residual porosity, which was removed through infiltration with a high temperature resin. A number of trials were carried out with this tool to examine to what extent the cycle time could be reduced. The minimum cycle time achieved was 10 mins, with a thermally insulated conformally heated tool, a 60% reduction in cycle time. In addition to this cycle time benefit it was found that in QA tests on the moulded components it was possible to discern between batches of elastomer compound, as the variability in test results from different batches of the same compound was less than the variability arising from moulding. This distinction was not one it was possible to make where conventional tooling was used. The use of conformally heated tooling can, therefore, provide improved part quality through providing more

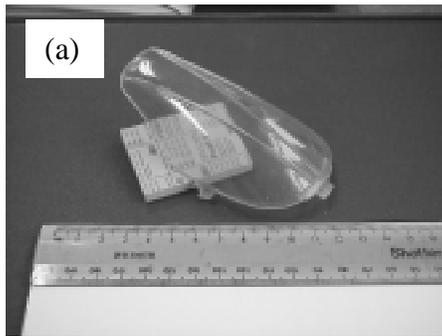
repeatable cure conditions to the elastomer compound, in addition to providing reduced cycle time.



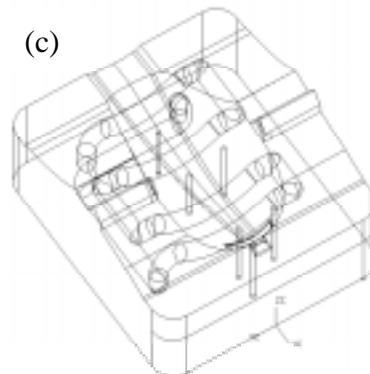
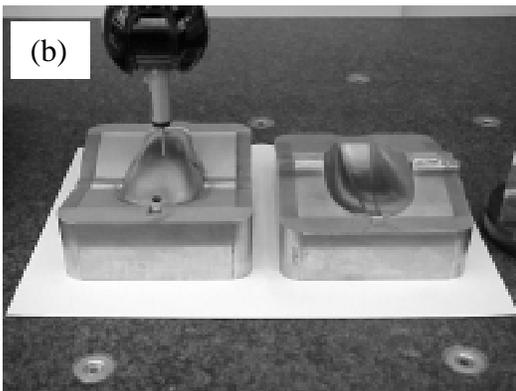
**Figure 5 - (a) Redesigned Tool, and (b) View of Conformal Heating Channels**

#### 4.2 Injection Mould Tool - Screen Component

The second productivity case study concerned a screen component, shown in Figure 6(a). This component forms part of a toy produced by Hasbro (Europe) Ltd. The conventional production tool (hardened tool steel) for this part ran with a cycle time of 26 secs. (of which 19.9 secs. was part cooling). The moulding material was Phillips K-resin, a butadiene-styrene copolymer. The conformally cooled tool, shown in Figure 6 was designed using the Moldflow injection moulding analysis package, and was manufactured using RapidSteel 2. Again to meet the accuracy needs of the application additional material was added to all mating and moulding surfaces on the 3D solid model, and was removed by machining or hand finishing after the near net shape tool had been manufactured.



**Figure 6 - (a) Screen Component  
(b) RapidSteel Tool  
(c) Wireframe Model Showing Conformal Channel**



In assessing injection moulding productivity it is important to understand the different elements of the cycle time. The cycle time generally has five elements: a nozzle delay time, an injection time, a packing time, a cooling time, and an open/close time. For a given component geometry only the cooling time is dependent on the cooling channel design, all of the rest will be dependent on the design and operating pressure of the injection moulding machine.

Two types of trial were performed, one with a cold runner, and the other with a hot runner. The hot runner trial was carried out after observing that, with a conformally cooled mould, a substantial proportion of the cooling time in the cold runner trial was time spent waiting for the sprue to cool, with the component itself ready to eject. The achieved cycle times and cooling times are shown in Table 1. The Moldflow predicted cooling time for the tool in a hot runner configuration was 8 secs. The reduction in cooling time to 9.5 secs. would allow the cycle time in production for this component to be reduced from 26 secs. to 15.6 secs.

	Cycle Time (secs)	Cooling Time (secs)
Conformally Cooled RapidSteel Tool - Cold Runner	20.6	14.5
Conformally Cooled RapidSteel Tool - Hot Runner	17.6	9.5

**Table 1 - Screen Tool Moulding Trial Results**

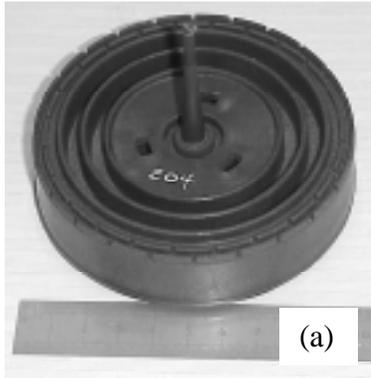
#### **4.3 Injection Mould Tool - Wheel Component**

The second injection moulding case study was based around a wheel component which is moulded by McKechnie Plastic Components Ltd for Dyson, and is shown in Figure 7(a). The conventional production tool (EN30B steel) runs with a cycle time of 46 secs., 28 secs. of which is cooling. The production moulding material was BASF Novolen 1100L, a talc filled polypropylene.

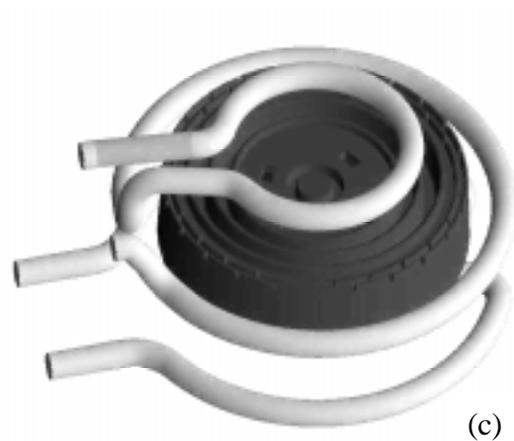
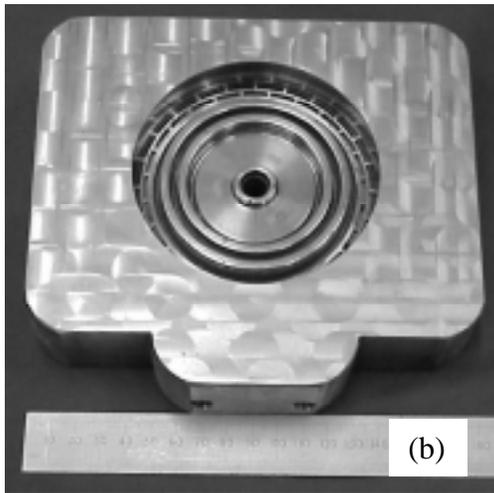
Again a conformally cooled tool was designed using the Moldflow package, and was manufactured using RapidSteel 2, see Figure 7. As for the other tools the RapidSteel process was used to create a near net shape tool, with machining and hand finishing used to generate the net shape. A significant amount of finishing was required, as this tool has a large number of small positive and negative features. The tool as used did not meet the full dimensional specification of the production tool, as some of the features proved impossible to finish to the production specification. With the benefit of hindsight, the small feature study reported in section 2.2 would have led us to reject this tool for manufacture using the RapidSteel process, had the information been available at the time the tool was selected. As with the damper tool residual porosity in the tool was removed through infiltration with a high temperature resin.

In this trial the moulding material was different from the standard production material, with Allied Signal Capron 8333, a 33% glass filled nylon, used to accelerate wear. The cycle time and cooling time data is shown in Table 2. Both the production and the RapidSteel tool were run in a cold runner configuration.

The Moldflow prediction data in Table 2 allows a production cycle time for the conformal tool, with the Novolen material, to be estimated at 36 secs., which would be a 10 sec. reduction on the 46 secs. currently achieved with the conventional tool.



**Figure 7 - (a) Wheel Component  
(b) RapidSteel Tool Fixed Half  
(c) Conformal Channel Path**



	Cycle Time (secs)	Cooling Time (secs)
Conventional Tool (EN30B) - Novolon material	46	28
Conformally Cooled RapidSteel Tool - Capron 8333	24	14
Predicted times for Conformally Cooled RapidSteel Tool - Capron 8333	-	15
Predicted times for Conformally Cooled RapidSteel Tool - Novolen	-	18

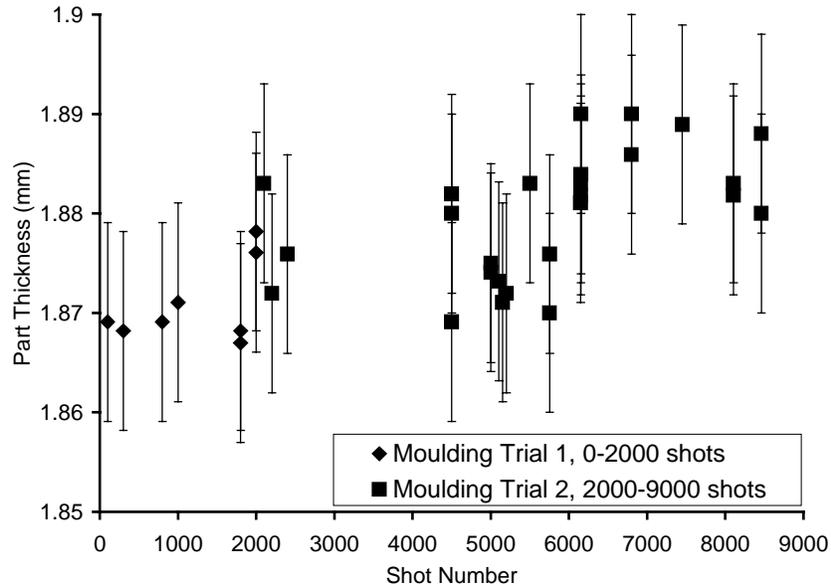
**Table 2 - Wheel Tool Moulding Trial Results and Moldflow Predictions**

### **5. Wear**

For both the injection moulding tools described in section 4 the manufacturing trials also included an assessment of wear. Wear was not considered a tool life determining criterion for the transfer moulding tool.

The screen tool was used to generate 9000 components in the Phillips K-resin material. Evidence of tool wear was assessed by three methods: CMM measurements of the tool before and after the trial, measurement of the thickness of the screens produced by the tool, and measurement of the weight of the screens produced by the tool. Figure 8 shows the results of the measurements of the screen thickness for a sample of the screens produced. The measurement point was close to the gate. The trial was run in two stages: in the first 2000 components were produced, and the tool was then removed from the moulding machine before being re-loaded at a

later date when a further 7000 components were produced. The thickness of the screens was measured using a Trimos Height Gage with a resolution of 1  $\mu\text{m}$ . The  $\pm 0.02$  mm confidence intervals shown in Figure 8 were developed through measurements of the thickness of the first 20 mouldings produced with the tool, to give an indication of both process and measurement repeatability. Figure 8 indicates that, to within the  $\pm 0.02$  mm confidence intervals, no significant wear has taken place on the tool. Measurements on the tool and measurements of the component weight also led to the conclusion that no significant wear of the tool had taken place.



**Figure 8 - Variation in Screen Thickness with Number of Mouldings Produced**

The wheel tool was used to generate 1000 components in 33% glass filled Nylon: again no statistically significant wear was found on the tool.

## **6. Conclusions**

Overall our conclusion has been that it is possible to manufacture production specification tooling using the RapidSteel process, and that such tooling can offer significant productivity benefits through the use of conformal cooling and heating channels. In doing so it must be accepted that the RapidSteel process generates a near net shape component which requires further work to be a finished tool, and that there are geometric limitations on the process with regard to small features. The wear study has shown that the tools are durable, but further work is required to fully characterise the wear characteristics of the material.

## **7. Reference**

1. Stewart, T.D., Dalgarno, K.W., & Childs, T.H.C., *Strength of the DTM RapidSteel 1.0 Material*, Materials and Design, 1999, Vol. 20, pp 133-138.

## **8. Acknowledgement**

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