STRENGTH OF THE DTM RAPIDSTEEL 1.0 MATERIAL

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ABSTRACT

This paper reports the results of a study into the strength of the DTM RapidSteel 1.0 material. Elastic modulus and strength of the metal/copper composite material was investigated as a function of the distance from the point of copper infiltration, the furnace cycle duration, and the furnace type. The microstructure of the RapidSteel material was also examined in an attempt to understand the science behind the infiltration process. The results have implications for the design of tools to be made using the RapidTool process in situations where the tool will be used as a production tool, rather than a prototype tool.

INTRODUCTION

Rapid prototyping has evolved over the past five years from the ability to produce polymer models for visualisation of a single prototype part to the ability to manufacture Rapidtooling from metals or ceramics for the manufacture of hundreds or thousands of parts. There are several different processes available for Rapidtooling each with it's own specialised materials which are a complex mixture of polymer binders, structural metal powder and some form of infiltrant. This paper considers one type of Rapidtooling produced by the DTM Corporation in Austin comprised of a steel/copper composite called RapidSteel 1.0.

RapidSteel is produced in a three stage process. Initially a green part is sintered from polymer coated steel powder using conventional selective laser sintering technology. The fragile green part is then placed in a bath of polymer resin and then dried providing additional support for handling and binding for the steel powder. Finally the part is placed in a furnace where the polymer is burned away leaving the steel powder which is lightly sintered into a weak porous skeleton defining the shape of the part. This structure is then infiltrated with molten copper which is absorbed from the base of the part by a wicking action which draws the copper through the porous matrix resulting ideally in a fully dense composite. The process of the copper infiltration into the steel matrix is referred to as Liquid Phase Sintering, and is most commonly experienced in powder metallurgy. German (1) described the time dependant nature of the infiltration process in which in powder metallurgy of steel/copper composites can require in excess of 10 hours at 1150 °C for fully dense parts to be produced.

Many studies have been completed on the variation in properties of materials produced by selective laser sintering (2,3,4) considering the effects of parameters such as energy density and laser orientation. The additional furnace infiltration required for the manufacture of RapidSteel adds a further source of this variation. Two furnace types are recommended by DTM for the processing of RapidSteel. The Carbolite furnace (Carbolite Furnaces Limited, Aston Lane, Hope, Sheffield S30 2RR) is a bottom loading hearth furnace with a sand seal, while the Lindberg furnace (304 Hart Street, Watertown, WI 53094) is a front loading furnace with a liquid cooled seal. The possibility of variable environments and temperature profiles produced from each furnace combined with the pressures to decrease cycle times was proposed as a possible source of anisotropy in material properties, hence this study was undertaken.

EXPERIMENTAL PROTOCOL

Cubic test blocks 80 millimetres in size were manufactured from RapidSteel 1.0 both at Leeds University and at DTM Germany (DTM GmbH, Otto-Hahn-Straβe 6 40721 Hilden, Germany), the size chosen to represent the thickest cross section expected in a tool. Green parts were manufactured using the DTM default settings which include a laser power of 30 watts, a scan speed of 1550 mm/s and a layer thickness of 0.1 mm. The infiltration process was completed using a Carbolite furnace at Leeds and a Lindberg furnace at DTM Germany. The different furnace cycles investigated are shown in Figure 1. The part temperature generally followed quite closely to the specified temperature as shown for the 24 hour cycle by "Part @24 hour" and "24 hour" curves respectively.

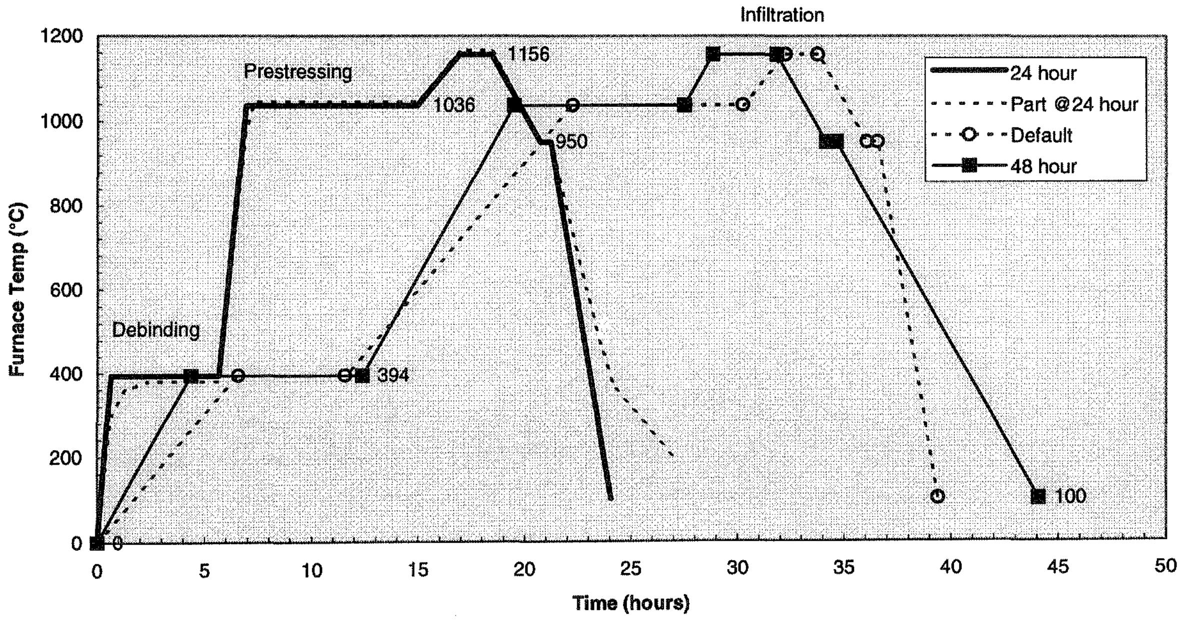


Figure 1. Variable Furnace Cycles

Each block was cut into sixteen 20 x 20 x 80 millimetre slices cut either horizontally or vertically which were then machined into tensile specimens. Strain gages were also mounted onto various specimens to obtain an accurate representation of the Young's Modulus. Tensile testing was conducted using a Dartec Universal Testing Machine (Dartec, Stourbridge, West Midlands, DY9 8SH, UK) at a fixed crosshead speed of 0.05 mm/sec. Crosshead position, load, and strain were recorded. Material samples from the fractured specimens were further evaluated under a microscope. Copper nitrate was used to etch samples for further analysis of grain boundaries. A typical test block for horizontal samples is shown in Figure 2 before machining. The copper was infiltrated at the base of the block along the length of sample A1. For vertical specimens the copper was infiltrated from the base of samples A1, B1, C1 and D1.

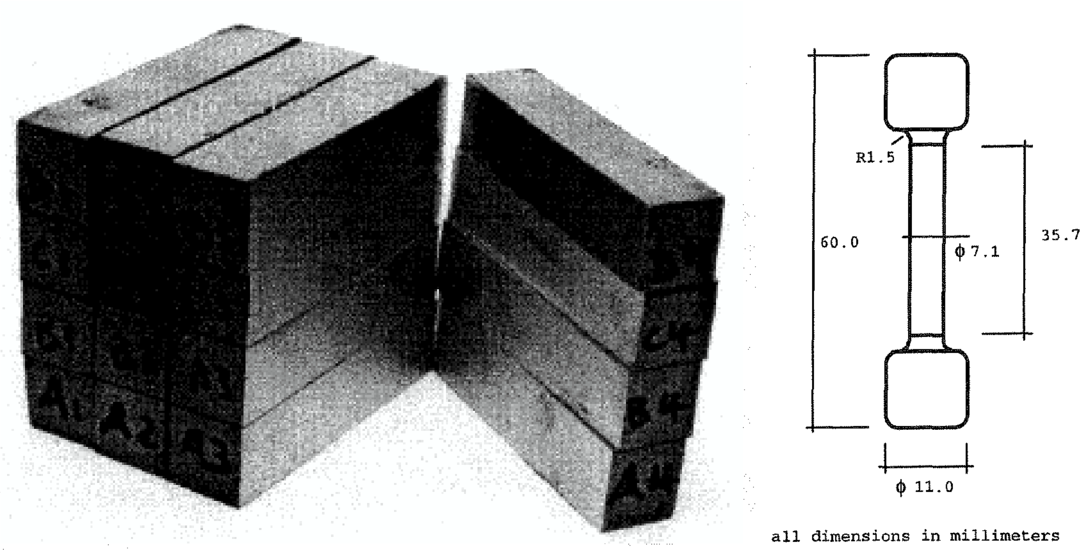


Figure 2. 80mm cubic RapidSteel block cut into horizontal sections for machining into tensile specimens.

RESULTS AND DISCUSSION

Typical stress Vs strain variations within a single block manufactured at Leeds using the DTM default furnace cycle are shown in Figure 3. Samples were cut horizontally, A1 is closest to the copper infiltration point while sample D4 is the farthest away. The Figure shows the fracture load for all of the samples as a function of the horizontal and vertical distance the sample was taken from the point of copper infiltration (A1).

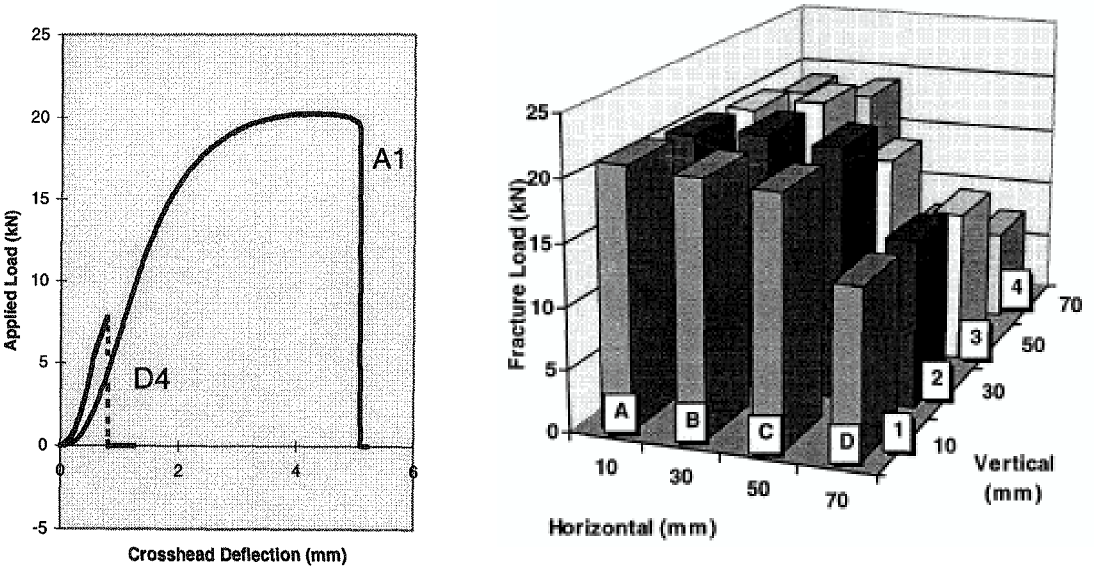
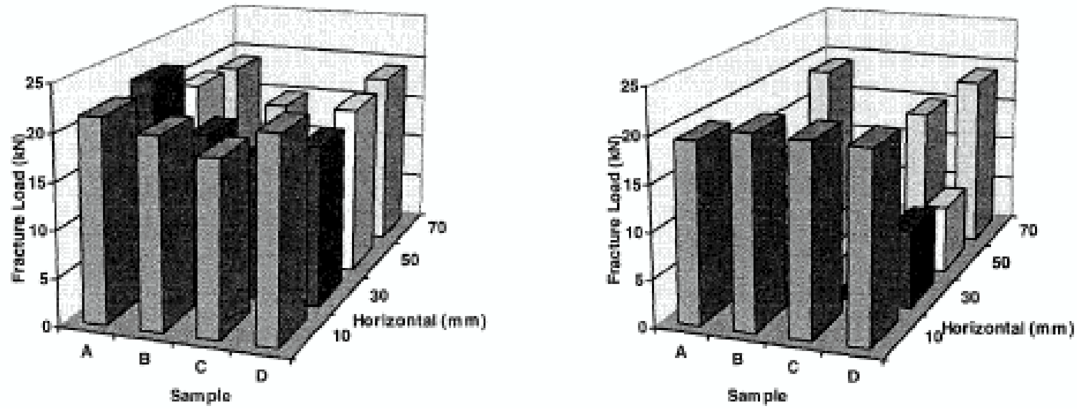


Figure 3. Variation in material properties of a Leeds sample cut horizontally.

A pattern of degradation appears to be present with strength decreasing with distance from the point of copper infiltration in both the vertical and horizontal directions. The yield strength of the RapidSteel material varied from 100 to 500 Mpa, with the elastic modulus remaining relativeley constant at 210 GPa.

When comparing the Leeds results to those taken from identical samples manufactured in Germany with the default furnace cycle a similar pattern is observed as shown in Figure 4. In this case samples were cut vertically and the Figure shows the fracture load as a function of horizontal distance from the copper infiltration which is essentially the same for all samples A to D.

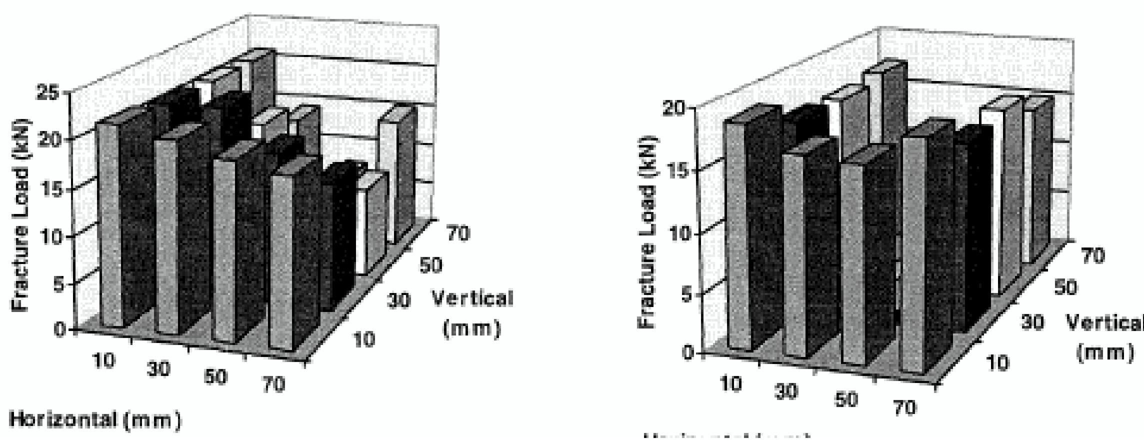


a. Leeds block b. DTM Germany block

Figure 4. Variation in Material Properties from Leeds and DTM Germany both cut vertically.

The majority of specimens which were taken vertically generally fractured at the top of the block and a similar trend of decreasing fracture load was observed with distance from the point of copper infiltration. Internal horizontal cracking was observed within the block manufactured by DTM Germany which limited the number of samples tested.

The variation in fracture load with furnace cycle duration is shown in Figure 5. Both blocks were manufactured at Leeds and cut horizontally.



a. 24 hour cycle b. 48 hour cycle

Figure 5. Variation in Material Properties as a function of cycle time.

The observed degradation in strength appears to be more prevalent with the shorter 24 hour furnace cycle than the 48 hour furnace cycle. Internal horizontal cracking was also observed, in this case in the block manufactured at Leeds with the 48 hour furnace cycle, limiting the number of samples tested. Cracking has only been observed in parts with thicknesses in excess of 60mm, and is, therefore, believed to be the result of incomplete drying or internal stresses developed during processing. As yet a systematic method has not been developed to avoid this effect .

A further visual inspection of the fracture surfaces was also completed. Figure 6 shows the side view of the block previously shown in Figure 2 and 3 manufactured at Leeds with the default furnace cycle.

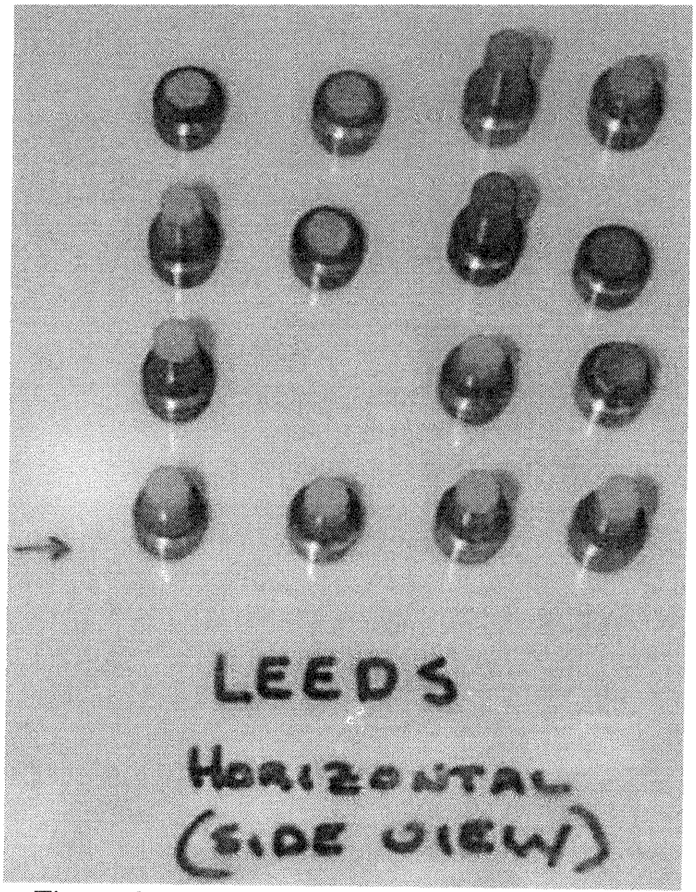
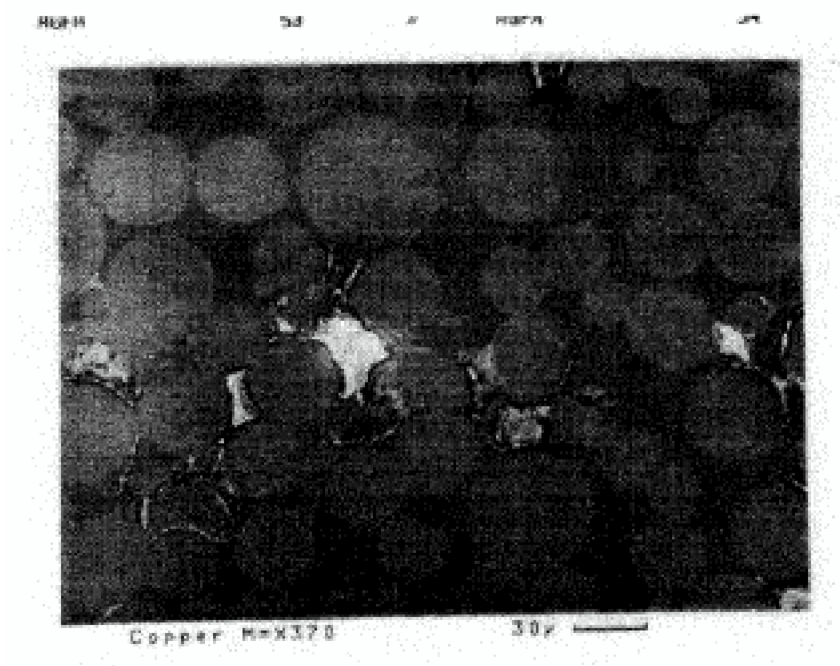


Figure 6. Visual inspection of fracture surfaces.

It can be clearly seen by visual inspection alone that with the default furnace cycle samples further away from the point of copper infiltration (marked as an arrow) are darker and have more porosity. The amount of porosity seen is also directly related to cycle time as the longer 48 hour cycle is noticeably less porous, and the shorter 24 hour cycle is more porous.

Analysis of the RapidSteel material under a microscope reveals spherical metal particles ranging from 10 to 60 μm in diameter located within the copper. Further detailed etching with Ferric Chloride will reveal the large copper grains approximately 200 μm in size. Other analysis techniques such as scanning electron microscopy (SEM) shown in Figure 7 will continue to be used in attempts to better understand the science behind the infiltration process.



CONCLUSIONS

The infiltration of copper into the DTM RapidSteel 1.0 material appears to have a time dependant nature to the process. The DTM default sintering time of 1.5 hours at 1156° C is for a typical 6 inch square block with a 2 inch thickness (5). Parts in excess of 2 inches thick may, therefore, need special attention with increased infiltration times to allow the wicking of the copper into the porous metal skeleton to complete naturally.

No significant variation in material properties was observed between samples manufactured in Leeds with the Carbolite furnace and those manufactured in Germany with the Lindberg furnace, as the fully infiltrated material was equally as strong and both displayed general decreases in strength with distance from copper infiltration. The fully infiltrated RapidSteel material was found to have a yield strength of 500 MPa and an Elastic Modulus of 210 GPa.

The nature of a rapid process for the manufacture of tooling may introduce pressures to increase the speed of the processing cycle. The furnace cycle which takes up a significant portion of the manufacturing time is, therefore, likely to be optimised by companies to the shortest possible time. Tooling may appear identical with faster cycle times as low as 12 hours, however, the resultant porosity within the material can significantly weaken the structure below 25% of its original strength. For prototype tooling this may be an acceptable risk, however, for long term success in a production environment the time dependent nature of the copper infiltration process should be considered.

Acknowledgements

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