The Effect of Layer Thickness on Ejection Forces for Injection Moulded Parts Made Using DMLS Tools

Candice Majewski and Neil Hopkinson

Rapid Manufacturing Research Group,
Wolfson School of Mechanical and Manufacturing Engineering
Loughborough University
Loughborough, LE11 3TU
United Kingdom
Tel: +44 (0) 1509 227564 Fax: +44 (0) 1509 227549

With thanks to EOS GmbH for production of DMLS tooling inserts and tool finishing

Abstract

Direct metal laser sintered (DMLS) parts have previously been shown to be suitable for some tooling applications, in particular for injection moulding of plastics. This work shows that recent developments in materials have increased the suitability of DMLS tools for injection moulding processes, in terms of the force required to eject a part from a tool.

Tools were manufactured for testing from two bronze (DirectMetal 50 and DirectMetal 20) and two steel (DirectSteel 50 and DirectSteel 20) powders, and the forces required to eject ABS parts from these tools were recorded. It can be seen that the more recent powder developments, sintered in 20 μm layers, showed a dramatic improvement over the older powders, sintered in 50 μm layers.

1.0 Introduction

The benefits of using Rapid Prototyping methods to create tooling have been shown throughout industry, in terms of the both the time and the cost required to produce the tooling. In some cases a reduction of 50% in each has been achieved by using Rapid Tooling techniques rather than conventional methods (Lohner, 1996).

Other well-publicised benefits of Rapid Tooling are the ease of producing intricate and complex geometries (Nelson, 2000), and the ability to produce thin-walled sections, which are generally difficult to machine (Dvorak, 1993). Internal geometries that would previously have been impossible to manufacture, can now be produced with relative ease. This allows the possibility of incorporating conformal channels within a tool, to provide better heating or cooling to specific areas of importance (Himmer et al, 1999, Dalgarno et al, 2001).

However, as with any technology, there are also some disadvantages to be found. The ‘stair-stepping’ effect inherent to all Rapid Prototyping processes can cause difficulties when attempting to remove a moulded part from a tool. In the case of laser-sintered tools, their porosity can further inhibit part removal, as moulded material ingresses into the tool itself.

High forces required to remove a part from a mould can lead to warpage and distortion of the parts, or in some cases parts becoming completely stuck. Another area of concern is in tools with fine or delicate features which are simply not strong enough to withstand the forces required. These features can become distorted or even break off completely. Material and equipment developments are therefore necessary in order to improve the surface quality of tools made using Rapid Tooling techniques, and consequently to reduce the ejection forces required.

2.0 Development of DMLS

The early stages of the development of direct metal laser sintering (DMLS), as with most Rapid Prototyping processes, focussed mainly on the speed of the process, rather than on the properties of the sintered part (Lind et al, 2002).

The very first powder developed for use in DMLS was a bronze powder to be sintered in 100 μm layers. Although this provided the ability to build parts relatively quickly, the amount of finishing work required to give the parts an acceptable surface finish could negate this time-saving. After the development of this early material, steel and bronze based powders were developed in 50μm layers, and most recently both powders have been developed in 20μm layers.

The smaller steps encountered on a Rapid Prototyped tools built with a small layer thickness, and in a finer powder, provide a naturally better surface finish than when built with a larger layer thickness. When using DMLS some finishing will generally be necessary once the build is complete, particularly if the part is to be used as a tool for injection moulding. Whereas previously large amounts of finishing would be required in order to render the product usable, shot peening is now commonly used to finish DMLS parts (Lind et al, 2002). Injection moulding tools made from the newer powders have been shown to require only shot-peening to give similar performance to an EDM tool in terms of ejection force (Majewski, 2001).

3.0 Research Aim

The newer powder developments for the DMLS process can be expected to give improved surface quality on tools produced in this way. The work described here quantitatively evaluates this improvement in terms of the ejection forces required for parts injection moulded into DMLS tools.

4.0 Methodology

Tools were produced with varying levels of finishing, in each of the four powders now available for use in DMLS – DirectMetal 50 and DirectMetal 20 (bronze-based powders) and DirectSteel 50 and DirectSteel 20 (steel-based powders). The following sections describe the tool design and moulding parameters used.

4.1 Tool Design

Previous work (Hopkinson 2000) on stereolithography tools involved a simple tool design; the same geometry has been used in this work. The design of the tool was intended to provide a good contact area with the moulded part, but also to minimize the time spent on sintering. The cavity side of each tool was therefore machined, as it would have no effect on the force required to eject the part. Another benefit of using a machined cavity was to reduce the possibility of the moulded part from being retained in the cavity side of the tool on mould opening.

The core side of the tool consisted of a machined surround to be used for each tool, with individual inserts screwed into this surround. In order to provide easier ejection, most inserts were shot-peened to give a lower surface roughness, and a draft angle of 0.5°. Figure 1 shows the tool design and geometry used.

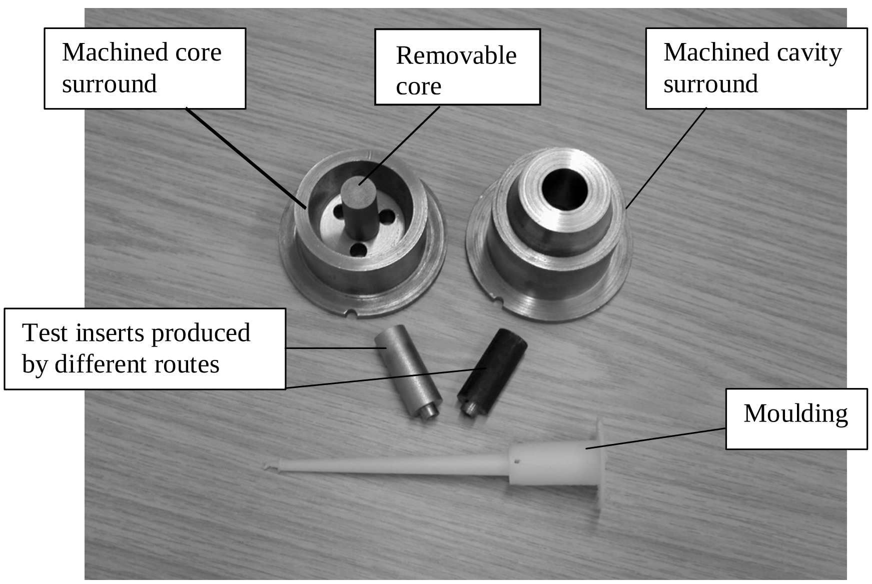

Figure 1 - Tool and part geometry

Whilst a simple geometry was chosen (particularly to enable easy production of the machined inserts), the inserts had a long line of draw. This provided a large area of contact between the mould tool and the moulded part, providing adequately difficult ejection to perform the required tests.

4.2 Injection Parameters

Throughout each test, the injection parameters (including pressure, speed and temperature) were maintained constant. Cooling time and mould opening were also maintained constant. Table 1 shows the parameters used.

Parameter	Value
Tool Temperature Prior to Injection	40 °C – 50 °C
Injection Temperature	225 °C
Cooling Time Prior to Mould Opening	15 seconds
Mould Open Time Prior to Ejection	0 seconds
Total Cycle Time	~ 120 seconds

Table 1 – Injection parameters

4.3 Moulding Material

The moulding material was ABS, as it provides a difficult material to mould and eject, and is also widely used in industrial applications of injection moulding. Ejection force measurements were only taken where the part produced was of a good quality, and suffered no distortion or flashing.

4.4 Number of Parts Moulded

In order to ensure that enough results were taken to give accurate measurements, 20 parts were moulded from each insert. It can be seen from the results section of this report that no substantial variations are apparent over the course of these 20 shots. It was therefore considered unnecessary to test a higher number of mouldings.

4.5 Tool Temperature Prior to Injection

Whilst in some inserts the temperature of the mould did not appear to make a large difference, on certain tools it was noticeable that if the insert was not cooled after each shot then the ejection force measured on the next shot was substantially lower. For this reason the temperature of the mould was maintained between 40° and 50° at the beginning of each moulding cycle.

4.6 Measurement of Ejection Force (F_e)

The tool design used three ejector pins arranged around the central upstand. Load cells were positioned behind each of these pins, and individual readings taken upon ejection of each part (see figure 2). The individual results taken from each load cell were added together to give a value for the total force required to eject the part. In order to give an accurate reading of the peak force, a sampling rate of 1200Hz was used over a three second ejection period.

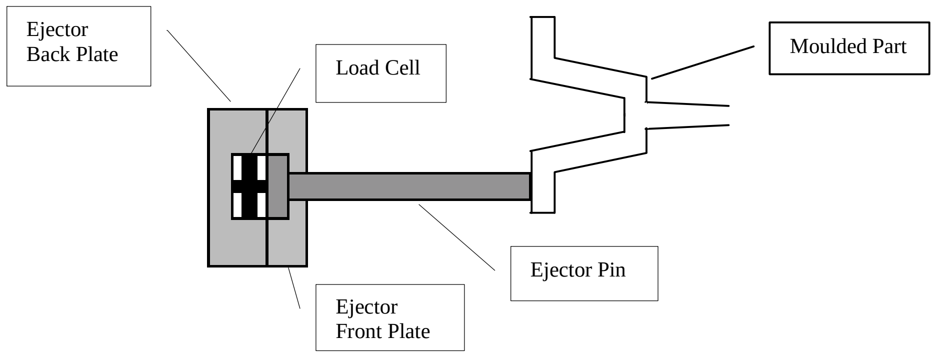

Figure 2 – Location of Load Cells

4.7 Finishing procedures

Table 2 shows the different finishing procedures applied to DMLS tools for this work.

Type of Finishing	**Description**	**Time Taken for Finishing**
Unfinished	No finishing procedures applied	N/A
Shot Peening (Type 1)	1. Organic medium to remove loose powder from tool surface 2. Steel medium to smooth and compact surface 3. Organic medium for further smoothing	10-15 minutes
Shot Peening (Type 2)	1. Steel Medium 2. Ceramic Compound	5-10 minutes

Table 2 - Description of Finishing Methods

5.0 Results

These tests were designed to compare the performance of injection moulding tools made by DMLS, and to identify any improvement to be found in the newer 20 μm powders. Ejection force measurements were recorded for each of the 20 shots produced on each insert. An insert produced by electro-discharge machining (EDM) was also tested for benchmarking purposes; this is a standard process for producing tools in industry, and is included in this work as an indication of an industrial acceptable level of ejection force. Table 3 below shows the average of these ejection forces. To provide an indication of the surface finish of each insert, surface roughness values (Ra) have been included.

Tool Material	Level of Finishing	Average Peak Ejection Force (N)	Surface Roughness Ra (N)
DS20	Unfinished	756	8.8
	Peened (1)	153	5.1
	Peened (2)	116	3.5
DS50	Peened (1)	505	8.5
	Peened (2)	560	9.5
DM20	Peened (1)	199	4.5
	Peened (2)	153	4.7
DM50	Peened (1)	426	9.6
	Peened (2)	437	9.3
Machined	EDM	170	5.2

Table 3 - Average ejection force and surface roughness recorded for each insert

5.1 Steel based powders

The following section discusses the results gained from the steel based powders – DirectSteel 50 and DirectSteel 20. Figure 3 below shows the ejection forces for each of the steel inserts tested, as well as those for the EDM insert.

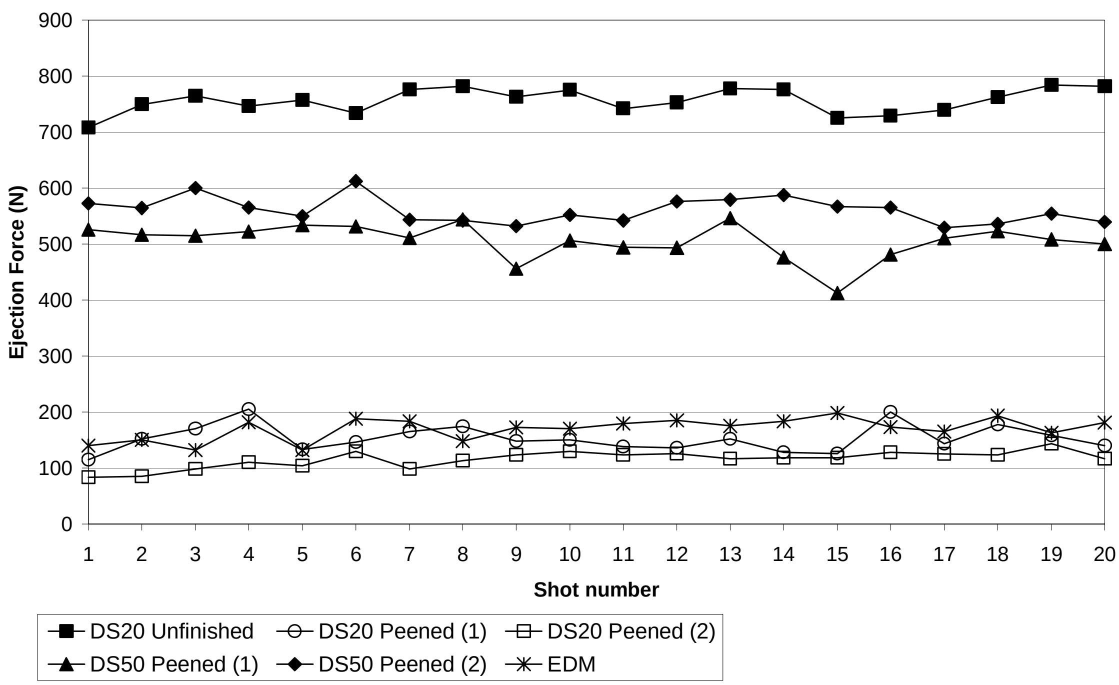

Figure 3 - Ejection Forces for Steel Based Powders

It can be seen from these results that neither of the DirectSteel 50 inserts tested, compare favourably in terms of ejection force with the EDM insert tested. The average values recorded (505N for an insert finished with type 1 peening, and 560N for that finished using type 2), are approximately three times higher than that for an EDM insert (170N).

In the case of the simple geometry chosen here, the higher ejection forces recorded on these inserts showed no apparent adverse effects on either the part or the tool. However, when moulding more difficult geometries, perhaps with fine features or thin-walled sections, these higher forces could potentially cause part distortion or damage upon ejection, as well as damaging the tool itself.

In the case of the two peened DirectSteel 20 inserts, the average ejection forces, (153N for type 1 and 116N for type 2), are both below that for the EDM tool. This would suggest that these inserts are at least as acceptable for injection moulding as tools made by the EDM process.

Also of interest is the average ejection force of 756N recorded on the unfinished DirectSteel 20 insert. Whilst this is still substantially higher than for the EDM insert, it is only approximately 200N higher than that of a DirectSteel 50 peened insert.

Shot peening is a standard recommended method of finishing for DMLS injection moulding tools, even for those made in the 50μm powders. On simple geometries therefore, especially where the surface finish of the part is not critical, these results would suggest that even a DirectSteel 20 insert with no finishing may be acceptable as an injection moulding tool. The obvious benefit of this would be a reduction in the overall lead time of a tool, as even peening procedures will add time to the process.

It can be seen from these results that there is a marked improvement in the performance of the 20μm powders over the 50μm ones. Table 4 shows the percentage reduction in ejection force found with the steel based powders.

Original Material	**New material**	**Level of Finishing**	**% Reduction in Required F_e**
DS50	DS20	Peened (Type 1)	70%
DS50	DS20	Peened (Type 2)	79%
DS50	DS20	Average	74.5%

Table 4 - Percentage reduction in ejection force (steel based powders)

This reduction in ejection forces would be expected to greatly improve the suitability of steel DMLS tools for injection moulding, particularly for more difficult or complex geometries, although it should be noted that a smaller layer thickness will require a greater sintering time.

5.2 Bronze based powders

The following section discusses the results gained from the bronze based powders tested – DirectMetal 50 and DirectMetal 20. Figure 4 shows the ejection forces recorded on each shot. As before the results for the EDM insert are included as a benchmark.

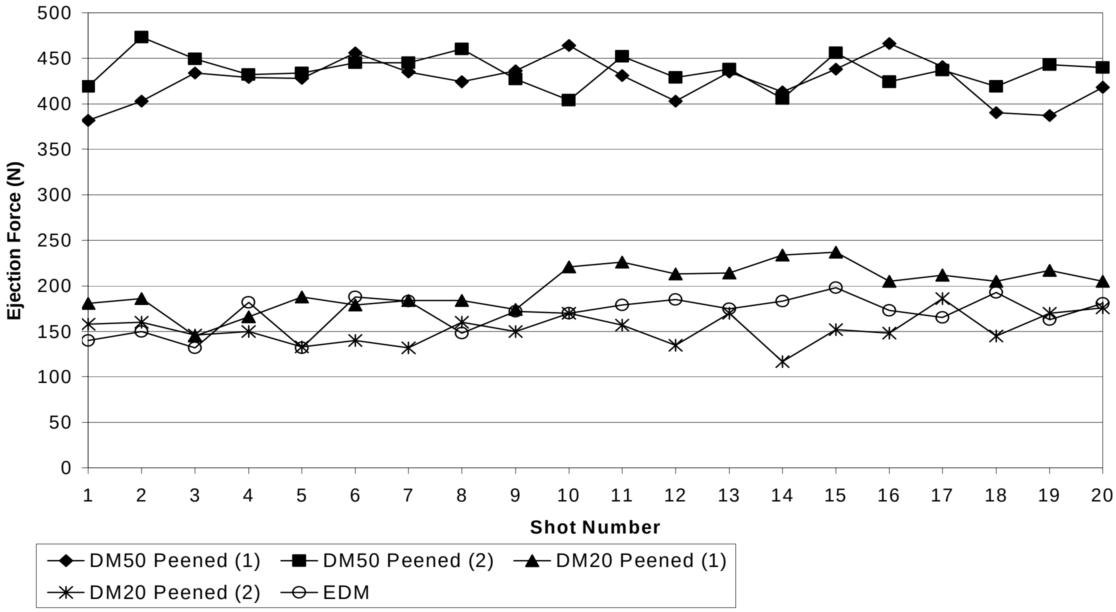

Figure 4 - Ejection Forces for Bronze Based Powders

The two peened DirectMetal 50 inserts recorded very similar average ejection forces of 426N and 437N for type 1 and 2 respectively. As with the DirectSteel 50 inserts, these forces would not necessarily render tools made in this way unsuitable for injection moulding, but a lower ejection force would in general be preferable.

In this case the DirectMetal 50 inserts recorded ejection forces of approximately 2.5 times those for the DirectMetal 20 or EDM inserts.

With type 1 peening, the average ejection force recorded from a DirectMetal 20 insert was 199N, and for type 2 peening it was 153N. These figures compare extremely favourably with the EDM insert tested, suggesting that they too are extremely suitable for injection moulding tools.

As in the case of the steel based inserts, the 20μm bronze powder has shown a marked improvement over the 50μm. Table 5 shows the percentage improvements seen here.

Original Material	**New material**	**Level of Finishing**	**% Reduction in Required F_e**
DM50	DM20	Peened (Type 1)	53%
DM50	DM20	Peened (Type 2)	65%
DM50	DM20	Average	59%

Table 5 - Percentage Improvement in ejection force (bronze based powders)

The average reduction in F_e of 59% is fairly dramatic, suggesting increased suitability of the 20μm tools for injection moulding. Whilst the percentage improvement seen is less than that for the steel based powders, it can be seen from table 3 that the ejection forces for the 50μm bronze powder were also lower than for the 50μm steel powder. The actual values recorded for all the peened 20μm inserts did not show a large amount of variation.

6.0 Conclusions

Poor surface finish is one of the most common concerns held by industry over the use of Rapid Prototyped tooling. However, the recent powder developments for the DMLS process have produced a marked improvement in terms of the ejection force required for injection-moulded parts.

In many cases the ejection forces found when using a peened tool made from either of the 50μm powders will be low enough to cause no problems when ejecting injection moulded parts. However, in the case of fragile sections or complex geometries, it is possible that even this level of ejection force may be enough to damage the part and/or the tool.

The newer 20mm powders showed dramatic reductions in ejection force of 74.5% and 59% for the steel and bronze based powders respectively. This reduction to the same level as an EDM tool suggests that the surface finish is no longer an obstacle to effective de-moulding from a DMLS tool.

It is important to realise that tools sintered in smaller layers will require a longer sintering time than with thicker layers, although the surface finish of parts moulded using these tools will generally be better. The choice of powder is then affected by which is the more important of these considerations.

It is still the case that a DMLS or Rapid Prototyped tool will not always be the best choice for injection moulding or any other process. Decisions must be made as to the required surface finish of the part, as well as the acceptable lead-time and cost of the tools. However, the new developments in materials for DMLS render this process much more suitable for tooling purposes than in the early stages of their development.

7.0 References

Dalgarno K, Stewart T, Allport, J, *Layer manufactured production tooling incorporating conformal heating channels for transfer moulding of elastomer compounds*, Plastics, Rubber and Composites, v 30, n 8, 2001, pp 384-388

Dvorak P, *Rapid Prototypes for Production Parts*, Machine Design, 1993, pp48-54

Hopkinson N, Dickens P, *Using Stereolithography Tools for Injection Moulding: Research into Tensile Tool Failure and Unexpected Benefits of the Process*, Proc Institution Mechanical Engineers-B, 2000, 214(B10), 891-89

Himmer T, Nakagawa T, Anzai M, *Lamination of Metal Sheets*, Computers in Industry 39, 1999, pp 27-33

Lind J, Hanninen J, Kotila J, Nyrhila O, Syvanen T, *Direct Metal Laser Sintering – From 100 μm to 20μm Layers*, Proceedings of the 2002 International Conference on Metal Powder Deposition for Rapid Manufacturing, 2002, pp 225 - 232

Lohner A, *Injection Mould Making the Quick Way – Laser Sintered Cavities and Mould Inserts*, Kunstoffe Plast Europe, November 1996, pp 7-9

Majewski C, *The Effect of Draft Angle and Level of Finishing on the Ejection Force Required when Injection Moulding Using Direct Metal Laser Sintered Tools*, M.Sc. Thesis, De Montfort University, Leicester, UK, 2001

Nelson C, *Mould Inserts for Plastic Injection Moulding*, Engineering Technology, 2000, pp37-40