



STRATASYS Objet50 CX2 printer.

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3D printing at work

SERGIO DULIO

In the earlier article, we mainly focused on state of the art in 3D printing or, to give it its better title, additive manufacturing (AM). It is a tricky subject because technologies in this field are developing rapidly and, in the past twelve months, there have been interesting evolutions that once more testify how vibrant and dynamic this sector is and how interest is growing concerning their applications. Although this second article is focused more on practical examples, it is worth at least mentioning two relevant elements that characterise these recent evolutions.

Those who have an interest or are driven by mere curiosity, will certainly be aware of the overwhelming proliferation of new models of printers, especially in the lowest cost range with literally hundreds of vendors and systems appearing priced between \$750 and \$5,000, which makes them suitable as true personal 3D printers. This is the result of the expiry of the first patents on

The July/August 2014 issue of *World Footwear* contained details of the latest advances in 3D printing. This further article features case histories of applications supported by numerical evidence and practical data on its applicability in footwear manufacturing.

some of the initial AM technologies. Established companies and start-ups have had access to the original patent contents and can build their machines on those principles, contributing to the widespread diffusion of the technologies and to a progressive democratisation of their adoption.

This has been accompanied by intensive research on materials that is expanding the range of applications and the amount of objects that can be 3D printed at an incredible pace. Variety and material properties are certainly important as was clearly stated in the earlier article. However,

another aspect of AM continues to hinder its adoption relative to more traditional techniques—the low accretion speed of objects being manufactured that results in processing times that are normally counted in (several) hours. That is why, at the recent Materialise World Conference held in Brussels at the end of April, some announcements on recent achievements to accelerate processing speeds were broadly welcomed by the more than one thousand participants present.

Two in particular are worth a mention: the CLIP system from

Carbon3D and the Multijet Fusion approach from Hewlett Packard. Both claim astounding reductions in printing time. HP stated in a recent presentation that its MultJet technology is ten times faster than any other on the market (an object once requiring ten hours processing time can now be made in approximately one), combined with unprecedented versatility in terms of usable materials. Carbon3D goes even further, stating that its technology is 25 to 100 times faster. A benchmark component shown on their website takes almost 3.5 hours to build using laser sintering, while the CLIP machine only needs 6.5 minutes. While it may sound—and probably is—a little too optimistic, it nevertheless gives a clear indication of where the struggle now lies; reducing the processing time to a level that can make 3D printing competitive with other manufacturing approaches and the final cost of the items produced.

These introductory remarks are necessary in order to understand how rapidly things are changing, even in the relatively short time frame of one year. While all this sounds interesting and exciting, there is a more fundamental question that we still have to answer: can 3D printing really work in the world of shoemaking? Can it be applied to replace or complement current manufacturing techniques and how will these technologies affect future products? These are the topics covered in this article and, in order to give exhaustive and comprehensible answers, a few benchmark objects well known in terms of traditional manufacturing have been selected that were all tested and produced with different kinds of AM machines. This work is part of an exploration being conducted by ATOMLab (*World Footwear* July/August 2015) in collaboration with STRATASYS (3D printing and AM systems) and Energy Group, an Italian vendor of STRATASYS machines and a service provider in the 3D printing domain.

BENCHMARK CASES

The items considered were a footbed, an unit sole and an injection mould, each of them being fairly representative of a whole category.

Footbed (Figure 1) – one of the structural

Results

Input – Footbed (Figure 1)

Requirements	The object is made in two parts, given as two separate CAD models for the front and the rear. The front must be soft and flexible and the rear rigid. There must be no assembly operations and the object should naturally combine the two parts.
Materials	Any rigid material for the back, any soft material for the front.
Finish	Low quality (invisible part).
Accuracy	High, especially in the back part.

Output - Footbed (Figure 5)

Machine	STRATASYS Connex 1 260.
Materials	ENDUR (rigid), Tango Black Plus (soft), support material.
Amounts used	ENDUR 138 grams, Tango Black 37gm, support material 131gm.
Process time	4 hours and 31 minutes.
Cost	€7.50 (including support material, wasted in the process).

**Delivered part looks accurate and with a good finish. Rigid part is certainly adequate while the front is too soft compared to the materials normally used, indicating that a much more rigid material should have been chosen. The two parts are directly bonded in the printing process and do not need any further assembly.*

Figure 1 – CAD insole

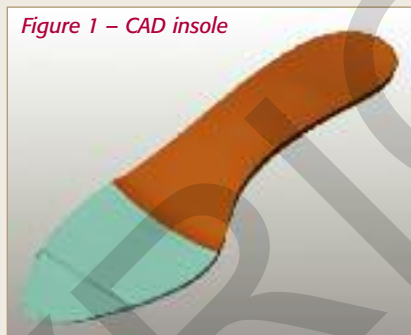


Figure 5 – Printed insole

Input – Unit sole (Figure 2)

Requirements	The CAD files represent a model of a trekking boot sole normally made in rigid, high resistance TPU. It must be produced as a totally finished object (no vacuum casting or other rapid tooling approaches).
Materials	High compactness materials, similar hardness and rigidity of TPU.
Finish	High quality, similar to the one obtained in moulding.
Accuracy	High.

Output - Unit Sole (Figure 6)

Machine	STRATASYS Object 30 Prime.
Materials	Tango Grey.
Amount used	Build material 338gm, support material 504gm.
Process time	20 hours, 36 minutes.
Cost	€165.00 (including support material waste).

**The object was actually produced in two variants; the first in a very strong material (RGD525) that was too rigid to be compared with the behaviour of a TPU-like sole. In the second version, TANGO Grey was used that was, on the other hand, extremely flexible to resemble the properties of a thermoplastic sole.*

Figure 2 – CAD unit sole



Figure 6 – Printed unit sole

components that make up the shoe and contribute to its structural integrity and mechanical resistance in the same way as the counter or toepuff. Invisible parts which do not have stringent aesthetic requirements, do not need a high level of finishing and do not demand extremely high dimensional accuracy.

The reason why a footbed was chosen instead of a counter or a toepuff lies in its higher manufacturing complexity. While the other two are simply cut and shaped, a footbed is normally made in several parts combining soft and rigid materials that are then put together and sometimes reinforced with a metal shank in a relatively complex assembly process. The purpose of the test was to see how much the process could be simplified by moving to AM and where the new process wins or loses.

Unit sole (Figure 2) – normally injection moulded in a material such as TPU or PVC, it needs a multi-part mould of variable and growing complexity depending on the design features of the sole itself and on the chemical nature of the materials used to produce it. The goal here was to see if, from an aesthetic, functional and cost point of view, 3D printing could represent a valid alternative.

Sole mould (Figure 3) – moulds are important and expensive pieces of equipment. They are normally produced through the NC milling of metal blocks, machined to the high accuracy needed to produce high quality and appealing soles or sole units. Since shoe companies do not possess the necessary know-how and the required machinery, this work is normally subcontracted to specialised suppliers (mould makers), which adds complexity, cost and often inefficiencies in the value chain. The purpose of the test in this case was to investigate if classical machining techniques could be replaced by AM to 'print' a mould instead of milling it and also show if and how long it could withstand the temperatures and chemical reactions that form the material in the mould.

There is one more case that was also investigated (Figure 4) which did not refer to any shoe part or even the shoe itself, but looked at a possible

Results continued

Input – Mould (Figure 3)	
Requirements	The CAD files contain the three parts of the mould; the bottom plate and the two side rings. The mould will be used in a direct bottoming machine, with two rings closing on the last and bottom plate completing the cavity into which PU will be injected.
Materials	Highly rigid material, resistant to high temperatures (minimum 80°C).
Finish	High quality, similar to the one obtained with metal moulds.
Accuracy	High.

Output - Mould (Figure 7)	
Machine	STRATASYS Object 30 Prime
Material	DIGITAL ABS
Amount used	Build material 6886grm, support material 775grm.
Process time	42 hours, 57 minutes.
Cost	€2,280.00 (including support material, wasted in the process).

**The three parts of the printed mould look very good, with a high level of finish and a mechanical accuracy that appears acceptable for the moulding process. Some warping and deformation effects were nevertheless visible which necessitated a final machining step to rectify the planarity of the side walls of the mould in order to fit it into the injection machine. These inaccuracies are not expected to affect the final processes. It is thought that the printed geometry could be better optimised leading to a considerable cost saving. The mould is, at the time of writing the article, ready to start injection tests.*

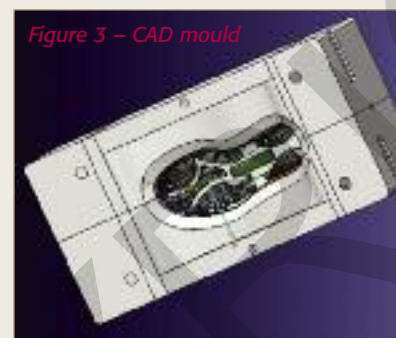


Figure 3 – CAD mould



Figure 7 – Printed mould

Input – Cutting table (Figure 4)	
Requirements	The CAD files refer to an important and critical part of the tool holder of an NC cutting table. This part is currently made in metal and then assembled with all the other components of the cutting head. High accuracy and durability are called for.
Materials	Highly rigid material, high resistance and durability.
Finishing	High quality.
Accuracy	High in order to allow precise fitting and assembling with other components.

Output - Cutting table (Figure 8)	
Machine	STRATASYS Connex 2 260.
Material	DIGITAL ABS.
Amount used	Build material 275grm, support material 198grm.
Process time	12 hours, 51 minutes.
Cost	€124.00 (including support material waste).

**The printed part is very good, with a high level of finish and accurate dimensions, so it looks perfectly adequate to be installed in the machine. Mechanical assembly tests are due to begin soon followed by endurance tests to evaluate the lifespan and reliability of the AM part.*



Figure 4 – CAD mechanical part

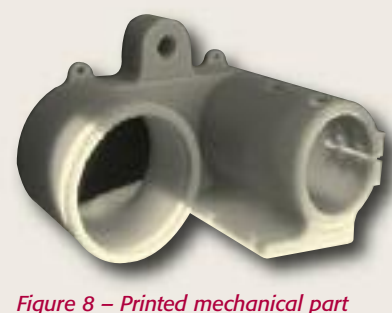


Figure 8 – Printed mechanical part

application of AM in another segment of the footwear pipeline, shoe machinery. In this scenario the aim was to see if some critical parts of a modern NC cutting table, typically cast or machined metal such as aluminium, etc., could be replaced by a 3D printed copy in an appropriate plastic material while still ensuring the necessary accuracy and durability. A positive result would open fascinating possibilities for digital manufacturing and maintenance.

This benchmarking activity took many months to prepare and some experiments are still on-going so it is not possible, at present, to provide full results and to draw final conclusions. However, some valuable indications are already available that offer a good idea of where and how AM can be applied proficiently. Results are shown in tabular format highlighting initial requirements and final outcomes.

CONCLUSIONS

Taking all four cases into consideration, there are some valuable conclusions that can be drawn on the possible application of 3D printing in

shoe making. The questions raised at the beginning of the article can be dealt with in three main parts: function, cost and quick response.

Function – if we think of the functions the different test objects have to fulfil, the answer is at least dubious. The footbed shows a possibility of obtaining pre-assembled parts directly by the process, which is certainly an advantage, although mechanical properties of the printed parts look to be still too far away from those of the traditional components, at least while we have 'traditional' shoes in mind. The distance, however, is not enormous and it is felt the gap could be rapidly filled.

The unit sole also indicates how far the material processed by the machine still is from those in current use. More recently, a follow up of this test was made using a special TPU formulation (Luvosint by German company Lehman & Voss) that can be laser melted. The resulting sole is amazingly good, with a look, feel and mechanical properties that seem to closely match those of real TPU. These physical properties will be



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soon tested against its twin made in real TPU to precisely assess this similarity.

Expectations are higher for the mould and the mechanical part whose functional properties appear to be close

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enough to the traditionally made ones. Tests are being done to assess these properties and when results become available they should hopefully provide more evidence in support of this statement.

Cost – this is the most critical point and one where AM seems to score quite low compared to traditional techniques, at least for most of the objects concerned. It is evident that comparing a footbed that would normally cost around €0.20 with a 3D printed one at €7.50 leads us nowhere even if we take into consideration the higher accuracy and geometric consistency the printed part can offer. The same is true for a sole at €165.00 when the standard cost could be €2.00-3.00 when mass produced in large quantities. The principal cause for this is the extremely high cost of the build material. This will no doubt go down as the market develops in the same way that printer cartridges have but, to what extent, we cannot predict.

The cases of the mould and of the mechanical part are different. AM costs are much closer to those found in

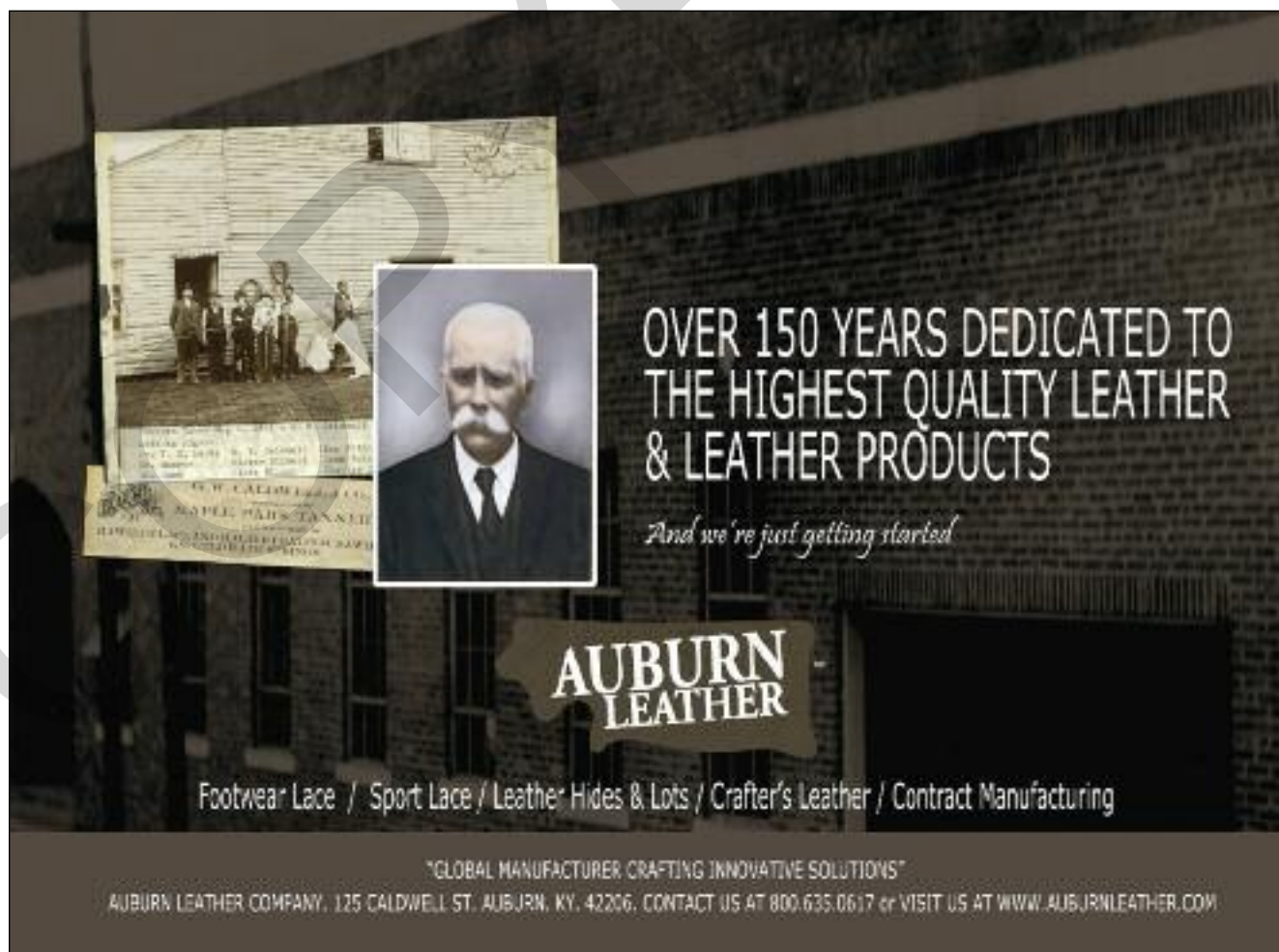
traditional production (or at least not too distant, considering that for the mould to material optimisation or part lightening was done which could reduce the cost by roughly 50%) and, assuming that these objects will perform in the same way (a statement yet to be demonstrated), 3D printing may appear as a valuable alternative, especially in advanced scenarios such as digital manufacturing or digital remote maintenance.

Quick response – this is where we see AM winning in almost every respect. A processing time of above four hours for a footbed, 20 hours for a prototype outsole or even 30 hours for the mould might seem excessively long. However, we cannot forget that in the normal footwear pipeline, these components are procured from external suppliers and their delivery lead time, especially when unit items or very small lots are needed, is counted in days if not weeks. The chance of having the needed component or required mould right in the office by just sending the file to the printer and retrieving the part some

hours later may turn out to be a very powerful driver for additive technologies.

Another approach that is being tried is to increase 'global' throughput by having a battery of printing heads working together in parallel. Twenty working on the same piece and taking 20 minutes to print it produces twenty pieces in twenty minutes or one piece per minute. Dutch research centre TNO is working on a concept of this kind.

Before concluding this analysis, there is one more thing. All that was said holds true of a 'constant product', i.e. assuming that shoes are and will stay the same as they are and have been so far. There are, however, already clear indications that things may change and that new product concepts will appear that will take full advantage of the potentials of AM technologies. Scenarios may combine the easiness of 3D printing with the appeal of personalisation, changing at the same time the business model, product value chain and the very DNA of the shoe itself. 



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