High SPE3D Printing with No Compromise.

CONSTRUCT3D

Made in the UK

CATAPULT High Value Manufacturing

European Union European Regional Development Fund

MADE SMARTER

MIDLANDS ENGINE HM Government

WMG THE UNIVERSITY OF WARWICK

Background:

CONSTRUCT3D have developed a cutting-edge technology Material Extrusion 3D Printer, targeting Rapid within Rapid Prototyping and Manufacturing, necessitates comparison with current 3D printer market leaders within the market sector they are targeting, of domestic 3D printers.

Aims:

1. To undertake a product review through comparison against current market leaders within the capabilities of WMG SME team and its current collaborators. Comparison will be through printing of parts, enabling time trials, capable of dimensional and property analysis, enabling direct comparison with current market leaders.
2. Review the product as a development user, providing feedback to CONSTRUCT3D as well as determining its suitability to the chosen market.

Overview: This review will look at existing 3D printing manufacturers of Material Extrusion.

Contents

1 Construct 1 Introduction – Need 4 SPE3D

CONSTRUCT3D have developed two models for the material extrusion 3D print industry: Construct 1 and Construct 1XL. This report relates to all tests carried out on the Construct 1 printer, designed to deposit thermoplastics onto a print bed capable of accepting the molten material, ensuring adhesion and cooling. The Material Extrusion technology is a stable market, that's evolved from fragile models to usable components through innovation of material technologies. The key process limitation for material extrusion is speed, related to the mass of moving components (build head or build plate), but this is something which industry and hobby users are currently willing to tolerate; the technology is still faster than traditional production methods. This is where the Construct 1 printer steps in, and claims capabilities of speeds not seen before, maintaining quality, resolution of prints without compromise towards CONSTRUCT3D, bringing back Rapid Production, with an emphasis on RAPID.

For the benefit of this report in remaining neutral, no printers' make, or model has been described, unless required for clarity; the printers will be identified using numerical assigned values of 1-8, with the exception that printer 8 is the Construct 1. Our work covered a wide range of printers, from domestic printers to heavy industry printers, across a price range of £150 - £150,000, wherein the printers are identified as domestic/hobby at <£1,500, commercial from £1,500-£20,000 and industrial at >£20,000. The broad range of printers allowed the performance against competitors to determine its location and viability within a market.

1.1 What are the benefits of 3D printing at speed?

Rapid prototyping as it was once known, was a game changing technology in which lower cost prototypes are manufactured, enabling rapid product development. Given the progress of material technologies for this industry, CONSTRUCT3D have taken the technology back to its roots, speeding up the rapid aspect of prototyping in which so many materials are able to take products direct to its consumers. The advancement of such technology had a significant impact on cost reductions and product deployment, not only for domestic users, but also industrial users. The cost-of-living crisis which currently has a global grasp on everyday life opens the floodgate to such disruptive technologies in which the costs are fixed for the printing of the components, reducing the costs proportionally as the print times reduce. Further work is required to determine the exact benefits of such technology, however there is no argument that this technology is reducing costs to its end user.

1.2 Initial Appearance

Looking at the printer, it has nothing special making it stand out from other printers within the Material Extrusion market, having a standard movable bed for the Z-axis and belts neatly out of sight for the X and Y-axis. The bed is coated with a metal sheet which is magnetically adhered to the bed's main heated structure, enabling ease of part removal, and whilst the material's composition is a trade secret, it is coated with Polyetherimide (PEI) on spring steel to aid adhesion on one side and a textured finish on the other, enabling good adhesion of materials which struggle to adhere to standard build beds.

The control system is integral with the printer and requires WIFI, enabling access remotely; the system looks user friendly and once connected provides a web based, comprehensive system enabling the machine to be operated by novices or experienced operators to get the most out of the printer. The system provides secondary controls for parameters whilst the printer is in operation, something rarely seen.

2 Construct 1 features and description

The Construct 1 is built around Cura software, using v5.1.0, compatible with multiple printers, and familiar with many within the 3D Print world, and communicates through the Wi-Fi system, enabling monitoring and parameter changes both remotely and through the on-board user interface touch screen.

Using basic parameters provided by the CONSTRUCT3D development team, quick and seamless printing was achieved. Whilst materials new to the printer were used, the printer performed effortlessly and as a Material Extrusion technology, enabled simple use and modification of settings towards optimum parameters, and whilst perfection could have been chased, for the purpose of this project, basic parameters were sufficient.

3 Comparison of Printer's Setup

For comparison and to remain neutral, it was determined to compare the benefits of the broad range of printers' available with the Construct 1, through printing 'Benchy Boats', as shown in Figure 1, known for benchmarking printers and capabilities, followed by ASTM D638 'Dog Bones', a standard used for rapidly measuring a material's tensile strength. This will be finalised with a cost comparison of the printers employed within this report.

All process times were measured from the point material was first extruded for the part until extrusion stopped at the end of the part print, enabling direct comparison of printers, negating any variations in cycling up, bed levelling or purge durations. Where control was given in the slicer software, only the component being printed was processed with no additional support material*. Wall ordering was outside to in, material temperatures were as per suppliers' recommendations with no additional build plate adhesion features.

Some printers used the Cura software whilst other printers used their own slicer software, materials, and recommended settings.

3.1 3D Benchy Boats

The 3D 'Benchy Boat' is designed to benchmark a printer's capability, enabling print parameter calibration with its various features, from thin wall, external/internal holes, overhanging surfaces and arches etc. enabling printers' capabilities to be determined. The 3D Benchy boats were printed by orientating individual at 45° to the X-Axis, both as a singular print and as a set of 3 prints in one build, spaced evenly at 60mm between the chimney centres and parallel along the boats' hull (Figure 1). These were printed with external wall's first, prior to internal walls, 20%* density, using a rectangular internal structure where possible.

*Printer 5 was unable to print below 24% infill density and required support material, a limitation of the slicer software.

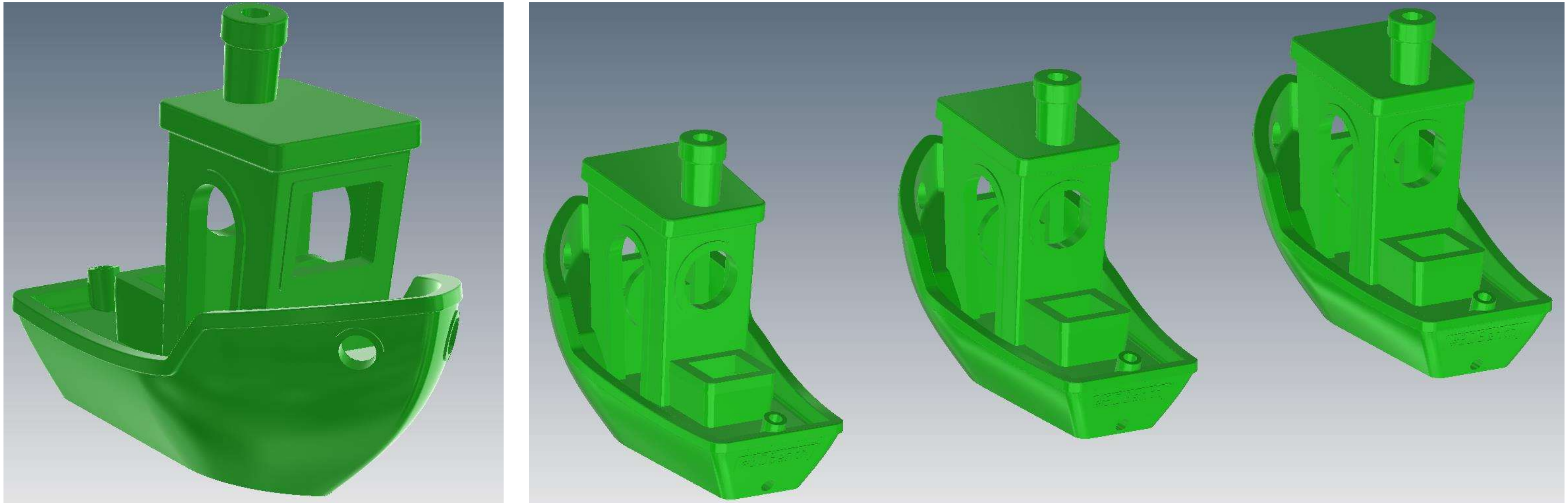

Figure 1 – Singular Benchy (Left) and 3 Benchy Boats, equally spaced at 60mm between chimney centres and orientated at 45° on the bed

3.2 ASTM D638 'Dog Bones'

The ASTM D638 is a standard dog bone arrangement seen in Figure 2, is a test method to determine the tensile properties of plastics. Given that the printer extrudes at a higher rate, it was critical that the effects of this were determined, which is a test ensuring that there is no negative effect on the material's characteristic properties. These can be also used as a secondary time analysis to the Benchy and as previously outlined for the Benchy, printed in the orientations of 0°, 45° and 90° (about the Z-axis) at 100% infill.

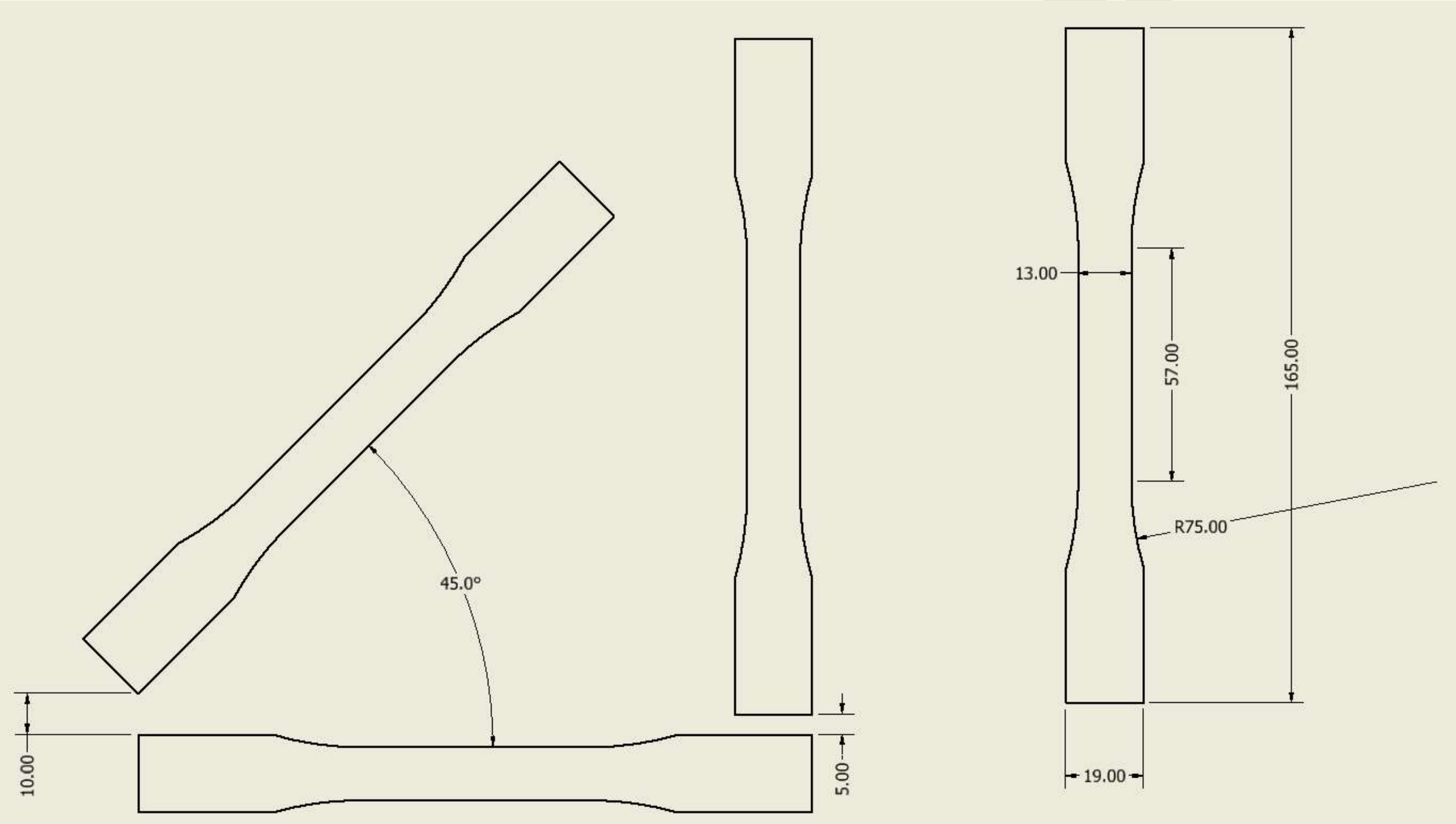

Figure 2 – ASTM D638 Dog bone dimensions (Right) and how they were laid out (left), the structure is 3mm thick

4 Printing

4.1 Benchy Boat Printing - PLA

Poly Lactic Acid (PLA) is the most popular low cost and biodegradable material for 3D printing within the range of domestic/hobby printers (Link). If strength and flexibility is required, then Acrylonitrile Butadiene Styrene (ABS) is used. The Construct 1 was compared against other printers using PLA for a singular Benchy boat. Initially this was going to be conducted using 3 Benchy boats, equally spaced, however it soon became evident that most printers within the market are not pre-set for the speeds required. Table 1 shows the times of each printer's times to print a singular boat and the average calculated prior to the visual representation within Figure 3.

Printer	Material	Print 1	Print 2	Print 3	Average Time (h:m:ss) (s)	Std Dev. (s)
1	PLA	1:00:00	1:00:03	0:59:59	1:00:01 (3600)	2
2	PLA	1:23:29	1:23:38	1:23:38	1:23:35 (5015)	5
3	PLA	1:30:01	1:31:35	1:30:07	1:30:34 (5407)	53
4	PLA	1:21:25	1:21:25	1:21:26	1:21:25 (4885)	1
7	PLA	0:28:39			0:28:39 (1719)	0
8 Construct 1	PLA	0:26:00	0:26:11	0:26:08	0:26:08 (1566)	6

Table 1 – Print times for Singular Benchy Boat in PLA (times in hh:mm:ss) (s), unless stated otherwise), Printer 7 was provided by a third party and only available for a singular print.

Printers 5 & 6 were not represented with PLA as these are commercial and industrial machines targeted at engineering grade materials and will be covered later in this report.

CATAPULT High Value Manufacturing
European Union European Regional Development Fund
MADE SMARTER
MIDLANDS ENGINE HM Government
WMG THE UNIVERSITY OF WARWICK

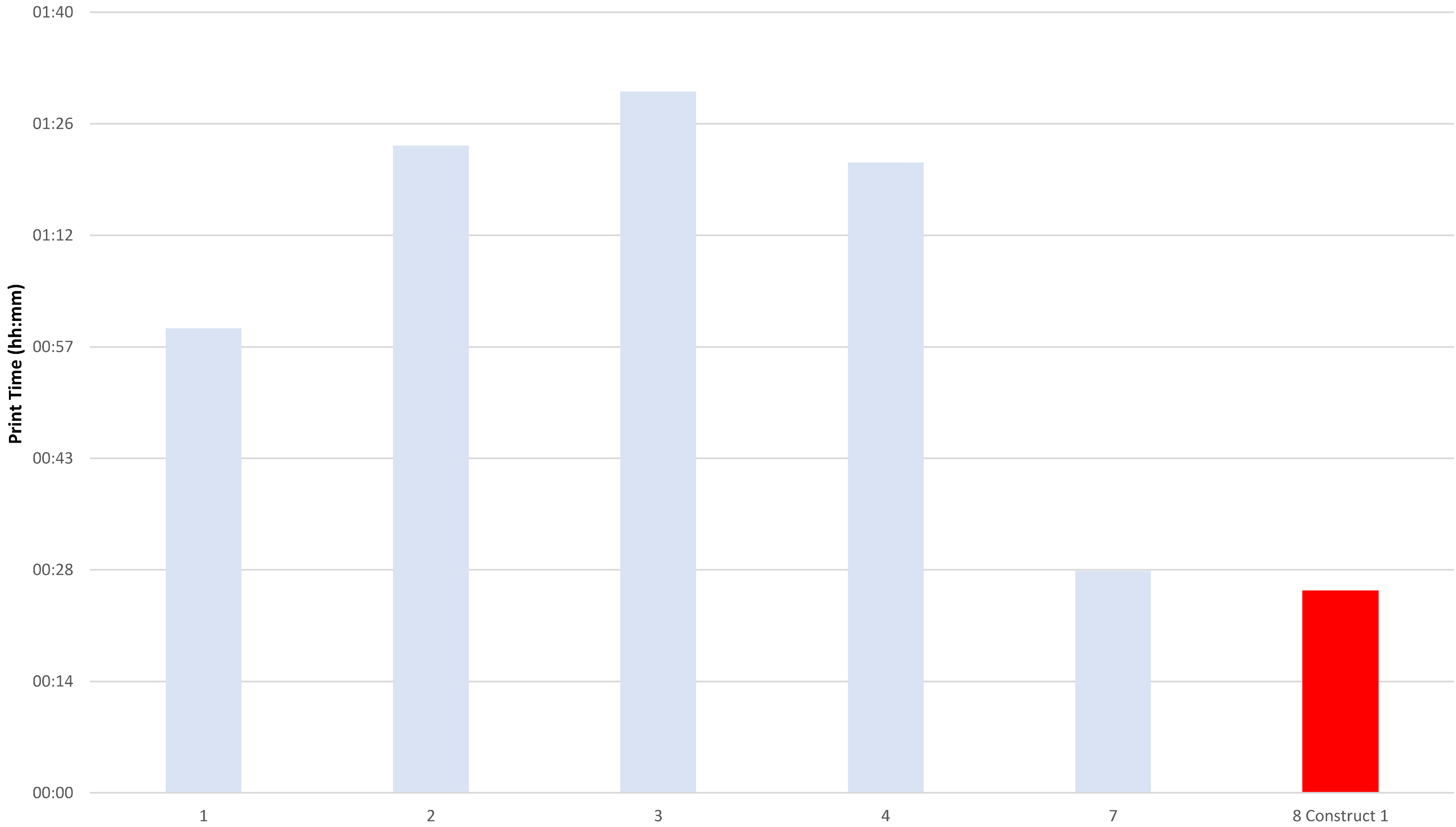

Figure 3 – Print times for singular Benchy Boat as shown in Table 1 with PLA

It is evident from Figure 3 that the print times of printers 7 & 8 are quicker than other printers for a single Benchy print boat within PLA, to be comparable with the industrial and commercial printers, these were further undertaken with their respective materials of ABS for printer 5 and Nylon for printer 6, the materials sourced from printers suppliers are vendor approved and their bread and butter products to ensure neutrality. To be comparable, the outcomes show even longer build durations for these, shown in Figure 4

Printer	Material	Print 1	Print 2	Print 3	Average Time (h:m:ss) (s)	Std Dev. (s)
1	PLA	1:00:00	1:00:03	0:59:59	1:00:01 (3600)	2
2	PLA	1:23:29	1:23:38	1:23:38	1:23:35 (5015)	5
3	PLA	1:30:01	1:31:35	1:30:07	1:30:34 (5434)	53
4	PLA	1:21:25	1:21:25	1:21:26	1:21:25 (4885)	1
5	ABS	2:28:01	2:27:55	2:28:00	2:27:59 (8879)	3
6	Nylon	1:48:31	1:48:33	1:48:31	1:48:32 (6512)	1
7	PLA	0:28:39	0:00:00	0:00:00	0:28:39 (1719)	0
8 Construct 1	PLA	0:26:00	0:26:11	0:26:08	0:26:08 (1566)	6

Table 2 – Previous Benchy times with the inclusion of printer 5 & 6 for a singular Benchy Boat print

Printer 5 struggled with an extensive print time and was limited by the inability to remove the support from the print, a limitation of the slicer, however printer 7 is on a par with the Contruct 1 print times and over 50% quicker than its next nearest competitor.

DRAFT

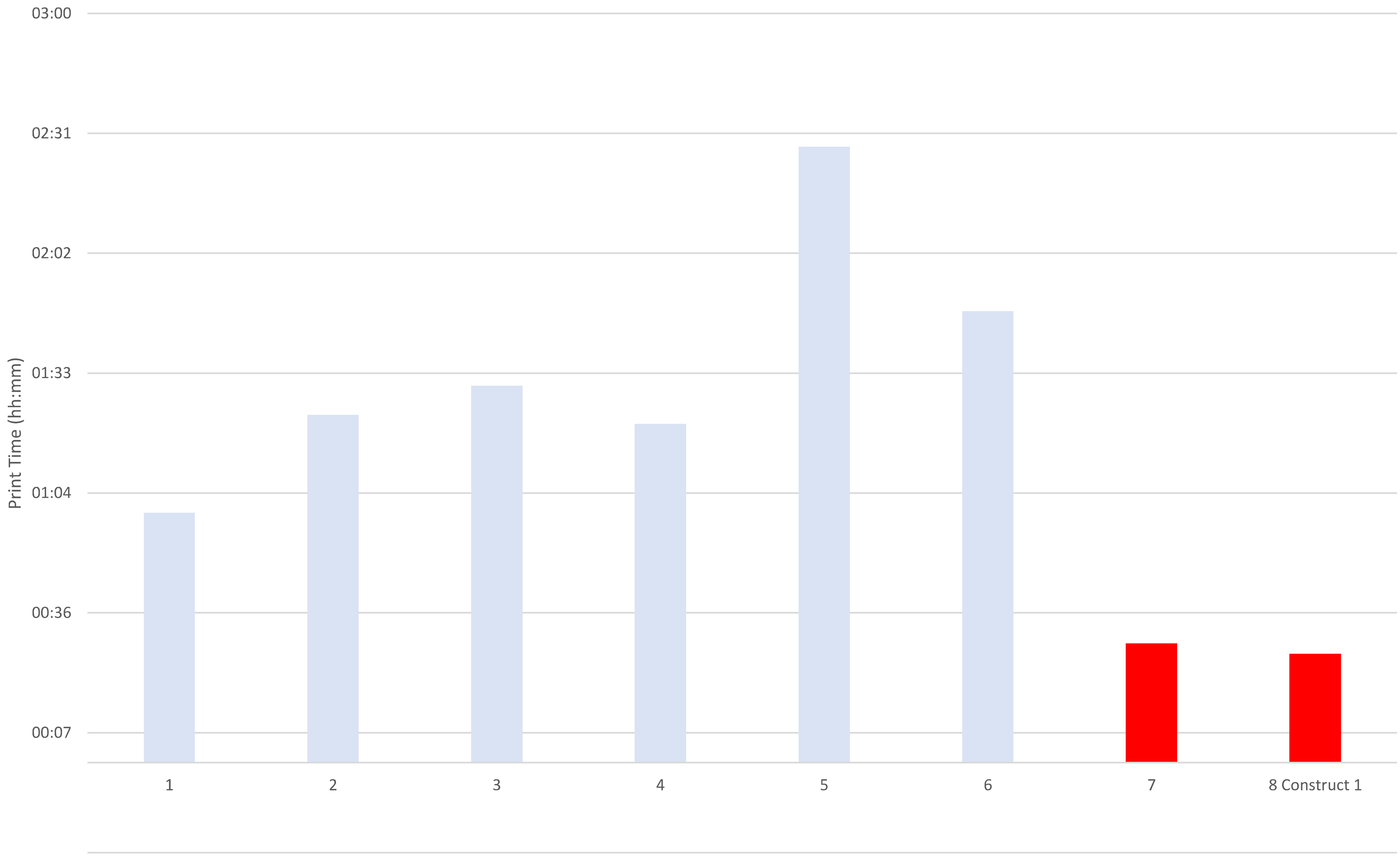

Figure 4 – Print times for Single Benchy with the inclusion of commercial (6) and industrial (5) printers and their engineering grade materials – See Figure 2

Catapult High Value Manufacturing · European Union European Regional Development Fund · Made Smarter · Midlands Engine HM Government · WMG The University of Warwick

4.2 PLA Benchy Images

Figure 5 – Printer 1, PLA

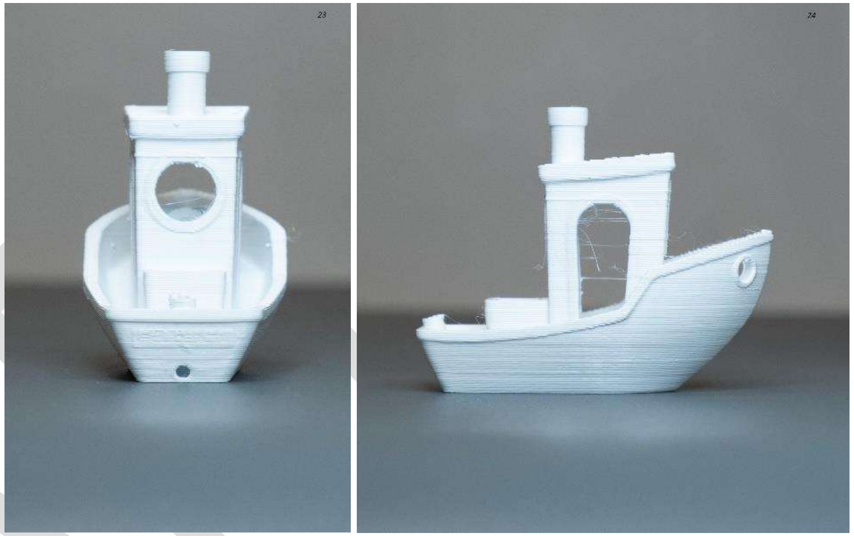

Figure 6 – Printer 2, PLA

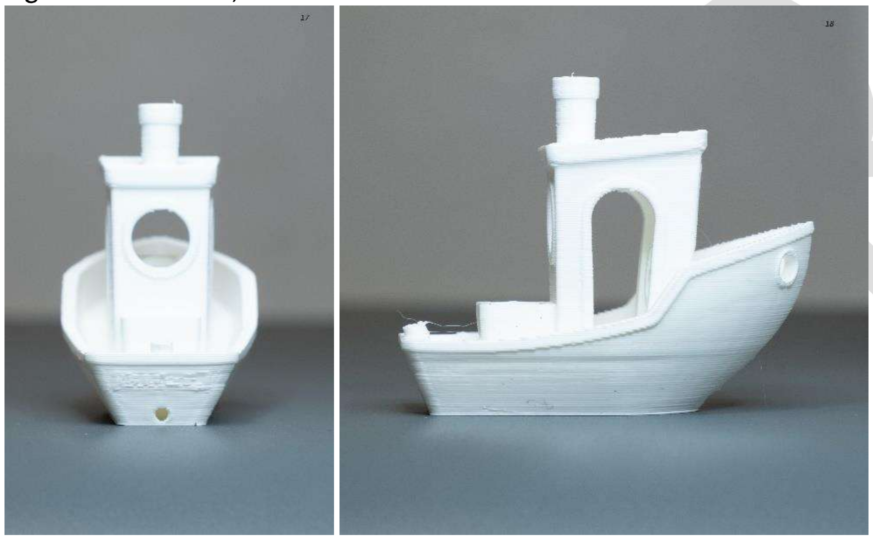

Figure 7 – Printer 3, PLA

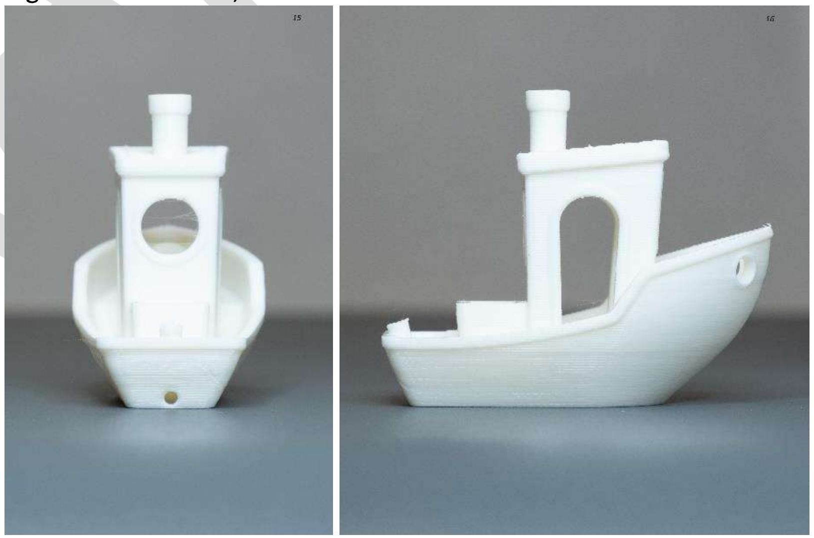

Figure 8 – Printer 4, PLA

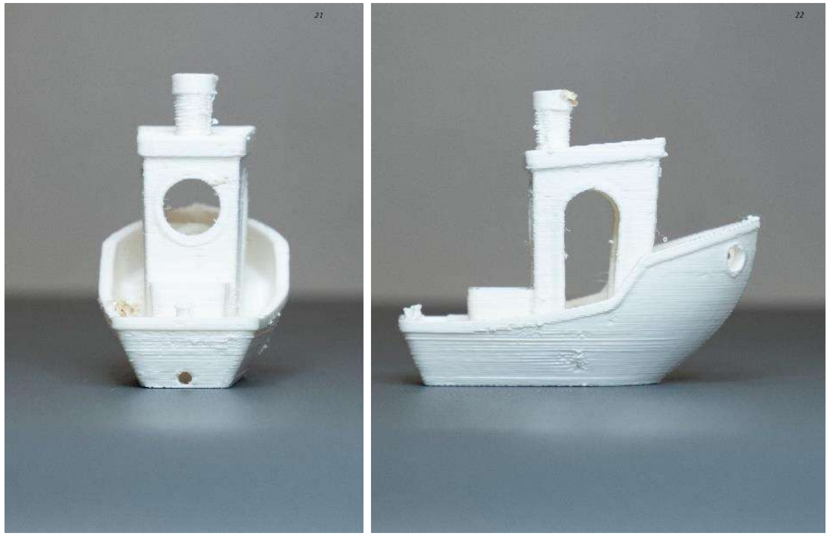

Figure 9 – Printer 5, ABS

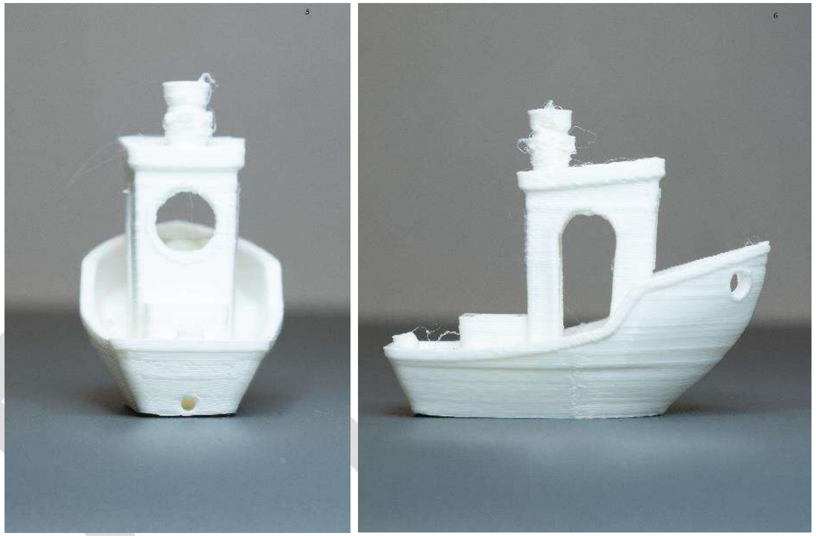

Figure 10 – Printer 6, Nylon

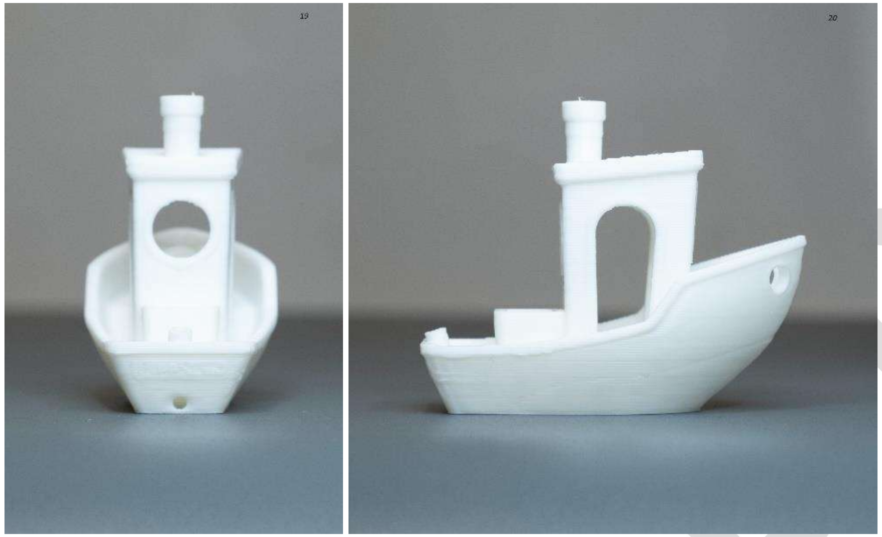

Figure 11 – Printer 7, PLA

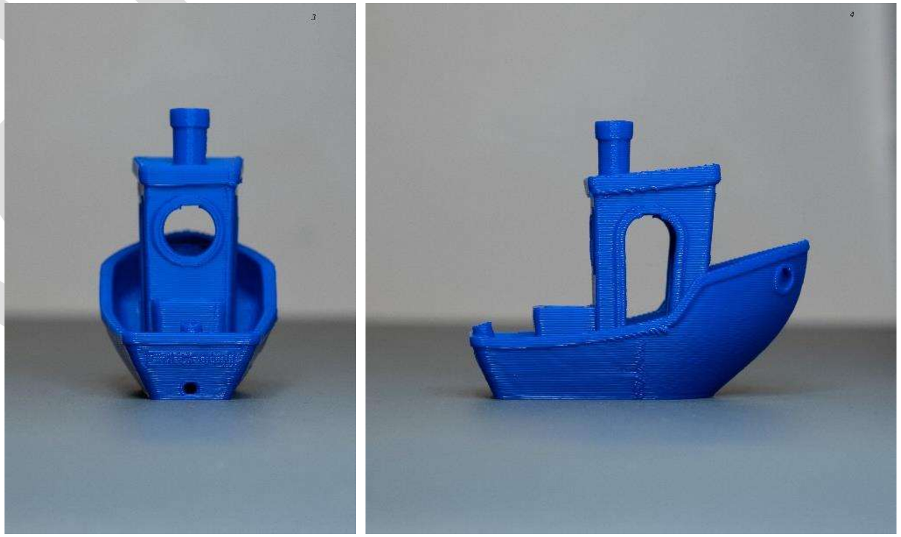

Figure 12 – Construct 1, Printer 8, PLA

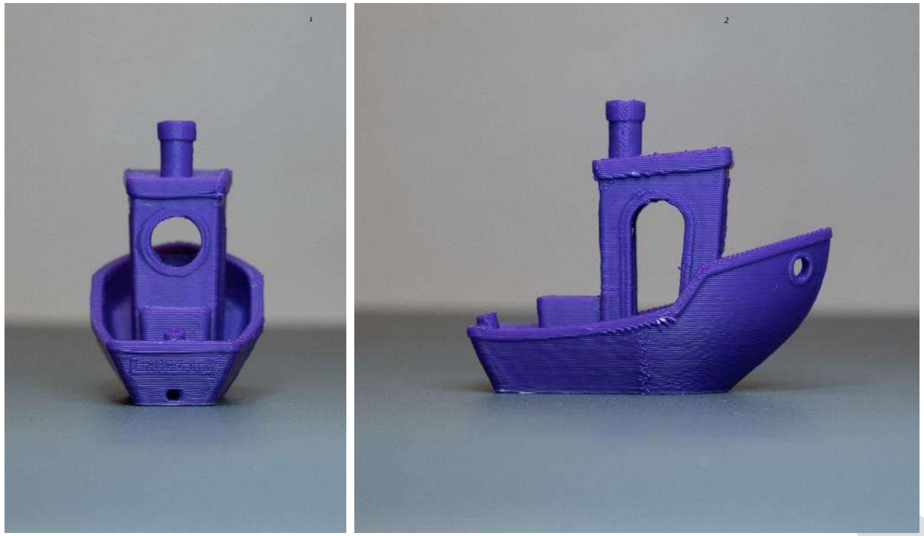
Figure 13 – Construct 1, Printer 8, ABS+


Figure 14 – Construct 1, Printer 8, PETg

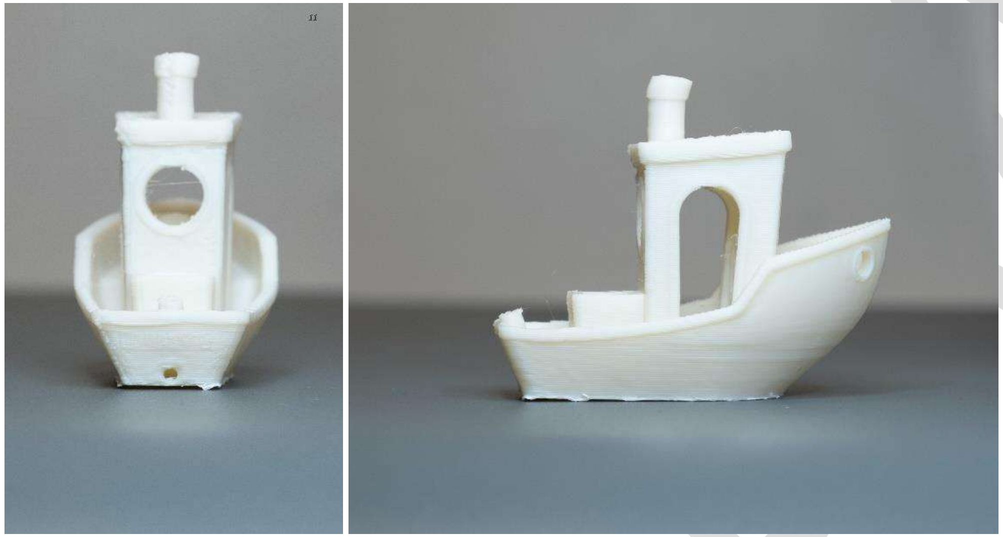
Figure 15 – Construct 1, Printer 8, ASA


Figure 16 – Construct 1, Printer 8, Nylon

4.3 Benchy Boats X3

In light of the printers ablity to build parts at speeds superior to other priners within the market, its ability was proven with the three builds equally spaced. The results shown in Table 3 and visualised in Figure 17 indicate further the increase in duration prints from half in Figure 4 to less than a third as a result of the increased print speed when traveling.

Printer	Material	Print 1	Print 2	Print 3	Average Time (h:m:ss) (s)	Std Dev. (s)
1	ABS				4:07:00 (14,820)	
5	ABS				5:05:00 (18,370)	
6	Nylon				9:18:00 (33,480)	
8 Construct 1	ABS	1:21:28	1:21:17	1:21:14	1:21:20 (4,879)	7
8 Construct 1	PLA	1:20:48	1:20:31	1:20:30	1:20:36 (4,836)	10

Table 3- Printers 1, 5 & 6 utilised slicer times, which were previously confirmed as accurate based on singular Benchy Boat print times

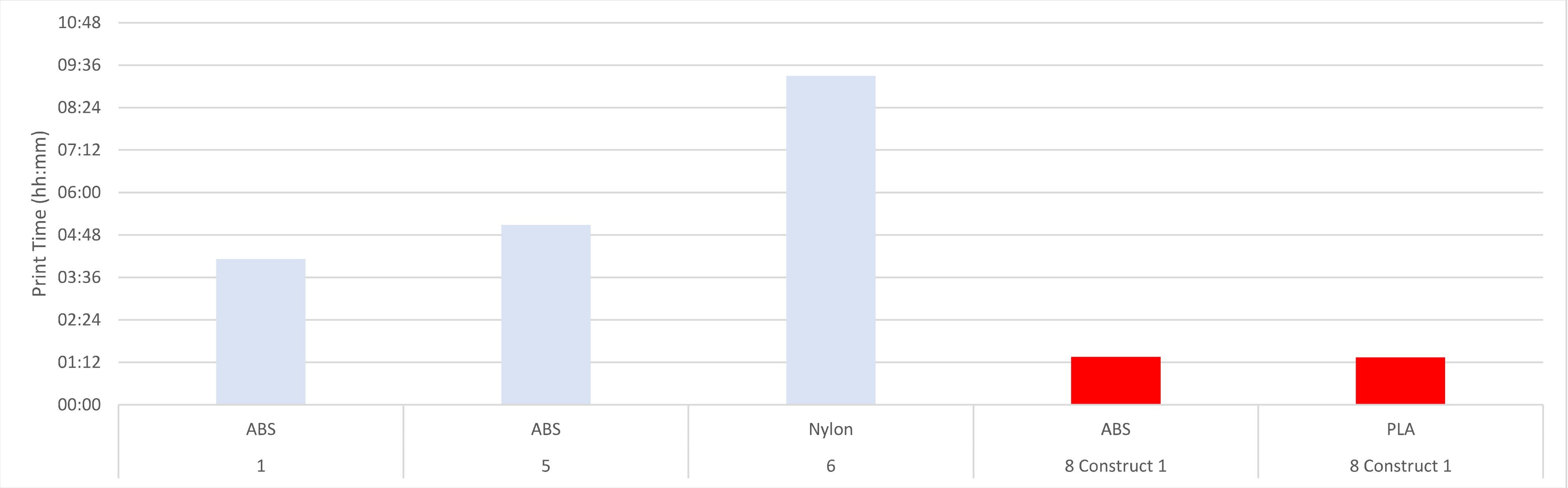

Figure 17 - 3 Benchy Boat Print Times, for printers 1, 5 & 6, these were sllcier times to their length of times, these had previously been verified by prints

4.4 ASTM D638 Dog Bone Printing

It was necessary to determine the extent of the printer's capability. To determine this, the materials' selection was broadened in order to detemine its full capability up against the industrial and commercial printers, having previously introduced some of these with the printing of a single benchy boat, therefore a selection of materials from each printer's capabilities was used alongside other engineering grade materials to push the printer's limit and these were as follows; PLA, ABS, ASA, PETg, PA (Nylon), PC.

The reslts of the timings is shown in Table 4, with the exception of Printer 1 in Nylon whose timing was previously determined using the slicers, which is reliable based on other slicings conducted and undertaken with that printer.

Printer	Material	Part 1	Part 2	Part 3	Average Time (h:m:ss) (s)	Std Dev. (s)
1	ABS	2:36:02	2:36:25	2:36:15	2:36:14 (9.362)	12
	PA				3:10:00 (11.400)	
	PC	3:06:00	3:05:59	3:06:01	3:06:00 (11,160)	1
	PLA	2:13:21	2:13:22	2:13:22	2:13:22 (8,002)	1
5	ABS	0:35:38	0:35:36	0:35:41	0:35:38 (2,138)	3
	PA				0:33:00 (1,980)	
6	PA	4:22:03	4:22:10	4:21:59	4:22:04 (15,724)	6
8 Construct 1	ABS	0:44:45	0:44:42	0:44:45	0:44:44 (2,684)	1
	ASA	0:36:19	0:36:22	0:36:22	0:36:21 (2,181)	2
	PA	0:45:02	0:44:28	0:42:35	0:44:02 (2,642)	77
	PETg	0:42:36	0:42:34	0:42:42	0:42:42 (2,557)	4
	PLA	0:45:09	0:45:10	0:45:12	0:45:10 (2,710)	2
	PC	0:44:53	0:44:53	0:44:54	0:44:53 (2,693)	1

Table 4 – Print times (hh:mm:ss) for 3 spaced and orientated ASDM D638 dog bones

It is clear within Figure 19 that printer 5 is on an equal footing with the print times, it would have been good to have also utilised the previous printer 7 for this print, however it was not available for this and would be advised when given the opportunity that this printer be tested for comparison.

DRAFT

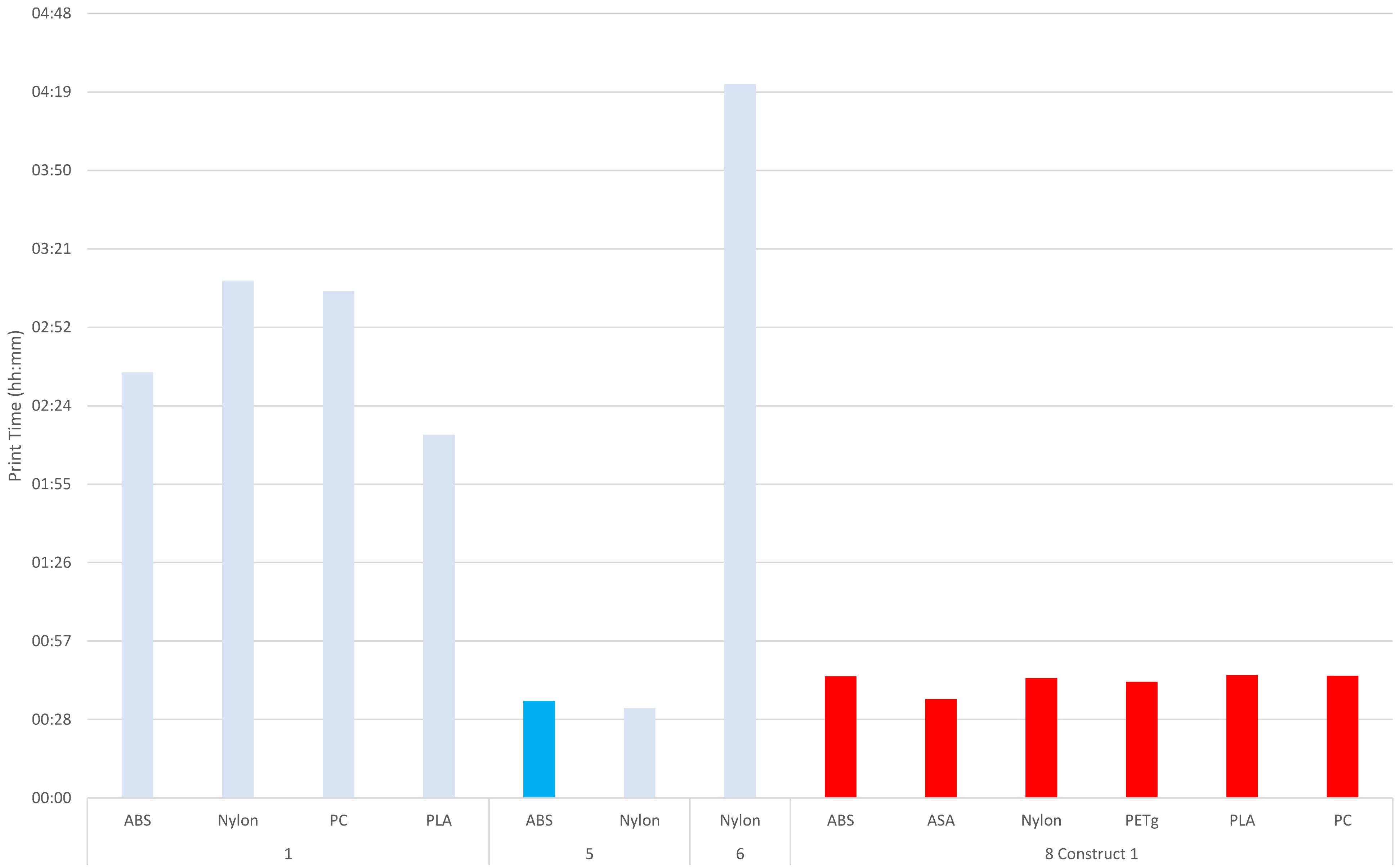

Figure 18 – ASTD D638 print times for 3 parts using various materials – see Table 4

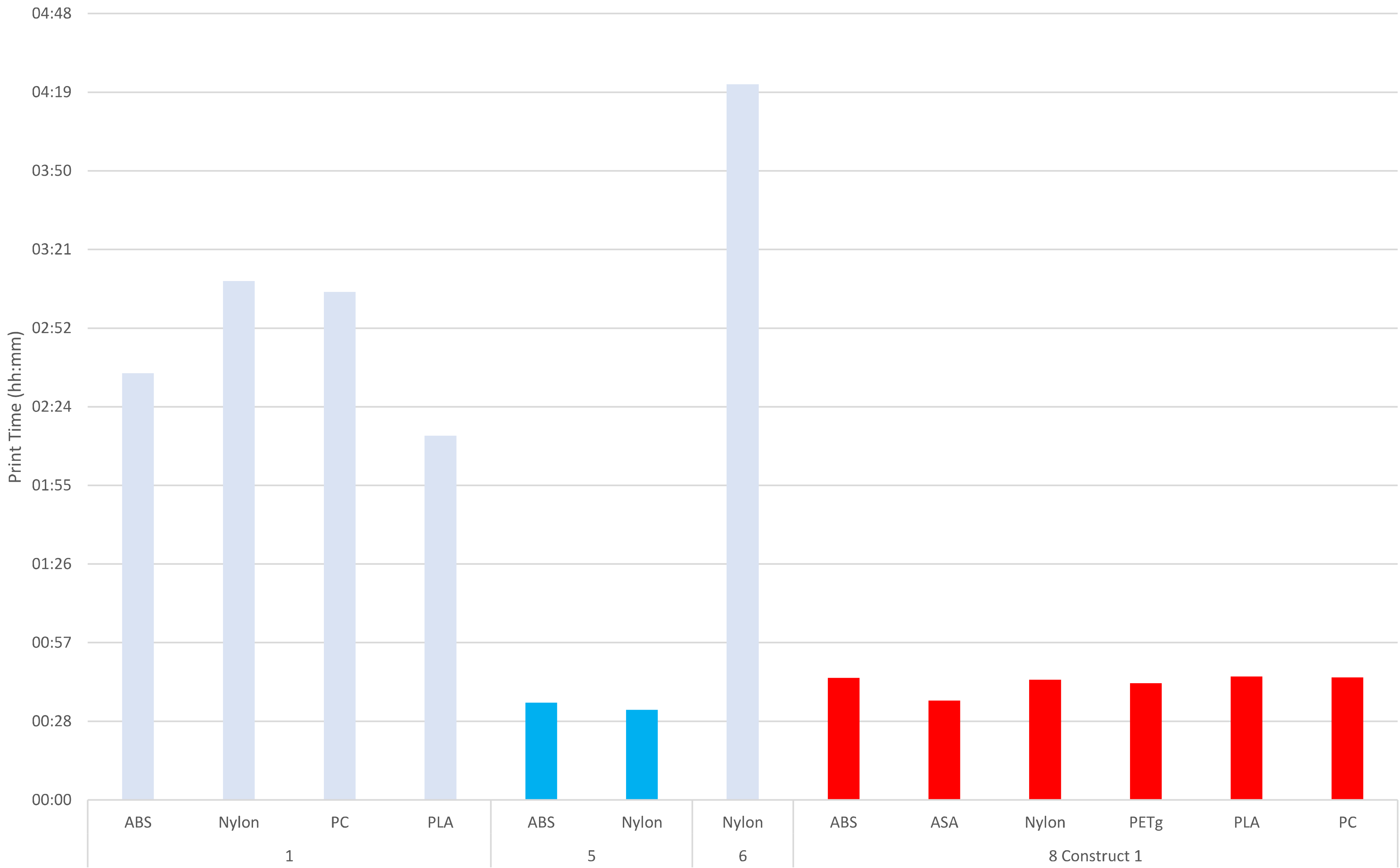

Figure 19 - Print Times for Three Spaced ASDM D638 Dog Bones

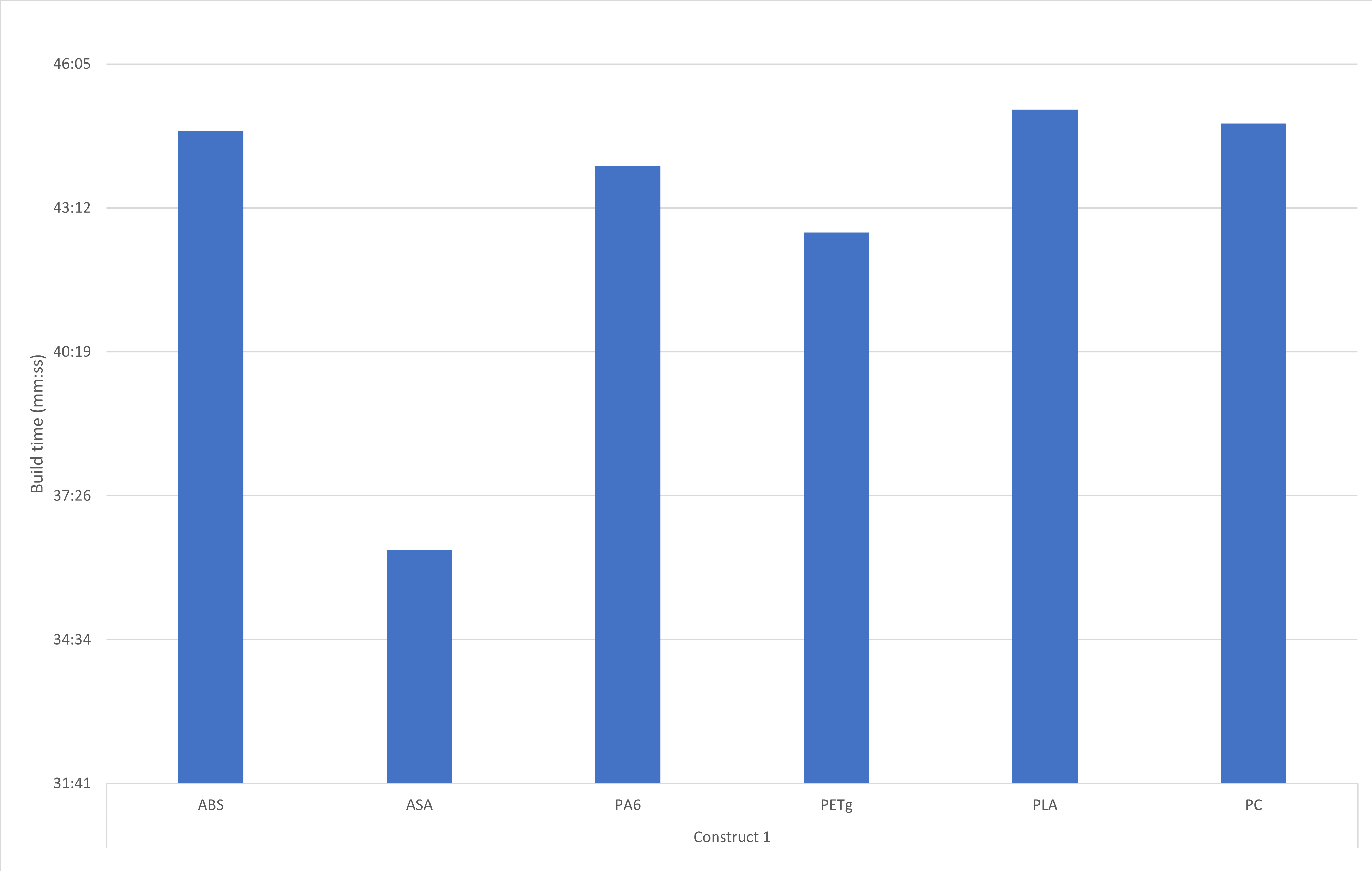

Figure 20 – ASTP D638 prints across a variety of materials.

4.5 What Poop!

The recent coined phrase of '3D Printer Poop' (Link) the excess material extruded, from purge or nozzle cleaning to prime towers or brim materials enabling adhesion to the bed. Wondering how the Construct 1 fared against all the others, besides some small pieces of filament sticking to the nozzle when extruding PETg, which were soon ironed out, there was nothing but a 2cm long and 2.5mm wide track deposited at the front of the build plate at the start of the print, with no shoot anywhere in site to clean or purge the nozzle, which provided clean printing throughout.

Whilst this was not measured within the context of this report, visually it was nothing in comparison to all the other printers, the industrial and commercial printers being the larger generators of poop waste within their systems.

4.6 Cost of 3D Printers

The following cost of printers was conducted based on cost at time of purchase and composed at the time of this report being created in 2022, costing. This is essential when comparing a product with the Construct 1 printer's capability, being that it is an important driver to any of the previously outlined industries and given the quality of parts being printed within their times, is worthy of printer's reviewing. Printer 7 is the current release cost of the product.

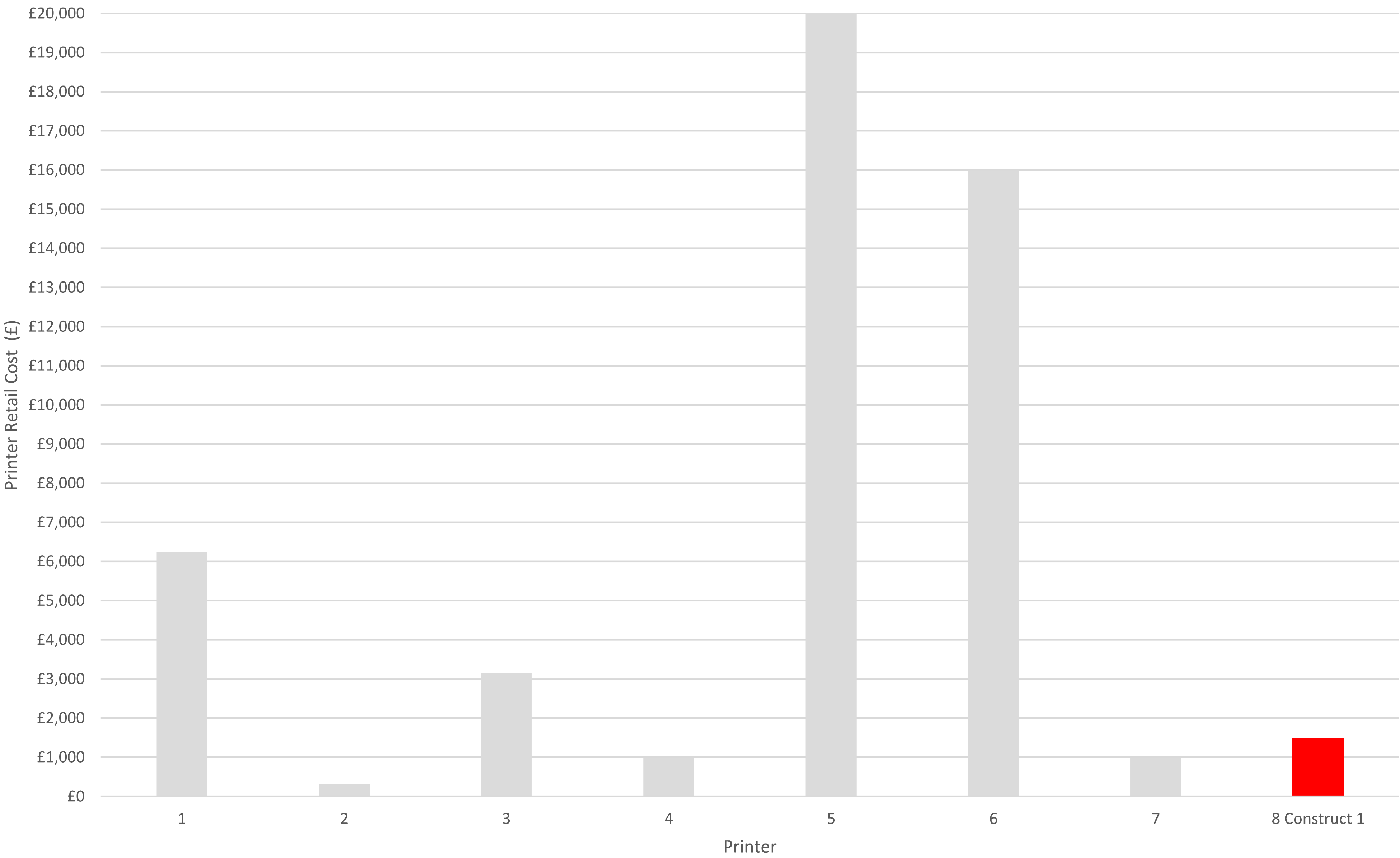

Figure 21 – Printer costs, printer 5 cost £125,000 – Cost of printer 8, the Construct 1 at time of writing is £1,495 retail with no discounts applied.

4.7 Construct 1 User Interface and Emergency Stop

This interface is not short of functions that did not take long to become familiar with, and whilst some were not utilised, their purpose for product development was clear, and such was the extent of features that anyone from a hobby printer to fully commercial operator would be at home with the technological advancements available at their fingertips. Some of the incorporated features cannot even be found on state-of-the-art research production printers, such as live alterations of feed rates, head temperatures and z-height alterations to name a few.

In addition to these features, for such a H&S world we live in, taking precautions to protect sometimes young operators within education establishments, the Construct 1 is not only fitted with a touch screen emergency stop function, also has a built-in system detecting collision of the mechanical systems, protecting operators from potentially dangerous pinching of the mechanics. The level of this system considering its speed has yet to be determined, however any step in the direction of safety is worthy of merit. This feature enables the operator to get closer, something which is lacking within caged systems employed to protect our audiences and users.

4.8 Printing Conclusion

To conclude this report, it was found that for a standard PLA print of a Benchy boat at 20% infill is equal to a newcomer in the market, Printer 7, which warrants further review, however, Printer 7 and the Construct 1 are double the speed of their nearest competitor and triple the speed of the slowest printer, standing up against the industrial machines, which were even slower than the domestic printers. These industrial printers are set up for large volume prints and one can speculate that these machines are not set up for these simple Benchy boats which necessitate support material as a limitation of the slicer.

Multiplication of boats on Printer 6, not only triples the print time, but increases as a result of travel time between parts from 1:48 (Table 2) to in excess of 9 hours (Table 3), whilst the industrial Printer 5 came alive with the large volume dog bones, having the quickest time of 33 minutes. Construct 1, came close at 36 minutes for the ASA, the pair of them only 27% of the time of the third quickest printer. This aligns the Construct 1 with an industrial printer and knowing the print parameters settings have more potential, these times will drop with the Construct 1. With Printer 5 coming in at £125,000 and the Construct 1 at £1,500, the domestic user can have access to industrial print times, along with the high-quality features of the Benchy Boat, which did not require support.

At a time when the energy crisis is subject on many tongues, this printer will reduce costs through its speed, maintaining quality and increasing output at the same energy costs, reviewing the finding for printing 3 Benchy boats in Figure 17 and Figure 3 with Table 1, where the next competitor's print times was at 1 hour, then for the same time, over 2 components were printed, and whilst the energy use figures were not reviewed within this report, it is something worth pursuing. Printer 5 uses 3 phase and compressed air to operate, whilst the Construct 1 uses a 13-amp fuse at 240v (UK variant).

To conclude, it was noted that the velocity of the print head clearly enabled higher angles to be printed without support, reducing further print time and waste materials to a technology that is ever reducing its carbon footprint towards a sustainable and affordable option for home construction (Link).

5 Report Summary

The author cannot put into writing the words of his colleague, witnessing the reality of this product before us, viewing the extruder moving at speed, as reality kicked in that this printer was "Rapid". Speed wasn't its only eye opener, from the outset it was easy to use with basic engineering knowledge of 3D print functions, and deserves the time of all Material Extrusion printer users, from hobby to industrial implementers that this product lives up to its marketing description of Rapid. Whilst the author of this report is familiar with 3D print technologies, this is the first time of using Material Extrusion with such high volume and intensity, with the printer performing effortlessly with materials that later were found, traditionally were difficult to adhere to the bed.

Reliability was faultless, with the printer previously doing hours of printing with the development team, nothing was out of the ordinary and the only problems encountered were those at a developmental level, and technical support was provided by the CONSTRUCT3D team throughout, and I hope such service would continue when the product goes to market. A life cycling review warrants further work; however, the system is composed of off-the-shelf components, nothing has not already been proven on other printers. The CONSTRUCT3D's firmware that requires testing to determine reliability.

The system-enabled printing parameter variation whilst printing; this feature could be complemented by being capable of sending the changes back to the slicer software, maintaining alterations towards improved print quality, otherwise it is necessary to undertake manual calculations to determine the correct values back in the slicer software prior to reprinting. Whilst this is no cost in comparison to the time saved using the Construct 1 printer, there is room for improvement.

It is evident that the industrial and commercial machines are built for large prototype features which are not expected when the Benchy was printed, however speed when printing the dog bones was evident with Printer 5, however Printer 6 was set up for other material (composite) compositions which are not represented within this report. Printer 7 warrants further review to determine if there are competitors with this product, however its generation of waste product (printer poop), is waste which cannot be tolerated in a market targeting the reduction of carbon footprint. Something that the Construct 1 clearly has in mind with minimal waste. This is evident with the parameters provided for the Construct 1 printer set up, to be slow on the initial layer, ensuring bed adhesion prior to changing gear for the remainder of the build.

Construct 1 Printer is clearly taking the Domestic market to a higher level of speed and accuracy to the general public, whilst clearly taking on the might of the industrial and commercial markets and their capability and whilst it is not a brute like those at this level, only time will tell if the Construct 1 and its bigger Construct 1XL will shake the markets.

It's clear that the CONSTRUCT3D team has truly brought Rapid back into rapid prototyping and maybe we should start referring to Material Extrusion technology as a manufacturing method. If you want a printer capable of producing parts at conventional speeds the system can be used at currently accepted speeds shared on various communities for printing materials. This printer has proved the evolution of the technology and why should we be satisfied looking back when life is just speeding up. This printer is sure to take the industry by storm (or 'at SPE3D?').

6 Further Reading: Websites

CONSTRUCT3D – Link

CONSTRUCT3Ds New High Performance 3D Printer at TCT3Sixty 2022 – Link

ASTM D638 – Link

MakerBot Thingiverse Benchy Boat – Link

3D Printing Offers Outstanding Sustainability Benefits, Whilst Also Avoiding Supply Chain Issues – Link