How to get the most out of your Magigoo – Build-plate temperature calibration and other tips and tricks

Introduction

Thermoplastic materials of different material compositions achieve optimum adhesion with different adhesion products. **PLA, ABS and PET-G** adhere firmly to the **Original Magigoo®** adhesive (Figure 1) when the build-plate is hot and are easy to remove once the build-plate cools down. In addition to the original Magigoo® adhesive which is suited for printing conventional FDM materials, the **Magigoo® Pro range** (Figure 1) consists of **four additional adhesives** designed specifically for use with **different engineering grade materials.**

The range includes:

- **Magigoo® PC** for polycarbonate filaments,
- **Magigoo® PA** for Nylon and reinforced Nylon filaments,
- **Magigoo® PP** for polypropylene and other poly-olefinic materials and
- **Magigoo® PPGF** which is specifically tailored for glass fibre reinforced polypropylene filaments.

Magigoo products are designed and tested to be used on **heated build-plates** with **glass surfaces**, yet Magigoo products also work on other build surfaces such as **aluminium, PEI and Kapton tape**.

At Magigoo our aim is to help make bed adhesion issues a thing of the past by suggesting the optimal settings for reliable bed adhesion each time. Unfortunately every FDM printer and its environment is different so different materials will require different printer settings for optimal adhesion.

Figure 1: Magigoo range, left to right: Magigoo® PPGF, Magigoo® PC, Magigoo® Original, Magigoo® PP, Magigoo® PA

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Currently the following materials have been tested with different Magigoo® adhesives on the Ultimaker S5. These settings are **specific to the Ultimaker S5** printer and the **specific materials from the manufacturers** in the table below.

Manufacturer	Material	Magigoo Type	1st layer build-plate temperature (°C)	Default Bed Temperature (°C)	Brim (mm)
BASF Innofil3D	Ultrafuse® PP GF30	PPGF	**100**	20	20
BASF Innofil3D	PP Natural	PP	**80**	70	20
BASF Innofil3D	ASA Natural	PC	110	110	No
BASF Innofil3D	PET CF	ABS	**80**	75	No
BASF Innofil3D	PAHT CF15	PA	**80**	75	No
Clariant	PA6/66 FR	PA	90	80	7
Clariant	PA6/66-GF20 FR	PA	80	80	No
Colorfabb	XT-Clear	ABS	75	75	No
DOW®	EVOLV3D™ OBC	PP	**110**	100	20
DSM	Arnitel® 2060 HT	Flex	**90**	80	20
DSM	Novamid® 1030CF	PA	**70**	65	No
DSM	Novamid® 1070	PA	**95**	85	20
DSM	Arnitel® 2045	Flex	**80**	70	20
DSM	Novamid® 1030	PA	80	80	7
DuPont™	Zytel® 3D1000FL	PA	**100**	90	20
DuPont™	Hytrel® 3D4100FL	PA/Flex	**105**	95	20
Fibreforce	Nylforce CF	PA	**90**	85	20
Fibreforce	Nylforce GF	PA	**100**	90	20
Filkemp	Nylon	PA	70	70	No
FormFutura®	Centaur PP	PP	**80**	70	20
IGUS®	I180	TBA	110	110	20
Lehmann Voss	LUVOCOM® 3F PAHT CF 9742 BK	PA	**105**	100	No
Lehmann Voss	PAHT	PA	70	70	No
Lehmann Voss	LUVOCOM® 3F PAHT GK 9874 NT	PA	70	70	No
Matterhackers	Nylon X	PA	**90**	80	8
Matterhackers	Nylon Pro	PA	70	70	7
Matterhackers	Nylon G	PA	**90**	80	8
Owens Corning	X-Strand™ GF30-PP	PPGF	**100**	20	20
Owens Corning	X-Strand™ GF30-PA6	PA	**75**	70	No
Polymaker	PolyLite™ PC	PC	110	110	No
Polymaker	PolyMide™ PA6-GF	PA	75	75	
Polymaker	PolyMax™ PC	PC	110	110	No
Polymaker	PolyMide™ PA6-CF	PA	**75**	70	No
Polymaker	PolyMide™ CoPA	PA	70	70	No
Taulman3D	Bridge	PA	**70**	60	20
Taulman3D	645	PA	**70**	60	20
Taulman3D	680	PA	**70**	60	No
Ultimaker	CPE	ABS	75	75	7
Ultimaker	TPU95A	ABS	0	0	8.75
Ultimaker	PC	PC	105	105	No
Ultimaker	Nylon	PA	**90**	80	No
Ultimaker	PP	PP	**80**	70	20
Ultimaker	ABS	ABS	85	85	7
Verbatim	PP	PPGF	**80**	70	20

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Why does the build-plate temperature need to be optimised?

What causes warping?

The FDM printing process requires that a polymer is molten and extruded onto a build-plate or a previous layer of extruded material, **layer by layer**. Each layer will thus be cooling at different rates leading to a **temperature differential** when the object is being printed. This manufacturing method will thus result in a part which is **cooling non-uniformly**, this leads to several issues including **warping and print-failure due to insufficient adhesion.**

Warping is when the print starts to **lift up from the corners** and **deforming in a lateral direction** (Figure 2). In extreme cases warping will cause the print to completely detach from the printer but even in mild cases it can be **detrimental due to loss of dimensional accuracy** which can lead to the part being unusable depending on the application. The severity of warp will depend on a number of factors with **some materials** being **more prone to warp than others.** It goes without saying that for a successful print this detrimental effect needs to be avoided as much as possible.

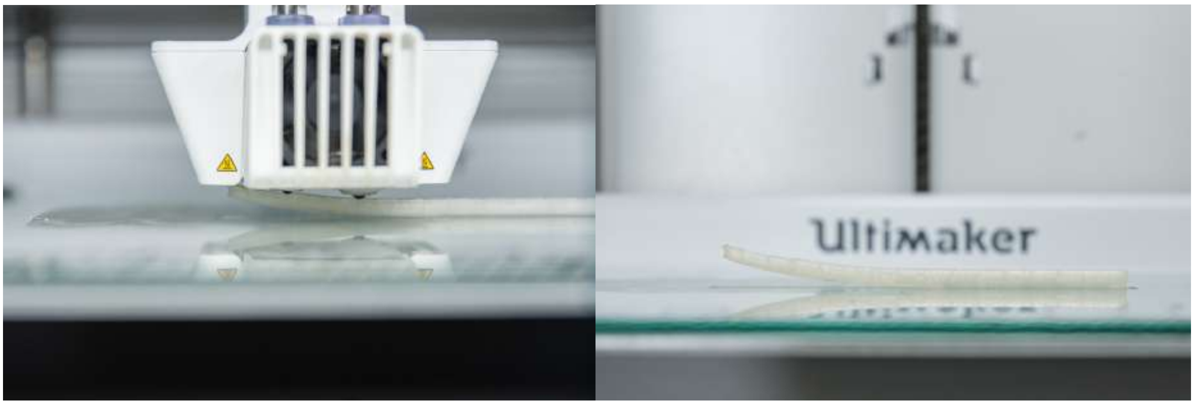

Figure 2: Nylon warping due to insufficient bed adhesion, one side is printed on regular glue stick, the other on Magigoo PA adhesive

The cause of warping can be attributed to the differential thermal contraction of each successive printed layer:

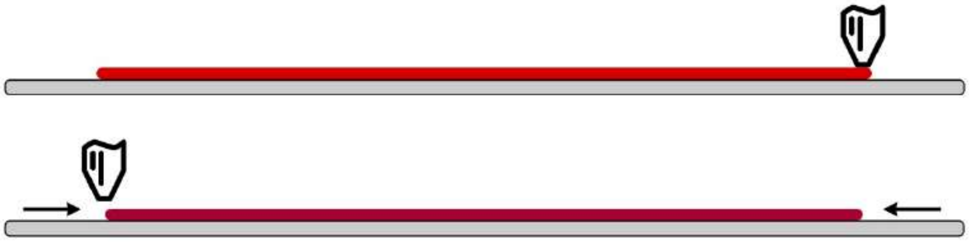

Figure 3: First layer

1. When the first layer is extruded onto the build-plate, **it starts immediately cooling down** to the build plate temperature, this will lead to the **first layer to contract slightly** (Figure 3).

Figure 4: Second layer

2. The second layer will be deposited on the already contracted first layer while also cooling down, thus contracting on top of the first layer. Since the bottom layer is already slightly contracted when the upper layer is deposited, **the upper layer will cause the layer below it to compress** (Figure 4).

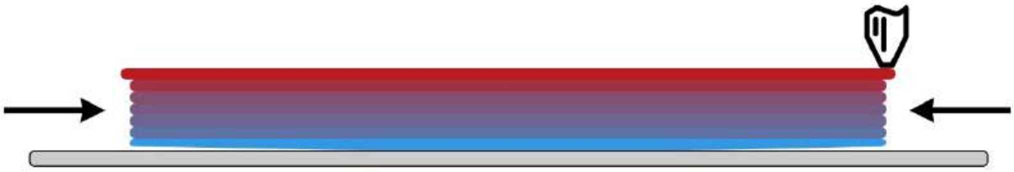

Figure 5: Print warp due to thermal gradient

3. This process will keep on repeating itself as new layers are added causing more **lateral compression of the lower layers.** This results in an **overall sheer force between the printed layers** which we can call **warping stress**. If the **warping stress** is larger than the stiffness of the part and the bed adhesion the bottom of the print will inevitably start pulling away from the build plate. (Figure 5).

The amount of warp depends on **several factors** including the material properties and the printing conditions **which are not independent of each other**. One of the most important material properties governing the amount of warp in a print is the **CTE (coefficient of thermal expansion)**. The CTE describes the tendency of a material to change its shape, area and volume as the temperature changes.

A material with a high numerical value for linear CTE exhibits large changes in length as a response to temperature change. As a result materials which have a **high CTE are more prone to warping than materials** which do not exhibit large changes in dimensions during the thermal changes present during FDM printing.

In addition to CTE, change in the crystallinity of the material during cooling need to be considered. Crystalline materials such as PP and PEEK will crystallise on cooling from the molten state. Crystallisation can lead to potentially higher shrinkage rates since crystalline structures tend to be more tightly packed. The crystallisation of a material depends on several factors and merits a discussion of its own, at this point it is sufficient to assume that crystalline materials such as PP, some nylons and PEEK tend to warp more than amorphous plastics.

Controlling the warp

The solution to prevent warp is to ensure that the adhesion between the first layer of the printed object and the build plate is larger than the thermal stresses on the first layer. The warp of a print can be mitigated by controlling build-plate adhesion and the thermal gradient. The first layer adhesion depends on several factors, these include:

- Build-plate material
- Adhesive used
- Type of material being printed
- Build-plate temperature
- Nozzle temperature
- First layer print speed
- First layer flow

The first layer adhesion is generally stronger when the bed temperature, nozzle temperature and first layer flow are high and the first layer print speed is low, however **these settings are highly dependent on the printer, material and environment combination.**

A good control of the thermal gradient during FDM printing can also help in reducing warp by reducing thermal stresses. This is generally, but not necessarily achieved by keeping the **internal build temperature slightly (10 ° - 20°C) lower than glass transition** of the material being printed. The glass transition temperature is the temperature, or rather a temperature range above which a thermoplastic material starts acting like a rubber, whilst below it the material is in a hard 'glassy' state. In layman's terms below the glass temperature the material is hard and strong while above this temperature the material is softer and less stiff. This means that **close to the glass temperatures the thermoplastic exhibits lower thermal stresses since it is softer.** For a large portion of FDM filament materials, **the temperature inside a printer without an actively heated and enclosed chamber is not enough to be close to the glass point of the material.** Nonetheless **keeping the build temperature constant is key to prevent printing issues** and it is always advisable to **prevent any drafts and sudden changes in temperature when printing.**

Some engineering materials such as Nylon and ABS can be easily printed in enclosed printers with heated beds. When a strong enough build-plate adhesive is used, a heated bed would be sufficient to keep the internal temperature of the printer high enough to mitigate warp. On the other hand high temperature materials such as virgin PC, PEEK, Ultem and PPSU will probably require a heated chamber in order to reduce the thermal stresses during printing which often leads to warping and other artefacts. **Other factors which may affect thermal stresses include, layer height, print speed, shell thickness and infill percentage, with higher values generally leading to a higher tendency to warp**.

Looking at this information above one might think that just increasing the build plate temperature as much as possible will solve all the problems of warping, unfortunately this is not the case with most FDM materials. **Increasing the build-plate temperature too much can cause three major issues:**

1. The most obvious issue is a loss in print quality due to the printed polymer on the build-plate being too soft, this will usually cause curling at sharp edges and leads to deformation of the part (Figure 6).

Figure 6: Benchy print using PLA, images on the left shows a benchy printed with the heated bed set to 60 °C, while the images on the right show a benchy printed at 80 °C, on closer it can be noted that the benchy on the right warped and also shows artefacts due to the layers curling up from excessive heat.

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2. As the print height starts increasing, the mass of material at the bottom of the print i.e. the first few millimetres or centimetres, need to be stiff enough to stop the thermal stresses from the newly deposited layers of the print to stop influencing the base of the print thereby arresting any further warp (Figure 7). **If the temperature of the build-plate is too high, this usually means that the base of the print will be soft enough to allow the additional layers on top of the print to pull on the base of the print**. A practical example is when comparing the behaviour of rigid printing materials to that of flexible materials. Rigid materials such as ABS or PC which usually do not continue to warp, or warp significantly less as the print reaches a certain height. On the other hand flexible materials such as PP or nylon will keep on warping significantly as the print progresses and reaches its full height, if the build plate adhesion is not strong enough.

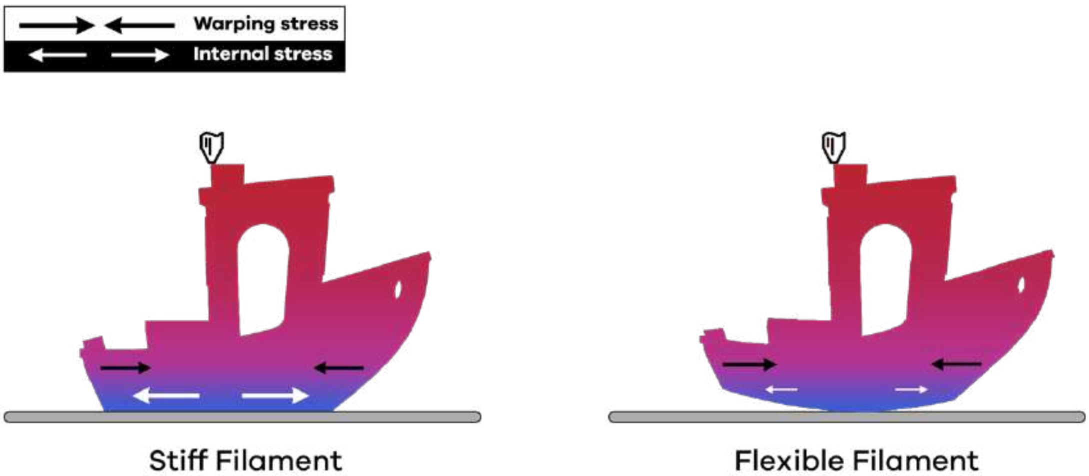

Figure 7: Printing with a stiff material versus a flexible material, the stiff material will be able to resist the warping stress, since the cooler material at the bottom of the print has enough strength (internal stress) to resist further warping. A flexible or soft material will not be strong enough to resist the warping stresses induced by the shrinkage of the uppermost layers of the print.

3. Another factor is related to the nature of the adhesive. While **at higher temperatures** the adhesion between the plastic and the adhesive is usually greater, **the actual strength of the adhesive layer will start decreasing.** Most adhesives, and even build-plate surfaces are made of polymers which soften as the temperature is increased. As a result, there will exist a range of temperatures for each material in which the warp of the part being printed is at a minimum. In this range there will be a compromise in which the first layer adhesion is maximised, the adhesive layer strength is also maximised and the thermal and warping stresses are minimised. For some materials this optimum range might be wide but for **most challenging materials the optimum printing temperature range can be as small as 5-10 °C.**

For these reasons determining the best printing temperature in your 3D printing system is important for best performance with Magigoo® adhesives.

How to determine the best build plate temperature

This process of finding the best build-plate temperature is relatively simple but often overlooked. One needs to print a test print specifically designed to assess the warping behaviour at different temperatures. This print is preferably small in order to minimise use of filament and also to save time, however also needs to be a good indicator of adhesive performance. **A print with a wide base and a low z-height is not an ideal indicator of adhesive performance**, on the contrary prints with narrow bases such as wedges (Figure 8) and prints with sharp corners are usually more prone to warp and more ideal for assessment of adhesive performance. Such prints can be easily found online on sites such as *www.thingiverse.com*, (Figure 9, Figure 10)

Figure 8: Wedge print, an ideal geometry for testing the first layer adhesion of your build surface, the narrow base limits the contact area with the build plate. This shape is one of the geometries used in the Magigoo testing labs to assess the adhesive performance with different material and adhesive combinations.

Figure 9: The Warpinator 5000 by Maker's Muse, this is a similar concept to the wedge print but slightly more extreme.

Figure 10: A simple warp test by Hagster, downloaded from Thingiverse

Tools and Materials:

Apart from a well-functioning and calibrated 3D printer and a 3D model for testing, one would also need some way to measure the amount of warp on a print. This can be done by visual comparison but can also be more accurately done using a feeler or slip gauge in order to determine the amount of warp (Figure 11). The calibration of 3D printer bed temperatures will be tackled in a future article.

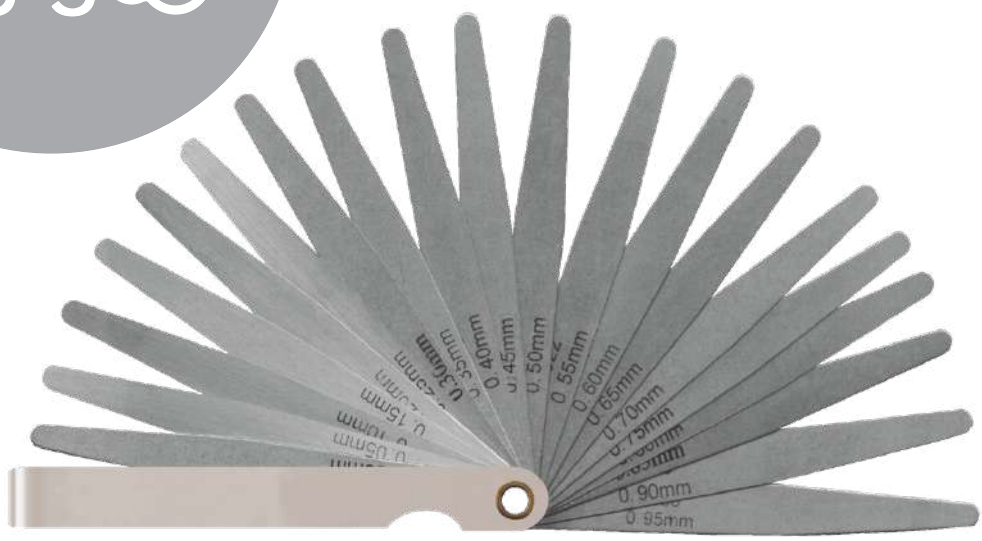

Figure 11: Feeler gauge, ideal for measuring small amounts of warp accurately

Method:

1. One can start the test from a recommended build plate temperature setting, either from the filament manufacturer or from other reliable sources or use the table below as a rough guide for the optimum printing temperature for each adhesive.

Material	Magigoo Adhesive	Build-plate temperature
PLA	Magigoo®	50-70 °C
PET-G	Magigoo®	60-90 °C
PET	Magigoo®	60-90 °C
Carbon filled PET	Magigoo®	60-90 °C
CPE	Magigoo®	60-90 °C
ABS	Magigoo®	80-110 °C
HIPS	Magigoo®	80-110 °C
Nylon	Magigoo® PA	60-100 °C
Glass filled Nylon	Magigoo® PA	60-100 °C
Carbon filled Nylon	Magigoo® PA	60-100 °C
PP	Magigoo® PP	60-90 °C
Carbon filled PP	Magigoo® PPGF	70-100 °C
PC	Magigoo® PC	90-120 °C
TPU/TPE	Magigoo® or Magigoo® PA (flex)	60-100°C
PEEK	TBA	150 °C

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2. Once the temperature at which testing will start is determined, let's call this T_0, one can print a test print at this temperature, wait for it to finish (if it finishes) and measure the warp at each end or corner of the print. If the print does not succeed, the point at which the print became completely detached from the build plate can be used as a data point (Figure 12).

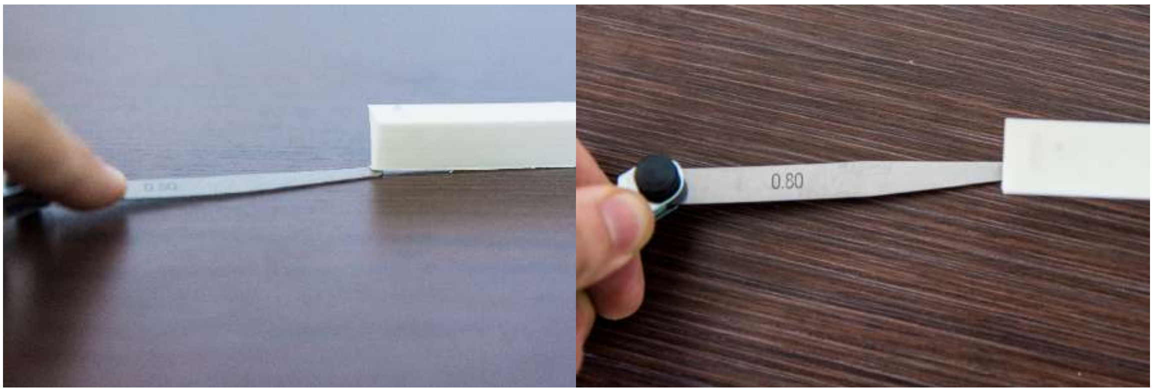


Figure 12: Measuring the warp on the edge of the wedge print using a feeler gauge

3. After this one can perform the same test using the same settings at different build plate temperatures **in steps of 10 °C above** T_0. At a certain stage of printing the test print at a higher temperature the amount of warp clearly starts increasing.

4. If the warp continues increasing on the next increment for the build-plate temperature, one can safely assume that further increasing the temperature beyond that point will cause the print to warp even more and thus can stop increasing the build-plate temperature.

5. The test is continued starting from **10 °C below** T_0 and decreasing in steps of 10 °C. Again if at a certain stage the warp will start increasing as the test print is performed at lower build-plate temperatures, one can stop testing.

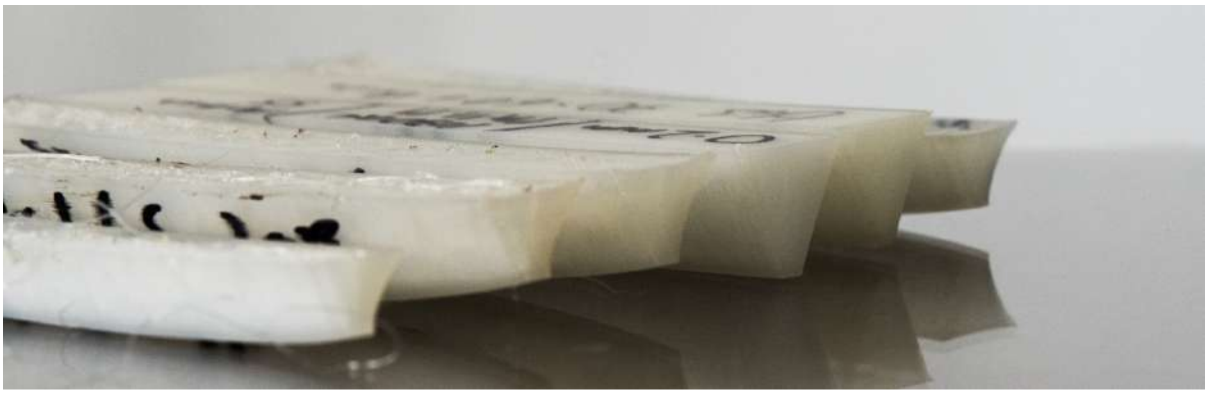
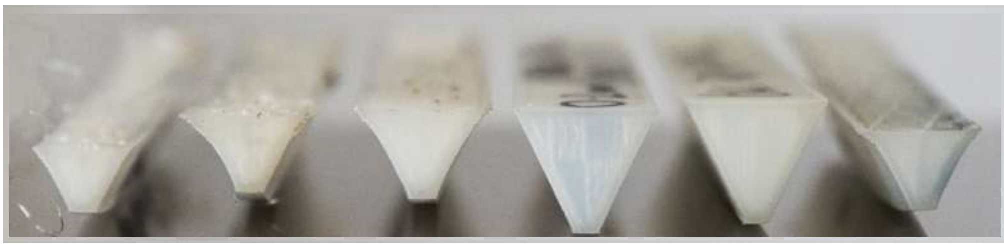


Figure 13: Wedge prints at different temperatures showing different amounts of warp and/or rates of completion

6. Once all the tests are performed the temperature at which the print with the least warp can be determined and that is your ideal build-plate temperature for the adhesive, material and printer combination (Figure 14).



Build-plate Temperature	**40 °C**	**50 °C**	**60 °C**	**70 °C**	**80 °C**	**90 °C**
Print progress (%)	50	69	100	100	100	76
Average warp (mm)	n/a	n/a	2	0.2	1	n/a

Figure 14: Results for bed temperature optimisation of a Nylon filament with Magigoo PA on the Ultimaker S5, the optimum bed temperature is around 70 °C

A blank template for noting and keeping record of the optimum build-plate temperature can be found in the next page.

Build-plate temperature optimisation test sheet

Filament:
Printer:
Adhesive:

	T_0 - 40°C	T_0 - 30°C	T_0 - 20°C	T_0 - 10°C	T_0	T_0 +10°C	T_0 +20°C	T_0 +30°C	T_0 +40°C
Build-plate Temperature (°C)									
Print progress (%)									
Average warp (mm)									

Additional Comments:

Filament:
Printer:
Adhesive:

	T_0 - 40°C	T_0 - 30°C	T_0 - 20°C	T_0 - 10°C	T_0	T_0 +10°C	T_0 +20°C	T_0 +30°C	T_0 +40°C
Build-plate Temperature (°C)									
Print progress (%)									
Average warp (mm)									

Additional Comments:

Improving adhesion further

With some engineering materials, **printing at the optimum build-plate temperature** and using a **designated build-plate adhesive might still not be enough to prevent warping.** Some materials will benefit from a heated build chamber which reduces the thermal stress however other method exists to mitigate warping and aid first layer adhesion. These include:

- Correct application of adhesive
- Setting first layer temperature slightly higher
- Using a brim
- Tweaking first layer deposition settings
- Tweaking other settings for certain materials

Application

Before application one must make sure that the build-plate is cleaned properly and free from oils and detergents which will negatively impact adhesion. Care must also be taken to apply the adhesive evenly, in some cases applying a double or triple layer of adhesive will improve adhesion. (Figure 15)

Figure 15: Apply Magigoo in an even layer on the area for printing, for a more detailed application guide visit (insert link to videos)

Using a slightly higher temperatures for the first layer:

An additional 5 °C, 10 °C or even 15 °C on the build plate over the base printing temperature can often help with improving the adhesion on the first layer, the build-plate can then be turned down to the base temperature to avoid problems associated with the build-plate being too hot. The same principle can also be applied for the nozzle temperature, an additional 5 °C - 15 °C on for the first layer usually aids with improving the interaction between the first layer and the adhesive.

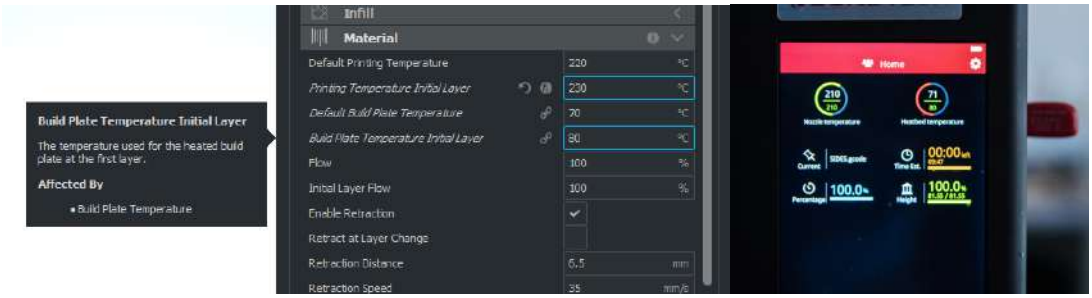


Figure 16: Adjust the first layer temperature settings from your printer or slicing software for better first layer adhesion

Using a brim

With certain materials such as PP, some Nylons, some Polycarbonate materials and Glass reinforced PP, **a brim is an absolute necessity with most parts** (Figure 17). For example polypropylene materials and some nylons show poor adhesion, are flexible, crystalline and have a high shrinkage rate, the perfect recipe for warping. This means that a wide brim will be needed to keep the part from peeling away from the build plate. On the other hand materials such as polycarbonate are very stiff and pull on the build-plate with large amounts of force, a brim will help distribute this force on the build plate and thus reduce warp. When using a brim it is also recommended to use the largest first layer height possible since a thicker brim is stronger and will thus be more effective against warping.

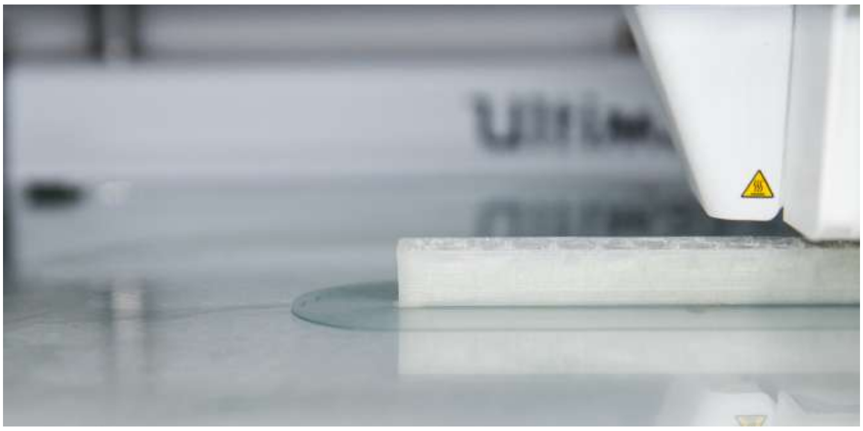


Figure 17: Using a brim helps mitigate warp with materials that are prone to warping

Tweaking other first layer settings

Slowing down the speed for the first layer helps improve the interaction of the melted plastic with the adhesive layer and thus will aid in first layer adhesion. Similarly slightly over extruding the first layer also improves first layer adhesion (Figure 18).

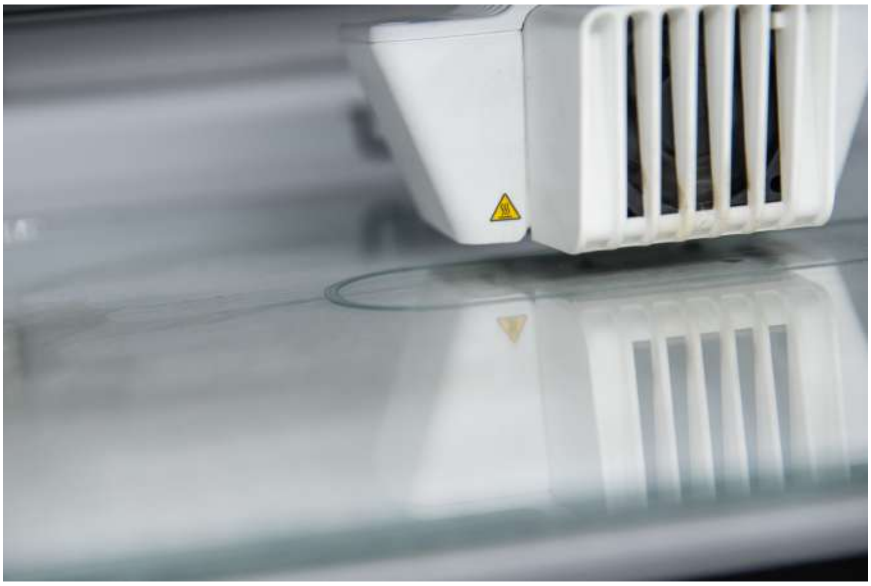


Figure 18: Tweaking the first layer extrusion settings can help with improving first layer adhesion

Turning off the build-plate after the first layer and using fan cooling for certain materials

Some exotic materials such as glass filled propylene and some flexible materials behave differently from other materials. These materials counterintuitively benefit from a cooler environment while printing. This can be brought about by disabling the heated build-plate after the first layer is completed or using an active part cooling fan. Since these materials are somewhat flexible the thermal stresses brought about by the uppermost layers of the print will have a large effect on the bottom of the print. By cooling the plastic the both base of the print and the build plate adhesive will become stiffer and thus restricting the uppermost layers from further deformation of the print. While this solution is highly effective for some filament types it can be disastrous for other filaments such as ABS, polycarbonate and which tend to detach once the build plate cools.

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