low-bondage ***warp-index***

1) warp:

Everybody who is printing 3D knows the problem. You want to print a bigger object, let's say more than 15 cm in x-y-plane, but it's not allowed to be because its ends might come off the the printplattform. A straight line is not straight, in any case not on a 3D printer. The line is bended, always bended upwards.

2) preventing warp:

We know about a lot of methods to minimize warp. These have not only been developed by the reprap scene, also by the company Stratasys that invented the FDM procedure almost 25 years ago (1989, by S. Scott Crump). Therefore Stratasys printers have a heated print chamber.
That means all objects are printed in a hot printroom and slowly cooled down.
This heated environment is separated in a very complex way from the printhead guidance and has been simplified or replaced by the reprap scene. They created the heated print plattform (bed).
With this you unfortunately can not completely nullify the warping effect, but at least reduce it considerably and that only in the lower z-axis values, because the heat of the bed does not affect the print in higher regions. Before the heated bed became a kind of standard, the scene managed the warp with brims, special stable rafts or constructive tricks to avoid occouring warp e.g. with slim slots to divide the object;
source: (BFB forum, ABS object, Kaipa; Mon, 2010-04-26 14:12)
http://elco.crsndoo.com/bfb/www.bitsfrombytes.com:8080/jpy/forum/post/no-warp-construction-techniques

3) warping will not end
In any case the warp will still keep us busy over a long time as it also bothers especially the filament producers.
Meanwhile all the manufacturers claim that his filament has " low " or " near to zero warp ".
However, often these are only empty marketing phrases and nobody is able to exactly define the warp.

4) measure the warp

To measue the warp is not that easy. You cannot just apply a ruler and read out any index!
It is a common misunderstanding to use the provided shrinkage values given by the polymer-producers, as indication for the expected warp.
The values for the shrinkage of a plastic –however- cannot be used 1:1 as indicator for the warp of a 3d printed plastic, because layer-wise printing is a complex thermal process, depending on more than a dozen of parameters.
Also, unfortunately the reasons for warping are not that easy to explain here, but Kai Parthy developed a method that enables everybody to determine the warp-index with a regular 3d-printer (also without heated bed, what would also be the best way to a standard that everyone could replicate). The measured values will provide an index (which moves between zero and seldom more than 10, like school grades: 0 = good, 10 = bad.)
This index states whether this filament tends to warp strong or not (under same conditions).

5) warp index - necessity?
Now everybody can test and check any filament whether the specifications given by the producers are correct. (mostly it is described like: filament with low warp, but what does LOW warp mean? Nobody would say: with much warp ;)
Main issue is that you need to have a flat bed scanner.
Important note, this test does not describe how to print with less warp!
No, the main topic is, to create a repeatable standard test to determine which material will achieve best print results because of the lowest warp tendency. Which material is more suitable for bigger objects and which is improper.

6) warp-index:
where would it end up for experts ?

Some modifications of the warp-test concerning the technical constraints as:

- printhead speed, layer-thickness
- printbed temperatur
- total time to print a layer

are already done. The results are schematically shown in the graphs of the white paper page 3.

7) the warp-index
In simple steps: how does it work?

- print a warp-test-object (downloadable)
- draw with a thick line with a permanent marker at the Z-levels that are relevant for the measurement of the (2D)scan.
- scan the object (at least 1200 x 1200 DPI) and
- measure the flexion of these layers with a graphics software (e.g. inkscape) to 1/100 mm
- the values of the flexion based on the measured layer length will give an index which can be easily compared to other values (0 is good, 10 is bad).

Because the calculated index is found from an almost unhindered warp, it might also be called
>> low bondage warp-index << .

8) some backround / testobject: „curtain"

- *curtain* was designed to be able to print a large object in one run with most of the -now and in the future- available materials, on a cold print plattform
- a further idea behind the curtain-form was, to create an object, where the area to be measured, has a very low contact and adhesion area to the plattform,
- each curtain-layer has the same lenght at each Z-hight, for the same amount of thermal energy applied to each layer

9) why a cold print plattform?

- cold conditions (20 – 25°C) are a common denominator, printable on each printer
- other, hot conditions are not reproducable at different printer settups
- yes a little thermal radiation caused by a big hotend heater will have a small influence at the curtains warp

10) incidentally

- there are several filaments that have a particularly low warp when they are printed in a cold environment,
- so please do not always heat up the bed - no, many amorphous polymers want to be printed cool and rapidly cooled
- a self stiffening effect will prevent here warp

11) credits

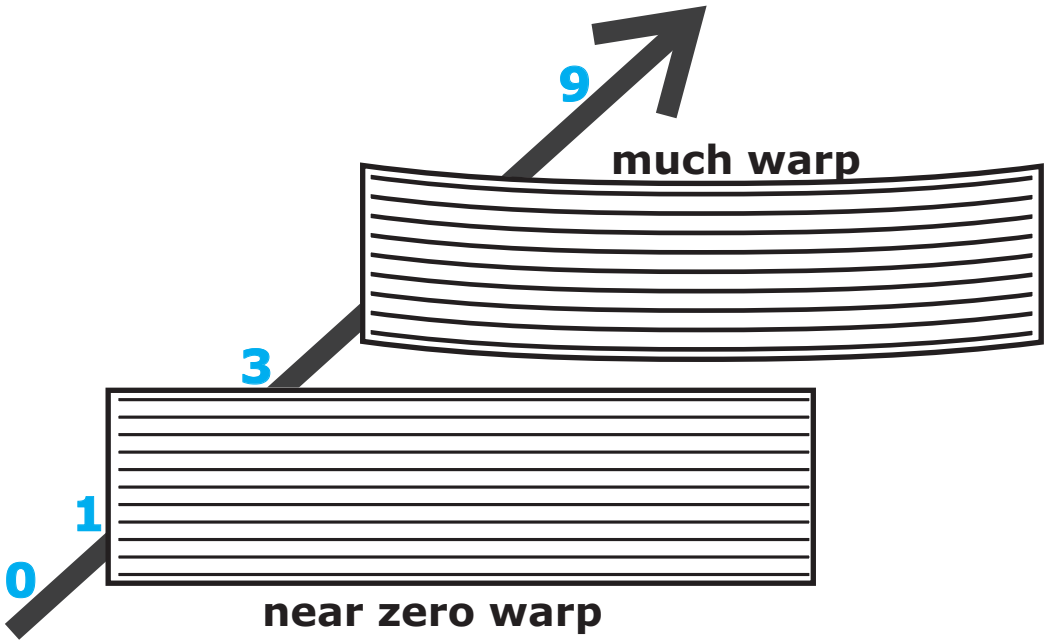
My special thanks applies to Joerg Draheim/innovativaggregat for more than 5 years with best help in 3D-printing-know-how and hard and software consulting.

>>> *low-bondage* ***warp-index <<<***
by Kai Parthy 2015

download:

standard warp-curtain; z=50mm;
https://www.dropbox.com/sh/m96toce40er54b7/AAB5onvMN_7l76zwE-d1eezHa?dl=0

how to measure a precise warp value ?



for benchmarking 3d printing filaments

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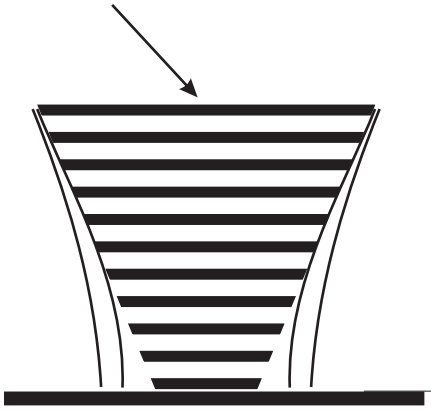
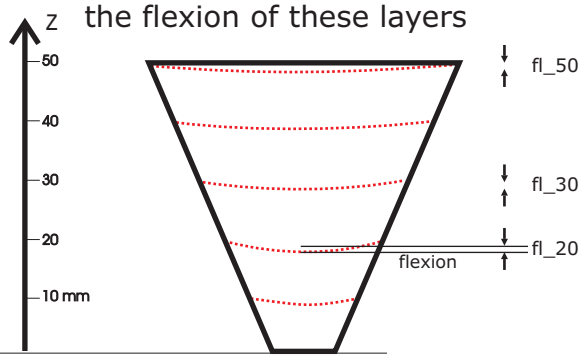
step A

print the warp-specimen "curtain"



step B

highlight five layers with a permanent marker, scan the print on a flatbed scanner and measure the flexion of these layers



step C

calculate five warp values and generate the average

$$\text{warp}(z) = \frac{\text{layer flexion}}{\text{layer lenght}} \times 1000$$

Z	layer-L	flexion	warp
50	66,844	0,085	1,27
40	56,509	0,099	1,75
30	46,636	0,102	2,19
20	37,320	0,120	3,22
10	27,256	0,178	6,53

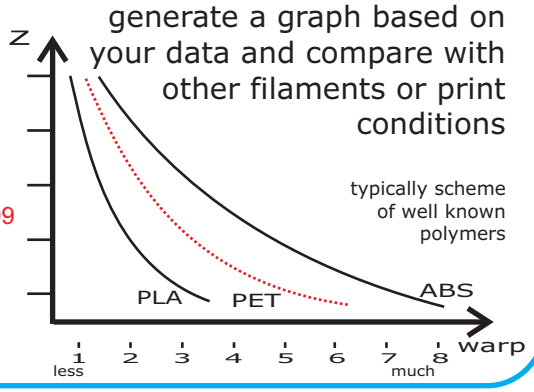
warp50 = 1,27

$\varnothing$ $\text{warp}_{\text{index}}$ = 2,99

warp10 = 6,53

step D

generate a graph based on your data and compare with other filaments or print conditions



how to measure the *low bondage* warp-index

test conditions

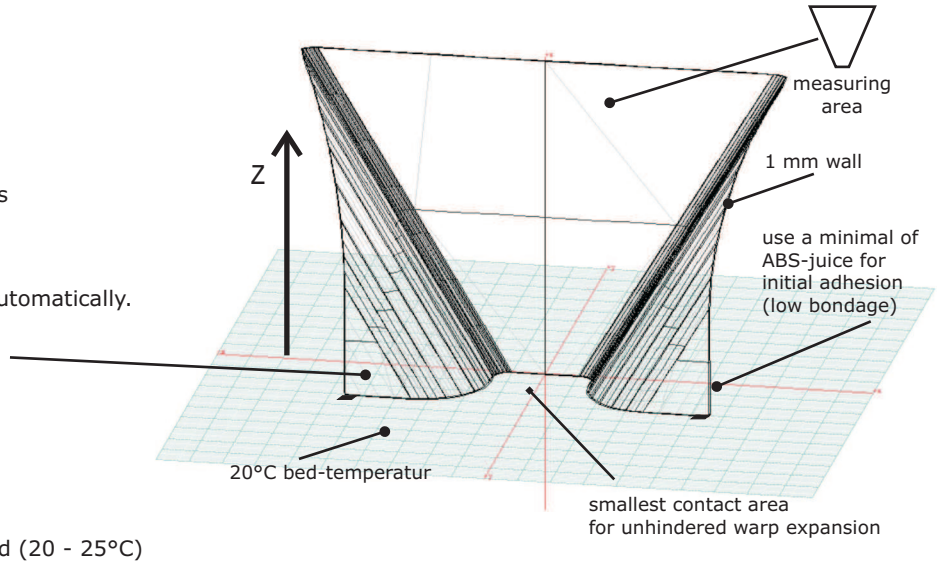
This method to find a precise warp-index is associated with technical constraints. No special 3d-printer, also no heated plattform is required. **For the method please do not use tricks to prevent warp.**

The warp-index will help you to determine, if the material that you want to use, is printable in large format and you may compare it with other materials.

Warp is one fundamental indicator for filaments, but further significant properties are:
- thermal stability,
- elongation at break,
- tensile strenght,
- melt viscosity,
- cristaline or amorph,
- transparency,
- conductivity,
- filled with organic or anorganic fillers
- roughness

and much more.

These properties do not correspond automatically.



test-object: warp-curtain (download)

print parameters:

- 0 % filling, 0 solid at top, 0 bottom
- 1 perimeter > ~ 1 mm wall
- 0.25 layer
- object object fan off
- plattform and environment unheated (20 - 25°C)
- 0.4 - 0.5 nozzle
- printspeed: 30 mm/sec

Warp-Index for filament-rating, necessary for your material-choosing

warp-index / technical constraints / nomenclature

it´s proposed to fill your identified values in that formation

warp - index		technical constraints
w-50 =	1.27	
w-10 =	6.53	
w =	2.99	(20°/20°C/1:1/0.25/0.4/v-30/1h/1:1)

20°/20°C	=	plattform temp. / environment temp.
1:1	=	for bigger printers scale the warp-curtain by whole numbers
0.25/0.4	=	layer-thickness / diameter of nozzle
v-30	=	print speed mm/s
1h	=	scan curtain within 1h and 2d (days) later for comparison
1:1	=	one test object / 1:3 = print 3 curtains for simulating bigger objects
w-50	=	warp at 50mm
w-10	=	warp at 10mm
w	=	warp-index (average)

range; 1= very good; 10 and more = extrem wrong

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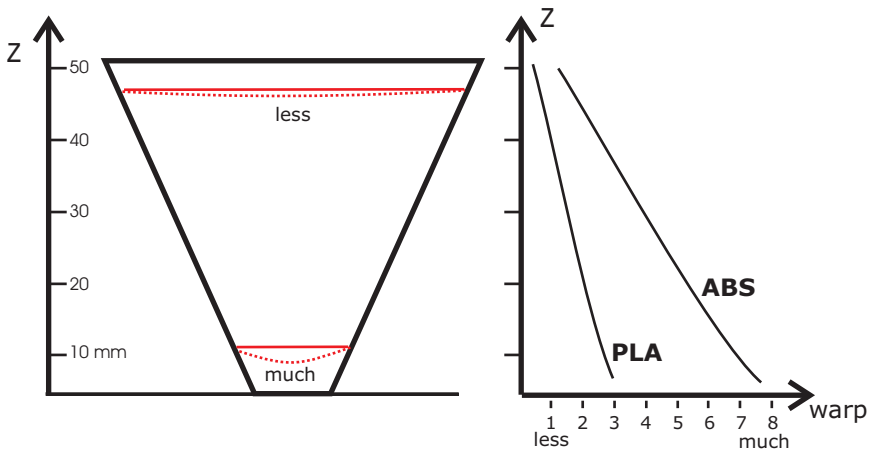
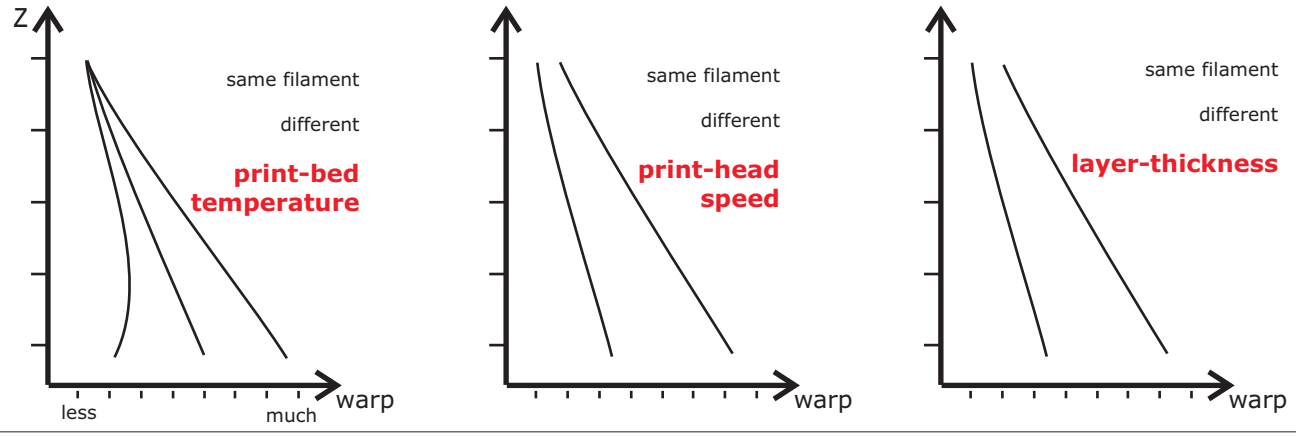
warp-index / variations of boundary conditions
expert section

Playing with boundary conditions, a lot of associations of print parameters and resulting warp, are possible to display in the graphs as shown below.
Visualizing the warp in charts will help to find more ways to minimize warp (with the help of future slicing softwares)
For example: slicing routins could contain different printing parameters for z-hight - inserted in graphic manner by the user.

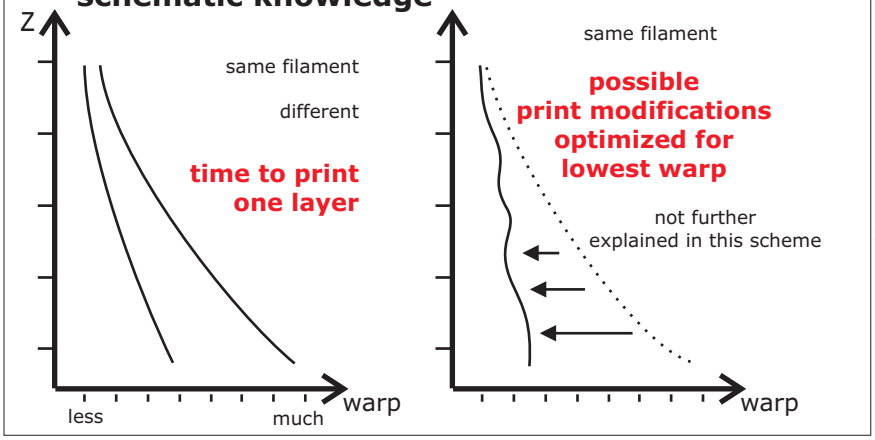
typical warp distribution by object hight



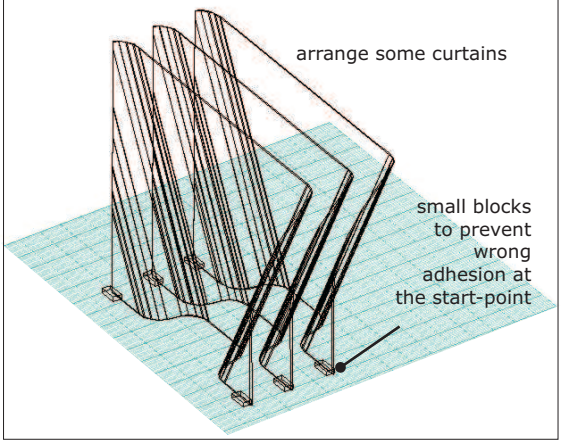
warp variation with different print conditions, schematic knowledge



warp variation with different print conditions, schematic knowledge



large scale print simulation



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