

Experiments in Puzzle Destruction

by George Bell

3D printed puzzles have exploded in popularity, it is a great way to make inexpensive puzzles. An entry-level 3D printer can now be purchased for under \$100 [1]. 3D printing is also an excellent way to prototype new ideas.



PLA – perfect for puzzle printing

The most common material for 3D printed puzzles is PLA (polylactic acid). This plastic is very easy to 3D print with, is relatively inexpensive, bridges huge gaps with ease, tolerates steep overhangs and leaps tall buildings in a single bound. In short, it is the superhero of 3D printing materials. No wonder it is so popular!

Figure 1. The melting *Rubik's Cube* is a popular internet meme. My theory to explain its popularity is that people enjoy seeing a puzzle that they are unable to solve being destroyed.

But, like any superhero, PLA has a critical weakness: it can't take the heat! For stability of a plastic puzzle, what matters is the material's glass transition temperature (GTT). This is the temperature at which a plastic makes the transition from a solid to a rubbery state (not a liquid state, which is the melting temperature). If the GTT is exceeded, the puzzle pieces may warp or fuse together.

The glass-transition temperature of generic PLA is around 60° C. This temperature can be exceeded in an enclosed space exposed to direct sunlight, the most common situation being a parked car (or mail truck!). Oskar Van Deventer has experienced shipping 3D printed PLA puzzles which were destroyed by heat exposure [2].

Table 1 shows the approximate glass transition temperature (GTT) for various plastics used in 3D printing. These GTT values should be taken as ballpark figures for several reasons. First, this temperature is not a well-defined value and is often given as a range. Second, many manufacturers add other ingredients to make their materials stronger (sometimes called PLA+), shinier (silk) or to increase temperature resistance (HTPLA). The **Use** column gives a general idea of the difficulty of 3D printing using this material. For example, some materials may require printing inside an enclosure, give off toxic fumes, or not stick to your 3D printer's bed. People who use PLA may be blissfully ignorant of these problems.

Material	~ GTT	Use
PLA	60° C	Easy
Nylon	70° C	Moderate
PETG	80° C	Easy
ASA	100° C	Moderate
ABS	105° C	Moderate
Prusa PC Blend	113° C	Moderate
Polycarbonate	147° C	Difficult

Table 1. Glass transition temperatures for various 3D printing materials [3].

What can be done to prevent heat destruction of 3D printed puzzles? Since I have an Etsy store selling puzzles [4], I set out to determine by direct experimentation how exposure in a hot car can destroy a puzzle, and explore possible ways to avoid it. This article presents my findings.

The idea behind my experiments was to expose actual puzzles to real-life conditions. The temperature in these experiments was not carefully controlled. I simply packed puzzles in a cardboard box and set it on my car's dashboard on a hot, sunny day.

Experiment 1: July 8th, 2022

I selected two *Flippe Ball* [5] puzzles, one made from ESun PLA+ and the other from Prusament PETG. These were placed in a small (white) cardboard box, which was then placed on my car's dashboard for over 4 hours in direct sunlight with all windows up. The outdoor high temperature this day was 33° C (92° F). Just before the puzzles were removed, a thermometer placed on the dashboard (in the shade) read 64°C (147° F)!

After the puzzles had cooled down, I inspected them for damage. Although they appeared visually unchanged, both seemed to have been glued together. The pieces had fused together. After considerable effort involving screwdrivers and a hammer, I was able to get them apart, deforming the pieces in the process.

I was particularly disappointed by PETG (Figure 2, left), since the measured temperature was below its glass transition temperature. It seems either the maximum temperature reached was considerably higher than 64° C (quite possible), or (more troubling) the pieces can fuse together at temperatures below the GTT.

The PETG copy was damaged and no longer worked as a puzzle. Surprisingly, despite significant damage, the PLA copy still worked.

Experiment 2: August 12th, 2022

Three more *Flippe Balls* [5] were sacrificed. Two were made from PLA, one copy was disassembled and each piece was placed in a separate plastic bag. The idea here was that the puzzle might survive if the pieces could not fuse together. The third puzzle I made from Prusament PC Blend [6], a polycarbonate blend made specifically for 3D printing. I did not experience any problems printing in PC Blend without an enclosure, but these parts are small (5 cm diameter).

As before the puzzles were placed in a cardboard box and placed on my dashboard for over 4 hours in direct sunlight. The high this day was 37° C (98° F). Upon removal the thermometer measured 52° C (125° F), but by this time the dashboard had passed into shade. The maximum temperature reached was likely similar to the first experiment.

Results: both PLA puzzles were destroyed. The assembled puzzle was fused together as before. The pieces that were separated had warped slightly and could no longer be assembled (Figure 2, middle). The good news was that the puzzle made from PC Blend was unaffected (Figure 2, right).



Figure 2. Notice: ~~No~~ puzzles were harmed in the making of this article. Right: the sole survivor made from PC Blend.

Analysis

To avoid heat damage, one solution is to make puzzles from Prusament PC Blend [6], or possibly any material below PETG in Table 1. Unfortunately, none of these materials are easy to use. It is probably not worth it to make all your puzzles from PC Blend on the small chance they may be damaged by heat during shipping.

Oskar Van Deventer has had good results using Woodfill PLA [2]. This is PLA with added wood fibres, this material may have a higher heat resistance due to the wood component.

Annealing PLA is another possibility. To anneal a finished puzzle, you heat up the pieces in a controlled manner, if done correctly this can increase the material's heat resistance. I have no experience with this, see [7] for more information. I am concerned that the article recommends printing at 100% infill (which slows printing down significantly), and also that annealed parts shrink non-uniformly (which can ruin the fit of a puzzle).

Another possibility is to ship your puzzles in an insulated box designed to keep the contents cool. If the box is exposed to heat for a short enough time, this could work.

Conclusions

PLA and PETG puzzles **can be** destroyed by heat exposure during shipping. If you sell 3D printed puzzles you should be aware of the symptoms: a puzzle which appears to have pieces fused together, or pieces that are warped and no longer fit together. There is no easy solution to this problem, short of switching to a less friendly material like PC Blend or the use of specialized, insulated shipping boxes.

Of course, exposing wood puzzles to temperatures over 60° C can't be good for them either. They may also be negatively affected, but hopefully suffer no permanent damage.

References

- [1] George Miller and Peter Knoppers, Getting Started with 3D printing, CFF 118, July 2022, p. 10-15.
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- [3] <https://3dsolved.com/3d-filament-glass-transition-temperatures/>
- [4] <https://www.etsy.com/shop/PolyPuzzles>
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- [6] <https://www.prusa3d.com/category/prusament-pc-blend/>
- [7] <https://www.matterhackers.com/articles/how-to-anneal-tough-pla-and-htpla>