Nozzles

Nozzles

Nozzles are where the rubber meets the road, so to speak.

To some extent almost any nozzle *can* print, but better quality nozzles will produce better surface finish, achieve higher flowrates, or last longer before wearing out.

External Geometry

Orifice Size

The key parameter of any nozzle is the orifice size.

This sets a tradeoff between detail and print speed. Larger nozzles have higher filament flowrates, while smaller nozzles can produce narrower lines, enabling the reproduction of finer surface features.

Most product lines of nozzles are available in a range of sizes, so you can pick what you need.

But you will seldom find hardened material nozzles in small orifice sizes because the filled filaments that need the wear resistance would likely clog the orifice. Likewise, you'll never find high-flow geometry nozzles in small sizes because filament melt rate is extremely far from being a bottleneck in small sizes.

If you want to use a very small nozzle, you need to make sure that your hotend is particularly good at avoiding heat creep.

Tip Geometry

Around the orifice before the conical surface begins, there is a small flat that helps maintain surface quality.

If you buy premium nozzles, this will always be nicely machined, but cheap nozzles with uneven flats may tear up the surface and cause poor print quality.

Some nozzles will round the corner between the flat and conical surface to improve surface finish even further.

Tip Shape

Most nozzles have a fairly blunt conical tip to maximize heat transfer in the presence of part cooling air, but some specialty nozzles are extra pointy with no significant flat for the purposes of nonplanar printing and use at angles for belt printers.

Material

Eventually, as a nozzle gets oodles of filament squeezed through it, and its tip is dragged long distances over the layers of prints in progress, the geometry changes.

This causes both the orifice size to increase and the tip flat to be worn back, significantly affecting print quality.

Different materials resist wear differently, but they present performance tradeoffs.

Single-Material Nozzles

- Brass nozzles are the cheapest you can get. Brass itself is inexpensive, easy to machine, and has good thermal conductivity. Additionally, it matches well with the thermal expansion coefficient of copper heater blocks. However, it is soft and wear-prone, and it becomes less strong at temperatures above 300 degrees C.
- Copper is an upgrade over brass with better thermal conductivity and higher temperature limits, but that isn't extremely impactful because the limiting factor is the rate of heat transfer within the plastic.
- Hardened Steel is an inexpensive material with greater hardness for minimizing wear. However, steel has much lower thermal conductivity than brass, so the hotend temperature may need to be set 10-15 degrees higher than with brass nozzles. It's also not completely impervious to wear, so it will still need periodic replacement.
- Tungsten Carbide is extremely hard and strong, with thermal conductivity almost as good as brass. Additionally, it has incredible temperature resistance letting you blowtorch them to clean out clogs if necessary (though this can damage some coatings). Because they're sintered from powder, solid tungsten carbide nozzles can be made with unique internal geometries that would be extremely difficult to produce in normal metals, such as the fins in Bozzle or the slot in Nanoflow. However, they often have not-so-great surface finish in the nozzle bore and this can cause trouble with tuning pressure advance. Additionally, they are fairly expensive.

Multi-Material Nozzles

Sometimes it's not possible to manufacture an entire nozzle with the material you want to use. To get around this, many nozzles are assemblies of a brass or copper threaded portion, for machinability and thermal conductivity, and a hard material used only for the tip.

These can offer the best of both worlds, but they also add a failure point where a leak may occur.

- Hardened Steel: These have less of the thermal downsides of single-piece hardened steel nozzles, but less of the upsides of better insert materials.

- Tungsten Carbide: These are more economical than full carbide nozzles, but cannot be blowtorch cleaned and thermal expansion differences can cause leaks.
- Sapphire (or Ruby): These inserts offer extreme hardness, even better than tungsten carbide, but worse thermal performance and the monocrystalline tip can crack under high forces. Sapphire-tipped nozzles are fairly expensive.
- Silicon Carbide: Silicon carbide is even harder yet than sapphire, and has excellent thermal conductivity. The only reason it's not used for entire nozzles is because it cannot be machined or sintered the way metal or tungsten carbide nozzles are. Like sapphire, it is vulnerable to cracking and fairly expensive.
- Polycrystalline Diamond (PCD): These are made of the hardest possible material with as good a thermal conductivity as you can get. Additionally, they have low friction, which reduces the amount of plastic that sticks. The polycrystalline material is also more crack-resistant than sapphire or silicon carbide. However, they are extremely expensive, and do not have the blowtorchability of solid tungsten carbide.

Internal Geometry

When trying to print quickly, one of the limiting factors is how fast you can get heat to the core of the filament to melt it. There are several approaches for enhancing the performance relative to a straight cylindrical bore, and they involve reducing the distance to the center.

Flow Splitters (aka CHT)

One prominent high flow geometry splits the flow of plastic into two or more narrower passages that reduce the distance to the center of the filament, before rejoining just before the nozzle tip. Because the splitter heats from the center outward, it is branded as Core Heating Technology by Bondtech.

If the filament is fully melted but not at the desired temperature before reaching the splitter, then CHT greatly improves heat transfer to the melt pool.

However, at the limits of flow for the hotend, the cold core of the filament is forced down only one of the paths at a time, and this can result in temperature gradients across the flow, causing the flow out the tip to squiggle around. However, this usually isn't noticeable in actual printing.

Projections

Bozzle, a cemented carbide nozzle, tries to improve heat transfer to the core of the filament by having fins protrude inward from the walls of the nozzle bore. Even at high flow rates, this allows the cold core to pass close to the fins, picking up heat faster without hitting an obstruction.

Slot

Nanoflow, another cemented carbide nozzle, simply narrows the meltzone to a thin slot. This results in a short maximum distance from any plastic to the wall, improving heat transfer.

Coatings

Low-end brass nozzles are often uncoated, but higher-end nozzles are coated to reduce the tendency for filament to stick to the nozzle.

Some manufacturers claim that their coatings are enough to significantly improve wear resistance, but it is difficult to verify by how much.

Hotend Compatibility

Nozzles must fit your hotend.

Some hotends can accept multiple types of nozzles using adapters, though sometimes with length changes.

Standard Nozzles

- V6: E3D's V6 nozzle is the standard for enthusiast printers, and you can get any nozzle material or geometry you'd like for it. It has a 12.5mm overall length, 7.5mm of M6 threads and 5mm of tip.
- Volcano: Like E3D V6 but 8.5mm longer threads to extend the meltzone. All volcano-compatible hotends can fit V6 nozzles with an internal "volcano adapter" threaded in, and V6 hotends can use volcano nozzles with a nut threaded on to improve heat conduction. 21mm overall length, 16mm of M6 threads and 5mm of tip.
- Supervolcano: This E3D standard is a ridiculously long version of V6, very rarely seen because of flaws in the original hotend. 51.5mm overall length, with 46.5mm of M6 thread and 5mm of tip.
- Mk8: This is an older nozzle standard from Makerbot. It has a shorter threaded section and a longer hex+tip than V6, and it's overall 0.5mm longer. Mk8 nozzles can usually function with a V6 nozzle if the part cooling ducts have enough clearance, but V6 hotends usually cannot work with Mk8 nozzles. 13mm overall length, 5mm of M6 threads, and 8mm tip.
- FIN: This newer Slice standard, created in collaboration with Bondtech and Micro-Swiss with a prescribed tip geometry to allow the hotend socks to cover most of the nozzle, reducing unwanted convective cooling of the nozzle tip by part cooling airflow. It also uses a shorter, smaller-diameter threaded section to minimize the effects of differential thermal expansion between the nozzle and heater block. Not many hotends are available for it, but hopefully more are coming... 9.5mm overall length, 4.4mm of **M5x0.8** threads plus some clearance, and 5.1mm from the heater block to the tip. The hex has 150 degree conical surfaces to allow for firm contact with the silicone sock.
- And many others, including various different length extended Mk8-tip-style nozzles used by Creality, Sovol, and others.

Integrated Heatbreak

Some hotends use nozzles that have the heatbreak installed directly into the nozzle body, relieving the heater block of any need to seal.

This more or less eliminates user error from improper tightening of nozzles, whether that be undertightening causing leaking, or overtightening and snapping the nozzle.

- E3D Revo: The original integrated heatbreak nozzle, Revo has the nozzle thread into the heatsink, and uses a spring-loaded heater block to transfer heat to the nozzle.
- Prusa Nozzle (for Nextruder): This resembles V6 in meltzone length and tip geometry. The nozzle is snugly screwed into the heater block, then the cold side of the nozzle is held into the heatsink using a setscrew. The hotend can be used with V6 nozzles using an adapter (basically just a heatbreak with a compatible cold side).
- Micro-Swiss Flowtech: These nozzles thread into the heater block, which is loosely retained using two structural screws. The heatbreak is placed in compression and the structural screws in tension.
- Creality Unicorn nozzle: This is similar to the Prusa Nozzle but uses a rigidly mounted heater block that the nozzle is snugly screwed into.
- QIDI Plus4 nozzle: this is like the Creality Unicorn nozzle, but it has a zirconia filament heatbreak to better prevent heat creep, taking advantage of the rigid heatblock mount.

Integrated Heater Block

Some printers integrate the heater block itself into the nozzle and heatbreak, and sometimes even the heatsink.

- Bambu Lab X1/P1: These have the entire hotend including heatsink and heater block as one unit. Changing the nozzle involves the user installing the heater and thermistor with a steel clip and screwing in the cold side fan.
- Bambu Lab A1/H2: These have the entire hotend including heatsink and heater block as one unit. However, the heater block clips onto a hard-mounted heater with temperature sensor, simplifying the nozzle change process.
- Sovol SV08: This only integrates the heatbreak, heater block, and nozzle. Changing nozzles is similar to the X1 and P1 but the heatsink is separate and does not need replacement. Later models may have swappable nozzles?

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