

The Same Material, the Same Shape, and the Orientation Decides

— In additive manufacturing the build-direction strength is only **40--60** per cent of the in-plane value — at the same **100 mm²** section the allowable load falls from **10000 N** to **4500 N** — a quantity that never appears on the drawing is doing the work — [Paper 419]

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— *From thinking to syncing.* —

Abstract

A drawing states the material and the shape. In additive manufacturing that does not settle the strength. This paper shows that the orientation moves the strength by a factor of **2.5**—and the orientation is not on the drawing. No new theorem or law is claimed. First, this is the core of the paper. The build-direction strength is **40--60** per cent of the in-plane value, and all three materials fall below six tenths (Section 2). Second, the weakest ratio is **0.4000** (Section 2). Third, at the same **100 mm²** section the allowable load falls from **10000 N** to **4500 N**, a drop of **55** per cent (Section 3). Fourth, for an isotropic material the ratio is exactly **1**. The control works (Section 3). Fifth, placed at **45** degrees it is exactly the midpoint, **72.5** per cent (Section 3). Sixth, the separator is a property of the material against a history of the process. Inside one material name, the process has written a direction (Section 4).

Scope of this paper (scope note): No new theorem or law is claimed—the anisotropy of additive manufacturing and the weakness of interlayer bonding are both standard and are common knowledge in the field. The strength values are not asserted as measurements—40, 60 and 45 per cent are representative and move considerably with machine, temperature, layer pitch and infill. No claim is made about any particular product. The mechanism is not decomposed—interlayer diffusion, crystallisation and void distribution are not the subject. No design guidance is given—how a part ought to be oriented is a design decision and is not the subject. Metal processes are not separated—metals show anisotropy differently and respond differently to heat treatment; only polymer values are used. Fatigue and impact are not treated—only static tensile strength. The intermediate angles are an interpolation—the 72.5 per cent at 45 degrees is a simple interpolation between the two endpoints, not a fit to data. Relation to earlier papers: Paper 418 showed that light has two angular momenta—there one name covered two quantities; here one material has two strengths. Paper 300 showed that common root and distinct root can be decided—“strength set by the material” and “strength set by the process” are distinct roots by that criterion. Paper 415 showed that the same glass became 5000 times more transparent—there a name did not fix a value; here it does not either. Paper 397 showed that the reversal of grain refinement is not the theoretical strength being reached—here too, what looks like a question of strength is settled by microstructure. What is added is tabulating the ratio for three materials, converting to allowable load in newtons, placing the isotropic ratio of 1 as a control, giving the intermediate angles at five points, and placing the separator at “material or process”.

1. Notation and the Question

Setting: Additive manufacturing builds a shape by stacking layers. The strength within a layer differs from the strength across layers.

$$r = \frac{\sigma_{\perp}}{\sigma_{\parallel}}$$

Here $\sigma_{\parallel}$ is the in-plane and $\sigma_{\perp}$ the build-direction tensile strength.

Observation 1.1

A drawing states the material and the shape. “ABS, these dimensions”—that this settles the part is the premise of a drawing.

Observation 1.2

With machining the premise holds. The part is cut from a block, so every direction is alike—there is no orientation to write down.

Question: Build it by stacking, and how much does it differ.

2. Below Six Tenths in the Build Direction

Computation 2.1: For three materials, take the in-plane value as 100 and give the build-direction strength.

Material	In-plane	Build direction	Ratio r
ABS	100.0	40.0	0.4000
PEEK	100.0	60.0	0.6000
PLA	100.0	45.0	0.4500

Observation 2.2

All three are below six tenths. The largest is **0.60**—changing the material does not remove the difference of direction.

Observation 2.3

The weakest ratio is **0.4000**. The same material, a factor of 2.5 from placement alone—since $1/0.4 = 2.5$.

Observation 2.4

What is weak is the interface between layers. Within a layer the material's own strength appears—across layers one is pulling apart a surface that was joined afterwards.

3. In Terms of Load

Computation 3.1: With a 100 mm² section and an in-plane strength of 100 MPa, give the allowable load.

In plane, 10000.0 N. In the build direction (PLA, $r = 0.45$), **4500.0 N**.

Observation 3.2

The same section loses **55** per cent. On the drawing it is precisely the same part—neither the dimensions nor the material changed.

Computation 3.3: As a control, take the same ratio for an isotropic material such as a machined part.

The ratio is exactly **1**.

Observation 3.4

The control does work. It shows the difference comes from direction—with an isotropic material, any placement gives the same number.

Computation 3.5: Vary the orientation (PLA, a simple interpolation between the endpoints).

Orientation	Strength [%]
0 deg	100.0000
30 deg	86.2500
45 deg	72.5000
60 deg	58.7500
90 deg	45.0000

Observation 3.6

The values at 0 and 90 degrees match the endpoints. 100.0000 and 45.0000—confirmation that the interpolation is implemented correctly.

Observation 3.7

At 45 degrees it is exactly the midpoint, **72.5000**. $(100 + 45)/2 = 72.5$ —as a simple interpolation must give. It is not a fit to data.

4. The Separator

The separator: is it set by a property of the material or by a history of the process.

Observation 4.1

With machining the material settles it. The block is isotropic and stays isotropic when cut—writing the material and the shape suffices.

Observation 4.2

With additive manufacturing the process settles it. The direction of stacking stays in the part—material and shape are written, and it is still not enough.

Observation 4.3

These are distinct roots by the criterion of Paper 300. Both are called “the strength of this part”—one can be looked up in a materials table, the other follows from a history.

Observation 4.4

So an item is missing from the drawing. Material, dimensions, tolerances, surface finish—and there “build orientation” belongs. Without it the part cannot be reproduced.

Observation 4.5

The same happens in other processes. Rolling, extrusion, fibre reinforcement—wherever a process writes a direction, the name of the material is not enough.

Observation 4.6

To be honest—40, 60 and 45 per cent are representative and move considerably with machine, temperature, layer pitch and infill. No claim is made about any particular product—what does not move is that the ratio never reaches 1.

Observation 4.7

One last thing—the 72.5 per cent at 45 degrees is a simple interpolation between the endpoints. The real angular dependence is not a straight line—what is shown is only the direction, that an intermediate orientation gives an intermediate strength; the shape of that curve is not claimed.

5. Roll Call and Closing

1. ABS gives 0.4000 (Computation 2.1): the weakest.
2. PEEK gives 0.6000 (Computation 2.1): the best of the three.
3. All three below six tenths (Observation 2.2): material does not remove it.
4. A factor of 2.5 from placement (Observation 2.3): that is 1/0.4.
5. 10000.0 N in plane (Computation 3.1): a 100 mm² section.
6. 4500.0 N in the build direction (Computation 3.1): the same section.
7. A drop of 55 % (Observation 3.2): the drawing is identical.
8. Isotropic gives exactly 1 (Computation 3.3): the control works.
9. Exactly 72.5000 % at 45 degrees (Computation 3.5): the interpolated midpoint.
10. The separator is material or process (Observation 4.3): distinct roots by Paper 300.

Closing: A drawing states the material and the shape, and with machining that settles the part—because a block is isotropic and stays isotropic when cut. Build it by stacking and the premise fails—the build-direction strength is 40–60 per cent of the in-plane value, with ABS at 0.4000, PLA at 0.4500 and PEEK at 0.6000, all three below six

tenths. Changing the material does not remove the difference of direction, and at the weakest ratio placement alone is worth a factor of **2.5**. What is weak is the interface between layers: within a layer the material's own strength appears, while across layers one is pulling apart a surface joined afterwards. In terms of load it becomes a difference between parts that are identical on the drawing—with a 100 mm^2 section and an in-plane strength of 100 MPa, the allowable load is **10000.0 N** in plane and **4500.0 N** in the build direction, a drop of **55** per cent, with neither the dimensions nor the material changed. That the difference comes from direction is shown by the control: for an isotropic material the ratio is exactly **1** and any placement gives the same number. Intermediate orientations give intermediate values, exactly **72.5000** per cent at 45 degrees, with 0 and 90 degrees matching the endpoints 100.0000 and 45.0000. One thing separates them—a property of the material or a history of the process. With machining the material suffices; with additive manufacturing the direction of stacking stays in the part. They are distinct roots by the criterion of Paper 300: one can be looked up in a materials table, the other follows from a history. So an item is missing from the drawing—alongside material, dimensions, tolerances and surface finish, “build orientation” belongs there, and without it the part cannot be reproduced. The same happens in rolling, extrusion and fibre reinforcement: wherever a process writes a direction, the name of the material is not enough. To be honest—40, 60 and 45 per cent are representative and move considerably with machine, temperature, layer pitch and infill; no claim is made about any particular product. What does not move is that the ratio never reaches 1. One last thing—the 72.5 per cent at 45 degrees is a simple interpolation between the endpoints, and the real angular dependence is not a straight line. What is shown is only that an intermediate orientation gives an intermediate strength; the shape of that curve is not claimed.

References

1. Ahn, S.-H., Montero, M., Odell, D., Roundy, S., & Wright, P. K. (2002). Anisotropic Material Properties of Fused Deposition Modeling ABS. *Rapid Prototyping Journal*.
2. Gibson, I., Rosen, D., & Stucker, B. (2015). *Additive Manufacturing Technologies* (2nd ed.). New York: Springer.
3. Bellehumeur, C., Li, L., Sun, Q., & Gu, P. (2004). Modeling of Bond Formation Between Polymer Filaments in the Fused Deposition Modeling Process. *Journal of Manufacturing Processes*.
4. Ashby, M. F. (2011). *Materials Selection in Mechanical Design* (4th ed.). Oxford: Butterworth-Heinemann.
5. Yamagishi, Y. (2026). *The Three Hundredth Census: Whether Two Things Share a Root Is Decidable* [Paper 300]. Zenodo. 10.5281/zenodo.22171914
6. Yamagishi, Y. (2026). *“Finer Grains Are Stronger” Fails, and Not Because the Theoretical Strength Was Reached* [Paper 397]. Zenodo. 10.5281/zenodo.22699316
7. Yamagishi, Y. (2026). *The Same Glass Became 5000 Times More Transparent* [Paper 415]. Zenodo. 10.5281/zenodo.22699790
8. Yamagishi, Y. (2026). *There Are Two of Them, and Only One Has a Ceiling* [Paper 418]. Zenodo. 10.5281/zenodo.22699908

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