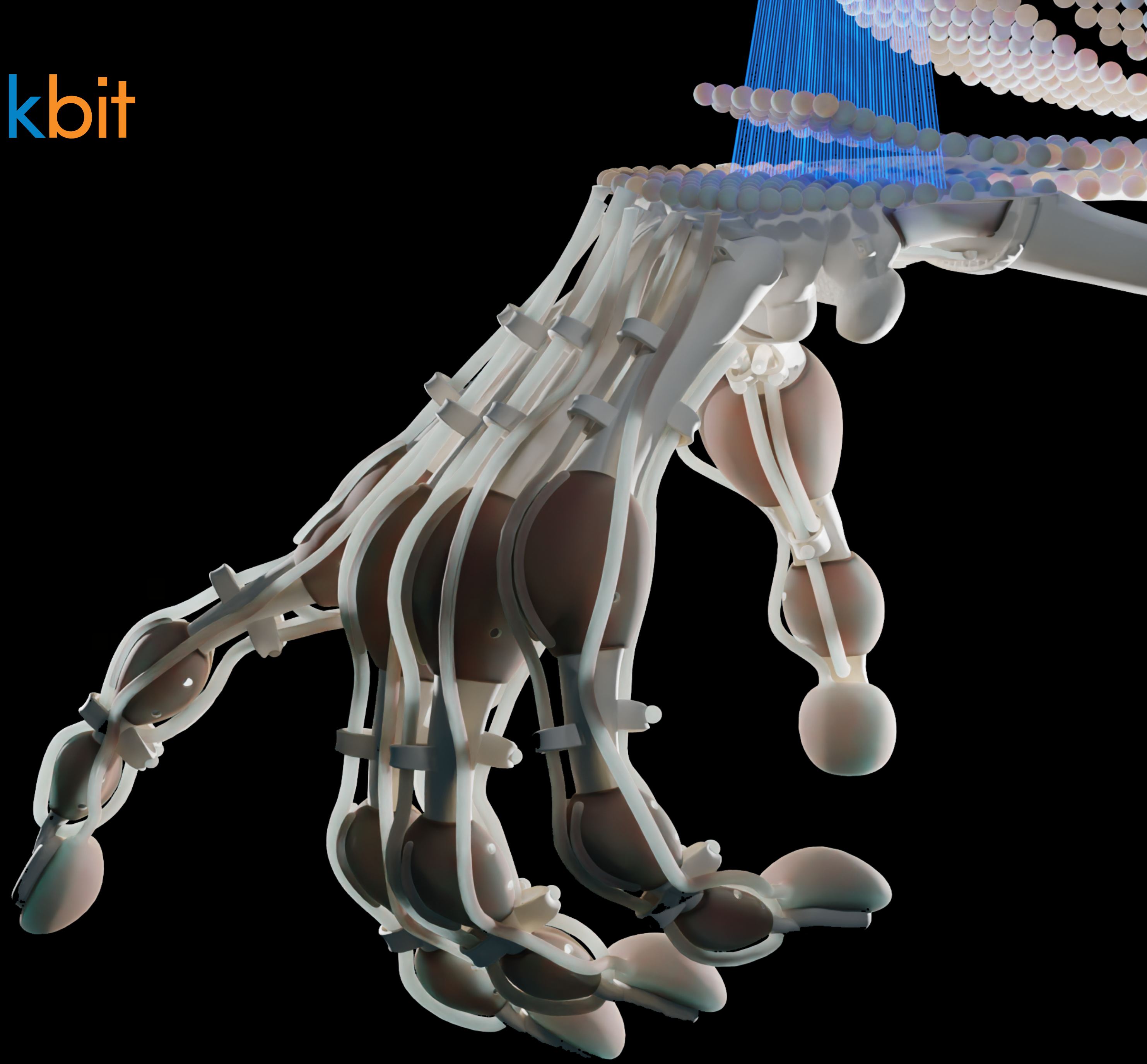


MULTI-MATERIAL DESIGN GUIDE

Inkbit Vista™

This guide demonstrates how to design and print multi-material parts using Inkbit's Vision-Controlled Jetting 3D printing system – the Vista, with a focus on Titan Tough Epoxy 85 and TEPU™ 30A material combinations.

Inkbit Multi-Material Design Guide

Inkbit's Vision Controlled Jetting (VCJ) printing process enables engineers to print multiple materials concurrently, integrated into a single part. With Inkbit's Vista, users may prototype overmolded components, incorporate seals into rigid housings, and produce end-use multi-material parts with functional material properties easily as no tooling or special post-processing are required. However, like all tools, multi-material printing with VCJ must be used correctly to deliver the best results. Specifically, not all materials printable with VCJ are chemically compatible with one another. There are two main material families: epoxies (Titan Tough Epoxy 85 and Titan Chem Epoxy), and thiol-enes (TEPU 30A and TEPU 50A). Materials within the same family can be printed in direct contact with each other and will chemically bond, while materials from dissimilar material families use intelligent, patented, Inkbit-developed software tools to securely interlock them mechanically.

	Titan Tough Epoxy 85	Titan Chem Epoxy	Vulcan Soft 30A Elastomer	Vulcan Soft 50A Elastomer
Titan Tough Epoxy 85		✓	🔗	🔗
Titan Chem Epoxy			Not Yet Tested	Not Yet Tested
Vulcan Soft 30A Elastomer				Not Yet Tested
Vulcan Soft 50A Elastomer				

✓ The materials are fully chemically compatible at the voxel level.

🔗 The materials can be printed together using mechanical interlocks.

Types of Mechanical Interlock Design

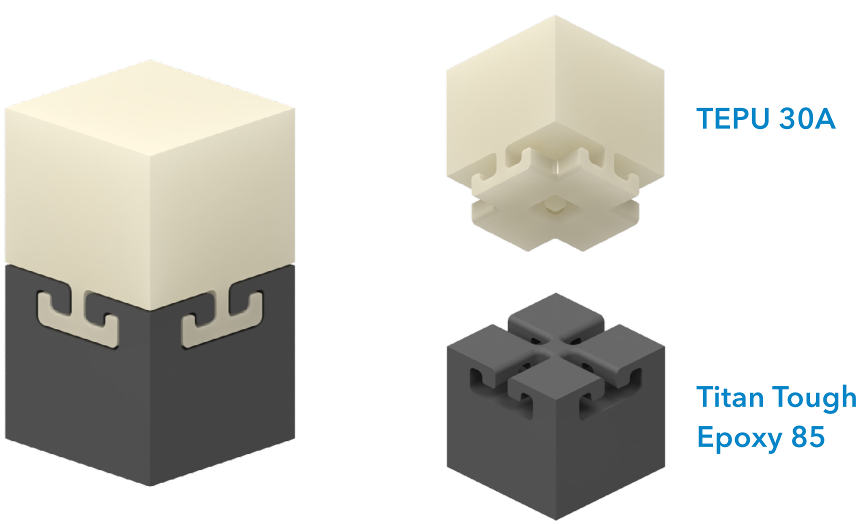
For chemically bonded materials, the two material types cure together at their boundary, effectively creating a single, uniform body. Gradients can be applied between the two bodies, producing varying material properties. For material combinations which require interlocking and are chemically incompatible (e.g. Titan Tough Epoxy 85 and TEPU 30A), a thin (~150 micron) wax gap is automatically generated between the two materials. During post processing, the wax is removed, and the two separate materials are left adhered to one another via mechanical connections. The design of mechanical interlocks can be done in two ways:

Automatic Interlock Design (AID): AID is used within Construct, Inkbit's build prep and multi-material design software, by applying repeating surface features to the common skins within a multi-material part. AID is limited to specific geometry sizes and topologies described immediately below. Inkbit handles all creation of AID part files, after raw part files are provided to the Inkbit 3D-Printing Service.

Manual Interlock Design (MID): For parts that fall outside of the requirements of AID, MID fills in as a set of recommendations to guide multi-material interlock CAD and is described in the following pages.

Automated Interlock Design (AID)

AID uses a single optimized interlocking pattern, shown here. In Construct, the user may specify which part the interlock penetrates. In the future, Inkbit will characterize additional AID patterns for use with other feature types. The testing described below was done using Titan Tough Epoxy 85 and TEPU 30A test specimens. In all following illustrations, white parts represent TEPU 30A and gray parts represent Titan Tough Epoxy 85.

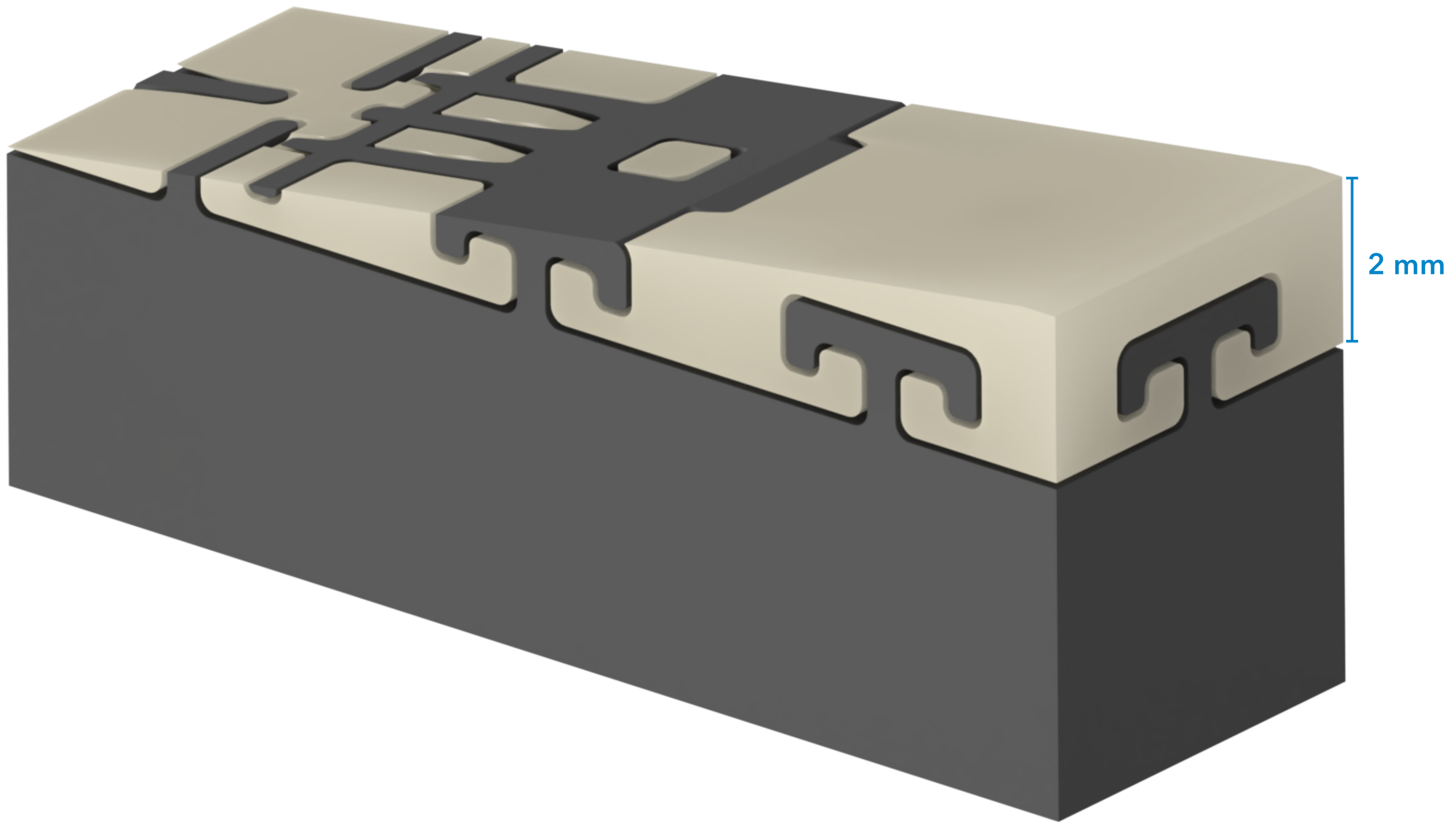


Part Feature Limitations

Part feature limitations are the primary drivers in determining what type of parts are suitable for use with AID. Various tests are shown below describing the adhesion performance with respect to different geometry metrics, shown here as a guide for designers to determine how to best utilize AID.

Thickness

For parts which are penetrated by interlocks, the part (at the interlock interface) should not be thinner than 2 mm (0.5 mm plus the thickness of the interlock). Thinner regions risk tearing or may even expose the interlocking features.

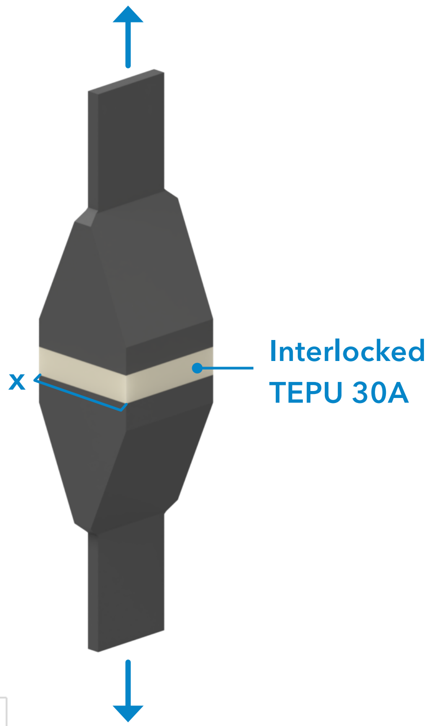


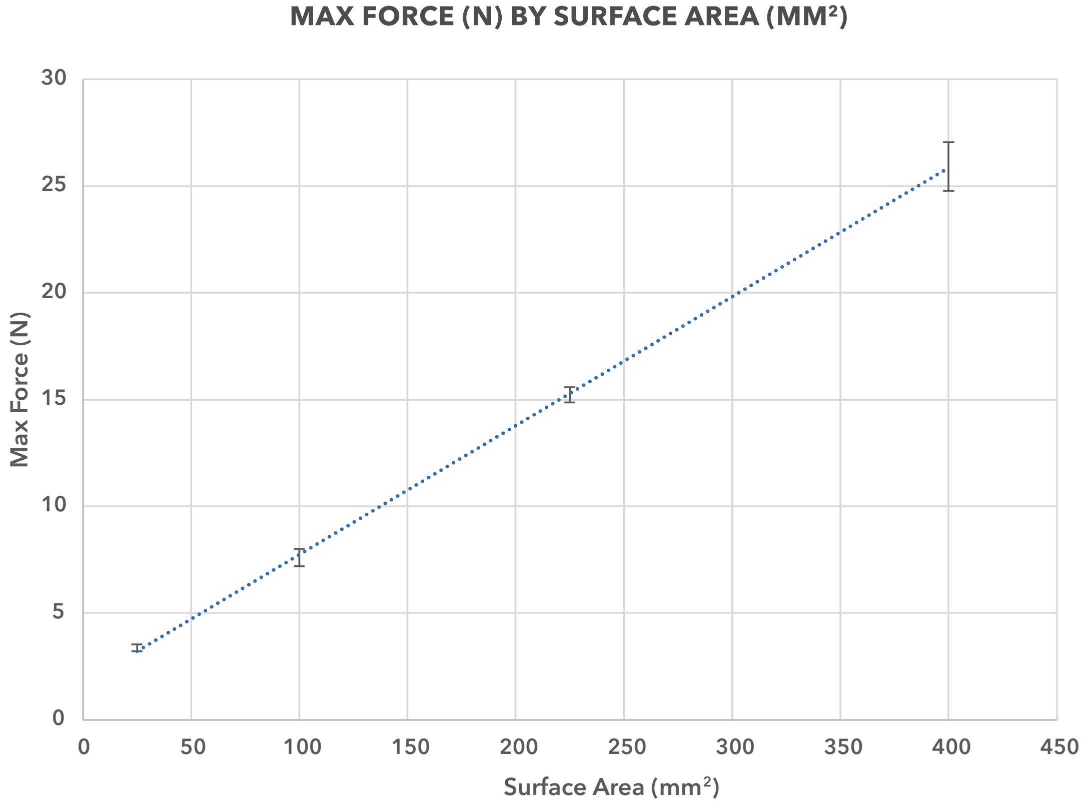
Contact Area

TEPU 30A – Titan Tough Epoxy 85 bond strength is the primary factor influencing contact area limits in parts using AID. This strength is measured by two separate tests: 90-degree peel and pull-out. The force required to separate the two materials in each mode is dependent on the surface area connecting the two materials. The below recommendations may be exceeded, but should be tested at the risk of insufficient bond strength between materials.

Pull

Shown below is an example of an AID pull test specimen — a soft section in the middle interlocks with both sides of rigid material. The below graph's horizontal axis is represented by the square of the specimen edge length "x." The contact area of one complete cell of the AID pattern is 5x5 mm^2, and there is a linear relationship between surface area and max force/UTS (think hanging weight). As a rough rule of thumb, every 100 mm^2 can hold about 1 kg of load. Parts with contact areas smaller than 15 mm^2 may exhibit sub-par adhesion. Note that the data collected below is not derived from a standardized test.



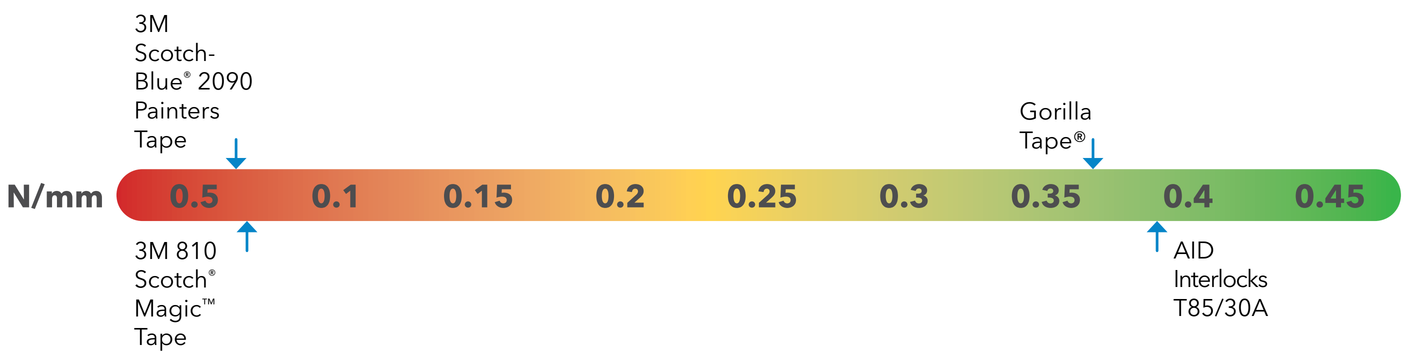


Peel

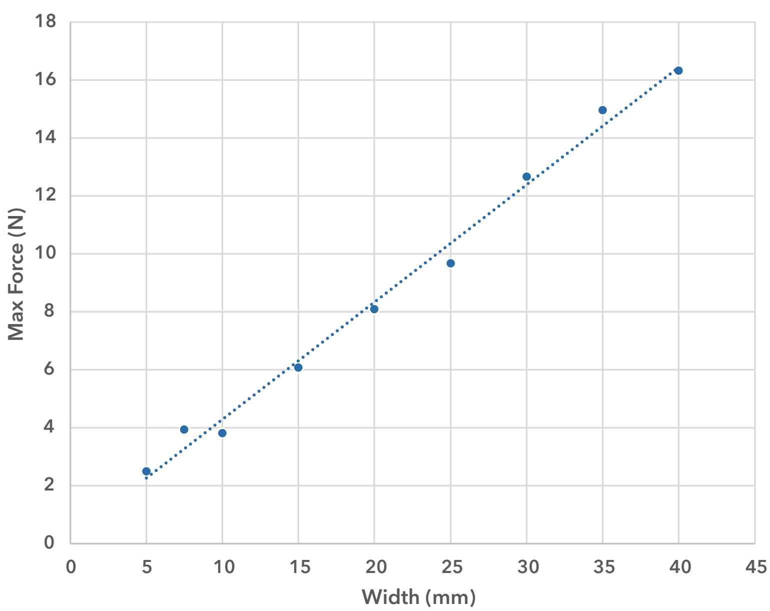
The peel test is less intuitive in two ways. First, peel is less straightforward than pull tests – for example, friction can cause a peel force that is difficult to measure. Second, due to the Vista's unique multi-material printing capabilities, a customized methodology to qualify peel strength was developed, and an illustration of the test rig is shown below. Accordingly, note that the data collected below is not derived from a standardized test.

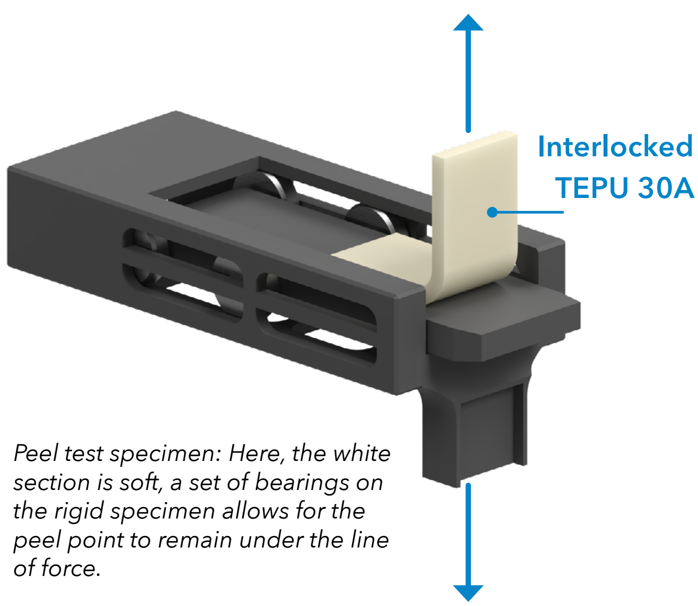
Despite being less intuitive, maximum peel strength has a linear relationship with specimen width, as shown in the below graph. It is not recommended to use a material width smaller than 15 mm for any application that requires peel resistance – like overmolding. Included below is data for some common tapes (3M 810 Scotch® Magic™ Tape, 3M Scotch-Blue® 2090 Painters Tape, Gorilla Tape®) performed with the same set up on a standard substrate (304 Stainless Steel) to provide some relatable comparisons. Per millimeter of sample width, AID interlocks have about the same peel strength as Gorilla Tape® on stainless steel.

AVERAGE PEEL FORCE/SAMPLE WIDTH OF COMMON TAPES ON 304 STAINLESS STEEL VS. AID INTERLOCKS



MAX FORCE (N) BY WIDTH (MM)





Peel test specimen: Here, the white section is soft, a set of bearings on the rigid specimen allows for the peel point to remain under the line of force.

Is AID appropriate for my part?

AID should not be used when any of the geometry limits are exceeded, at the risk of creating fragile connections. Instead, use the guidelines describing MID. The geometry limits for AID are summarized in the table below:

PART FEATURE	SIZE MINIMUM
Multimaterial Contact Area	15x15 mm^2
Multimaterial Contact Width	15 mm
Material Thickness	2 mm

How can I print a part using AID?

For now, Inkbit handles the implementation of all AID for production through the Inkbit 3D-Printing Service. Once a part is deemed acceptable for use with AID, ensure that the part meets the following conditions:

- Parts of differing materials which are intended to be interlocked should contain flush boundaries, without gaps or overlaps as shown below:

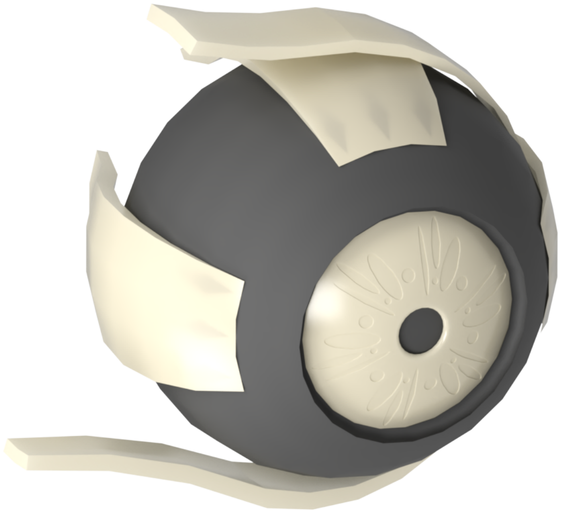
- Parts may be submitted as either:
    - » multi-body STEP, no surface bodies
    - » multiple single-body STL, OBJ, 3MF, or STEPs defined within the same coordinate space
- In all file format cases, an annotated image or appropriate file names should be included with the submission to communicate material assignment.
- If applicable, specifications for which parts are to be penetrated by interlocks should be communicated. By default, AID will place rigid interlocks such they penetrate soft parts.

Manual Interlock Design (MID)

Manual Interlock Design (MID) should be used when the geometry limits for AID are exceeded. Often, this applies to either parts with fine features or those which are too complex. MID can be used to apply interlocking features which follow delicate contours specific to the part geometry, or leverage interlocking techniques beyond those which are used by AID. Some examples of parts that would benefit from MID are shown below.

Eye

In this medical model part example, the connection points between the soft muscles and the rigid eyeball are smaller than the recommended contact area. It would be more effective to use MID in this context, as connectors can be placed precisely within the bounds of the contact area.

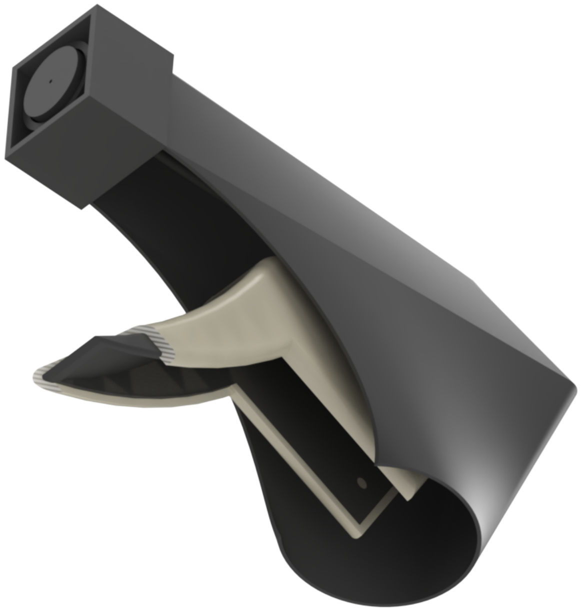


Manifold

Similarly, the contact patches between the manifold and the O-rings are too narrow to appropriately apply AID. In addition, MID connectors can easily be added using a few simple CAD features.

Spray Bottle

In this final example, both the soft and rigid components of the handle are too thin to apply AID between them. A designer could either use MID to intentionally create visible connections on the back of the handle or thicken either section.

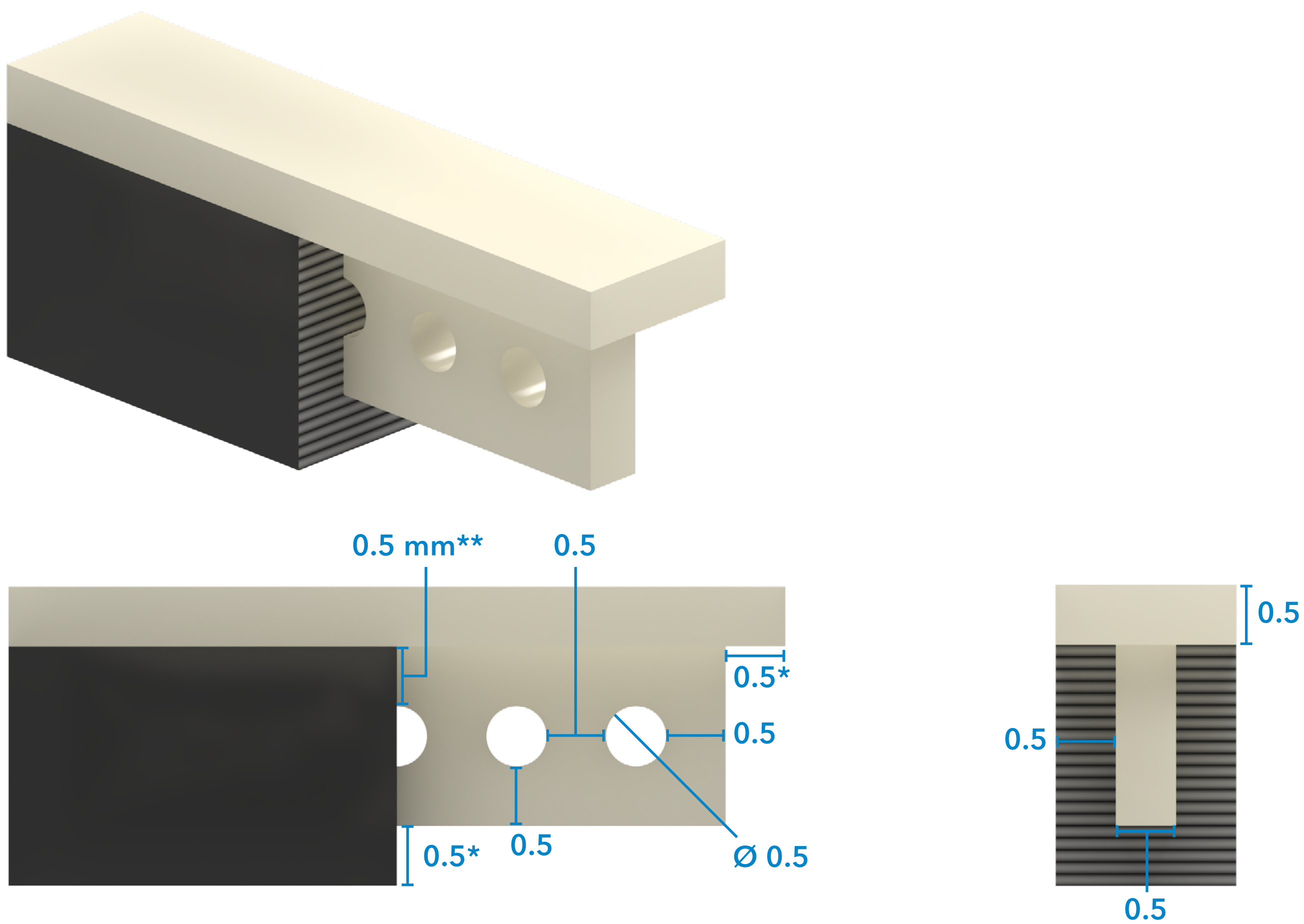


MID Connection Types

There are four primary connection types that work well with multi-material parts, listed below. As a rule, no dimension of any of the below connectors should be smaller than 0.5 mm. When space allows, larger and a greater number of connectors will always result in more robust connections. Wherever possible, aim to design connections that interlock (like a chain link), rather than connections that are separable (such as a soft mushroom connection deforming out of a rigid hole). Note that the graphics below show examples without a wax boundary – all MID parts will have a 150-micron gap placed between faces of differing materials. Since this process is automatic within Construct, Inkbit's build preparation software, it is recommended that MID parts supplied to Inkbit's 3D-Printing Service are designed flush with one another. All dimensions shown below are minimums unless otherwise noted.

Tab with Pins

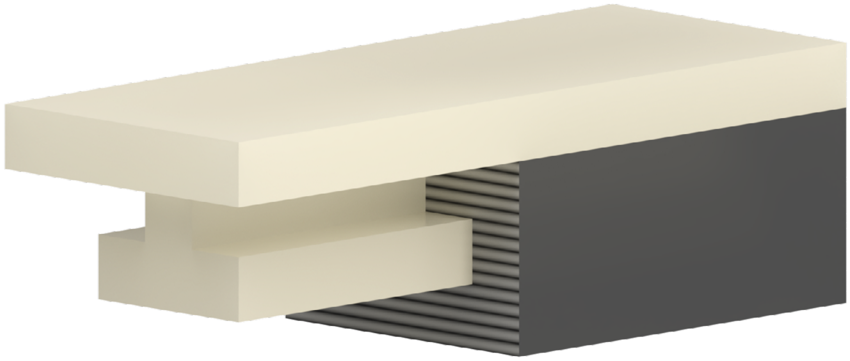
This is one of the most preferred methods for interlocking two parts together, as it's impossible to separate two interlocked parts without breaking the material, and it is the most space efficient. One downside to this connection type is that it can be more complicated in CAD software to pattern holes along tabs, especially when the tabs follow a complex curve.

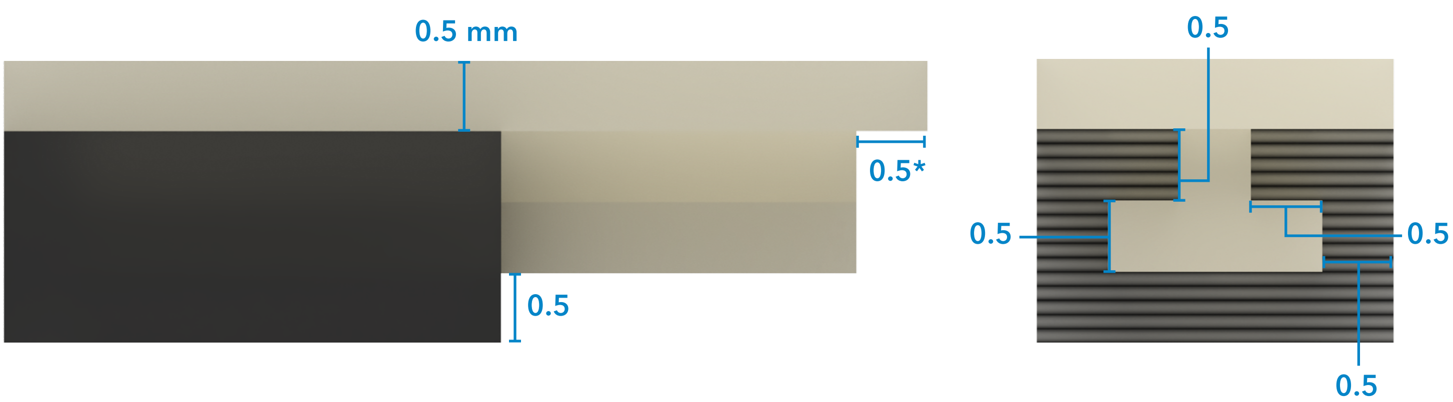


*Tab with pins interlock. *These dimensions show a minimum thickness for covering interlock features and are not necessary if it does not matter that the interlock is exposed. **This dimension can be smaller (down to 0 mm) so long as there is at least .5 mm of material to the top of the white component.*

Tee

This connection type is strong, but soft parts can still deform to pull out of the connection. To limit this behavior, the white, soft "tee" should penetrate a rigid substrate. Designers may also opt to use an "L" shape to save space, however, this connection type is not as strong. Adding extra "legs" to create a spiral interlock may also provide a suitable solution with added interlock strength, but designers should follow the same "0.5 mm rule" for the thicknesses of the features for each interlocking component.

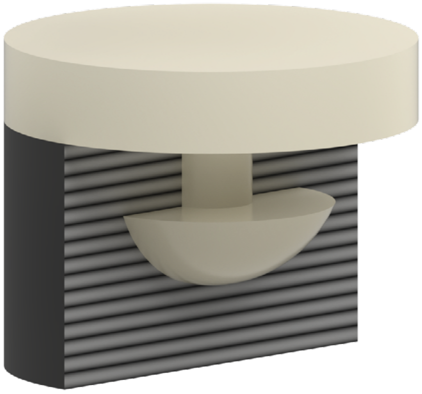


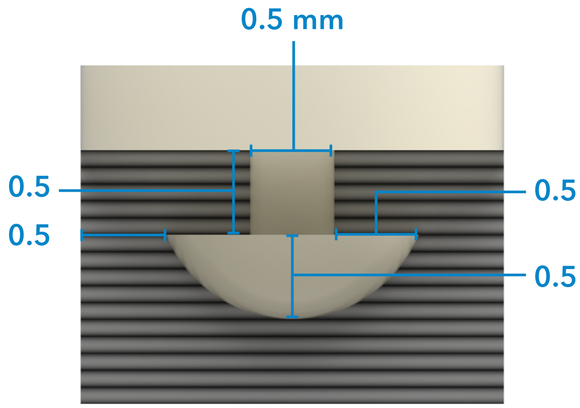


*Tee interlock. *This dimension shows minimum thicknesses for covering interlock features and are not necessary if it does not matter that the interlock is exposed.*

Mushroom

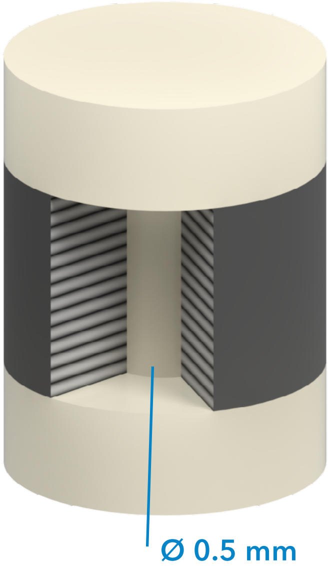
A circular version of the tee connector, the mushroom cap is a convenient method for small, single point connections. However, this type may still be pulled out with material deformation alone.

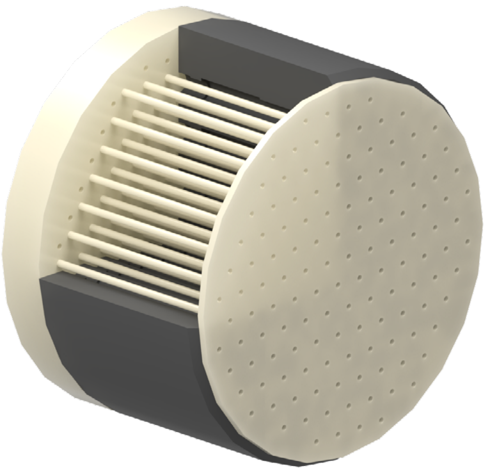




Connected Ends

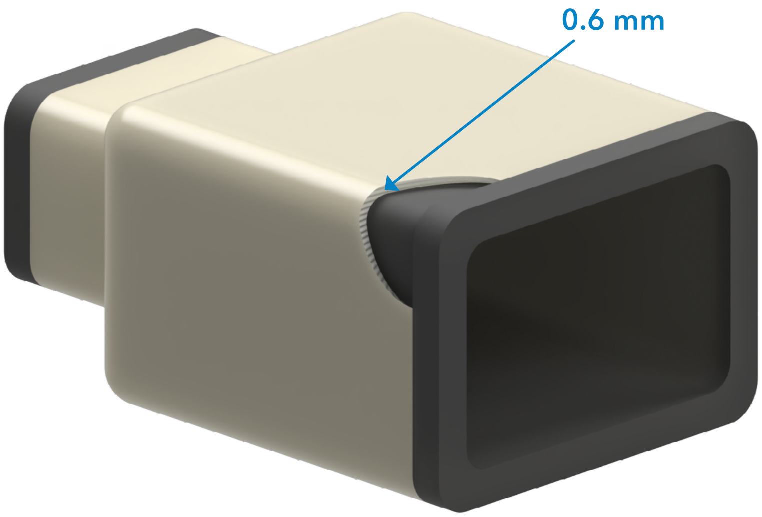
Shown below is a very simple version of this concept, but in situations where there is limited space, designers may run multiple thin strands of material through the length of a part to connect to slices of material in a multi-material sandwich. A good use case for this technique is in the design of a multi-material electrical insulator. In this example, there is not enough space to incorporate traditional interlocks to adhere sections of soft gasketing on either end of the insulator to the rigid body. Instead, they can be connected by many thin strands of material running through the interstitial regions between electrical pin holes.





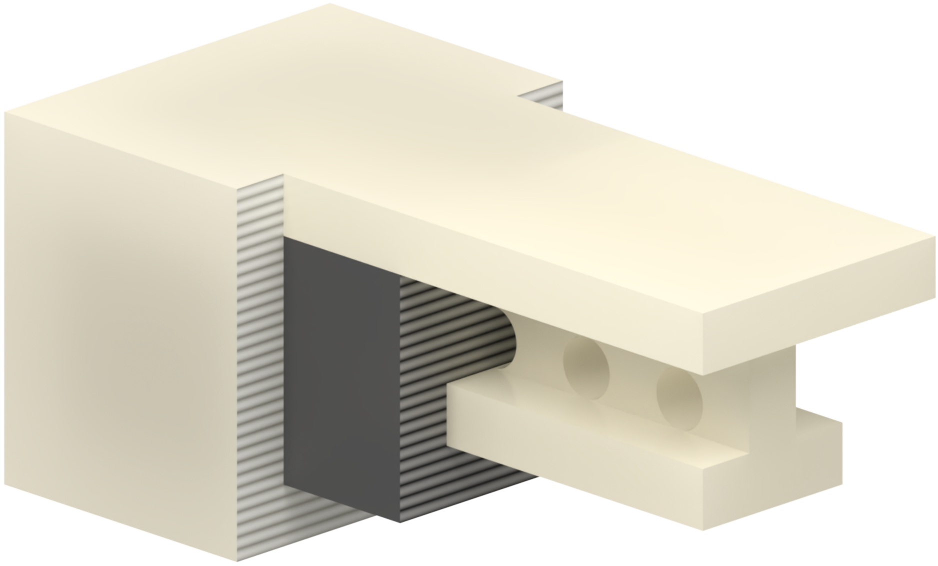
Encapsulating Overmold

At times, interlocking features are not even required. For example, the soft white overmold on the connector body below naturally conforms to the rigid substrate. To limit opportunities to peel up the soft overmold, designers may incorporate rigid brims about the edges of the overmold, creating a flush surface. The thickness of the overmold layer should be at least 0.6 mm. Note that this may only provide good results for smaller parts, as there is a significant accuracy difference between the two materials when printed together, noted in the final section of this guide.



A Combination of Multiple Strategies

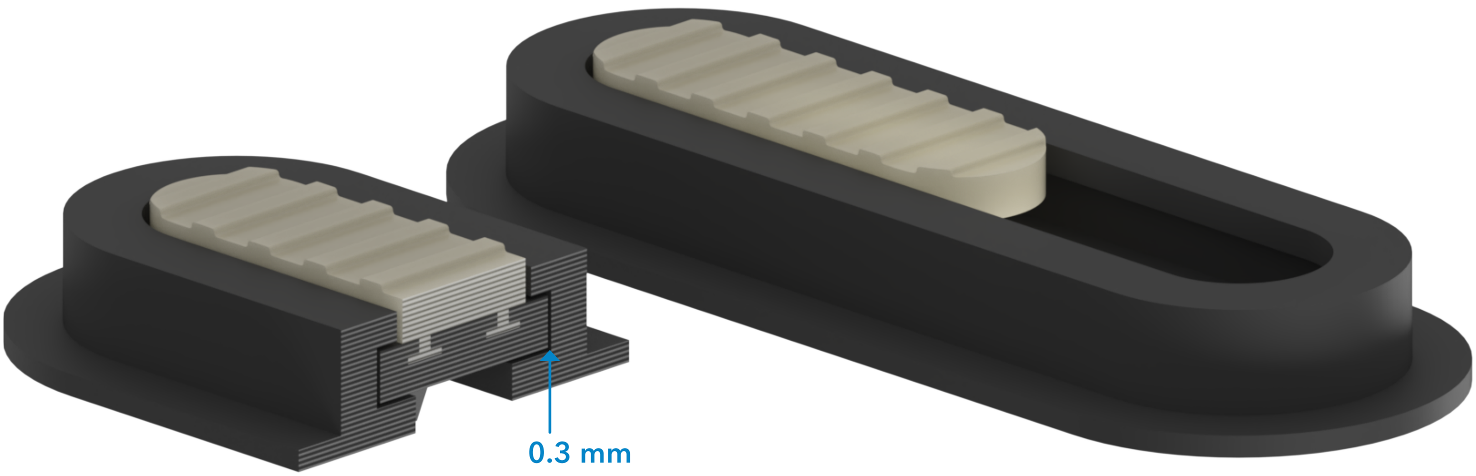
Stronger connections may be created by incorporating a variety of different interlocking features together, such as holes through tee connectors, or even overmolds.



Best Practices

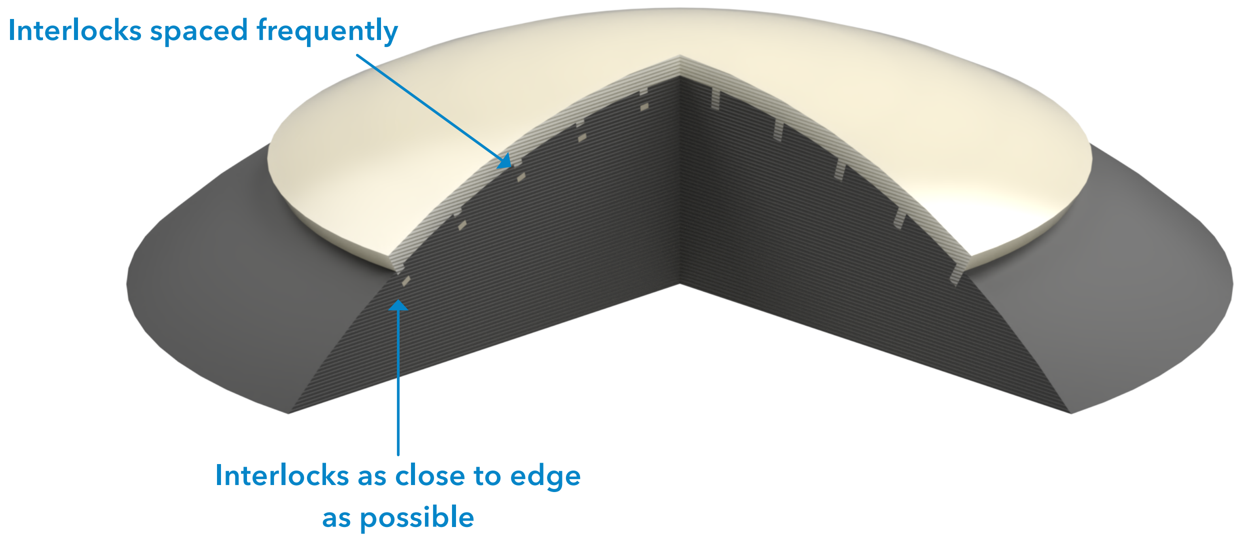
Print-in-Place Assemblies

For multi-material assemblies containing gaps for moving or sliding components, allow at least a 0.3 mm gap between moving part boundaries. Users may be able to resolve smaller gaps for specific geometries, but testing is required. For a list of all other resolvable features, please refer to the Inkbit Vista Design Guide published on the Inkbit website.



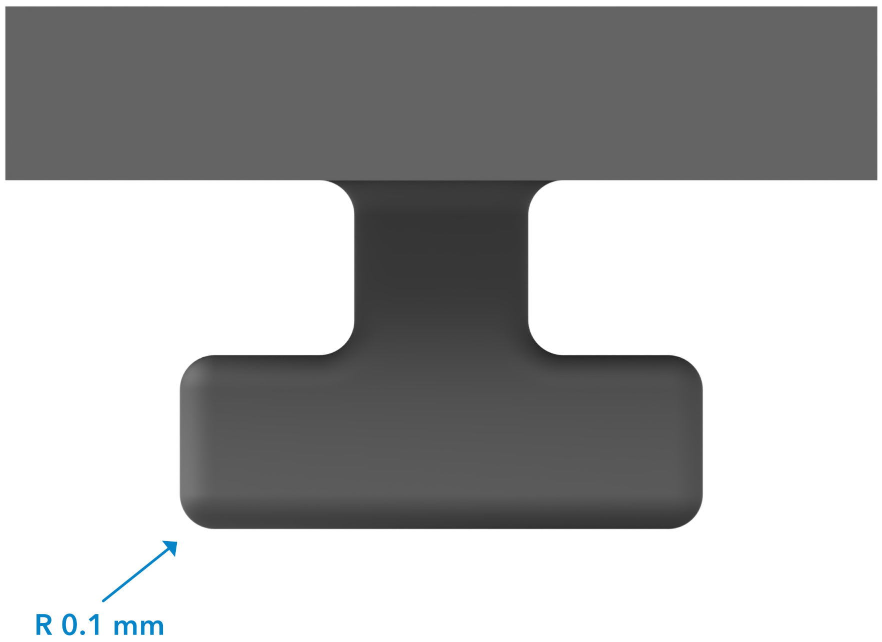
Interlock Placement

All connection examples below show a minimum amount of material to "hide" the interlock. It is always better to have interlocks be as close as possible to the edges of opposing parts, to limit the possibility for edges to peel. For large spans of thin, soft material on rigid material, include interlocks every 5 – 15 mm to avoid soft material from bubbling up away from the rigid substrate. When allowable, wax evacuation holes through either material will also limit bubbling.



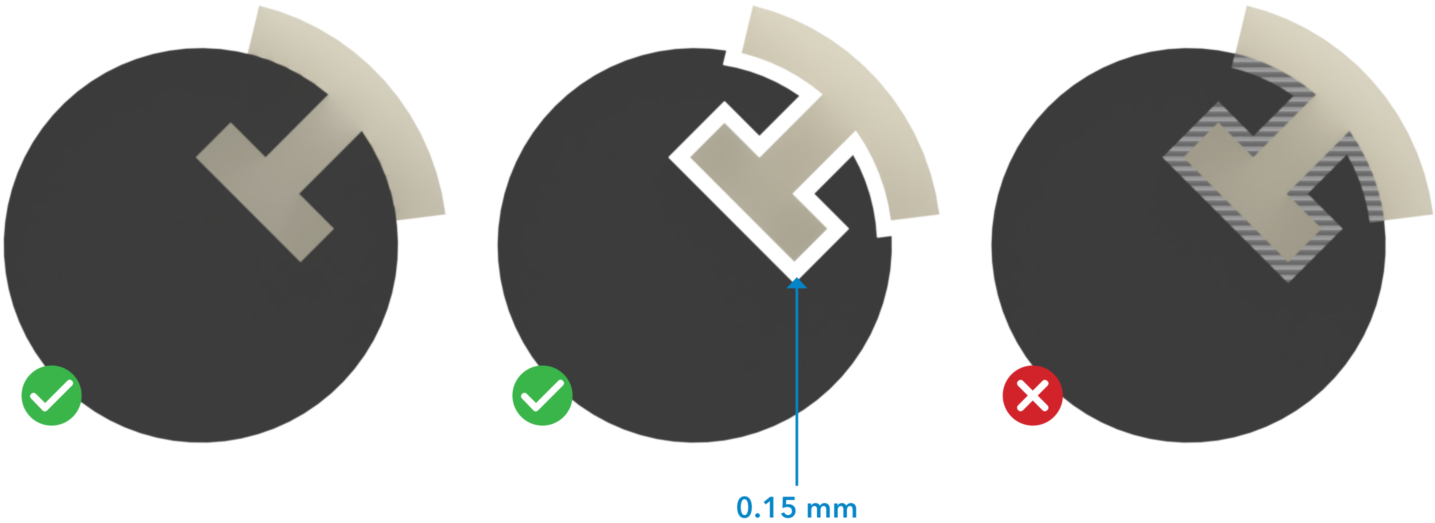
Interlock Fillets

While not strictly necessary, designers may also add fillets on the edges of interlocking features. Fillet radii should be no smaller than 0.1 mm.



How can I print a part using MID?

Similarly to parts for use with AID, parts designed using MID should have flush boundaries between bodies, as a 150-micron wax boundary is added in Construct, handled by Inkbit during part production. If preferable, users may also create these gaps in CAD software and should note this upon part submission. Interlocking bodies should not overlap or have gaps other than 150-microns.

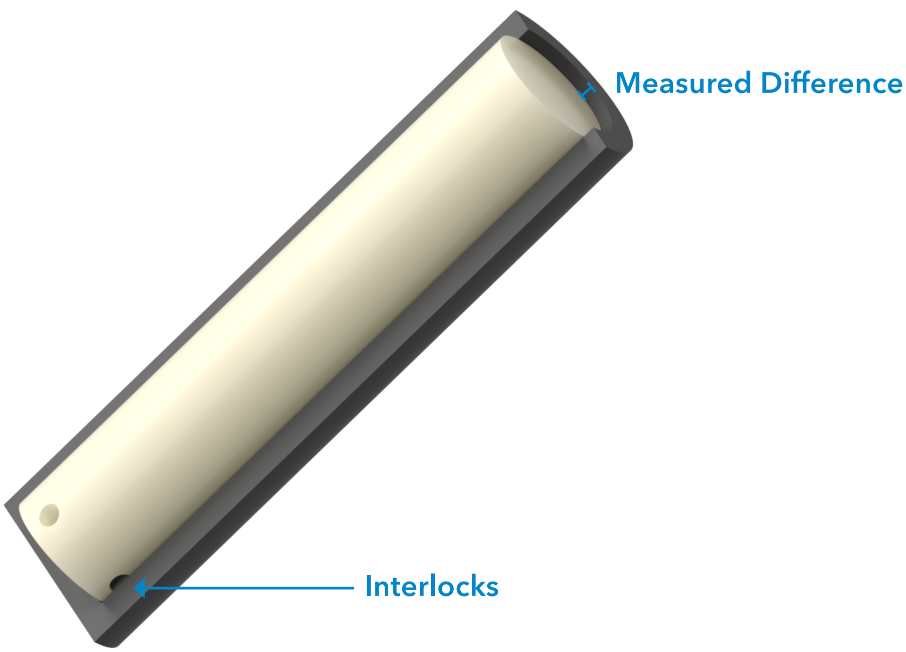


- Parts may be submitted as either:
  - » multi-body STEP, no surface bodies
  - » multiple single-body STL, OBJ, 3MF, or STEPs defined within the same coordinate space
- In all file format cases, an annotated image or appropriate file names should be included with the submission to communicate material assignment.

Accuracy of Multi-Material Parts

To achieve the accuracy delivered by VCJ single-material printing, a unique scaling factor is applied to each material. Applying separate scaling factors to two materials in a single part creates unmanageable geometry conditions. Instead, within all forms of multi-material printing, the scaling factor of the material with the largest part volume is applied to the entire part. For example, if a mostly Titan Tough Epoxy 85 part with a TEPU 30A sealing flange were printed, the scaling factor for Titan Tough Epoxy 85 is applied to both Titan Tough Epoxy 85 and the TEPU 30A components.

Differences in coefficients of thermal expansion and the kinetics of the materials may lead to accuracy mismatching when printing multi-material parts. While this issue can be mostly mitigated by **fully-interlocking** the parts along their entire length (versus connecting them in only one spot), it is important to understand the consequences of printing **partially-interlocked** parts. Seen below is a cross-section of a partially-interlocked accuracy coupon, interlocked only on the bottom of the part. The distance measured between the ends of the TEPU 30A and Titan Tough Epoxy 85 sections provides the data for the below table. A fully-interlocked part would look the same except with AID interlocks placed at all material boundaries. The same accuracy benefits achieved by AID interlocked patterns may be applied to MID parts, and should inform the frequency of MID interlocks if soft part accuracy is critical.



GAP BETWEEN TITAN TOUGH EPOXY 85 AND TEPU 30A	PARTIALLY-INTERLOCKED	FULLY-INTERLOCKED
XY	+1.5% of part size (TEPU larger)	+/- 0.1% of part size
Z	-0.85% of part size (Titan larger)	+/- 0.1% of part size

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