Figure 1: Full-sized car body used hot air welding and solvent to bond over 16 ABS-M30™ sections.

Bonding

Overview

Joining pieces and repairing parts are routine operations for all manufacturing processes, including additive manufacturing. While there are many bonding options, the primary considerations when selecting a bonding method should be the strength of the bonded joint and compatibility with an FDM® material.

Common applications where bonding is applicable are:

- Joining sectioned parts (for details, see the Best Practice: Sectioning Oversized Parts)
- Embedding inserts (for details, see the Best Practice: Embedding Hardware into FDM Parts)
- Repairing parts
- Joining assemblies
- Making composite structures

There are many methods, and even more materials, for bonding FDM parts. The processes for adhesive, solvent, and welding methods are covered in the options section.

Reference materials	
Processes	• Best Practice: Sectioning Oversized Parts
	• Best Practice: Embedding Hardware into FDM Parts

Bonding

1. Options

1.1. Bonding method selection

Table 1: Bonding Method Characteristics.

Bonding Methods	Option	Cost (Dollars)	Pot Life (Minutes)	Cure Time* (Days)	Viscosity*	Bond Strength*	Chemical Resistance*	Heat Resistance*
Adhesive	Loctite® Plastics Bonding System (Cyanoacrylate)	Low	0.5	0.01	Low	Medium	Low	Low
	Hysol E-20HP (Epoxy)	Medium	20	1	Medium	High	Medium	Medium
	Magnolia 6166 (Epoxy)	High	60	7	High	Medium	Medium	High
Solvent	Micro-Mark® SAME STUFF	Low	5	0.33	Low	High	High	Low
Welding	Hot Air	Low	15	NA	High	High	High	High
	Ultrasonic spot	Low	5	NA	NA	High	High	High

* See manufacturer's data sheet for details.

Table 2: Compatibility of Bonding Method with FDM Materials.

Method	Type	ABS Family	PC	PC-ABS	PC-ISO	NYLON 12	PPSF/PPSU	ULTEM™ 9085 resin
Adhesive	Cyanoacrylate - Loctite Plastics Bonding System (Cyanoacrylate)	✔	✖	✔	✖	✖	✖	✖
	Epoxy – Hysol® E-20HP	✖	✖	✔	✖	✖	✔	✔
	Epoxy - Magnolia® 6166	✖	✖	✖	✖	✖	✖	✔
Solvent	SAME STUFF	✔	✔	✔	✔	✖	✖	✔
Welding	Hot Air	✔	✔	✔	✔	✔	✔	✔
	Ultrasonic Spot	✔	✔	✔	✖	✔	✔	✖

Bonding

1.2. Bonding Method Descriptions

1.2.1. Adhesive: Cyanoacrylate – Loctite Plastics Bonding System (Figure 2)

- Description
  - – Short shelf life
  - – Fast-curing
- Characteristics
  - – Easy to use

1.2.2. Adhesive: Epoxy – Hysol E-20HP

- Description
  - – Two-part adhesive
- Characteristics
  - – Creates high tensile strength joint

1.2.3. Adhesive: Epoxy - Magnolia 6166

- Description
  - – Structural paste
  - – FST (flame, smoke and toxicity) compliant epoxy
- Characteristics
  - – Maintains FAA FAR 25.853 on ULTEM™ 9085 resin FDM parts

1.2.4. Solvent: Micro-Mark SAME STUFF

- Description
  - – Chemically melts surfaces (Figure 3)
- Characteristics
  - – Greater bond strength than cyanoacrylate or epoxy
  - – May blister at temperatures above 70°C (158 °F)

Figure 2: Cyanoacrylate adhesives.

Figure 3: SAME STUFF solvent chemically melts plastic.

Bonding

1.2.5. Welding: Hot Air

- Description
  - Melts plastic with hot air
  - Uses thermoplastic filament as a filler (Figure 4)
- Characteristics
  - The bond has similar properties and characteristics as the FDM part

TIP: Hot air plastic welding requires some skill. Practice is recommended to develop the technique that produces good bonds.

NOTE: This method is not recommended for thin-walled parts. For ULTEM™ 9085 resin and PPSF/PPSU, thin wall is < 3.2 mm (< 0.13 in). For all other materials thin wall is < 2.0 mm (0.08 in).

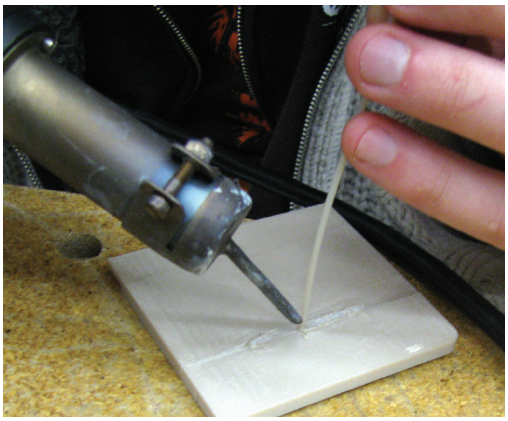

Figure 4: Draw the hot air welding tool and plastic filament along the seam.

1.2.6. Welding: Ultrasonic Spot

- Description
  - Uses ultrasonic vibration to melt and bond plastic
- Characteristics
  - Welds are stronger than surrounding material
  - No foreign material is introduced
  - Ideal for applications that have strict material requirements
  - One side of the bond joint has a visible imprint from the spot weld

Bonding

1.3. Optimizing Bond Strength

In practice, the strength of the bond will vary with method, wall thickness and geometry type. However, bond strength may be improved by selecting the appropriate type of joint. For example, replace a butt joint with a dove or lap joint when shear forces are going to be applied. Another option is to combine bonding methods. For example, start with hot air plastic welding for a thick-walled joint and then follow up with a chemical bonding agent.

NOTE: When using ultrasonic spot welding, a lap joint is required.

2. Process

2.1. Adhesive: Cyanoacrylate and Epoxies

STEP 1: Scuff bonding area using sandpaper.

NOTE: Sanding the surfaces until the visible surface toolpaths are blended together will dramatically improve the bond strength.

STEP 2: Clean the bonding area with isopropyl alcohol.

STEP 3: Thoroughly mix the adhesive's two components if necessary (Figure 5).

NOTE: Consult the manufacturer's instructions for ratios and details.

STEP 4: Apply adhesive to mating surfaces and join (Figure 6).

TIP: Use an applicator, such as a brush, putty knife or mixing dispenser to apply the adhesive to the joint.

STEP 5: Hold or clamp work pieces while the adhesive sets (Figure 7).

NOTE: Consult the manufacturer's instructions for cure times.

TIP: Accelerate curing time with heat per the manufacturer's recommendations.

Figure 5: Mix the two components of the adhesive.

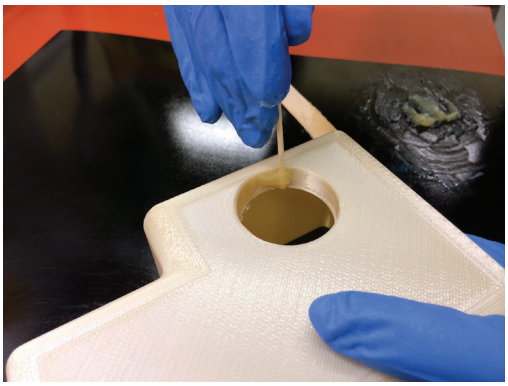

Figure 6: Apply the epoxy to mating surfaces

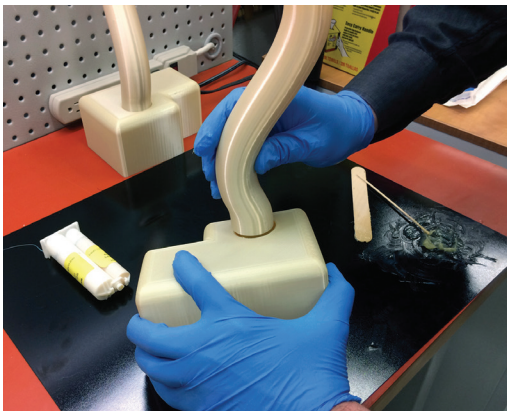

Figure 7: Mate pieces and hold or clamp.

Bonding

STEP 6: Remove excess adhesive.

STEP 7: After curing, sand the seam to achieve a uniform surface.

STEP 8: Adhesive bonding with cyanoacrylates and epoxies procedure complete.

2.2. Solvent: Micro-Mark SAME STUFF

STEP 1: Clean and prepare surfaces to be bonded.

NOTE: Sanding the surfaces until the visible surface toolpaths are blended together will dramatically improve the bond strength.

STEP 2: Apply solvent to the bonding surfaces (Figures 8 and 9).

TIP: Use an applicator, such as a brush or needle tip to apply the solvent to the joint.

STEP 3: Mate the pieces and hold until the bond sets, which is usually just a few seconds (Figure 10).

STEP 4: Allow the part to sit for 8 hours to reach full mechanical strength.

STEP 5: Sand the seam to achieve a uniform surface.

STEP 6: Chemical bonding with Micro-Mark SAME STUFF procedure complete.

2.3. Welding: Hot Air

STEP 1: Clean and prepare surfaces to be bonded.

STEP 2: Mate the pieces that will be bonded and secure them.

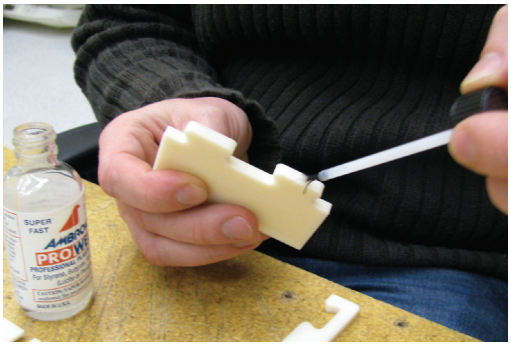

Figure 8: Brush solvent onto mating surfaces.

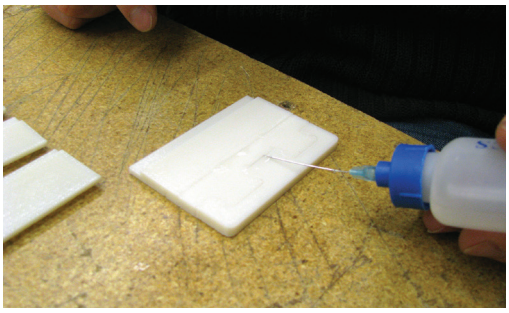

Figure 9: The low-viscosity solvent also flows well into seams and cracks.

Figure 10: Align and clamp the mating pieces until the bond has set.

Bonding

STEP 3: Set the hot air welding tool's temperature and fan speed for the FDM material to be bonded (Table 4).

Table 4: Hot Air Tool Temperature Settings.[1]

Material	Temperature
ABS Family/Nylon 12	201°C (395°F)
PC-ABS	246°C (475°F)
PC/PC-ISO	282°C (540°F)
PPSF/PPSU	379°C (715°F)
ULTEM™ 9085 resin	332°C (630°F)

STEP 4: Slowly draw the hot air welding tool and FDM plastic filament along the seam, applying constant downward pressure with the filament on the bond joint (Figure 11).

STEP 5: Parts are fully cured as soon as the FDM thermoplastic cools.

TIP: Maximum bond depth will be approximately equal to the diameter of the welding filament. A "V" groove is typically used to increase the mating surface area (depth) to be welded (Figure 12).

STEP 6: Sand the seam to achieve a uniform surface.

STEP 7: Hot air plastic welding procedure complete.

Figure 11: Hot air plastic welding.

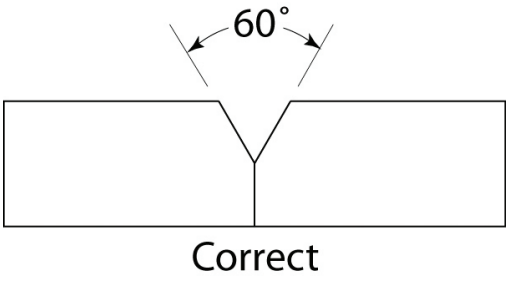

Figure 12: Establish a "V" notch at the joint for hot air welding.

2.4. Welding: Ultrasonic Spot

STEP 1: Clean and prepare surfaces to be bonded.

STEP 2: Use a test part to determine equipment settings for the type and thickness of plastic being bonded.

1 Table does not include all Stratasys FDM materials.

Bonding

STEP 3: Mate the pieces that will be bonded and secure them in place (Figure 13).

STEP 4: Place the tool on the joint to weld the pieces (Figures 14 and 15). Parts may be used immediately after bonding (Figure 16).

STEP 5: Ultrasonic spot welding procedure complete.

3. Safety

Observe manufacturer's recommendations for safety, material handling and storage. This information can be found in the Safety Data Sheet (SDS).

4. Tools & Supplies

4.1. Adhesive: Cyanoacrylate and Epoxies

- Loctite Plastics Bonding System
- Hysol E-20HP
- Magnolia 6166
- Applicator: brush, putty knife or mixing dispenser
- Oven (optional)

4.2. Solvent:

- Methylene Chloride (Micro-Mark SAME STUFF)

4.3. Welding: Hot Air

- Welding tool (Leister® Hot Jet S)
- FDM material filament

4.4. Welding: Ultrasonic Spot

- Spot welding tool (Dukane iQ series)
- Ultrasonic horn
- Spot welding tip

4.5. General

- Sand paper
- Respirator with filter (N100 or better)
- Clamps
- Isopropyl alcohol

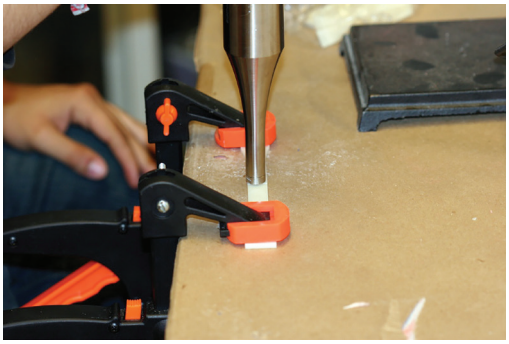

Figure 13: Clamp pieces for ultrasonic welding (ultrasonic horn shown).

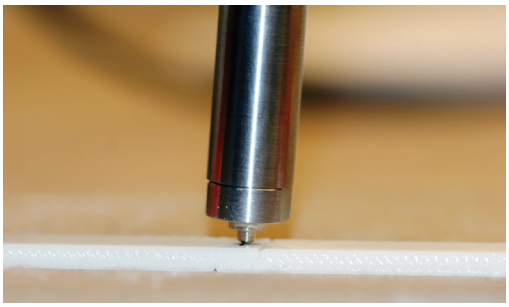

Figure 14: Touch the spot welder to the work piece.

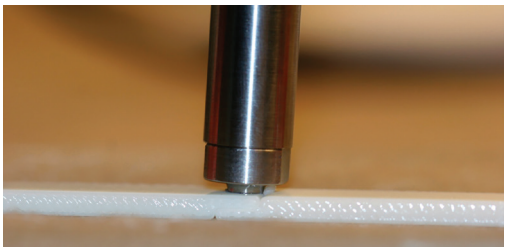

Figure 15: Depress the tool into the work piece to weld.

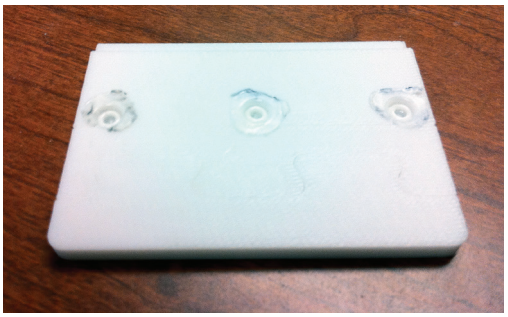

Figure 16: Spot welds from an ultrasonic welder.

Bonding

5. Materials:

- ABSplus™
- ABSi™
- ABS-M30
- ABS-M30i™
- ABS-ESD7™
- ASA
- PC
- PC-ABS
- PC-ISO™
- Nylon 12
- PPSF/PPSU
- ULTEM™ 9085 resin

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