



Comparison of Bonding Methods for FDM Materials

There are many methods, and even more materials, for bonding FDM parts. To assist in selecting the best approach, Stratasys, Inc. conducted a study to evaluate seven common methods for joining parts made from eight FDM materials.

The primary considerations when selecting a bonding method are the strength of the bonded joint and the compatibility with each FDM material. For strength data, lab testing at the University of Texas El Paso (UTEP) was performed to measure tensile strength. Stratasys personnel evaluated all other selection criteria. These criteria include time, cost, difficulty, part configuration and general performance.

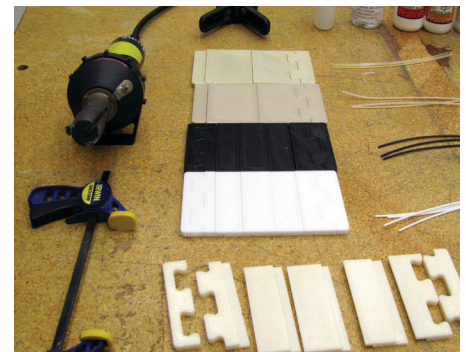


TABLE OF CONTENTS

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

1. OVERVIEW	3
1.1. Selecting a bonding method.	3
1.2. Bonding method review includes:	3
1.3. Safety note:	4
2. CONSIDERATION – TENSILE STRENGTH	4
2.1. Sub-optimal bonds.	4
2.2. To optimize bond strength.	4
3. SELECTION MATRICES	4
3.1. Compatibility – method and material.	4
3.2. Compatibility – method and material.	5
4. BONDING METHOD	5
4.1. Adhesive (cyanoacrylate).	5
4.2. Adhesive (Hysol E-20HP epoxy).	5
4.3. Adhesive (Hysol EA 9394 epoxy).	6
4.4. Solvent. (Figure 13)	6
4.5. Hot air plastic welding.	7
4.6. Ultrasonic spot welding.	8
4.7. Mechanical fasteners.	9
5. TENSILE STRENGTH	9
5.1. By material.	9
5.2. By method.	13
6. RECAP - CRITICAL SUCCESS FACTORS	16
6.1. Keys to selection:	16
6.2. Optimize bond strength	16

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

1. Overview

1.1. Selecting a bonding method.

A bonding method is selected for its compatibility with an FDM material and its bond strength. Additionally, operational considerations will influence selection.

1.2. Bonding method review includes:

1.2.1. Seven bonding methods.

- Adhesive (cyanoacrylate)
- Adhesive (epoxy)
 - Hysol E-20HP
 - Hysol EA 9394
- Solvent
- Hot air plastic welding
- Ultrasonic spot welding
- Mechanical fasteners

1.2.2. Eight FDM materials.

- ABSi
- ABS-M30
- ABS-M30i
- PC (polycarbonate)
- PC-ABS
- PC-ISO
- PPSF (polyphenylsulfone)
- ULTEM 9085
- PC-ABS
- PC-ISO
- PPSF (polyphenylsulfone)
- ULTEM 9085

1.2.3. Evaluation criteria:

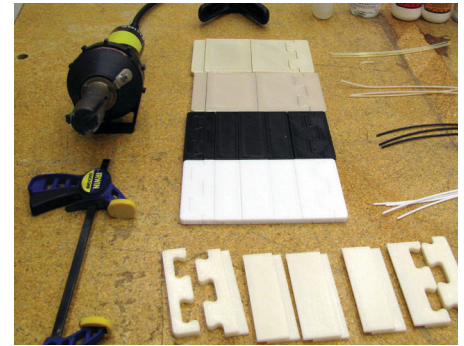
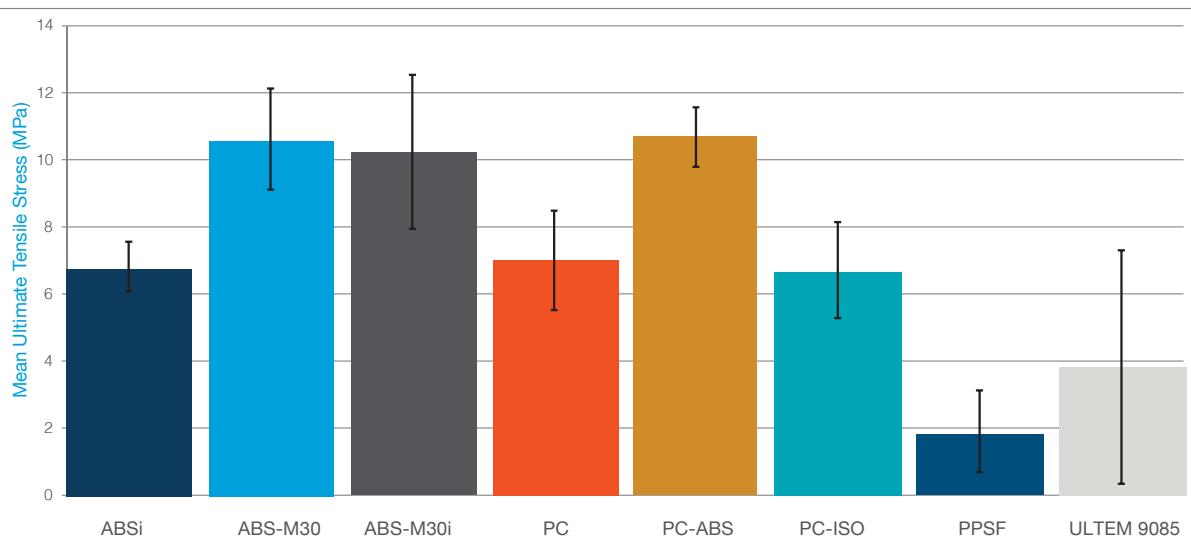


Figure 1: Parts and supplies for the various bonding methods.



I standard deviation

Figure 2: Example of tensile strength measurements for six bonding methods and eight FDM materials.

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

- Strength: Tensile strength of the bond.
- Cost: Relative expense of materials and consumables.
- Processing time: Time needed for application.
- Cure time: Time needed for part to fully cure.
- Additional equipment: Does process require equipment for application?
- Ease of use: Difficulty or skill level required to have acceptable results.
- Geometry dependent: Is process dependent, in any way, on part geometry?
- Part size: Recommended size of FDM part.
- Joint type: Recommended design of bonded surfaces.
- Bond strength: Quality of the bond in tension.

1.3. Safety note:

Follow manufacturer's safety recommendations when performing any bonding method. Also, wear personal protective equipment to avoid injury.

Strength data is based on a single test and should be used for reference only.

2. Consideration – Tensile Strength

2.1. Sub-optimal bonds.

To report conservative results for tensile strength, test samples used sub-optimal bonding techniques.

- Joint type: butt.
 - Exception: lap joint for ultrasonic welding.
- No consideration for wall thickness.
 - Test samples: 0.125 in. (3.18 mm).

2.2. To optimize bond strength.

In practice, the joint type will vary with bonding method, wall thickness and geometry type. Also, for optimal bonds, methods may be combined. For example, a thick-walled part may use solvent welding followed by hot air plastic welding.

3. Selection Matrices

3.1. Compatibility – method and material.

	ABSi	ABS-M30	ABS-M30i	PC	PC-ABS	PC-150	PPSF	ULTEM 9085
Adhesive (cyanoacrylate)	✓	✓	✓	✓	✓	✓	x	x
Adhesive (epoxy) Hysol E-20HP	✓	✓	✓	✓	✓	✓	✓	✓
Adhesive (epoxy) Hysol EA 9394	✓	✓	✓	✓	✓	✓	✓	✓
Solvent	✓	✓	✓	✓	✓	✓	x	x
Hot air welding	✓	✓	✓	✓	✓	✓	✓	✓
Ultrasonic spot welding	✓	✓	✓	✓	✓	✓	✓	✓
Fasteners	✓	✓	✓	✓	✓	✓	✓	✓

Table 1: Compatibility of FDM materials with bonding methods.

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

3.2 Compatibility – method and material.

	Cost	Process Time	Cure Time	Add. Equip.	Skill Level	Strength	Geo. Depend	Sugg. joint
Adhesive (cyanoacrylate)	\$	5 m	¼ hr	No	Low	See tensile strength charts	No	Any
Adhesive (epoxy) Hysol E-20HP	\$\$	10 m	24 hr	No	Mod.		No	Dove Lap
Adhesive (epoxy) Hysol EA 9394	\$\$	10 m	1 hr	No	Low		No	Dove Lap
Solvent	\$	5 m	8 hr	No	Low		No	Any
Hot air welding	\$	15 m	NA	Yes	High		Yes	Dove
Ultrasonic welding	\$	5 m	NA	Yes	Low		Yes	Lap
Fasteners	\$	Varies	NA	No	Low		Yes	NA

Table 2: Selection criteria results for bonding methods.

4. Bonding Methods

4.1. Adhesive (cyanoacrylate).

4.1.1. Description.

Familiarly known as “super glue,” cyanoacrylate is a fast-curing adhesive used for quick and easy repairs as well as light-duty bonds (Figure 3).

4.1.2. Process.

Apply to mating surfaces (Figure 4) and join. Hold or clamp while adhesive sets (usually in a few minutes). Optionally, apply an accelerator to decrease setting time (Figure 5). Note, however, that overexposure to accelerator may have a negative effect on the strength of thermoplastics.

4.1.3. Characteristics.

Bond strength exceeds that of many epoxy adhesives. But resistance to high temperatures, chemicals and solvents is poor. So, cyanoacrylate is best suited for concept models and form/fit prototypes rather than functional prototypes or manufactured parts.

4.2. Adhesive (Hysol E-20HP epoxy).

4.2.1. Description.

This medium-viscosity, two-part epoxy adhesive is promoted as an industrial-grade material. It has a short working time (approximately 20 minutes), which makes it a bit more challenging to use than other epoxies.

4.2.2. Process.

Like all two-part epoxies, thoroughly mix the two components. Then apply the epoxy with a brush or putty knife. Optionally, a mixing dispenser may be used (Figure 6).



Figure 3: Cyanoacrylate adhesives.



Figure 4: Apply cyanoacrylate to mating surfaces.



Figure 5: Optionally, spray bond with accelerator.

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

After application, clamp the pieces and allow the epoxy to cure for 24 hours (Figure 7).

4.2.3. Characteristics.

Hysol E-20HP provides good bond strength (Figure 8) and chemical resistance. Although heat resistant, its strength will decrease as temperatures rise. When compared to Hysol EA 9394, this epoxy has the highest tensile strength for all FDM materials with the exception of polycarbonate.

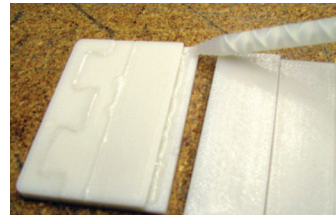


Figure 6: Hysol E-20HP may be hand-mixed or dispensed through a mixing nozzle (shown).

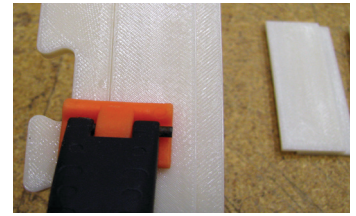


Figure 7: Clamp parts and allow to cure for 24 hours.

4.3. Adhesive (Hysol EA 9394 epoxy).

4.3.1. Description.

This epoxy is a high-viscosity, structural paste. Its consistency makes it ideal for filling large gaps as well as bonding large, structural components.



Figure 8: Hysol E-20HP epoxy has good bond strength and chemical resistance.



Figure 9: Supplies for application of Hysol EA 9394 epoxy.

Hysol EA 9394 has a long working time of approximately 70 minutes.

4.3.2. Process. (Figure 9)

Mix the two components (Figure 10) of the epoxy and apply with a putty knife or similar tool (Figure 11). Next, clamp the pieces and allow the bond to cure for three to five days at room temperature.



Figure 10: Mix the two components of the epoxy.

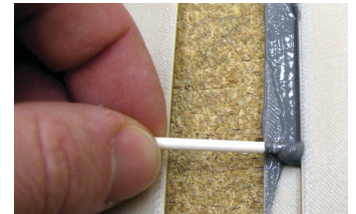


Figure 11: Apply the epoxy to mating surfaces.

Curing may be accelerated to one hour if heat is applied.

4.3.3. Characteristics.

In general, Hysol EA 9394 has lower tensile strengths than Hysol E-20HP, but it has superior temperature resistance and is good for filling gaps. Its bond strength remains excellent at temperatures beyond 350° F (177° C). It is also resistant to chemicals and solvents (Figure 12).

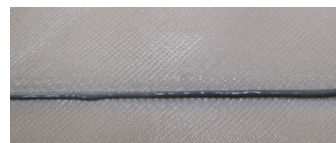


Figure 12: Cured bond of Hysol EA 9394 epoxy has good bond strength at elevated temperatures.



Figure 13: Solvent, application and mating pieces.

4.4. Solvent. (Figure 13)

4.4.1. Description.

Solvent bonding works by chemically melting the plastic on the surfaces to be joined. The solvent can be brushed onto or injected into a seam or existing crack.

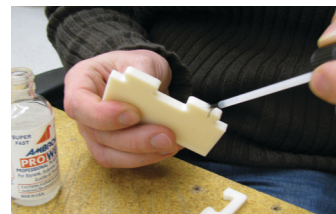


Figure 14: Brush solvent onto mating surfaces.



Figure 15: The low-viscosity solvent also flows well into seams and cracks.

As with cyanoacrylate, the process is simple, and the bond sets in seconds.

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

4.4.2. Process.

Apply solvent to the bonding surfaces (Figure 14) or inject it into seams (Figure 15). Mate the pieces and hold until the bond sets, which is usually just a few seconds (Figure 16).

To reach full strength, allow the bond to harden for eight or more hours.

4.4.3. Characteristics.

Solvent welding has several advantages over adhesives. In general, the bond strength is greater than that of cyanoacrylate or epoxy. Also, no foreign material is introduced. After evaporation, the bonded part will contain only FDM material.

If subjected to temperatures exceeding 176 - 212° F (80-100° C), surface blistering may occur.

Solvent welding is not suitable for bonding PPSF or ULTEM 9085. These FDM materials are chemically resistant, so there is little reaction to the solvent.

4.5. Hot air plastic welding.

4.5.1. Description.

Hot air plastic welding is similar to oxy-acetylene welding of metal. However, a jet of hot air replaces the flame, and a filament of FDM material replaces the filler rod (Figure 17).

The process is fast and inexpensive. The resulting bonds are strong.

4.5.2. Process.

Mate the pieces that will be bonded and secure them. Slowly draw the hot air welding tool and plastic filament along the seam (Figure 18). The FDM plastic filament melts and fuses to the bonded pieces. A "V" groove is typically used to provide additional mating surface area (depth) to be welded.

Parts may be put into services as soon as they are cool to the touch (Figure 19).

4.5.3. Characteristics.

This method produces bonds that are stronger than those of all other processes.

Since the bonding material is a small piece of FDM plastic, the cost is negligible. Another advantage is that there is material continuity. The bond has the same properties and characteristics as the part.

Hot air plastic welding requires some skill. To develop the technique that produces good bonds, practice is recommended.



Figure 16: Align and hold the mating piece until the bond has set.



Figure 17: Hot air plastic welding is similar, in concept, to oxy-acetylene welding.

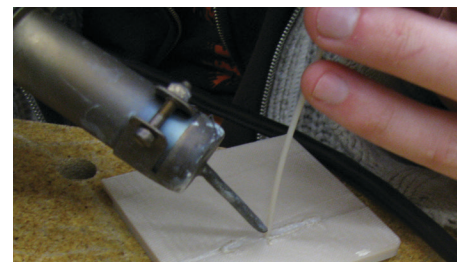


Figure 18: Draw the hot air welding tool and plastic filament along the seam.



Figure 19: Bonded pieces before sanding the weld bead flush to the surrounding surfaces.

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

This method is not recommended for thin-walled parts, which are:

- ULTEM 9085 and PPSF: <0.125 in. (3.18 mm)
- All others: <0.080 in. (2.03 mm)

4.6. Ultrasonic spot welding.

4.6.1. Description.

A handheld ultrasonic welding tool emits sound waves that melt localized areas of the joint.

There are many advantages, including process speed, cost and bond strength.

4.6.2. Process.

Ultrasonic welders use interchangeable horns to achieve different types of bonds. For this report, a horn with a spot welding tip [a 0.125-inch (3.175-mm) diameter] was used.

Pieces to be bonded are mated and secured (Figure 20). The tool is placed on the seam to join the pieces (Figures 21 and 22). Part may be used immediately.

To establish correct settings for the part's FDM material and the bond's wall thickness, work with a disposable sample. Adjust the welder's settings until the results are satisfactory. (Figure 23)

4.6.3. Characteristics.

Compared to other bonding methods, there are few, if any, disadvantages to ultrasonic welding beyond the need to purchase the welding tool.

It yields strong bonds—the weld tends to be stronger than surrounding material. Yet, the tensile strength is not as great as that of hot air plastic welding.

No foreign materials are introduced, so accuracy and properties are not altered. This also makes the process ideal for medical and food handling applications that have strict material requirements.

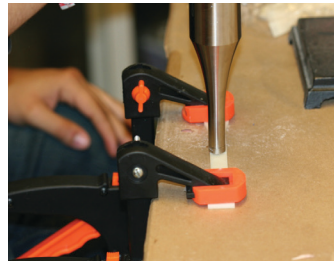


Figure 20: Clamp pieces for ultrasonic welding.

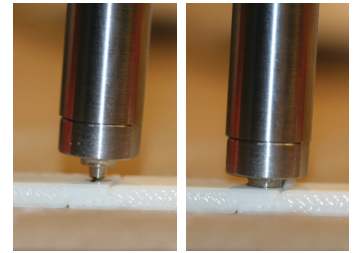


Figure 21: Touch the spot welder to the work piece.

Figure 22: Depress into work piece to welding the parts.

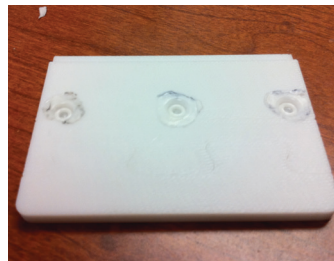
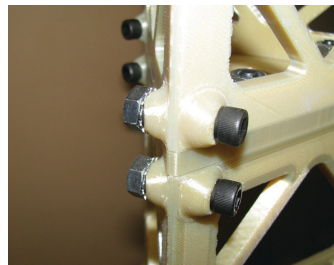


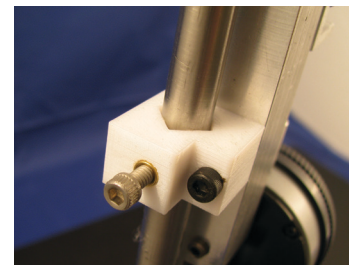
Figure 23: Spot welds from an ultrasonic welder.



Clamping device with a variety of mechanical fasteners.



Nut and bolt attachments for multi-piece structure.



Threaded insert integrated in part during FDM build.

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

4.7. Mechanical fasteners.

4.7.1. Description.

Fasteners are an effective alternative to bonding FDM parts. There are many options, including:

- Threaded inserts for machine screws.
- Tapped holes for machine screws.
- Self-tapping screws.
- Nuts & bolts.

4.7.2. Process.

The processes for mechanical fasteners are as numerous as the fasteners themselves.

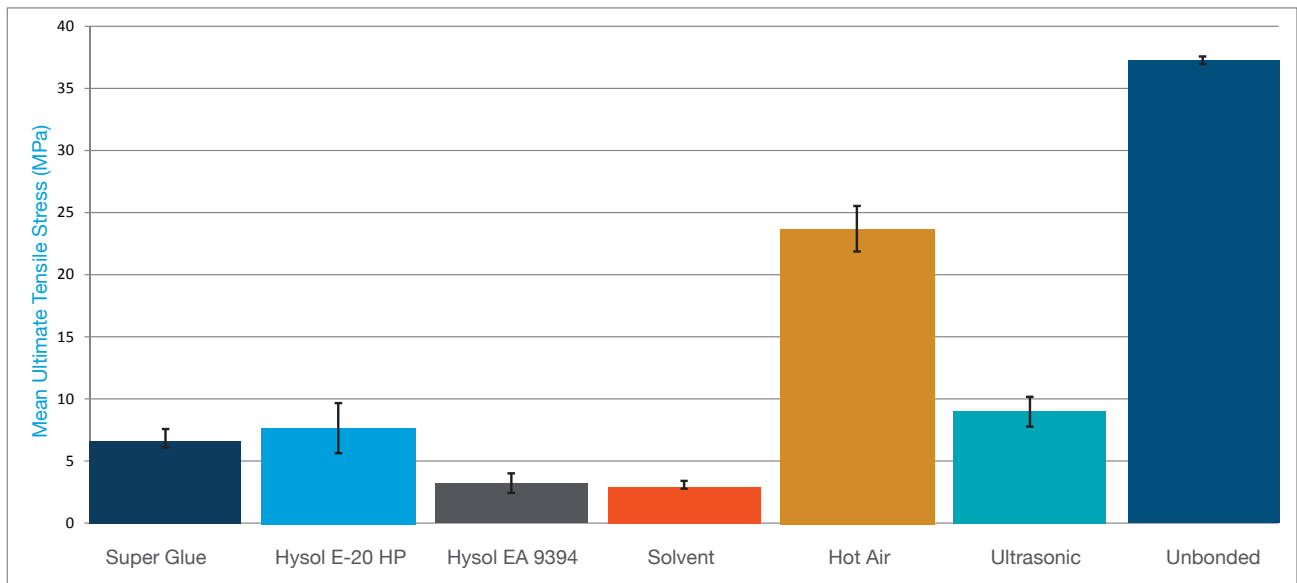
To optimize the process and part strength, the FDM build process may be adjusted. For example:

- Pause a build and place threaded inserts in partially built part.
- Adjust toolpath parameters to add strength to the walls of a tapped hole.

5. Tensile Strength

5.1. By material.

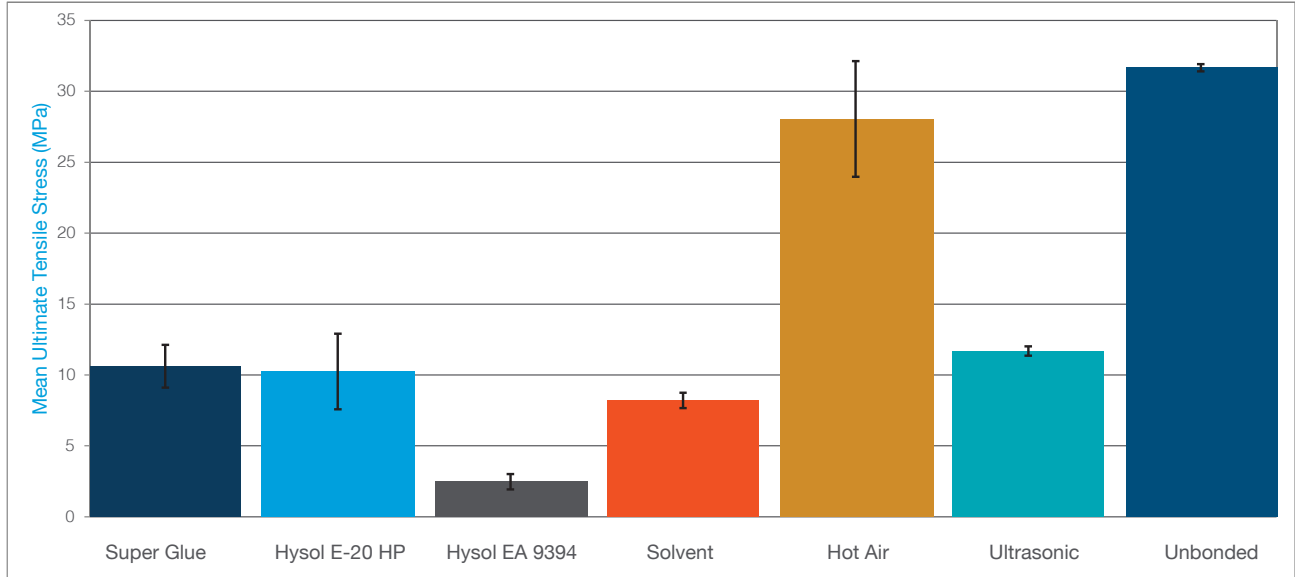
5.1.1. ABSi



I standard deviation

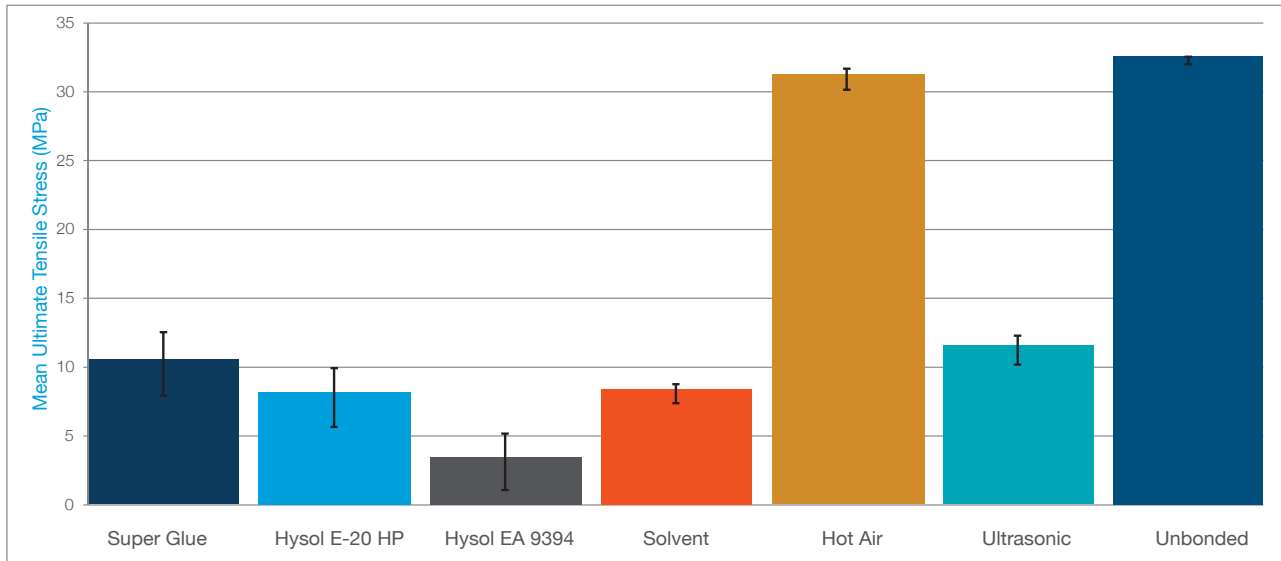
COMPARISON OF BONDING METHODS FOR FDM MATERIALS

5.1.2. ABS-M30



I standard deviation

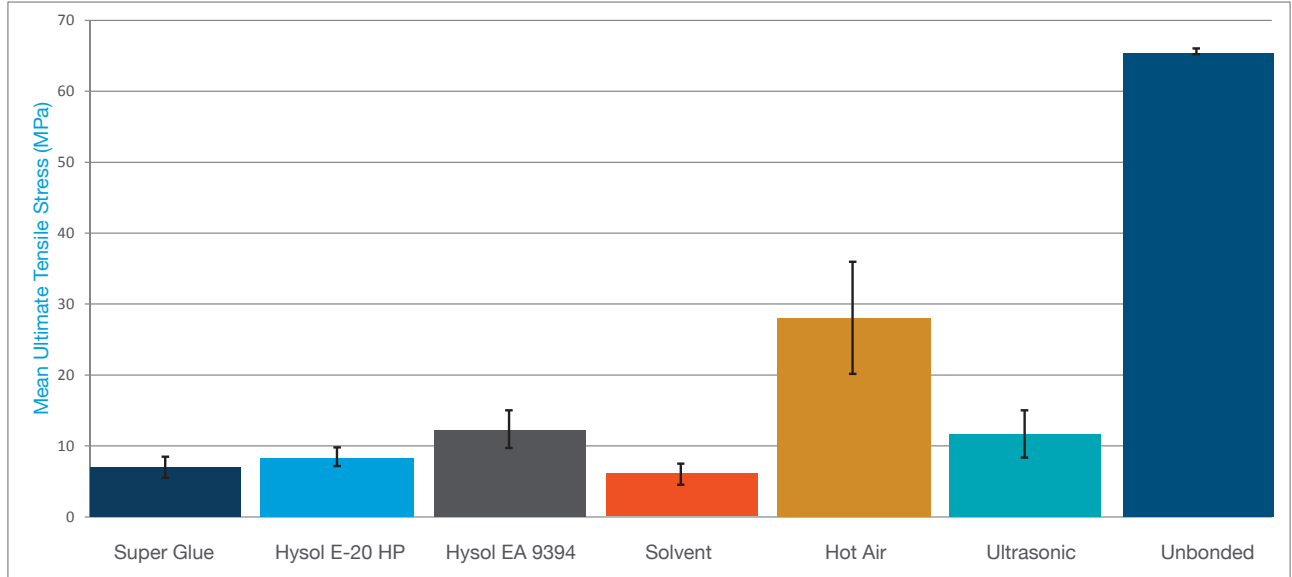
5.1.3. ABS-M30i



I standard deviation

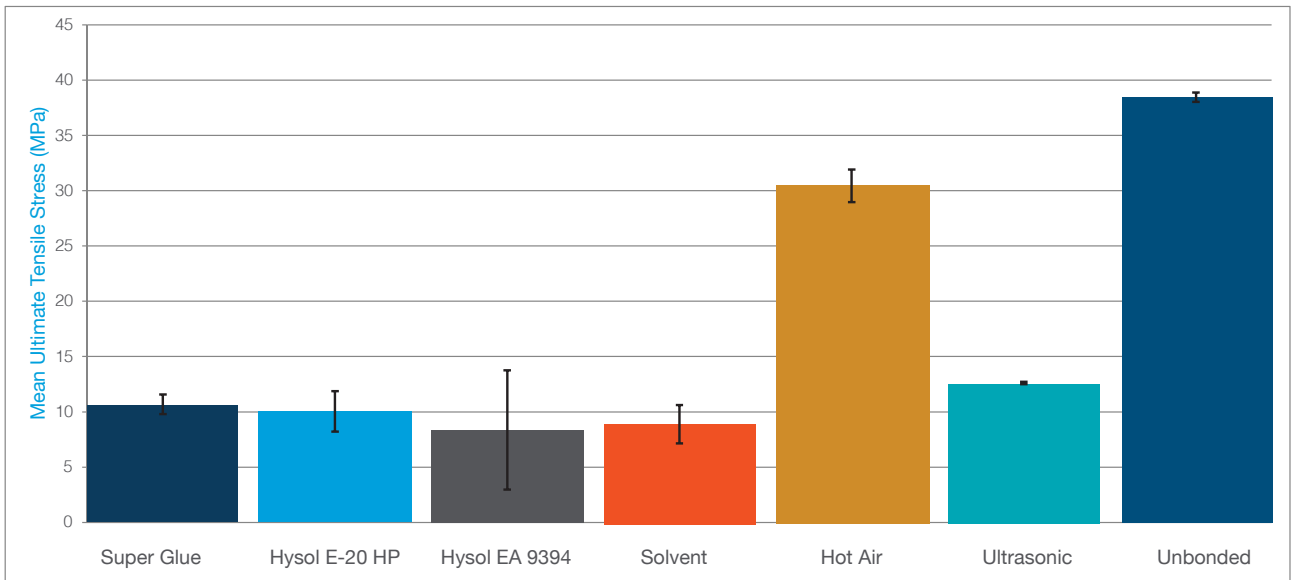
COMPARISON OF BONDING METHODS FOR FDM MATERIALS

5.1.4. PC



I standard deviation

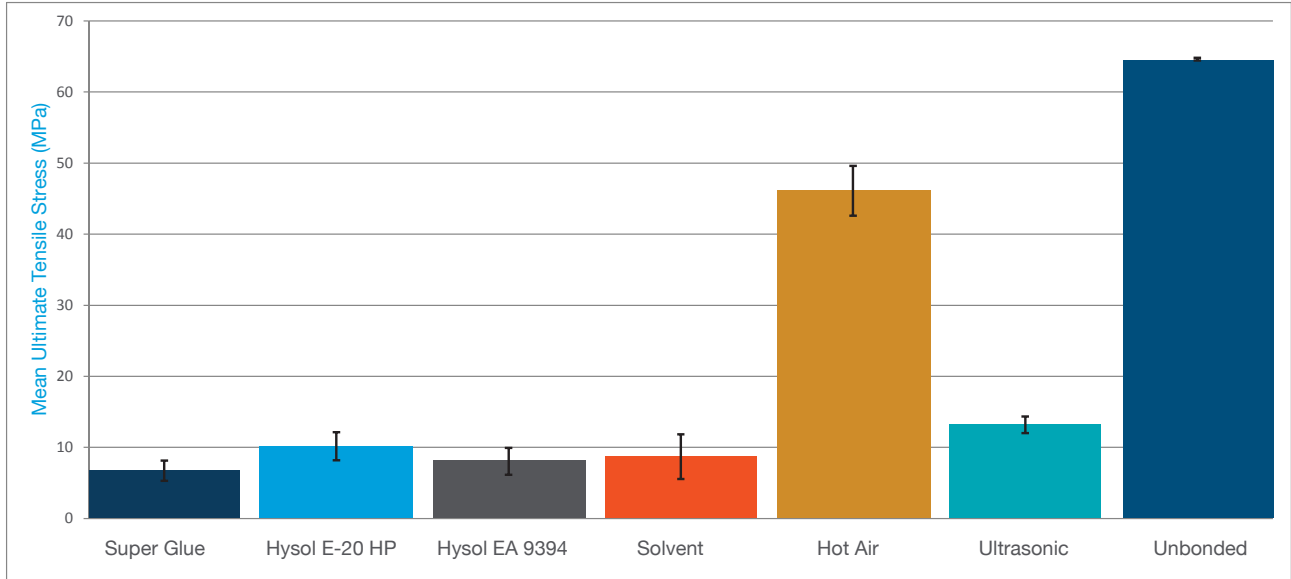
5.1.5. PC-ABS



I standard deviation

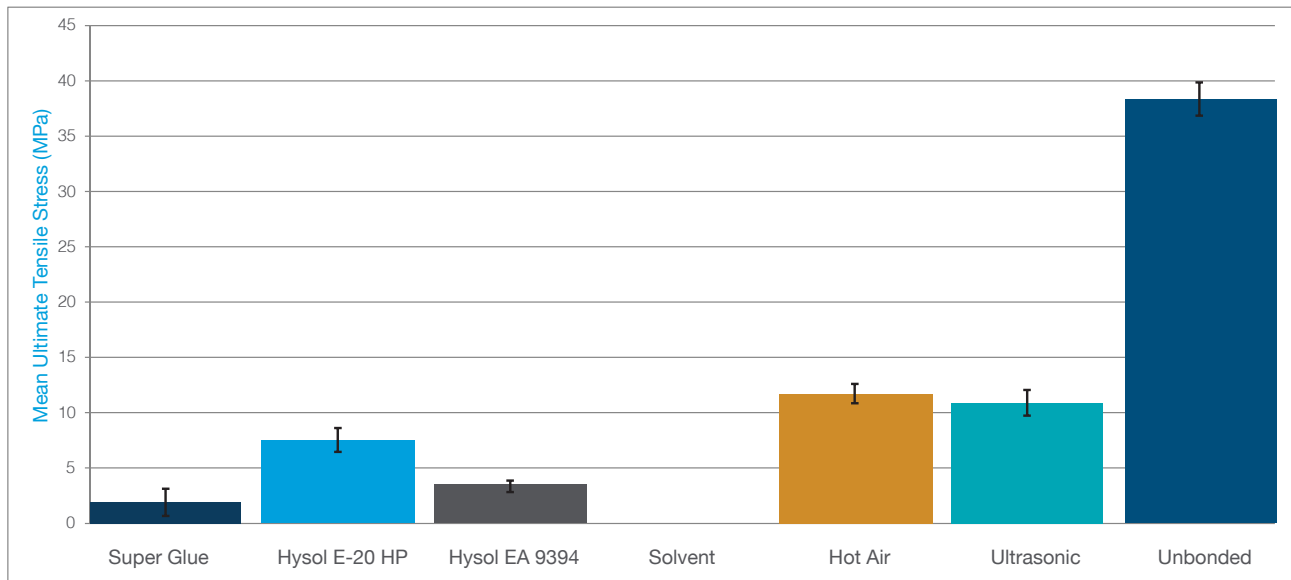
COMPARISON OF BONDING METHODS FOR FDM MATERIALS

5.1.6. PC-ISO



I standard deviation

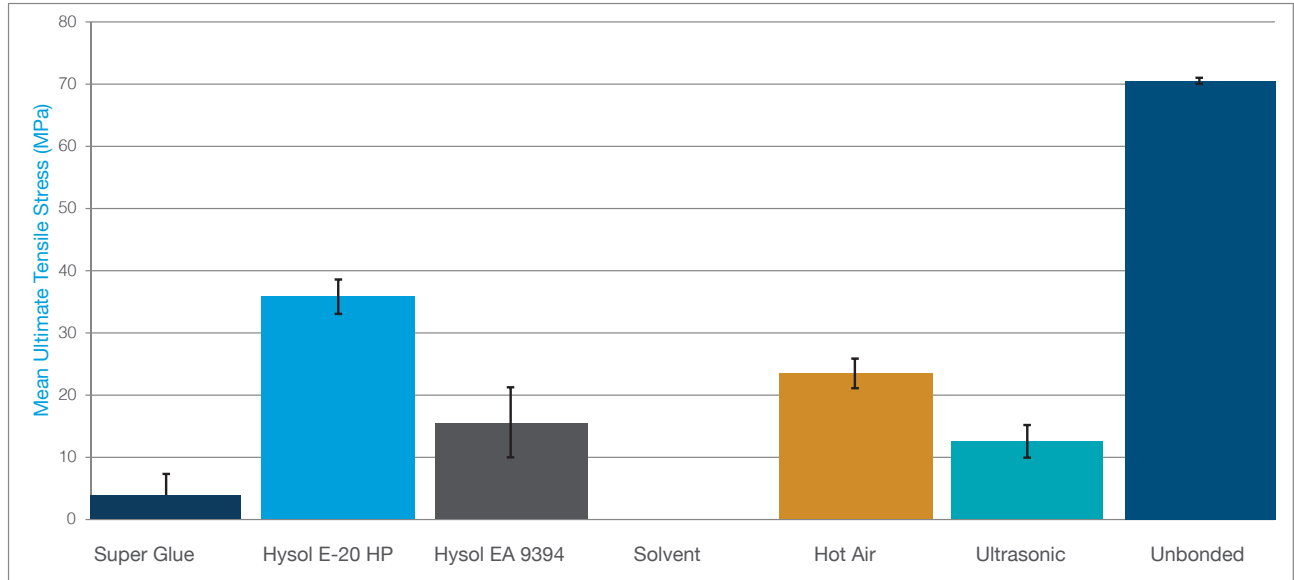
5.1.7. PPSF



I standard deviation

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

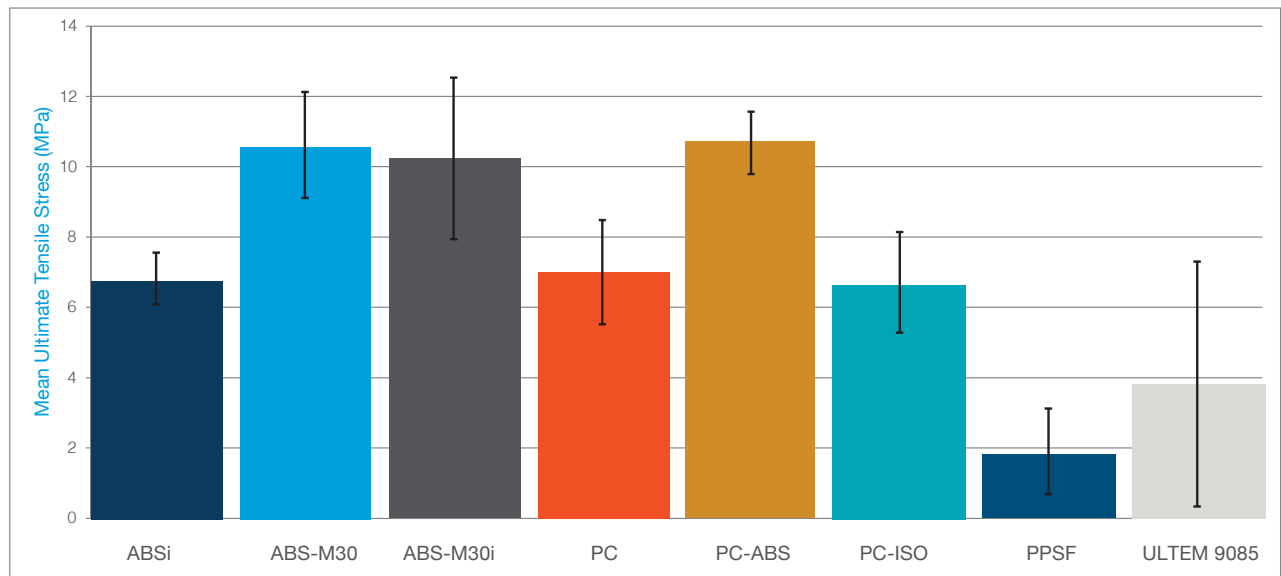
5.1.8. ULTEM 9085



I standard deviation

5.2. By method.

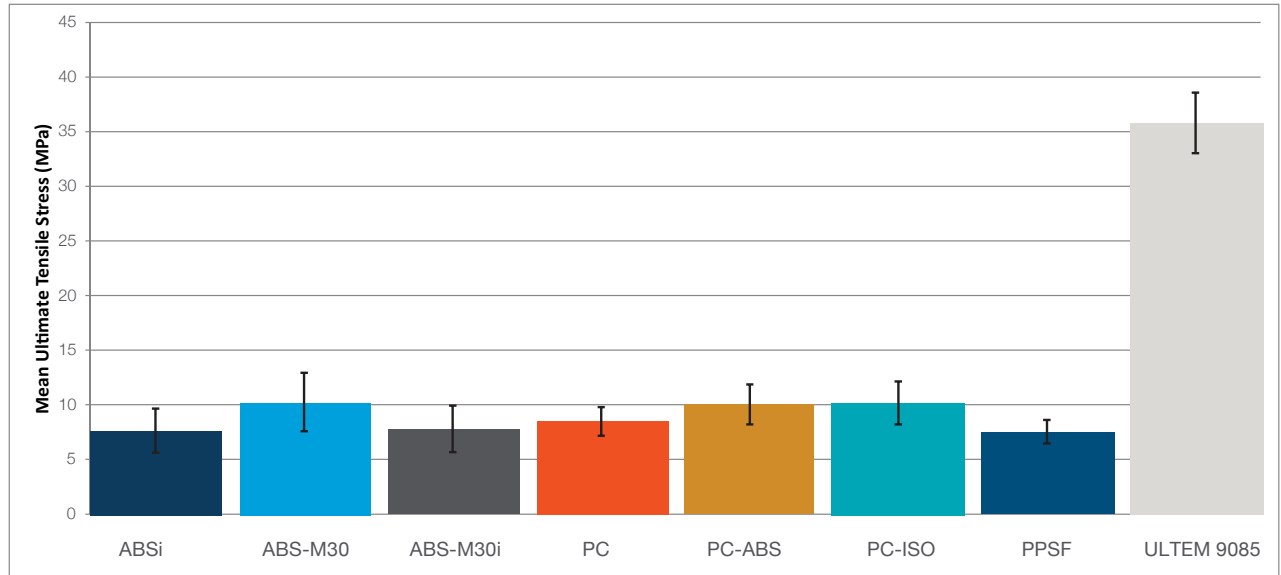
5.2.1. Adhesive (cyanoacrylate)



I standard deviation

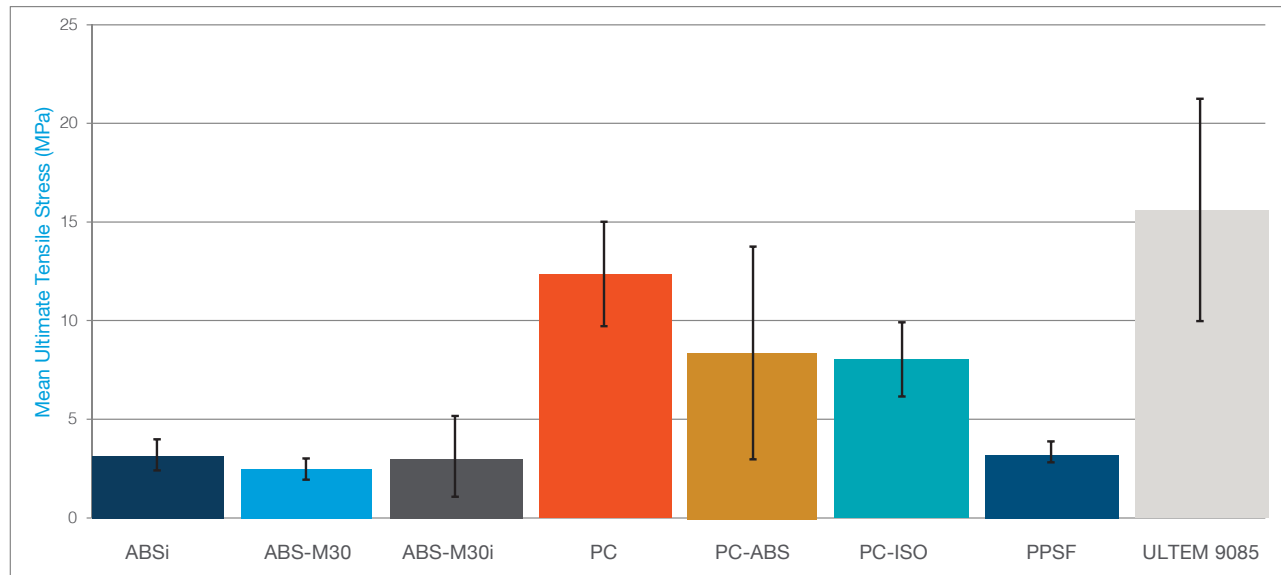
COMPARISON OF BONDING METHODS FOR FDM MATERIALS

5.2.2. Adhesive (Hysol E-20HP Epoxy)



I standard deviation

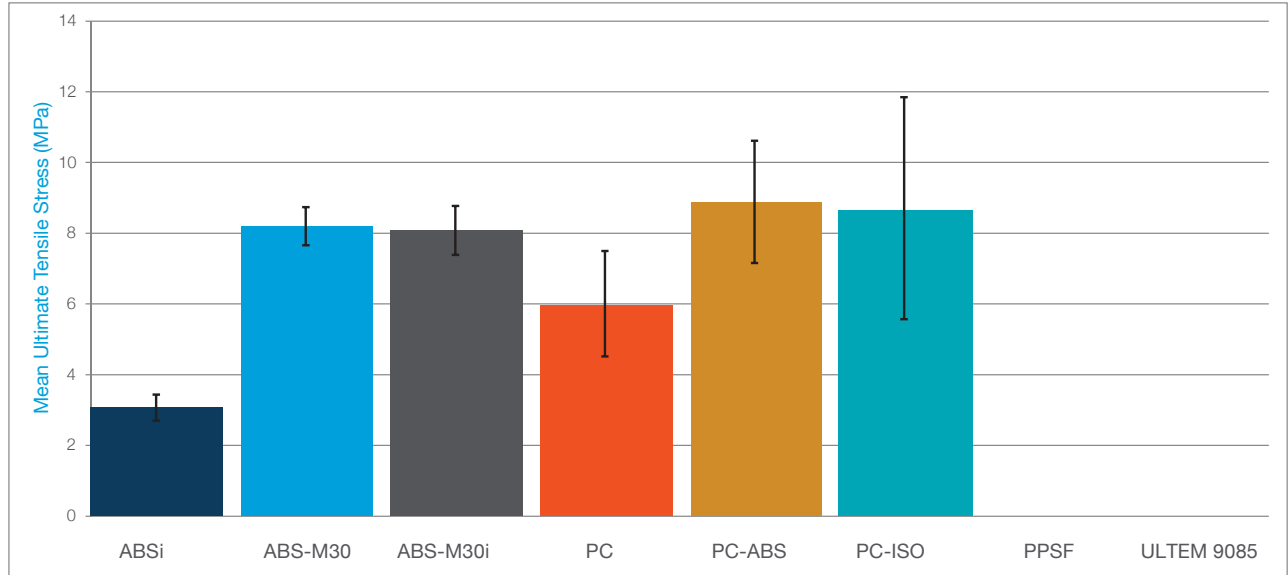
5.2.3. Adhesive (Hysol EA 9394 Epoxy)



I standard deviation

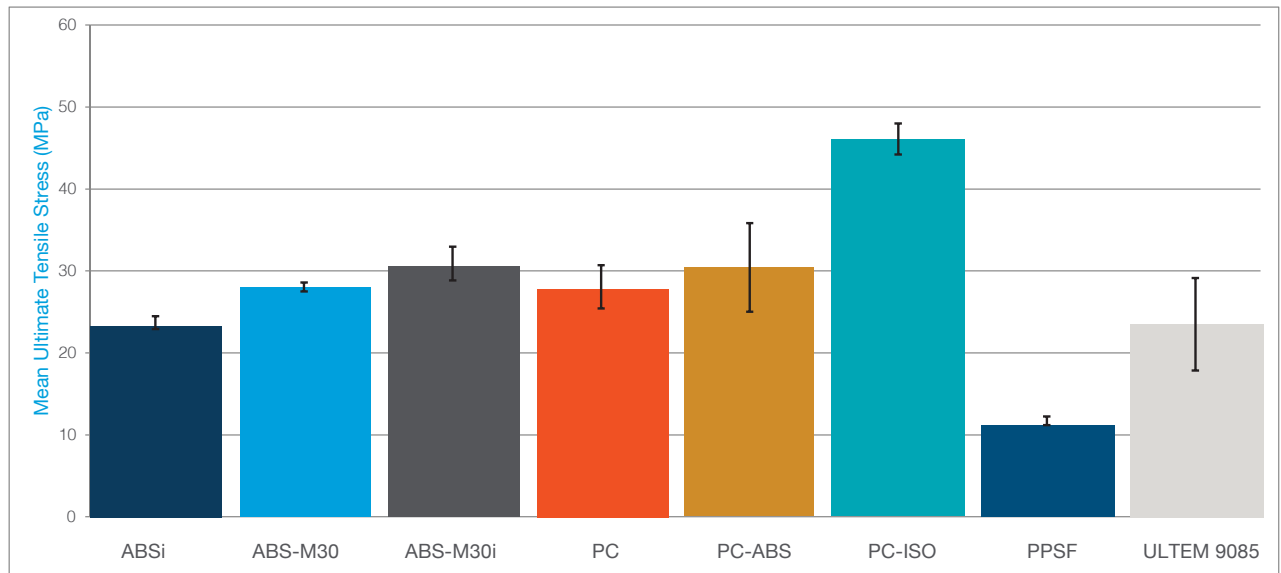
COMPARISON OF BONDING METHODS FOR FDM MATERIALS

5.2.4. Solvent



I standard deviation

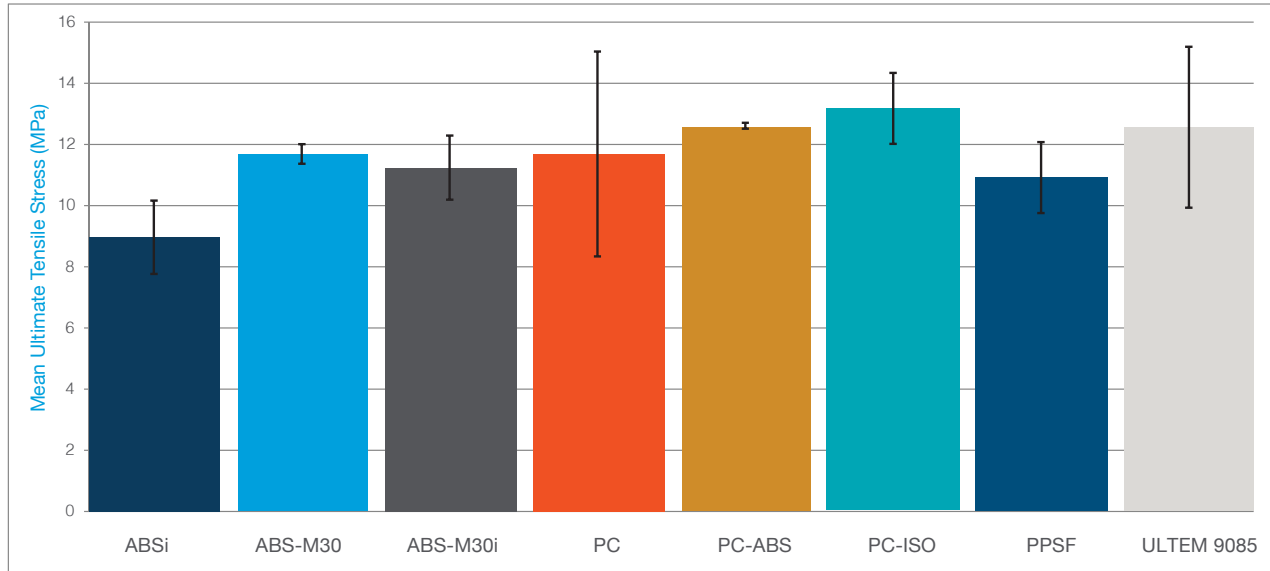
5.2.5. Hot air plastic welding



I standard deviation

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

5.2.6. Ultrasonic welding



I standard deviation

6. Recap - Critical Success Factors

6.1. Keys to selection:

- Material compatibility.
- Wall thickness.
- Bond strength.
- Safety, time, tools and supplies.

6.2. Optimize bond strength

- Joint type.
- Combine methods.

COMPARISON OF BONDING METHODS FOR FDM MATERIALS

CONTACT

For questions about the information contained in this document, contact Stratasys at www.stratasys.com/contact-us/contact-stratasys.



E info@stratasys.com / STRATASYS.COM

HEADQUARTERS

7665 Commerce Way, Eden Prairie, MN 55344
+1 888 480 3548 (US Toll Free)
+1 952 937 3000 (Intl)
+1 952 937 0070 (Fax)

2 Holtzman St., Science Park, PO Box 2496
Rehovot 76124, Israel
+972 74 745-4000
+972 74 745-5000 (Fax)

ISO 9001:2008 Certified

© 2011 - 2015, 2014 Stratasys Inc. All rights reserved. Stratasys, FDM and Fortus are registered trademarks and Fused Deposition Modeling, FDM Technology, Fortus 250mc, Fortus 360mc, Fortus 400mc, Fortus 900mc, Insight and Control Center are trademarks of Stratasys Inc., registered in the United States and other countries. ULTEM™ is a registered trademark of SABIC or affiliates. All other trademarks are the property of their respective owners. Product specifications subject to change without notice. TAG_FDM_Bonding_EN_1015