WHITE PAPER

Lap Shear Bonding Strength for 3D Systems Figure 4® Materials Bonded with Bostik Adhesives

3D SYSTEMS
Additive Manufacturing Solutions

1. Background

Many 3D Systems customers have expressed a desire to use adhesives with their Figure 4® solutions to create assemblies of parts. In order to enable our customers and their applications, 3D Systems partnered with Bostik, Inc., a leader in adhesive technology, to evaluate and recommend adhesives suitable for use with Figure 4 materials.

2. Material selection

3D Systems Figure 4 additive manufacturing platform offers a range of robust material options. 3D Systems selected two Figure 4 materials for use in this study to represent a range of acrylate-based chemistries: Figure 4® PRO-BLK 10, a production-grade material with rigid acrylic-like properties, and Figure 4® FLEX-BLK 20, a durable and flexible material with polypropylene-like properties. Table 1 describes the main properties and features of the materials selected.

3D Systems Material	Features	Tensile Strength Ultimate (MPa)	Tensile Strength at Yield (MPa)	Tensile Modulus (MPa)	Elongation at Break (%)
Figure 4 FLEX-BLK 20	• High elongation at break and notched impact strength • Engineered for long term environmental stability • Easy to clean	36	24	1150	76
Figure 4 PRO-BLK 10	• Durability and strength • Exhibits thermoplastic behavior in necking at tensile break point	63	63	2320	12

Table 1: Main properties of Figure 4 materials selected by 3D Systems

Based on the chemical and physical properties of the substrates, Bostik selected products from its instant adhesives product range Born2Bond™: Born2Bond Structural; and from its methyl methacrylate range SAF: SAF Ultimate. Both SAF Ultimate and Structural's packaging allow easy manual dispensing. SAF Ultimate is supplied in cartridges that can be used with a manual gun and Structural can either be supplied in cartridges or in smaller syringes that do not require the use of a gun.

Born2Bond Structural is a two-component methoxyethyl cyanoacrylate. Compared to commonly used ethyl cyanoacrylate adhesives, methoxyethyl cyanoacrylate adhesives have lower odor and show lower blooming (white powder around the bondline). This two-component product contains an activator, which allows it to cure even if there is a gap between the substrates, unlike classic one-component cyanoacrylate adhesives. While it has an open time of 20 to 25 minutes, it still shows a fast fixture time when the substrates are placed against each other, allowing for high process flexibility.

SAF Ultimate is a two-component methyl methacrylate with high environmental and impact resistance. Its key features include minimal surface preparation requirements for the substrates, no sagging when applied on vertical surfaces, and high elongation. Table 2 describes the main properties of the adhesives selected.

Based on knowledge of the substrate and adhesive chemistries, and in order to keep testing to a practical number of samples, Figure 4 PRO-BLK 10 was tested with Born2Bond Structural and Figure 4 FLEX-BLK 20 was tested with SAF Ultimate. Because these materials represent a range of acrylate-based chemistries, the results are assumed applicable to all Figure 4 materials.

Adhesive Name	Base	System	Appearance	Temperature Use Range (°C)	Open Time	Fixture Time	Tensile Strength @ Break (MPa)	Hardness (Shore D)	Elastic Modulus (MPa)	Elongation at Break (%)
Structural	Cyanoacrylate	2 component - 4:1 mix ratio (volume)	Transparent	-40˚ to 120˚	25-35 min	30 sec	16	65	800	17
SAF Ultimate	Methyl Methacrylate	2 component - 4:1 mix ratio (volume)	Resin: Off-white Hardener: Off-white	-50˚ to 150˚	6-8 min	10-15 min	7	55-60	300-500	100

Table 2: Main properties of adhesives selected by Bostik

3. Testing methodology

3.1 SAMPLE PREPARATION

All sample preparation, bonding, and lap shear testing was done by Bostik according to ISO 4587 – "Determination of lap-shear strength of rigid-to-rigid bonded assemblies." This standard specifies bonding area, bonding thickness, machine grip location, machine speed, and expression of results.

All bonding was done with a metal jig that was designed to make ISO 4587 standard lap shears. After substrates were cleaned with isopropyl alcohol, one test sample was put onto the jig and secured. A small line of adhesive was applied near the edge of the test sample. Another test sample was brought in and placed onto the opposite end of the jig. Small binder clips were placed on each side of the bonded area to ensure a consistent, firm pressure on the bond. Any excess adhesive was squeezed out of the side of the bond area, thus ensuring every sample had a bond area of approximately 12.5 mm x 25 mm. Figure 1 shows an example of bonding a sample using this jig. Four replicas were bonded for each adhesive/substrate combination.

Bonded samples were then placed in Bostik's controlled environment lab, which is held at a constant 23+/-2C and 50+/-5% RH. After 24 hours, the adhesives are fully cured and the binder clips were removed. Samples were laid out onto racks for an additional 6 days before testing. This conditioning allows the bonded samples to come into equilibrium with the testing room's conditions (temperature and humidity).

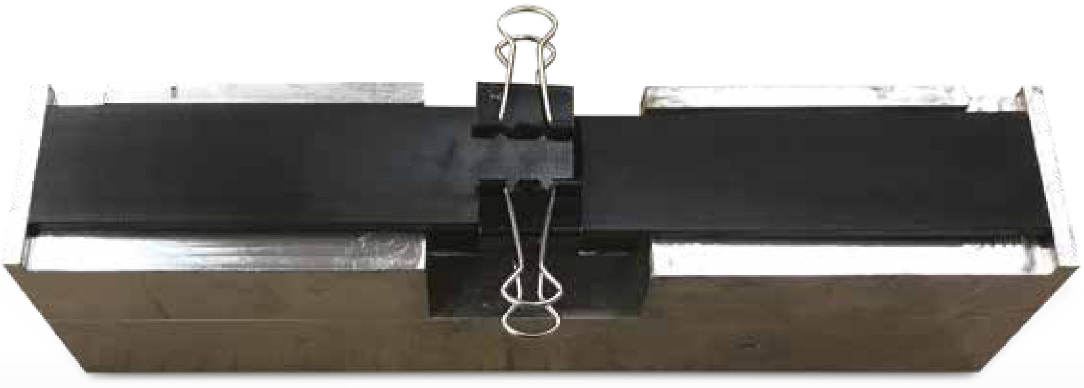

Figure 1: Jig used for bonding substrates

3.2 TEST METHOD

Lap shear bonding strength testing was conducted using an Instron tensile tester. Spacers were used to ensure a consistent gripping location. The spacers also guaranteed consistently perpendicular alignment with the Instron jaws. ISO 4587 stipulates that a constant test speed should be used so the average joint will be broken in 65 ± 20 seconds. This resulted in speeds ranging from 0.06 to 0.3 in/min depending on the material, adhesive, and aging conducted on the sample.

4. Results

4.1 INITIAL BONDING STRENGTH

In order to determine initial bonding strength, a set of samples for the two substrate/adhesive pairs was tested. Results are shown in Table 3.

3D Systems Substrate	Bostik Adhesive	Lap Shear Bonding Strength (MPa)	Standard Deviation (MPa)	Failure Mode
Figure 4 FLEX-BLK 20	SAF Ultimate	3.5	0.4	CF
Figure 4 PRO-BLK 10	Born2Bond™ Structural	7.2	1.2	SF

Table 3: Initial bonding strength. Failure mode is either a cohesive failure (CF), in which a break in the adhesive leaves residue on both sides of the bonded area, or a substrate failure (SF), which is a break in the substrate away from the adhesive. For Figure 4 PRO-BLK 10 with Born2Bond Structural adhesive, the reported bond strength is a lower limit, as the substrate failure indicates that the adhesive is stronger than the substrate.

Figure 4 FLEX-BLK 20 paired with SAF Ultimate adhesive results in a mid-range bonding strength of 3.5±0.4 MPa and a cohesive failure at break. This type of failure refers to a break in the adhesive which leaves residue on both sides of the bonded area.

Figure 2. Example of a cohesive failure (left); example of a substrate failure (right)

Figure 4 PRO-BLK 10 paired with Born2Bond Structural adhesive has a high bonding strength > 7.2±1.2 MPa and results in a substrate failure at break. This type of failure indicates that the adhesive bond is stronger than the substrate itself, and therefore only a lower limit on the adhesive strength can be specified. Figure 2 shows examples of both cohesive and substrate failures.

When compared to traditional polycarbonate bonded with Born2Bond Structural, Figure 4 PRO-BLK 10 has slightly higher lap shear bonding strength, as show in Table 4. Both materials result in substrate failures with this adhesive.

	Bostik Adhesive	Failure Mode
Polycarbonate	> 5.0 ± 0.6 MPa	Substrate Failure
Figure 4 PRO-BLK 10	> 7.2 ± 1.2 MPa	

Table 4. Lap shear bonding strength of Born2Bond Structural on polycarbonate and Figure 4 PRO-BLK 10

4.2 LONG-TERM ENVIRONMENTAL STABILITY

3D Systems Figure 4 production-grade materials are engineered to give long-term environmental resistance to UV light and humidity, retaining a high percentage of initial mechanical properties over time. In order to evaluate the long-term stability of assembled parts using Bostik adhesives, bonded lap shear coupons were subjected to the same long-term environmental stability aging testing that Figure 4 materials were subjected to during development. These include ASTM D4329 for indoor long-term stability and ASTM G154 for outdoor long-term environmental stability.

4.2.1 INDOOR LONG-TERM ENVIRONMENTAL STABILITY

In order to evaluate long-term stability for indoor use, bonded lap shear coupons prepared per the method described in section 3.1 were aged in a Q-LAB QUV weathering tester according to the ASTM D4329 standard. Samples were pulled at 2.5-, 5.0-, and 7.0-year equivalents and tested per the method described in section 3.2. Results are shown in Figure 4.

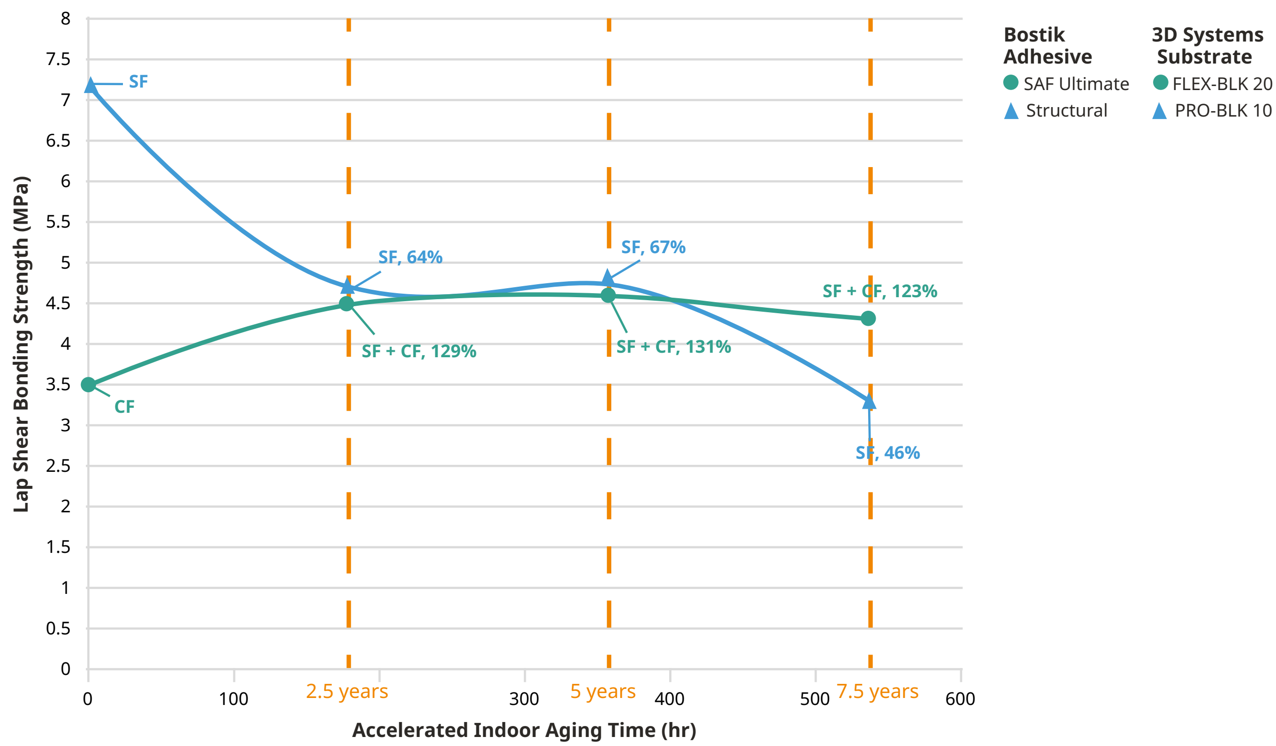

Figure 4. Accelerated indoor aging results. Percentages are shown relative to the initial bonding strength.
SF = substrate failure, CF = cohesive failure

Figure 4 PRO-BLK 10 with Born2Bond Structural adhesive exhibits a decrease in lap shear bond strength over time, however the failure mode remains a substrate failure throughout the entire aging period. This indicates that the adhesive bond strength remains higher than the substrate material strength regardless of age. As a result, Born2Bond Structural adhesive is recommended for use with Figure 4 PRO-BLK 10 for indoor applications. Based on material chemistry, it is also expected that Born2Bond Structural adhesive will perform similarly with all other Figure 4 materials.

Figure 4 FLEX-BLK 20 with SAF Ultimate adhesive initially exhibits a lower bond strength, and cohesive failure instead of substrate failure. However, it exhibits a slight increase in bonding strength over time (~20-30%). This increase is likely due to additional curing of the adhesive due to the heat applied as part of the accelerated aging process. SAF Ultimate is therefore recommended for use with Figure 4 materials for indoor applications where the material specifications fit the intent of the engineering design.

4.2.2 OUTDOOR LONG-TERM ENVIRONMENTAL STABILITY

In order to evaluate long-term stability for outdoor use, bonded lap shear coupons prepared per the method described in section 3.1 were aged in a Q-LAB QUV weathering tester according to the ASTM G154 standard. Samples were pulled at 0.5-, 1.0-, and 2.0-year equivalents and tested per the method described in section 3.2. Results are shown in Figure 5.

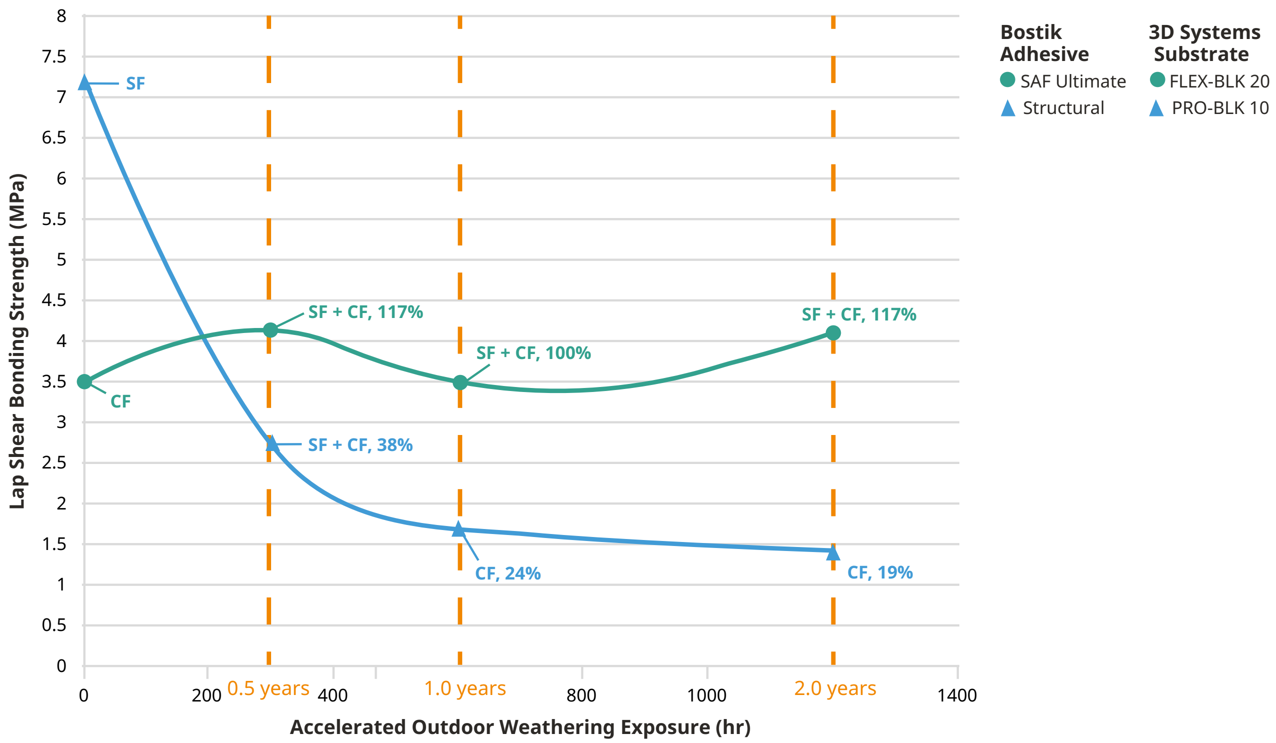

Figure 5. Accelerated outdoor aging results. Percentages are shown relative to the initial bonding strength.
SF = substrate failure, CF = cohesive failure

Figure 4 FLEX-BLK 20 with SAF Ultimate adhesive starts with a lower bonding strength, but similarly to the indoor aging test, it remains constant or slightly improved over the entire accelerated aging period. Based on this data, SAF Ultimate adhesive is recommended for use with Figure 4 materials in outdoor applications.

Figure 4 PRO-BLK 10 with Born2Bond Structural adhesive displays a rapid loss in lap shear bonding strength in a less than 0.5-year outdoor equivalent. Additionally, the failure mode changes from a substrate failure to a cohesive failure, indicating a loss of adhesive strength. Based on this data, Born2Bond Structural adhesive is not recommended for use with Figure 4 materials in outdoor applications.

5. Conclusions

Lap shear bonding strength was tested for two different 3D Systems Figure 4 3D printing materials with two different Bostik adhesives. Both sets of material were tested for initial strength and long-term environmental stability under both indoor and outdoor conditions. All testing was performed per the appropriate ASTM standards. Bostik Born2Bond Structural adhesive is recommended for use with Figure 4 materials in indoor environments, but not recommended for use in outdoor environments.

Bostik SAF Ultimate adhesive is recommended for use with Figure 4 materials in indoor and outdoor environments. This makes it a very versatile single-material solution for use with Figure 4 materials.

RESOURCES:

https://www.bostik.com/global/en/

https://www.bostik.com/us/en_US/

https://born2bond.bostik.com/en/home

https://www.3dsystems.com/materials/figure-4-pro-blk-10

https://www.3dsystems.com/materials/figure-4-flex-blk-20

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