Evolve's **General Purpose ABS Material** Displays Excellent Physical Properties

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EVOLVE
ADDITIVE SOLUTIONS

STEP TECHNOLOGY

The selective thermoplastic electrophotographic process (STEP™) technology is a commercial additive manufacturing technology by Evolve Additive Solutions. The STEP process is fundamentally different from MJF, SLS, DLP and FDM and combines the speed and accuracy of electrophotographic 2-D printing with the thermal processability of commercial plastics to produce strong engineering grade parts. Evolve Additive Solutions' first commercial engineering material is a black, general-purpose ABS product.

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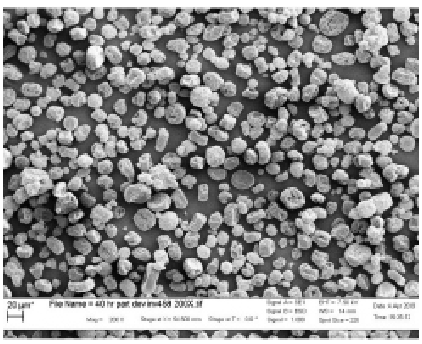
ABS is well-known for its good balance of material properties, including toughness, heat resistance, dimensional stability, and it is light-weight. The material properties are the most important for our customers' applications. Evolve's general purpose ABS parts display density, strength, ductility, and modulus that meet American Society for Testing and Materials (ASTM) and International Organization for Standardization (ISO) testing of engineering grade plastics.

STEP™ PROCESS DESCRIPTION

Prior to printing, the ABS resin pellets are converted into micron-sized toner particles formulated for STEP. A closer look at these micronized ABS particles by Scanning Electron Microscopy (SEM) shows the morphology and size of the individual particles. The particles are uniform in size and enable excellent part quality.

Left, ABS resin pellets. Right ABS toner particles



SEM picture of Evolve's ABS toner particles.

In the STEP printing process, the ABS particles are selectively printed layer by layer along with particles of a pH-responsive support to form a 3D build under heat and pressure. The process repeats until the build is complete.

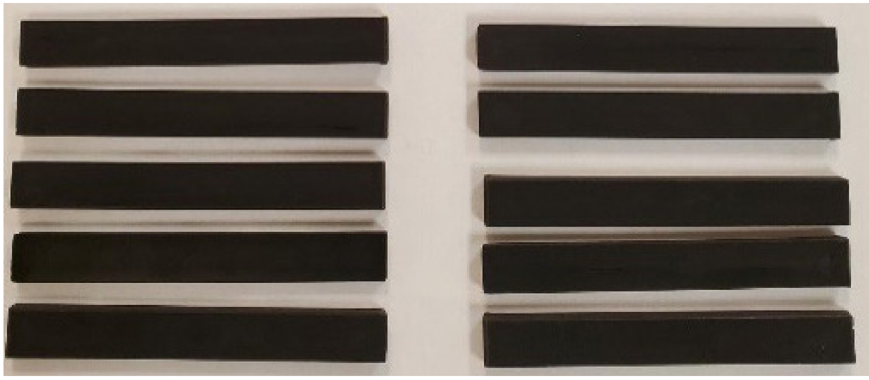
After printing, the support is removed in elevated pH solution and the final parts are isolated as individual parts.

Left, ABS toner particles. Right 1 layer of ABS part and support particles

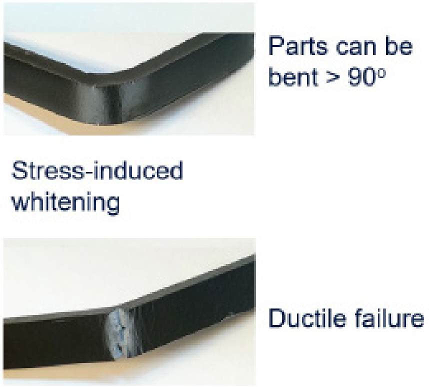
PHYSICAL PROPERTIES OF EVOLVE'S ABS MATERIALS

The physical properties of the Evolve's ABS materials enable a wide range of customers' ABS applications. In order to evaluate these properties, Charpy bars and tensile bar specimens were printed for testing and analysis. The process to make these test specimens is the same process as producing STEP geometric parts for Evolve's customers, and these test parts may be printed within the same build as customer parts.

An application bending test shows that the material is ductile and has stress-induced whitening upon bending. These materials are ductile and have good toughness.



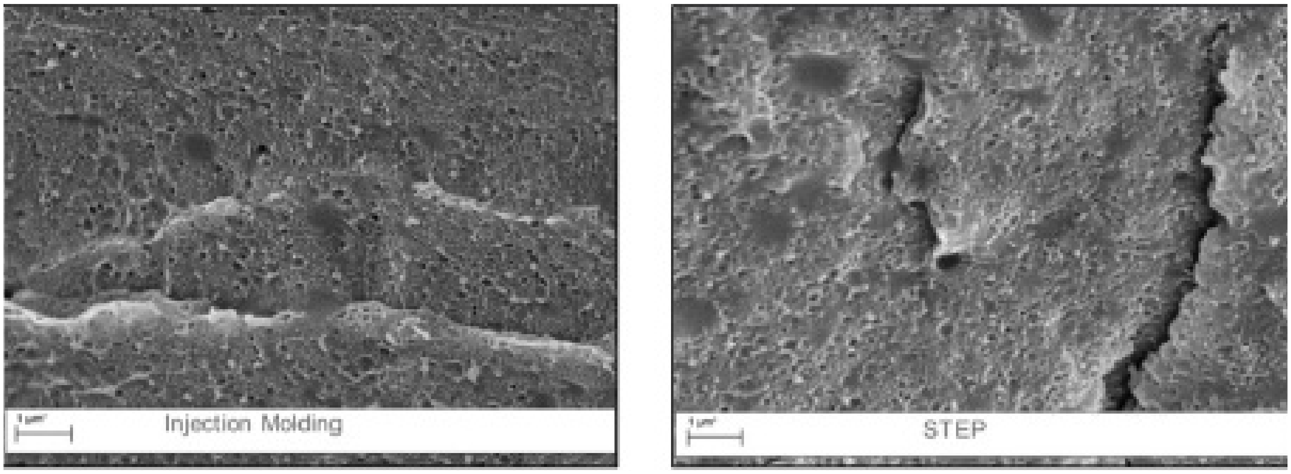
Charpy bar test specimens



The density of the final parts is equivalent to commercial injection-molded ABS.

Density of ABS made by injection molding versus STEP technology.		
Manufacturing	**Injection Molding**	**STEP Technology**
Mean Density (g/cm³)	1.026	1.026
Std. Dev	0.002	0.004

The microstructure of ABS made by the STEP technology resembles the microstructure of ABS made by injection molding. SEM analysis shows the microstructures below.



SEM micrographs of ABS made by Injection Molding and STEP Technology

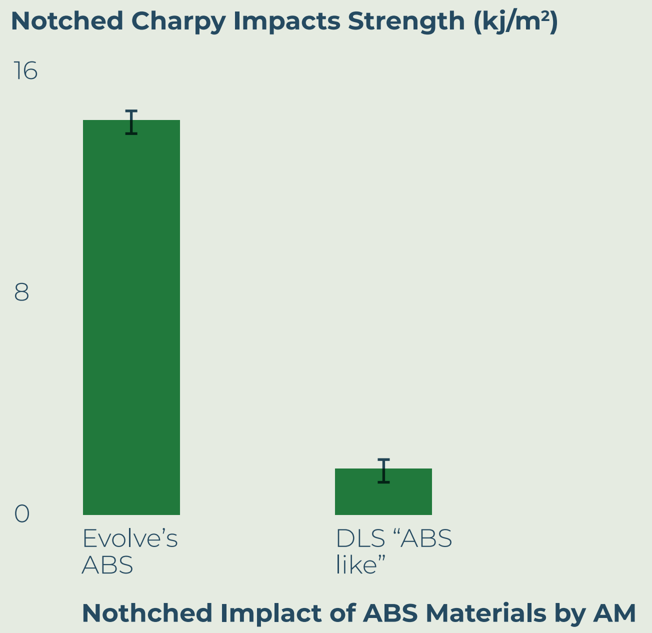
NOTCHED CHARPY IMPACT TESTS BY 3RD PARTY DATAPOINT LABS (ITHACA, NY)

Two ABS types of materials were evaluated by Datapoint Labs using ISO 179-1:2010 method.

- **Evolve's ABS: produced by Evolve Additive Solutions (Minnetonka, MN)**
- **DLS (Digital Light Synthesis) — "ABS-like" (RPU-70, Black): produced by Xometry (Gaithersburg, MD)**

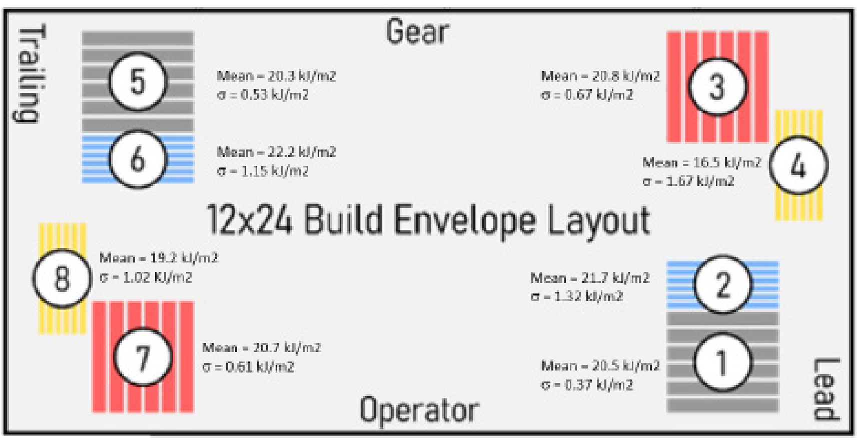
The notched impact strength of the ABS and "ABS-like" samples showed that the ABS material had a much higher impact strength than the ABS-like material made by DLS.

Impact Strength by 3rd Party Datapoint Labs (Ithaca, NY) of ABS and "ABS-like" materials



The notched impact strength data shown in the figure above was generated from Evolve's alpha machine with a build envelope of 5" x 8" (y,x). Evolve's ABS has high impact strength and fractured in a ductile fashion, and the DLS "ABS-like" material was brittle and had low impact strength. Since the DLS "ABS-like" does not have the same polymer composition as ABS then, it is not likely to have physical properties similar to ABS. Evolve's ABS is more consistent with injection-molded ABS properties than the "ABS-like" material made by an alternative additive manufacturing technology. The polymer composition of the Evolve's ABS is the same as injection molded ABS, and the density of Evolve's ABS material is equivalent to injection molded ABS, so it correlates well to ABS materials' impact strength.

A mechanical property evaluation was subsequently performed on Evolve's SVP™ commercial machine to look at the consistency of the notched impact strength of Evolve's ABS across the full build envelope of 12" x 24" (y,x). The SVP™ machine prints a rectangular build and there are 4 sides of the rectangular build. If a machine operator is looking directly at the build in the machine, the side of the build closest to the operator is called the operator side (6 o'clock position). Moving clockwise from the operator side to the 9 o'clock position is the trailing side, and this signifies the trailing end of the build as it proceeds through the transfuse roller. Moving clockwise to the 12 o'clock position is the gear side. Moving clockwise again to the 3 o'clock position is the leading side, which signifies the leading end of the build as it enters into the transfuse roller. In-process bars are defined that the Charpy parts were printed parallel to the trailing edge and the leading edge. Cross-process means the parts were printed perpendicular to the trailing edge and leading edge. The build area was divided into 4 quadrants with Charpy bars in 4 different orientations:



Notched impact strength of Evolve's ABS across the build envelope of Evolve's SVP™ System.

There were 144 total samples measured (18 samples per quadrant). The data clearly shows a consistent, high notched-Charpy impact strength for the ABS parts with an impact strength of 16.5-22.2 kj/m^2. These strength values are on par with values obtained for general purpose injection-molding ABS grades (13-37 kj/m^2).

1) Flat bars printed in-process in the lead/operator quadrant of the build

2) On-edge bars printed in-process in the lead/operator quadrant of the build

3) Flat bars printed cross-process in the lead/gear quadrant of the build

4) On-edge bars printed cross-process in the lead/gear quadrant of the build

5) Flat bars printed in-process in the trailing/gear quadrant of the build

6) On-edge bars printed in-process in the trailing/gear quadrant of the build

7) Flat bars printed cross-process in the trailing/gear quadrant of the build

8) On-edge bars printed cross-process in the trailing/gear quadrant of the build

TENSILE PROPERTY TESTING

Tensile Strength, Tensile Modulus, and % Elongation to Break measurements were also performed with Evolve’s commercial ABS material on Evolve’s SVP System across the full build envelope of 12" x 24" (y,x). An intra-build and build to build repeatability study was performed over 16 replicate builds.

Each build was divided into the same 4 quadrants shown above for the Charpy impact strength study:

1) Gear/Trail

2) Operator/Trail

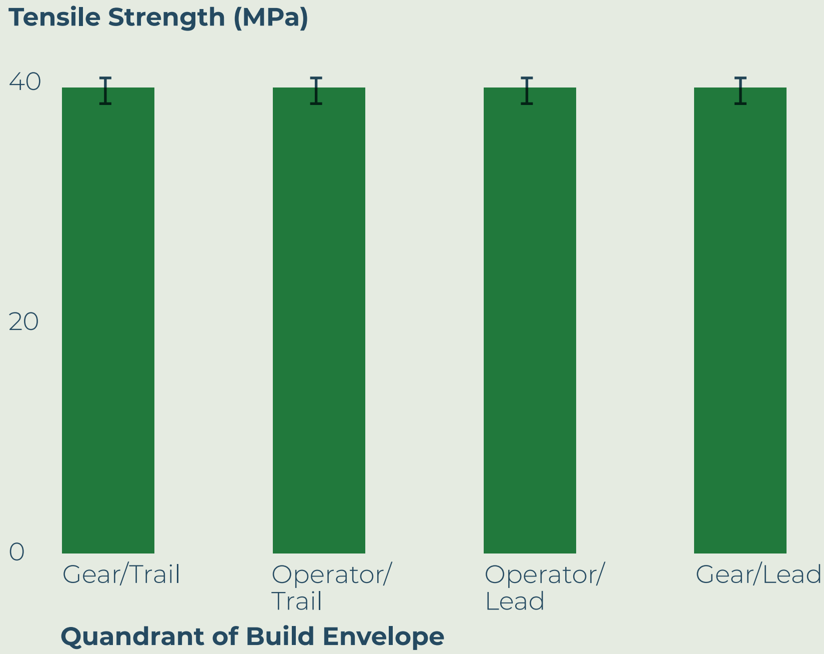
3) Operator/Lead

4) Gear/Lead

Tensile Strength of Evolve’s ABS Across Full Build Envelope

The tensile strength of Evolve’s ABS material for 283 samples measured over the 16 builds showed an equivalent tensile strength of 39.3 MPa and standard deviation of 0.3 MPa in all 4 quadrants of the SVP build envelope.

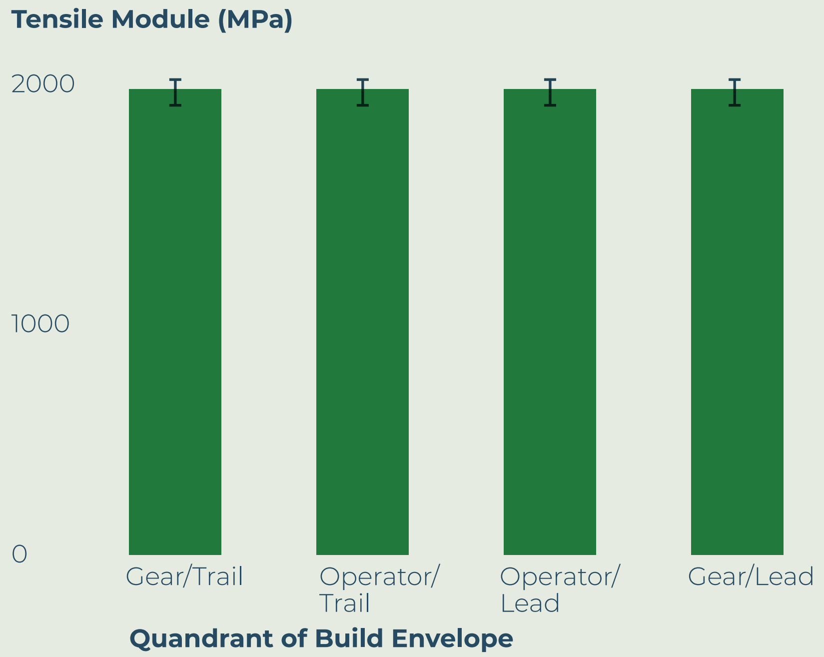
The tensile strength of general purpose injection molded ABS is in the range of 33-46 MPa.



Tensile Modulus of Evolve's ABS Across Full Build Envelope

The tensile modulus of Evolve's ABS material for 283 samples measured over the 16 builds showed an average tensile modulus of 1921 MPa and standard deviation of 40 MPa in all 4 quadrants of the SVP build envelope.

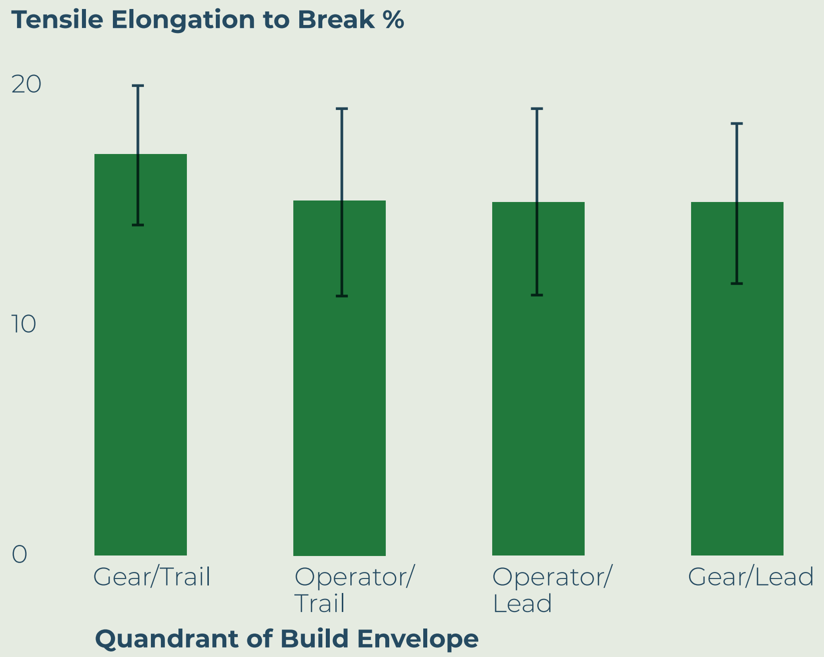
The tensile modulus of general purpose injection molded ABS is in the range of 1650-2450 MPa.



% Tensile Elongation to Break of Evolve's ABS Across Full Build Envelope

The % elongation to break of Evolve's ABS material for 283 samples measured over the 16 builds showed an average tensile elongation to break of 15.5% and standard deviation of 3.6% in all 4 quadrants of the SVP build envelope.

The % elongation to break of general purpose injection molded ABS is a minimum of 10%.



SUMMARY

Overall, Evolve's general-purpose black ABS performed well in physical property testing. The tensile properties, density, and notched-Charpy impact strength were on par with injection molded ABS used in the market today and much higher than "ABS-like" materials from other additive manufacturing technologies. In terms of physical property robustness across the full build envelope, the Charpy impact strength and tensile properties were both consistent within the same build and build to build. This general-purpose ABS is a great fit for applications which require high impact strength and ductility. The material will also be a good fit in applications that require good dimensional stability and resistance to moisture because the ABS is dense and does not undergo significant dimensional changes in the environment.

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