

ORBITAL CONSTRUCTION PIONEERS

Orbital Construction Pioneers (OCP) has been an advocate for the use of in-situ resources in the construction of large space structures from its inception. It is our firm belief that if humanity is to inhabit space, we will need artificial gravity produced by rotating structures to keep people healthy and happy. Due to the limitations of human physiology in withstanding inner ear disruptions (spatial disorientation) from rotation, the size of the rotating structures will need to have a diameter greater than 300 meters for Moon normal (1/6 Earth) gravity and up to a diameter of 2 kilometers for Earth normal. Building structures of this size using traditional methods would be extremely expensive and time-consuming. Thus, the need for the use of in-situ resources.

OCP has been doing extensive research into additive manufacturing using thermosets mixed with a filler for the construction of large space structures. We have tested several different types of epoxies and RTVs mixed with fillers that can be mined or manufactured on the Moon. Initial results showed that the concept was valid but it would require mining infrastructure on the Moon. OCP's latest concept uses 100% bio derived thermosets and fillers providing the ability to grow the required in-situ materials.

The purpose of our recent biomaterials research was to determine if biomaterials can withstand the space environment and be useable in an additive manufacturing system. For this determination molded samples were subjected to five different tests at three different temperatures. Our research used three different mixes of bonding material combined with filler.

Filler is used because it is assumed that the process of converting plants into bonding material results in a higher volume / mass of plant material than bonding material. The use of fillers reduces the amount of bonding material used and increases system efficiency by reducing waste while enhancing desirable mechanical properties.

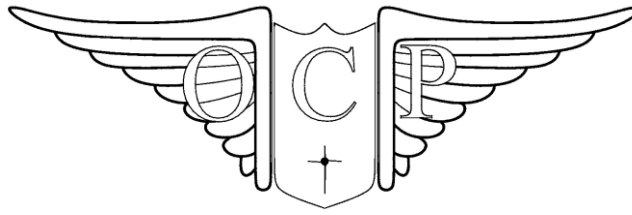
The material used were:

Bonding material (Epoxy)

- Change Climate Byoxy 100% bio-epoxy – An epoxy 100% derived from plants and donated to OCP for testing.

Filler

- Hemp Hurd – Hemp has long been used in items that required flexibility and strength; used in naval ropes, textiles, and construction. The hemp hurd, also known as shiv or shive, is the woody center of the hemp plant. This is ground and sifted through a 60-mesh screen.
- Hemp Silk (bast)- This is the part used for rope and textiles. It was cut into approximately 6 mm lengths.
- Additive - This is a common additive to epoxy to make it more robust and less brittle.



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MIXES

Three different mixes were tested. The mixes were developed to research the properties of the epoxy and how the different fillers affected the epoxy properties. The mix batch formulas are as follows:

- Epoxy – Hemp Hurd, Mix 45
 - Resin
 - Hardener
 - Hemp hurd
- Epoxy – Additive, Mix 46
 - Resin
 - Hardener
 - Hemp hurd
 - Additive
- Epoxy – Hemp Silk, Mix 47
 - Resin
 - Hardener
 - Hemp hurd
 - Hemp silk

NOTE: The volume of our mixing equipment limits that amount that can be mixed at one time. Thus, we will mix the same formula multiple times to reach the number of samples needed. Mix formulas are designated by a whole number, such as 46, batches are designated with a dash or decimal point. An example would be 46-1 or 46.1 which would indicate mix formula 46, batch 1.

Two types of test samples were molded:

Hexagon

60 mm short diagonal

13 mm thick

Dog bones

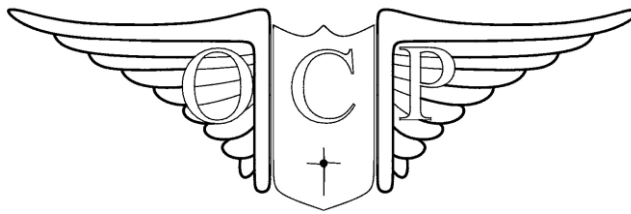
Approximately 69 mm in length

With a cross section, in the thin test part, of approximately 20 mm²



TESTS

- Drop test
 - Simulating a slow speed impact, a 1 kg steel ball is dropped from 1.5 meters onto a hexagon sample that is suspended by its edges. To pass, the sample must remain intact, with only surface cracks.



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- Shot test
 - Simulating a high-speed impact with a small object, the sample is shot with a .22 caliber 36-grain jacketed hollow point bullet, with a muzzle velocity of 390 m/s, at a distance of 3 m. To pass, the sample is not required to stop the bullet, but the sample must maintain structural integrity and not eject a large amount of material from the exit site.
- Flame test
 - Simulating a fire on or in a structure, a propane flame is held to a test sample for 10 seconds. The blue tip of the flame is placed just touching the surface of the sample. To pass, the sample may flame up while the torch is touching the surface but must self-extinguish after the flame is removed.
- Tensile strength test
 - A dog bone sample is subjected to pulling forces in a manually operated testing apparatus until it breaks. The digital force meter records the peak force used up to 520 newtons (rated limit is 500 N) and the elongation is measured with a micrometer. There is no pass / fail criterial, but a high tensile strength is desirable.
- Expansion / Contraction test
 - Testing the percentage of material contraction from the cold and expansion from heat. The sample's short diagonal is measured at room temperature and then compared to a new measurement after it has thermally stabilized at the test temperature.

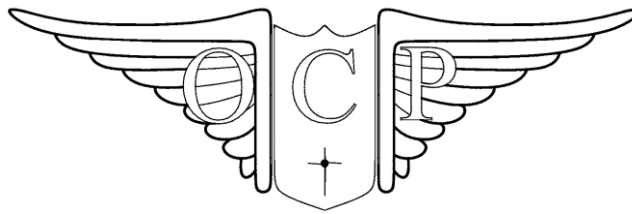
TEMPERATURES

All tests were done at three different temperatures; room (20°C to 22°C), hot (122°C), and cold (-80°C). Earth orbital temperatures can range from 121°C to -157°C however, our equipment is only capable of -80°C. The theory is if the material is unable to withstand -80°C then it would not withstand the colder orbital temperature. All samples are soaked for 24 hours at the prescribed temperatures before testing to ensure consistent thermal stabilization.

RESEARCH PLAN

Five samples would be used for each test and temperature, except for the expansion / contraction test, as this is a non-destructive test and can be done on the samples used for the drop test before they are tested. This required 45 hexagon samples and 15 dog bones per mix formula for a total of 135 hexagons and 45 dog bones.

NOTE: We had insufficient epoxy material and were only able to produce 104 hexagons. Tests that had insufficient testing samples will be noted in the results section.



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RESULTS

Room Temperature

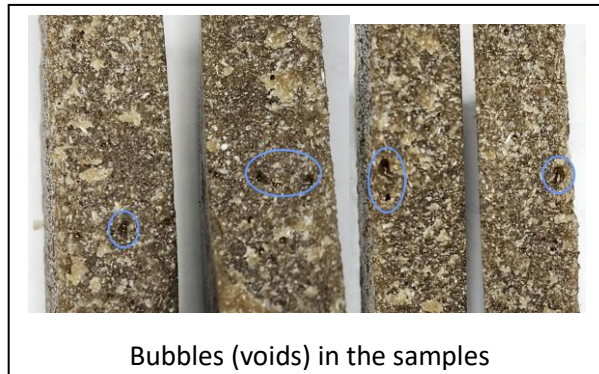
Mix	Room				Extrudable
	Drop	Shot	Flame	Tensile	
45 Epoxy - Hurd	P	F	P	19.3 MPa El 21.7%	Y
46 Epoxy - Add- Hurd	P	F	P	13.3 MPa El 17%	Y
47 Epoxy - Silk - Hurd	P	F	P	14.5 MPa El 22.3%	Y

(P=Pass, F=Fail, X=test not done)

Drop Test

All samples performed in a similar manner, with all passing.

NOTE: Experiment 220, using mix 46 batch 7, had two samples break in half. Examination showed that the break was caused by a bubble in each sample. The three other samples passed.

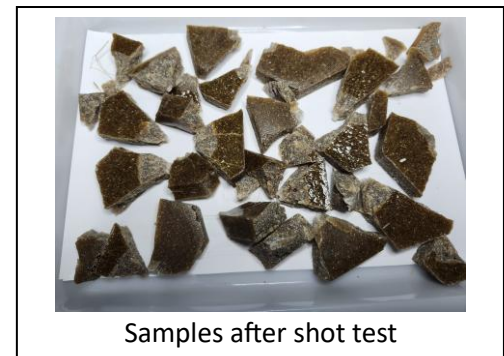


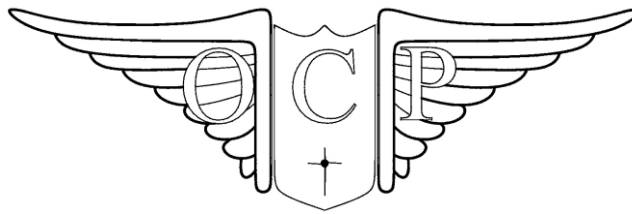
NOTE: Test of mix 47 used only two samples.

Shot Test

All mixes failed this test with the samples shattering from the impact.

NOTE: Test of mix 47 used only three samples.



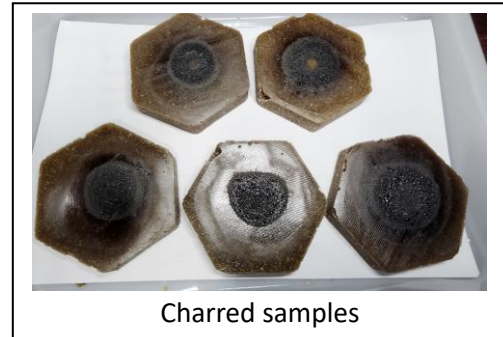


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Flame Test

All samples tested ignited and produced flames about an inch tall while the torch was applied. All self-extinguished in under 10 seconds leaving a charred area. No deformation or weakening of the sample structures.

NOTE: Test of mix 47 used only one sample.



Charred samples

Tensile Strength

Our experience has shown that fillers adversely affect the tensile strength of epoxies. However, this epoxy has the highest strength of any we have tested. With a strength of approximately 19 MPa it is within the range of some soft polymers, certain composites, and low-strength plastics.

NOTE: Experiment 204, using mix 45 batch 1, exceeded the capacity of the force meter. The force entered was the meter maximum of 520 N for the calculations.



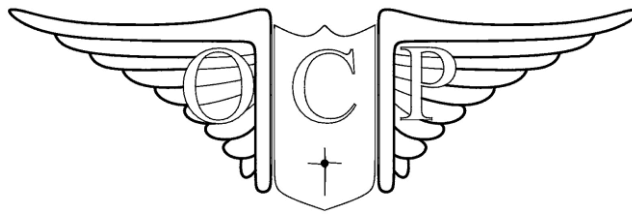
Dog bones after test

Extrusion test

Extrusion was only attempted at room temperature. All mixes were able to be extruded through an orifice of 8 mm.



Extruded material



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Cold Temperature

Mix	Cold				
	Drop	Shot	Flame	Tensile	Contraction
45 Epoxy - Hurd	P	F	P	19.6 MPa El 16.7%	0.41%
46 Epoxy - Add - Hurd	P	F	P	16.5 MPa El 14%	0.76%
47 Epoxy - Silk - Hurd	P	F	X	19.6 MPa El 20.8%	0.27%

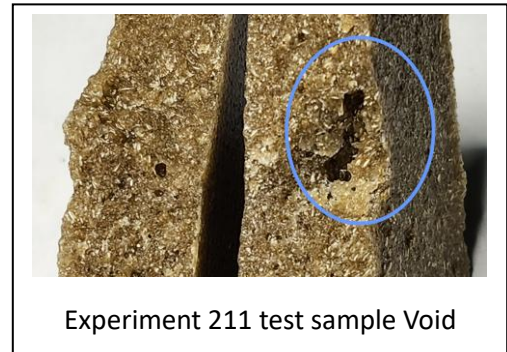
(P=Pass, F-Fail, X=test not done)

Drop Test

All samples performed similar to samples tested at room temperature. One sample had a small surface impact mark.

NOTE: Experiment 211, using mix 46 batch 1, had one sample break. Examination showed that the break was caused by a bubble (void). The four other samples passed.

NOTE: Test of mix 47 used only three samples.



Experiment 211 test sample Void

Shot Test

All samples performed similar to samples tested at room temperature. All mixes failed with the samples shattering from the impact.

NOTE: Test of mix 47 used only three samples.

Flame Test

All samples tested ignited and produced flames about an inch tall while the torch was applied. All self-extinguished in under 10 seconds leaving a charred area. No deformation or weakening of the sample structures.

NOTE: Due to the lack of samples this test was not conducted on mix 47. Previous tests of other mixes indicated that this test would perform in the same manner as the room temperature test.

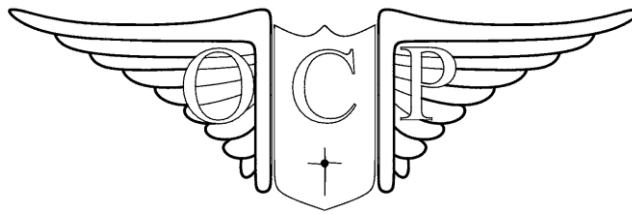
Tensile Strength

Additive caused a slight weakening of the epoxy bonds.

NOTE: Experiment 231, using mix 47 batch 1, broke at a bubble (void) in the dog bone. The data collected was not used in the calculations.



Experiment 231



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Material Contraction

The change in size was surprisingly low and affected by the type of filler.

NOTE: Test of mix 47 used only three samples.

Hot Temperature

Mix	Hot				
	Drop	Shot	Flame	Tensile	Expansion
45 Epoxy - Hurd	P	P	P	19.6 MPa El 11.3%	0.54%
46 Epoxy - Add - Hurd	P	P	P	17.1 MPa El 15.7%	0.61%
47 Epoxy - Silk - Hurd	P	X	X	24.2 MPa El 21.9%	0.47%

(P=Pass, F=Fail, X=test not done)

Drop Test

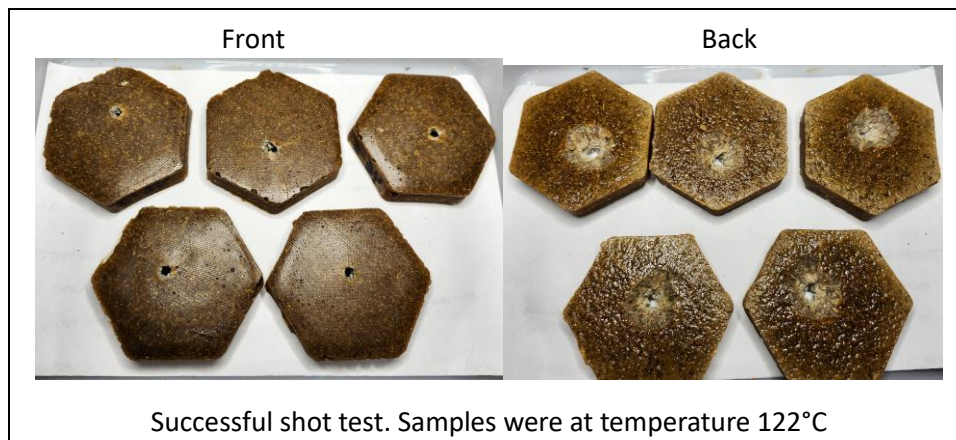
All samples performed similar to samples tested at room temperature.

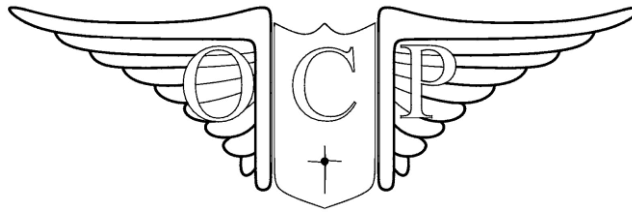
NOTE: Test of mix 47 used only three samples.

Shot Test

All samples stayed intact with minimal material ejected from the impact. Some samples had observable surface cracks that radiated from the impact site, but samples maintained structural integrity.

NOTE: This test was not performed on mix 47. All previous mixes had passed this test, providing a strong indication that this mix would also pass.





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Flame Test

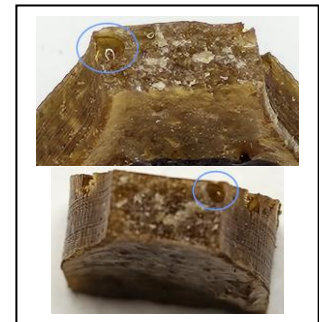
All samples tested ignited and produced flames about an inch tall while the torch was applied. All self-extinguished in under 10 seconds leaving a charred area. No deformation or weakening of the sample structures.

NOTE: Due to the lack of samples this test was not conducted on mix 47. Previous tests of other mixes indicated that this test would perform in the same manner as the room temperature test.

Tensile Strength

The Additive caused a slight weakening of the epoxy bonds.

NOTE: Experiment 216, using mix 46 batch 2, and experiment 234 using mix 47 batch 1, both had two samples break at bubbles (voids) in the dog bones. The data collected from the failed samples were not used in the calculations.



Material Expansion

The change in size was surprisingly low and affected by the type of filler.

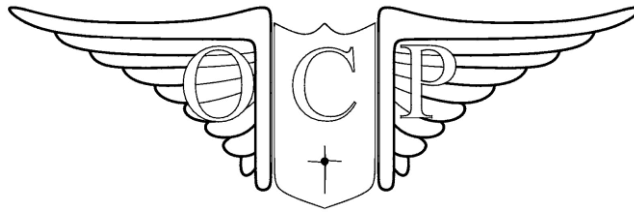
NOTE: Test of mix 47 used only three samples.

CONCLUSION

Pros: The epoxy mixed well with the fillers used. The mixes were homogeneous and only separated when put under extreme pressure (during extrusion test). Samples were able to withstand slow impacts at all temperatures and exhibited extraordinary physical stability at temperature extremes with very low contraction / expansion rates. Tensile strength is the highest of any epoxy tested by OCP, and the overall sample strength is relatively unaffected by temperature.

Cons: The epoxy is too brittle to withstand high velocity impacts, unless the sample is heated.

The two-part epoxy supplied by Change Climate has many advantages over other epoxies that we have tested, and it is recommended that additional testing be done with the assistance of Change Climate.



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FUTURE TESTING

- To increase robustness without sacrificing strength:
 - Explore the use of Epoxidized Natural Rubber latex as an additive.
 - Explore use of small natural rubber particles as a partial filler.
 - Explore an increase of Additive in the mix.
- To facilitate 3D printing:
 - Explore the use of a UV activated hardener with a traditional hardener.
 - Explore the possibility of faster cure rates.
 - Explore curing at temperature extremes.

