BINDER VARIATION EFFECTS ON A POROUS STATE-CHANGE MATERIAL

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Introduction

There is a growing interest in alternatives to metallic tooling for composite material fabrication. Metallic tooling is expensive and often requires sophisticated machining techniques. 2Phase Technologies, Inc. has developed a Reconfigurable Tooling System (RTS) and state-change material intended as an alternative to the machining of metallic molds [1]. The RTS utilizes a state-change material that, through the application of heat and vacuum, is capable of transitioning for a formable/liquid state to a force resisting/solid state. Then, through the application of moisture, the material transitions back to the formable/liquid state. The material is a mixture of glass microspheres in a water-based binder solution.

In this study, experimental testing was completed to determine the ideal binder formulation. State-change material was made from two different types of binder and tested to determine the flexural properties. Also, to examine the effect of fiber reinforcement, state-change material was composed with the addition of fiberglass mat layers and then tested in flexure.

Experimental

Materials

The state-change material is a liquid-particulate mixture. The particulate component is glass microspheres ranging in diameter from 100 to 250 microns. Adequate binder flow results in a well-consolidated material and superior mechanical properties [2-3].

The liquid component is a solution of water and a water-soluble refractory binder. The percentage of water in the solution is a function of the binder's viscosity. Binder materials with higher viscosity levels are mixed with greater amounts of water to allow for adequate binder flow. The binder lubricates the spheres when the material is in a liquid state and "glues" the spheres together when the material is hardened. The binder is water based and remains soluble in water throughout the process. Therefore, returning water back to the solid material mixture can dissolve it back to the liquid state

Material for testing was fabricated with two different types of binder. Table 1 summarizes physical properties of the two binders.

Table 1: Physical characteristics of the two binder types

	Type 1	Type 2
$\%Na_2O$	8.9	10.6
$\%Si_2O$	28.7	26.5
Density (g/cm^3)	1.38	1.40
Viscosity (cP)	180	60

Experimental observations of the binder's viscosity determined that water should account for approximately 20% of the solution by volume when using binder type 1. Also, there is no need for water in the solution made with the type 2 binder, as it has a much lower viscosity.

Specimen Preparation

Large bricks of the state-change material were manufactured in an environment mimicking the temperature and vacuum conditions of the RTS [4]. A total of four bricks were manufactured for testing. Two bricks were composed with the differing binder types with no fiber reinforcement and two bricks were composed with the differing binder types with the addition of fiberglass mat layers.

Individual test specimens were removed from the large bricks with a band saw and then sanded to the desired dimensions. The final tests specimens had a width of 12.3 mm and a height of 14.3 mm. Most specimens were at least 254 mm long.

Testing Methods

A four-point flexural test method was based upon aspects of ASTM standards C580-98, C947-99, and D6272-02. A special loading fixture accounted for rigid/uneven specimens and eliminated any eccentric loads. All tests were completed on a United Testing Machine equipped with a 4.4 kN load cell. Specimens were preloaded and then tested to failure under displacement control, with a constant crosshead descent rate of 1.4 mm/min. An LVDT was mounted beneath specimens during testing to determine mid-span deflection. Upon completion of testing, the force and deflection data were used to determine the flexural strength and modulus.

Results

Binder Type 1

Flexural testing was completed for the state change material fabricated with binder type 1. There were two test groups, each consisting of six specimens. State-change material for the first test group was plain (no fiber reinforcement), while material for the second test group contained two layers of fiberglass mat. Table 2 summarizes the flexural strength and modulus results.

Table 2: Flexural results for binder type 1 material

Group #	Strength (MPa)	Modulus (GPa)
1 (no reinforcement)	3.91± 9%	3.17 ± 13%
2 (2 layers fiberglass)	4.15± 2%	3.72± 2%

When loaded, test material from both test groups showed a linear stress-strain relationship up to a brittle failure point. Figure 1 is a representative stress-strain curve.

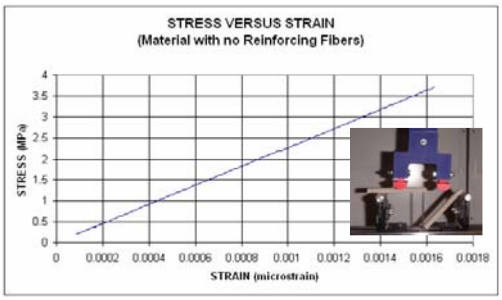

Figure 1: Example stress-strain curve for binder type 1

Binder Type 2

Flexural testing was completed for the state change material fabricated with binder type 2. There were two test groups, each consisting of six specimens. State-change material for the first test group was plain (no fiber reinforcement), while material for the second test group contained two layers of fiberglass mat. Table 3 summarizes the flexural strength and modulus results.

Table 3: Flexural results for binder type 2 material

Group #	Strength (MPa)	Modulus (GPa)
1 (no reinforcement)	4.25± 5%	3.39 ± 15%
2 (2 layers fiberglass)	4.00± 9%	3.27± 13%

When loaded, test material from both test groups showed a linear stress-strain relationship up to a brittle failure point. Figure 2 is a representative stress-strain curve.

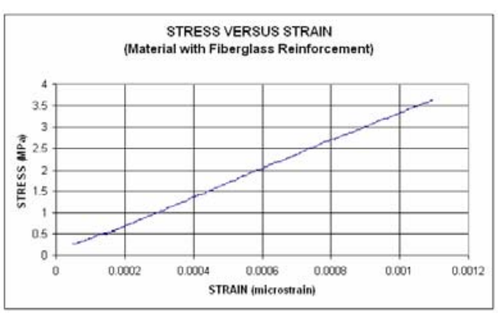

Figure 2: Stress strain curve for binder type 2

Conclusions

Flexural testing was completed for different formulations of the 2Phase state-change material to understand the effect of binder variation and fiber reinforcement. Several observations can be made from the presented data:

- For material composed without fiber reinforcement, binder type 2 gives slightly higher flexural properties than binder type 1.
- The fiberglass mat layers improved the properties for the binder type 1 material, but slightly decreased the properties for the binder type 2 material.
- The reinforced material composed with binder type 1 gives a similar strength to and a higher modulus than the binder type 2 material with no reinforcement.

Based on the results of this investigation, the ideal state-change material liquid component is the water-diluted type 1 binder solution. As observed from the reported data, the best flexural properties are achieved with the fiber reinforced, binder type 1 material. Also, when observing the data for the material made without reinforcement, the binder type 2 material gives only slightly higher flexural properties than the binder type 1 material. Additionally, the water diluted type 1 binder solution proves to be more cost effective, as less binder material is consumed overall.

References

1. Jacobson T., Crowley J., and Clements L., “Improvements in Multi-Part Low-Cost, Reformable Tooling Systems for Part Fabrication and Repair,” *Int. SAMPE Tech. Conf.*, Seattle, WA, Nov. 2005.

2. Nelson, K., O’Toole, B., Raagas, S., Rahman, S., Calvert, G., and Clements, L., “Characterization of State-Change Reconfigurable Tooling Materials”, *Int. SAMPE Tech. Conf.*, Seattle, WA, Nov. 2005.

3. O'Toole B., Rahman S., Malpica J., Thota J., and Raagas S., “High Temperature Properties of a State-Change Material,” *SAMPE Journal*, 44 (2008), pp 42-52.

4. B. O’Toole, S. Rahman, J. Malpica, K. Nelson, S. Raagas, G. Calvert, L. Clements, “Micromechanics and Bulk Properties of a Porous State-Change Material”, Int. SAMPE Symp. and Exhibition, Long Beach CA, May 2006.