MECHANICAL CHARACTERIZATION OF A POROUS STATE-CHANGE MATERIAL FOR WATER SOLUBLE TOOLING

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Introduction

There is a growing interest in composite materials. With this increasing interest, there is also a growing demand for alternatives to metallic tooling. 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 [1-2].

The RTS utilizes a state-change material that is capable of transitioning from a formable/liquid state to a force resisting/solid state and then back to the liquid state. Given this capability, the state-change material is also being considered for water-soluble tooling applications.

Several previous investigations have taken place to characterize the formulation of the state-change material used in conjunction with the RTS [3-4]. The objectives of this study are to characterize the formulation of the state-change material being considered for water-soluble tooling and determine the formulation's usefulness for tooling applications. Ambient temperature compression and flexural mechanical properties will be presented. In addition to the mean property values, the corresponding precision intervals will be determined for probability/confidence levels of 50% and 90% as a predictive utility of the finite sample sizes (assuming a normal distribution).

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. This size range results in superior binder flow around the microspheres as the material transitions from a liquid to a solid. Adequate binder flow results in a well-consolidated material and superior mechanical properties [5].

The liquid component is a solution of water and a water-soluble refractory binder. 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 material hardening process. Therefore, returning the water component to the solid material mixture can dissolve it back to the liquid state. The state-change material's dissolvability changes as a function of the percentage of binder present in the liquid component. Complete transition from solid to liquid is more easily achieved when lower percentages of binder are used. The binder accounts for 20% of the solution by volume in the material formulation for water-soluble tooling, while the binder account for nearly 80% of the solution in the RTS material formulation.

Specimen Preparation
Compression and flexural test specimens were molded into net shapes in an environment mimicking the temperature and vacuum conditions of the RTS. The compression specimens were cylindrical in shape with a diameter of 25.4 mm and a height of 50.8 mm. The flexural specimens were rectangular bars with a width of 50.8 mm, a length of 292.1 mm, and a depth of 14.7 mm.

Testing Methods
Compression test methods were based upon aspects from ASTM standards C579-01 and D1621-94. Special loading fixtures were implemented to prevent eccentric loads. Tests were performed using displacement control; with a constant crosshead rate of 5.08 mm/min. Instantaneous force and strain data were recorded at regular intervals of 0.1 seconds. Strain was read from strain gages. Upon completion of testing, compressive yield strength and modulus were determined.

Flexural test methods were 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 with a 445 N load cell. Tests were performed using displacement control, with a constant crosshead rate of 4.1 mm/min. An LVDT was mounted beneath specimens during testing to determine mid-span deflection. Upon completion of testing, the flexural strength and modulus were determined.

Results

Compressive Properties
Compression testing was completed for the material consisting 20% binder by volume. The test group included nine specimens. Table 1 gives the compressive strength and modulus mean values and the precision intervals.

Table 1: Compression results of the 20% binder material

	Sample Mean Value	Precision Interval (P=50%)	Precision Interval (P=90%)
Strength	2.26 MPa	±0.12 MPa	±0.32 MPa
Modulus	2.32 GPa	±0.37 GPa	±0.99 GPa

When loaded in compression the material showed a linear stress-strain relationship up to an initial failure point followed by a significant drop in carried load. Then the load would increase to a level just below the initial failure point and then stay somewhat constant as the specimen would crush and densify (Figure 1).

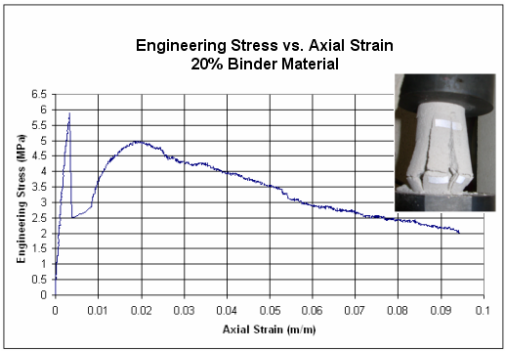

Figure 1: Representative compressive stress-strain curve

Flexural Properties

Four-point flexural testing was completed for the material consisting of 20% binder by volume. The test group consisted of six specimens. Table 2 gives the mean values and the precision intervals for the flexural strength and modulus. When loaded in flexure, the material showed a linear stress-strain relationship up to a brittle failure point (Figure 2).

Table 2: Flexural properties for the 20% binder material

	Sample Mean Value	Precision Interval (P=50%)	Precision Interval (P=90%)
Strength	1.69 MPa	±0.40 MPa	±1.22 MPa
Modulus	2.11 GPa	±0.08 GPa	±0.23 GPa

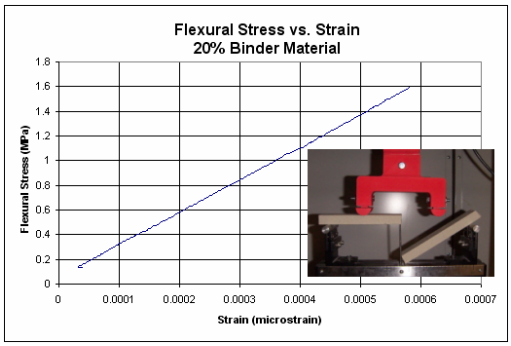

Figure 2: Representative flexural stress-strain curve

Conclusions

The 2Phase state-change material was investigated for its usefulness as a water-soluble tooling material. Mean values and precision intervals were determined for the material's compressive and flexural properties. The precision intervals representing the 90% confidence level are large in comparison to their mean values and require discussion of the material's homogeneity. Deviations of these magnitudes are not uncommon for materials of this type. Several material factors contribute to this non-homogeneous behavior. Primarily, the microspheres range in diameter and wall thickness. Also, there is a binder density gradient through the thickness of the material. As a result of the material manufacturing process the binder density tends to be greater in the lower thickness levels. The binder distribution is somewhat variable and cannot be controlled.

However, based on the mean value results of this study, the state-change material may be suitable as a water-soluble tooling material. As an example, the most common vacuum pressure encountered during the manufacturing of a composite part is 0.101 MPa. Therefore, based on the compressive and flexural strengths determined from this investigation, the state change material should be strong enough to withstand the forces and pressures that are expected during basic composite manufacturing practices.

References

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