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USING FINITE ELEMENT METHOD TO ESTIMATE THE MATERIAL PROPERTIES OF A BEARING CAGE

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14. ABSTRACT

This report summarizes the development of a material model for a cotton-phenolic based bearing cage. After performing a literature search, limited mechanical material property data was available. As a result, a novel approach was developed to empirically test the phenolic cage and to determine the respective elastic and failure material properties.

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INTRODUCTION

In the absence of mechanical material data, empirical experiments may be performed to estimate necessary parameters. Bearing components, including the raceways and balls, are typically manufactured to a specific material specification. However, the material specifications of non-metallic bearing cages are typically not supplied by the manufacturer. In order to setup a finite element analysis of a standard ball bearing with a cotton-phenolic cage, an estimate of the material properties of its cage had to be determined.

Cotton-phenolic materials vary by manufacturer, and potentially may vary from unit to unit. After performing a literature search, limited mechanical material property data was available. As a result, a novel approach was developed to empirically test the phenolic cage and to determine the respective elastic and failure material properties.

EXPERIMENTAL

Bearing Cage Testing

Several cotton-phenolic bearing cages (fig. 1) were removed from commercial bearings. A split ring fixture with a radius of 0.834 in. was developed and used to test the bearing cages on an Instron tensile tester (fig. 2). The bearing cage has an inner diameter of 1.728 in., which gives 0.060 in. of clearance for an easy slip fit and no induced stress. The flat center portion was milled to allow for room to adjust the gage length when mounted on the tensile tester and to reduce the effects of a stress riser at the edge of the fixture. The flat side of the bearing cage was placed against the back wall of the fixture to limit the yaw moment when tested. The gage was measured at 1.72 in. at the 12 o’clock and 6 o’clock position of the fixture. Force displacement curves for each bearing cage were recorded after conditioning at ambient and 145°F.

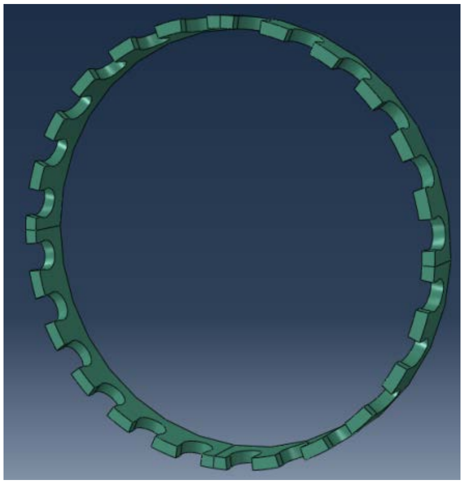
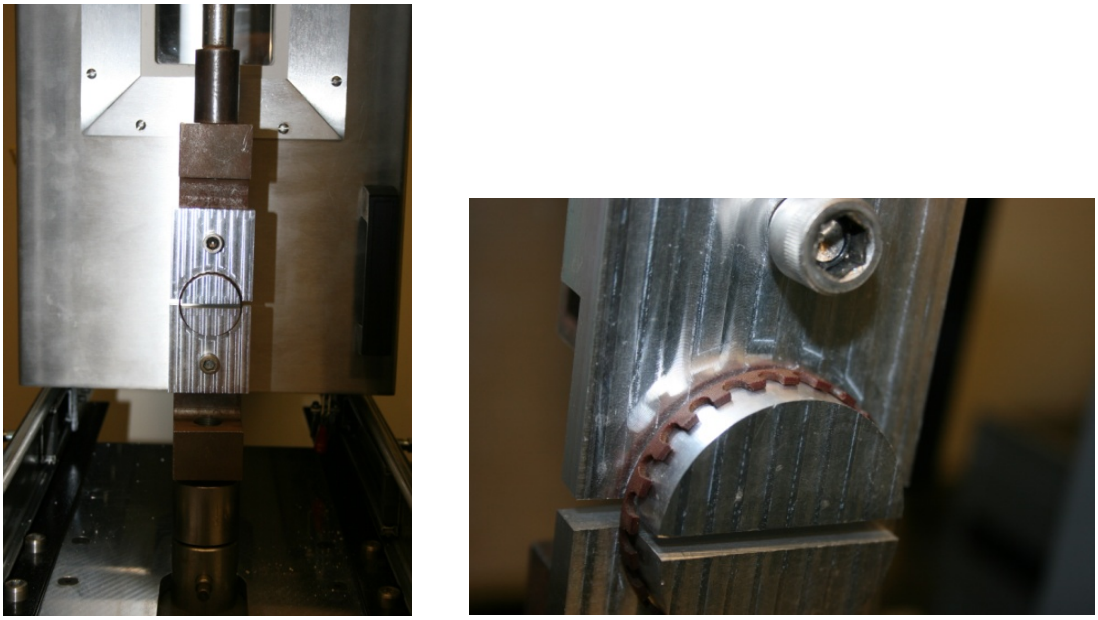


Figure 1
Phenolic bearing cage



(a)
Split ring fixtures and bearing cage mounted

(b)
Close up look at the bearing cage mounted on the fixture

Figure 2
Instron tensile tester setup

Modeling and Simulation

The bearing cage pull test was modeled using the general purpose finite element software ABAQUS Explicit version 6.12 (ref. 1). The analysis was explicit dynamic with mass scaling, non-linear materials, and non-linear geometry. The parts were acquired from Pro-Engineer files. The bearing cage and tooling was defeatured to decrease computing time, and the tooling was made rigid. The elements employed were 8-node brick elements with reduced integrations. Hourglass control was selected.

Friction is assumed at the interface between the bearing cage and the tooling, and the friction coefficient was estimated to be 0.01. Figure 3 displays the boundary conditions employed in the analysis. Figure 4 depicts the load applied to the assembly. The file name for this analysis was pgk_bearing15feb13.cae with input file phenolic22jan13strainDisp207fine.inp. The bearing cage material properties are initially estimated; the goal of the analysis was to match the force displacement data from the pull test to improve the material parameters used in the material model of the bearing cage.

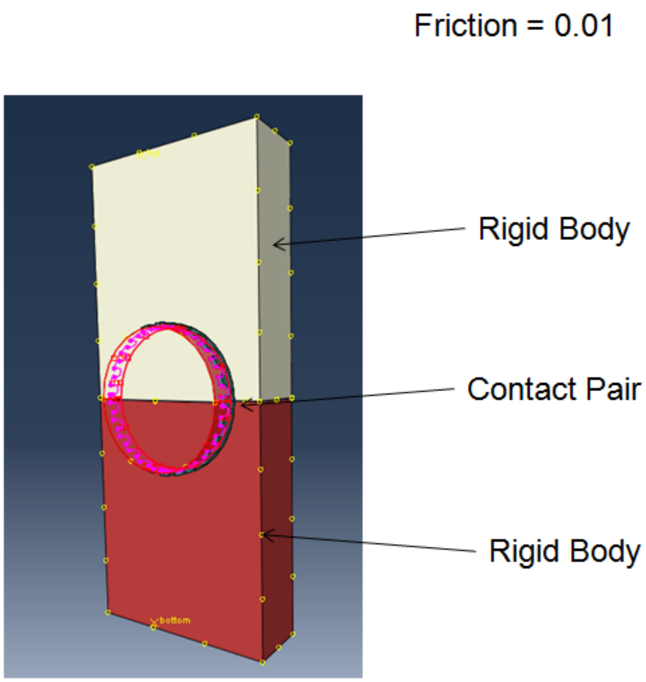


Figure 3
Interaction and constraints on simulated components

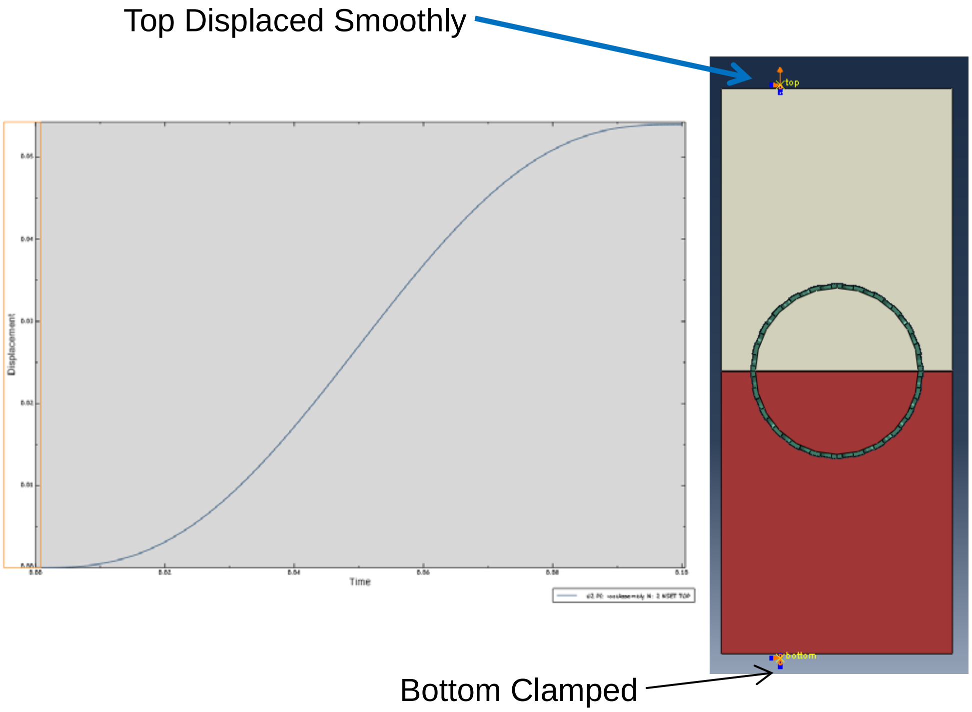


Figure 4
Boundary conditions and loads

RESULTS

Pull Test

The bearing cages were measured for the thickness along the circle and measured at the indents. The samples were placed on the fixture and tested at 0.2 in./min crosshead speed. Two specimens were tested at room temperature and two at 145°F after aging in an environmental chamber for 4 hrs. The 145°F specimens were tested immediately on the tensile tester after removal. Bearing cage test data is shown in table 1.

Table 1
Tensile data for the bearing cage test

		in.	in.	lbs
	Sample	Thickness	Thin section	Max load
72°F	1	0.0495	0.045	34.256
	2	0.05	0.045	50.46
145°F	3	0.05	0.045	35.552
	4	0.051	0.052	43.332

Figure 5 depicts results from the bearing cage pull tests. Because of limited sampling, all results fall within the error of the test data. The peak load measured for the ambient samples was 34.2 ± 11.4 lbf. The peak load measured for the samples conditioned at 145F was 39.4 ± 5.5 lbf.

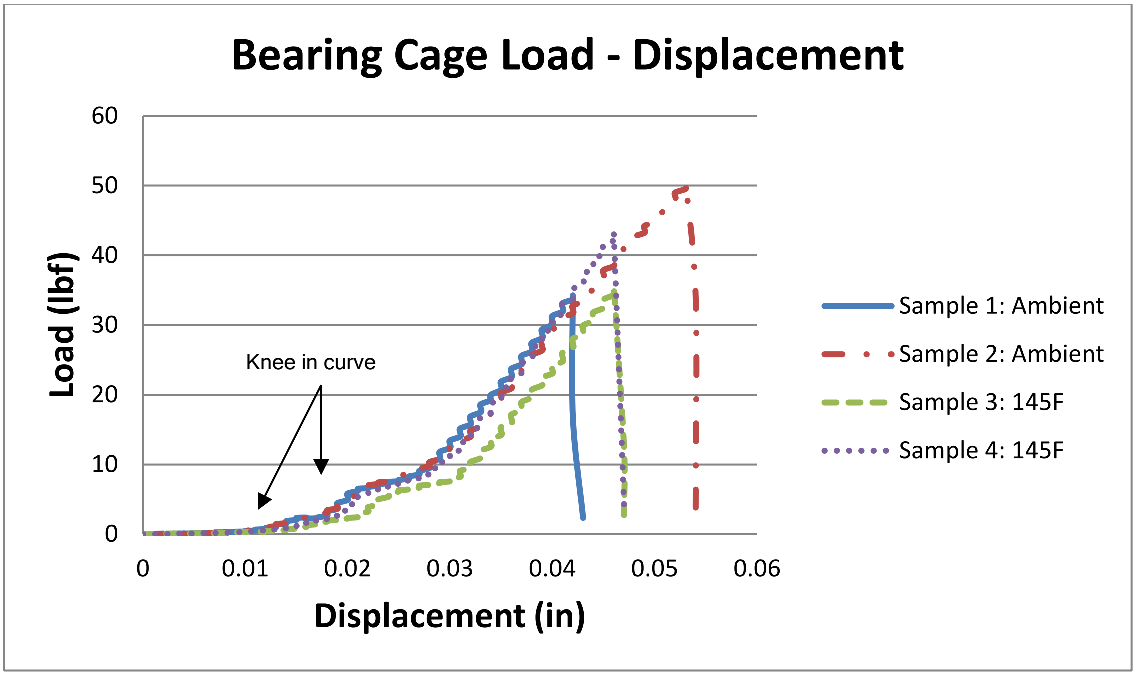
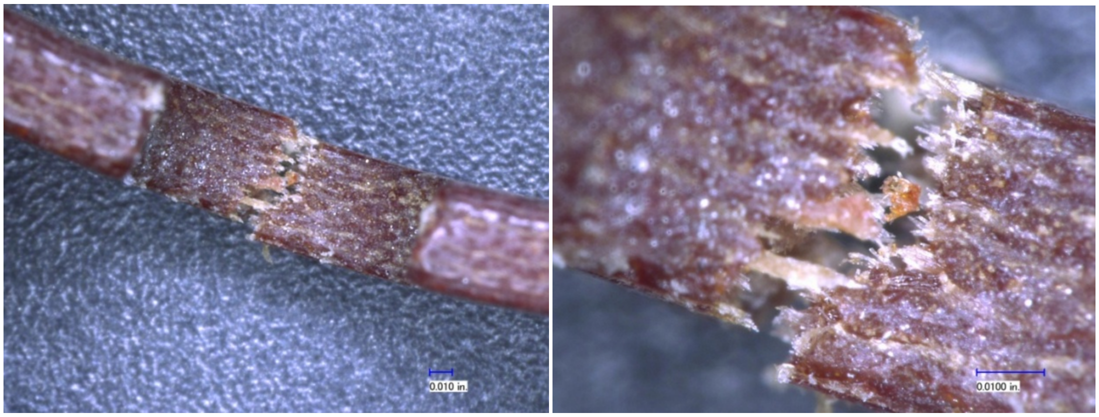


Figure 5
Bearing cage pull tests results

All of the bearing cages broke in the race section where the ball bearings would sit (fig. 6). The pictures of the broken bearing cages show that the failures occur in the thinnest sections. The images at 150 times magnification show the fibers that make up the phenolic material structure as being torn and frayed, indicating signs of ductile failure instead of brittle failure. The phenolic did not have a smooth failure plane, which is typical of most brittle failures. The fibers also show some pullout from the resin matrix. Figure 6 is representative of the failures seen in all four samples.



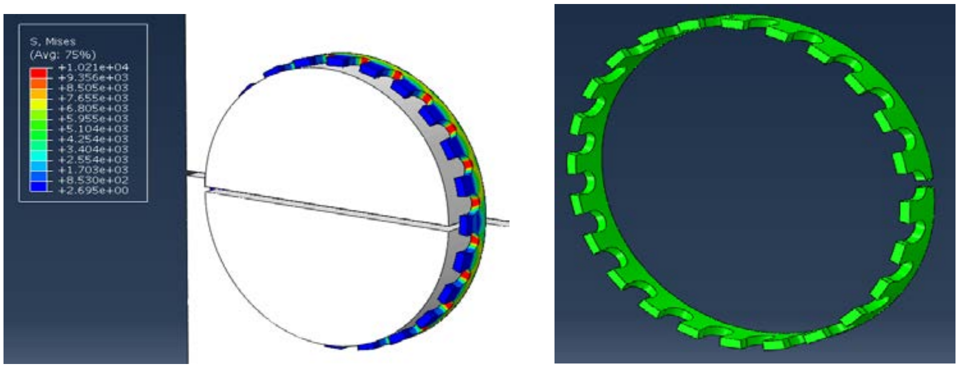
(a) 50 times magnification

(b) 150 times magnification

Figure 6
Bearing cage failure

Modeling and Simulation

The test data for sample 4 was used to baseline and develop the stress strain curves for parameterizing the bearing cage material model. This was accomplished by simulating the pull test with test data estimates for the modulus, Poisson's ratio, and yield stress for the bearing cage. Several runs were completed until the output matched the load-displacement data for test sample 4 and the failure matched that of the test (fig. 7). Figure 8 displays the experimental versus simulated load displacement curves. Once this was accomplished, the hoop stress – hoop strain curves were recorded from the output and used to finalize the elastic parameters for the bearing cage material model. Hoop stress – strain data was collected from the simulation results as this is the primary loading the bearing cage is subjected to in its intended application. Figure 9 shows the hoop stress-hoop strain curve for the bearing cage used to parameterize the material model.



(a) Von Mises stress (psi) just before failure

(b) Bearing cage after failure

Figure 7
Simulation results of bearing cage pull test

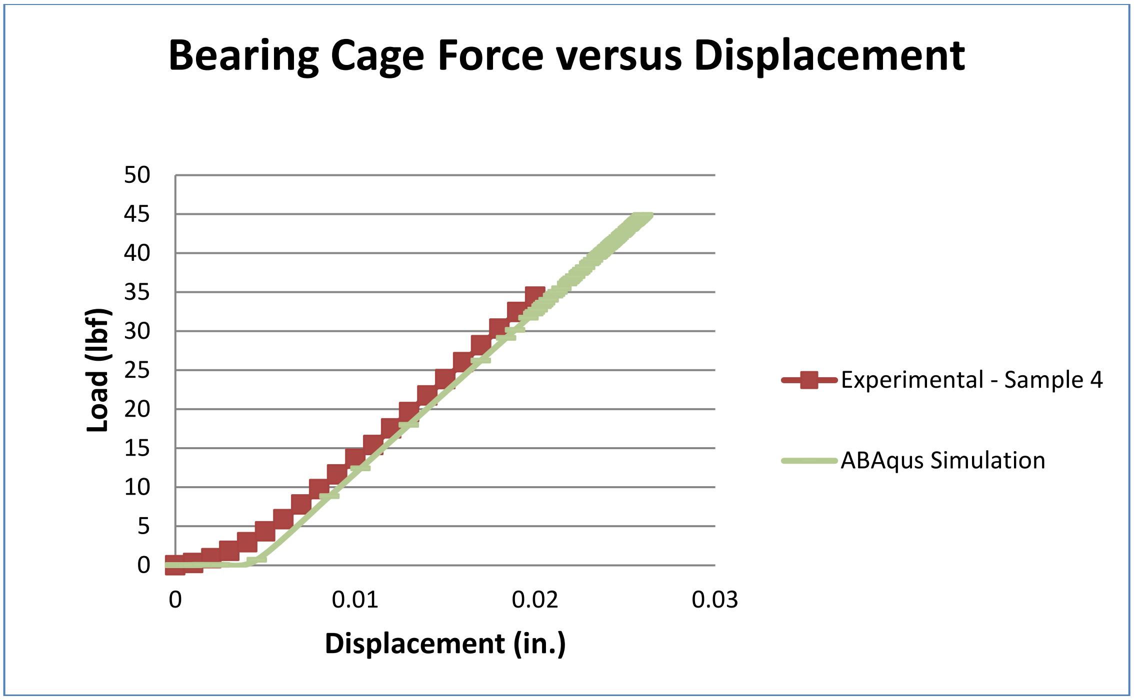


Figure 8
Simulated versus experimental force displacement curves

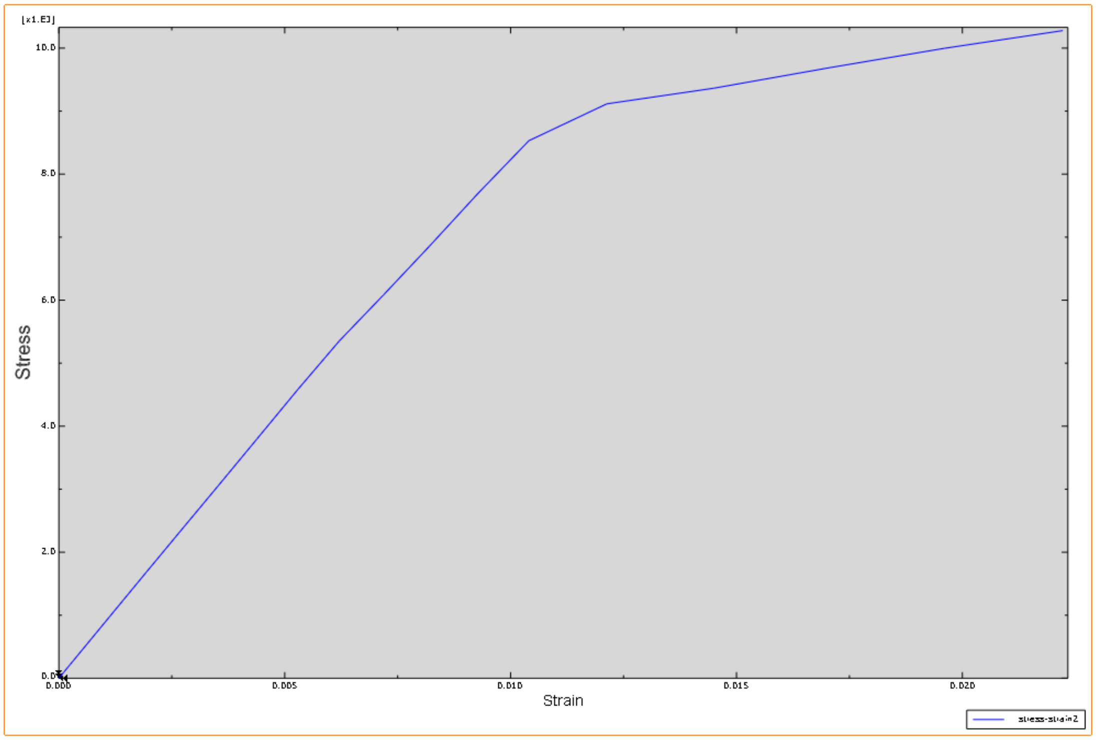


Figure 9
Simulated hoop stress-strain curve

Tables 2, 3, and 4 list the material assumptions for the bearing cage estimated from the simulations performed above. The elastic modulus calculated from the finite element study is within 10% of reported ambient values (ref. 2). With the tooling being a rigid part, no material properties need to be assigned. Johnson-Cook damage properties were estimated from the force displacement curves acquired from the pull testing for sample 4. The melting and transition temperatures used are estimates from literature (ref. 3) for a cotton phenolic. Phenolics won't necessary melt but will decompose under exposure to high temperatures. The D1 value is an estimate of the displacement at which damage may start occurring as observed as the knees in the curves in figure 5. Because of the nature of this material, the bearing cage may begin to tear before finally failing.

Table 2
Assumed material properties for parts

	Density (Lbf*s^2/in^4)	**Elastic** (psi)	**Poisson's Ratio**	**Yeild stress** (psi)
Phenolic	1.27e-4	859,418	0.3	10,206
Tooling	Rigid	-	-	-

Table 3
Assumed Johnson-Cook damage properties

	D1	**D2**	**D3**	**D4**	**D5**	**Melting Temp F**	**Transition Temp F**	**Reference Strain Rate**
Phenolic	0.012	0	0	0	0	400	390	0

Table 4
Damage evolution constraints

	Type	**Softening**	**Degradation**	**Displacement at Failure**
Phenolic	Displacement	Linear	Maximum	1e-5

CONCLUSIONS

This report summarizes efforts to develop a material model for a cotton-phenolic based bearing cage. Samples were directly acquired from bearing assemblies as test samples could not be acquired from the vendor of the bearing. Due to the complexity of the shape of the bearing cage, U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, engineers developed a technique to capture structural properties of the bearing cage and used that data to aid in development of a material model for the bearing cage material through modeling and simulation. By matching the test data acquired from the bearing cage pull tests, analysts were able develop stress-strain curves that were then used to parameterize the bearing cage material model. The material model is in essence validated instantly by this approach as analysts were successfully able to match both the experimental results and failure of the bearing cage.

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