CAST URETHANES FOR HIGH STRESS DYNAMIC APPLICATIONS

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CAST URETHANES FOR HIGH STRESS DYNAMIC APPLICATIONS

This study has evaluated commercially available high performance urethane systems primarily for use in high dynamic stress applications. The program was conducted with the objective of replacing Styrene Butadiene Rubber (SBR) in a high stress, high cyclic military application.

Urethane systems were tested statically at ambient, elevated temperatures and dynamically at various thicknesses to determine the effect shape factor has on the hysteretic properties (heat build-up) of each system.

Fillers and reinforcements were incorporated in the softer urethanes (85-90 Shore A) primarily to improve the dynamic compression fatigue properties without adversely effecting their other beneficial properties.

INTRODUCTION

The work in this program was directed toward finding a material replacement for styrene butadiene rubber (SBR) presently used for tank track pads. SBR was marginally acceptable for tanks lighter than the M-1. In applying the SBR material to the M-1 tank, the additional weight and their higher maximum speeds resulted in premature failure of the SBR pads, thus a program was initiated to find a substitute material.

Urethane elastomers with their superior cut growth resistance, high load bearing properties and ease of processing make it a viable candidate for SBR replacement in the tank pad application. The data obtained from this program could also be applied to any area which requires a material that has to withstand high dynamic stress at high cyclic rates.

PROCEDURE

Commercially available high performance urethane systems were researched and selected for evaluation. The urethanes were selected generically to cover the major available systems.

The systems selected for evaluation were as follows:

- TDI/Ether/Diamine Cure
- TDI/Ester/Diamine Cure
- TDI/Ether-ester/Diamine Cure
- MDI/Ester/polyol Cure
- MDI/Ether/Polyol Cure
- NDI/Ether/Polyol Cure
- PPDI/Ether/Polyol Cure

The primary tests selected for evaluation were compression fatigue (heat build-up), hot tear (Die "C") and hot tensile. The urethane samples listed in Table 1 designated by letters, were received and tested in this program.

TESTS

1. Tensile Tests

Tensile test specimens were fabricated per ASTM D412-80 and tested at 75°F, 200°F, 250°F, and 300°F.

2. Tear Die "C"

Tear specimens were fabricated per ASTM D624-81 and tested at 75°F, 200°F and 250°F.

3. Compression Fatigue Test

The urethane blocks received from the vendors were machined into test samples 2" x 2" x 1/2", 2" x 2" x 3/4" and 2" x 2" x 1" thick. In some cases, cylinders were received instead of blocks. The cylinders were machined to 2" diameter and specimens made 0.5", 0.75" and 1.00" thick. The test samples were bonded to 3" x 3" x 1/8" thick steel plates with a modified epoxy adhesive. The shape factor of the block and cylinders were the same for the corresponding thicknesses.

Prior to dynamic testing, each of these blocks were then tested statically to obtain a load and unload curve (one cycle hysteresis) for each specimen thickness. The loads applied to obtain the curve for the 2" x 2" specimens was 0 to 3200 lbs then back to 0; the load for the 2" diameter disc was 0 to 2500 lbs then back to 0. See Figure 1 for a representative one cycle load/unload curve.

The area between the load and unload curves represents the work done in a load deformation cycle. The rapidly repeated deformations can cause considerable hysteresis energy which must be dissipated as heat. This build-up of heat can damage or even destroy the part. The amount of mechanical energy converted to internal heat during each deformation cycle can vary within each urethane family.

The reason for the different thickness blocks was to determine the effect the Shape Factor has on heat rise. The Shape Factor, designated as "S", is derived from the loaded area divided by the force free area. See Figure 2 for calculation of shape factor.

Urethane elastomers across their entire hardness range are affected by Shape Factor in the same manner as conventional rubber. It can be seen from the Compressive Stress/Strain curves that as the Shape Factor increases, the compressive stress needed to produce a given strain also increases. See Figure 3.

COMPRESSION FATIGUE SETUP

A close-up of the mounted specimen and the constant load fatigue machine and auxiliary equipment are shown in Figures 4 and 5. The equipment used on the compression fatigue test is listed below.

a. Fatigue Testing Machine
   Baldwin Lima Hamilton Corp.
   Universal Fatigue Testing Machine
   Model SF IOU - Capacity 0-10,000 lbs

b. Temperature Recorder
   Fluke Data Logger
   Model 2240 A
   Type T Thermocouple

c. Digital Strain Indicator
   BLH Model 1200

d. Load Cell, Budd No. 251

e. Chart Recorder
   Gould Brush 240
   2 Channel

SAMPLE TESTING IN COMPRESSION FATIGUE

A 1/16" diameter hole was drilled into the center of the urethane block for the insertion of a thermocouple wire to record the core temperature. A thermocouple wire was also placed on the surface of the test sample for the surface temperature. Insulator blocks (Transite) were placed on both sides of the urethane sample. The sample was then attached to the fatigue machine. See Figure 6.

The ambient, surface temperature and core temperatures were recorded every 30 seconds. The samples were tested at a frequency of 30 Hz and a constant load of 2,000±1,500 lbs for the 2" x 2" specimen and 1,570±1,178 lbs for the 2" diameter specimen. The test was terminated when the specimen failed or reached 100,000 cycles.

TEST RESULTS

The results of the tensile and tear strengths are shown in Tables 2 and 3. The compression fatigue results are shown in Table 4. The cycles vs. heat rise curves for the 1" thick (0.5 S), 3/4" thick (0.67 S), and 1/2" thick (1.0 S) are shown in Figures 7, 8, and 9.

Figures 10 thru 14 show the different failure modes of the urethane specimens in the compression fatigue test.

System "B" had the lowest heat build-up of all systems tested regardless of thickness after 100,000 cycles without failure. This system was selected for fabrication of parts for field test.

EFFECT OF DYNAMIC STRESS

Two systems, "A" & "F", were selected for retest at a lower dynamic stress keeping the cyclic rate the same to determine the effect a lower stress would have on heat build-up. The 1" thick specimens (0.5 S) of the two systems selected failed at the 2,000±1,500 lb stress level but survived 100,000 cycles at all thicknesses when subjected to the lower stress, 2,000±1,200 lbs. The steady state temperature for system "A" was higher than system "F" for all thicknesses. See Figure 15 for cycles vs. heat rise curves.

COMPARISON OF THE LOAD AND UNLOAD CURVES OF SYSTEM "B" AFTER 100,000 AND 200,000 CYCLES

Static load and unload curves were taken prior to compression testing and after 100,000 cycles. Figure 16 shows the difference in the hystereses curves after 100,000 cycles. The static hysteresis curve taken after 200,000 cycles superimposed perfectly over the 100,000 cycle curve indicating that stabilization occurred sometime during the first 100,000 cycles.

MODIFIED URETHANES

In order to improve the compressive fatigue properties without adversely effecting abrasion resistance and coefficient of friction properties, urethanes (85-90 Shore A) were modified with fillers and/or reinforcements.

Two systems were selected for modification, System "A", tested previously, TDI/Ether/Diamine Cure, and a MDI/Ether/Polyol Cure, System "P".

The following were used as modifying agents:

a. 1/32 milled fibers (Owens Corning P-739BD)

b. 1/16 milled fibers (Owens Corning 737-AA)

c. 1/8 chopped glass (Owens Corning 405-AA)

d. Processed mineral fiber (PMF) Jim Walters

These modifications significantly improved the compression fatigue properties from the base material but degraded the other properties from base material. The system modified with 1/32 milled fibers (O.C P-739BD) exhibited the lowest heat build-up in the compression fatigue test of all the reinforcements. See Table 5 and Figure 17 for cycles vs. heat rise curves.

COEFFICIENT OF FRICTION TESTS

A test apparatus was fabricated for determining the coefficient of friction of the urethanes. See Figure 18 for setup.

Urethane samples 1" x 1" x 3/4" thick were bonded to steel plates, 2" x 2" x 1/8" thick using Hughson 310 epoxy. Three (3) samples were required for each test.

The bonded samples were attached by machine screws to the large metal plate as shown in Figure 18.

Weights were added until 184 psi was obtained. The urethane was in contact with a concrete surface. After the weights were added, the fixture was pulled at 6"/minute over the concrete surface by a hydraulic cylinder. The load was recorded by a X-Y plotter. Three (3) runs were made on each sample, dry and wet. The results of the test are in Table 8. The results show that the modification decreased the coefficient of friction from the base material.

NBS ABRASION TEST

Abrasion tests were made on the modified and unmodified urethanes per ASTM-D-1630. SBR taken from a tank pad was used as the control. See Table 9 for abrasion test results.

Results show the pronounced reduction in the abrasion resistance of the modified urethanes from the base urethane.

MODIFIED URETHANE STATIC TEST RESULTS

Tensile and Die "C" samples were made using System "A" and System "B" (both tested previously without modification) to determine the effect modification had on their properties. See Tables 6 and 7. Results show that the modifications degraded the static properties from base material.

CONCLUSIONS

- TDI/Ether/Diamine urethane systems in general performed better in the dynamic fatigue tests than the other urethane systems.
- The Shape Factor, defined as the ratio of the loaded area to the total force free area, has a marked effect on the dynamic performance of polyurethane.
- The urethane systems which failed in the compression fatigue test can be related to the rapid temperature rise characterized by splitting, shattering, softening and, in some

cases, extrusion of molten material through a fissure in the side.

- The load/unload curves when checked statically after 200,000 cycles on the System "B" was the same as that after 100,000 cycles, showing complete stabilization occurred somewhere during the first 100,000 test cycle.

- Fillers, in general, degrade the properties from the base material except compression fatigue.

- The dynamic compression test is a good screening test for materials used in a dynamic mode.

- The butadiene styrene rubber had a higher core temperature and the least cycles to failure than any of the urethanes tested regardless of thickness.

- Laboratory testing indicates that some high performance urethanes are far superior to SBR in dynamic and static properties and could be a viable substitute for SBR tank pads.

TABLE 1 - URETHANE SAMPLES

SAMPLE	HARDNESS SHORE A	TYPE
A	90	TDI/Ether/Diamine
B	95 (52D)	TDI/Ether/Diamine
C	95	TDI/Ether/MOCA
D	95	TDI/Ether/Diamine
E	95	NDI/Ether/Polyol
F	95	PPDI/Ether/Polyol
G	90	MDI/Ester/Polyol
H	95	TDI/Ester-Ether/MOCA
I	92	TDI/Ester-Ether/MOCA
J	85	TDI/Ether/MOCA
K	95	TDI/Ether/MOCA
L	95	MDI/Ether/Polyol
M	90	MDI/Ester/Polyol
N	95	TDI/Ester/MOCA

TABLE 2 - URETHANE EVALUATION - TENSILE STRENGTH

	TENSILE STRENGTH (psi) 2-in MINUTE TEST SPEED			
SPECIMEN	@ 75°F	@ 200°F	@ 250°F	@ 300°F
A	8,471	2,543	1,367	-
B	8,550	2,795	2,314	66
C	8,367	1,833	1,121	731
D	6,013	1,219	509	-
E	2,505	805	-	-
F	3,575	1,186	844	383
G	2,362	0	-	-
H	6,299	2,268	1,255	201
I	4,756	1,562	954	-
J	1,936	1,173	-	-
K	6,017	3,918	1,458	400
L	6,516	1,241	-	-
M	6,073	1,601	-	-
N	9,200	1,342	-	-
SBR*	2,900	N/A	N/A	

* Minimum requirement MIL-T-11891B

TABLE 3 - URETHANE EVALUATION - TEAR STRENGTHS DIE "C"

	POUNDS LINEAL INCH	2-in MINUTE TEST SPEED	
SPECIMEN	@ 75°F	@ 200°F	@ 250°F
A	531	294	251
B	615	359	273
C	339	208	205
D	N/A	N/A	N/A
E	231	125	-
F	781	398	278
G	484	0	-
H	309	394	321
I	529	432	331
J	446	299	-
K	589	439	365
L	700	279	-
M	627	267	-
N	595	410	-
SBR*	300	N/A	175

N/A - Specimen not available.

* Minimum requirement MIL-T-11891

TABLE 4 - URETHANE EVALUATION COMPRESSION FATIGUE CORE VS. SURFACE TEMPERATURE @FAILURE OR 100,000 CYCLES

SAMPLE	THICKNESS	CORE TEMP °F	SURFACE TEMP °F	CYCLES
A	1/2	148.7	117.5	100,000
	3/4	366.4	293.4	47,000 F
	1.0	307.1	162.5	21,000 F
B	1/2	130.2	108.5	100,000
	3/4	147.2	113.2	101,000
	1.0	163.1	115.0	100,000
C	1/2	143.0	147.0	106,000
	3/4	313.0	265.0	65,000 F
	1.0	312.0	205.0	19,000 F
D	1/2	100.0	85.5	113,000
	3/4	176.4	192.0	15,000 F
	1.0	153.0	220.5	7,000 F
E	1/2			
	3/4			
	1.0	330.7	244.5	23,000 F
F	1/2	103.0	98.1	100,000
	3/4	132.4	107.0	106,000
	1.0	324.7	322.8	54,000 F
I	1/2	190.8	151.5	108,000
	3/4	329.5	211.4	32,000 F
	1.0	360.0	202.3	9,000 F
K	1/2	155.4	136.1	101,000
	3/4	201.7	151.9	102,000
	1.0	241.5	144.1	103,000
L	1/2	128.5	108.1	103,000
	3/4	179.0	131.5	101,000
	1.0	324.0	168.0	55,000 F
Rubber from T-142 Pad	1/2	414.0	385.0	14,000 F
	3/4	378.4	309.2	8,000 F
	1.0	343.5	273.8	5,000 F

F - designates cycles at failure.

TABLE 5 - COMPRESSION FATIGUE - TEST SAMPLES
REINFORCED URETHANES

30 Hz at 2,000±1,500 lbs Constant Load
SAMPLE SIZE - 2" x 2" x 3/4" S.F. 0.67

SAMPLE	AMBIENT TEMP °F	CORE TEMP °F	SURFACE TEMP °F	CYCLES
A - 0% Glass	73.4	383.6	272.8	29,000 F
A - 10% 1/32 Glass	72.6	207.4	131.3	100,000
A - 20% 1/32 Glass	72.3	180.7	122.0	100,000
P - 0% Glass	72.9	326.5	267.1	17,000 F
P - 10% 1/32 Glass	74.2	233.6	152.6 TC broke	27,000 F
P - 20% 1/32 Glass	70.7	243.0	153.7	100,000
SBR Rubber from Tank Pad	69.2	419.4	482.1	6,000 (Smoked, deformed, would not hold load)

F - designates cycles at failure.

TABLE 6 - STATIC PROPERTIES - TENSILE STRENGTH

REINFORCED SYSTEMS A & B	psi 2-in MINUTE TEST SPEED		
SPECIMEN	@ 75°F	@ 200°F	@ 250°F
A Control	8471	2800	1367
A 10% 1/32* Glass	7126	1725	1506
A 20% 1/32 Glass	6204	1627	1286
B Control	8550	2543	2314
B 10% 1/32 Glass	7639	2455	1592
B 20% 1/32 Glass	6817	2110	1622

* O.C. P 739 BB
Based on Resin Weight

TABLE 7 - STATIC PROPERTIES - DIE "C"

REINFORCED SYSTEMS A & B — psi 2-in MINUTE TEST SPEED

lbs/lineal inch

SPECIMEN	@ 75°F	@ 200°F	@ 250°F
A Control	531.5	293.7	251
A 10% 1/32* Glass	552.8	236	172
A 20% 1/32 Glass	513	218	226
B Control	656	279	241
B 10% 1/32 Glass	634	311	243
B 20% 1/32 Glass	645	313	252

* O.C. P 739 BB
Based on Resin Weight

TABLE 8 - COEFFICIENT OF FRICTION ELASTOMER ON CONCRETE

SAMPLE	184 psi DRY	184 psi WET
A - 0% Glass	0.64	0.50
B - 0% Glass	0.71	0.66
A - 10% 1/32 Glass	0.57	0.53
P - 0% Glass	0.52	0.52
P - 20% 1/32 Glass	0.50	0.50
SBR from Tank	0.76	0.65