MODIFICATION AND EVALUATION OF ELASTOMER TEST MACHINE (ETM)

U.S. ARMY - ERO CONTRACT NO.

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INDEX

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TABLES:

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The Elastomer Test Machine (ETM) which was constructed under Contract No. DAJA 45-85-C-0044 in May 1988 has been modified to include synchronization of the linear table with the 'Ram Action' of the press, a new linear Model 2, measurement of the horizontal force of the sample and a slip ring system for the measurement and control of temperature. The Elastomer samples can now be tested at different temperatures (>140°C) in the stationary impact mode, in two linear abrasion mode and in a rotational mode (and combinations thereof). Temporal qualitative data on load and displacement can be recorded which may provide a qualitative anal[y]sis of the elastomer degradation processes.

A comprehensive set of test data were obtained with the ETM using all the modes for 57 different elastomer samples, provided by the US Army (51 samples) and the US Navy (6 samples). The ETM tests provide a performance analysis of any track pad elastomer material and may predict a projected service life.

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ABSTRACT

The Elastomer Test Machine (ETM) which was constructed under Contract No. DAJA 45-85-C-0044 in May 1988 has been modified to enhance the capabilities and, therefore, its performance. The capabilities of the machine are reflected by the number of different 'MODES' of operation which have access through the ETM control panel. Elastomer samples can now be tested at different controlled temperatures not exceeding 140^{0}C in the following 'MODES':

(i) Stationary sample mode (single impact and autocycle multiple impact);

(ii) Rotating sample mode (single impact and autocycle multiple impact);

(iii) Linear Mode 1:
Tool bit is embedded in the sample to a preset depth. The linear movement of the sample, back and forth, generates a highly abrasive condition.

(iv) Linear Mode 2:
This mode is an extension of the linear mode 1 in which the sample linear movement is synchronised with the press ram stroke such that the tool bit is embedded during our traversal of the sample and then raised whilst the sample traverses in the opposite direction. At the extreme displacement of the sample table, the tool bit is lowered again for another cycle with continuous repetition. The ETM provides temporal data for quantitative load and displacement which may be used for quantitative analysis of the degradation process.

Fifty seven elastomer samples have been tested in the linear and rotational modes including the six round robin (US Navy samples). The results provide not only sufficient confidence in the operation of the ETM but also assess the nature of aging following a standard code of test procedure.

1. INTRODUCTION

Present report provides a description of the modification of the Elastomer Test Machine (see Final Report ERO Contract No. DAJA 45-85-C-0044). It also gives an analysis and correlation of test data for track pad material provided by the Materials Technology Laboratory, Watertown, M.A., using the modified Elastomer Test Machine (ETM). Elastomeric materials, provided by the Department of the Navy (USA) were also tested by the ETM in a multi-laboratory testing programme and an evaluation of such data is also provided in this report.

2. MODIFICATION OF THE ELASTOMER TEST MACHINE

An Elastomer Test Machine (ETM) was designed and constructed at the School of Electronic Engineering Science, University of Wales Bangor (see Final Report: Contract No. DAJA 45-85-C-0044). The ETM can apply stresses to elastomers in a controlled and observable manner, thereby providing information on comparative performance and aging of such materials under test. Only a brief description of the ETM will be given here as it has already been described in detail in the Final Report of the Contract No. DAJA 45-85-C-0044[1].

The ETM consists of a six ton half body press, manufactured by Rother Machine Tools Ltd., and the major constituent parts of the system are as follows:

(2.1) RAM PRESS

The pneumatic ram press operates with an air supply of 80 p.s.i. pressure. The vertical impact of the ram causes a tool bit (figure 2) to impinge upon the surface of an elastomer sample, mounted on the test bed. The ram can operate both in a single shot mode or in an autocycle mode. In either mode the machine can be stopped by raising the protective transparent guard. A load cell pressure transducer, located appropriately above the tool bit detects the vertical loading.

(2.2) SAMPLE HOLDER & STAGE

The sample holder consists of a nickel plated copper block which houses a $63.5 \times 63.5 \times 16mm^3$ block of the material under test. The copper block accommodates two 100 watt cartridge heating elements along with a J-type thermocouple sensor. The block temperature can be controlled upto 200^0C using an Eurotherm Model 820 temperature controller which is set by push button controls on the instrument facia.

The sample holder may be located horizontally or at an angle of $> 30^0$ from the horizontal direction (TILTED MODE). It may also be rotated (ROTATIONAL MODE) or operated in a LINEAR CYCLIC MODE. For the last two modes the sample is located horizontally These three modes are in addition to the STATIONARY MODE.

(2.3) DATA ACQUISITION AND OPERATION

The outputs from the load cell and temperature transducers are fed into a display unit and also to a CIL Microsystems PCI 6380 interface and a Personal Computer via a General Purpose Interface Bus (GPIB).

(2.4) MODIFICATION

The following modifications were incorporated in the existing ETM, constructed with the funding provided by the ERO (Contract Number DAJA 45-85C-0044) to improve its usefulness and performance.

(i) Synchronization of the Linear Table with the 'Ram Action', of the Press.

(ii) New Linear 2 Mode.

(iii) Measurement of the 'Horizontal Force' on the sample.

(iv) Slip-Ring System for the measurement and control of temperature.

The synchronization of the linear table with the press ram stroke was achieved by installing a dummy cylinder with its magnetic piston coupled to the linear table (figure 1). The linear movement of the table moves this piston whereby its inbuilt magnet activates the proximity switches set at any selected position within the range of travel. The two proximity switches, in turn, control the power to energise the solenoid operated pneumatic valves to raise or lower the press ram. This arrangement, therefore, couples directly the sample's linear position with the point of entry and the withdrawal of the Ram/Tool bit. This is now known as Linear Mode 2.

This new Linear 2 Mode is an extension of the original linear mode for which the tool was permanently embedded. In this mode the ram impacts with the sample, the tool bit remaining embedded for one traversal of the table. The ram is then automatically raised whilst the traversal of the table continues in the opposite direction. At the extreme displacement of the table the tool bit is lowered again by the ram, initiating another impace drag cycle. This is repeated continuously and it leads to eventual tearing with debris being accumulated at one edge of cut produced. Linear 2 Mode enables vertical impact damage and linear mode damage to be inflicted on the sample under test.

Two further load cells (RDP Electronics Ltd) have been incorporated in a modified tool bit holder (figure 2). With the positions, shown in figure 2, when the tool bit is embedded in a sample and with a linear movement applied in either direction, the sample resistance is transmitted directly to each load cell which has a full scale calibrated capacity of 500lb.

Silver-Graphite brushes have been installed with silver plated slip rings. This arrangement ensures good stability of contact resistance over a long period of time and this provides an accurate control of the sample temperature within $\pm 1^{\circ}C$ at temperatures not exceeding $140^{\circ}C$ which is set by a push button control on the Eurotherm Controller.

One other item has also been incorporated in order to conform to the Health & Safety at Work Act U.K. (1974) namely that the airpress control system have had a safety modification kit installed to the makers instruction. This brings the press up to the present safety standards of the U.K.

3. TEST MODES

(i) Vertical Impact Test:

Stationary Mode.

In this mode the ram drives up and down on the sample for a required number of impacts, say 500 or for a set time.

The stationary mode may also be used in conjunction with the sample being located at a tilt angle (Tilt Mode). The tilting of the table, of course, inhibits any movement of the test bed.

(ii) Abrasion Test:

Linear Mode 1.

Here the platform moves linearly forward and back in a horizontal plane at a set rate. The tool may be permanently embedded in the sample causing abrasion and eventual erosion.

Linear Mode 2.

In this case after each traversal in one particular direction, the embedded tool bit may be raised by the ram for the duration of the return traversal, the tool being ready to impact at the beginning of the next cycle. This process in then repeated automatically.

In both the linear modes the testing occurs for a set time, typically several minutes or for a registered number of impacts for the Linear Mode 2 only.

(iii) Rotational Mode (Radial Rotational Wear)

In this mode, the tool bit is embedded in the centre of the sample and the table rotates at a frequency set by the operator. Alternatively, the ram can be set to impact repeatedly on the sample as the sample rotates (i.e., auto/cycle mode).

4. DATA ACQUISITION OF ETM

The outputs from the Eurotherm Model 820 temperature controller and the three load cells are fed into digital display units which form a composite block. The signals from the display units are also fed into a CIL Microsystem PCI 6380 Microcomputer Interface and into a Personal Computer via a General Purpose Interface Bus (GPIB). The Data acquisition and start/stop operations are provided on the ETM by an IBM PC Computer (figure 3).

The CIL Microsystem PCI 6380 has four output channels, four relays, eight input channels and a 15-bit digital output from the rear panel. It has internal software consisting of 4K bytes on EPROM, 6K bytes of RAM, of which 4K is user accessible. The output from the temperature controller and the three load cells are fed into channels 10, 11, 12 and 13 respectively. One of the Relay channels 'RO' is used for starting and stopping the ETM via the computer keyboard.

The GPIB has its own Z80 microprocessor and operating software, upto 40K bytes of RAM being available. A BASIC Program enables the acquisition of the data.

The complete system is microprocessor controlled.

A video guide for the operation of the ETM, together with the Instruction Manual are available for training of the personnel in the operation of the ETM.

4. SPECIFICATION OF THE ELASTOMER TEST MACHINE

(i) Electricity Supply: 110 volts at 60Hz.

(ii) Air Pressure: 80 p.s.g. max.

(iii) ETM is free standing on its own plinth. The motive power for the impacting of the samples is generated by an air operated "Toggle" press capable of supplying 6 tons maximum force in either single impact or continuous cycle modes (selectable). Both the tonnage and the stroke or adjustable.

A separate supply of 80 p.s.g. is required to operate the linear oscillating mode. The ram head has a facility for selection from different blade forms to apply differing cut characteristics to the sample.

(iv) Modes.

A sample can be tested in four modes with reference to the line of impact and these are as follows.

Vertical Impact Test:	Single or Continuous.
Rotational Mode:	3 rev/sec max.
Linear Modes 1 & 2:	up to 2" max.
Tilt Mode:	30 degrees from horizontal.

(iv) Impact.

Force upto 5000 lbs max. (load cell max)

Frequency (proportional to the stroke length):	1-4 per sec.
Cycle:	single or continuous.
Sample Penetration Depth:	15mm max.

(v) Sample.

Size:	4" x 4" x 2½" thick max.
Temperature:	Room temperature to 140°C.

5. AGING BEHAVIOUR OF TEST SAMPLES: RESULTS & ANALYSIS

A comprehensive set of test data were obtained with the ETM using all the modes for 57 different elastomer samples, 51 samples being provided by the U.S. Army (MTL - Watertown, MA.) and the remaining six belonging to the

U.S. Navy (Dahlgren, VA.). The Navy samples have also been tested for the TTCP round robin programme organized by Dr. Bruce Hartman of the Naval Surface Wareface Centre (Dahlgren, VA.). The aim of the tests carried out with the ETM is to give a performance analysis of any track pad elastomer and to predict in comparison with other similar materials, a projected service life.

All testing was conducted at $60^{0}C$ for seven minutes for each sample which was weighed prior to testing and again after testing to determine the weight loss. The variation of load was monitored for each test and the level of deterioration established as a percentage. The relative performances have been assessed with respect to the weight loss and the percentage load depreciation and the results have been tabulated in an expected order of overall durability for both the Army and the Navy elastomer materials.

Figure 4, 5 and 6, show the typical recorded plots of the abrasion test in the LINEAR MODE 1 for the elastomer samples 15TPU, MB2690 and 15TP-1417X respectively, the test running in each case for 7 minutes. These recorded traces have several salient features which are as follows. The graph for loading has two visible parts for each load cell plots of the side to side thrusts. These consist of a first shoulder preceding a second peaked shoulder. The relative prominence of the first shoulder and the peak change with time during the course of the LINEAR MODE test in which the first shoulder rounds off and decreases in height where as the second peak is seen to increase in prominence, although its overall height often is observed to decrease. Between the shoulder and the peak an inflexion is observed where a peak begins to form. This location has been used as a measure of the values of the load for the reason explained in the following observation.

It was observed that as the tool bit traversed across the sample debris accumulated at the extreme points of the tool travel. It is suggested that this was responsible for the creation of an additional resistance pad which increased the magnitude of the load displayed at these positions, and hence a possibly exaggerated peak. The first traversal (forward and return) of the tool bit induced comparatively higher loads than at any other time in the linear mode testing. This phenomena can be seen at the beginning of the plots of the first minute of the test with a sample. The load is observed to decrease to lower values during the successive traversals. It is thought that the first travel breaks down the surface resistance and softens the material to a certain degree. The 'stress relaxation' may also occur in the process of the lowering of the measured load as the experiment progresses. however, the stress relaxation is known to occur under a static load. The load depreciation during the test run was thus due to the breaking up of the sample surface. In general, where a damage occurred in the sample, the form of the chart recorder trace at the beginning of the test run differed in size from that towards the end of the test run, the latter being reduced with sharper peaks.

The schematic representations in figures 7 and 8 show the forms of the output obtained from the recorded trace. Figure 7 shows the behaviour of a relatively soft sample whereas figure 8 represents a typical nature of load behaviour for a hard sample. The first shoulder, and the oncoming peak are denoted by A and B respectively in figures 7 and 8 from which it may be observed that the initial shoulder becomes rounded and diminishes whereas the peak becomes more pronounced with time, although its magnitude may reduce. The level of the inflexion between the two humps also decreases with time as the sample cuts and breaks apart.

Another interesting aspect of the chart recorder traces, obtained with the harder samples can be explained in terms of crack-development under loading. A fracture of thermosetting polymers such as epoxies (LORD and XPE - series) strongly depend on the test temperature and the loading rate. AT low temperatures and high loading rates the crack growth is brittle. At intermediate temperatures and loading rates a fracture tends to be discontinuous (stick/slip process). This was thought to be the situation in the case of the linear mode testing at 60°C for such XPE 10 and LORD 4608-62 developed high loading to > 200 lbs. The damage incurred was very dynamic and vigorous with some particles of debris travelling short distances when dislodged.

A typical load-time curve during crack growth for an epoxy specimen is shown in figure 9. The crack grows for a while with falling load until it arrests. This is known as stick-slip growth. The initial crack growth requires a larger load than to propagate the crack.

Three patterns of load variations were observed in the linear mode for the elastomers tested in this work. These are as follows:-

(i) The load will begin at a high value, for example 59 lbs for the sample 15TPT and then, as cutting/chauking is initiated, loading would begin to decrease, reaching a low value of 31 lbs.

(ii) The load will begin at a very low level for exceptional samples, such as A8-MOCA and AM-CYAN 85-69. No damage will be observed except for a slight marking of the materials surface. At the end of the test run, the load will still be very low. However, after a time equivalent to three or four test runs (21-28 minutes) damage will occur when the final result will be equivalent to the tear damage observed in poorer samples. At the onset of damage the load was observed to increase first before decreasing, for samples in this category.

(iii) For samples which initially displayed a high loading (> 150 lbs), the load was seen to be increasing at the end of the test run. For this third category, care was taken not to confuse the reading with the peak due to debris formation. Some of the Army samples, where a greater range of compounds were tested, fall into this category.

The HARDNESS of the samples was obtained from the value of loading over the first traversal in the linear test. This value, in pounds (lb), was obtained by averaging the reading for both the left and the right load cells. A hard material may be expected to be brittle.

With the ROTATIONAL MODE the vertical load deterioration was reliably monitored at 30 seconds intervals, and graphs of load against time provide useful comparison of weight loss for samples. Figures 10 and 11 for example, show typical weight loss behaviour with time for sample 37721C (most resilient) and sample NSWC17 (least resilient).

It was noted that the vertical load measured by the E-307-2 would gradually decrease after the ram was brought down with the tool positioned in the sample, the deterioration amounting to a few pounds (lbs). This was thought to be solely due to stress relaxation in the material. However, once the rotation of the platform was started, deterioration was observed to be quite fast and considerable.

The horizontal loading in the rotational mode was found to be constant, its numerical value being different for each material. It should be noted that when the platform rotates in a given direction, only one of the load cells will show a useful load reading and this occurs at a time during the rotation when the tool is caused to pivot into that load cell.

Initial loading in the rotational test can also serve to determine the hardness. Thus, for both the linear and the rotational modes the ETM will function as a DUROMETER, a device specifically designed to measure the hardness of rubber.

The greatest source of potential error probably lies in the initial setting and subsequent maintaining of sample cut depth. To this end, such settings are now carried out on the ETM by using an inbuilt LVDT instrument with its calibrated display unit where accurate monitoring of cut depth is simply achieved.

The results of the tests for the Army (MTL) samples are shown in the Tables 1-5 which similarly the measured data for the Navy samples are shown also in appropriate orders in Tables 6-10.

6. CONCLUSION

A standard testing procedure has been developed with the ETM by experimenting with the Navy and the Army elastomer samples. Overall, the results are encouraging and give credence to the various modifications which have been implemented on the ETM which is easy to operate and gives reproducible results.

7. REFERENCE

E. Tozowanah
B.Sc. (Hons.) Dissertation "The Elastomer Test Machine", University of Wales Bangor, 1991.

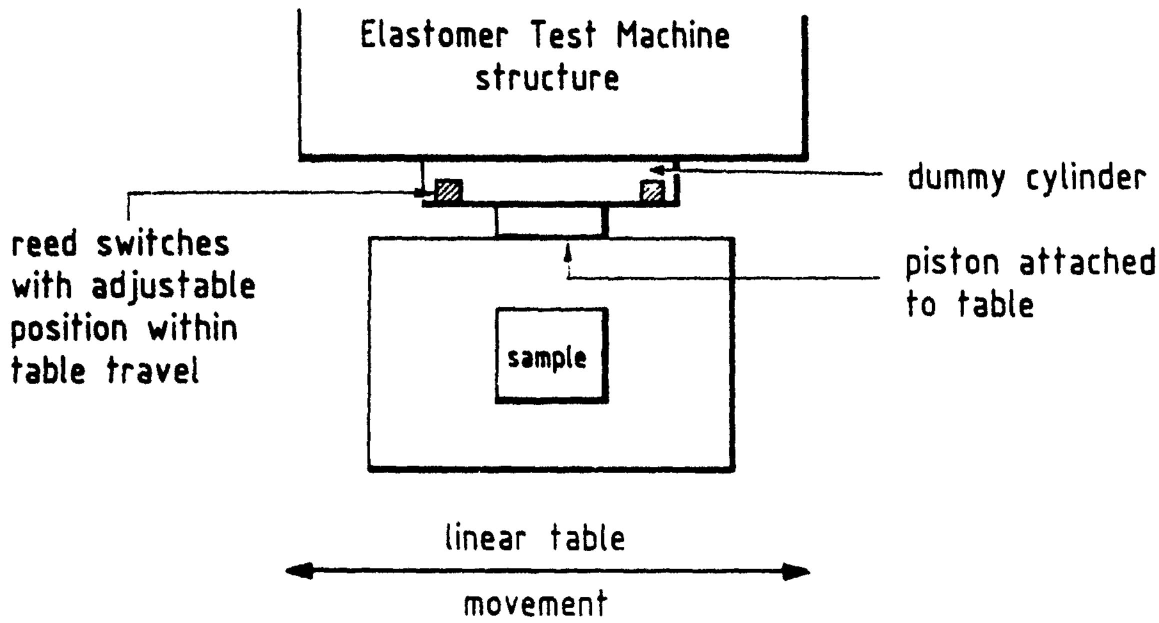


Fig. 1. Ram stroke / linear table coordination.

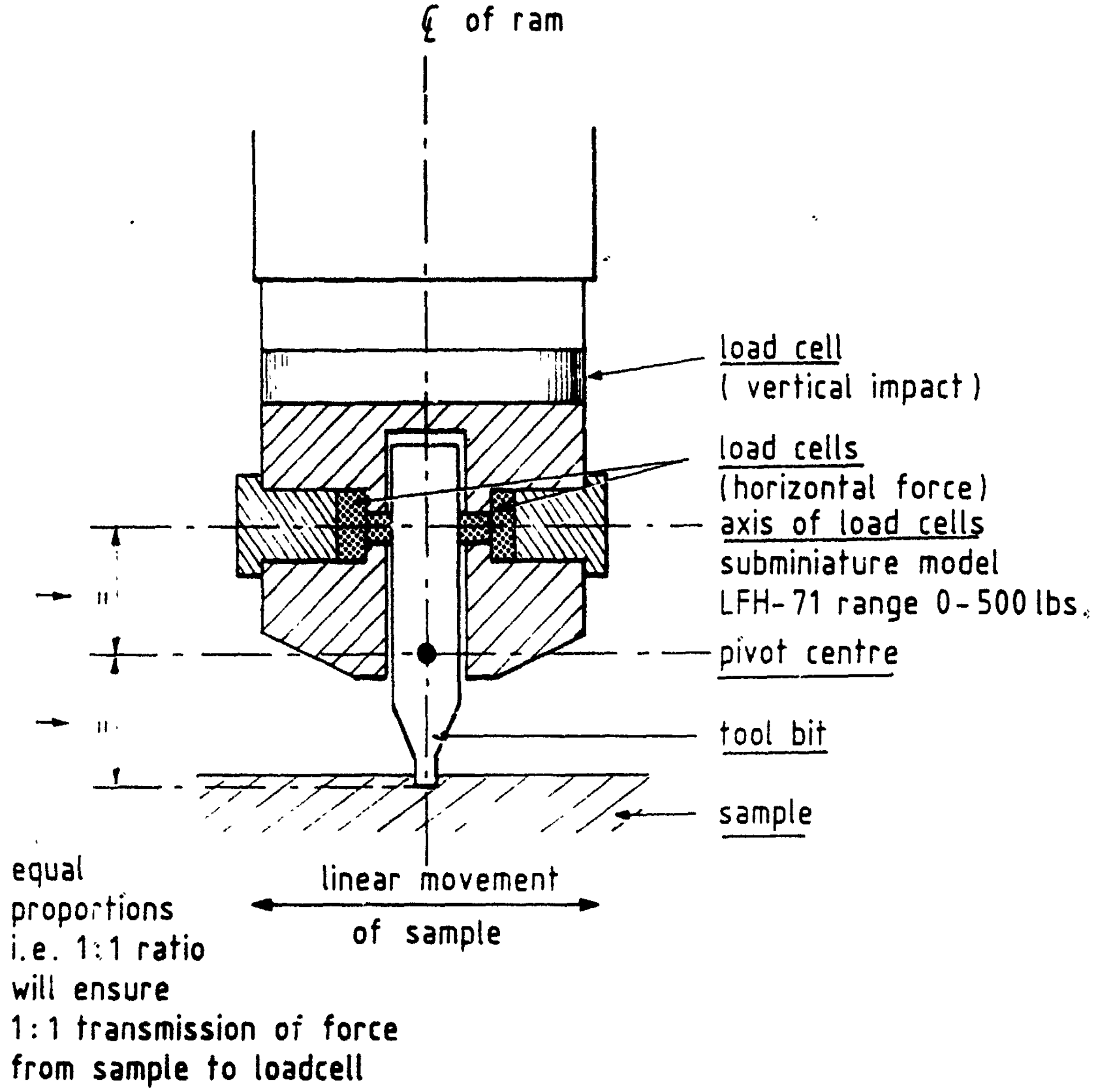


Fig. 2. Configuration of 3 load cell assembly
for sample load monitoring.

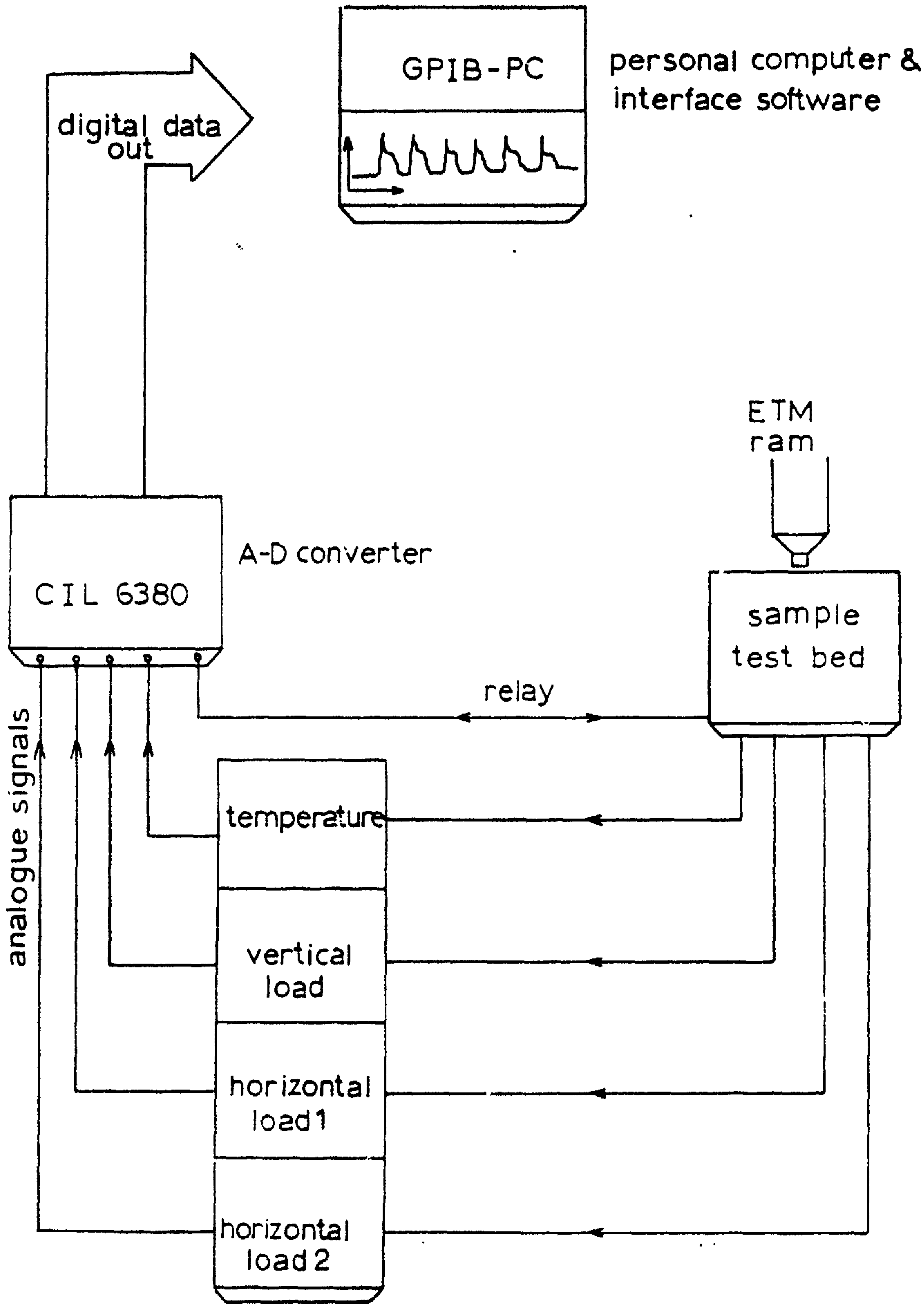


Fig. 3. ETM signal collection, logging and display.

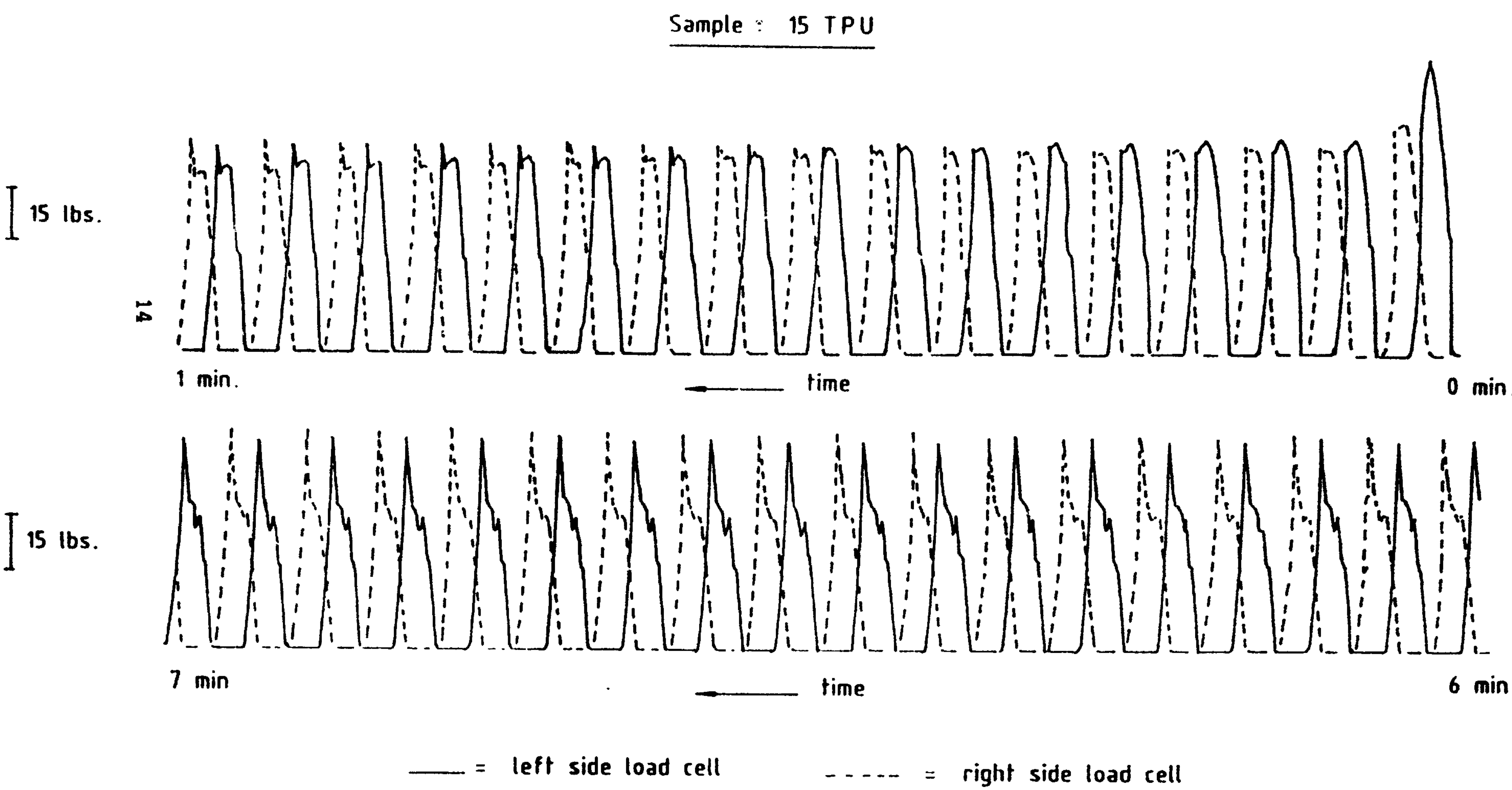
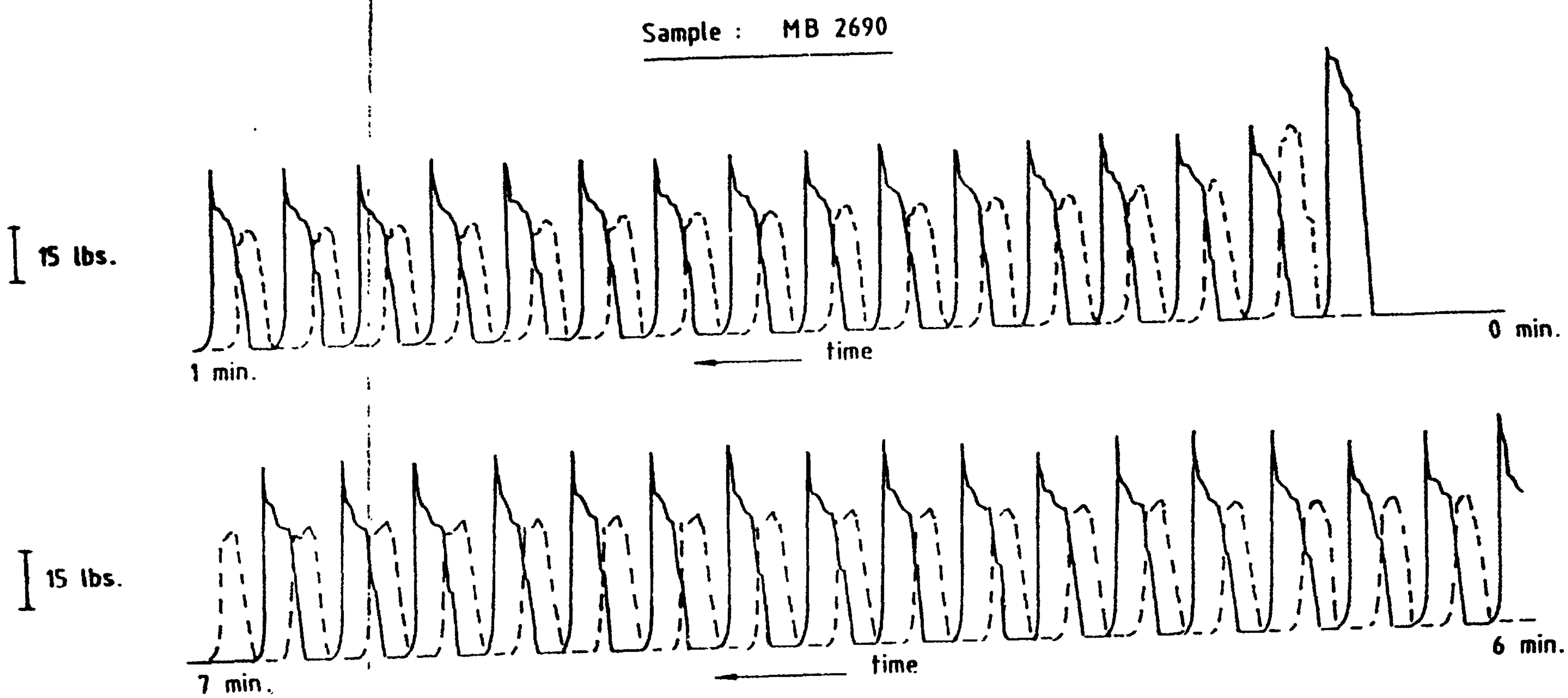


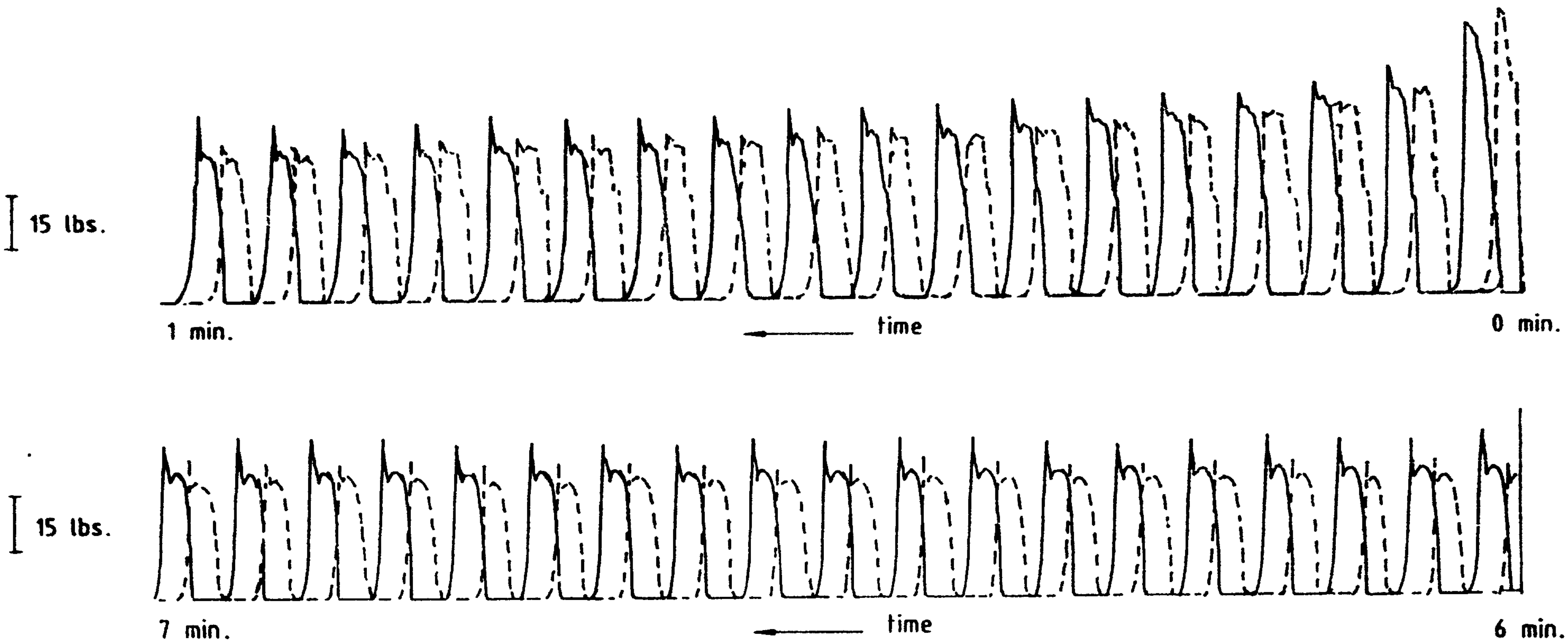
Fig.4 Chart recorder output for impact loading in the Linear mode 2. for sample 15 TPU.



—— = left side load cell ——. = right side load cell

Fig.5 . Chart recorder output for impact loading in the Linear mode 2 for sample MB 2690

Sample : 15 TP-14 AX



—— = left side load cell ——. = right side load cell

Fig. 6. Chart recorder output for impact loading in the Linear mode 2 for sample 15 TP-14 AX

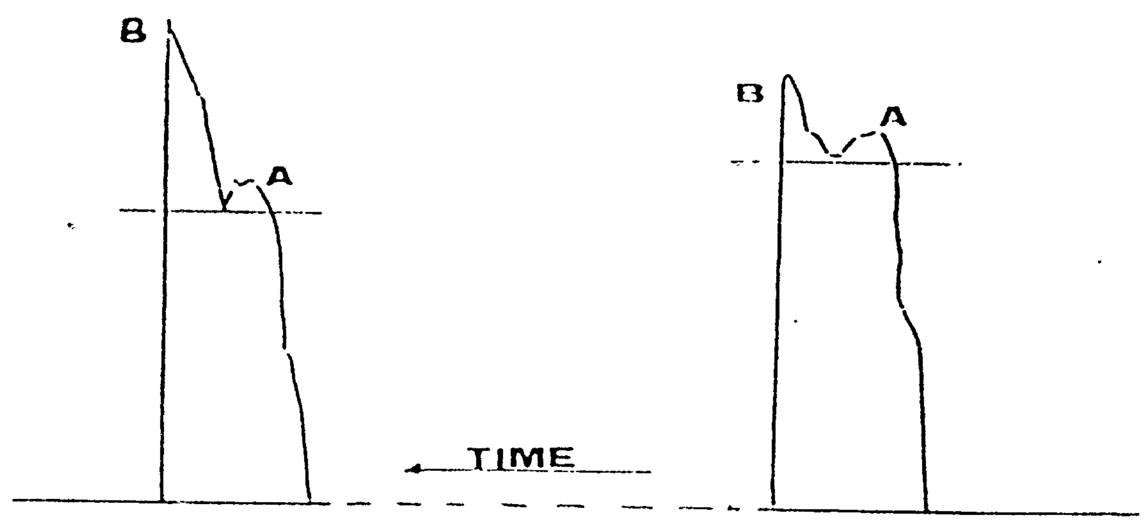


Fig 7 Impact trace (recorded) for a compliant material

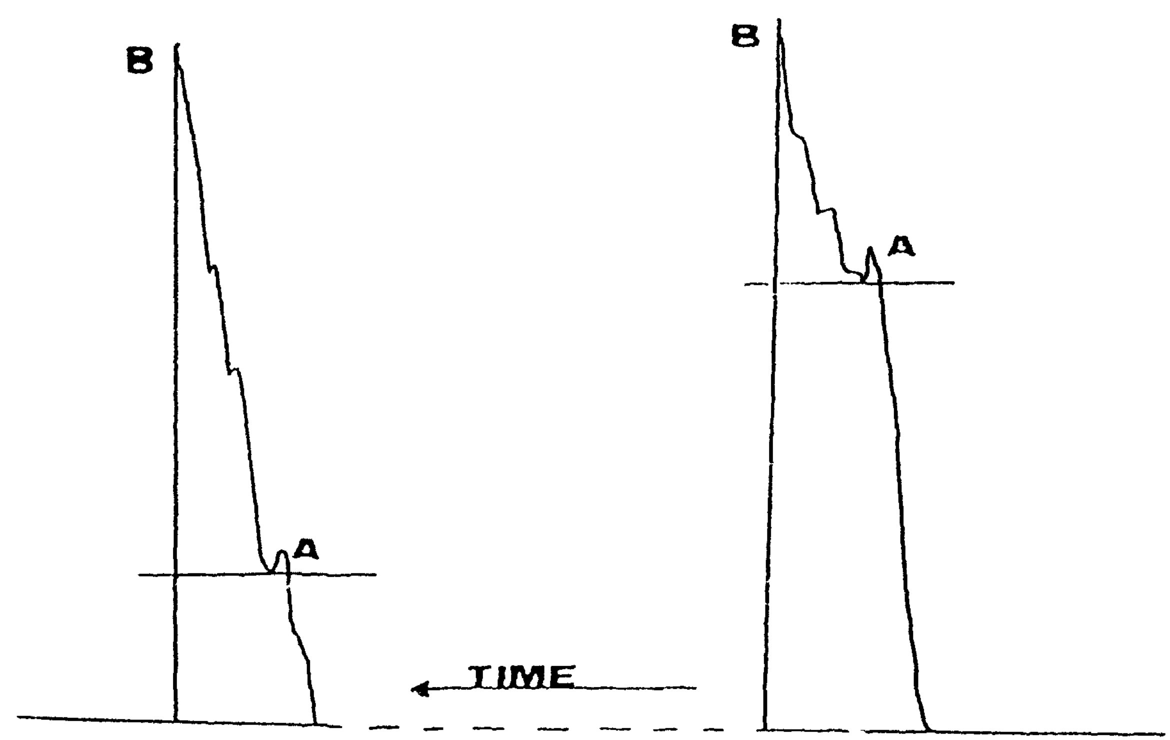


Fig.8. Impact trace (recorded) for a hard elastomer material.

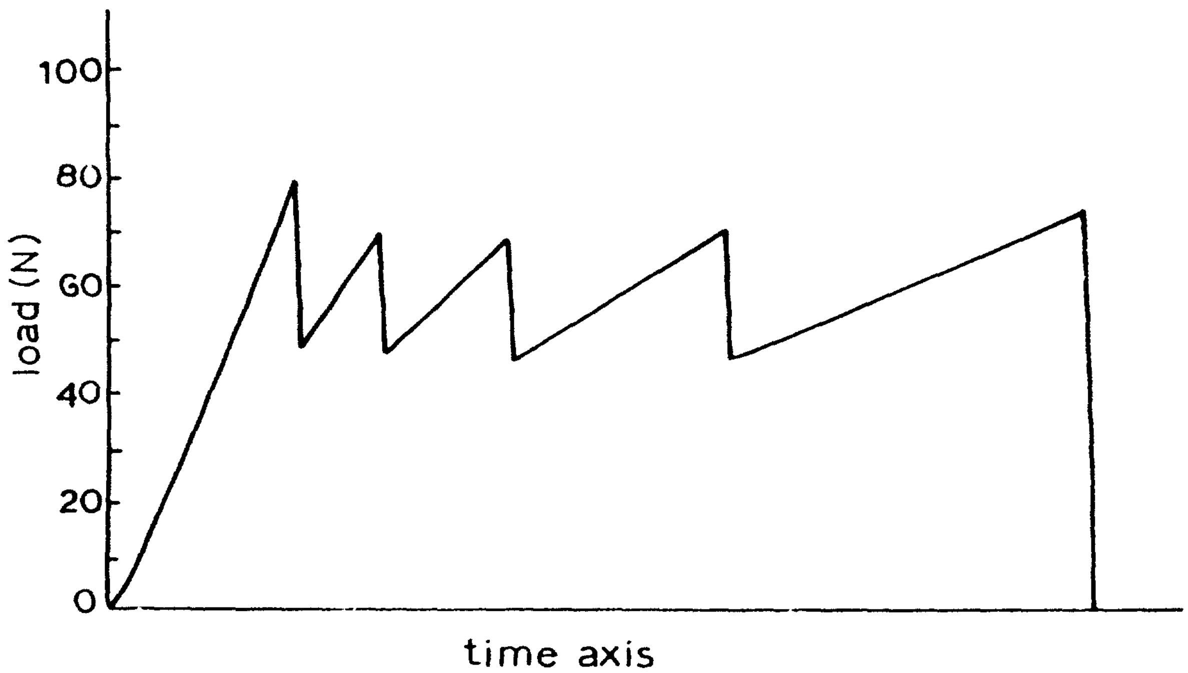
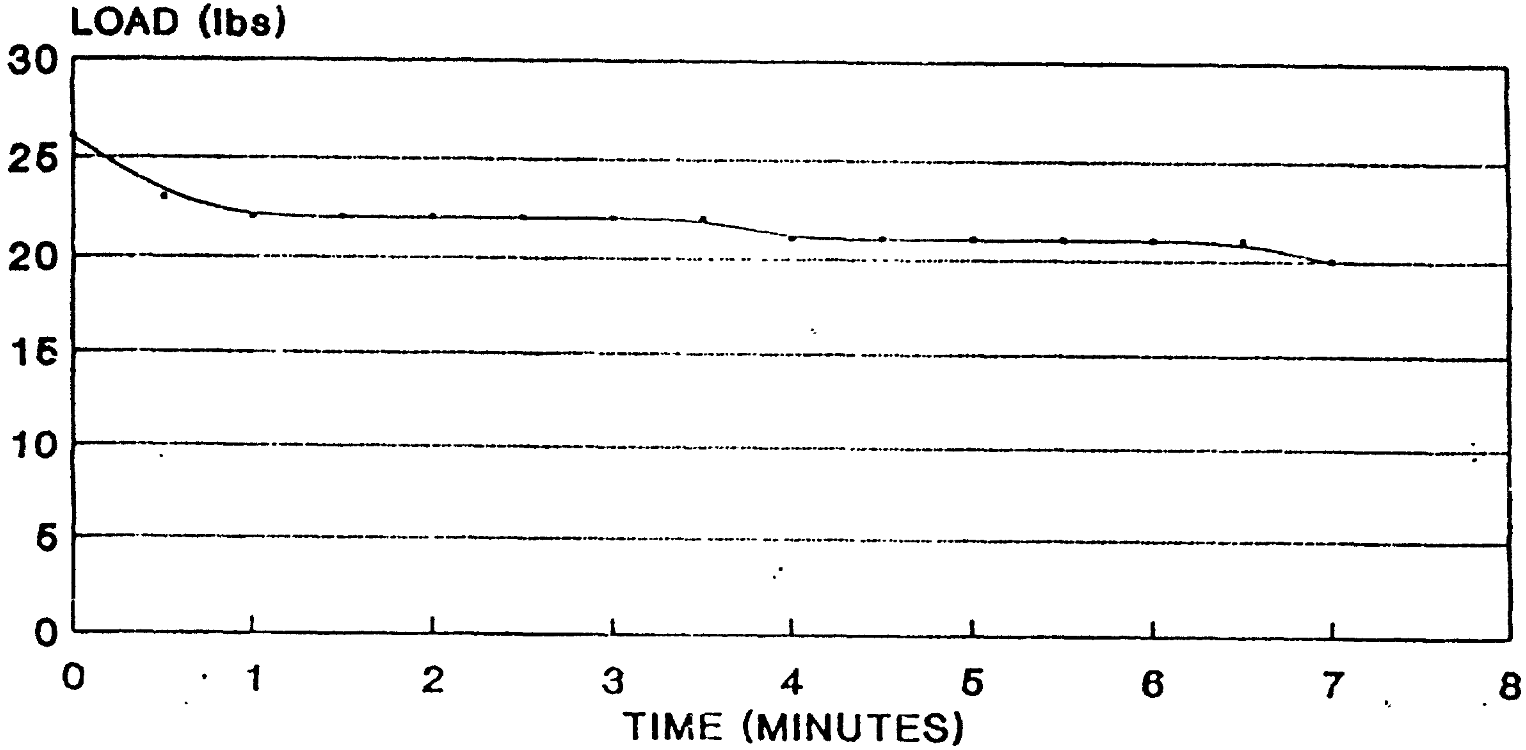


Fig.9 . A typical load-time curve for an epoxy during stick-slip crack propagation

ROTATIONAL MODE
RAM LOAD VARIATION



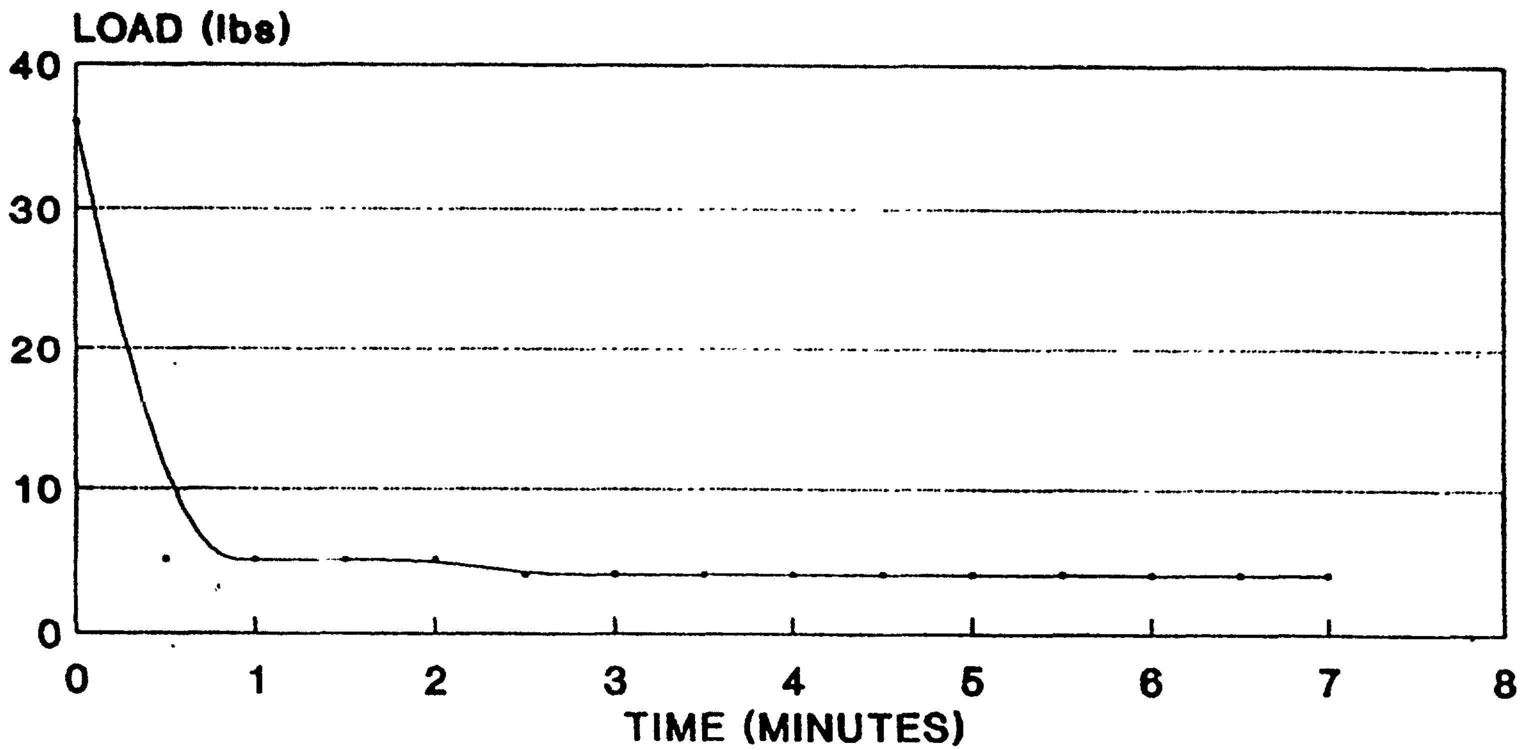
U.S.NAVY SAMPLE

37721C

WEIGHT LOSS:=0.03g

Fig.10. Ram load variation with time for sample 37721C

ROTATIONAL MODE
RAM LOAD VARIATION



U.S.NAVY SAMPLE

POLYUR'N (NSWC 17)

WEIGHT LOSS:-0.31g

Fig.11. Ram load variation with time for sample NSWC 17

Table 1

ORDER OF HARDNESS:-ARMY BATCH OF SAMPLES

	SAMPLE	BREAK-IN LOAD (lb)	
1.	A7-MOCA	13.0	(softest)
2.	F-242	19.5	
3.	LD.4827-5E	30.5	
4.	A8-MOCA	32.5	
5.	15OTR15	34.3	
6.	15NAT57	35.3	
7.	MB2680	42.5	
8.	15NAT1	53.0	
9.	AM.CYAN.8568	57.5	
10.	15NSP33	58.8	
11.	15SBR26	60.8	
12.	0001AG	61.5	
13.	MB-2690	63.3	
14.	15NAT22A	64.2	
15.	0001AD	67.5	
16.	0001AL	75.0	
17.	15TP14AX	81.5	
18.	LD.4869-33A	83.1	
19.	15NAT60	86.1	
20.	CAYTUR21	87.2	
21.	15NSP2A	87.5	
22.	15TPU	90.5	
23.	0001AC	99.6	
24.	15NSP34	103.5	
25.	CAYTUR31	106.0	
26.	0001AK	107.9	
27.	0001AF	108.3	
28.	STEIN.M.L83	108.4	
29.	15TPT	109.7	
30.	RTC.2000	110.7	
31.	1080-MOCA	112.7	
32.	0001AH	117.6	
33.	0001AA	118.5	
34.	LD.4827-5C	123.8	
35.	WR	135.1	
36.	CYAN.84-200	145.5	
37.	AK20	147.0	
38.	SPONGE.A.MOCA	155.6	
39.	15TPS	161.0	
40.	LD.4655-66	168.0	
41.	XPE20	171.0	
42.	XPE30	188.4	
43.	LD.4718-53	204.0	
44.	LD.4718-22	207.6	
45.	LD.4827-5B	211.5	
46.	XPE10	229.4	
47.	LD.EP4933-75	234.9	
48.	LD.4608-62	278.6	
49.	LD.4608-60	288.0	(hardest)

<u>Table 2</u>

RESULTS:-LOAD DEPRECIATION (ARMY BATCH) LINEAR 1 MODE

	SAMPLE NAME	INITIAL LOAD POUNDS	FINAL LOAD POUNDS	DEP. POUNDS	DEP. %
1.	MB-2690	38.0	39.3	-1.3	*
2.	A7-MOCA	11.0	12.0	-1.0	*
3.	F-242	16.0	17.0	-1.0	*
4.	A8-MOCA	18.6	18.3	0.3	1.60
5.	AM.CYAN.8569	31.9	28.5	3.4	10.66
6.	XPE30	105.7	94.0	11.7	11.07
7.	CATUR31	61.5	54.2	7.3	11.95
8.	15SBR26	41.9	36.0	5.9	14.18
9.	15NAT1	34.5	28.5	6.0	17.39
10.	000AL	45.6	35.5	10.1	22.15
11.	XPE20	107.3	82.5	21.2	23.11
12.	15OTR15	26.7	20.0	6.7	25.23
13.	1080-MOCA	32.2	23.3	8.9	27.60
14.	0001AG	32.0	22.8	9.2	28.75
15.	SPONGE.A.MOCA	72.0	51.0	21.0	29.20
16.	LD.EP4933-75	81.0	57.0	24.0	29.63
17.	LD.4718-53	86.7	59.3	27.4	31.66
18.	15NAT60	58.5	39.3	19.2	32.80
19.	15NSP34	66.0	44.0	22.0	33.33
20.	0001AH	76.5	51.0	25.5	33.33
21.	15TP14AX	51.4	33.8	17.6	34.24
22.	15NAT57	26.3	17.3	9.0	34.29
23.	15TPU	62.8	40.5	22.3	35.46
24.	MB-2680	31.3	31.0	11.2	35.78
25.	0001AK	55.8	35.5	20.3	36.38
26.	0001AD	47.2	30.0	17.2	36.44
27.	LD.4608-62	106.2	67.5	38.7	36.44
28.	LD.4608-60	94.8	58.5	36.3	38.29
29.	AK20	73.3	45.0	28.3	38.61
30.	0001AA	64.9	39.5	25.4	39.14
31.	RTC.2000	22.5	13.5	9.0	40.00
32.	15NSP2A	57.9	34.3	23.6	40.76
33.	0001AC	60.6	35.6	25.0	41.23
34.	LD.4689-33A	36.8	21.0	15.8	42.94
35.	LD.4655-66	88.3	49.5	38.8	43.94
36.	15NAT22A	45.4	25.0	20.4	44.93
37.	15TPS	66.0	36.3	29.7	45.00
38.	LD.4718-22	83.8	46.0	37.8	45.11
39.	0001AF	60.4	33.0	27.4	45.36
40.	STEIN.M.L-83	59.4	32.4	27.0	45.45
41.	LD.4827-5B	53.0	28.5	24.5	46.23
42.	15TPT	59.0	31.0	28.0	47.46
43.	LD.4827-5C	59.8	31.0	28.8	48.16
44.	0001AC	61.7	31.8	29.9	48.54
45.	CYAN.84-200	88.0	45.0	43.0	48.86
46.	CAYTUR21	51.9	26.0	25.9	49.90
47.	WR	89.8	42.6	47.2	52.52
48.	XPE10	146.6	51.2	95.4	65.08

* *no positive deterioration.*

Table 3

WEIGHT LOSS (ARMY SAMPLES) IN LINEAR 1 MODE

SAMPLE NAME	INITIAL MASS GRAMMES	FINAL MASS GRAMMES	LOSS GRAMMES
1. F 242	69.97	69.97	0.00
2. A8 MOCA	73.93	73.93	0.00
3. AM CYAN 8569	74.67	74.67	0.00
4. MB 2690	68.93	68.92	0.01
5. 15 TP14 AX	62.50	62.47	0.03
6. 15 SBR 26	61.50	61.46	0.04
7. 0001AD	70.83	70.70	0.04
8. 0001AL	67.93	67.89	0.04
9. LD 4655 66	64.28	64.23	0.05
10. 15 NAT 57	52.77	52.71	0.06
11. 15 NAT 22A	68.52	68.45	0.07
12. 0001AK	70.37	70.30	0.07
13. LD 4827 5B	66.11	66.04	0.07
14. 15 NSP 2A	73.37	73.29	0.08
15. 15 TPT	70.31	70.23	0.08
16. 15 OTR 15	65.34	65.25	0.09
17. 0001AA	74.42	74.33	0.09
18. 15 TPU	70.24	70.15	0.09
19. 15 NAT 1	65.36	65.26	0.10
20. CAYTUR 31	64.41	62.31	0.10
21. 15 NSP 34	73.19	73.09	0.10
22. WR	81.24	81.14	0.10
23. 15 TPS	70.74	70.63	0.11
24. XPE20	65.57	65.46	0.11
25. 0001AC	76.02	75.91	0.11
26. LD EP4933 75	66.71	66.59	0.12
27. CAYTUR 21	62.99	62.87	0.12
28. 15 NSP 33	69.46	69.34	0.12
29. LD 4718 53	64.13	64.00	0.13
30. 0001AG	71.60	71.46	0.14
31. 0001AF	76.35	76.21	0.14
32. 0001AH	74.94	74.79	0.15
33. 15 NAT 60	65.52	65.37	0.15
34. MB 2680	64.32	64.16	0.16
35. CYAN 84 200	64.34	64.17	0.17
36. STEIN L83	63.72	63.55	0.17
37. XPE30	64.98	64.78	0.20
38. LD 4827 5D	64.90	64.70	0.20
39. 80 5 MOCA	63.60	63.39	0.21
40. AK20	64.04	63.84	0.22
41. LD 4608 62	67.79	67.56	0.23
42. LD 4827 5C	63.41	63.17	0.24
43. XPE10	63.95	63.71	0.24
44. LD 4718 22	72.09	71.84	0.25
45. A7 MOCA	81.22	80.93	0.29
46. LD 4689 33A	65.74	65.43	0.31
47. LD 4608 60	67.04	66.71	0.33
48. LD 4827 5E	64.89	64.55	0.34
49. 1080 MOCA	62.95	62.58	0.37
50. RTC 2000	57.13	56.75	0.38
51. A.MOCA	75.20	74.77	0.43

Table 4

RESULTS FOR ARMY SAMPLES LINEAR 2 MODE

SAMPLE	WEIGHT LOSS (g)	LOAD DEPRECIATION (%)	
MB 2590	0.01	0	
15 NSP 34	0.04	16	
15 NAT 57	0.05	15.3	
15 NSP 2A	0.05	15.4	
15 OTR 15	0.06	1.1	
15 NAT 60	0.06	14.8	
15 SBR 26	0.07	10.3	
0001AL	0.07	14.7	
15 NAT 25A	0.07	21.2	
F 242	0.08	-21.7	*
PL 1500	0.08	24.4	
0001AD	0.09	14.6	
15 TPU	0.09	19.1	
WR 1	0.09	21	
0001AL	0.10	12.7	
15 NSP 33	0.10	16.9	
0001AK	0.10	17.9	
PL 1000	0.10	19.2	
15 NAT 1	0.10	22	
0001AC	0.11	10	
15 TP14 AX	0.11	15.3	
15 TPT	0.11	20.9	
15 TPS	0.11	31.8	
15 NAT 22A	0.12	22.4	
0001AF	0.13	13.1	
0001AG	0.13	19.7	
LD 4718 53	0.14	20.5	
0001AA	0.16	25.9	
CAYTUR 21	0.17	17.3	
LD 4608 60	0.17	14.6	
A8 MOCA	0.18	- 3.7	*
EP 4933 75	0.19	13.2	
LD 4608 62	0.19	14.6	
8569	0.23	- 1.5	*
0001AH	0.28	48	
A.MOCA	0.28	52.9	
LD 4655 66	0.29	25	
PL 2000	0.29	37.9	
LD 4827 5C	0.30	26.8	
LD 4718 22	0.31	17.9	
CAYTUR 31	0.34	26.2	
80 5 MOCA	0.34	43.8	
STEIN L83	0.37	19.2	
XPE 10	0.42	10	
AK20	0.44	20.9	
XPE20	0.47	26.3	
XPE30	0.53	9.3	
LD 4689 33A	0.53	32.8	
RTC 2000	0.53	45.1	
A7 MOCA	0.54	14.9	
CYAN 84 200	0.59	81.2	
LD 4827 5E	0.63	57.1	
MB 2680	0.63	41.7	
1080 MOCA	0.69	47.3	

* NO POSITIVE DETERIORATION

Table 5

RESULTS SHOWING SAMPLES ORDERED IN TERMS OF LOAD DEPRECIATION FOR LINEAR 2 MODE

SAMPLE	DEPRECIATION (%)
1. F 242	- 21.7
2. A8 MOCA	- 3.7
3. 6569	- 1.5
4. MB 2690	0
5. 15 OTR 15	1.1
6. XPE30	9.3
7. 0001AC	10
8. XPE10	10
9. 15 SBR 26	10.3
10. 0001AL	12.7
11. 0001AF	13.1
12. EP 4933 75	13.2
13. 0001AD	14.6
14. LD 4608 60	14.6
15. LD 4608 62	14.6
16. 0001AL	14.7
17. 15 NAT 60	14.8
18. A7 MOCA	14.9
19. 15 NAT 57	15.3
20. 15 TP14 AX	15.3
21. 15 NSP 2A	15.4
22. 15 NSP 34	16
23. 15 NSP 33	16.9
24. CAYTUR 21	17.3
25. 0001AK	17.9
26. LD 4718 22	17.9
27. 15 TPU	19.1
28. PL 1000	19.2
29. STEIN L83	19.2
30. 0001AG	19.7
31. LD 4718 53	20.5
32. 15 TPT	20.9
33. AK20	20.9
34. WR 1	21
35. 15 NAT 25A	21.2
36. 15 NAT 1	22
37. 15 NAT 22A	22.4
38. PL 1500	24.4
39. LD 4655 66	25
40. 0001AA	25.9
41. CAYTUR 31	26.2
42. XPE20	26.3
43. LD 4D27 5C	26.8
44. 15 TPS	31.8
45. LD 4689 33A	32.8
46. PL 2000	37.9
47. MB 2680	41.7
48. 85 5 MOCA	43.8
49. RTC 2000	45.1
50. 1080 MOCA	47.3
51. 0001AH	48
52. A.MOCA	52.9
53. LD 4827 5E	57.1
54. CYAN 84 200	81.2

U.S. NAVY SAMPLES

TABLE 6. ETM LINEAR 2 MODE RESULTS (333K)

	NBR-12	TP-14AY	89EV110	58R74	37721C	POLYURETHANE
DEP.(%)	.35.0	18.0	36.0	15.0	5.4	45.6
WEIGHT LOSS (g)	0.10	0.11	0.24	0.06	0.05	0.36
HARDNESS (lbs)	65.0	55.0	103.0	63.0	45.0	35.0
DENSITY (293K)	1.13	1.15	1.13	1.15	1.13	1.10

TABLE 7. ETM LINEAR 1 MODE RESULTS (333K)

	NBR-12	TP-14AY	89EV110	58R74	37721C	POLYURETHANE
DEP.(%)	16.3	2.7	48.7	32.1	25.7	69.7
WEIGHT LOSS (g)	0.04	0.08	0.04	0.08	0.04	0.23

TABLE 8. ETM ROTATIONAL MODE RESULTS (333K)

	NBR-12	TP-14AY	89EV110	58R74	37721C	POLYURETHANE
DEP.(%)	51.4	17.6	81.5	34.1	23.1	89.0
WEIGHT LOSS (g)	0.14	0.08	0.07	0.02	0.03	0.31

TABLE 9. LINEAR MODE EROSION RESULTS (333K)

Sample	Failure Mode	Rating
37721C	Debris displacement after 2.5 minutes. Fine black particles. Light damage area. Damage zone 22mmx4.5mm.	Good
58R74	Scraping of surface leading to material loss after 30 seconds. Similar wear texture to 37721C. Damage zone 22mmx4.4mm.	Good
15TP-14AX	Little material lost. High resilience. Low damage. Smooth wear track 21mmx4mm.	Good
NBR-12	Chips of debris lost. Tear flaps visible. Some debris adhesion.Damage zone 18mmx5mm.	Fair
89EV110	Small chunks of debris with adhesion. Damage zone 17mmx6mm.	Fair
NSWC 17	Immediate danmage. large chips of transluscent debris. Deep trough cut by tool. Damage area 26mmx5.5mm.	Poor

U.S. NAVY SAMPLES

TABLE 10. ROTATIONAL MODE RESULTS (333K)

Sample	Failure Mode	Rating
37721C	Shallow circular track surrounding central plug. minimum amount of material loss.	Good
58R74	Circular track as for 37721C. Fine particles of material lost.	Good
15TP-14AX	Spiral cuts in the circular groove around small plug.	Good
NBR-12	Stringy black debris. Familiar wear pattern with raised central plug.	Fair
89EV110	Small pieces of material removed. More notable damage than other black rubber samples.	Fair
NSWC 17	Immediate damage onset. Jelly-like pieces of debris. Large hole excavated. central projection completely removed.	Poor