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EVALUATION OF SRM FLEX BEARING MATERIALS AND PROCESSES

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EVALUATION OF SRM FLEX BEARING MATERIALS AND PROCESSES

I. INTRODUCTION

As a result of the large number of failures at Thiokol in fabricating a full scale flex bearing, an in-house effort encompassing a materials program, a tooling evaluation, and a process analysis was established. A list of nine problem areas of concern was prepared, and Materials and Processes Laboratory personnel with expertise applicable to the SRM flex bearing established the priority of each problem area. Three of the nine areas of concern were given a high priority. A materials, mold design, and temperature controls study was undertaken in an effort to resolve the failure modes occurring in the fabrication of the flex bearing.

II. HARDWARE DESCRIPTION

The SRM flex bearing is a large (~ 7000 lb) complicated structure. It consists of 12 metal pieces and 11 rubber pads, cured and bonded together at one time. The metal shims and end rings are primed and then coated with two more adhesive materials. Presently, Chemlok 205 is the primer, and Chemlok 220 and 2658 tycement are the two adhesives.

The purpose of this bearing is to function as a universal joint which allows the motor nozzle to swivel in any direction to achieve thrust control. The movement is attained by stretching the 11 rubber pads between the metal shims and the two end ring structures.

The complexity of this bearing is further indicated by a unique series of functional requirements which require a very soft natural rubber with special requirements of modulus, torque load, bondability in a large assembly and stability with time.

The special rubber physical properties were obtained by using a relatively incompatible liquid diluent to acquire the necessary softness and low modulus.

III. APPROACH

It was desirable to simulate the various types of loading seen in fabricating and curing the SRM flex bearing. To assess these conditions, specimens were prepared to obtain tensile, shear, peel, elongation, modulus, and shrinkage characteristics. Initial materials including primers, adhesives, tycements, and rubber stock were obtained from Thiokol to begin this investigation. Additionally similar materials were obtained from other sources, along with in-house compounded tycements and rubber stocks.

Test specimens were prepared using several combinations of primer, adhesive, tycement and rubber stock cured under various time and temperature conditions.

IV. TEST PROCEDURES AND EXPERIMENTAL DATA

A. TENSILE SPECIMENS

The tensile specimens consisted of a 0.300 in. thick rubber disc vulcanized between two 0.75 by 2 in. steel discs. All tensile tests were made on an Instron test machine with certified load cells. The specimens were installed and pulled at a constant speed of 5 in./min.

1. Typical Tensile Specimens. Eleven specimens prepared side by side using Chemlok 205, Chemlok 220, tycement 2658 and TR 3005 rubber stock were cured at 300°F for 1 hr. These data presented in Table 1 show the typical strength spread obtained using these bonding materials.

TABLE 1. TYPICAL DISC SPECIMENS

Specimen No.	Strength (psi)
1.	146
2.	338
3.	129
4.	280
5.	304
6.	221
7.	121
8.	229
9.	202
10.	360
11.	231
Average	234

2. Effect of Tycement Thickness. A series of tensile specimens was prepared by increasing the tycement thickness. Two tycements 2658 (Hycar-incorporated diluent) and 2827 tycement (No Hycar) were evaluated in this thickness study. The data presented in Table 2 indicate that tycement thickness is critical, with six coats (3-4 mils) being near the optimum.

TABLE 2. EFFECT OF TYCEMENT THICKNESS

	Tycement With Hycar		Tycement Without Hycar	
	Strength (psi)	Cohesive Failure (%)	Strength (psi)[a]	Cohesive Failure (%)
1 Coat	244	-	273	-
2 Coats	220	78	272	98
4 Coats	311	95	482	-
6 Coats	467	98	600	96
8 Coats	393	99	472	97

a. Average of 3 specimens.

3. Effect of Time at Temperature. A set of seven specimens was press cured at 300°F and individual samples were withdrawn for testing at 30-min intervals. The data collected for the time study are presented in Table 3. No discernable trend is evident over this time span.

TABLE 3. EFFECT OF TIME AT TEMPERATURE

Time (Min)	Strength (psi)
30	506
60	152
90	487
120	240
150	321
180	221
210	415

4. Effect of Temperature on Cured Tycement-Chemlok Adhesion. Seven tensile specimens were prepared using Chemlok 205, Chemlok 220, tycement 2827 plus a 0.20 in. thick disc of tycement gum and TR 3005 rubber stock. The data obtained in this study are presented in Table 4 and show strength decreased as the temperature increased.

TABLE 4. EFFECT OF TEMPERATURE ON TYCEMENT-CHEMLOK ADHESION

Temperature (°F)	Strength (psi)
RT	422
200	241
225	234
250	208
275	171
300	155

5. Intentional Contamination. Tensile test specimens were prepared with various kinds of contaminants in an attempt to create voids and/or debonds in the process of bonding rubber to metal. The type of contaminants do not drastically affect the bond strength in this particular case.

TABLE 5. INTENTIONAL CONTAMINATION

Adhesive - Chemlok 205/233 Tycement - 2827	
Sample	Strength (psi)
(1) Control	191
(2) Dirty Hands	125
(3) Dust	236
(4) Uncured Silicone	181
Adhesive - Chemlok 205/220 Tycement - 2658	
Sample	Strength (psi)
(1) Control	210
(2) Dirty Hands	135
(3) Dust	232
(4) Uncured Silicone	281

TABLE 5. (Concluded)

Adhesive Chemlok 205/223 No Tyeement					
Sample	Surface	Strength (psi)	Elongation	Location of Failure	Cohesive Failure (%)
1A	Clean	190	1.52	A	95
1B	Clean				
2A	Clean	124	1.37	A	90
2B	Dirty Hands				
3A	Clean	235	1.68	A	97
3B	Shop Dust				
4A	Clean	181	1.55	B	95
4B	Uncured Silicone				

Adhesive Chemlok 205/220 5% Silicone Added to Rubber	
Sample	Strength (psi)
Control	229
Silicone	189

6. Loads Due to Shrinkage. A 2 in. disc specimen was cured for 60 min at 300°F. While this sample was still hot and inside the mold cavity, it was connected to an Instron Load Cell. Time, temperature, and load were recorded every 5 min from 300°F to 75° for 4 hr. A "delta" load of 81 lb resulted during cooldown of this sample, as shown in Table 6.

In the first four temperature readings, the stainless steel hookup rods were absorbing heat and were expanding causing a load loss which would have resulted in higher load reading if this problem were minimized or eliminated.

Two larger samples of the configuration originally designed to simulate a shim and rubber bond were tested to get a larger test piece. These are identified as "Old" and "New" samples. The old sample was cured about 3 years ago. It was installed in a hot air oven preheated to 150°C, stabilized 30 min at temperature, and connected to an Instron test machine.

TABLE 6. SHRINKAGE TEST OLD SAMPLE

Time (min)	Temperature (°C)	Load (lb)
0	133	2
30	88	26
60	63	51
90	49	63
120	40	72
150	35	76.5
240	28	81
	New Sample	
0	0	150
60	170	98
120	171	82
180	174	70
240	170	65
300	165	60
360	165	56
	2 In. Disc	
30	88	26
60	63	51
90	49	62.5
120	40	71.5
150	35	76.5

Over a 5 hr period, a total load of only 5 lb resulted during cooldown. It was apparent from this very small load that these results were not consistent with the previous 2 in. disc sample. We cleaned this sample, cured a new rubber sample 60 min at 300°F, and hooked it up to the load cell as fast as possible. The hot air oven was already at 300°F, and the sample was allowed to return to this temperature. The data collected for these shrinkage specimens are presented in Table 6. It is evident that cooling in the mold adds stress to the rubber bond line.

B. RUBBER SHRINKAGE

To determine if the rubber was separating due to shrinkage during mold cooldown, five samples of SRM flex bearing rubber were molded and cured, and measured by the Reliability and Quality Assurance Office personnel. The mold dimensions were 0.755 by 0.659 by 8.566 in. The shrinkage was not uniform in all directions. The sample shrank an average of 2.32 percent in length, 2.89 percent in width and 2.62 percent in height. The shrinkage values for each sample are as follows:

Rubber Sample No.	Width (%)	Height (%)	Length (%)
1	2.33	1.52	2.50
2	3.34	3.13	2.22
3	3.20	2.81	2.18
4	3.20	2.81	2.40
5	2.40	2.81	2.29

These samples were made in a mold coated with mold release so that the samples were free to change dimensions in any direction. In a second series of tests, an 11 by 0.309 in. molded disc was heat cured and cooled under a simulated time/temperature flex bearing cure cycle. The 11 in. specimen cure cycle is illustrated in Figure 1. The resultant volume shrinkage was 5.3 percent. A second 11 by 0.309 in. disc was molded and bonded to all surfaces of the mold. After cooling, the assembly was subjected to nondestructive evaluation. Using x-ray and acoustical techniques, no debond or non-bond could be detected. The mold was then cut into eight pie shaped segments. Except for one very small area ($\sim$ 2 cm^2), the rubber was tenaciously bonded to all surfaces of the mold in spite of the 5.37 percent volume shrinkage. This failure mode was lack of bond to one surface. The two plates, when torn apart, had part of the rubber bonded to each half. The visual appearance of the very small debond zone was very similar to the type of debond failure observed on the shim of flex bearing No. 9. The debond apparently occurred between the tycement and the Chemlok 220 adhesive. As a result of these tests, it can be stated that an adequate rubber to steel bond has enough internal volumetric "stretch" to easily withstand the 5.37 percent shrinkage experienced during the cool-down cycle.

C. PEEL SPECIMENS

The peel specimens are machined 2 by 4 by 1/4 in. steel plates with 8 by 1-1/2 in. rubber strip vulcanized to one side. All peel testing was made on an Instron test machine with certified load cells. The specimens were installed at a 30 degree angle and pulled at a constant speed of 0.2 in./min.

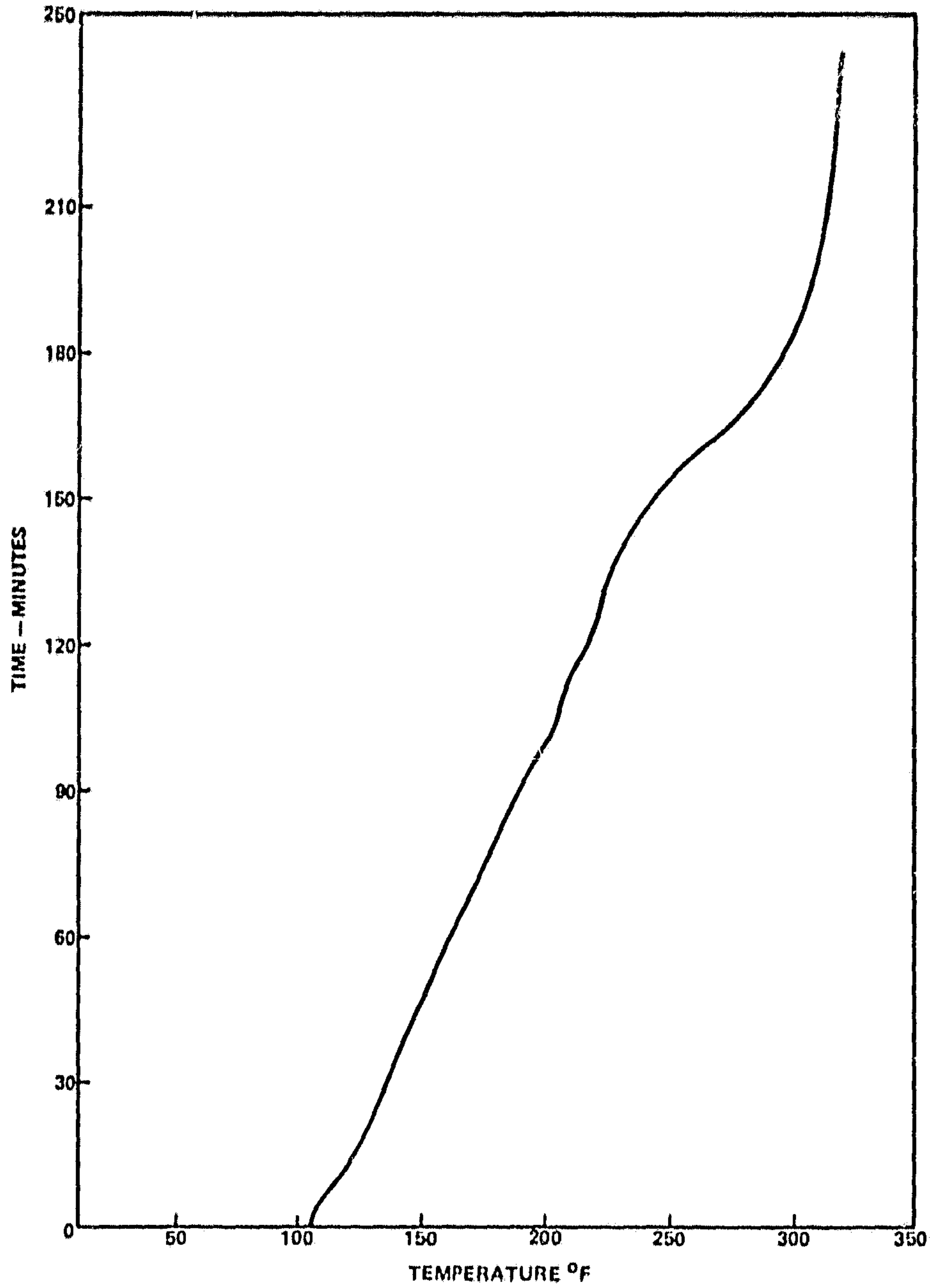

Figure 1. Eleven inch specimen cure cycle.

Typical test specimens with various combinations of primers, adhesives, tycements, and rubber stocks are presented in Table 7. Four sets of peel specimens were prepared using two tycements prepared in-house and two furnished by Thiokol to determine any differences in peel strength from the two sources of materials.

TABLE 7. IN HOUSE VERSUS THIOKOL TYCEMENTS

	In-House		Thiokol	
	2658 (psi)	2827	2658 (psi)	2827
	34	35	38	32
	34	36	34	36
	49	31	34	35
	46	32	36	35
	28	37	34	33
Avg.	38	34	35	34

D. PRIMER AND ADHESIVE THICKNESS SPECIMENS

The specimen substrates were 2 by 4 by 1/16 in. 1010 steel plates. Coating thickness measurements were made using a General Electric, Type B and Gardo Dry Film thickness gages. The gages were adjusted with plastic and brass shims to give readings of 1, 2, 3, and 5 mils on a 1010 steel blank, then a 2 mil brass shim was placed over the tacky tycement coating and the readings are as shown in Table 8. A third type thickness gage, a Permascope by Twin City Corporation, was also used in measuring the adhesive system thickness.

V. RESULTS AND DISCUSSION

The tensile testing resulted in a range at room temperature of values from 125 to 400 psi (Table 9). The failures typically observed were occurring at the adhesion, tycement and rubber stock interfaces. A 2 in. disc tensile specimen was cured and immediately installed hot in the Instron tester while still mounted in the mold. The shrinkage-generated load during cooldown was measured at 81 lb. No evidence of damage was observed, and the specimen pulled to failure in excess of 302 psi.

The intentionally "contaminated" tensile specimens yield similar strength data to that obtained from clean, "uncontaminated" specimens.

TABLE 8. THICKNESS MEASUREMENTS

Specimen No.	205	220	Tycement	G.E.	Gardo	Permascope
1	1			0.2	0.25	
2	1	1		0.3	0.5	
3	1	2		0.85	0.85	
4	1	2	2	1.5	1.75	
5	1	2	2	1.5	1.75	
6			1	0.5	0.50	
7	2					1.10
8		2				1.27
9	1					0.60
10			1			0.60
11		1				0.47
12			2			0.32
13	1	1	1			1.18
14	1	1	1			1.02
15	2	1	1			1.42
16	1	2	1			1.70
17	1	1	1			1.00
18	1	1	2			1.32
19	1	2	2	1.5	1.75	
20			2	0.75	0.80	
21			3	1.60	1.50	
22			4	2.50	2.20	
23			5	3.00	3.00	
24			6	3.50	4.30	
25			8	6.50	7.50	

TABLE 9. TYPICAL PEEL

No.	Primer	Adhesive	Tycement	Rubber	Cure Time (min)	Temperature (°F)	Ultimate Load (lb)	Failure Mode	Remarks
1	205	220	No. 2	A625N	30	305	30	Tycement	100 percent
2	205	220	No. 2	A625N	30	305	28	Tycement	100 percent
3	205	220	No. 2	A625N	60	305	26	Tycement	100 percent
4	205	220	No. 2	A625N	60	305	25	Tycement	100 percent
1J	205	220	2658	A625N	30	305	26	Cohesive	5 percent
2J	205	220	2658	A625N	30	305	23	Cohesive	7 percent
3J	205	220	2658	A625N	60	305	33	Cohesive	80 percent
4J	205	220	2658	A625N	60	305	31	Cohesive	70 percent
5J	205	220	2658	A625N	120	305	36	Cohesive	70 percent
6J	205	220	2658	A625N	120	305	36	Cohesive	80 percent
1	205	220	2658	A625N	60	305	40	Cohesive	90 percent Stock rubber failed
2	205	220	2658	A625N	60	305	44	Cohesive	100 percent Stock rubber failed
3	205	220	2658	A625N	60	305	37	Cohesive	100 percent 1/2 to 1/8 peel 1, 2, 3, 4
4	205	220	2658	A625N	60	305	44	Cohesive	70 percent
5	205	220	2658	A625N	60	305	35	Cohesive	No peel stock failed
1A	205	220	2658	3005	30	300	28		
2A	205	220	2658	3005	60	300	32		
1B	205	220	2658	3005	30	310	33	Rubber	1/8 in. peel with clean break
2B	205	220	2658	3005	60	310	33	Rubber	1/8 in. peel with clean break
3B	205	220	2658	3005	120	310	35	Rubber	1/8 in. peel with clean break
1C	205	220	No. 2	3005	60	300	24	Peel	Tycement on Rubber and 220
2C	205	220	No. 2	3005	60	300	27	Peel	Tycement on Rubber and 220
3C	205	220	No. 2	3005	60	300	24	Peel	Tycement on Rubber and 220

TABLE 9. (Continued)

No.	Primer	Adhesive	Tycement	Rubber	Cure Time (min)	Temperature (°F)	Ultimate Load (lb)	Failure Mode	Remarks
4C	205	220	No. 2	3005	60	300	24	Peel	Tycement on rubber and 220
1D	205	220	2658	Tygum 2827	30	300	26	Peel	Rubber smooth
2D	205	220	2658	Tygum 2827	60	300	32	Peel	Rubber smooth
3D	205	220	2658	Tygum 2827	120	300	30	Peel	Rubber smooth
1E	205	220	No. 2	Tygum 2827	60	300	34	Rubber	1 2 in. tycement separation
2E	205	220	No. 2	Tygum 2827	60	300	32	Rubber	1 2 in. tycement separation
3E	205	220	No. 2	Tygum 2827	60	300	37	Rubber	1 2 in. tycement separation
1F	205	220	2658	Tygum 2827	30	300	36	Rubber	1 in. peel before failure
1G	205	220	None	A625N	30	305	11	Unzip	Smooth 220
2G	205	220	None	A625N	30	305	11	Unzip	Smooth 220
3G	205	220	None	A625N	60	305	12	Unzip	Smooth 220
4G	205	220	None	A625N	60	305	12	Unzip	Smooth 220
5G	205	220	None	A625N	120	305	12	Unzip	Smooth 220
6G	205	220	None	A625N	120	305	11	Unzip	Smooth 220
1H	205	220	2827	A625N	30	305	34	25%	Specimen peel on test
2H	205	220	2827	A625N	30	305	28	7% Cohesive	Terminated at 2 in.
3H	205	220	2827	A625N	60	305	28	10% Cohesive	Terminated at 2 in.
4H	205	220	2827	A625N	60	305	29	10% Cohesive	Terminated at 2 in.

TABLE 9. (Concluded)

No.	Primer	Adhesive	Tycement	Rubber	Cure Time (min)	Temperature (°F)	Ultimate Load (lb)	Failure Mode	Remarks
5H	205	220	2827	A625N	120	305	34	20% Cohesive	Terminated at 2 in.
6H	205	220	2827	A625N	120	305	28	10% Cohesive	Terminated at 2 in.
1	205	220	No. 2	A625N	60	305	23	Tycement	Peel 1/2 in. rubber failed
2	205	220	No. 2	A625N	60	305	30	Tycement	Peel 1/2 in. rubber failed
3	205	220	No. 2	A625N	60	305	31	Rubber	Failed no peel
4	205	220	No. 2	A625N	60	305	28	Tycement	Peel 1/2 in. rubber failed
5	205	220	No. 2	A625N	60	305	31	Tycement	Peel 1/2 in. rubber failed

Peel testing was considered more representive of the conditions seen in the fabrication of the SRM flex bearing. Peel testing resulted in strengths between 20 to 40 psi at 30 degree peel. One set of peel specimens was cured by introducing heat from one side only. Half the specimens were cured from the metal side and half with the heat from the rubber side. There were no observed differences between these specimens and specimens cured by normal procedures.

Using an in-house technique for measuring Poisson's Ratio, n, a measurement of the n of TR 3005 stock was 0.462. In the same test, the tensile modulus in the 0 to 6 percent elongation range was 390 psi. Using these values, the stress at the bond line of a totally enclosed and fully bonded specimen was calculated to be 26.7 psi.

The shrinkage specimens showed that shrinkage was not uniform. The average values found were 2.32 percent in length, 2.89 percent in width, and 2.62 percent in height. Loads obtained due to shrinkage on the 11 in. specimen were measured at up to 175 lb.

In handling the cured 11 in. diameter specimens the exposed part of the cemented mold surface was observed to be tacky and appeared to be reverted. Subsequent testing of compatibility of the Chemlok 220 and tycement combinations showed that:

1) Tycement in contact with Chemlok 220 and exposed to 300°F in air reverts after several hours exposure.

2) Tycement not in contact with Chemlok 220 and given the same exposure cures without reversion.

3) Tycement in contact with Chemlok 220 and exposed to 300°F for 6 hr in the absence of air does not revert.

Thickness measurements were made using three types of thickness gages. Coated specimens (2 by 4 by 1/16-in. steel plates) were averaged at top, middle, and bottom. Each specimen was measured three times and shuffled after each reading to determine if a reproducible reading was obtained. Measurements on the G. E. and Gardo gages gave similar and reproducible results.

Fillers were removed from samples of Chemlok 205 and 220 with a high speed centrifuge. Using Gel Permeation Chromatographic methods, the materials were found to contain two high and one low molecular weight components. These three components were isolated and submitted for chemical analysis. Infrared analysis revealed mixtures rather than pure compounds.

VI. CONCLUSIONS

The tensile and peel test specimens consisting of Chemlok 205, 220 and tycement cured for 1 hr at 300°F gave a wide range of data; but all were well above the strength required for bonding a usable SRM flex bearing. There was no significant difference found in using three tycements prepared in-house and two furnished by Thiokol.

From data collected, there are indications of incompatibility between Chemlok 220 and tycements. Varying the time at temperature during cure shows no adverse trends from data obtained from the normal cure cycle.

There is no adhesion obtained between rubber stock and Chemlok 220 without a tycement coat. At least 1 mil of tycement is essential in obtaining a good bond line.

The G.E. and Gardo thickness gages give accurate measurements of the uncured adhesive system thickness and either should be adequate as an inprocess control tool.

Rubber shrinkage during mold cooling adds stress to the rubber bond line; but not enough to cause concern of debonding in the flex bearing.

An indepth mold design study by the MSFC tooling experts revealed no tool redesign necessary at this time. However, several recommendations have been made to create a more uniform temperature distribution throughout the mold.

Data collected from the Thixon adhesive systems study indicates that satisfactory bonds are obtained, but no clear advantage over the Chemlok 205/220 adhesive system is apparent.

APPROVAL

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By Thomas E. Wood

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or nuclear energy programs or activities has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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