Document Type: TWR
Document No: TWR-19666
Document Rev: -
Change No: 000
Work Order: N/A

SPACE SHUTTLE
Solid Rocket Motors
Thiokol Corporation

FINAL REPORT FOR ETP-0492, MEASURED RESIDUAL STRESSES IN CYL S/N 53 FRETTED AREA

IN-39-CR
118222

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

Contract No.	NAS8-38100
DR No.	5-3
WBS. No.	4C205
ECS No.	00010932
ECP No.	

THIOKOL

P. O. Box 707, Brigham City, UT 84302-0707 (801) 863-3511

ABSTRACT

This test report presents the results of a residual stress survey of the inner clevis leg of lightweight cylinder S/N 053 as described by ETP-0492. The intent of this testing was to evaluate the residual stresses that occur in and around the fretting damage to the inner clevis leg at the capture feature contact zone during a normal flight cycle. Lightweight case cylinder segment 1U50717, S/N L053 from Flight STS-27 exhibited fretting around the circumferential contact zone of the inner clevis leg and the capture feature of the field joint. Post flight inspection revealed several large fretting pits on the inside of the inner clevis leg. This cylinder was assigned for both residual stress and metallurgical evaluation. This report is concerned only with the residual stress evaluations. The effects of glass bead cleaning and fretting were evaluated using the x-ray diffraction method.

Document Type:	TWR
Document No:	TWR-19666
Document Rev:	-
Change No:	000
Work Order:	N/A

SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

FINAL REPORT FOR ETP-0492, MEASURED RESIDUAL STRESSES IN CYL S/N 53 FRETTED AREA

SR&QA	Date	PREPARER	Date
Not Required		Ronald L. Webster:03681	28-OCT-1997
PM	Date	DE_SUPERVISOR	Date
Scott R. Stein:13537	17-NOV-1997	Jay V. Daines:03741	31-OCT-1997
DE	Date	DATA_MANAGEMENT	Date
Vicki B. Call:13022	03-NOV-1997	Irma Nieto:19249	18-NOV-1997

RELEASED
18-nov-1997 10:58:50

Table Of Contents

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Since the introduction of an interference fit between the new capture feature on the tang and the inner clevis leg of the field joints of the Space Shuttle Reusable Solid Rocket Motors (RSRM) there have been incidences of fretting on the contact interfaces. One of the concerns about this fretting has been the residual stress levels developed by the fretting process. Fretting occurs from the heat and abrasion induced by small relative frictional motions where there is strong contact between mating parts. The concern for the levels of residual stresses comes from considerations of stress corrosion cracking. The conditions for stress corrosion cracking to occur are a combination of the following:

1. A sustained surface tensile stress exceeding the stress corrosion susceptibility limit (about 30 ksi for a 0.100 in. deep crack in the RSRM case material).
2. A sustained corrosive environment (salt water, salt air exposure)

There is an assured exposure to a corrosion environment prior to flight during assembly, roll-out, and on-pad operations. A significant sea water exposure of the field joints occurs during recovery operations. The critical issue for stress corrosion cracking is how high the tensile stresses can be during the corrosive exposure. The fretting residual stresses are a potential means of obtaining sustained tensile stresses.

The intent of this testing was to evaluate the residual stresses that occur in and around the fretting damage to the inner clevis leg at the capture feature contact zone during a normal flight cycle.

1.1 TEST ARTICLE DESCRIPTION

The RSRM cylinder segments are fabricated from D6AC steel per STW4-2606 and heat treated according to STW7-2608. Lightweight case cylinder segment 1U50717, S/N L053 from Flight STS-27 exhibited fretting around the circumferential contact zone of the inner clevis leg and the capture feature of the field joint. Post flight inspection revealed several large fretting pits on the inside of the inner clevis leg. This cylinder was then assigned for residual stress evaluation. Two large pits were selected for evaluation. The primary one was located at approximately the 288° angular position. The other was 8° away at 280°. Figure 1 shows local details of the primary pit and identifies nine points used in the evaluation. A tenth evaluation point was located near the center of the second pit. Figure 2 shows the orientations measured.

This testing was done on the intact cylinder before any material was removed. A separate test coupon was used to evaluate the effects of glass bead blasting. This specimen was one of the typical 1 in. by 1 in. coupons excised from a scrapped case segment (not this test cylinder). A sketch of this specimen is shown in Figure 3. The residual stresses in this sample were assumed to be representative of those induced in a case surface during glass bead cleaning.

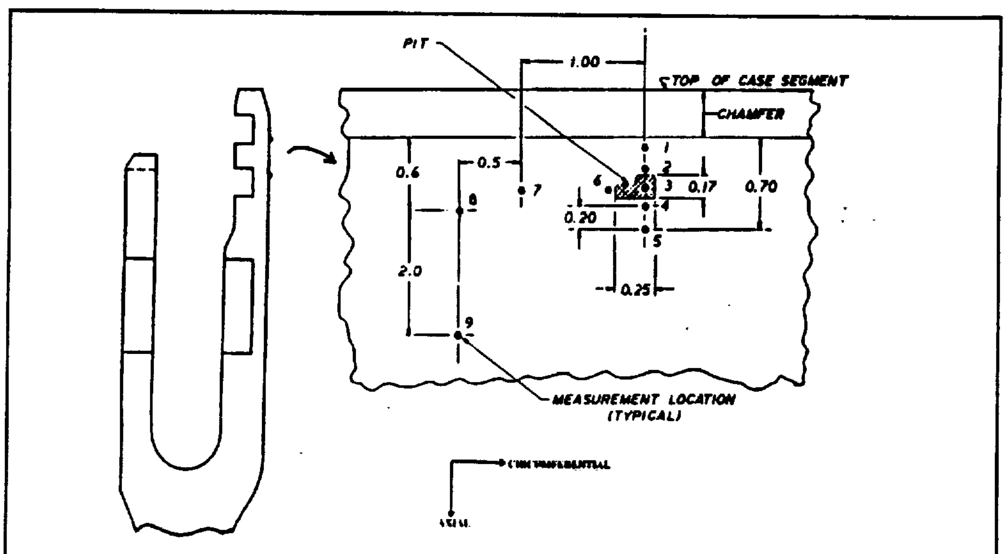

Figure 1 Layout of Primary Test Zone Showing Measurement Points

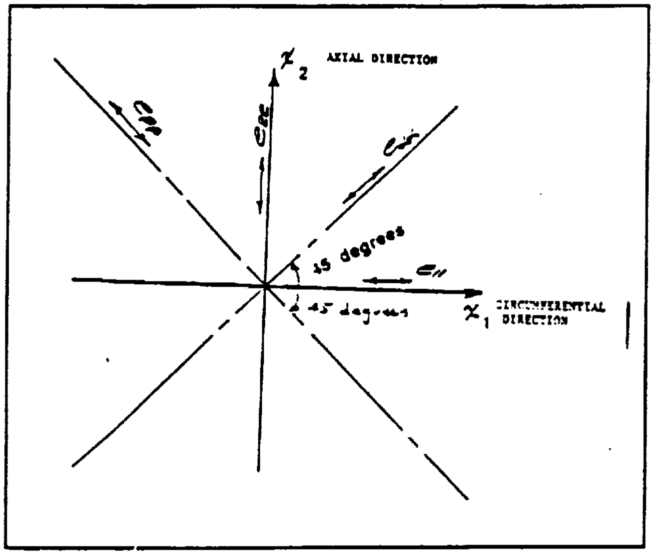

Figure 2 Planned Measurement Directions for Each Point

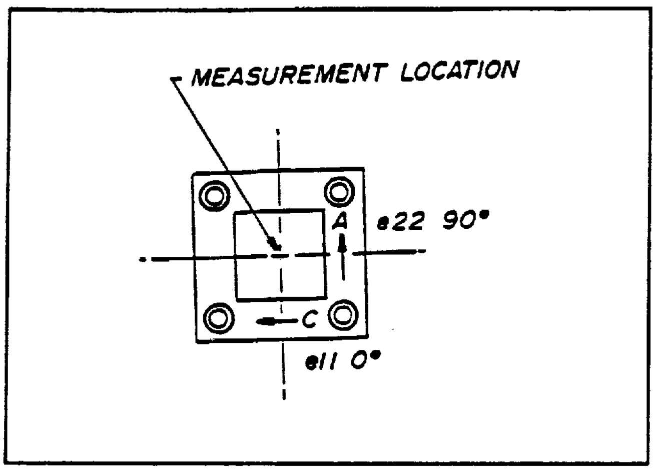

Figure 3 Sample Used to Evaluate Effects of Glass Bead Blasting

2. OBJECTIVES

The objectives of this test were to measure the residual stresses in the fretted zone of a cylinder that had been used in flight and evaluate the structural integrity issues resulting from the fretting.

3. EXECUTIVE SUMMARY

3.1 SUMMARY

All test objectives were met. There were no abnormal occurrences or adverse findings. Table 1 summarizes the results obtained.

Table 1 Summary of Test Results

	RESIDUAL STRESSES, ksi		
EVALUATION DEPTH	NOT IN FRET	PRIMARY FRET	SECONDARY FRET
surface	-128 to -153	-82 to -110	-114 to -158
5 to 25 mils	-29 to +13	-51 to +5	not evaluated

The residual stress surveys of the centers of two large pits and the region around one of them for depths of from 0 to 25 mils showed general compression on the undisturbed surface in excess of 100 ksi. This is comparable to the surface compressive residual obtained from a case sample that was subjected to glass beading.

The initial readings at the center of the two pits showed a general reduction of the compressive residual stress by as much as 40 ksi.

Residual stress readings for locations where material was successively removed by electropolishing show a dramatic drop in compressive residual at a depth of 5 mils. Small tensile residual readings were obtained at depths between 10 and 25 mils.

Only one tensile reading was obtained at the center of the two pits. That was 4.6 ± 4.3 ksi in the 0° orientation at a depth of 17 mils at the primary pit. Readings at the primary pit center at a depth of 25 mils were all compressive. At the location where the tensile value had been obtained at a depth 17 mils, the residual stress was -16.0 ± 4.6 ksi at 25 mils. The other orientations at that point were small compression with the uncertainty factors slightly exceeding the measured values.

No crack indications were found in this test.

3.2 CONCLUSIONS

These results suggest there are no surface tensile residual stresses in or around the fretting pits. The compressive residual stresses were near or exceeded 100 ksi. Some low tensile residual stresses may occur in the depth of the material. The maximum tensile value found (in depth) was 12.7 ±8.8 ksi. All of the tensile readings obtained were within or close to the uncertainty band of the x-ray diffraction process.

These measurements indicate that there are no opportunities for stress corrosion cracking in the contact zone even though the parts may be exposed to sea water or sea moisture in humid air.

3.3 RECOMMENDATIONS

Because of the positive effect from the shallow compressive residual stresses developed from glass bead cleaning operations, it is recommended that local glass beading be repeated, where ever feasible, on critical regions where it is necessary to do local rework that is likely to disturb the surface residual stresses (e.g. blending) after the initial cleaning.

4. INSTRUMENTATION

The only instrumentation required was supplied by the testing vendor as part of the x-ray diffraction system used to measure the residual stresses. This equipment conformed to MIL-STD-45662.

5. PHOTOGRAPHY

Still photographs were taken of the primary fretted zone at various stages of the measurement process.

6. RESULTS AND DISCUSSION

6.1 TEST DESCRIPTION

Surface residual stress measurements using the x-ray diffraction process is nondestructive for steel. When subsurface evaluations are sought, it is necessary to locally remove material between measurements. This makes the process destructive. This is the approach taken in the test. The test was conducted in accordance with the test plan, ETP-0492 (ECS-2432). The test plan left the selection of the primary and alternate pits to be determined. This selection was done by the test team in concert with the testing vendor. The exact number and locations of the test points plus which ones would be measured in each sequence of testing were determined just prior to the test. The final working plan was arrived at by agreement between the test engineer and the testing vendor. Since it was known that the effects of glass beading imposed a surface compressive stress, it was decided to evaluate this effect directly. A specimen was flame cut from a scrapped case and trimmed to a square by grinding. It was evaluated before and after the glass beading to show the change in residual stresses induced by the glass beading.

Table 2 lists the sequence of steps used in the test measurements at the points shown in Figure 1.

Table 2 Test Evaluation Sequence

SEQUENCE	TASK DESCRIPTION
0	Prepare a square test specimen of case material. Measure residual stresses at the center prior to glass bead blasting. Glass bead blast by the normal process. Measure residual stresses at center.
1	Establish the layout of the test points per Fig. 1. Measure residual stresses before etching at points 1 through 9 and F (center of alternate pit).
2	Electropolish (etch) the test points to a depth of approx. 10 mils. Measure residual stresses at points 1 through 8.
3	Electropolish the test points to a depth of approx. 15 mils. Measure residual stresses at points 1 through 6 and 8.
4	Electropolish the test points to a depth of approx. 25 mils. Measure residual stresses at points 3 and 8.

Table 3 summarizes the points evaluated.

Table 3 Locations and Conditions for the Test Evaluations

TEST SEQ	DESCRIPTION	POINTS EVALUATED
1	No etching	1-9,F
2	Points etched 5-10 mils	1-8
3	Points etched 15 mils	1-6,8
4	Points etched 25 mils	3,8

6.2 TEST PREPARATIONS

The test preparations consisted of identifying the case segment to be evaluated and selecting the primary and alternate evaluation locations. The test article was then moved to the test location and positioned for convenient access. Thiokol also excised and prepared a special test specimen used in test sequence 0.

6.3 TEST FACILITIES

The tests were conducted at Thiokol Space Operations in Building M-179 in a convenient location that provided power and protection for the vendor equipment and access to the test cylinder. The test vendor (Technology for Energy Corporation, TEC, Knoxville, TN) provided the equipment needed to conduct the test.

6.4 TEST PROCEDURES AND INSTRUMENTATION

The test procedures were those appropriate for x-ray diffraction measurements of residual stress in steel. This included the x-ray beam generator and the equipment to measure the x-ray diffraction. This was augmented with equipment and material to do local material removal by the electropolishing (etching) process. All of this equipment and the depth measuring devices were provided and certified by the testing vendor. No additional instrumentation was required.

The test procedures were those appropriate for beam diffraction measurements of residual stress in steel. This included the beam generator (x-ray tube or nuclear reactor) and the equipment to measure the diffraction angle. The x-ray diffraction equipment was augmented with equipment and material to do local material removal by the electropolishing process. All of this equipment and the depth measuring devices were provided and certified by the testing vendor.

The procedure is based on electomagnetic wave diffraction and utilizes Bragg's Law. It uses the wave diffraction angle to estimate the strains present in the material where the beam is focused. Having the strain estimates at various directions at a point, the stresses are computed using Hooke's Law for the material. Qualitative estimates of the dislocation density are obtained from the full-width half-maximum (FWHM). This is the diffraction peak width at half of its maximum intensity.

Electropolishing was used to remove material from the test points in the x-ray diffraction method because the x-ray is only capable of penetrating the steel a few microns. Electropolishing minimizes the disruptions to the residual stress field by not inducing thermal/mechanical forces during material removal.

6.5 SIGNIFICANT FINDINGS

6.5.1 GENERAL OBSERVATIONS

The testing provided generally consistent and reasonable data. No "bad" data readings were obtained. Only 4 of the 105 readings needed to be repeated to validate the reading. Each data point measurement provided an estimate for the residual stress and an uncertainty level. Only in the low values of residual stress were the uncertainty levels near the value of the measured value. No cracks were found in or around the fretted zones through all of the evaluations. Photographs of the primary test zone are shown in Figures 5-7. The surface residual stresses from glass beading (seq. 0) are reported in Table 2. Because of the test specimen preparation process, the values of the residual stresses before the glass beading are not representative of the condition of typical flight hardware. The data indicates that the glass beading produces a nearly uniform surface compressive residual stress in excess of 100 ksi that overwhelms the previous residual stress.

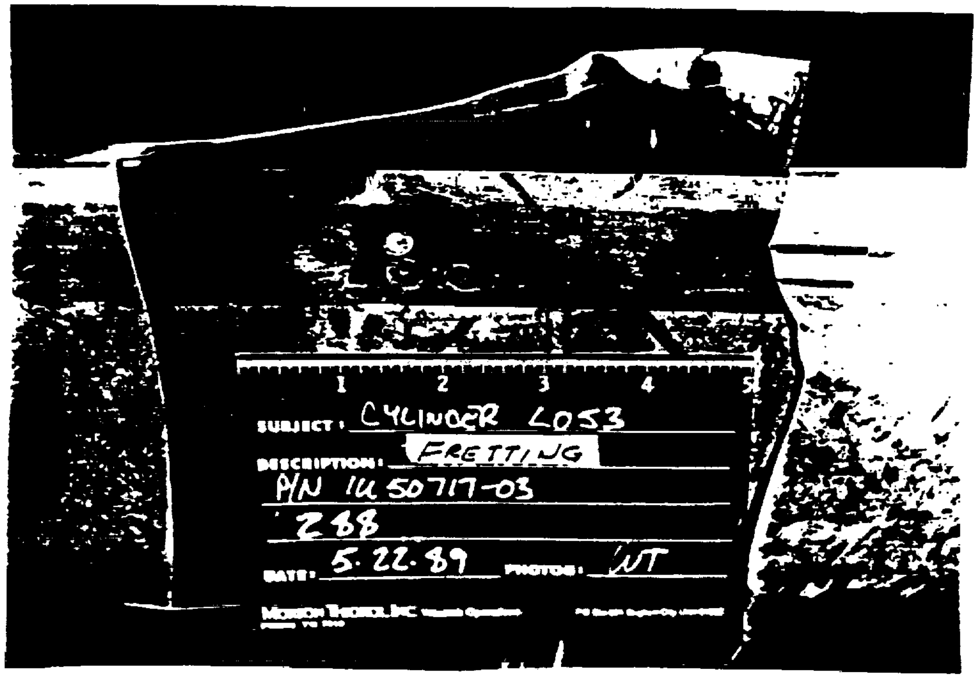

Figure 4 Photograph of Primary Fretted Zone During First Etching

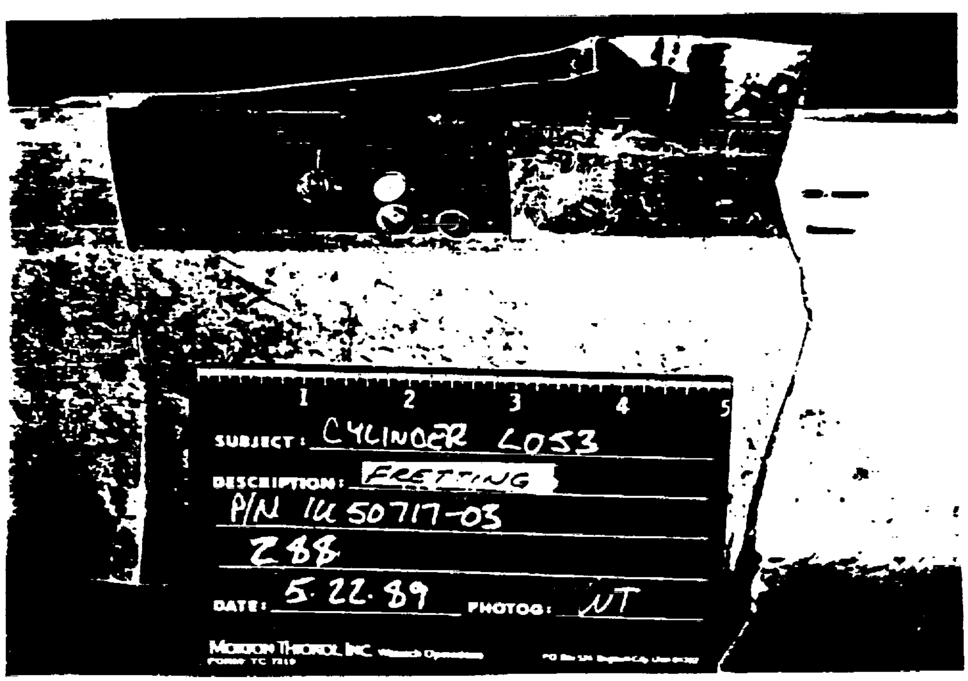

Figure 5 Photograph of Primary Fretted Zone For Replicated Reading

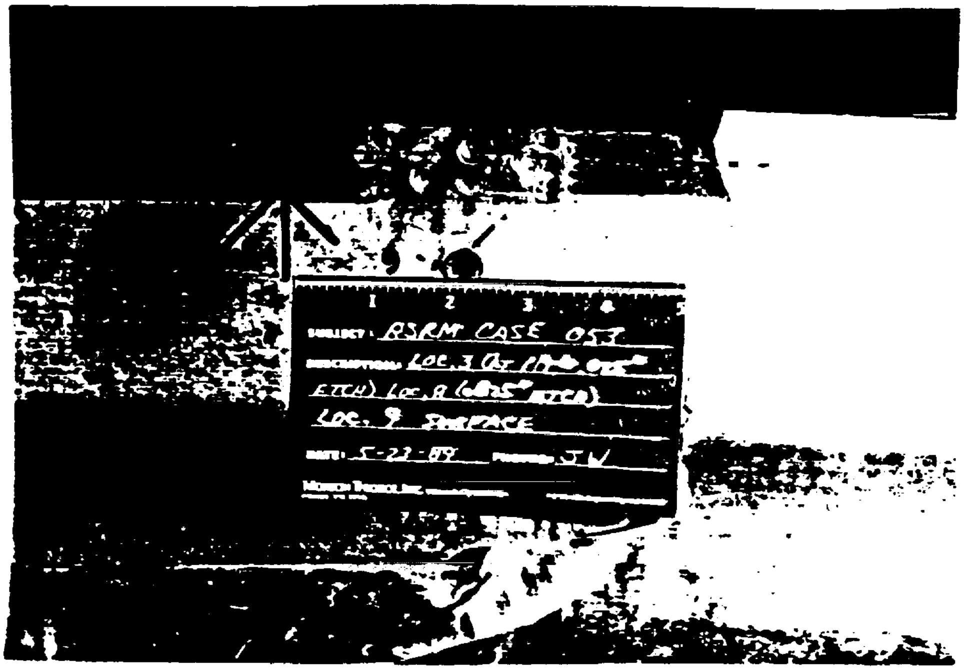

Figure 6 Photograph of Primary Fretted Zone After Last Etching

Table 4 Results of Evaluation of Glass Bead Blasting

		RESIDUAL	STRESS, ksi	
MEASUREMENT ANGLE	0°	45°	90°	135°
Before	- 38.8 ±8.6	- 17.2 ±9.7	- 59.7 ±7.3	- 56.5 ±7.2
After	-158.0 ±8.9	-142.3 ±7.0	-144.3 ±12.0	-143.7 ±6.4

Table 3 summarizes the residual stress values obtained in and around the primary pit and the center of the alternate pit. More detailed data on these readings can be obtained from Appendix A.

Table 5 Summary of Residual Stress Measurements on Cylinder S/N L053

MEASUREMENT ANGLE			RESIDUAL STRESS, ksi 0°	45°	90°	135°
TEST SEQ.	PT.	ETCH DEPTH mils				
1	1	0	-138.0±8.6	-141.4±10.3	-156.7±5.5	-153.8±6.3
	2	0	-145.3±6.2	-144.3±10.9	-154.1±7.3	-147.6±7.4
	3	0	-110.6±16.7	- 84.3±16.6	-122.7±21.7 -107.8±20.4	-82.0±16.8
	4	0	-134.4±8.8	-147.4±10.9	-147.3±7.3	-151.2±8.7
	5	0	-138.5±5.8	-132.7±7.0	-151.0±8.0	-138.0±6.5
	6	0	-135.8±5.1	-128.0±8.4	-150.0±5.6	-152.5±5.4
	7	0	-144.6±5.6	-136.6±11.6	-163.7±9.8	-146.8±9.1
	8	0	-139.5±8.0	-139.5±9.2	-151.9±6.7	-144.1±5.9
	9	0	-162.4±6.3		-131.2±9.0	-117.±12.4
	F	0	-114.1±9.0	-158.2±10.3	-120.6±13.1	-133.1±12.8
2	1	10	-49.8±7.4	- 54.5±7.4	-52.0±4.5	-31.4±9.6
	2	5	-103.1±7.6	- 68.6±7.7	-46.1±8.8	-58.9±8.1
	3	5	-16.7±7.1	-26.1±6.4	-50.8±5.2	-38.0±16.9 -38.6±12.9
	4	10	+8.4±6.4	+12.0±5.0	-13.7±3.9	-3.0±9.7
	5	10	-2.4±4.1	-15.5±7.1	-19.3±8.2	-29.3±8.7
	6	10	-6.5±5.6	-7.0±9.0	-19.1±9.0	-11.5±5.0
	7	15	-1.9±8.1	+12.7±8.8	-8.1±5.6	-6.4±9.2
	8	10	-7.1±5.0	+0.8±4.7	+1.7±6.7	+1.8±9.0
3	1	16	-18.3±6.2	-8.7±6.9	-15.9±4.9	-20.5±5.5
	2	15	-69.8±12.6	-61.±5.2	-32.5±7.5	-34.5±16.4 -51.5±12.9
	3	17	+4.6±4.3	-4.5±6.9	-14.0±6.9	-7.2±3.6
	4	14	+7.6±7.3	-1.6±6.7	-12.2±4.9	-8.0±6.1
	5	15	-8.0±5.6	+5.1±6.4	-13.0±4.4	-4.7±8.3
	6	16	-6.0±4.0	-7.6±6.6	-4.1±4.6	-3.9±7.2
	8	16	-15.5±6.9	-6.1±4.2	+0.5±7.3	-0.6±4.9
4	3	25	-16.0±4.6	-6.3±7.5	-2.2±5.1	
	8	25	-2.5±5.6	-3.3±7.0	+0.3±9.4	

6.5.2 TEST DATA EVALUATIONS

These data clearly show the influence of the compressive residual stresses developed by the glass beading. The undisturbed surface (test sequence 1) generally had compressive residual stresses well in excess of 100 ksi, and are comparable to the stress levels obtained in test sequence 0. The two readings in the bottoms of the pits (points 3 and F) show reduced magnitudes of compressive stress by about 20 to 40 ksi. The effect was more pronounced in the data at the location of the primary pit. It appears that the fretting/pitting action disrupted the compressive residual stress state by removing layers of stress material and setting up a local residual stress. For some unexplained reason the primary pit showed more reduction in the 45° and 135° orientations, while the alternate pit shows the reductions in the 0° and 90° directions.

A dramatic reduction of residual stresses occur below the surface. Removing from 5 to 10 mils of material drops the magnitude of the compressive stresses to a range of zero to 100 ksi. Tensile residual stress up to about 20 ksi were measured. This means that the compressive stresses from glass beading are very shallow, perhaps only a few mils. Penetrations of 15 to 25 mils show mixed tension and compression residual stresses of relatively low magnitude.

The testing found no tensile residual stresses that would be exposed directly to a corrosive environment. It did not appear that the fretting process produced tensile residuals in or near the heat affected region of the pit. Only one tensile reading was obtained under the pit. That was in the primary pit with an etching depth of 17 mils. Only the stress in the 0° orientation was tensile with a magnitude of 4.6 ksi and an uncertainty of ±4.3 ksi. The readings in the pit with an etched depth of 25 mils were all compressive with uncertainty values that could allow for small tensile stresses.

Those subsurface tensile residual stresses measured across all of the points and test depths were small (less than 20 ksi). This implies there is very little opportunity for stress corrosion cracking to develop.

7. APPLICABLE DOCUMENTS

Number	Title
ETP-0492	Measurement of Residual Stresses in Fretted Area of RSRM Case Segment 1U50717 S/N L053
1U50717	Case Segment, Light Weight Cylinder
STW4-2606	Steel, Alloy, High Strength, D6AC (for Space Shuttle SRM Case Components)
STW7-2608	Heat Treatment, Alloy Steel, D6AC (for Space Shuttle SRM Case Components).
MIL-STD-45662	Calibrate System Requirements
—	Electropolishing Machine Instruction Book

APPENDIX A - RESULTS OF X-RAY DEFRACTION MEASUREMENTS

The following pages are direct copies of the data sheets provided for each orientation evaluated for the various test points and etching depths at the fretting locations on the inner clevis leg of light weight cylinder S/N 053. Two fretted zones were evaluated. The primary fretted zone for the evaluation was at RSRM angular position 288°. The second fretted zone was at 280°. Figure 1 shows the 9 evaluation points in the primary zone. Point "F" (not shown in the Figure) was located at the center of the pit in the second zone.

The x-ray diffraction method was used to make the residual stress evaluations. Four different conditions were evaluated across the 10 points. Table 3 shows the four conditions and the points evaluated.

The tests were conducted in M-179 and the Thiokol Space Operations Plant. The test vendor was Technology for Energy Corporation, TEC, of Knoxville, TN.

See Data Management for a copy of the following Vendor Reports :

TEC Fretting Residual Stress Data SN 053 SEQ 1 - May 89
TEC Fretting Residual Stress Data SN 053 SEQ 2-4, May 89)