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Development of an EPDM Elastomeric Material for use in Hydrazine Propulsion Systems

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Abstract

Elastomeric diaphragm and bladder tanks using ethylene propylene diene modified (EPDM) polymers such as AF-E-332 have considerable successful flight heritage. However, it has been documented that some contaminants are leached from the current EPDM rubbers into the hydrazine and under certain operational conditions some small catalytic thrusters may experience performance degradation. Furthermore, the current base rubber used in the EPDM formulations is no longer available. The SIFA material has been developed to retain the manufacturability and performance heritage of AF-E-332 elastomeric diaphragms, provide enhanced chemical compatibility in contact with hydrazine and uses an alternative, available base rubber formulation. Specifically, the following technical challenges have been set and met:

i) formulate a material that will not leach any of the material's primary constituents - defined as totaling less than 1 ppm after 1000 days at 40°C with a S/V =1 - into hydrazine,

ii) greatly reduced catalyst residuals, metals content and NVR content compared to the current available materials,

iii) produce a material that retains the mechanical (i.e. hardness, tensile strength, tear and compression set), permeability and gas evolution characteristics of PSI's AF-E-332,

iv) can be manufactured – compounded, molded and processed – on existing AF-E-332 equipment and tools, and

v) use materials made with the latest technology in an attempt to ensure their long-term availability and achieve a new standard for predictability in EPDM performance.

The report summarizes the test results assembled to date and describes the on-going test programs being performed.

1.0 Introduction

Although elastomeric diaphragm and bladder tanks using ethylene propylene diene modified (EPDM) polymers such as Pressure Systems Inc.'s AF-E-332, MIL-R-83412 and former Royal Ordnance's D11 material have tremendous flight heritage in hydrazine propulsion systems, it is well documented that a number of contaminant materials are released from the rubber into the hydrazine and some thrusters may experience performance degradation.

The most widely discussed and principle concern in the European space community is the clogging of thruster injectors by silicon compounds leached from the diaphragm over time by the hydrazine. The suspected origin of which are the Aerosil® (silica) particles that are

used as filler in the elastomer. A number of studies have confirmed this leaching and attempted to quantify the rate of extraction. This phenomena has been used to explain why nearly all spacecraft of the OTS (Orbital Test Satellite) family (OTS2, ECS, MARECS, TELECOM1A and TELECOM1B) have experienced severe performance degradation in their North-South station-keeping hydrazine thrusters. Similar phenomenon has also been observed in ESC-1, ECS-4 and MARECS-A. Recent ESA programs such as Infra-Red Space Observatory (ISO), Solar & Heliospheric Observatory (SOHO) and International Gamma-Ray Astrophysics Laboratory (Integral) have all expended considerable effort and analysis to acknowledge the potential mission effects of silicon leaching.

In 1995, recognising the desire for an elastomer having enhanced chemical compatibility in the presence of hydrazine, iab Consulting embarked on a privately funded research and development (R&D) program. The culmination of this work was the development of a family of proprietary EPDM materials, named SIFA. Reference (1) describes some of the background work performed in the development of SIFA.

In addition to the widely published silicon leaching it has also been documented that a number of other fillers are leached from EPDM formulations in contact with hydrazine It is it is likely that many other potential EPDM fillers will also cause catalyst problems if leached into the hydrazine in any appreciable quantity.

In reality, it is recognised that any of the blocking phenomena are a function of complex thermal, chemical and chemical interactions rather than simple, single source contamination from the diaphragm. To model any potential thruster degradation with such a complex issue is fraught with uncertainty. In addition, the replacement of conventional monopropellant hydrazine thrusters with arcjets, electrothermal hydrazine thrusters or other thrusters with significantly smaller injector tubes, makes assessment potentially more critical.

In search of an improved material for use in hydrazine propulsion systems, consideration was given to other, more modern materials. However, in view of the tremendous flight history of EPDM diaphragms, it is believed that much confidence with respect to manufacturability, mechanical integrity, permeability and gas evolution will be retained with an EPDM material, compared to a different material for which new unknown or hidden problems may well arise. Specifically our studies on fluoropolymers have raised issues relating to permeability, mechanical reliability due to environmental stress cracking, mass and unit cost.

In view of the above, the desire was to develop a material that retains the manufacturability and performance heritage of AF-E-332 elastomeric diaphragms and bladders, yet provides enhanced chemical compatibility in contact with hydrazine. Specifically, we set ourselves the technical aim of formulating a material that will not leach any significant constituent, total greater than 1 ppm (S/V =1) after 1000 days at 40°C, into the hydrazine and has greatly reduced catalyst residuals, metals content and NVR content. In addition we have chosen materials made with the latest technology in an attempt to ensure their long-term availability and achieve a new standard for predictability in EPDM performance.

It is also important to note that the base Nordel rubber used to date in the current EPDM rubbers is no longer an in-production material since the manufacturers, DuPont Dow Elastomers, stopped production in late 1999. SIFA formulation and development has pre-empted this and we have chosen an alternative, recently introduced, EPDM base rubber formulation.

The test program has evaluated two formulations, SIFA 35 and SIFA 32. SIFA 32 is a lower strength rubber with greater flow capabilities, whilst SIFA 35, which does not flow quite so easily, is comparable to AF-E-332. Both materials are readily formable by compression moulding however the press capability i.e. tonnage for large diaphragms, will

have to be greater for SIFA 35. The importance of SIFA 35 is that it offers superior mechanical strength, desirable for larger diaphragms or situations where AF-E-332 heritage needs to be retained. Chemical compatibility results are presented for both materials since they have the same chemical formulation and the test results are a good indication of SIFA's basic compatibility in hydrazine.

2.0 Mechanical Properties of SIFA35

Since every diaphragm cannot be destructively tested, it is important that before any design can be committed to, the design allowables and process controls are well defined. A robust evaluation at the start of a material formulation program will provide the knowledge to define well-founded process control and acceptance criteria during all subsequent diaphragm production programs.

In order to demonstrate the reproducibility of the proposed formulation, two independent sub-contractors were initially used to produce material. Some material was produced by the Defense Research Agency (DERA) at Farnborough in England and some material was produced by the Tun Abdul Razak Research Centre (TARRC) in England. The process was subsequently transferred to Pressure Systems Inc (PSI). Using the process history established for AF-E-332 over 30 years, batches of SIFA material were processed and tested. The results lead to the establishment of the specification values shown in Table 1.

SIFA 35 specification meets the AF-E-332 mechanical properties specification in all aspects except for a slightly reduced minimum elongation at break. The elongation at break for SIFA 35 has been conservatively set at this time based on the values achieved during the development program. Data from the first flight standard production run of diaphragms at PSI show that the material meets the AF-E-332 specification and indeed has a minimum elongation of 270% at break. The slightly reduced elongation value for SIFA is of no design impact for PSI diaphragm tank design. Figure 1 shows some SIFA diaphragms.

In order to provide additional confidence in the SIFA material a 22" diaphragm, manufactured during preliminary manufacturing trials in 1999, underwent a stringent diaphragm cycling campaign. The tests were run from 1/14/03 through 2/05/03. The summary of the testing is as follows:

- 50 fill and drain cycles – complete reversal in both positions – with distilled de-ionized water and an end of cycle pressure of 10 psig.
- Disassemble and inspect - no visual anomalies
- Slosh testing @ 60% fill fraction (approx. 120lbs. water) 4" total displacement at 1.5 Hz for a total of 6 hours and 20 minutes comprising of the a number of different orientations:
  - Propellant side up, 1 hour, no visual anomalies

Table 1: Specification Values for SIFA 35

Property	SIFA 35	MIL-R-83412
Tensile strength - MPa (psi)	>11.4 (1650)	>11.4 (1650)
Elongation at break (%)	>240	>260
Tear strength - kN/m (lb/in)	>52.5 (300)	>52.5 (300)
Hardness IRHD (^{o})	90±5	90±5
Compression set (%)	<22	<22
Density (g/cc) - calculated nominal	1.12	1.10

  - Propellant side down, 1 hour, no visual anomalies
  - Propellant side up, rotated 90 degrees. (as viewed from the top), 1 hour, no visual anomalies
  - Propellant side down, 1 hour, no visual anomalies
  - Girth perpendicular, propellant side towards shaker, 1 hour, no visual anomalies
  - Girth perpendicular, propellant side away from shaker, 1 hour, no visual anomalies
  - Propellant side up (same as a.) while expelling water, approx. 20 minutes, no visual anomalies

- 55 fill and drain cycles - complete reversal in both positions – with distilled de-ionized water and an end of cycle pressure of 10 psig.

- Disassemble and inspect - no visual anomalies

- High-pressure expulsion (end of life) with water @ 150 psid, hold expelled position for 1 hour

- Disassemble and inspect - no visual anomalies

- High-pressure expulsion (end of life) with water @ 350 psid, hold expelled position for 1 hour

- Disassemble and inspect - no visual anomalies

Figure 2 shows the slosh test tank.

3.0 Hydrazine Compatibility Evaluation

3.1 Overview

This work involved the storage of rubber samples in hydrazine together with a control containing no rubber samples and the analysis of the residual hydrazine for trace contaminants including silica, titanium, zinc, aluminium, calcium and zirconium by Inductively Coupled Plasma Analysis (ICP). The ICP procedure is carried out to an accredited sub-contractor specification. The test method and test results are presented in Sub-Sections 3.2 and 3.3 of this Section. All results are presented for a surface to volume ratio (i.e. surface area of diaphragm to volume of hydrazine) of one (unit length) $^{-1}$. Reference (1) discusses some of the background to the selection of the analytical techniques for the detection of leached filler elements.

ICP testing has evaluated two formulations, SIFA 35 and SIFA 32. Although the preferred material is undoubtedly SIFA 35 because of its similarity to MIL-R-83412 type material, the ICP results for SIFA 32 are very important since they provide added confidence to the hydrazine compatibility of the basic chemical system.

Several significant ICP trials have been performed on SIFA 35 since early 1998. The first trial was performed at Daimler-Benz Aerospace (DASA – Trauen) and ran for 98 days at 40°C.

The second trial was performed under ESA contract (No. 13901/99/NL/PA) – identified as ESA1 in the following data summaries - new samples were generated and underwent hydrazine immersion for 205 days at 40°C. This program of work was extended with private funding yielded test data of 1023 days at 40°C (8th February 2003).

In mid-2001 ESA awarded a follow-on contract – identified as ESA2 - to generate a new batch of SIFA material and place an additional twelve test vessels on test for 1095 days at 40°C. To date this has yielded ICP test data in excess of 600 days at 40°C. This ICP program will continue for a total duration of at least 1095 days and be extended with private funding in excess of 2000 days at 40°C

Non-volatile residue (NVR) tests have been performed on hydrazine exposed to rubber samples using the method given in MIL-P-26536D. These results are presented in sub-section 3.5.

Gas evolution trials have been performed using a method similar to that described in MIL-R-83412A. These results are presented in sub-section 3.6.

Following immersion in hydrazine the samples underwent mechanical testing - results are presented in sub-section 3.7 – and swell measurement – results are presented in sub-section 3.4.

3.2 Storage in hydrazine, test analysis for Contaminants

The following experimental outline describes the general method used for ICP testing. Despite the advances in ICP techniques and software, ICP is not foolproof. Experience and great care must be taken in the preparation of standards, blanks and samples. Elastomer samples are prepared per the Material Formulation Specification and Process Specification. The samples are standard ISO rubber tensile dumb-bells with a known surface area. The precise surface area is a function of actual specimen thickness and this is measured on each sample. The samples are cleaned before exposure. After drying the samples are identified by cutting off a small piece from the corners. Each sample is weighed and the sets of five samples placed in re-sealable, clean bags. Five (5) elastomer samples are fully immersed in each hydrazine test vessel. Each test vessel contains a known amount of hydrazine of hydrazine so as to provide a surface area (elastomer) to volume of hydrazine (S/V) ratio (cm^{-1}) of 1.0. The vessels are of a size so as to ensure the samples remain immersed in hydrazine. They also contain small holes to avoid any pressure build up. Before use the test vessels are precision cleaned and all steps taken to prevent any further contamination. The test vessels are placed inside sealable glass vessels purged with dry nitrogen and the hydrazine kept under the cover of gas at all times. Blank samples of hydrazine from the same batch are included as hydrazine control samples. All test vessels are maintained at the designated temperature, typically 40°C, in an air-circulating oven.

After a designated period of time, a test vessel is removed from the oven and cooled down to room temperature. After removal from the glass vessel, the hydrazine test vessel is shaken and opened, taking care on opening since the vessel could contain positive pressure. A known amount of hydrazine is transferred by clean pipette to a clean vessel containing a known amount of deionized/demineralised water and shaken. The hydrazine to water ratio may be altered as required by the ICP analysis calibration. All samples are analysed by Inductively Coupled Plasma – Optical Emissions Spectroscopy for the filler elements. The deionized/demineralised water used for the dilution is also analysed as well as a sample from each blank hydrazine vessel.

Prior to the ICP measurements a quality control standard for each element is measured and the ICP machine results are considered acceptable for reporting if the analysis of the control is within 5% of the standard's certified value. For each ICP determination a multiple measurements are taken allowing computation of a standard deviation (SD). The limit of detection (LOD) reporting limits is defined as 5 times the SD. Any results that are less than the LOD are recorded with a "<" sign along with the LOD. The elastomer samples are removed from the remaining hydrazine, blot dried, individually weighed and tensile tested.

3.3 Hydrazine Contamination Results

The following tables present some of the ICP analysis results. All ICP results presented are for a surface to volume ratio (i.e. surface area of diaphragm to volume of hydrazine) of one (unit length) $^{-1}$.

Table 2 presents a summary of the test data from the initial SIFA 35 trials undertaken at DASA-Trauen.

Table 2: DASA-Results Summary - Net Extractable Hydrazine Contaminants as a Result of Exposure to SIFA 35 Sample (Concentration of elements in ppm)

Days @ 40°C	Si	Filler 2	Filler 3	Filler 4
25	<blank	<0.1	<0.1	<0.1
52	<blank	<0.1	<0.1	<0.1
75	<blank	<0.1	<0.1	<0.1
98	<blank	<0.1	<0.1	<0.1

Table 3 presents a summary of the net hydrazine contaminant - generated by subtracting the hydrazine blank values from the sample measured values. Where the resulting value is equal to or less than the blank, a value of 0.00 is recorded.

Table 3: Net Hydrazine Contaminants as a Result of Exposure to SIFA 32 & SIFA 35 (ESA1 & IAB/PSI Extended Program Results - Blank hydrazine deducted) Concentration of elements in ppm

Days @ 40°C	Si		Filler 2		Filler 3		Filler 4		Filler 5		Filler 6	
	SIFA 32	SIFA 35	SIFA 32	SIFA 35	SIFA 32	SIFA 35	SIFA 32	SIFA 35	SIFA 32	SIFA 35	SIFA 32	SIFA 35
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00	/
56	0.00	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00	/
56	0.00	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00	/
79	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00
100	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00	/	0.02
105	0.00	/	0.02	/	0.00	/	0.00	/	0.10	/	0.02	/
205	0.00	0.00	0.04	0.02	0.02	0.01	0.00	0.00	0.23	0.18	0.02	0.02
464	/	0.06	/	0.00	/	0.00	/	0.00	/	0.04	/	0.00
464	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00
607	/	0.00	/	0.00	/	0.00	/	0.00	/	0.01	/	0.00
607	/	0.16	/	0.00	/	0.00	/	0.00	/	0.06	/	0.00
1000	/	0.64	/	0.02	/	0.00	/	0.00	/	0.03	/	0.02
1000	/	0.21	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00
1023	/	0.48	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00
1023	/	0.11	/	0.00	/	0.00	/	0.00	/	0.00	/	0.00

Table 4 presents a summary of the net hydrazine contaminants generated by subtracting the hydrazine blank values from the measured sample results.

Table 4: Net Hydrazine Contaminants Analysis as a result of Exposure to SIFA 35(Concentration of elements in ppm – ESA2 Program)

Days @ 40°C	Si	Filler 2	Filler 3	Filler 4	Filler 5	Filler 6
50	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	0.00
400	0.00	0.00	0.01	0.00	0.01	0.00
500	0.00	0.00	0.00	0.00	0.00	0.00
600	0.00	0.00	0.00	0.00	0.00	0.00

For durations of up to 607 days the maximum net detectable reading for any filler element for SIFA 35 is 0.18 ppm and overall the results suggest, within the detectable limits of measurement, that no filler element is leaching into the hydrazine. All trace elements, except silica, show net extractable of less than 0.18ppm after 1000 days at 40°C. The silica readings range from 0.11 ppm to 0.64 ppm after 1000-1023 days with an average value of 0.36 ppm. Silica only exists in the base formulation at trace levels within the filler system and the high blank and measurement values are not expected. Three possible reasons are suggested. Firstly the levels are real and are readings of the trace levels present in the filler system. Secondly, the HDPE vessels used in the ESA1 trial contain traces of silica (some signs of reaction with the vessel were apparent - i.e. bubbling of vessel), the vessel is contaminating the results. In ESA 2 the vessels were changed. Thirdly, silica from a glass pipette is contaminating the hydrazine samples during sampling.

3.3 Swell in Hydrazine

The rubber samples are weighed before immersion in hydrazine. On withdrawal the rubber samples are blotted dry and reweighed thus giving a measure of their swell in hydrazine.

Figure 4 presents some of the assembled swell in hydrazine data at 40°C and 50°C.

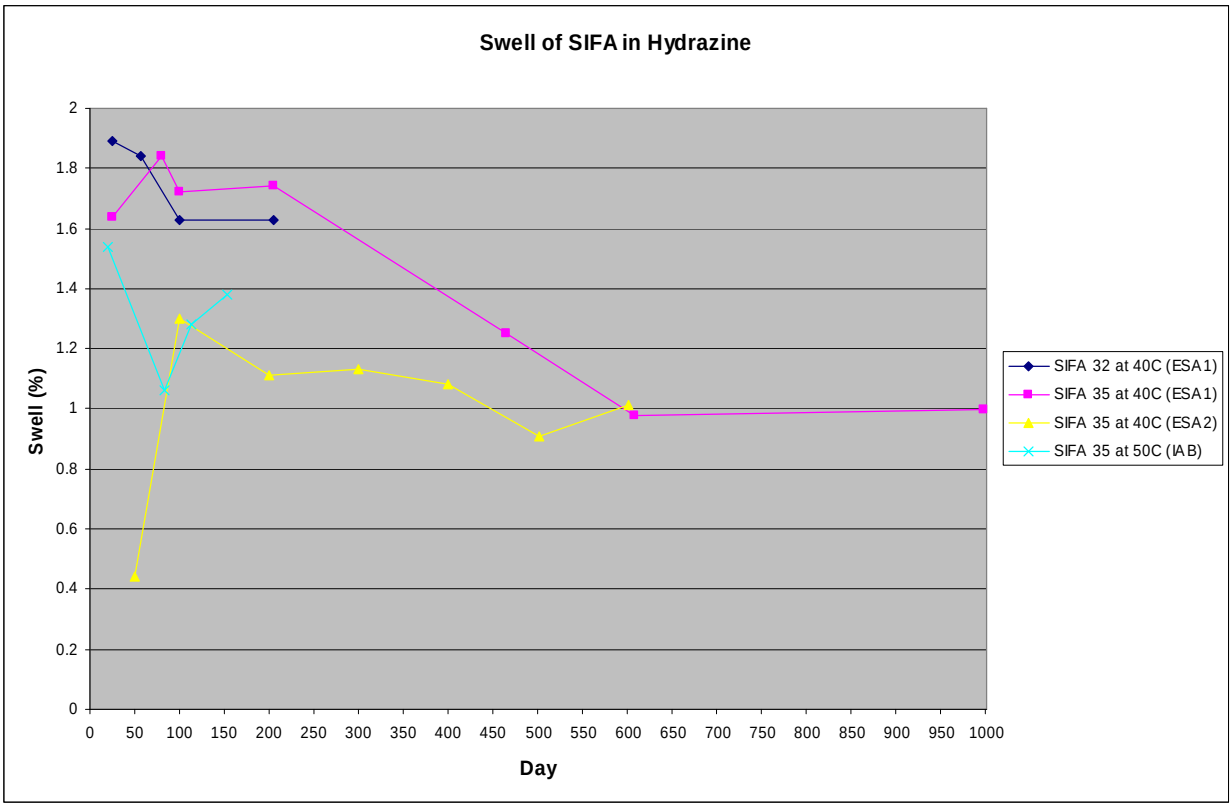

Figure 4 – Swell of SIFA in Hydrazine

Table 5 presents swell results for samples immersed at 71°C per MIL-R-83412A fuel resistance test. The specification's allowable swell after 96 hours at 71°C is 3%. The results show that the swell of SIFA 35 after 192 hours – double the specification – was 1.92 %.

Table 5: Swell in Hydrazine at 71°C

	SIFA 35 – 192 hours		
	Initial Mass (g)	**Final Mass (g)**	**Swell %**
Sample 1	1.5685	1.5995	1.98
Sample 2	1.5219	1.5512	1.93
Sample 3	1.4123	1.4399	1.96
Sample 4	1.5125	1.5415	1.92
Sample 5	1.4107	1.4366	1.84
Average	/	/	**1.92**

Table 6: Compilation of NVR Data, S/V approx. 1, for SIFA 35

Rubber	Temp. °F	Duration Days	S/V Ratio cm^{-1}	Control Hydrazine NVR mg/ml	Exposed to Rubber NVR mg/ml
SIFA 35	104	200	1.00	0.064	0.085
SIFA 35	104	300	1.00	0.066	0.11
SIFA 35	104	700	1.00	Due Oct 2003	Due Oct 2003
SIFA 35	104	1095	1.00	Due Nov 2004	Due Nov 2004

3.5 Non-Volatile Residue (NVR)

After 200 days in the ESA2 program the hydrazine from the vessel containing the samples and the blank hydrazine underwent non-volatile residue (NVR) determination in general accordance with MIL-P-26536D, Rotary Evaporation, paragraph 4.5.7.2. Table 6 presents the results.

3.6 Compatibility to Hydrazine at 71°C

SIFA elastomers were tested in general accordance with MIL-R-83412A paragraph 4.6.2 The test was performed for SIFA 32, SIFA 35 and hydrazine control samples at 160°F (71°C) for 96 hours and at 160°F (71°C). The maximum allowable pressure difference between the test sample vessel and the control sample was less than 2 psig, in accordance with MIL-R-83412 requirements.

In addition, following exposure to hydrazine for 96 hours at 71°C, the SIFA 32 rubber samples were tested to determine the tensile, elongation and swell change. The summary results are:

- Tensile Strength Change (% max.) = 0% for SIFA 32 (-20% allowed by MIL-R-83412A).
- Elongation Change (% max.) = 7.6% for SIFA 32 (-20% allowed by MIL-R-83412A).
- Swell (% max). = 2.53 % for SIFA 32 (3% allowed by MIL-R-83412A)

These results show conformance to MIL-R-83412A with respect to fuel resistance. The SIFA 35 samples remained on test for an additional 4 days, giving a total of 192 hours at 71°C.

- Tensile Strength Change (% max.) = 15.2% for SIFA 35.
- Elongation Change (% max.) = 21% for SIFA 35.
- Swell (% max.) = 1.92 % for SIFA 35.

It may be noted that the tensile strength results after 192 hours – double the specification duration – still meet MIL-R-83412. The swell requirement meets MIL-R-83412A and the elongation change only fails the allowed change by 1% after double the required exposure.

3.7 Tensile Tests on Immersed Samples

Following withdrawal from the hydrazine, the tensile dumb-bell samples were blotted dry, weighed and returned for tensile testing. Figure 5 presents some of the tensile strength change data following immersion in hydrazine. Figure 6 presents some of the change in elongation properties following immersion in hydrazine.

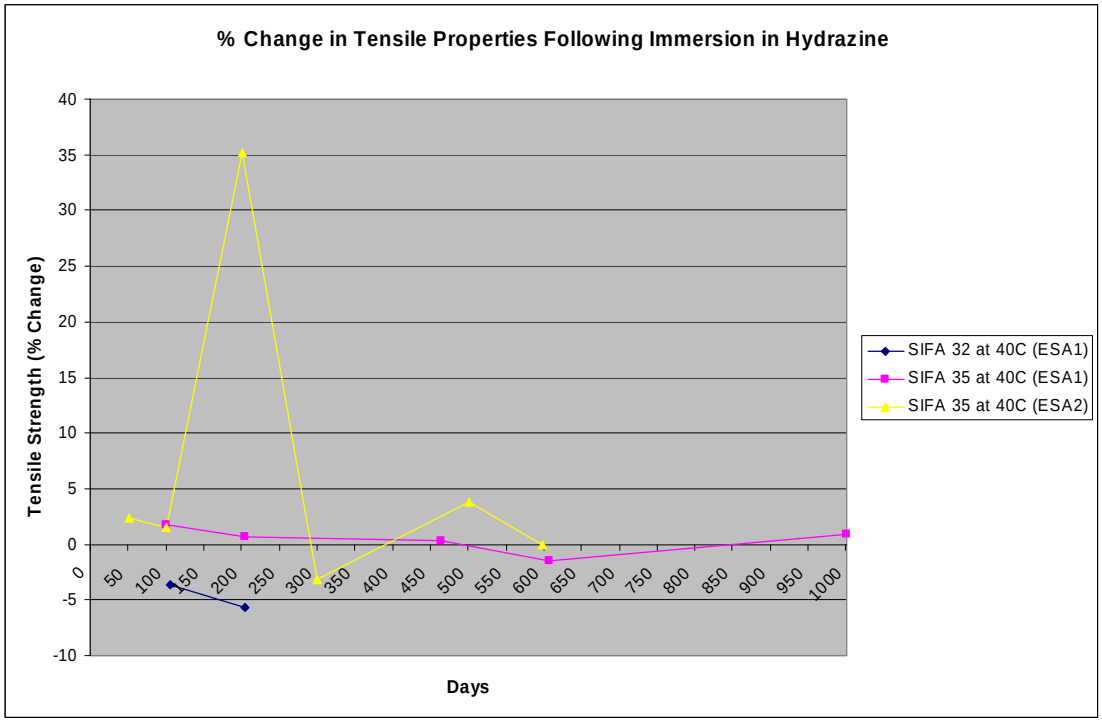

Figure 5 % Change in Tensile Properties Following Hydrazine Immersion

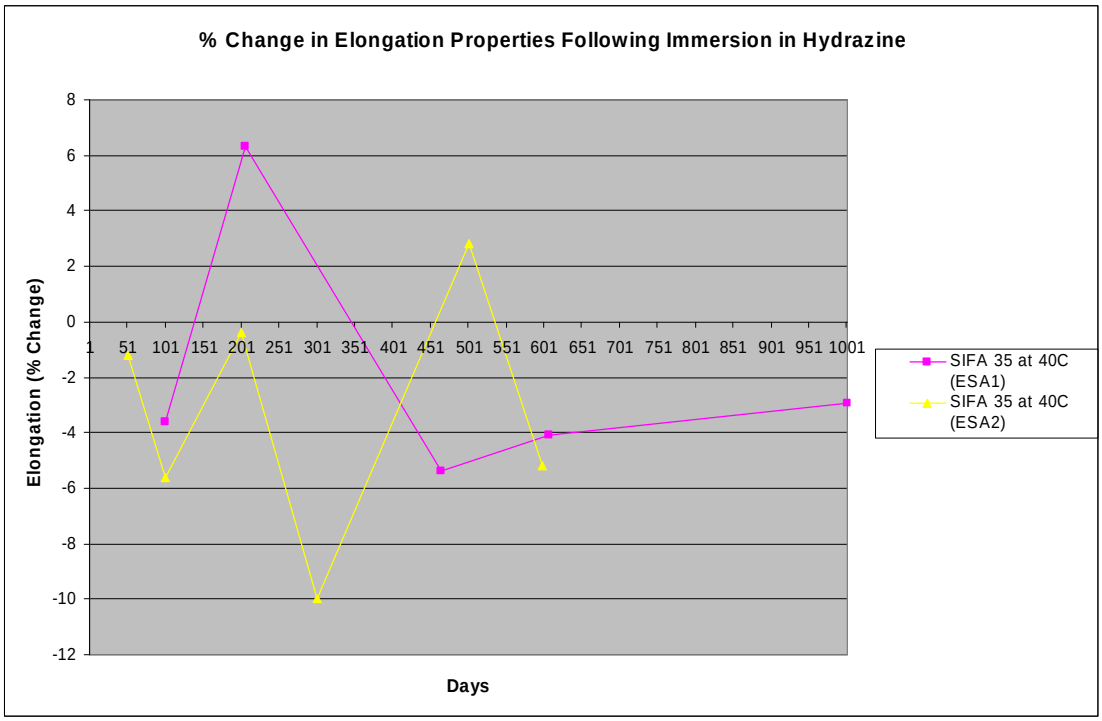

Figure 6 % Change in Elongation Properties Following Hydrazine Immersion

The test results indicate that at 40°C there is little change in tensile strength or elongation at break. After 1000 days at 40°C in the ESA1 trial the tensile strength shows no degradation and the elongation is 3% lower than the room temperature controls. After 500 days in the ESA2 trails there is no discernable change in tensile strength or elongation. Diaphragm samples stored at 50°C for 83 days also show very little change.

4.0 Additional Testing

In addition to hydrazine compatibility testing the SIFA material test program includes programs to evaluate:

- Compatibility to IPA - 2 months at 40°C followed by hydrazine immersion – No detectable leaching of any element found in the IPA following the sample immersion.
- The NVR following 2 months at 40°C following the immersion test are presented in Table 7
- Exposure of the material to a vacuum – exposure to1 x 10^{-4} mbar for 110 hours
- Thermal cycling - temperature cycles between –10°C and +55°C
- Fungi - 28-day exposure test per British Standard 2011 Part2, Variant 1 – successfully completed
- Radiation exposure - exposed to a total radiation dose of 3.12 x 10^{5} rads.
- Permeability to Helium – direct comparison with AF-E-332
- Permeability to Hydrazine – direct comparison with AF-E-332
- Gas Evolution in contact with hydrazine – direct comparison with AF-E-332 - 20 day period of immersion in hydrazine at 70°C.

5.0 Thruster Firing Test

As ultimate confirmation of the SIFA material and diaphragm processing PSI are supporting a customer with a thruster firing test campaign of a 1N thruster. PSI have constructed a 120 liter titanium tank and loaded it with 54724cm^2 of diaphragm wetable surface area. See Figure 3. The test tank has been configured to simulate an accelerated simulation of a 6 year mission. The test storage period has been reduced by making use of i) temperature related Arrhenius law and ii) increasing the surface to volume ratio in the test tank. The tank is to be loaded with high purity grade hydrazine and stored at elevated temperature of 45°C – 50°C. The S/V ratio of this tank is nearly 17 times higher than the flight configuration S/V ratio.

6.0 Conclusions

Mechanical testing and diaphragm processing has shown that SIFA 35 is very similar to AF-E-332 type material. With the exception of elongation at break, SIFA 35 is capable of meeting all of the process requirements of the AF-E-332 specification.

Table 7: NVR Results Following Storage for 60 days @ 40°C (104°F), S/V = 1 (cm^{-1})

Sample	Average Mass (mg/ml)
Blank IPA – Control – 200 days	0.105
IPA Exposed to Samples – 200 days	0.118

The assembled hydrazine immersion data comprising of analyses of residual hydrazine for trace contaminants, swell, NVR and post immersion mechanical properties – indicates that SIFA offers enhanced chemical compatibility with hydrazine. The long term immersion database, now in excess of 1000 days at the elevated temperature of 40°C with S/V ratio of 1, provides confidence that SIFA is suitable for use in long mission durations. The completion of the thruster firing test will provide extremely valuable information about the validity of the experimental work performed to date.

The successful manufacture of a number of diaphragms by compression molding with existing tools has confirmed that no new manufacturing methods are required. Indeed, diaphragms manufactured from SIFA are interchangeable with any tank design developed for D11 or AF-E-332.

The successful completion of a thruster firing test will provide final confirmation of SIFA's hydrazine compatibility.

7.0 Acknowledgements

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8.0 References

(1) AIAA-99-2830, "Development of an Enhanced EPDM Elastomeric Material for use in Hydrazine Propulsion Systems" by I. A. Ballinger & Dr. D.

(2) AIAA-95-2534, "Review and History of PSI Elastomeric Diaphragm Tanks," by I. A. Ballinger et al.

Figure 1 SIFA 35 Diaphragms

Figure 2 Slosh Testing

Figure 3 Thruster Firing Tank