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Compatibility of an elastomeric material with hydrazine propellant

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Abstract. In aerospace industry, different kinds of elastomeric materials have been used in low-cost, light weight diaphragms and bladders in hydrazine propellant tanks. The compatibility of a new kind of vulcanized rubber compound 1803-1 with hydrazine propellant is studied experimentally, including immersion test, catalytic decomposition test and penetration test. The experiment process and test data are given about the permeation rate, mass change rate, volume change rate and other mechanical properties. The results show that most of the properties of material 1803-1 after compatibility test comply with the requirements of Chinese national standard. Rubber compound 1803-1 provides a reference when selecting the material for diaphragm tank bladders.

1. Introduction

As an important fuel storage equipment of an astrovehicle, diaphragm tanks can provide reliable storages of propellant during on-orbit mission, and provide sustaining propellant supply for the thrusters with stable flow rate during re-entry. In a diaphragm tank, liquid phase and gas phase are segregated by the diaphragm, so that the tank can adopt in any acceleration or any flow rate operation conditions. Thus, the performance of the diaphragm is significant for the propellant tanks. Diaphragm tanks can be easily folded and provide reusable storages of more than 50 cycles. However, one of the disadvantages is the low compatibility with liquid propellant. For N₂O₄ propellant, few kinds of rubber material are long-term compatible.

Researchers and engineers are searching for different materials for diaphragm tank bladders. Some kinds of rubber material compatible with anhydrous hydrazine were developed in past decades. Normane Beach [1] gave a rearrangement of the published compatibility data from the standpoint of the plastic (or elastomeric) material by grading their behaviours in different oxidizers and propellants. Among the listed materials, ethylene propylene diene-modified (EPDM) elastomeric materials have been widely used in hydrazine propellant tanks [2]. Ethylene-propylene elastomer AF-E-332 is capable of ten-year 100-mission operation lifetimes with minimum refurbishment. Coulbert [3, 4] carried out long-time tests to compare compatibilities of two kinds of ethylene-propylene elastomers EPT-10 and AF-E-332 with hydrazine. In swelling test, a weight increase of over 30% for EPT-10 was recorded, compared to 3% for the AF-E-332. However, due to obsolescence issues with the EPDM rubbers used in the AF-E-332, a new formulation named SIFA has recently been developed using alternative EPDM rubbers [5]. Ping Li, et al. [6] studied the compatibility of EPDM AF-E-332 by histogram analyses of atomic force microscopy (AFM) phase images.



Aiming at an application on a return vehicle equipped with 15L diaphragm tanks, a new kind of elastomeric material, nominated with rubber compound 1803-1, is developed by Xi-an Aerospace Propulsion Institute. Its main component is vulcanized rubber, shown as khaki elastomer in Figure 1. The mechanical properties under normal conditions are listed in Table 1. In this paper, compatibility of this vulcanized rubber compound with anhydrous hydrazine is studied experimentally. To guarantee the long term stable storage of anhydrous hydrazine, compatibility tests including immersion, catalytic de-composition and penetration are carried out during a period of half year. Performances changes after tests are summarized. The compability of the rubber compound 1803-1 with anhydrous hydrazine is concluded.



Figure 1. Rubber compound 1803-1 material piece.

Table 1. Mechanical properties of rubber compound 1803-1 under normal conditions.

index	item	value
1	Hardness (Shore)	70±5
2	Tensile strength (MPa)	≥14.5
3	Stretching strength of 100 % (MPa)	≥2.0
4	Elongation at rupture (%)	400~630
5	Tearing strength (N/mm)	≥30
6	Compression set (70°C×72h compression in hot air 20%) (%)	≤35
7	120°C×72h hot air aging	stretching strength(MPa)
		elongation at rupture (%)
		≥12.0
		≥200

2. Experimental

2.1. Experimental conditions

Temperature: Operating temperatures are (23±2)°C for immersion test, 50°C catalytic decomposition test and 43°C penetration test.

Periods: Catalytic decomposition test: 15 days; Immersion test: 14days; Penetration test: 180 days.

Test medium: The test medium anhydrous hydrazine is achromatous transparent liquid. The anhydrous hydrazine should be up to standard of propellant-level according to national standard [7], as shown in Table 2.

Table 2. Anhydrous hydrazine composition.

parameter		Propellant-level	Normal-level
hydrazine %	≥	98.5	98.5
H ₂ O %	≤	1.0	1.0
particulate matter mg/L	≤	1	1
non-volatile residue %	≤	0.003	0.005
Fe %	≤	0.0005	0.002
chloride %	≤	0.0005	0.0005
CO ₂ %	≤	0.02	0.02

2.2. Experiment process

2.2.1. *Immersion test.* The process of the immersion test is given below.

- a) Every five sample pieces are grouped and suspended in a numbered immersion container with immersion time and operating temperature marked. The hanging height and the volume of anhydrous hydrazine are controlled to ensure the sample piece immersed in liquid phase. The sample should not contact the container wall.
- b) The sample groups with different immersion time are placed in different test containers. Square sample pieces and dumbbell sample pieces with same test conditions are placed in the same closed container. Propellant is filled only after the air tightness test is acceptable.
- c) Anhydrous hydrazine should be filled into the containers until the volume area ratio is 44.2mm.
- d) Perform the immersion test at room temperature, check the tightness of the containers during the test, and take appropriate measures in case of any leakage;
- e) Open the container after 180 days, make the following examine.
 - Take out the sample and record the appearance of the test;
 - Clean the test pieces with distilled water and absolute ethanol, and wiped off the liquid on the piece surface with filter paper. Sample pieces are weighed after keeping the test pieces in the air for 30 minutes at room temperature. The mass change rates after the immersion are calculated. The volume of the sample is calculated by the drainage method, then volume change rates after the immersion are calculated;
 - The tensile strength test is performed to get the mechanical property of the sample piece, and mechanical properties such as tensile strength and elongation at break are obtained;
 - The composition of the propellant is analyzed based on Chinese national standard [8], and the amount of non-volatile residue and chemical composition change after the immersion test were measured.
- f) After the tests above, the mass change rate, volume change rate, mechanical properties and propellant composition of the test piece under different time conditions can be obtained.

2.3. *Catalytic decomposition test.* The process of the immersion test is given below.

- a) Refer to Chinese national standard [9] for catalytic decomposition test about the test pieces in anhydrous hydrazine;
- b) The test lasts for 15 days, and the test temperature is 50°C;
- c) Each kind of sample piece is tested for three times in parallel. The median value is taken as test results.
- d) The volume of generated gas in the propellant decomposition is $V=V_t-V_0$, where V_t is the final volume of gas, and V_0 is the initial volume of gas.
- e) The gas generation rate S_s in the standard state is converted by the following formula:

$$S_s = 2.694 \frac{V \cdot P}{F \cdot t_1 \cdot T} \quad (1)$$

where

S_s - The gas generation rate S_s in the standard state (mL/cm²•d);

P - Test environment atmospheric pressure (kPa);

F -Surface area (cm²);

t_1 -Test time(d);

T -Test temperature(K).

2.3.1. *Penetration test.* The process of the penetration test is given below.

- Refer to national standard [10] for the penetration test of material test pieces and anhydrous hydrazine;
- The test lasts for 14 days, and the test temperature is 43°C;
- Each kind of test piece was tested in parallel for three times, and the median value was taken as the test result, accurate to three decimal places.
- The propellant penetration rate of the test piece is calculated by the following formula:

$$V = \frac{W_0 - W_t}{S \cdot t} \quad (2)$$

where

V - Permeation rate, (g/(m²·h));

W_0 -Initial mass of the penetration cup, (g);

W_t -Final mass of the penetration cup, (g);

S -Active area, (m²);

t - Penetration time, (h).

3. Results

3.1. Immersion test

Based on national standard [8], a 180-day immersion test of the rubber compound 1803-1 in anhydrous hydrazine was performed, and change rate of mass and volume for the test piece were examined. Part of mechanical properties are measured based on the national standard [9]. The mechanical properties and propellant composition were analyzed. The test results are shown in Table 3, Table 4, Table 5, and Table 6, respectively.

Table 3. Mass changes after immersion test.

Test label	Period (day)	Initial mass(g)	Final mass(g)	Change ratio (%)	average
1	180	1.4710	1.5488	5.2889	5.4337
2	180	1.4295	1.5068	5.4075	
3	180	1.4015	1.4770	5.3871	
4	180	1.3272	1.4022	5.6510	
5	180	1.3599	1.4338	5.4342	

Table 4. Volume changes after immersion test.

Test label	Period (d)	Initial volume (mL)	Final volume (mL)	Change ratio (%)	average
1	180	1.2902	1.3484	4.5109	5.2320
2	180	1.2545	1.3187	5.1176	
3	180	1.2268	1.2937	5.4532	
4	180	1.1635	1.2265	5.4147	
5	180	1.1830	1.2500	5.6636	

Table 5. Mechanical properties after immersion test.

Test label	Period (d)	Tensile strength (Mpa)	Longation at rupture (%)	Permanent compression set ratio (%)	Hardness (ShoreA)
1	180	20.23	672.95	19.1	61.0
2	180	18.62	610.25	13.1	60.9
3	180	21.7	661.52	16.38	60.5
4	180	22.58	680.54	18.3	61.0
5	180	20.97	657.99	16.6	61.0
Mid-value		20.97	661.52	16.6	60.9

Table 6. Chemical constituents changes of anhydrous hydrazine after immersing 180 days.

label	items	Initial value	Final value	Requirements in national standard[7]
1	hydrazine %	99.76	99.80	≥ 98.5
2	H ₂ O %	0.07	0.05	≤ 1.0
3	particulate matter mg/L	0.15	0.66	≤ 1
4	non-volatile residue %	0.00048	0.00059	≤ 0.003
5	Fe %	0.000027	0.000027	≤ 0.0005
6	chloride %	0.0000072	0.000030	≤ 0.0005
7	CO ₂ %	0.00093	0.00067	≤ 0.002
8	appearance	Colorless transparent uniform liquid	Colorless transparent uniform liquid	Colorless transparent uniform liquid

3.2. Catalytic decomposition test

Based on national standard [10], the decomposition rate of the test piece in anhydrous hydrazine during 15 days was measured. The test results are listed in Table 7.

Table 7. Catalytic decomposition test results of rubber compound 1803-1.

Pieces label	Period (d)	Volume of decomposition (mL)	Superficial area (cm ²)	decomposition rate (mL/cm ² d)	decomposition rate (mid-value) (mL/cm ² d)	Requirements in national standard[11] (mL/cm ² d)
1	15	0.015	5.5064	0.0002		
2	15	0.185	5.3270	0.0020	0.0002	< 0.002
3	15	0.015	5.0469	0.0002		

3.3. Penetration test

Based on national standard [12], the permeation rate of the test piece in the anhydrous hydrazine after test was measured for 336 hours duration. The test results are listed in Table 8, respectively.

Table 8. Penetration test results of rubber compound 1803-1.

Mass of penetration cup after 72 hours (g)	Final mass of penetration cup(g)	Effective penetration area(m ²)	Penetration time (h)	Penetration rate (g/m ² h)	Penetration rate (mid-value) (g/m ² h)	Requirements in national standard[11] (g/m ² h)
78.323	78.3083	0.000491	336	0.0891		
75.1259	75.0987	0.000491	336	0.165	0.0891	< 0.25
74.9003	74.887	0.000491	336	0.0806		

4. Conclusions

The catalytic decomposition test, permeation rate test and immersion test of the rubber compound 1803-1 were carried out in the anhydrous hydrazine medium. The results show that the catalytic decomposition rate of rubber compound 1803-1 is 0.0002mL/cm²•d; The rate test results show that the permeation rate of 1803-1 rubber to anhydrous hydrazine is 0.0891 g/m²•h. These performances of elastomeric material are complied with national standard [11], useable under the compatibility restrict for hydrazine propellants.

The 180-day normal temperature immersion test showed that the mass change rate of the test piece was 5.4%, and the volume change rate was 5.2%. The analysis results show that the quality of anhydrous strontium does not change significantly before and after immersion. Although the particulate matter and non-volatile residue increase after immersion, it still meets the technical specifications of Chinese national standard [7], and the non-volatile residue increment is less than 50ppm. It is indicated that the rubber compound 1803-1 does not have a concernful effect on the anhydrous hydrazine.

After immersion test, the mechanical properties of 1803-1 still shows good tensile strength and elongation. However, the shore hardness is only 60.9, decreased about 11.7%~14.2%, which does not meet the requirment for Grade B anhydrous hydrazine resistant in standard [11]. It should be cautious when being selected as the material for diaphragm tank bladders.

References

- [1] Beach Norman 1966 Compatibility of Plastics with Liquid Propellants *Fuels and Oxidizers*. Dover, New Jersey
- [2] Ballinger I, Lay W, Tam WJAJ 2013 Review and history of PSI elastomeric diaphragm tanks
- [3] Coulbert CD, Cuddihy EF, Fedors RF 1973 Long-time dynamic compatibility of elastomeric materials with hydrazine
- [4] Coulbert CD, Cuddihy EF, Fedors RFJI 1984 Research ECP, Development. Long-time dynamic compatibility of two ethylene-propylene elastomers with hydrazine.
- [5] Ballinger I, Sims D, editors 2013 Development of an enhanced EPDM elastomeric material for use in hydrazine propulsion systems *Aiaa/asme/sae/asee Joint Propulsion Conference and Exhibit*
- [6] Li P, Aguirre F, Killpack MO, Rodgers SL, Ballinger IAJJoE 2014 Plastics. Compatibility of hydrazine and EPDM rubber containing polybutadiene coagent *Journal of Elastomers & Plastics*
- [7] Ministry of Chemical Industry, Ministry of Aerospace Industry. Anhydrous Hydrazine: GJB 98-86. Beijing : Standards Press of China, 1987
- [8] Ministry of Chemical Industry. Vulcanized rubbers - Resistance to anhydrous hydrazine - Methods of test Part 1: Immersion test: GJB 465.1-88. Beijing: Standards Press of China, 1989
- [9] National technical committee for standardization of rubber and rubber products. Rubber, vulcanized or thermoplastic: Determination of tensile stress-strain properties: GB/T 528-2009. Beijing: Standards Press of China, 2009
- [10] Ministry of Chemical Industry. Vulcanized Rubber- Resistance to Anhydrous Hydrazine- Method of Test Part 3: Catalytic Decomposition Test: GJB 465.3-88. Beijing : Standards Press of China, 1989
- [11] Ministry of Chemical Industry, Ministry of Aerospace Industry. Rubber Material for Anhydrous Hydrazine Resistant: GJB 989-90. Beijing : Standards Press of China, 1991
- [12] Ministry of Chemical Industry. Vulcanized Rubber- Resistance to Anhydrous Hydrazine- Method of Test Part 2: Permeation Test: GJB 465.2-88. Beijing : Standards Press of China, 1989