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AN EVALUATION OF TECHROLL SEAL FLEXIBLE JOINT MATERIAL

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ABSTRACT

An Evaluation of Techroll Seal Flexible Joint Material

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On April 7, 1983 a Tracking and Data Relay Satellite (TDRS) launched from Space Shuttle 6 failed to reach geosynchronous orbit. The conclusion reached from an intensive investigation was that the satellite tumbled out of control due to failure of an oil seal in the rocket system known as Inertial Upper Stage (IUS). The oil seal is a flexible joint permitting swivel or gimbal of the rocket nozzle to control direction of flight.

This study evaluated the materials utilized in the flexible joint for possible failure modes. Studies undertaken included effect of temperature on the strength of the system, effect of fatigue on the strength of the system, thermogravimetric analysis, thermomechanical analysis, differential scanning calorimeter analysis, dynamic mechanical analysis, and peel test.

These studies indicate that if the joint failed due to a materials deficiency, the most likely mode was excessive temperature in the joint. In addition, the joint material is susceptible to fatigue damage which could have been a contributing factor.

Introduction

The Air Force Space Division Inertial Upper State (IUS) is a three-axis stabilized, two-stage vehicle used to take payloads from low earth orbits to other regions of space such as a geosynchronous orbit. The primary propulsion system is composed of two solid rocket motors built by Chemical Systems Division (CSD) of United Technologies Corporation. The first stage (SRM-1) contains 2[illegible],400 lb of propellant and is used as a perigee kick motor to provide the energy required to go from low earth orbit to geosynchronous orbit. The second stage (SRC-2) contains 6000 lbs of propellant and is used as an apogee kick motor to provide the energy to circularize the geosynchronous orbit. On a typical shuttle mission the IUS could place up to 5100 lbs into geosynchronous orbit. SRM-1 and SRM-2 were designed with as much commonality as practical to improve reliability and minimize cost. Common items include case material and strength level, insulation and liner material, nozzle material, thrust vector control, thrust vector control actuators, ignition system, flexible joint concept, and identical manufacturing procedures and techniques.

The flexible joint concept (Techroll seal) was developed to permit the use of a low-weight electromechanical actuation system as required by the stringent use parameters in the shuttle program. The movable Techroll seal is a constant volume, fluid-filled bearing using a seal configured with two rolling convolutes which permit omniaxial deflection of the nozzle assembly. The Techroll seal consists of two layers of Kevlar-29 fabric layered between two sheets of neoprene rubber with steel cable beads for seal retention. One layer of the Kelvar-29 fabric is sufficient for load carrying. The second layer is redundant for extra safety.

Typical operating temperature for the motors ranges from 45°F to 82°F. These temperatures are maintained at this level by insulation and heaters. However, prior to use the motors are exposed to other temperatures in various transportation sequences.

A Tracking and Data Relay Satellite (TDRS) launched from Space Shuttle 6 failed to reach geosynchronous orbit. The ensuing investigation concluded that the satellite went out of control due to the failure of the Techroll seal. This study was conducted to identify possible failure modes for the flexible joint. Specific materials properties were determined regardless of probability of the Techroll seal system being exposed to exactly the same physical parameters.

Material Evaluation

Several tests were conducted to determine possible failure modes of the composite Techroll seal material. These tests included:

a. Strength versus temperature

Tests were conducted utilizing a Model 1113 Instron Universal Testing machine with a 5000 lb capacity. Specimens were brought up to temperature, held for five minutes, and pulled to failure in tension, at a pull rate of 10 in/min.

b. Strength versus number of fatigue cycles

Flexural fatigue cycles were obtained at room temperature on a MIT Folding Indurance Testor per ASTM D-2176-63T under an applied load of 1 kg. Strength was then determined at room temperature by pulling the flexed specimens to failure in tension utilizing a Model 1113 Instron Universal Testing Machine with a 5000 lb capacity.

c. TGA

Thermogravimetric analysis in Air and N_2 was conducted utilizing the DuPont 1090 system with the Model 951 TGA attachment. Additional TGA tests were conducted in vacuum utilizing a Mettler Model TA-2.

d. TMA

Thermomechanical analysis was conducted utilizing the DuPont 1090 system in conjuction with the Model 943 TMA attachment.

e. DSC

Differential scanning calorimeter tests were conducted utilizing the DuPont 1090 system with the Model 910 DSC attachment.

f. DMA

Dynamic mechanical analysis was performed utilizing the DuPont 1090 system in conjunction with the Model 982 DMA attachment.

g. Peel Test

Bond strength of the various layers of the Techroll seal composite was determined utilizing the Model 1113 Instron Universal Testing Machine.

h. SEM Evaluation

Scanning electron microscope analysis was conducted utilizing a Cambridge Stereoscan Model 250 MK2.

Results

Strength of the Techroll seal composite at various temperatures is shown in Figure 1. This data indicates the strength deteriorates rapidly at temperatures in excess of 200°F with only 54% of the original room temperature strength remaining at 500°F.

The slight increase in strength from 75°F to 200°F is attributed to increase in ductility of the Kevlar fibers, whereby a greater load sharing capacity overides the decrease in individual fiber strength. The decrease in strength of the composite material as it is subjected to flexure cycles is shown in Figure 2. The strength decreases rapidly with number of flexure cycles up to 1000 cycles, where the rate of decline in strength decreases.

The differences in rate of strength deterioration between flat sheet material and Techroll seal material is attributed to the difference in the lay-up configuration and bond strength between layers. The flat sheet material had 47% of non-flexed strength left after 1000 cycles while the Techroll seal had 57% after 1000 cycles.

Thermogravimetric analysis (TGA) results as shown in Figures 3,4,5 and Table 1 show that the material is stable over the anticipated operating temperature range. However, if the temperature should exceed 75°C, the neoprene begins to decompose, with rapid decomposition occurring above 285°C. The Kevlar fibers begin to deteriorate at 350°F, with the rate dependent upon environment. The vacuum environment causes the greatest loss of weight up to the 350°F range, while air causes the greatest loss of weight above that temperature. This latter weight loss is attributed to an oxidation process.

TMA results shown in Figure 6 indicate uniform properties in the range of -33°C up to 100°C. No change in these properties would be anticipated until decomposition temperatures are reached The abrupt change in the slope of the curve shown at -33.3°C is connected to the Tg of the system.

DSC results shown in Figure 7 indicate no reactions in the range of 0-100°C, with two minor indothermic reactions occurring between -45°C and 0°C, with the first reaction occurring at the Tg of neoprene.

DMA results shown in Figure 8 indicate stable conditions in the anticipated use temperature range of 7°C up to 28°C. No further change would be anticipated until decomposition temperatures are reached. The large decrease in E and increase in damping capacity at approximately -30°C is connected to the Tg of the system.

Peel test results shown in Table 2 indicate that bonding between layers in the composite is very weak, a known problem with Kevlar fibers. A good bond strength would be in the range of 15 lb/in.

SEM analysis indicates the primary mode of damage to the fiber during flexure is splitting of fiber into many other fibers of much smaller diameter, and breakage of these smaller fibers. This type of damage is shown in Figure 9.

Discussion of Results

The evaluation of the flexible joint materials revealed the following:

a. The strength of the composite degrades rapidly at temperatures above 200°F.

b. The Kevlar fibers are very susceptible to flexural cyclic damage.

c. Bonding rubber to Kevlar, and Kevlar to Kevlar produces a very weak bond which percludes much load-sharing ability of the system.

d. Neoprene begins to decompose at 75°C with rapid decomposition above 285°C in vacuum. This would permit the fluid to escape from the seal, causes loss of swivel ability and thereby loss of control.

The most likely mode of failure of the Techroll seal would be excessive temperature with flexure damage being a contributing factor.

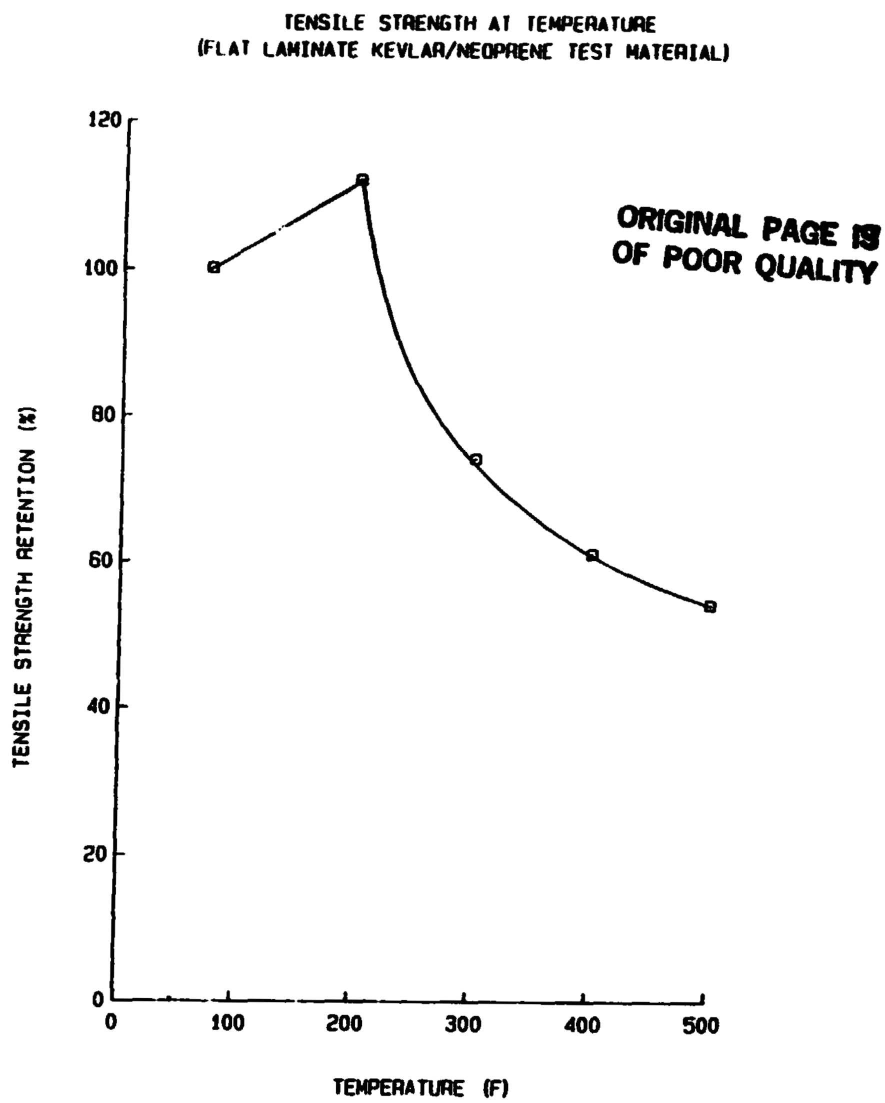

Figure 1. Per cent room temperature tensile strength retained versus test temperature.

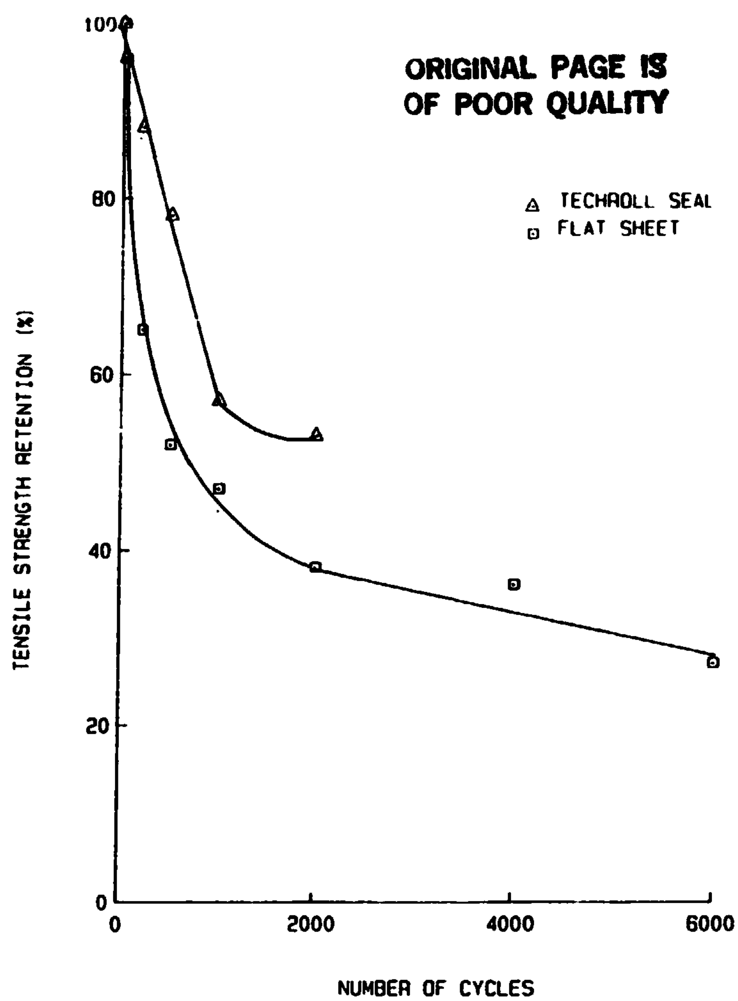

Figure 2. Per cent unflexed tensile strength retained versus number of flexed cycles.

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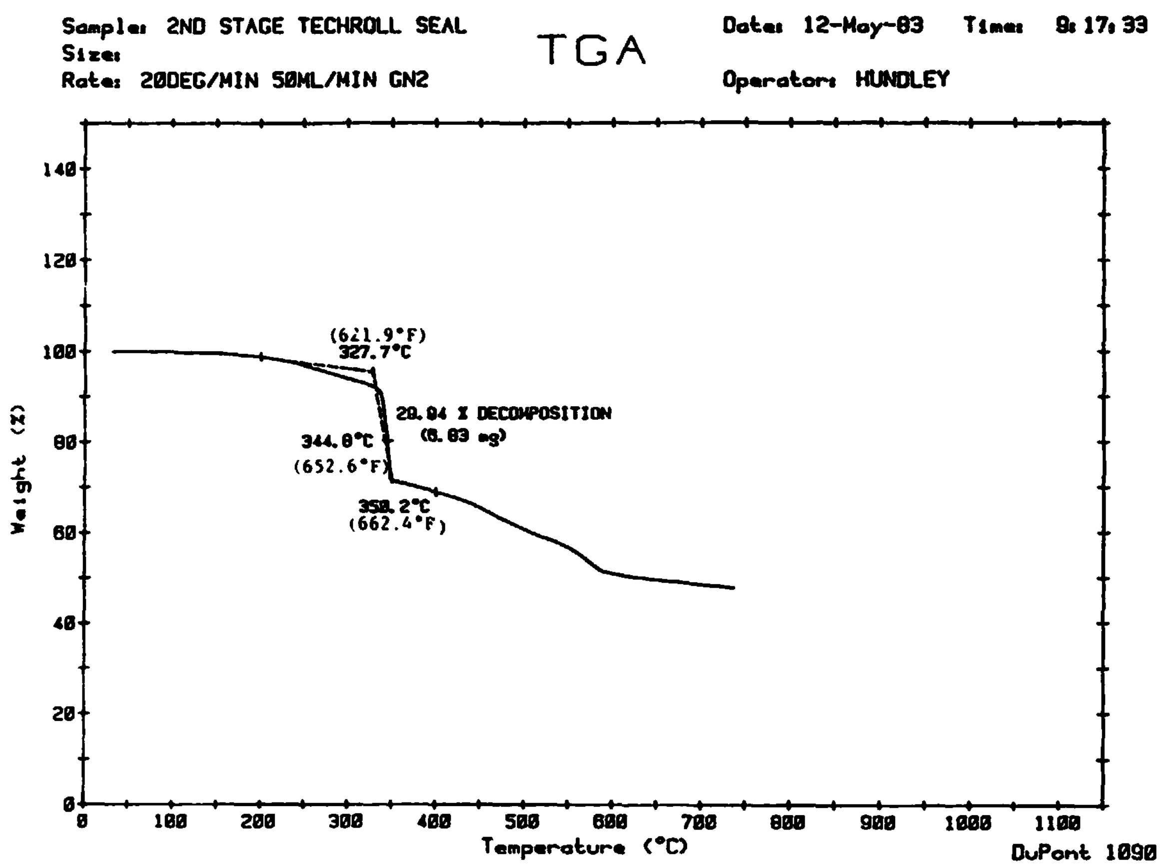

Figure 3. Thermogravimetric analysis of Techroll seal material in N_2 atmosphere

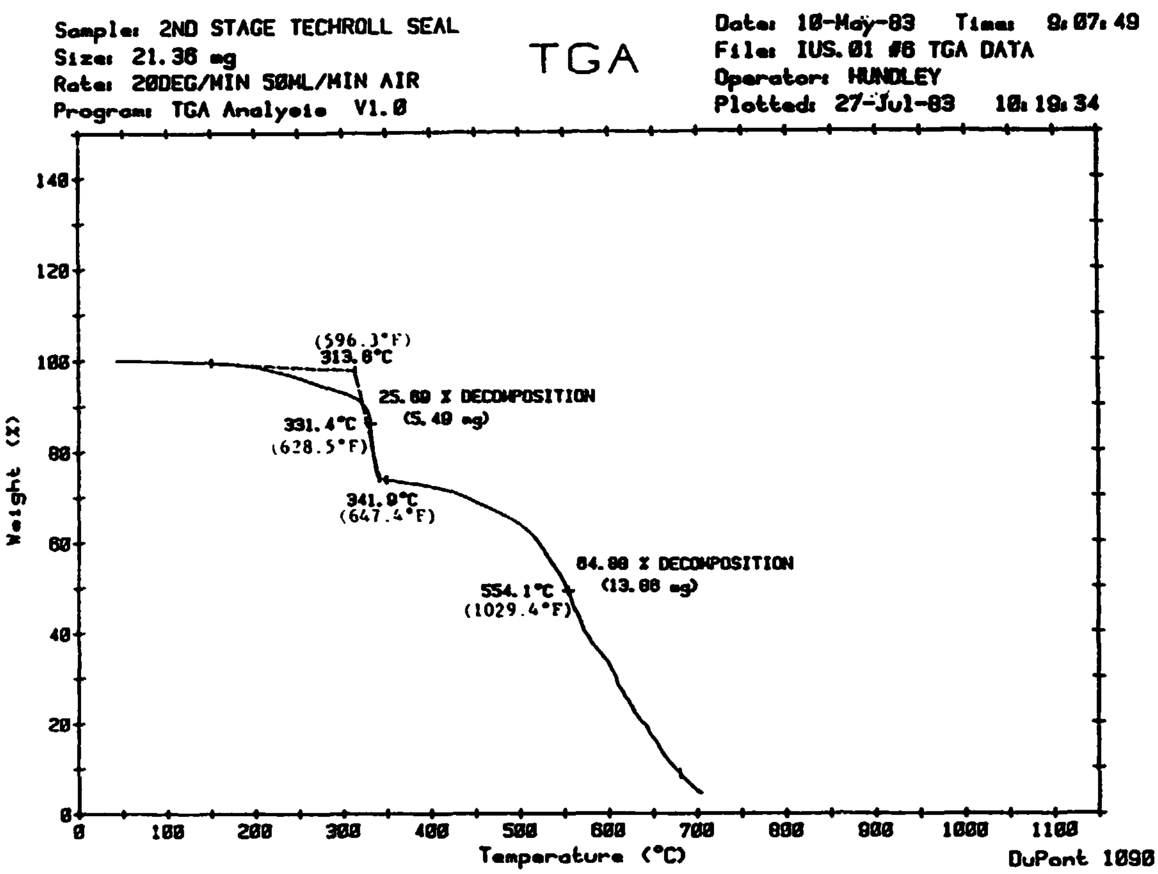

Figure 4. Thermogravimetric analysis of Techroll seal material in air atmosphere.

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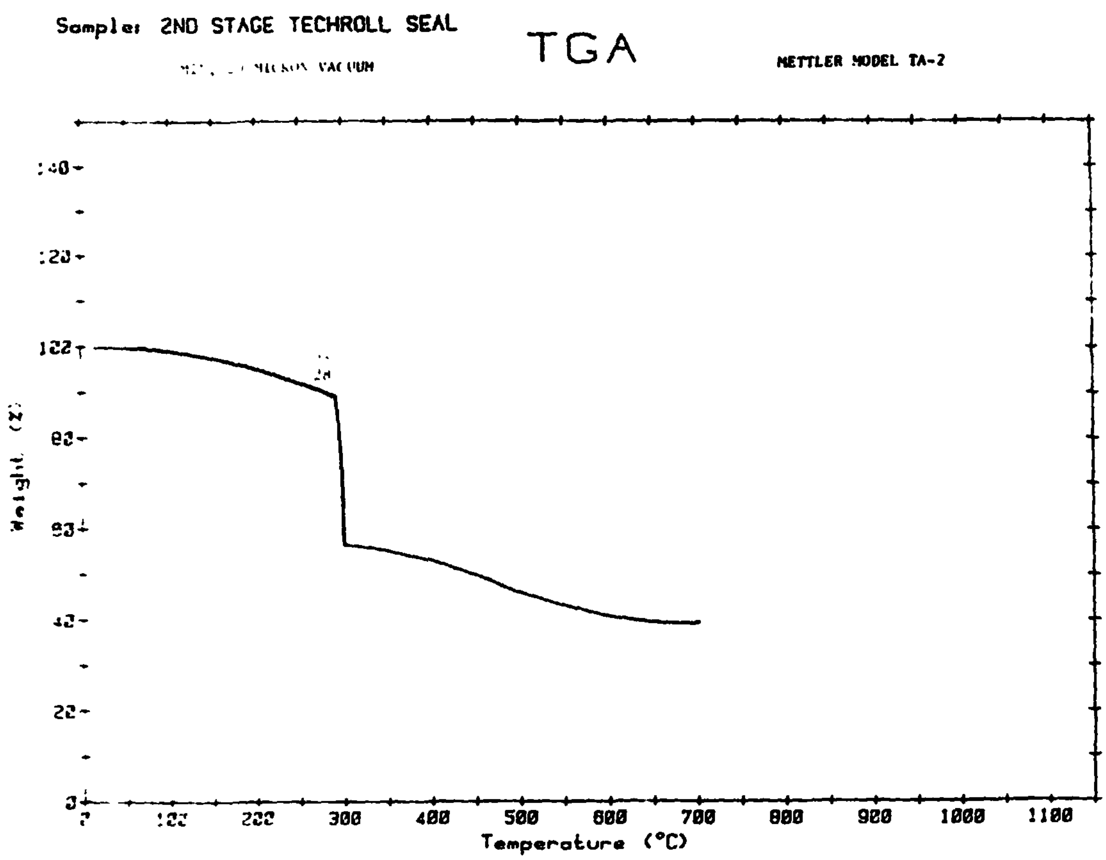

Figure 5. Thermogravimetric analysis of Techroll seal material in vacuum.

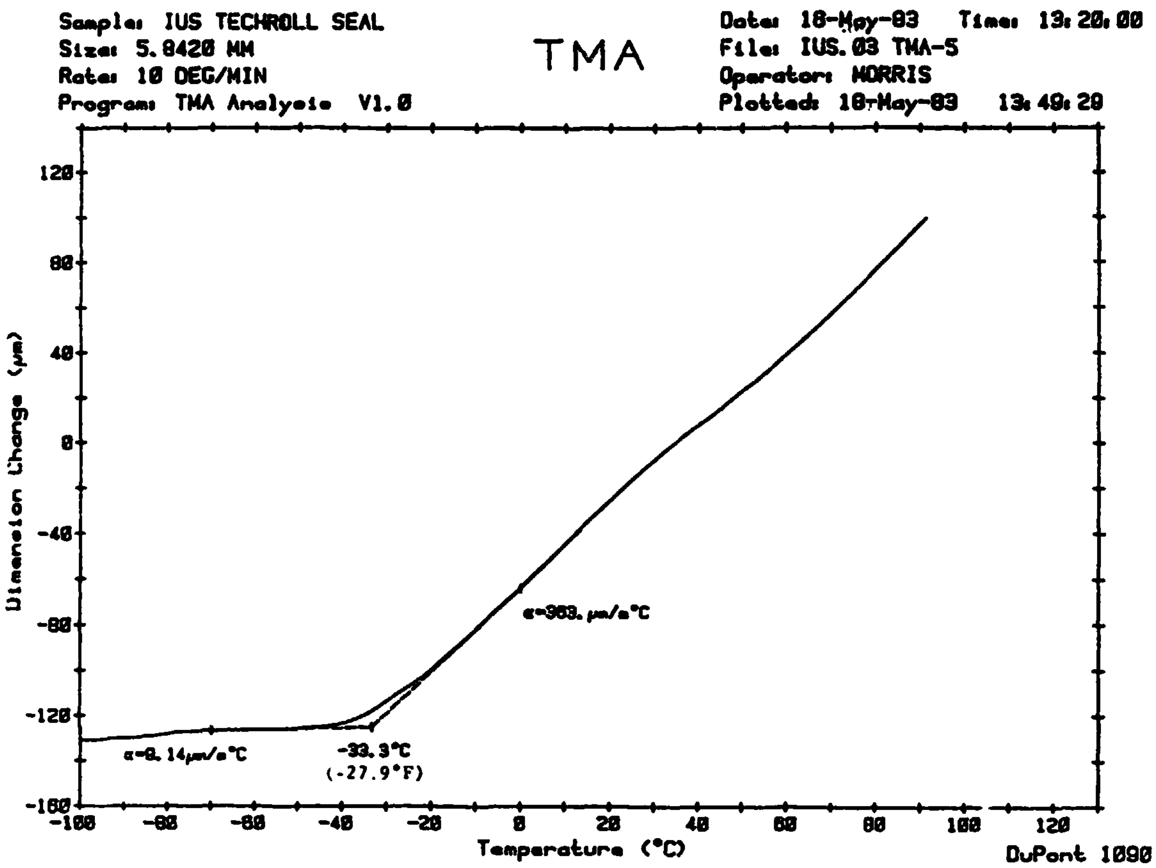

Figure 6. Thermomechanical analysis of Techroll seal material.

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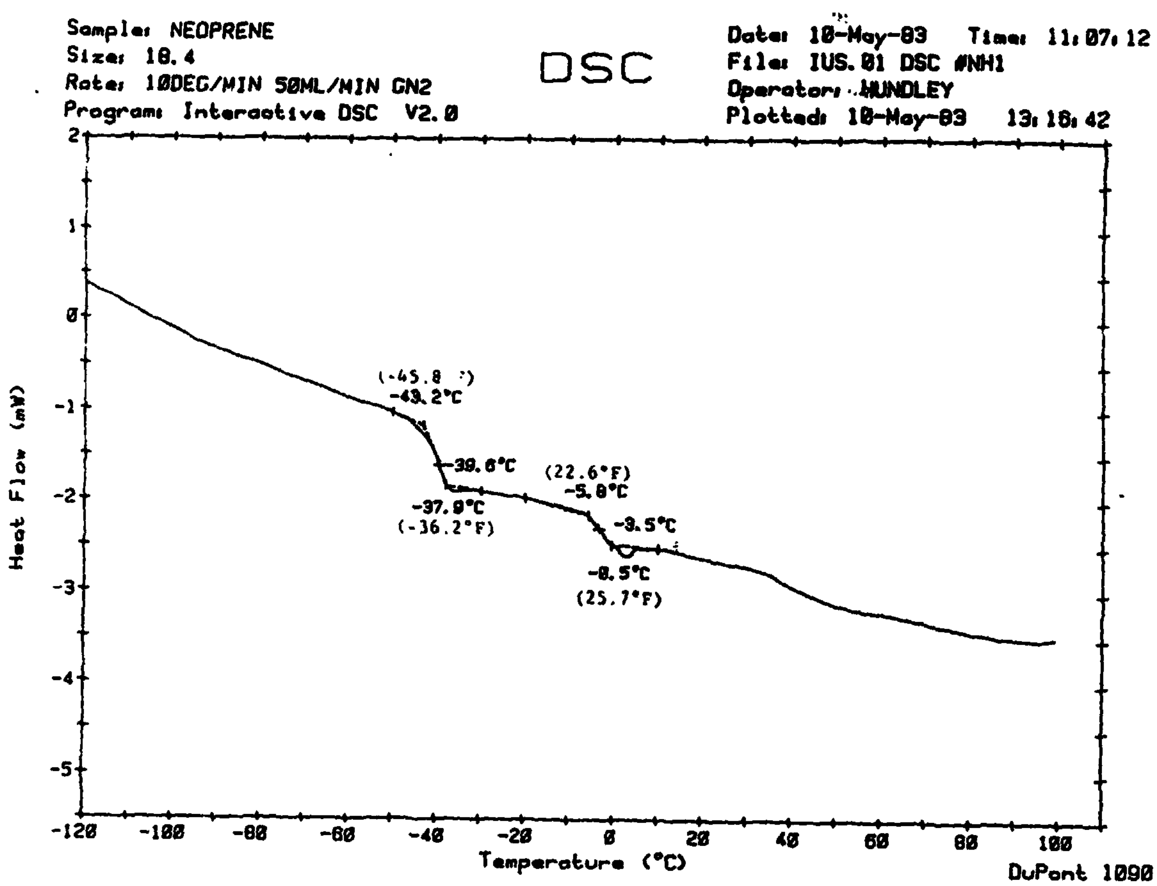

Figure 7. Differential scanning calorimeter analysis of neoprene.

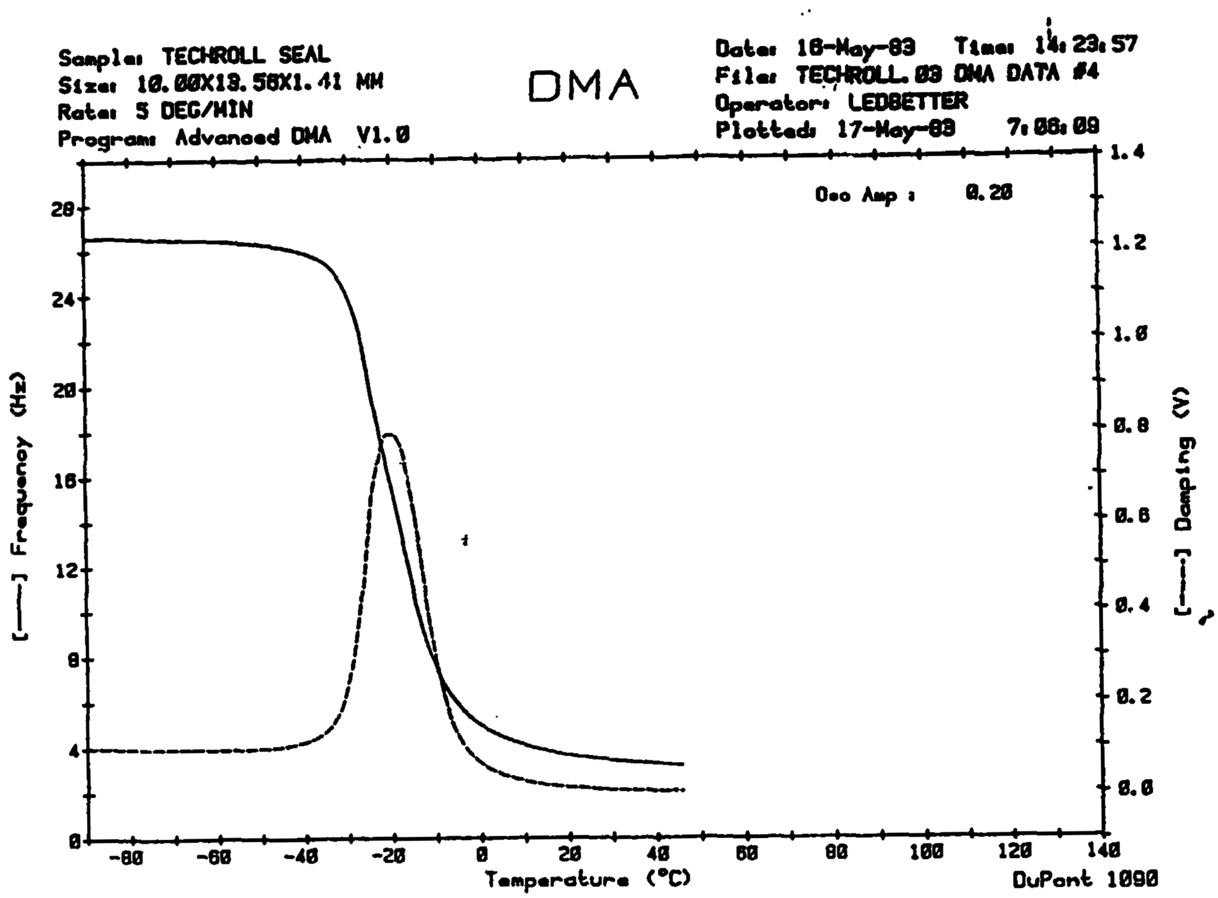

Figure 8. Dynamic mechanical analysis of Techroll seal material

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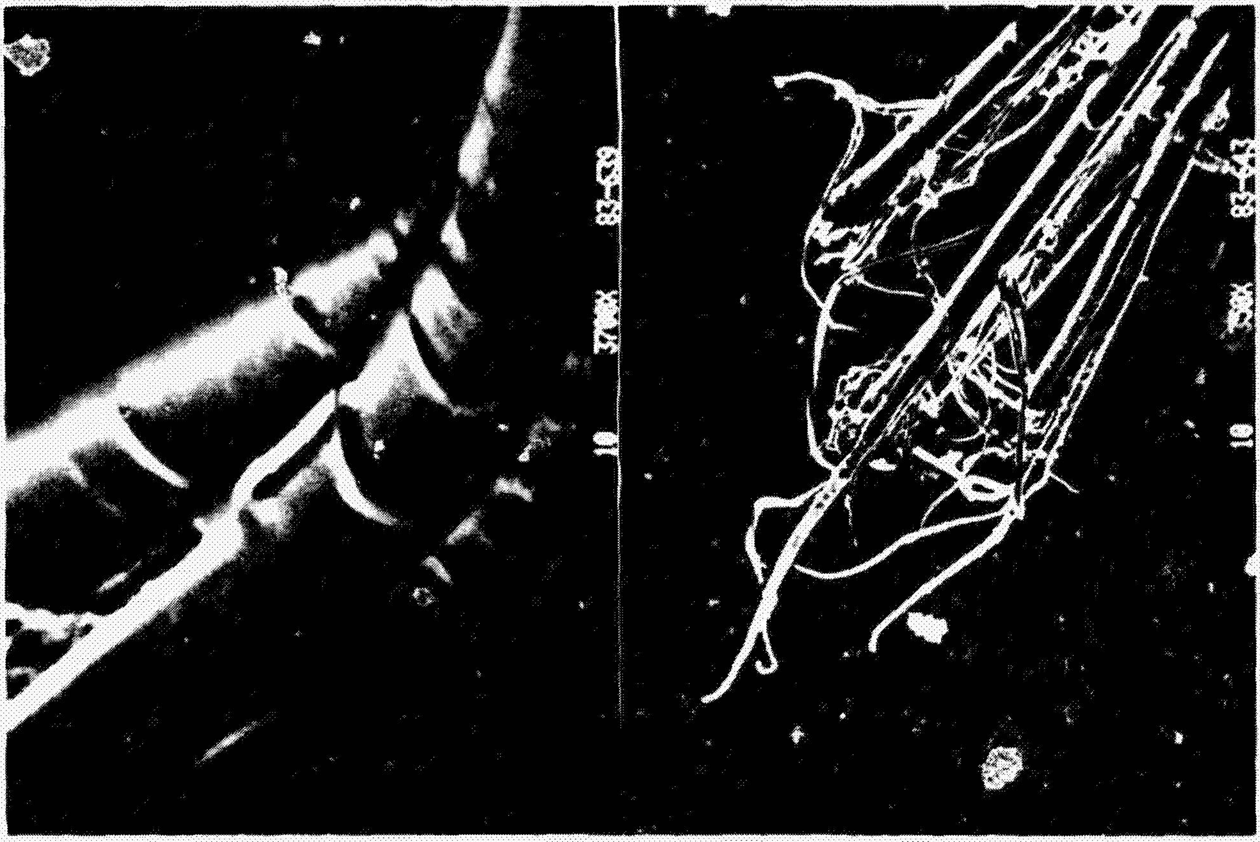

Figure 9. SEM analysis of Kevlar fiber degradation due to flexure.

Atmosphere	Temperature of first weight loss (°C)	Neoprene Decomposition Temperature (°C)	Total weight loss (%)
Vacuum	75	285	57
Air	150	314	95
N_2	200	328	52

Table 1. Comparison of Thermalgravimetric analysis of Techroll seal material in different environments.

180 DEGREE PEEL TEST

FLAT SHEET	PEEL STRENGTH, LBS./INCH
0.010" RUBBER TO KEVLAR	2.0
0.010" KEVLAR TO KEVLAR	4.5
0.035" RUBBER TO KEVLAR	4.0
TECH ROLL SEAL	
0.013" RUBBER TO KEVLAR	3.0
0.013" KEVLAR TO KEVLAR	0 - 4.0
0.040" RUBBER TO KEVLAR	4.0

INHERENTLY LOW BOND STRENGTH BETWEEN KEVLAR AND NEOPRENE OBSERVED

LARGE AREAS OF DELAMINATION PRESENT IN TRS

Table 2. Peel strength of Techroll seal composite.