ENERGY ABSORBING SEAT CUSHIONS FOR USE IN GLIDERS

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Abstract

Energy absorbing cushions are used to reduce the incidence and the severity of spinal injury in the event of a heavy landing or an accident in a glider. The special properties of the polyurethane material used in the cushions is due to their molecular structure. The seating foam is an open cell material. The mechanism of energy absorption is discussed. Impact experiments on a test track using Hybrid 111 anthropometric test devices showed a significant reduction in spinal load when energy absorbing seat cushions were used. Technical methods for testing the foam are described. The result of these test methods in relation to energy absorbing properties is discussed, but it is not possible to give a permissible range of numerical values for the test results. Advice is given as to the fitting of energy absorbing seat cushions in gliders.

Nomenclature

There has been discussion as to whether the foam should be called energy absorbing foam or energy attenuating foam. Definitions are as follows. (Ref. 1).

Absorb. 'To reduce the effect or intensity of (sound or an impact)". Attenuate. "To reduce the strength, effect, or value of'.

It is seen that both words have the same meaning. I therefore consider the foam should be called energy absorbing foam as this is a well known and understandable term.

Introduction

This paper discusses the molecular and physical structure of polyurethane foam, and the effect of the environment on the foam. The three phases of compression loading are described. The <u>mechanism</u> of energy absorption is discussed. Technical test methods for the properties of foam are described, and the significance of the results discussed in relation to energy absorption. It has not been possible to assign specific numerical values to the test results. The relation between seating comfort and the risk of spinal injury is discussed. Advice is given on fitting energy absorbing cushions into gliders.

Duration of the Applied Acceleration

The duration of the applied acceleration is of significance. (Ref. 2).

<u>Short duration acceleration</u> lasts from 0.1s - 0.5s and is the time course for an impact event.

Intermediate duration acceleration lasts from 0.5s - 2.0s and is experienced during ejection from an aircraft, catapult launches and deck landings.

Long duration acceleration lasts longer than 2.0s, may last for minutes, and is experienced during aircraft manoeuvres. This is not relevant to the present study into impact.

Many experiments on seat cushions have been carried out in regard to ejection from aircraft due to the importance of ejection in regard to military aircrew. However, the findings may not be applicable to impact events owing to the different time scale.

The Molecular Structure

The molecular structure of polyurethane materials explains their special properties. (Ref. 3). Polyurethane is an elastomer. (An elastomer is defined as a natural or synthetic polymer having elastic properties). Polyurethane consists of long flexible molecular chains with some degree of mechanical entanglement, containing large numbers of polar groups. (A polar group has an electrical or a magnetic field). The polar groups form strong physical-chemical bonds, preventing the chains sliding easily over each other. This results in an elastomer of high modulus. (Modulus is defined as a constant factor or ratio relating a physical effect to the producing force). Reinforcing fillers are not needed, so an elastic material can be obtained with a level of hardness not possible with conventional rubbers. At elevated temperature, the polar crosslinks are relatively easily broken, so the properties of polyurethanes decrease more rapidly at high temperature than is the case with other elastomers.

The Physical Structure

An open cell foam should be used for energy absorbing cushions. Care is required in the manufacturing process as variation in density and large air voids will adversely affect the energy absorbing properties. (Ref. 4, 7).

The Effect of the Environment

(Ref. 3)

High Temperature. All properties are adversely affected. For many applications, 80°C represents a maximum temperature. Below 80°C, polyurethanes are regarded as stable for continuous service.

Low Temperature. The properties are affected but no degradation occurs and the effect is completely reversible. There is only a small increase in torsional stiffness as the temperature falls from +20°C to -25°C, then there is a rapid increase in stiffness. Polyurethanes only become brittle at temperatures of -60°C to -80°C.

Hydrolytic Stability. Polyurethanes degrade over time due to attack by water, either by being immersed in water or by being exposed to moist air. This is due to the chemical composition of the main molecular chain.

Light Resistance. The resistance to ultraviolet light and to outdoor weather is good. On exposure to sunlight the surface darkens. On exposure to very bright sunlight some surface deterioration can occur, although this does not spread through the mass of the material.

The Effect of Compression Loading

This has three phases, as follows. (Ref. 7).

The first phase. This is a phase of high compression modulus, the material behaving like a stiff spring during which the cell walls remain largely undistorted.

The second phase. This is a phase of low modulus where small increments of pressure produce large compressions due to the collapse of the cell walls.

The third phase. This is a return to a high modulus when most of the air has been expelled and it behaves like a solid.

During recovery. During recovery from compression loading the foam shows marked hysteresis. The hysteresis is greater in polyester polyurethanes than in polyether polyurethanes. (Hysteresis is defined as a phenomenon in which the value of a physical property lags behind the changes in the effecting property causing the change).

Energy Absorbing Properties

There are several mechanisms of action. These are quantified by measurements of resilience, hysteresis energy and damping properties. (Ref. 3).

The resilience. The resilience alone of the foam is not a sufficient measure of its energy absorbing properties. The energy absorbed is greater than the effective crush distance alone would indicate. It is probable that tensile stresses and shear stresses around the periphery of the compressed zone play a large role in the total forces resisting compression. (Ref. 5).

Hysteresis energy. When a stress is applied to an elastomeric material there is a small time lag before before the material takes up the corresponding strain. This time lag is caused by the need for the intermolecular attractions to be overcome by the vibrational energy of the atoms. The result is that the stress-strain curve in recovery does not follow the same path as when the stress was applied. There is consequently a loss of energy from the foam material, which is converted into heat energy.

Damping. An oscillation is induced in the foam and a measurement made of the fast and second compressive wave. The ratio of the height of the second wave to that of the first wave provides a measure of the degree of damping. The lower the height of the second wave and the shorter its duration the more effective the damping.

Impact Test Results

This test (Ref. 6) used three Hybrid 111 anthropometric test devices (manikins) - 5th percentile female, 50th percentile male and 95th percentile male. The impact parameters were 17g and 9.4m/s. The manikin was strapped onto the seat of the test sledge in the vertical position. The seat was then rotated through 90°. This resulted in a load on the cushion that was being tested of 1g. Different thicknesses of foam cushions were used. The test results for the loads on the lumbar spines of the test manikins when using energy absorbing foam cushions follow.

The test showed there was a significant reduction in the spinal load of the pilot manikin, on impact, with increasing thickness of the energy absorbing foam cushion. The following figures show the thickness of the test cushion and the resulting spinal load on the test manikin.

<u>5th Percentile Female Manikin.</u>

No cushion		1,249 lb.f.	5,558 kN
1/2 inch	1.25 cm	1,083 lb.f.	4,819 kN
1 inch	2.5 cm	1,038 lb.f.	4,619 kN
2 inches	5.0 cm	823 lb.f.	3,662 kN
4 inches	10.0 cm	767 lb.f.	3,413 kN

<u>50th Percentile Male Manikin.</u>

No cushion		2,195 lb.f.	9,767 kN
1/2 inch	1.25 cm	1,981 lb.f.	8,817 kN
1 inch	2.5 cm	1,823 lb.f.	8,110 kN
2 inches	5.0 cm	1,512 lb.f.	6,729 kN
4 inches	10.0 cm	1,276 lb.f.	5,677 kN

<u>95th Percentile Male Manikin.</u>

No cushion		1,851 lb.f.	8,235 kN
1/2 inch	1.25 cm	1,608 lb.f.	7,156 kN
1 inch	2.5 cm	1,451 lb.f.	6,455 kN
2 inches	5.0 cm	1,338 lb.f.	5,961 kN
4 inches	10.0 cm	1,139 lb.f.	5,068 kN

Technical Test Methods (A)

The following information was taken from Reference 7.

DENSITY. This is a routine measurement.

TENSILE STRENGTH. The tensile strength increases with density. It is not of great significance, although the material will be more durable.

ELONGATION AT BREAK. This varies greatly, and is not of significance.

COMPRESSIBILITY. Sequential loading is carried out, allowing for 30 seconds between each additional weight. As already described, a sigmoid shaped curve is obtained with a hysteresis effect on the return curve. The PERCENTAGE COMPRESSION is defined as the percentage reduction in thickness from its original thickness. To give protection from an impact event, foam should only compress slightly under the resting weight of the pilot.

ELASTIC MEMORY. RATE OF RECOVERY FOLLOWING COMPRESSION. This describes the rate of recovery of a material after deformation. The test commences at 75% compression and the time taken to recover to 10% compression taken. The recovery time for a period of compression of 5 seconds, 15 seconds, 30 seconds and 60 seconds is taken. A short recovery time would result in a cushion able to bounce too much. The rate of recovery depends on the resilience of the foam material, and the resistance to airflow of the communication between air cells.

COMPRESSION SET. This is the permanent deformation resulting from prolonged compression, expressed as a percentage reduction of the original thickness. The test is carried out for a period of twenty four hours and also for seven days. After release from compression the measurement is taken after thirty minutes. It is important that the compression set is small so that the foam will suffer as little permanent deformation as possible in normal use.

DYNAMIC PROPERTIES OF FOAM. The following two methods are used:

1) COEFFICIENT OF RESTITUTION.

A steel ball is dropped onto the foam from a known height. The height of the first bounce is measured and expressed as a decimal fraction of the initial drop height, giving the coefficient of restitution. If no energy were to be absorbed by the foam, the ball or the air, the coefficient of restitution would be one. The lower the figure, the greater the energy absorbed by the foam. This is a simple test to carry out. However, the foam is tested in an unloaded condition.

2) DAMPING UNDER LOAD. PERSISTENCE RATIO.

The foam sample supports a lead mass, which is then set into oscillation by dropping onto it a further lead mass. Most of the air is expelled from the foam so there will be little further change in its properties. Oscillation recordings are made. The ratio of the height of the second wave to the first is termed the persistence ratio, and is a measure of the damping properties of the foam. The more the foam is damped, the more rapidly the oscillations die away and the lower the persistence ratio. As the foam is tested in a loaded condition, this is a more representative and realistic test.

Technical Test Methods (B)

The following information was taken from Reference 5.

COMPRESSION SET TEST. The foam is compressed between two flat plates larger than the specimen, under specified conditions of time and temperature. The reduction of thickness of the specimen is noted after removal of the load.

LOAD DEFLECTION TESTS. The following two methods are used:

1) INDENTATION LOAD DEFLECTION (ILD).

This is the load necessary to produce a specified 25% or 65% indentation under a circular indenter foot of 50 square inches area (322.6 sq.cm)

2) INDENTATION RESIDUAL GAGE LOAD (IRGL). Using the same indenter foot, the deflections under loadings of 4.45 N, 111 N, and 222 N are obtained, and of 111 N during unloading.

DYNAMIC DROP TEST. This more closely simulates impact conditions, although the foam is unloaded initially. An acceleration-time curve is obtained from a transducer on the impactor. The test parameters are the drop height (giving the impact velocity), the weight and the surface area of the impactor, and the thickness of the foam.

LOAD DEFLECTION TESTING OF URETHANE FOAMS FOR AUTOMOTIVE SEATING. This records the thickness of the cushion under an average passenger load, the initial softness, and the resiliency. A further test determines the thickness of the cushion under loads of 1 pound, 25 pounds and 50 pounds, with a circular indentor foot.

TEMPERATURE SENSITIVITY. A curve is drawn plotting Strain (percent) against Stress (pounds per square inch) under conditions of different temperature. Different types of foam vary in their response to temperature difference. Temperature sensitivity must therefore be considered as a selection criterion.

Notes on Test Methods

1) Some of the above papers quote recommended values for seating cushions for aircraft ejection seats. These values may not be applicable to the impact situation, owing to the different time scales of the impact and ejection situations.

2) Both the above reference documents present a mathematical analysis of the response of energy absorbing foam to impact and aircraft ejection seat conditions.

Seating Comfort and Protection from Spinal Injury

The following quotation (Ref. 8) is of relevance:

"Aircrew member comfort is essential for operational effectiveness in high-performance aircraft, particularly during long-duration missions lasting several hours".

Glider pilots experience considerable discomfort after flying for several hours on a firm grade of energy absorbing foam cushion. This is due to pressure on the ischial tuberosities of the pelvic bones. A thin layer of a soft grade of energy absorbing foam, on top of a thicker layer of a firm grade of energy absorbing foam, would provide seating comfort while still providing spinal protection on impact. The contact pressure at the ischial tuberosities would be decreased, and the load of the pilot's body would be distributed more evenly across the buttocks.

However, a possible problem arises from the requirement for a thicker seat cushion. If there is restricted headroom under a low cockpit canopy there may not be room to fit such a cushion.

An impact test was carried out using a layered seat cushion (Ref. 9). A ½ inch (1.25 cm) thick firm grade energy absorbing foam layer, was placed on top of a 1 inch (2.5 cm) thick hard grade energy absorbing foam layer. A pilot manikin was fitted with an accelerometer at the base of the spine. The manikin was strapped firmly onto the seat on the test sledge. The seat was then rotated through 90°, so the foam was loaded to 1g. The impact velocity for the test was 8.1 m/s. The following peak g readings were recorded.

Bare seat 35g

Ordinary soft foam cushion 45g

Energy absorbing layered foam cushion 26g

These test results showed that the layered energy absorbing foam cushion absorbed considerable impact energy, as well as providing pilot seating comfort. A further point of considerable interest and importance was the demonstration of the increased acceleration experienced by the spine on impact when ordinary soft foam was used as a seat cushion.

Advice on Fitting Energy Absorbing Foam Cushions

The cushion cover should be made of a material that is porous to air. The upper surface of the cushion should not be covered by an airtight structure. In the case of a motor glider, the material should be fire retardent. The cushion should be attached firmly to the underlying seat pan, but should be removable. The foam is firm, and if it were to slip forward it could prevent full movement of the control column.

Energy absorbing foam may also be used for padding sharp edges and corners in areas within the strike envelope of the pilot (Ref. 5). The edges and corners to be padded should have a minimum radius of 1/2 inch (1.25 cm) to prevent the foam being cut or broken away.

Conclusions

Energy absorbing seat cushions have been shown on testing to absorb considerable impact energy, so having the effect of reducing the severity of spinal injury in gliding accidents. If a layered cushion is used consisting of a softer grade of energy absorbing foam placed on top of a harder grade of energy absorbing foam, pilot comfort can be improved while retaining the protective effect of the cushion on the spine. The material is of low cost, and can be retro-fitted to existing gliders. The use of energy absorbing foam cushions is recommended.

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