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Ageing effect of non-metallic materials used within RAM packages

Author - Colin Turner
International Nuclear Services
Hinton House
Risley
Warrington
Cheshire
Tel: 01925 833197
e-mail: colin.turner@innuserv.com

Abstract

An integral design requirement of any transportation Type B flask used within the movement of radioactive material is the ability to retain its integrity, providing shielding and containment of the contents during routine, normal and accident conditions.

A key element of the package containment system is the lid seal assembly, which typically uses elastomeric seals and therefore has operating temperature limits. As the internal contents of the package are a source of heat, a key requirement of any package design is the ability to dissipate heat away from the seal, whilst minimising the effects of external temperatures.

To assist in preserving the integrity of a transportation flask, a shock absorbing feature is often incorporated into the design. Acting as an impact medium, minimising deformation or damage to the internal contents, shock absorbing materials have commonly been in the form of wood, alloys and polymers.

In physically, high mass large flask designs, the thermal protection and shock absorbing features are often positioned on the extremities of the package, resulting in reduced exposure to high temperatures. However, in smaller packages, the mechanical and thermal protection is located much closer to the heat source, resulting in higher operating temperatures during transportation.

This paper will discuss a detailed investigation undertaken to understand the mechanical and thermal characteristics of two such materials used within a Type B package. The findings will assist in understanding the effect of cyclic exposure to high temperatures on both organic and synthetic materials over the lifecycle of a re-usable package.

Introduction/Background

'all packagings are periodically inspected and, as necessary, repaired and maintained in good condition so that they continue to comply with all relevant requirements and specifications, even after repeated use.'

Paragraph 306 - Regulations for the Safe Transport of Radioactive Materials TS-R-1 2009 Edition [1]

When performing periodic maintenance procedures and serviceability checks on packages, standard assessments will often relate to the replacement of consumable items with a defined operational lifespan in the form of seals, visual checks of the outer body, concentrating in particular on abnormalities in the form of denting or abrasions on the outer skin or evidence of non-conformities around welded areas. Due to its ability to withstand corrosion and operate within high and low temperatures, stainless steel is a material commonly used as the primary structure within re-usable RAM packages.

It is relatively straightforward to identify anomalies, quantify their effects and implement a counteractive solution on solid uniform materials; however, can the same be said for organic and synthetic materials? How can we quantify the operational condition and the requirement to comply with safety regulations of substances that are inaccessible and have been subjected to operating temperatures during cyclic loading?

These are some of the questions which formed the basis of an investigation into two such materials, cork and TISAF [2] (Thermal Insulating Shock Absorbing Foam).

Cork: is a natural organic material consisting of a form of granulated wood (cork bark) mixed with a resin bond to form a solid structure (Fig 1). Key strengths of the material derive from its distinctive cellular structure. Cork is unique in that 50% of the material is captive air resulting in excellent compressive & elastic properties, low thermal conductivity and a superior resistance to heat.

Due to these properties, cork is used as a shock absorber and/or insulator within small packages.

TISAF: is a synthetic chemical composite material and is produced by the reaction of a phenolic resin with acid in the presence of mineral filler (Fig 1). The reaction is exothermic and results in a rigid closed cell foam structure. TISAF has relatively high mechanical strength, demonstrating good shock and impact absorbing characteristics in addition to good thermal resistance properties. In cases where the material is exposed to fire, TISAF displays excellent self extinguishing and fire retardant characteristics.

Fig 1: TISAF & Cork material

Testing

To establish the mechanical and thermal properties of the materials following multiple uses or thermal cycles (ageing) of a package under transport conditions, a series of tests was carried out on low density cork (230 kgm^{-3}) and TISAF (350 kgm^{-3}) samples (Ø74.9 x 50mm) [3], within a temperature range of (-20ºC to 200ºC) focusing on the following characteristics –

- Compression
- Recovery
- Conductivity
- Specific Heat

To replicate the thermal effect encountered during transport conditions, the material samples were ‘conditioned’ or ‘aged’ within temperature controlled chambers (Fig 2) for a period of up to 6 months. At monthly intervals, samples of each material were removed from the chambers and subjected to mechanical and thermal testing.

Fig 2: Test Sample ageing process

Mechanical Testing

The mechanical tests performed consisted of quasi-static compression testing to determine the stress/strain curves and recovery characteristics for both new material and samples aged at various temperatures and time periods.

The test specimens of cork and TISAF were radially constrained within a cylindrical pot and heated to replicate their ageing temperature. Using a servo-electric testing machine, within a temperature controlled chamber (Fig 3), the material samples were heated to their specified test temperatures and a compressive force was exerted vertically until the specimen had either displaced 60mm, was solid or the load capacity of the machine had been reached. The load vs. displacement data was recorded during the tests to allow evaluation of the stress/strain curves. Following the removal of the load, the specimen thickness was measured at various time intervals to determine the material recovery rate.

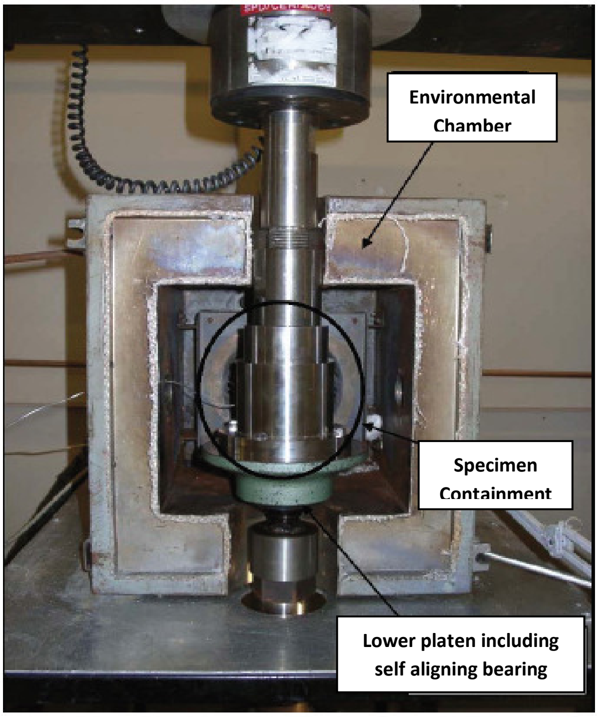

Fig 3: Compression test arrangement

Thermal Testing

<u>Specific Heat</u>: this test method was used to determine the effect of ageing on the thermal capacity of both cork and TISAF. Specific heat is the measurable physical quantity that characterises the amount of heat required to change the temperature of a material by 1ºC.

The technique used for determining the specific heat capacity was Differential Scanning Calorimetry (DSC) (Fig 4). This is a technique for measuring the energy necessary to establish a nearly zero temperature difference between a substance and an inert reference material, as the specimens are subjected to identical temperature regimes in a controlled environment.

Fig 4: Differential Scanning Calorimetry

Thermal Conductivity: this test was used to determine the effect that ageing may have on the ability of cork and TISAF to conduct heat. By understanding the thermal conductivity co-efficient of a new sample of material, through testing, we can determine if the cyclic loading or ageing of the material has any effect on the speed at which heat moves through it.

The technique used for the determination of steady state heat transfer properties, the thermal conductivity co-efficient and thermal resistance was the Guarded Hot Plate method (Fig 5), which is based on the principle of steady state heat flow measurement by passing a defined quantity of heat through a specimen. Due to the test equipment used within the process the dimensions of the material samples increased to 300mm x 300mm.

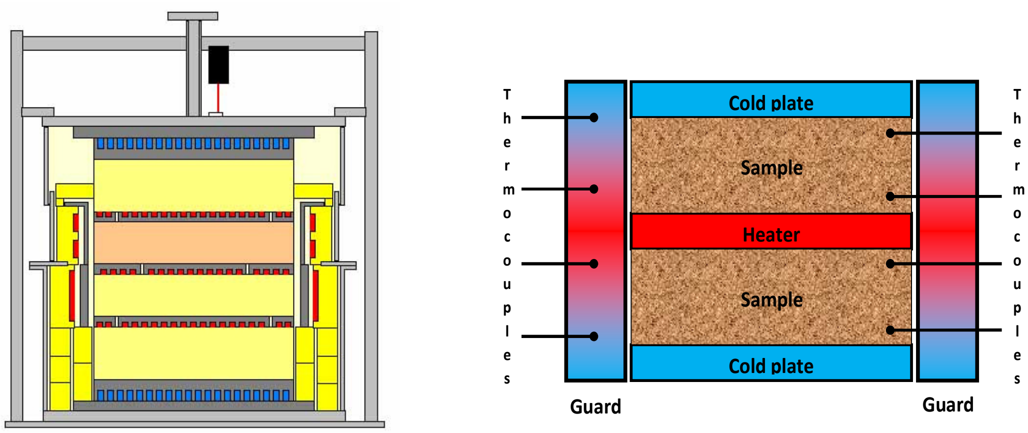

Fig 5: High-Temperature Guarded Hot Plate

Through the performance of mechanical and thermal testing on new and aged specimens, we can determine if significant changes to material properties occur during the lifetime of the package.

Results

Mechanical Testing

Cork: Test results show that aged samples up to four months at 150ºC (Fig 6) demonstrate similar stress/strain characteristics to that of a newly manufactured material sample [4]. Beyond this time period, a change occurs in the materials ability to deform, leading to the requirement of a higher applied load to compress the sample. This is due to the organic nature of the material. As the samples are subjected to prolonged periods of exposure to a constant temperature the moisture within the material evaporates, reducing material elasticity and changing the physical structure. The tests show that the cork effectively 'cooks', leading to discolouration of the sample and a reduction in overall dimensions.

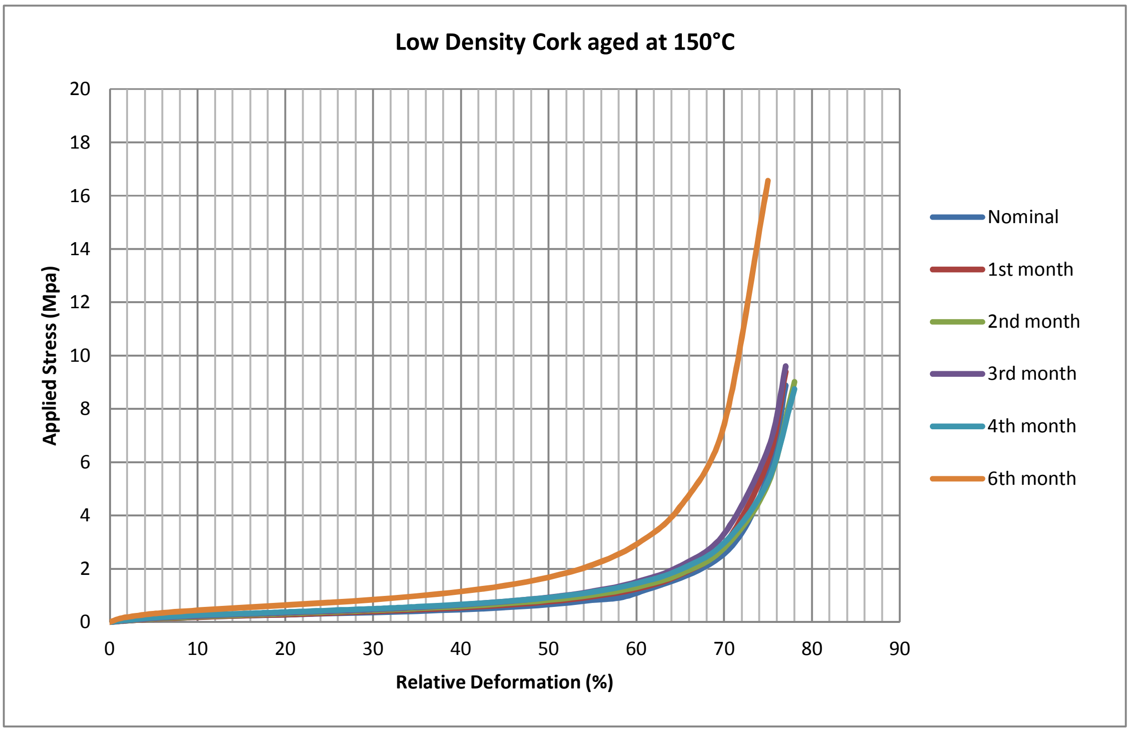

Fig 6

After six months of ageing, test results confirmed that the cork samples retained the ability to recover to approximately 92% of their original size, which were similar levels to those witnessed in previous months. However, due to the increase in stiffness, the initial recovery rates of six month aged samples were lower.

TISAF: Results show that samples aged for a period of six months at 100ºC exhibit a small reduction in relative deformation after month one, but subsequently there does not appear to be a significant difference between these and the tests performed at six months. (Fig 7)

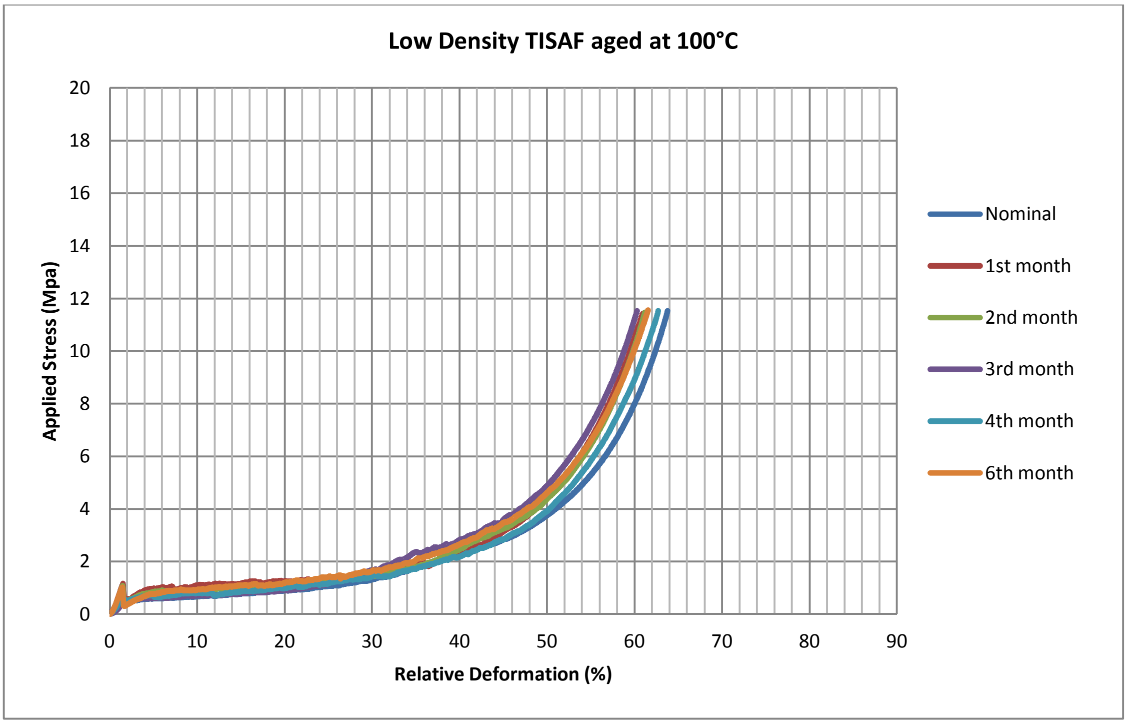

Fig 7

Due to the molecular structure and composition of TISAF, the introduction of an applied load resulted in the permanent deformation of the material through crushing until full compaction occurred. There was little or no measurable evidence of recovery following the removal of the load. In addition to this, temperature variation and ageing had no measurable effect on material recovery.

Thermal Testing

Specific Heat

Cork: Throughout the ageing process a reduction in specific heat capacity was observed between nominal and aged material samples. The results displayed endothermic reactions in the form of an increase in energy between 50-110ºC. This was attributed to the presence of moisture, as the effect reduced significantly due to the ageing process.

TISAF: The results obtained from the specific heat capacity tests performed on the TISAF material samples were similar to those observed on the cork material. The results again displayed endothermic reactions in the form of an increase in energy around 60ºC. The nominal test results observed two significant endothermic peaks between 70-180ºC This was attributed to both the presence of moisture and the loss of volatiles, as the effect again reduced significantly following the ageing process.

Thermal Conductivity

Cork: Test results demonstrate that the low density cork material samples retain a low thermal conductivity value up to four months of ageing at 150ºC. As demonstrated in the mechanical tests, after this period changes occur to the material composition and structure, which results in an increase in the rate of conductivity.

TISAF: The results performed on TISAF confirm that a constantly low value of conductivity is retained throughout the ageing process, with no significant changes in the rate of conductivity.

Conclusion

The test results demonstrate that due to the organic nature and material structure of cork, when produced at the specified density and operating at average temperatures of 150ºC, the components should be regarded as consumable; having a specified service life and being replaced at regularly defined intervals.

With respect to TISAF, the results show that when manufactured in the specified low density form and operating at average temperatures of 100ºC, there are no significant detrimental changes to the mechanical and thermal properties. Therefore the material can be used within a re-usable package, providing that operating parameters are controlled.

References

[1] International Atomic Energy Agency (IAEA) Safety Standards - Regulations for the Safe Transport of Radioactive Materials TS-R-1 2009 Edition

[2] Copyright of Croft Associates Ltd, Abingdon, Oxon OX14 3DB

[3] CP420 – Procedure for Mechanical and Thermal Testing of Cork and TISAF Materials (Croft Associates Ltd)

[4] SERCO/TCS/004597/001 – Quasi-static, Uniaxial, Compression Testing of Non-Aged and Thermally Aged Cork and TISAF