Elastothermoplastic polymer material for vibration insulation applications

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Abstract

Viscoelastic material such as rubbers and polyurethanes are widely used for acoustic attenuation and vibration insulation. Synthesised termoplastic copolyester elastomers are characterized by high values of the loss factor ($\eta_D =$ 0.13 to 0.36) over a broad frequency range (from 35 to 4500 Hz). The energy adsorbing abilities were measured by dynamic thermomechanical analysis and vibration transfer function method.

1 Introduction

The vibration control problems are usually identifiable as directly associated with some abnormal dynamic behavior of the part affected, and not with some far distant point which may be the source in the case of some other noise problems. The one phenomenon which dominates the dynamic behaviour of structures and machines is resonance. In order to reduce the amplitude at each resonance to a low value, energy must be dissipated in the structure (Figure 1) before it has the opportunity of generating high resonant amplitudes. This is what is meant by “damping”. Useful damping, however, can be introduced into a structure only by using materials or techniques which dissipate much larger amounts of energy than resonating structures customarily do.
Figure 1: A mass isolated from a structure by means of a damping material which has spring-like properties [1]

Most materials used for structural purposes are not noteworthy for the amount of energy which they are capable of dissipating under cyclic strain and, indeed, such behavior would be regarded as unacceptable for most design purposes unless dynamic response criteria were of primary importance. However, it is time that all materials, when strained cyclically, do dissipate some energy no matter now little it may be in some degree.

The damping behaviour of most elastomers, or rubberlike materials is the most readily amenable to characterisation and analysis as compare with metallic class of materials (Table 1).

Table 1. Loss factor $\eta_D$ for some selected materials [2]

<table>
<thead>
<tr>
<th>Material</th>
<th>$\eta_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>0.0016-0.0028</td>
</tr>
<tr>
<td>Cast-iron</td>
<td>0.036</td>
</tr>
<tr>
<td>Copper</td>
<td>0.05</td>
</tr>
<tr>
<td>Wood</td>
<td>0.016-0.02</td>
</tr>
<tr>
<td>Insulating materials based on natural rubber</td>
<td>0.02-0.16</td>
</tr>
<tr>
<td>Plastics (elastomers)</td>
<td>0.064-0.16</td>
</tr>
<tr>
<td>Cork</td>
<td>0.0064</td>
</tr>
</tbody>
</table>

The way in which the large number of available elastomeric materials differ from each other is in the variation of Young's Modulus $E_D$ and loss factor $\eta_D$ with frequency, temperature and strain amplitude. For example, polyurethane with microsphere as fillers [3,4] exhibit high damping properties over a wide frequencies range with loss factor values amounting from 0.09 at 20 Hz to 0.25 at 1000 Hz.

The variation of $E_D$ and $\eta_D$ with temperature for an elastomer, at fixed frequency and cyclic strain amplitude, are typical of the form shown in Figure 2.
Figure 2. Variation of modulus ($E_D$) and loss factor ($\eta_D$) of elastomers with temperature.

Three distinct temperature regions are observed, namely the glassy region, the transition region, and the rubbery region. It is important to realize that both $E_D$ and $\eta_D$ are temperature dependent, thus, the damping material must be selected on the basis of the temperature at which it is to be used. The rubbery region with plateau determines the temperature range at which an elastomer can be utilized.

Copolyesters are very interesting materials among thermoplastic elastomers. They are suitable for use under high loads, resist creep, are operational over a broad service temperature range without significant change in properties, and are chemical-resistant. They can also be processed by injection or moulding like other thermoplastic materials, with the added bonus of unusual process versatility [5].

The task of the presented paper is to determine experimentally the correlation between chemical composition of the synthesised polyesters and elasticity, and damping capacity of the elastomers using dynamic thermomechanical analysis and vibration transfer function method.

2. Characteristics of the material

The object of our investigations were segmented block polyesters synthesised in our laboratory [6]. Poly(butylene terephthalate)(PBT), as a component of the hard segments was modified by dimer fatty acid (DFA) (constitutional unit of the soft segments). The ratio of the mass concentration of hard and soft segments in resulted copolymers (PED) varied from very soft polymer (26%,-wt. of DFA) to a hard one (100% of PBT)(Table 2).
Table 2. Composition and mechanical properties of the synthesised copolymers

<table>
<thead>
<tr>
<th>Mass concentration</th>
<th>σr [MPa]</th>
<th>ε [%]</th>
<th>H</th>
<th>Shore D</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBT [%]</td>
<td>DFA [%]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>74</td>
<td>5.2</td>
<td>772</td>
<td>19</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td>12.8</td>
<td>705</td>
<td>37</td>
</tr>
<tr>
<td>45</td>
<td>55</td>
<td>16.5</td>
<td>682</td>
<td>42</td>
</tr>
<tr>
<td>64</td>
<td>36</td>
<td>29.7</td>
<td>606</td>
<td>57</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>34.1</td>
<td>596</td>
<td>69</td>
</tr>
<tr>
<td>90</td>
<td>10</td>
<td>37.2</td>
<td>389</td>
<td>73</td>
</tr>
<tr>
<td>100</td>
<td>-</td>
<td>46.2</td>
<td>35</td>
<td>76</td>
</tr>
</tbody>
</table>

σr - stress at break, ε - elongation, H - hardness

3. Measurement method

Temperature dispersions of the storage modulus (E'), loss modulus (E''), and loss tangent (\tan \delta) for the polymer film specimens were measured using a Rheovibron DDV-II viscoelastometer at frequency of 35 Hz, in the temperature range from -80°C to the melting endotherm of polymer, with heating rate 10 °C/min using dynamic thermomechanical analysis (DMTA).

In order to find the loss factor (\eta_D) of synthesized PED polymers in a high frequency range, the measurement method of vibration transfer function has been used [7]. The components of Young's complex modulus (E*) were determined, i.e. dynamic Young's modulus component, E_D, and loss modulus, E_l (E_l=E_d \cdot \eta_D, \eta_D - the loss factor) as a function of the frequency. Longitudinal vibrations were excited with an electrodynamic vibrator. A prism-shaped specimen of 1 cm² in cross-section and about 12 cm in length was bonded with a perfectly hardening adhesive to the impedance head A_1 (Brüel & Kjaer, type 8000) and the accelerometer A_2 (Brüel & Kjaer, type 4366). The amplitude of vibration acceleration of the vibrator was kept constant and adjusted carefully not to exceed the dynamic strain limit of linear properties of the investigated material. The measurements were taken at room temperature within the frequency range of 80 Hz to 4500 Hz. The error in calculating loss factor did not exceed 10%.

4. Results and discussion

In Figures 3 and 4, the DMTA traces taken at 35 Hz of the studied polymers as a function of temperature show relaxating processes during the transition from the glassy region to the polymer melt.
Figure 3. Dependence of storage modulus \((E')\) of block copolymers on temperature.

The logarithm of storage modulus \((\log E')\) (Fig. 3) shows rapidly decreasing \(E'\) values near the glass transition \((T_g)\), a wide rubber plateau where the soft segments are in viscoelastic state and hard segments are in crystalline form. After that, quick decreasing of \(E'\) values near the melt temperature is observed.

Logarithmic traces of tangent \(\delta\) (Fig. 4), shows in low-temperature part, relatively sharp maximums which are shifted to higher temperature with increasing the hard segments concentration. The sharp maximums observed in polymers containing many values of the amorphous phase provide information concerning the homogenous state.

Figure 4. Dependence of loss tangent of block copolymers on temperature.

Damping capacity (loss factor) of the synthesized polymers have been investigated based on the vibration transfer function method within the
frequency range of 80 Hz to 4500 Hz. It can be concluded from Figure 5 that investigated polymers exhibit high damping properties.

The property is evidenced by the high value of the loss factor amounting to 0.36 within the investigated frequency range (the loss factor values for PEE consisting of PBT hard segment and soft segment of PTMO oligoether are close to 0.15 [8]).

![Figure 5. Loss factor ($\eta_D$) and tangent $\delta$ as a function of polymers composition.](image)

Figure 5. Loss factor ($\eta_D$) and tangent $\delta$ as a function of polymers composition. ▼ 35 Hz (DMTA), ◇ 80 Hz, ◊ 600 Hz, ▣ 1000 Hz, ★ 1500 Hz, ▲ 2000 Hz, ▲ 4500 Hz

5. Conclusions

The method for synthesis of thermoplastic elastomers was elaborated and new material was characterised. The copolymers consist of oligomeric hard and soft segments which are alternated along the polymer backbone. It was found that these polymers exhibit a good damping ability within the temperature range at which the hard segments are in crystalline state and the soft segments are above the glass transition region (i.e. rubbery plateau). Obtained copolymers can be considered as a new construction material. Analysis of the loss tangent traces show that copolymers based on dimer fatty acid exhibit higher energy dissipation ability than those obtained from typical oligoether (tetramethyleneoxy diol). Good mechanical properties, good resistance for hydrolysis and weathering of synthesised polymers can make them well suited for potential practical uses such as vibration insulation material.
6. References

2. *VD-Berichte* Nr 1082, Dusseldorf 1993, 103