Vibration Reduction Ability of Polymers, Particularly Polymethylmethacrylate and Polytetrafluoroethylene

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SUMMARY

The vibration reduction ability of thermoplastics (PMMA, PTFE, PA-66 and acetal) and of a thermoset (epoxy) was compared by dynamic flexural testing at ≤ 1.0 Hz. Among these polymers, PMMA exhibited the highest loss modulus, while PTFE exhibited the highest loss tangent. A synthetic rubber had an exceptionally low loss modulus, but an exceptionally high loss tangent. Epoxy and acetal exhibited the lowest loss tangent.

INTRODUCTION

Vibrations are undesirable for structures, due to the need for structural stability, position control, durability (particularly durability against fatigue), performance, and noise reduction. Vibrations are of concern to large structures such as aircraft, as well as small structures such as those related to electronics.

Vibration reduction can be attained by increasing the damping capacity (which is expressed by the loss tangent, tan δ) and/or increasing the stiffness (which is expressed by the storage modulus). The loss modulus is the product of these two quantities and thus can be considered a figure of merit for vibration reduction.

Because of their viscoelastic behaviour, polymers (particularly thermoplastics) can provide damping[1,2]. Rubber is particularly well-known for its damping ability[3,4]. However, rubber suffers from its low stiffness, which results in a rather low value of the loss modulus[5]. Other polymers used for vibration damping include polyurethane[6], a polypropylene/butyl rubber blend[7], a polyvinylchloride/chlorinated polyethylene/epoxidized natural rubber blend[8], a polyimide/polyimide blend[9] and a polysulphone/polysulphone blend[9]. In relation to fibrous structural composites, viscoelastic polymeric interlayers are often used for damping, due to the dissipation of the vibrational energy through shear deformation of the constrained viscoelastic film[10-12]. Although the vibration reduction ability of polymers is of practical importance, there has been little systematic research on this subject[1,2].

This paper describes a comparative study of the vibration reduction ability of a number of polymers, including thermoplastics (polymethylmethacrylate, polytetra-fluoroethylene, polyamide-66 and acetal) and a thermoset (epoxy). The objective was to identify polymers that are good for vibration reduction. The vibration reduction ability of PTFE has been studied before[13], but this ability of PMMA has not. It is of practical significance that PMMA is superior to both PTFE and neoprene in the loss modulus. This finding opens up a new application direction for PMMA.

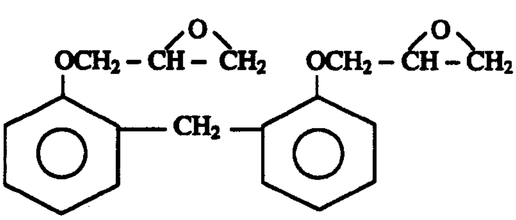
EXPERIMENTAL METHODS

Dynamic mechanical testing (ASTM D4065-94) at controlled frequencies (0.2 and 1.0 Hz) and room temperature (20°C) was conducted under flexure using a Perkin-Elmer Corp. (Norwalk, CT) Model DMA 7E dynamic mechanical analyzer. Measurements of tan δ and storage modulus were made simultaneously at various frequencies. The specimens were in the form of beams of length about 145 mm under three-point bending, with the span being 115 mm. The width of the specimens ranged from 13 to 16 mm. The thickness ranged from 2.6 to 3.2 mm. The width and thickness of each specimen were separately measured. The loads used were all large enough so that the amplitude of the specimen deflection was from 8.5 to 9.0 μm (over the minimum value of 5 μm required by the equipment for accurate results). The loads were set so that each type of specimen was always tested at its appropriate stress level. Three specimens of each type were tested, except that only two specimens were tested for the acetal case.

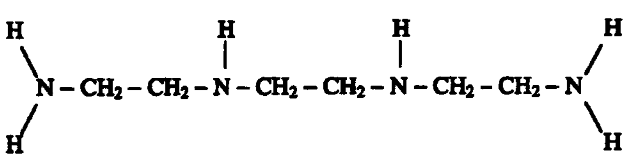
The PMMA material was obtained by free radical polymerization of methylmethacrylate (MMA, Fisher Scientific Co., Pittsburgh, PA), using 0.025 mol % 2,2'-azobisisobutyronitrile (AIBN, Aldrich Chemical Co., Milwaukee, WI) as the initiator. The MMA was purified using a standard technique[3]. After mixing the purified MMA with AIBN, the solution was pre-polymerized at 59°C for 50 min and then poured into a mould and allowed to sit at 40°C for 4 days, followed by heating at 90°C for 1 h.

The PTFE and acetal materials were kindly provided by TSE Industries (Clearwater, FL). The polyamide (nylon-66) was kindly provided by A.L. Hyde Co., Grenloch, NJ.

The epoxy material was obtained by curing epoxy resin (Epon 862, with 15.4 wt.% triethylenetetramine (TETA) EPI-CURE 3234 curing agent, Shell Chemical Co., Houston, TX). The structure of Epon 862 is



The structure of TETA is



After mixing the resin and the curing agent, the solution was poured into a mould, allowed to sit at room temperature for 24 h, and then heated (post cured) at 121°C for 2 h.

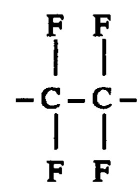
RESULTS

Table 1 gives the loss tangent, storage modulus and loss modulus of the various polymers studied in this work as well as those of Neoprene rubber®, which was studied in Ref. 5 using the same equipment as in this work. Of all the polymers listed in Table 1, neoprene rubber exhibits the highest loss tangent, 1.1 at 1 Hz, but the lowest storage modulus, and hence the loss modulus. PMMA exhibits the highest loss modulus, 375 MPa at 1 Hz, due to its combination of relatively high loss tangent and storage modulus. PTFE exhibits a lower loss modulus than PMMA, but a higher loss tangent. PA, acetal and epoxy have lower loss moduli than PMMA.

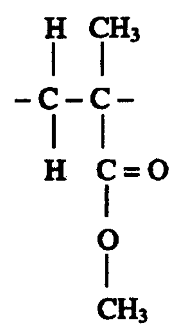
DISCUSSION

The repeat unit of each of the thermoplastic polymers studied is shown below.

PTFE



PMMA



Acetal

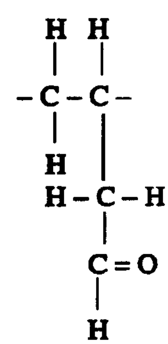
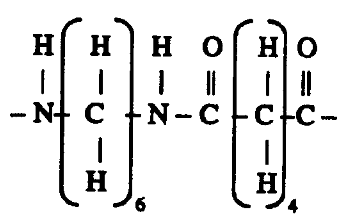


Table 1 Loss tangent, storage modulus and loss modulus of various polymers

Material	Property	0.2 Hz	1.0 Hz	Ref
PMMA	Loss tangent Storage modulus (GPa) Loss modulus (MPa)	0.093 ± 0.019 3.63 ± 0.24 336 ± 70	0.100 ± 0.038 3.49 ± 0.7 375 ± 83	This work
PTFE	Loss tangent Storage modulus (GPa) Loss modulus (MPa)	0.1885 ± 0.0005 1.22 ± 0.05 229 ± 9	0.224 ± 0.008 1.34 ± 0.05 300 ± 15	This work
PA-66	Loss tangent Storage modulus (GPa) Loss modulus (MPa)	0.043 ± 0.009 4.35 ± 0.05 187 ± 41	0.078 ± 0.035 4.45 ± 0.08 349 ± 161	This work
Acetal	Loss tangent Storage modulus (GPa) Loss modulus (MPa)	0.033 ± 0.006 3.73 ± 0.05 125 ± 25	0.063 ± 0.005 3.76 ± 0.04 238 ± 20	This work
Epoxy	Loss tangent Storage modulus (GPa) Loss modulus (MPa)	0.030 ± 0.007 3.20 ± 0.31 105 ± 24	0.039 ± 0.015 3.50 ± 0.07 116 ± 36	This work
Neoprene rubber	Loss tangent Storage modulus (MPa) Loss modulus (MPa)	0.67 ± 0.14 7.45 ± 0.28 6.72 ± 1.50	1.12 ± 0.08 7.83 ± 0.11 8.23 ± 0.76	5

PA-66



A high value of the loss tangent is associated with ease of movement of side chains, side groups, functional groups, chain segments and even entire molecules in the polymers. Hydrogen bonding, induced by the presence of electronegative atoms (such as oxygen and nitrogen) in the molecule, restricts movement, thereby decreasing the loss tangent. The loss tangent is high for PTFE because of the presence of fluorine atoms and the helical coil morphology of PTFE molecules[14]. The other three thermoplastics all exhibit hydrogen bonding between the molecules. The proportion of atoms that can form hydrogen bonds in the molecular chain is smaller in PA-66 than in PMMA or acetal. However, the C=O group of PMMA is less accessible than that of acetal for forming hydrogen bonds. The consequence (not completely understood) is that PMMA has a higher loss tangent than PA-66, which in turn has a higher loss tangent than acetal. The difference in T_g among the thermoplastics fails to explain the trend. PTFE has the lowest T_g (-73°C), whereas PMMA has the highest T_g (116°C). Epoxy has a lower value of the loss tangent than any of the thermoplastics, because of its crosslinked structure, typical of thermosets.

CONCLUSIONS

Among thermoplastics (PMMA, PTFE, PA-66 and acetal) and a thermoset (epoxy), PMMA exhibits the highest value of the loss modulus, while PTFE exhibits the highest value of the loss tangent. Neoprene rubber is exceptionally low in loss modulus, although it is exceptionally high in the loss tangent. Epoxy and acetal exhibit the lowest values of the loss tangent.

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