REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
21-07-2003	Final Report	23 September 2002 - 23-Mar-03

4. TITLE AND SUBTITLE

Liquid Crystalline Elastomers as Functional Damping Materials

5a. CONTRACT NUMBER
FA8655-02-M4088

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Dr. Eugene M Terentjev

5d. PROJECT NUMBER

5d. TASK NUMBER

5e. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Cambridge
Cavendish Laboratory
Cambridge CB3 0HE
United Kingdom

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0014

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
SPC 02-4088

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report results from a contract tasking University of Cambridge as follows: The research program shall address two issues critical to the development of damping materials based on liquid crystalline elastomers (LCE). An increase in temperature of liquid crystal transition, required for broadening the range of high-dissipation regime, will be achieved by adding new high-Tc terphenyl nematic components as side-groups to siloxane copolymer constituting the LCE network. A reduction of glass transition will be achieved by applying the microemulsion principle, combining the mainstream LCE with silicone liquids. This idea, emanating from some biological examples of high damping, has not been yet tried in LCE technology.

15. SUBJECT TERMS
EOARD, Liquid Crystals, Polymers, Polymer Crystal Structure, Damping Materials, Elastomers

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18, NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Charles H. Ward, Lt Col, USAF
UNCLAS	UNCLAS	UNCLAS	UL	4	19b. TELEPHONE NUMBER *(Include area code)* +44 (0)20 7514 3154

Liquid Crystalline Elastomers as Functional Damping Materials

Dr. Eugene M Terentjev

Cavendish Laboratory
Department of Physics
University of Cambridge
Cambridge
United Kingdom

EOARD Contract: FA8655-02-M4088

21 July 2003

(1) In accordance with Defense Federal Acquisition Regulation 252.227-7036, Declaration of Technical Data Conformity (Jan 1997),

"The Contractor, University of Cambridge, hereby declares that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. FA8655-02-M4088 is complete, accurate, and complies with all requirements of the contract.

DATE: 21.07.03

Name and Title of Authorized Official: _____

(2) In accordance with the requirements in Federal Aquisition Regulation 52.227-13, Patent Rights—Acquisition by the U.S. Government (Jun 1989), the following statement is included in the FINAL REPORT:

"I certify that there were no subject inventions to declare as defined in FAR 52.227-13, during the performance of this contract."

DATE: 21.07.03

Name and Title of Authorized Official: _____

Liquid Crystalline Elastomers as Functional Damping Materials

EOARD ref: SPC 024088; contract no: FA8655-02-M4088
University of Cambridge ref: RG36531
PI Dr. Eugene M Terentjev

Grant Report

This project explored a possibility of collaboration of our research group with EOARD. For us this was important, because the government-funded aerospace industry is a natural end user for a range of new technologies based on liquid crystalline elastomers. One of the main goals, and achievements, was to identify the requirements and interest areas, as well as the assessment criteria, by which new technology and new materials could be measured and compared.

The original proposal and the Interim Report outline the scientific background[1] and the principles behind the high vibration damping by nematic elastomers[2]. Independently mobile internal degree of freedom leads to the novel phenomenon of "soft elasticity" when a certain set of strains is not resisted elastically (or resisted very weakly). For these modes, the mechanical dissipation is the leading response. Unlike when studying delicate and strongly dependent on geometry effects of soft elasticity, which requires monodomain aligned nematic director in a rubber, high dissipation requires a much simpler material preparation: it is sufficient, and in fact beneficial, to work with polydomain materials. The main focus is then on the material design, obtaining nematic rubbers with the required (and the widest) temperature and frequency intervals where the high vibration damping occurs. In the short time of this project, we have not been able to identify particular industrial settings or engineering designs where new damping materials could be used. We, therefore, focused on three standard tests: Free layer vibration dissipation; Constrained layer vibration and Impact dissipation.
Characteristic Master Curves have been shown in the Interim Report and are published in the literature[3]. Much remains to be understood about the fundamental processes and polymer relaxation in liquid crystalline elastomers. However, the practical effect of high mechanical loss is unambiguous and versatile, both in temperature and frequency of application. From the experience of a number of different material designs, we came to a conclusion that "improvements", such as making a damping pad porous with liquid oil filling the cavities, or leaving free uncrosslinked chains in the network, does not lead to a noticeable advantage. Accordingly, the main result of this short project is the group of

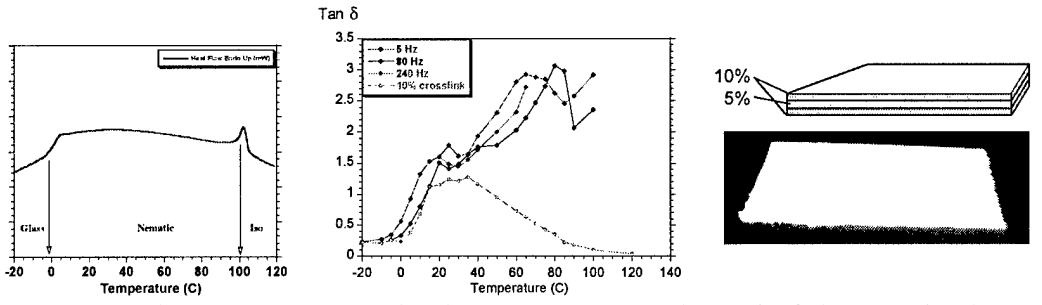

Figure 1. Left panel: DSC scan showing the temperature interval of the nematic phase – between 100C and 0C. Central panel: loss factor Tan d, as function of temperature, for several frequencies, showing a comparison between 10% and 5% crosslinked networks. Right panel: the composite demonstration pad supplied with this report. White color is due to light scattering on nematic polydomains – the material will become transparent in isotropic phase, above 100C.

side-chain nematic polymer materials, with the clearing point at T*~100C and the glass transition below 0C. Figure 1 shows its key thermal transitions and damping characteristics, while the generic chemistry is summarized in Fig. 2. As agreed, we also prepared a demonstrator device – a "damping pad". One must be aware that such a pad is designed rather blindly, with no specific test or optimization in mind. The elastic modulus of this material is below 1MPa and this has to be born in mind in setting the test conditions. The pad is made composite, combining the same material in three layers; the two outer layers crosslinked at 10% (and thus carry most of the elastic load) while the inside is crosslinked at 5% (hence maximizing the loss factor). The gradient of stiffness across the pad thickness should also serve to improve energy transfer from a rigid vibrating substrate into the dissipating polymer layer.

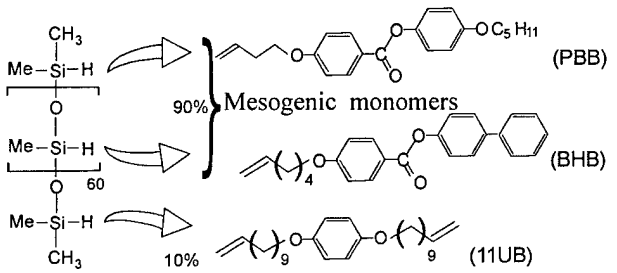

Figure 2. The generic chemical composition of side-chain nematic polymer, with siloxane backbones crosslinked by 2-functional groups (11UB). The base nematic group is PBB; adding BHB increases the upper transition temperature (but too much of it will result in various detrimental smectic phases).

In the process of this work and communications with the research staff at WPAFB, it has become clear that two other properties of nematic elastomers may be of immediate interest. These are the large-stroke mechanical actuation, induced by temperature or UV light (see the details in the literature). Large uniaxial strains (or stress of ~1-300kPa in the isostrain regime) are the inherent feature of nematic networks, with applications in such devices as micro-pumps, valves, and variable tension fibers. Interestingly, a focused effort in this field is currently applied at the Naval Res. Labs in Washington[4], although that group is not yet up to speed on the international scale. Tunable optical filters, narrow and broadband, photonic bandgap systems[5] and low threshold lasers[6] are natural practical applications of cholesteric elastomers.

In summary, the work progressed successfully. The grant provided only a small support for a pilot study of damping properties in a new liquid crystalline elastomer system, showing possible directions of future work. We were able to purchase a polarizing optical microscope (which helps routine phase identification in the production lab) and a sufficient amount of raw chemical consumables (to enable wider spread of chemical synthesis and material testing, pursuing broader temperature range).

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