Effects of Fumed Silica Particles on the Elastic Modulus of UV-Cured Base Film for Magnetic Tape

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This study compared the effects of two grades of fumed silica particles on the elastic modulus, E', of magnetic base film, with the goal of making a UV-curable acrylate base film with an E' of 10 GPa. Such a film would be an affordable way to increase overall storage density of magnetic tape. Results indicated that LM-150 fumed silica particles could increase the E' of a particle-unloaded film by 24%.

Introduction

Companies archive large amounts of information over a number of years, such as credit card statements or payroll records, with magnetic tape. Magnetic tape cartridges presently hold information longer, cost less per megabyte of stored information, and occupy less space than hard drives or CDs. For example, a $20 magnetic tape cartridge can store up to 200 gigabytes (GB) of information. In contrast, it would take 350 CDs, each with a 700 megabyte (MB) capacity and costing altogether approximately $200, to store the same amount of information. Also, the space needed to store these CDs would be at least ten times larger than a single 200 GB tape cartridge. Individual owners of several hundred CDs of information, video, or music value the ease of locating a particular piece of information within a few seconds. Companies with warehouses full of stored tapes, however, find compact storage space more important than extremely fast access speed.

The Anatomy of Magnetic Tape

Macroscopically, magnetic tape is thin, but microscopically, it has four sizable layers. At the top lies a magnetic layer (0.5 microns)[1] where information is stored through the direction of magnetization of embedded magnetic particles. The underlayer, or primary coat (1.5 microns) acts as an adhesive between the magnetic layer and the base film (6-10 microns), the mechanical skeleton of magnetic tape [1]. The base film is usually made of polyethylene terephthalate (PET) or polyethylene naphthalate (PEN), both inexpensive, effective, and easy materials with which to work [2].[2] The final layer, the base coat (0.5 microns), is rough-textured compared to the other layers. Fused with relatively large carbon black particles, the base coat helps dispel static charges that develop during the winding and unwinding in tape use. It also allows air to enter between tape loops and prevents separate sections of tape from sticking [1].

Increasing Memory Storage

In the past, to increase magnetic tape's storage density, more "highways," or tracks, for data were added in the magnetic layer. New cartridge readers with increasingly smaller heads were developed to scan these "highways." Soon tapes with 384 tracks will be on the market, a dramatic increase compared to the two-track system that was state-of-the-art in the 1950's [3], but the number of tracks cannot continue to increase indefinitely to accommodate more storage. Also, as the number of tracks increase, the error of tape readers increases exponentially. The tape head reader, due to the vibrations of the machine itself, can unreliably skip tracks, leading to a jumble of information. Additionally, if there are too many tracks on a reel of magnetic tape, the natural deformation from usage of the tape affects the ability of the machine to read the tracks accurately [4].

Dr. David Nikles, University of Alabama Professor of Chemistry and Materials Science [1,2], offers a solution. Since base film is about 75%-90% of the volume of magnetic tape, why not decrease the thickness of the base film? More tape could be

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[1] As a frame of reference, a human hair has a diameter of 80-100 microns.

[2] PET is the same material from which plastic bottles are made; the largest source in industry of recovery of PET is recycled materials.

reeled onto a cartridge which, in turn, could hold many times more information than cartridges presently available. However, this size reduction poses a problem. Plastics used today in base films, such as PET and PEN, are too weak mechanically in the thickness range of 3-4 microns [5]; new polymeric materials have to be made to withstand normal usage stresses at that thickness.

Novel Materials and Processes

On the market now is a film, Micron, that can function as a base film in the 3-4 micron range. It is not used widely in industry, however, because the disposal of the solvents used during processing is too costly, making the film too expensive for the magnetic tape industry to use. Even for commonly used magnetic tape, cost of solvent disposal is a major concern for magnetic tape manufacturers [4].

To eliminate solvents in the manufacturing process, Dr. Jin Young Huh, as part of his doctoral dissertation research [6], tested several commercially available acrylate oligomers and monomers to find a combination for a thermal, ultraviolet, or electron-beam curable, mechanically strong film at an E' of 10 gigapascals (GPa). Ten GPa would supersede most stretching and deformation and prove to be dimensionally stable over time. Through tests of electron-beam-cured acrylate films, the highest modulus film without particles yielded an E' of 0.65 GPa, while formulations with Fe_2Co_3 particles all yielded higher E' of 0.86 to 1.32GPa [6]. New acrylate components with higher individual elastic moduli were chosen in subsequent replications of Dr.Huh's study [5]. Of all particle-unloaded combinations comprised of these new components tested during summer of 2004, the formulation that exhibited the highest modulus was chosen as the control formulation for the current study, as explained below.

Purpose

The purpose of this study was to compare the effect of the addition of two different grades of fumed silica particles on the elastic modulus in films. The fumed silica particles used were much smaller than the Fe_2Co_3 used in prior studies. In the way that small rocks build the modulus of concrete, it was expected that small silica particles would build the elastic modulus of the film better than the much larger 0.23 micron-long Fe_2Co_3 cylinders. Two separate grades were chosen because of their differences in size microscopically. The LM-150 particles' smaller surface area would allow for more even dispersions throughout the films, but the HS-5 particles' larger surface area would encourage more reinforcement [7].

Materials and Machines

The materials used to make formulations for this study are identified in the following table:

Table 1 : Formulation Components

Common Name	Chemical Name	Manufacturer
CN120B80	Bisphenol A Epoxy Diacrylate with 1,6 Hexanediol Diacrylate (HDODA) Esters	Sartomer
SR506	Isobornyl Acrylate Esters	Sartomer
SR9035	Ethoxylated Trimethylopropane Triacrylate	Sartomer
LM-150	Synthetic Amorphous Silicon Dioxide with surface area 130 m^2/g	Cab-O-Sil
HS-5	Synthetic Amorphous Silicon Dioxide with surface area 350 m^2/g	Cab-O-Sil
UV Initiator	2-Benzyl-2-(dimethyl amino)-4'-morpholinobutyrophenone, 97%	Aldrich

The Ultraviolet Systems and Equipment Model HC-6 was used to cure all films in this study; the Rheometrics Solids Analyzer RSA II performed all the tests.

Preparation of Films

The control formulation for this project was 40% wt. CN120B80, 40% wt. SR506, and 20% wt. SR9035 from Sartomer, Inc. (see Table 1 above). To compare loading effect of particles on the modulus of the control formulation, three weight percents of both Cab-O-Sil Fumed Silica grades HS-5 and LM-150 were added to the control formulation: 0.5% wt., 1.0% wt., and 2.0% wt.

Formulations at these low weight percents are easy to cast, relative to those with weight percents over 3%. For each formation, 4%wt. initiator was added to induce UV curing. All leftover weight fit in the 40:40:20 ratio, CN128B80: SR506: SR9035, as shown in Table 2 above.

Table 2: Formulations by Weight: Actual (Calculated)

Formulation	CN120B80	SR506	SR9035	Initiator	Amount Particle	Total
Control	38.36g (38.4)	38.80g (38.4)	19.58g (19.2)	4.16g (4.0g)	0.00g	100.9g (100)
0.5% HS-5	38.15g (38.2)	38.21g (38.2)	19.15g (19.1)	4.25g (4.00)	0.54g (0.5)	100.3g (100)
1.0% HS-5	38.05g (38.0)	39.03g (38.0)	19.01g (19.0)	4.06g (4.0)	1.11g (1.0)	101.26g (100)
2.0% HS-5	40.87g (37.6)	36.83g (37.6)	19.28g (18.8)	3.93g (4.0)	1.95g (2.0)	102.86g (100)
0.5% LM-150	38.18g (38.4)	39.18g (38.4)	20.71g (19.1)	3.94g (4.0)	0.49g (0.5)	102.5g (100)
1.0% LM-150	37.35g (38.0)	38.16g (38.0)	21.43g (19.0)	4.10g (4.0)	0.95g (1.0)	101.95g (100)
2.0% LM-150	42.00g (37.6)	38.00g (37.6)	19.04g (18.8)	4.22g (4.0)	2.09g (2.0)	105.35g (100)

Each 100g formulation batch was mixed in a ball mill for six to eight hours for thorough mixing. A portion of the 100g formulation was double cast separately onto window glass with a 6 mil garner blade for even casting. Each formulation was UV-cured with three passes of 400 watts per inch at 2.7 meters per minute for a complete cure [6]. The distance from lamp to film-cast glass was set between two and a half inches to four inches.

Testing of Films

Preliminary testing. For each of the tests, sample sizes were 6 mm wide with film thickness being measured for each film. The control formulation film and all six particle-loaded films were first tested at a standard 0.5% with a Dynamic Frequency Sweep Test to determine which grade demonstrated the higher modulus. Dynamic Frequency Sweep Tests on the RSA II pulled on the 6 mm samples at varying cycles per second while keeping the same temperature, force, and strain percent of the sample constant to measure E' and simulate long-term wear and tear on the material. These results were not absolute but allowed a relative comparison of E' between the two grades. As shown in Table 3 below, the LM-150 grade produced higher elastic moduli than HS-5 in this set of tests. Therefore, subsequent tests were conducted using only LM-150 particle-loaded films compared to the original formulation film without particles.

Table 3 : E' at 10 rad/s Results from Initial Comparative Tests at 0.5% Strain Percent

Formulation	Average E' (GPa)
Control	0.0256
0.5% wt. HS-5	0.012
1.0% wt. HS-5	0.349
2.0% wt. HS-5	0.213
0.5% wt. LM-150	0.689
1.0% wt. LM-150	0.560
2.0% wt. LM-150	0.086

Final testing. LM-150 next underwent Dynamic Strain Sweep Tests, which at a specified temperature, varied the strain percent on the sample to find E’ as a function of strain percent. The linear region of the E’ vs. Strain percent log-log plot of each of the films offered an optimum strain percent at which to perform the second group of Dynamic Frequency Sweep Tests. The last few linear strain percents in the E’ vs. Strain percent plots divided in half were considered to be the optimum strain percents. For instance, if the last linear point was at 0.20% strain percent, then another sample of the same film was tested with a Dynamic Frequency Sweep Test at 0.10%. None of these optimum strain percents were the same because they were material-dependent. The results of the second group of Dynamic Frequency Sweep Tests at the optimum strain percent were considered to be the film’s true E’.

Results

As shown below, an increase in weight percent of LM-150 over 0.5% wt. yielded an increase in elastic modulus in the cast films. An unexpected finding was that the formulation with the lowest E’ in initial comparative tests (see Table 3), 2% wt. LM-150, resulted in the highest E’ in the final tests.

Table 4 : E’, Last Linear Strain %, and Safe Strain % Found in Final Testing

Formulation	E’ (GPa)	Last Linear Strain %	Safe Strain %
Control	1.56	0.14%	0.070%
0.5% LM-150	1.29	0.065%	0.033%
1.0% LM-150	1.83	0.030 %	0.015%
2.0% LM-150	1.94	0.085%	0.042%

Conclusions

Although the goal modulus of 10 GPa was not reached, LM-150 fumed silica particles did increase the control film’s modulus approximately 24%. If future research employs a particle-unloaded formulation that yields 8-8.5 GPa, then the elastic modulus of fumed-silica-loaded film could reach 10 GPa.

Films loaded with HS-5 fumed silica particles should be examined in future research with the Dynamic Frequency Sweep Test at their safe strain percents. Such testing was omitted in the current study primarily because of time constraints.

References

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[5] Bain E.; Brunson B. Center for Materials for Information Technology, University of Alabama, Tuscaloosa, AL. Personal communication, 2004.

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[7] Overview of CAB-O-SIL® Untreated Fumed Silicas. http://www.cabot-corp.com/cws/businesses.nsf/CWSID/cwsBUS01182001034300PM9596?OpenDocument&ctM=&ctPF=Fumed%20Metal%20Oxides&PF=Fumed%20Metal%20Oxides&Mkt=Adhesives%20&%20Sealants (accessed Aug. 2004).

Appendix

Figure 1: Average Values for Formulations Tested with LM150
Initial Comparative Tests

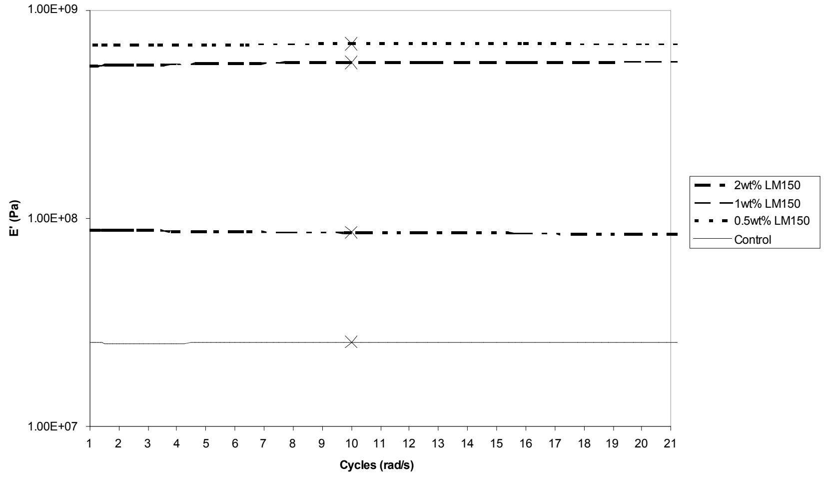

Figure 2: Average Values for Formulations Tested with HS-5
Initial Comparative Tests

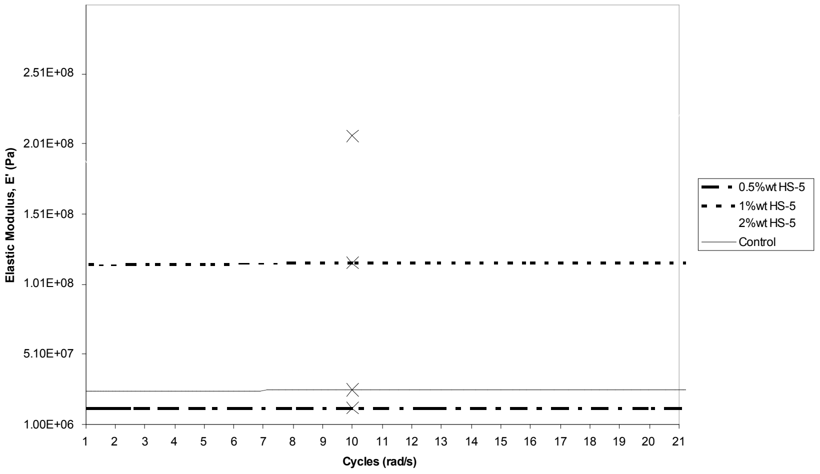

Figure 3: Average Values for Formulations Tested with LM-150
Final Tests