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THE PRESERVATION OF MAGNETIC TAPE COLLECTIONS: A PERSPECTIVE

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EXECUTIVE SUMMARY

This report retraces IPI's approach to the preservation of magnetic media. It reports on information gathered from the field and focuses on the major issues related to preserving magnetic media. The report also presents research conducted at IPI during the project. IPI's Survey of Magnetic Tape Archives had as its main objective the assessment of current preservation practices. Data based on laboratory testing of magnetic tapes are reported and discussed. Results are assessed from the perspective of studying the feasibility of developing a diagnostic tool for magnetic tape collections. Conclusions drawn from the research are presented as well as a series of guidelines for preserving magnetic media based on the current situation.

IPI's research focused on investigating three indicators of tape decay. They involved the assessment of tape binder condition using three laboratory testing procedures: free acidity, acetone extraction, and friction tests. The study was designed as a primary step in the development of a simple diagnostic tool. The overall research involved more than 1,150 tests conducted on tape samples prepared through accelerated aging and on naturally aged tapes. Free acidity determinations and acetone extraction test results provided valuable information on the effect of temperature and humidity on tape deterioration. The only nondestructive test used in the study did not provide a way to monitor tape binder deterioration. Overall, the data developed during the research cast doubt on the feasibility of developing an easy-to-use diagnostic device for assessing tape condition. Although the study was conducted on a relatively small sample of tape types, these displayed different behaviors during incubations at 60°C and 80°C. In addition, levels of free acidity remained low and were associated with a high percentage of acetone extractables. Such observations indicate that free acidity determinations as performed in the study did not provide a suitable indicator of tape binder decay. Data developed during the research are reported in detail and discussed in the report.

IPI research has reconsidered the approach for preserving magnetic tape collections and proposes a perspective based on three main strategies which address (1) the need for optimizing tape storage, (2) the need for facilitating the emergence of new automated tape transfer technology, and (3) the creation of a decision-making tool for implementing prioritized transfer programs.

INTRODUCTION

In 2003, the National Endowment for the Humanities (NEH), Division of Preservation and Access, awarded funding to the Image Permanence Institute (IPI) at Rochester Institute of Technology, Rochester, New York, for a research project dealing with the preservation of magnetic tape collections. The project was a three-year investigation designed to identify the major issues for preserving the physical integrity of magnetic tape collections and to evaluate the possibility of developing a nondestructive diagnostic tool for magnetic tape collections. The present report reviews the premises of the research, describes the research program, and reports the conclusions of the study.

MAGNETIC TAPE MEDIA

During the second half of the past century magnetic tape media penetrated the audio-visual world. Attempts to capture sound and/or moving images have relied upon the use of audiotape or videotape. All domains using sound, image, and data recording have been supported and affected by the use of magnetic records. As is true for photographic film, which created the cinema industry and the home movies market and supported a wide range of documentary and scholarly ventures, magnetic records have invested areas where the recording, archiving, copying, and re-playing of sound and moving images are necessary. From news reporting to private homes, from fiction to documentaries, from oral history to video installations, magnetic media are a major part of our audio-visual heritage and play an invaluable role wherever efficient information-recording systems are required.

Today, the common perception is that magnetic records are endangered for three main reasons. First, the medium itself is deteriorating through natural aging; significant parts of the holdings are already damaged or may be at a state beyond recovery and are lost forever. Second, the profusion of recording formats that have been conceived through the evolution of magnetic media leads to the risk of information losses based upon what is known as format obsolescence. Over the years, recording formats and the hardware needed for recording/viewing/copying came and disappeared according to the evolution of technology, the market trends, and the decreasing availability of working equipment and experts. Such evolution increases the risk that archives are preserving unreadable and therefore useless materials. Finally, the third element that seems to compromise the preservation of magnetic records is the often-mentioned lack of adequate resources in the form of funding, training, and expertise within the institutions. These three aspects of the problem contribute to the perception of a lost or, at best, very challenging, battle for preserving the content of magnetic tape collections in museum, libraries, and archives.

Considering the diversity and the number of institutions that potentially contain a huge number of magnetic records among their audiovisual materials, the assumption that magnetic records can be lost is immediately disturbing, and the task of preventing these losses is daunting. The Library of Congress study on Television and Video Preservation[1] includes figures describing the holdings for major studios, television networks, public television, several public archives, and other institutions that preserve television materials. The information collected in that report gave a measure of what could be lost in terms of human knowledge. Other initiatives, such as the European-funded PrestoSpace project, provide similar assessments, which underscore the enormous amount of material, and therefore knowledge, that is at stake. Several other studies focusing on specific activities reflect the diversity of magnetic record collections held in institutions today. In short, magnetic tape preservation is essential if we are to safeguard this repository of human knowledge for future generations.

MAGNETIC TAPE LONGEVITY

While it is evident that preserving machine-readable records such as magnetic tapes is strongly dependent on the sustainability of the format itself and the availability of format-specific equipment, the useful life of tape collections may also be limited by material deterioration. Earlier studies have demonstrated that the structure and components of magnetic media influence their inherent stability. Therefore, the tape substrate, the nature of the magnetic particles, the binder, and other additives may be equally important in determining the life expectancy of magnetic media. While it is important to know that polyester tape support is more stable than cellulose acetate tape support,[2,3,4] or that using iron oxide magnetic particles rather than chromium dioxide magnetic particles may affect media stability,[5] being able to identify the most unstable component and knowing how to

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[1] Report of The Library of Congress, *Television and Video Preservation 1997: A Report on the Current State of American Television and Video Preservation*, Volume 1: Report, Library of Congress, Washington, D. C, October 1997.

[2] P. Z. Adelstein and James L McCrea, “Permanence of Processed Estar Polyester Base Photographic Films,” *Photographic Science and Engineering*, v.9 (1965), pp.305-313.

[3] P. Z. Adelstein and James L McCrea, “Stability of Processed Polyester Base Photographic Films,” *Journal of Applied Photographic Engineering*, v.7 (1981), pp.160-167.

[4] P. Z. Adelstein, J. M. Reilly, and F. G. Emmings, Stability of Photographic Film: Part VI—Long-Term Aging Studies, *SMPTE Journal*, pp. 136-143 (April 2002).

[5] R. Bradshaw, B. Bhushan, “Chemical and mechanical performance of flexible magnetic tape containing chromium dioxide,” *IBM J. Res. Develop.*, 1986, vol. 30, No. 2, pp. 203-216.

control its deterioration is key for maximizing the longevity of the medium. Magnetic tape can fail for a series reasons, but it is generally recognized that the deterioration of the binder is the most common cause for tape failure. It is also important to note that similar polymeric binders (polyester polyurethane) are commonly used for audiotapes and videotapes. The polymer used as binder in the tape structure is subject to chemical decay through a process known as hydrolysis. As the deterioration progresses, long polymer molecules become shorter, and the integrity of the binder is reduced. The process may lead to softening, brittleness, loss of cohesion, and the formation of "sticky" products, and the tape may become unplayable.

Although it has been generally accepted that the life expectancy (LE) of magnetic tape can be from ten to thirty years near normal room climate conditions, it is important to understand that environmental storage conditions can optimize, or seriously compromise, the life span of magnetic records. Earlier stability studies have attempted to chart the impact of storage conditions on the longevity of the magnetic media. The life span of magnetic media was estimated based upon the effect of temperature and relative humidity (RH) on the stability of the polymer binder as reflected by its degree of hydrolytic deterioration. An early study recommended storage environments based on the level of binder hydrolysis. Temperature and RH recommendations were determined to meet requirements for both tape storage and use.[6] These recommendations were based on the relationship between acceptable degrees of hydrolysis and operational problems when tapes were played. Later publications provided insights into the life span of tapes. Based on a given end-of-life criterion, LEs were quantified based upon data obtained through accelerated aging. It was recognized that polyester polyurethane degrades through hydrolysis. Higher humidity promotes the breakage of polyester linkage by the reaction with water. Degradation byproducts such as organic acids are believed to accelerate binder hydrolysis. The model makes life span predictions possible and establishes a relationship between storage conditions and LE values. Estimates for tape life expectancy may vary from less than ten years to several decades, depending on temperature and RH levels.[7] As a general rule, lower temperatures and drier conditions lead to longer life span. It should be noted that the link between chemical stability and climate conditions is not specific to magnetic tape alone but applies to a wide range of organic materials, such

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[6] H. N. Bertram, and E. F. Cuddihy, "Kinetics of the Humid Aging of Magnetic Recording Tape," *IEEE Transactions on Magnetics*, Vol. 18, No. 5, September 1982, pp. 993-999.

[7] J. Van Bogart, *Magnetic Storage and Handling, A Guide for Libraries and Archives*. (Washington, DC: National Media Lab, and The Commission on Preservation and Access, June 1995).

as photographic film. While studies done on photographic materials relied on indicators of decay, such as image density (color materials), tensile properties (polyester film base), or free acidity (nitrate and acetate film support), early research on tapes has revolved around the determination of the percentage of hydrolyzed binder and its relationship to tape operational failures. This situation underscores the difficulty of reliably predicting tape life expectancy, since tape failure could be caused by the hardware, could result from magnetic signal loss, could result from lubricant loss and dimensional changes, or could be caused by head clogging. However, environment control, which has been used effectively to preserve film, photographs, paper, and other types of information-recording media, provides an important option for magnetic media preservation.

MAGNETIC TAPE STORAGE

Proper storage for magnetic tape collections is often presented as having been integrated in preservation strategies for a long time. In fact, earlier stability studies conducted on magnetic tape concluded that storage environments that maintained normal room conditions were suitable for tape storage. An environment maintained near 20°C, 40% RH was presented as optimum.[8,9] Study data led to the definition of storage conditions that would be acceptable for both use and storage. Such studies led to the publication of ISO recommendations for long-term storage, which for various reasons may or may not be applied in the field. For extended-term storage ISO[10] recommends a temperature range between 11°C and 23°C and a related range of RH levels between 20% and 50%. In practice, the maximum temperature (23°C) must be associated with the lowest RH (20% RH) for suitable storage, and vice versa. A study by the Library of Congress provides an objective picture of the storage conditions used during the late 1990s in a large number of institutions.[11] It seems that magnetic media collections are often stored at room conditions. If storage conditions facilitate immediate use of the materials, they also may significantly compromise the chemical stability of these materials. ISO recommendations suggest the use of cooler temperatures and low RH to optimize the stability of the polymeric binder. The stability of magnetic tape and of other information-recording

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[8] H. N. Bertram, and E. F. Cuddihy, "Kinetics of the Humid Aging of Magnetic Recording Tape," *IEEE Transactions on Magnetics*, Vol. 18, No. 5, September 1982, pp. 993-999.

[9] E. F. Cuddihy, "Stability and Preservation of Magnetic Tape," *Proceedings of Conservation in Archives*, International Symposium, Ottawa, Canada, May 10-12, 1988, pp. 191-206.

[10] ISO 18923: 2000—*Imaging materials—Polyester-base magnetic tape—Storage practices* (Geneva: International Standard Organization), 2000.

[11] Report of The Library of Congress, *Television and Video Preservation 1997: A Report on the Current State of American Television and Video Preservation*, Volume 1: Report, Library of Congress, Washington, D. C, October 1997.

media is strongly influenced by the storage environment. Heat and moisture promote tape binder deterioration[12,13] just as they accelerate color dye fading[14] or acetate deterioration.[15] The effects of these two factors on magnetic tape collections, together or alone, can necessitate copying or reformatting in order to avoid loss of the recorded information. Copying and reformatting are daunting tasks for most institutions, especially those with large holdings. Over time, it will become more and more difficult for institutions to cope with the increasing number of materials that urgently need copying. Today, proper storage may still be an efficient option to improve the preservation of magnetic media until the point at which reformatting becomes necessary to cope with technology changes. Until that time, which will come sooner or later, and until resources are available, maintaining the physical integrity of tape collections is extremely important.

MAGNETIC MEDIA FORMAT OBSOLESCENCE

Reviews from the field indicate that format obsolescence has been a determining factor for reformatting analog video collections. Selection criteria and priorities have been determined by categorizing the future availability of video formats present in collections. The descriptive terms used, such as *near extinct*, *endangered*, and *vulnerable*, illustrate the importance of the threat of format obsolescence.[16] The U-matic video format, for instance, which was used widely in the 1980s and 1990s, appears consistently at the top of the list for transfer to a new format.[17] It can be said that magnetic tape transfer may be largely determined by format vulnerability, not a collection's state of preservation.

Whether material degradation or format obsolescence is more critical depends on numerous factors and may vary from one situation to another. The history of magnetic tapes indicates that many tape formats are short-lived, and the advent of digital formats

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[12] H. N. Bertram, and E. F. Cuddihy, "Kinetics of the Humid Aging of Magnetic Recording Tape," *IEEE Transactions on Magnetics*, Vol. 18, No. 5, September 1982, pp. 993-999.

[13] E. F. Cuddihy, "Storage, Preservation, and Recovery of Magnetic Recording Tape," *Environnement et conservation de l'écrit, de l'image et du son, Actes des deuxièmes journées internationals d'études de l'ARSAG,* Paris, 16-20 mai 1994, pp. 182-186.

[14] James M Reilly*, Storage Guide for Color Photographic Materials* (Albany, NY: The University of the State of New York, New York State Education Department, New York State Library, The New York State Program for the Conservation and Preservation of Library Research Materials, 1998).

[15] James M Reilly, *IPI Storage Guide for Acetate Film* (Rochester, NY: Image Permanence Institute, Rochester Institute of Technology, 1993).

[16] D. Frambourg, "Stratégies pour la migration vers le numérique des programmes de television archives dans des formats video analogiques, "*Joint Technical Symposium Paris 2000*, pp. 196-202.

[17] A. Lee, R. Prytherch, and A. King, "U-Matic Preservation," *Joint Technical Symposium Paris 2000*, pp. 177-186.

may promote even faster changes.[18] Of the more than 65 magnetic tape formats that have been brought into the market, only a few are available today.[19] This situation requires the movement of information from one format to the next without any other consideration. In that context, ten-year-old tape collections may be threatened by format obsolescence. This might suggest that tape preservation is mostly format-specific. The physical stability of a tape may be irrelevant if that particular tape format was supported for only a very short period of time. The assumption is that as soon as the life expectancy of the medium is greater than the period during which the machine that can read it is available, physical stability is not a critical issue. On the other hand, greater physical stability would benefit tape formats that are supported for relatively long periods, and those for which hardware, software, and expertise would endure over longer periods.

TRANSFER/REFORMATTING STRATEGIES

Reformatting tape collections is a difficult task that requires high expertise, extensive handling of the materials, and specific equipment. The management of such projects is complex and involves a variety of critical tasks, which include tracking the materials during the entire operation, assessing the condition of the tapes prior to transfer, cleaning them, and then copying or reformatting them. A number of projects have demonstrated the scale of such an undertaking in terms of work load, decision-making, and, ultimately, cost. A recent survey initiated in Europe underscored the insufficiency of reformatting resources in comparison with the size of the holdings.[20] The survey identified the need for developing "high-efficiency preservation factories" across Europe. A new approach that is being developed in the U.S.—automated reformatting (SAMMA™ Systems)—might provide viable options to facilitate collection reformatting in the future.[19] Such developments are believed to be crucial for dealing with large-scale reformatting projects in a cost-effective way. But even if such important advancements were widely available today, one of the most difficult questions in planning a copying program might be: What should be copied? Related questions that need answers are: What are the determining factors for selecting the materials to be copied first? and Which new carrier materials and recording formats should be used?

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[18] J. Rothenberg, *"Ensuring the Longevity of Digital Documents," Scientific American, January 1995, pp. 42-47.*

[19] J. Lindner and G. L. Rosner, "Moving Beyond Manual Media Migration," *IS&T Archiving 2005 Final Program and Proceedings*, 2005, pp. 193-196.

[20] BBC. *Annual Report on Preservation Issues for European Audiovisual Collections* (D22.4). Retrieved from http://www.prestospace.org/project/public.en.html

MAGNETIC TAPE PRESERVATION TODAY

A wide majority of the preservation community has expressed concern regarding the viability of preserving magnetic records for a long time. Ironically, the magnetic medium's performance, its versatility, and the continuing evolution of formats and equipment have contributed to making it so universal that its use remains unavoidable. The obvious consequence is that large collections of audiotapes and videotapes have been built and must be dealt with. Important publications based on magnetic tape stability studies came out as early as the early 1980s, and an effort was made to communicate to the field the best strategy for preserving magnetic media. In that respect, the work conducted at the National Media Lab (NML) provided long-lasting benefits to the preservation community. Essential guides like *Magnetic Tape Storage and Handling*, [21] published in 1995, helped clarify tape preservation issues and defined specific needs for magnetic record collections. Within that framework, the International Organization for Standardization (ISO) has contributed several publications dealing with storage, care, and handling practices.[22,23] Today, the implications of the evolution of magnetic records technology —this includes the proliferation of digital formats as well as the threat of loss of valuable analog format collections—lend a sense of urgency to the development of new strategies for preserving magnetic tape collections.

PRESERVATION OF MAGNETIC TAPE RESEARCH—IPI'S OBJECTIVES

The goal of the project was to develop simple diagnostic tools to identify deteriorating tapes and integrate those tools into an overall preservation management strategy for magnetic tape collections. Such an approach was successfully developed for collections of acetate-base materials. IPI developed A-D Strips®, detectors with which to assess the state of preservation of acetate film, and the *IPI Storage Guide for Acetate Film,*[24] which made it possible to define new preservation strategies for acetate collections. In practice, knowing the state of preservation of acetate-base collections and evaluating the quality of the current storage environment make possible informed decisions in terms of storage, prioritized duplication, and condition monitoring. In some ways, the methodology that led to new film preservation strategies served as a model to approach the challenge of

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[21] J. Van Bogart, *Magnetic Storage and Handling, A Guide for Libraries and Archives*. (Washington, DC: National Media Lab, and The Commission on Preservation and Access, June 1995).

[22] ISO 18923: 2000—*Imaging materials—Polyester-base magnetic tape—Storage practices* (Geneva: International Standard Organization), 2000.

[23] ISO 18933: 2006—*Imaging materials—Magnetic Tape—Care and handling practices for extended usage* (Geneva: International Standard Organization), 2006.

[24] J. M. Reilly, *IPI Storage Guide for Acetate Film*, (Rochester, NY: Image Permanence Institute, 1993).

preserving magnetic tape collections. Despite specific issues—such as format obsolescence of electronic media, which may necessitate frequent reformatting of collections— extending the life span of the original materials was believed to be an important aspect of the preservation of tape collections. One simple reason for this is that tape collections are so large that it is doubtful that reformatting could keep up with the increasing need for copying if collection transfer technology does not evolve drastically in the near future.

This situation already exists in the field of film preservation. However, after the relationship between film life expectancy and storage temperature and RH was established, and after A-D Strips were developed for diagnosing the level of decay in acetate film, film preservation strategies began to focus on controlling the decay rather than on duplication. This approach first requires an evaluation of the state of preservation of collections; then the environmental needs of the collections can be determined. In this way, environmental storage requirements can be adjusted to fit the institution's mission and resources.

No diagnostic tool like A-D Strips exists for magnetic media. It has been recognized that the storage environment plays an important part in the preservation of magnetic tape collections.[25,26,27,28] Still, the task of assessing the condition of tapes is difficult. At the same time, there is a general consensus that many tape collections are threatened by advanced decay. A number of surveys illustrate this situation,[29,30,31,32] but only a few have produced quantitative data on the condition of tape collections. In these rare instances, the evaluation of tape condition was based on playback analysis.[33] This lack of

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[25] H. N. Bertram, and E. F. Cuddihy, "Kinetics of the Humid Aging of Magnetic Recording Tape," *IEEE Transactions on Magnetics*, Vol. 18, No. 5, September 1982, pp. 993-999.

[26] J. Wheeler, "Long-Term Storage of Videotape," *SMPTE Journal*, Vol. 92, No. 1, June 1983, pp. 650-654.

[27] G. Welz, "On the Problem of Storing Videotapes," *Archiving the Audio-Visual Heritage: A Joint Technical Symposium*, FIAF, FIAT, IASA, Berlin, Germany, May 20-22, 1987, pp. 61-69.

[28] J. Van Bogart, *Magnetic Storage and Handling, A Guide for Libraries and Archives*. (Washington DC: National Media Lab, and The Commission on Preservation and Access, June 1995).

[29] BBC. *Annual Report on Preservation Issues for European Audiovisual Collections* (D22.4). Retrieved from http://www.prestospace.org/project/public.en.html

[30] A. Smith et al., *Survey of the State of Audio Collections in Academic Libraries*, (Washington, DC: Council on Library and Information Resources, 2004).

[31] The Library of Congress, *Television and Video Preservation 1997: A Report on the Current State of American Television and Video Preservation*, Volume 1: Report, Library of Congress, Washington, D. C, October 1997.

[32] *Survey of Endangered Audiovisual Carriers*, UNESCO's Information Society Division, 1995 and 2003.

[33] A. Lee, R. Prytherch, and A. King, "U-Matic Preservation," *Joint Technical Symposium Paris 2000*, pp. 177-186.

quantitative data indicates that the development of an easy-to-use and nondestructive diagnostic tool for magnetic tape collections would be of great benefit.

Today the preservation strategy for magnetic tape collections consists of just a few possible actions, none of which actually addresses the challenge of preserving a large quantity of material that is likely to become obsolete over time. Proper storage at a cool temperature and low RH improves binder stability. ISO provides temperature and RH guidelines for long-term storage of magnetic tape.[34] However, while proper storage has the potential to improve tape stability, it cannot solve the problem of information loss due to format obsolescence. To date, tape copying or migrating remains a complex and cumbersome task, driven mostly by format obsolescence and incidental disaster that have affected entire or parts of collections. There may be no easy way to evaluate tape condition such that condition assessment could play a significant role in the development of preservation strategies. It was the primary aim of this research to determine if this is the case.

IPI RESEARCH ON MAGNETIC TAPE

MAGNETIC TAPE DEVELOPMENT—STABILITY AND ITS LIMITING FACTOR

The generic term *magnetic tape* covers a wide variety of information-recording systems that have been developed to store sound, images, or data, in either analog or digital format.[35] That said, a magnetic tape can be described by its structure, its width, its recording system, the nature of its information, or its "container." In fact, magnetic tapes have appeared on the market in a wide variety of formats. Since the introduction of practical audiotape and videotape recorders in the 1940s and mid-1950s, respectively, the number of formats on the market has grown, with the expected consequence that earlier formats, or unsupported formats, have become obsolete over time. Data collected on videotape formats indicate that in 1997[36] between 30% and 40% of the formats once produced were still in production. Information contained in *The Vidipax™ Videotape Format and Preservation Guide*[37] illustrates the decreasing number of videotape formats

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[34] ISO 18923: 2000, *Imaging Materials—Polyester-base magnetic tape—Storage practices,* (Geneva: International Organization for Standardization, 2000).

[35] C. Denis Mee and E. D. Daniel, editors, *Magnetic Recording Handbook: technology and applications*, McGraw-Hill, Inc. 1990.

[36] Report of The Library of Congress, *Television and Video Preservation 1997: A Report on the Current State of American Television and Video Preservation,* Volume 1: Report, Library of Congress, Washington, D. C, October 1997.

[37] *VidiPax Videotape Format Guide* at: www.vidipax.com.

in production. In the year 2000, only three analog video formats launched before or at the same time as the first digital videotape in 1986 were still in production.

Since videotape preservation must deal with the magnetic media and with the equipment as well, the activity is strongly format-specific and is extremely dependent upon the availability of the media and the hardware and software for digital formats, and therefore it will be strongly governed by the possibilities offered by the ever-changing market. IPI research has focused on the evaluation of the medium itself. Over the years, the generic structure of magnetic tape has evolved in terms of the nature of its components.[38,39,40] The tape support has evolved from paper to polyvinyl chloride (PVC), to cellulose acetate, to polyethylene terephthalate (PET). Tape manufacturers have relied on iron oxides, chromium dioxide, metal particulate (MP), or metal-evaporated (ME) particulate to record and retain magnetic signals. Binder formulations, which included lubricants, have been most commonly based on polyester polyurethane. As is true for all information-recording media, the composition and the construction of the medium composite govern its intrinsic vulnerability. Organic materials are commonly prone to spontaneous chemical decay, and metallic particles in the presence of oxidizing compounds are subject to oxidation. As a result, the oxidation of magnetic materials can compromise the retrieval of magnetic information when tapes are stored under adverse humidity conditions.

It has been recognized that the effects of temperature and moisture are critical in determining the life span of acetate support and tape binder. Acetate decay has been extensively studied for film preservation; acetate is a fast-decaying plastic compared to polyester.[41] As a result, audiotape on acetate substrate from the 1940s to 1950s is likely to be endangered by vinegar syndrome. Videotape, always on polyester support, is not subject to base deterioration. Tape binder hydrolysis was pointed out in early tape stability studies as a major problem for the preservation of all types of tape.[42,43] Later

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[38] R. Mueller, “Magnetic Tape Development,” *The BKSTS journal*, April 1986, pp.204-210.

[39] E. D. Daniel, C. D. Mee and M. H. Clark, editors, *Magnetic Recording: The First 100 Years*, New York: IEEE Press, 1999.

[40] F. K. Engel, “Magnetic Tape: From the Early Days to the Present,” J. Audio Eng. Soc. Vol. 36, No.7/8, 1988 July/August, pp. 606-613.

[41] P. Z. Adelstein, J. M. Reilly, and F. G. Emmings, Stability of Photographic Film: Part VI—Long-Term Aging Studies, *SMPTE Journal*, pp. 136-143 (April 2002).

[42] H. N. Bertram, and E. F. Cuddihy, “Kinetics of the Humid Aging of Magnetic Recording Tape,” *IEEE Transactions on Magnetics*, Vol. 18, No. 5, September 1982, pp. 993-999.

[43] E. F. Cuddihy, “Aging of Magnetic Recording Tape,” *IEEE Transactions on Magnetics*, Vol. Mag-16, No. 4, July 1980, pp. 558-568.

studies further confirmed that binder oxidation and hydrolysis were important limiting factors for tape stability.[44,45,46,47,48] The ultimate objective of the IPI research was to evaluate poor tape condition resulting from binder vulnerability.

SURVEYING MAGNETIC TAPE COLLECTIONS

IPI's primary research objective for surveying magnetic tapes was to explore ways to quantitatively evaluate the state of preservation of tape collections, and the first tasks were to review previous survey initiatives and to gain knowledge of the evaluation practices currently used. At the same time, these tasks provided an opportunity for better understanding the various approaches currently implemented for the preservation of magnetic tape collections.

A number of surveys of magnetic tape collections have been conducted in past years. Several publications provided valuable insights into the evaluation processes involved, as well as results and analysis of the information collected. These studies included the examination of audio and video collections and dealt with the various aspects of preservation. Most surveys have addressed issues such as collection management, organization, cataloguing, metadata recording, and the problem of access, which invariably leads to copying/migration and reformatting strategies. However, it seems that very little quantitative assessment of the state of preservation of magnetic tape collections has been published. One explanation for this may be the lack of a diagnostic tool. Recently, however, a standard methodology has been included in ISO recommendations.[49] When the characterization of tape condition has been attempted, interpreting the information has been difficult. Criteria such as *in good condition, some concerns*, and *obviously decaying* have been used in an attempt to categorize the state of

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[44] L. E. Smith, "Factors Governing the Long-Term Stability of Polyester-based Recording Media," *Restaurator,* Vol. 12, 1991, pp. 202-218.

[45] M. Edge, N. S. Allen, M. Hayes, T.S. Jewitt, K. Brems and V. Horie, "Degradation of magnetic tape: Support and binder stability," Polymer Degradation and Stability, Vol. 39, 1993, pp. 207-214.

[46] M. T. Baker, "Lifetime Predictions for Polyurethane-based Recording Media Binders: Determination of the "Shelf-Life of Videotape Collections." In: *Resins: Ancient and Modern,* edited by M. M. Wright and J. H. Townsend, Edinburgh: The Scottish Society for Conservation and Restoration, 1995, pp. 106-110.

[47] M. Edge, and J. Whitehead, "The Decay of Polymers in Information Storage Carriers," *Technology and our Audio-Visual Heritage: Technology's Role in Preserving the Memory of the World, Fourth Joint Technical Symposium,* London, January 27-29, 1995, pp. 20-30.

[48] R. D. Weiss, *Environmental Stability Study and Life Expectancies of Magnetic Media for Use with IBM 3590 and Quantum Digital Linear Tape Systems, report to Natioanl Archives and Records Administration* # NAMA-01-F-0061, 2002.

[49] ISO 18933: 2006—*Imaging materials—Magnetic Tape—Care and handling practices for extended usage* (Geneva: International Standard Organization), 2006.

preservation of various collections.[50] Other approaches have consisted of assessing tape problems based on replay analysis.[51] These characterizations remain difficult to interpret, however, and invariably the terms to describe the current state of collections remain descriptive at best. Despite the impression, or the assumption, that large quantities of magnetic tapes may be in an advanced state of deterioration, the description of that state remains undocumented in most cases. For example, the published results of the *National Dance Heritage Videotape Registry*[52] questionnaire obtained in 2003 states that "more than 25% of the respondents believed that at least some of their tapes were physically damaged." The PrestoSpace project conducted a survey in order to evaluate the state of preservation of European audiovisual heritage.[53] The study on magnetic tape was based on 400 institutions. The analysis of the data collected underscores the lack of knowledge of the current condition of magnetic tape. While collections managers have stated that 70% of the materials are either in *acceptable*, *good*, or *very good* condition, the report points out that half of the archives don't have controlled climate conditions, and it identifies the overall lack of awareness of preservation issues as the biggest problem to be overcome. The study indicates that audiotape and videotape materials represent the largest percentage of collections (i.e., more than 60% in terms of number of items). Other findings from the Dance Heritage Coalition (DHC) study are even more significant, including the reported shortage of "information and/or the staff to evaluate their collections" for half of the respondents and the fact that 80% "have no procedures in place at all to ensure long-term preservation of their tapes." Such situations are not unique in the field of audio-visual materials preservation and send a strong message to the preservation community.

MAGNETIC TAPE PRESERVATION CURRENT PRACTICES—IPI SURVEY

In order to investigate the current situation, IPI designed a web-based survey form. The purpose of the form was to collect a wide variety of information that is pertinent to the preservation of magnetic tape. The form was organized in eleven categories, which are summarized in Table I. Drawing on IPI's past involvement in media preservation, a list of 93 institutions including museums, libraries, and archives was compiled, and representatives were contacted. Although only 17 institutions answered the questionnaire

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[50] *Survey of Endangered Audiovisual Carriers*, UNESCO's Information Society Division, 1995 and 2003.

[51] A. Lee, R. Prytherch, A. King, "U-Matic Preservation," *Joint Technical Symposium Paris 2000*, pp. 177-186.

[52] *Digital Video Preservation Reformatting Project: A Report* prepared by Media Matters, LLC for the Dance Heritage Coalition presented to The Andrew W. Mellon Foundation, June 2004.

[53] BBC, *Deliverable D22.6 (2005) Preservation Status, Annual Report on Preservation Issues for European Audiovisual Collections*, 2005.

(18% of the institutions contacted), the survey did provide useful data. Figures 1 to 6 illustrate some of the responses gathered during the survey.

Table I: Information requested in IPI survey.

1. Institution	Institution's name, address, and contact information
2. Collections	Size and period covered by the holdings, and significance of the collection
3. Access	Who uses the collection and how frequently is it accessed?
4. Tape formats	Evaluation of the quantity of specific formats for both audio and video
5. Playback equipment	Machines owned and used by each institution
6. Storage	Institutions were asked to described the arrangement of the materials in storage and to characterize the type of environment(s) used for storing collections. Options included in the form to help respondents classify storage environments were *Room*, *Cool*, *Cold* or *Frozen*.
7. Enclosures	Types of containers and enclosure materials
8. Handling	Handling practices and procedures within the institution
9. Tape condition	Institutions were asked to describe their experience with magnetic tape decay by indicating 1) which types of decay manifestations they have observed and 2) what proportion of the collection displayed signs of decay.
10. Management plan	Institutions were asked to describe existing collection management plans.
11. Criteria for copying	Institutions were asked to rank the main criteria for initiating and planning a copying or reformatting program.

Collection Size, Uses, and Formats

Figure 1 indicates that most institutions keep rather large collections containing more than 5,000 items. All of these holdings are accessed frequently by users. Almost 60% of the institutions acknowledge daily requests for access to their collection content (Figure 2). Such use has a major impact on institutional copying and reformatting programs. Library and archives collections generally include materials in a wide variety of formats. Although the purpose of the recording initially dictated the format and equipment choice used in the field,[54] the act of collecting produces collections made up of various tape formats. With the collections in place, the next step for the institutions is to provide access to the information. Figures 3 and 4 illustrate the availability of playback equipment throughout the collections surveyed. These data identify machines that are dramatically decreasing in number and formats, such as ½" VHS, and that are still commonly used for viewing access copies. This type of information will certainly evolve over time, and the disappearance of today's most common formats will be seen. The great diversity of equipment associated with the different tape formats highlighted imminent access problems. Access is a major driving force for copying or reformatting original materials, but it was also important to see if other criteria were taken into account when

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[54] A. Lewis, "A History of Television Newsgathering Formats," in: S. Davidson, G. Lukow, editors, *The Administration of Television Newsfilm and Videotape Collections: A Curatorial Manual*, American Film Institute, Louis Wolfson II Media History Center, 1997, pp. 11-30.

deciding which materials should be transferred to a new support. During the survey, attempts were made to identify the most predominant factors. The assessment was obtained by simply adding the rankings attributed by each institution to the criteria on the survey form. On a scale from 1 to 5, 1 was the predominant factor. Thus, the lowest score identifies the predominant factor overall for initiating the copying/reformatting of the materials (Figure 5). The value or importance of the materials appeared to be the most important criterion for copying. However, responses indicated that decisions may be made based on other criteria, listed here in descending order of importance: (1) tape condition, (2) request for access, and (3) format obsolescence. These factors are difficult to quantify, however.

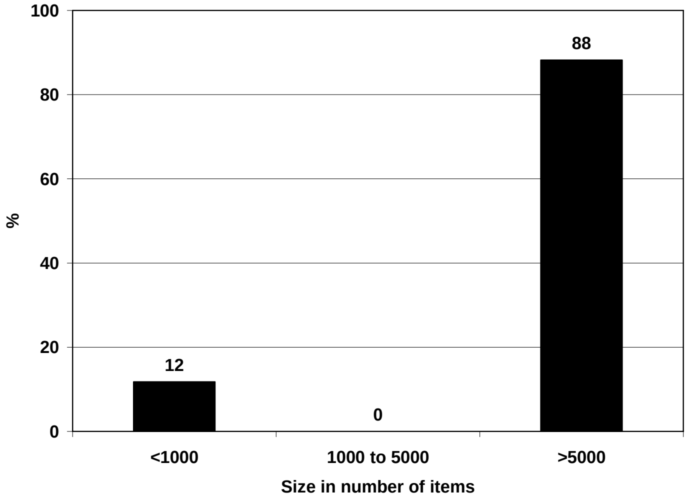

Figure 1: Distribution of the magnetic tape collections in terms of size. Sample size: 17 institutions across the US.

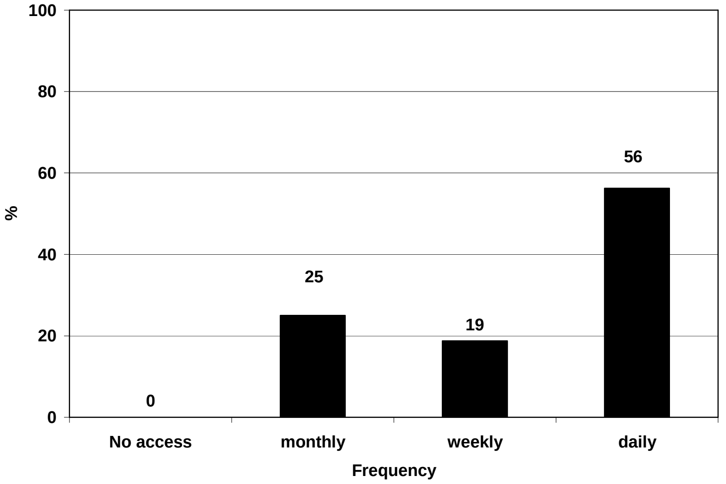

Figure 2: Level of use of the collections.

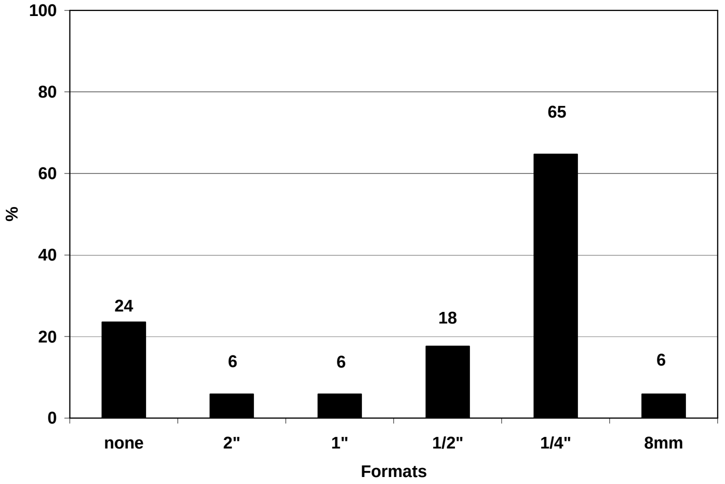

Figure 3: Availability of reel-to-reel playback equipment.

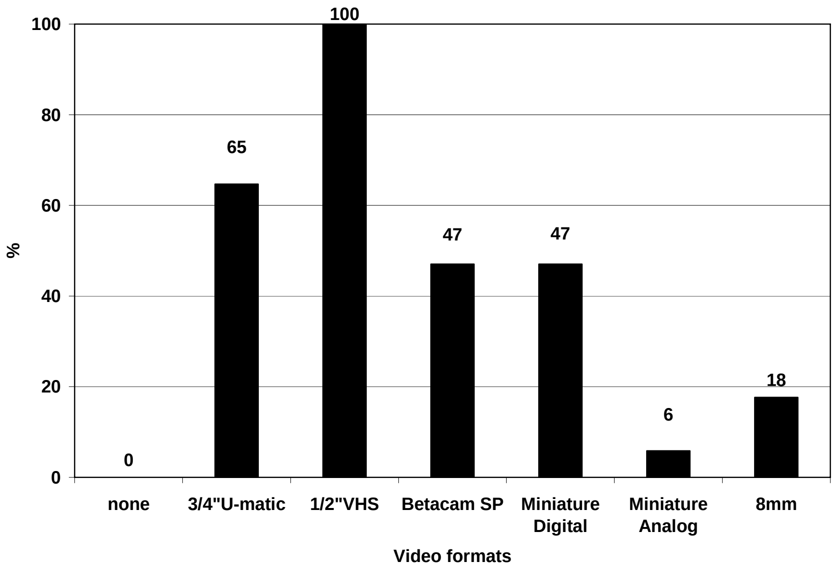

Figure 4: Playback equipment currently available in institutions for various video formats.

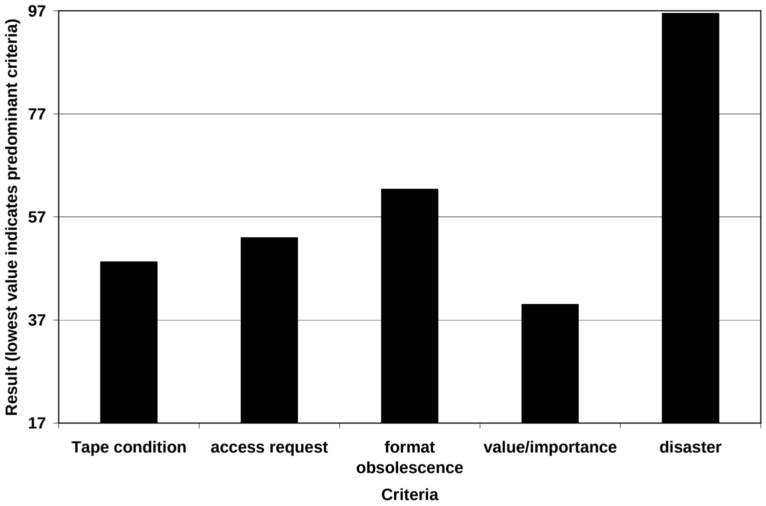

Figure 5: Ranking of most important criteria for transferring materials onto new support or format. Lowest value indicates predominant factor of decision based on survey results.

Decay Manifestations

Of particular interest within the framework of this research was the perception that tape condition is an important factor for planning tape transfer. Today, however, condition assessment for magnetic tape is not an easy task, since no diagnostic tool is available. Tapes are generally assessed by visual examination and by playback. Figure 6 provides some insight into the realm of tape decay manifestations. Collection managers were asked to indicate if they had witnessed several types of decay manifestations. The survey results are not indicative of the *extent* of the various signs of deterioration but reflect only how frequently these problems have been recognized in the field. A significant proportion of organizations have had experience with tape decay. Around 80% of the institutions have observed various decay manifestations and 35% have been unable to replay materials due to decay. Figure 6 indicates that collection managers have been aware of tape decay. However, as in previous surveys, the extent of decay throughout collections is either unknown or relatively low.

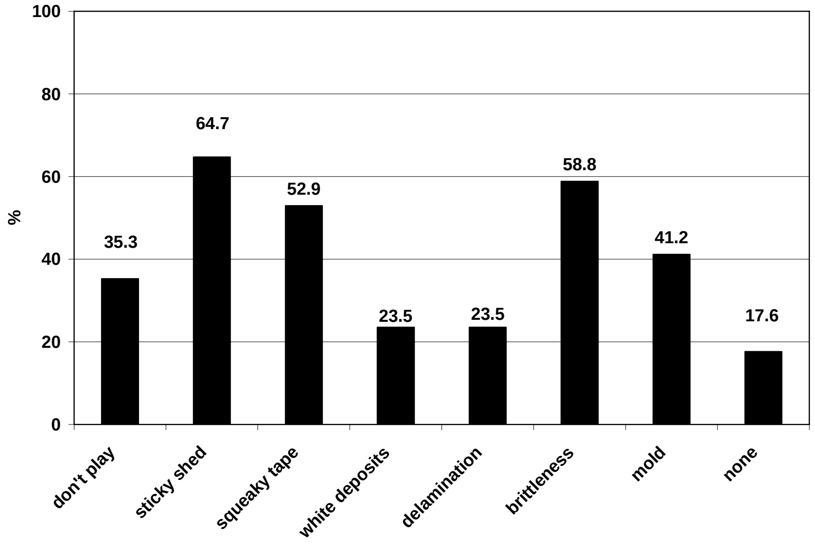

Figure 6: Major manifestations of decay observed in tape collections. Percentage of institutions having witnessed each decay manifestation in their collections.

Storage Environment

The IPI survey also addressed the issue of storage environment. Answers indicated that about 70% of collections are stored in fully or partly climate-controlled vaults (Figure 7). However, further analysis showed that 67% of the storage areas provide near-room-temperature conditions (i.e., near 20°C/68°F). Figure 8 illustrates the answers based on the storage categories defined in the *IPI Media Storage Quick Reference*.[55] That approach allowed the characterization of storage categories based on temperature. Only about 33% of the storage areas implement cool storage (i.e., around 12°C/54°F).

Humidity level has been identified as critical for preserving magnetic tapes. About 60% of the storage areas provide either moderate or low RH conditions. Around 40% of the collections are stored at RH levels greater than 50% (Figure 9). The survey information

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[55] P. Z. Adelstein, *IPI Media Storage Quick Reference*, Image Permanence Institute, Rochester Institute of Technology, Rochester, NY, 2004.

indicates that magnetic tapes are generally stored according to standard recommendations in terms of temperature, but that a significant proportion of collections (i.e., around 40%) would benefit from RH control. In addition, based on the fact that more than 80% of the institutions surveyed stated that materials are stored in either uncontrolled or partly controlled environments, it is expected that a full evaluation and subsequent optimization of storage environments would greatly benefit the stability of the collections.

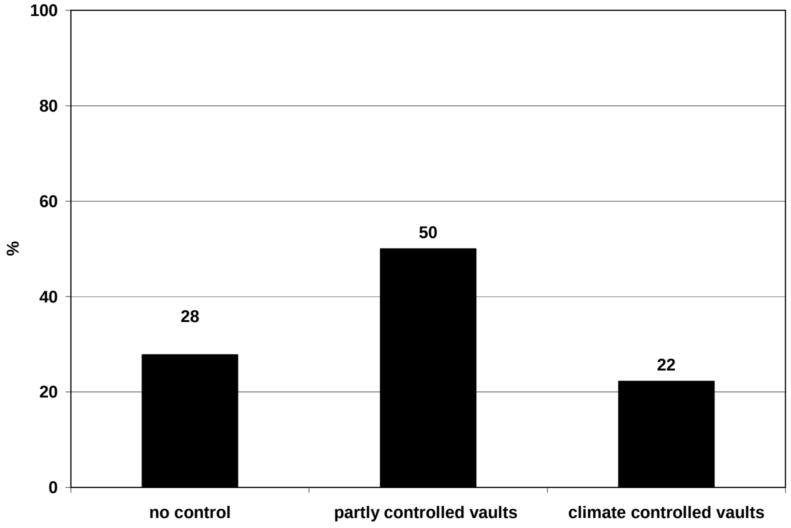

Figure 7: Storage environments.

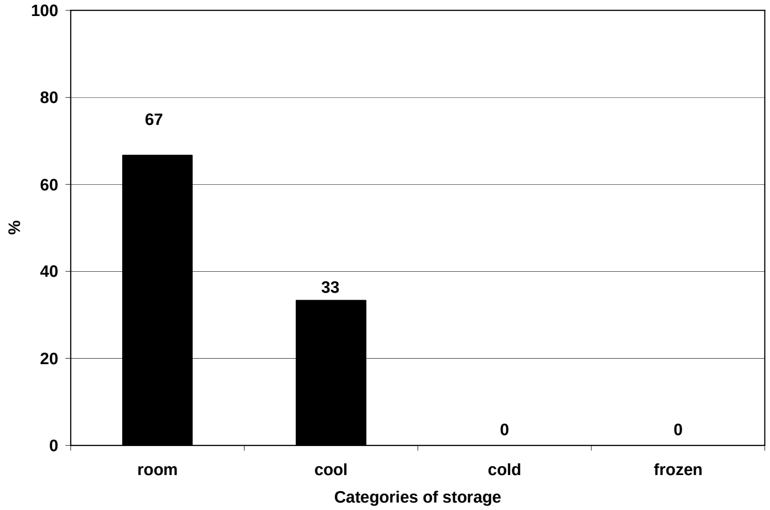

Figure 8: Storage temperature based on storage categories, as defined in the IPI Media Storage Quick Reference.

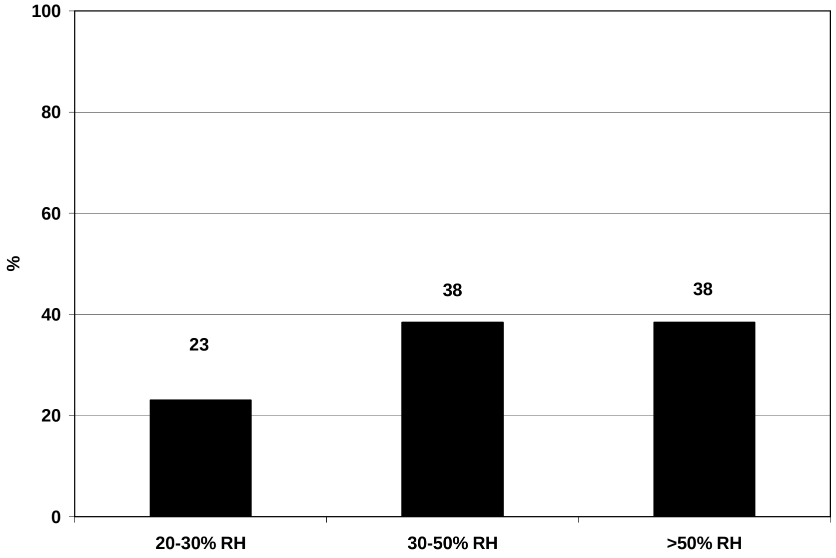

Figure 9: Relative humidity level maintained in tape storage areas.

Survey Results—Summary

Despite the small number of responses received by IPI, the information collected provided valuable insights into the preservation management of magnetic tape collections. The answers led to important conclusions:

In practice, material transfer through copying or reformatting is essentially driven by material value, request for access, or format obsolescence.

Library and archives collections contain a wide variety of tape formats that already are, or may soon become, obsolete. The lack of availability of playback equipment required for specific tape formats is a growing obstacle to information access.

Institutions commonly report anecdotal evidence of tape deterioration and failure. The extent of the problem remains mostly unknown, however, due essentially to the lack of an easy-to-use diagnostic tool for determining tape condition.

The implementation of environment-based storage strategies for magnetic tape collections is not a common practice. Survey data indicate that a significant proportion of collections are exposed to climate conditions that are inappropriate for extended-term storage.

SURVEYING A MEDIA COLLECTION—REQUIREMENTS

Initially, IPI planned during the research project to conduct condition surveys at a number of collection sites using current evaluation methods. In short, any condition survey consists of four main tasks: sampling, testing, analyzing data, and reporting the results. Each of these four tasks must be planned in advanced according to the main objective of the survey. It was hoped that the methodology developed by IPI for assessing acetate-based materials would provide a useful model for other types of media like magnetic tapes. Strategies for preserving film materials have been developed based on three consecutive NEH-funded research projects.[56, 57, 58] These studies focused on (1) the identification of the best indicator of decay, (2) the relationship between storage conditions (temperature and RH) and the rate of chemical deterioration, and (3) the development of A-D Strips, a diagnostic tool for assessing acetate film condition. These elements, used together, help to determine the best-fit preservation strategy for any real-life situation. It was believed that a similar approach applied to the preservation of magnetic tapes would help to quantify the extent of decay throughout tape collections and to prioritize preservation actions such as deciding on reformatting initiatives based on the current condition of collection materials or initiating storage improvements to stabilize collections. A prime requirement to achieve such an objective is the identification of reliable and practical evaluation criteria for a tape collection survey.

CONDITION EVALUATION CRITERIA FOR MAGNETIC TAPES

During the initial phase of the project, two consultants, Sarah D. Stauderman and Peter C. Brothers, were invited to be part of the research program to present their approach to assessing the state of preservation of magnetic tape collections. Each consultant was invited for one day. Both provided valuable insights into the complexity of evaluating tape condition. They shared their experience and understanding of the field and described survey methodologies in detail. Their insights, comments, and advice contributed to the development of IPI's web-based survey discussed earlier in this report.

In practice, tape inspection relies on visual examination and evaluator expertise. There is no doubt that visual information gathered by inspecting the tape container, the integrity of

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[56] J. M. Reilly, P. Z. Adelstein, and D. W. Nishimura, *Preservation of Safety Film*, Report to the Office of Preservation, National Endowment for The Humanities, Grant # PS-20159-88, Image Permanence Institute, Rochester Institute of Technology, March 28, 1991.

[57] J. M. Reilly, P. Z. Adelstein, D. W. Nishimura, and C. Erbland, *New Approaches to Safety Film Preservation*, Final Report, NEH Grant PS-20445-91, April 27, 1994.

[58] J.-L. Bigourdan and J. M. Reilly, *Environment and Enclosures in Film Preservation,* Final Report to the Office of Preservation National Endowment for the Humanities, September 15, 1997.

the tape, the tightness and aspect of the winding, the presence of detectable odor, and the detection of surface contamination provides a valuable picture of the item's condition and, by extension, of the state of preservation of an entire collection, when the inspection is conducted on the basis of random sampling. This type of approach has been referred to in ISO recommended practices as a *seven-step physical inspection.*[59] Its implementation on a large scale may be difficult, however, and requires extensive handling of the tapes. In the search for an understanding of tape deterioration and for a method of evaluating tape condition, a number of alternatives have been explored over the years. These can be grouped into three types of examination: visual, playback, and laboratory testing. While the first two have been used in the field, the latter has received renewed interest as part of efforts to develop nondestructive techniques for the condition assessment of tape collections. From that perspective, the research conducted at the Centre de Recherches sur la Conservation des Documents Graphiques (CRCDG) in Paris has been investigating several analytical techniques and their applicability to the evaluation of magnetic media condition.[60] These include several tools currently under development. However, researchers have concluded that finding a "unique" indicator of condition would require considerable effort. This is essentially due to the fact that deterioration processes and, therefore, intrinsic tape stability are highly dependent on manufacturing practices. Based on that assessment, the CRCDG has oriented its efforts toward developing a tape database that would serve as a reference for material identification, potential vulnerability, and playability.

DETECTION TESTS FOR TAPE DEGRADATION

IPI conducted a series of laboratory tests on magnetic tapes. In an effort to evaluate several methods for monitoring tape condition, IPI investigated the possibility of producing degraded tapes using accelerated aging. Three laboratory tests were explored, and test procedures were finalized. Finally, a series of samples was incubated and tested over time for condition. The data developed during the study provided insights into the property measurement methods and into the degradation of magnetic tapes.

Property Measurements

Three methods for quantifying the degree of degradation of the tapes were investigated:

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[59] ISO 18933: 2006—*Imaging materials—Magnetic Tape—Care and handling practices for extended usage* (Geneva: International Standard Organization), 2006.

[60] B. Thiebault, L. B. Vilmont, B. Lavedrine, *PrestoSpace, D6.1: Report on video and audiotape deterioration mechanisms and considerations about implementation of a collection condition assessment method*, 2006.

Acetone extraction

Acidity test

Friction test

The first task was to finalize each test method. This was achieved by testing magnetic tapes that were aged under accelerated conditions. Based on earlier tape stability studies, samples were exposed to thermal degradation under various humidity conditions. The goal of the aging procedure was to produce measurable property changes within a practical time frame to provide an evaluation of the responses that each property measurement method could provide.

Acetone Extraction

Although the acetone extraction test is not suitable for use as a field diagnostic, it did provide valuable information in some of the earliest work on tape binder stability.[61,62] The degradation products of the polyurethane binder were found to be soluble in acetone, and the weight percent (wt.%) of extractable was considered to be a measure of the degradation. Tape binder degradation is the result of polymer breakdown that occurs in reaction with humidity (i.e., hydrolysis). Hydrolytic breakdown causes a change in the structure of the polymeric chain, producing low-molecular-weight fragments. These end-fragments are compounds that are mobile and tacky, and they are likely to be extractable in acetone. The acetone extraction test was chosen based on its ability to measure an increasing proportion of extractable end-fragments from the polyurethane polymer as binder hydrolysis proceeds. Measuring the percentage of extractable in acetone provides an indication of tape condition and reflects tape playability. Such a measurement indirectly detects the presence of low-molecular-weight products and is a good indicator of either degraded or unstable polyurethane binder. Other tape components, such as lubricants, might also be soluble in acetone, however, and this may alter the results. Since tape formulation may vary in significant ways, it was expected that the wt.% of extractable may also vary from one type of tape to another regardless of the degree of binder hydrolysis. Significant variation due to differences in format, manufacturer, or production batch was expected. However, it was believed that results obtained from

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[61] E. F. Cuddihy, “Aging of Magnetic Recording Tape,” *IEEE Transactions on Magnetics*, Vol. MAG-16, No. 4, July 1980, pp. 558-568.

[62] H. N. Bertran and E. F. Cuddihy, “Kinetics of the Humid Aging of Magnetic Recording Tape,” *IEEE Transactions on Magnetics*, Vol. MAG-18, No. 5, September 1982.

accelerated aging would have value. For this reason, results from incubated test samples were compared with baseline data from an unincubated sample of the same tape. It was believed that the difference between the two would reflect the condition of the test sample during the incubation period.

Extraction Time

A series of preliminary tests was conducted at IPI. Results indicated that the wt.% of extractable is influenced by a variety of factors, most notably the duration of the acetone extraction. Thirty-minute immersion in acetone provided repeatable results. Shorter extraction times led to inconsistent results, and longer extraction times did not significantly increase the amount of extractable compounds. Table II reports results obtained on ¾" and 1" magnetic tape using 30-minute, one-hour, and two-hour extractions in acetone. Average values were determined based upon four evaluations for each extraction time and tape width. It was shown that increasing the duration of acetone extraction beyond 30 minutes did not significantly alter the final results for tapes. The values determined for each set of four measurements conducted on each tape displayed small differences (see Table II). Based on these results it was concluded that the method could be valuable for the study. For practical reasons, a 30-minute extraction time was chosen.

Table II: Effect of acetone extraction time on the determination of percent acetone extractable. Average values were calculated based on four measurements for each test. The percent acetone extractable is expressed in wt.% based on the weight loss of the tape sample.

Tape width		**% acetone extractable obtained for various extraction times**		
		½ hour	**1 hour**	**2 hours**
¾"	**Max.**	2.4	2.5	2.5
	Min.	2.1	2.3	2.3
	Average	2.2	2.4	2.4
1"	**Max.**	1.7	1.8	1.8
	Min.	1.6	1.7	1.8
	Average	1.6	1.7	1.8

Based on this work, IPI finalized an acetone extraction method for use in the research. The method provided reproducible results within an acceptable range. Each evaluation is based on four measurements. This procedure drastically increases the number of laboratory test to be performed, but it greatly improves the reliability of the results. The data discussed in the following sections were determined following the procedure described in Table III.

Table III: Acetone extraction method used at IPI for testing magnetic tapes.

Step	Description
1. Sample preparation	Sample weight: approx. 0.5 mg. Length of tape sample was based on tape width (e.g., 18" sample for 1" tape, 36" sample for ½" tape) Four test samples were prepared for each tape tested.
2. Conditioning	Sample was conditioned to 21°C, 50% RH, for at least one hour.
3. Weighing	Sample was placed in a weighing bottle and weighed on precision scale (±0.0001gram).
4. Acetone extraction	Sample was accordion-folded and immersed in 30 mL of acetone for 30 minutes.
5. Drying	Sample was retrieved and rinsed in acetone. Then, it was placed on filter paper for 15 minutes to drain and to let the acetone evaporate. Sample was placed in dry oven at 50°C for 15 minutes.
6. Conditioning	Sample was conditioned to 21°C, 50% RH, for at least one hour.
7. Reweighing	Sample was placed in a weighing bottle and weighed on precision scale.
8. Calculation	Acetone extractable was expressed in wt.% based on weight loss of sample. Final determination was expressed as average value based on four determinations for each tape tested.

Acidity Test

Because earlier studies had described the formation of carboxylic acids during the process of tape binder degradation, the detection of acidity was included in the experimental program. Recent research conducted at the CRCDG[63] using analytical techniques has demonstrated the presence of acidic binder deterioration byproducts.[64] Although binder behavior may vary, these data underscore the possibility of using acidity measurement as an indicator of tape condition. Based on preliminary results, the determination of free acidity was chosen for further evaluation. The measurement is usually based on pH determination or titration. It was understood, however, that the method would evaluate only the water-extractable acidic products. It was not expected that the acidity results would reflect all organic acids that may be present in the magnetic layer.

The water-leaching method used in this study was one developed by IPI for determining the rate of decay of acetate-based photographic film.[65] When the study was being designed, it was recognized that the method developed for acetate film was not

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[63] *Centre de Recherches sur la Conservation des Documents Graphiques* (CRCDG), Paris, France.

[64] PrestoSpace, *D6.1: Report on video and audiotape deterioration mechanisms and considerations about implementation of a collection condition assessment method*, authors: B. Thiebault, L. B. Vilmont, B. Lavedrine, 2006.

[65] P. Z. Adelstein, J. M. Reilly, D. W. Nishimura, and C. J. Erbland, “Stability of Cellulose Ester Base Photographic Film: Part III—Measurement of Film Degradation,” *SMPTE Journal*, Vol. 104, May 1995, pp. 281-291.

necessarily applicable to tape. (However, the water-leaching test did detect the formation of higher acidity levels when tapes were incubated at high temperatures and under humid conditions.) The composition of the byproducts of tape degradation is likely to be rather different from that of the byproducts of acetate film degradation. While acetate decay leads to the release of compounds composed of small acid molecules (e.g., acetic acid), tape binder degradation is likely to also form compounds composed of larger molecules that may or may not be water-extractable. In addition, measurable levels of free acidity may reflect an extremely damaged tape condition; such a situation may be outside the range of interest. Finally, it was not known whether the acid-base indicator used for acetate film testing (i.e., meta-cresol purple) could be adapted to titrate the carboxylic acids that might be produced by the degrading tape. This aspect was addressed during the study by measuring pH change during titration. Despite these limitations, it was believed that the detection of tape acidity over various periods of incubation might provide useful data on tape decay. Thus, the water-leaching acid determination method was applied to magnetic tape analysis during this study. Preliminary experiments addressing the suitability of the method for free acidity change on incubated magnetic tape are discussed below, and the test procedure is summarized in Table IV.

Table IV: Test procedure for water-leaching free acidity test.

1. Sample preparation	Sample weight: approx. 1 gram. Length of tape sample was based on tape width. Tape sample, including magnetic layer and all coatings and support, was cut into small pieces and placed in 100mL of deionized water.
2. Water extraction	Tape sample was allowed to soak in water for at least 24 hours at 38°C, with continuous moderate stirring.
3. Filtration	Aqueous solution was filtered to remove tape pieces.
4. Titration	Solution was titrated with 0.1N sodium hydroxide solution after adding meta-cresol purple indicator.[66] A blank titration was made using the same deionized water used for water extraction (2).
8. Calculation	Free acidity was expressed as milliliters of 0.1N sodium hydroxide per gram of magnetic tape. Four measurements were performed for each test.

Water Extraction Time

Two steps of the water-leaching test method were re-evaluated. The minimum duration of 24 hours for the water-extraction phase was found adequate for testing tape. A longer time (48 hours) did not lead to a higher level of free acidity of the incubated tape sample.

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[66] Indicator solution is 0.1 g meta-cresol purple dissolved in 13.1 mL 0.2 N NaOH and diluted to 250 mL. Volume of indicator solution used is 0.84mL.

Figure 10 illustrates the results obtained from testing a series of six magnetic tape samples using 24-hour and 48-hour water extraction times. The figure indicates significant differences between the samples and shows that 48-hour extraction did not significantly alter the free acidity determinations.

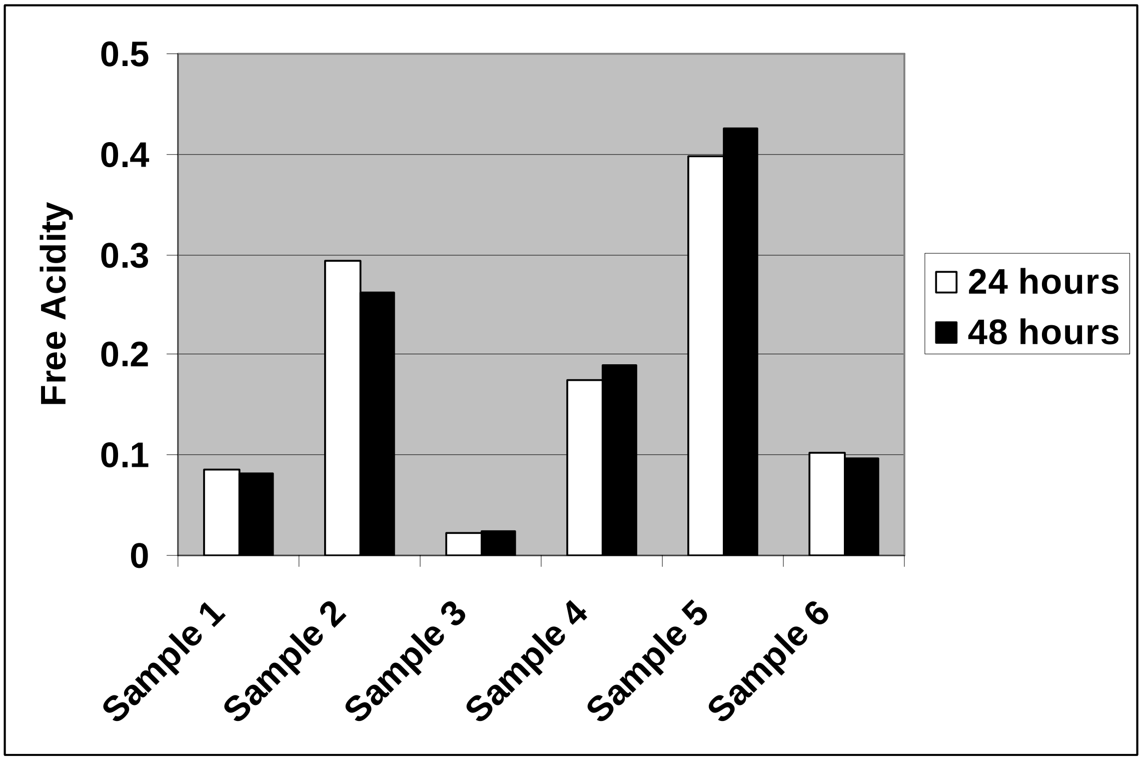

Figure 10: Free acidity test on magnetic tape samples. Results obtained by using 24-hour and 48-hour water extractions.

<u>pH Color Indicator</u>

The suitability of the meta-cresol purple color indicator was investigated by monitoring the pH change during titration of a series of tape samples. The purpose of these tests was to investigate the end point of the titration. Seven magnetic tape samples were titrated by gradually adding 0.1N sodium hydroxide solution to the water extract obtained after a 24-hour extraction at 38°C. Each test sample weighed around one gram. After each addition of sodium hydroxide, the pH value was recorded once it was stabilized. Figures 11-17 depict titration curves for seven test samples as pH versus added milliliters of 0.1N sodium hydroxide. Sample codes and descriptions are provided in Table V. The magnetic tapes used for the investigation either were aged under accelerated conditions or were aged naturally.

Table V: Sample code and description of the magnetic tape test sample.

Sample code	Width	Manufacturer and type	Sample obtained by
A	2"	3M digital data tape	Accelerated aging at 80°C for 118 days in sealed bag. Initially moisture conditioned to 21°C, 75% RH.
B	1"	Fuji H621 videotape	
G	2"	Scotch Quad videotape	Natural aging
I	2"	Scotch Quad videotape	Natural aging
J	2"	Scotch Quad videotape	Natural aging
M	¼"	Ampex 406 audiotape	Natural aging
N	¼"	Sony PR-150 audiotape	Natural aging

The shape of each titration curve shows one end point that is located in the basic region of the titration (i.e., above pH 7). The magnitude of the pH change around the end point of the titration indicates that the determination of the equivalent point could be conducted using an acid-base color indicator. Based on the location of the end point on the titration curve, an indicator displaying a color change in the basic region is suitable. The meta-cresol color indicator exhibits a change from yellow to purple within the pH range of 7.4 to 9.0. Thus, the indicator is suitable for titration of a weak acid (e.g., acetic acid) with a strong base (e.g., sodium hydroxide). Although using meta-cresol purple for testing magnetic tape samples might result in slightly greater free-acidity values, the method would allow for some discrimination between samples. Figure 18 illustrates the titration curves of four magnetic tape samples and underscores significant differences. Despite the relatively small acidity values, duplicate determinations indicate that the range of acidity may vary by a factor of almost 5. A relatively high acidity level was measured on sample B after incubation. The lowest acidity level was determined on sample J after natural aging. It was concluded that acidity measurement could provide valuable information for magnetic tape research and that using the previously developed determination method for acetate-base film would be adequate for magnetic tape testing. The testing procedure adopted for the research is described in Table IV.

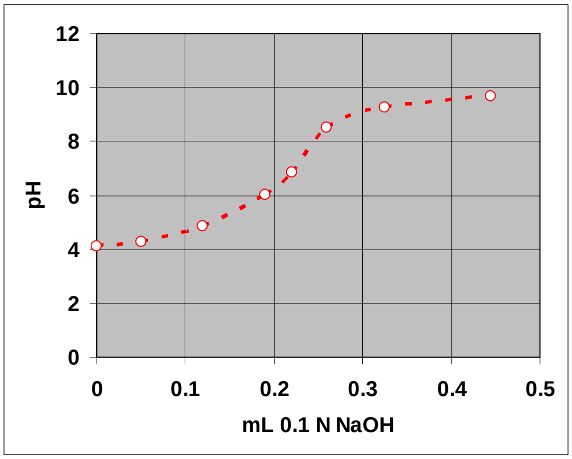

Figure 11: Free acidity determination—pH titration curve for sample G.

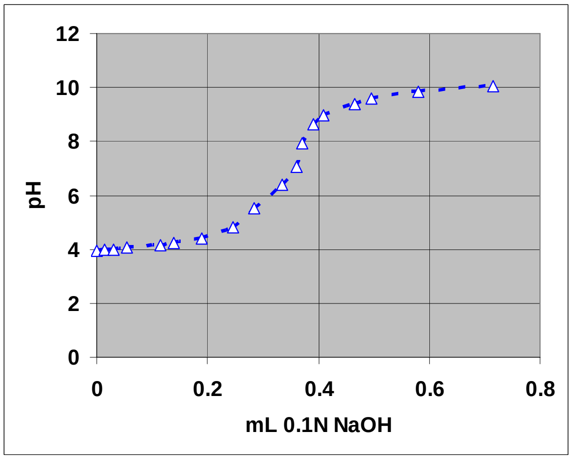

Figure 12: Free acidity determination—pH titration curve for sample M.

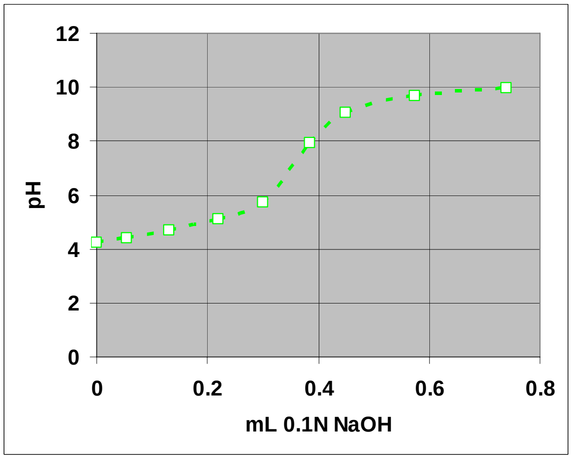

Figure 13: Free acidity determination—pH titration curve for ¼" audiotape (Sony PR-150) after 24-hour water extraction at 38°C.

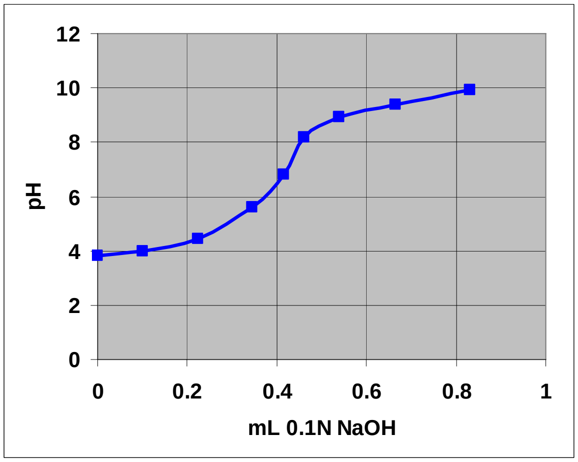

Figure 14: Free acidity determination—pH titration curve for sample B incubated at 80°C for 118 days. Sample B was initially moisture-conditioned to 21°C, 75% RH prior to incubation in sealed bag.

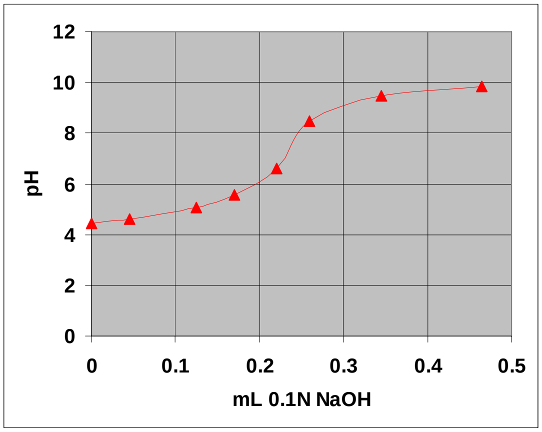

Figure 15: Free acidity determination—pH titration curve for sample A incubated at 80°C for 118 days. Sample A was initially moisture-conditioned to 21°C, 75% RH prior to incubation in sealed bag.

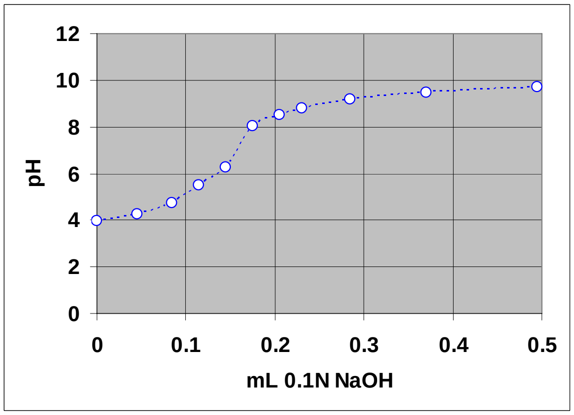

Figure 16: Free acidity determination—pH titration curve for sample J.

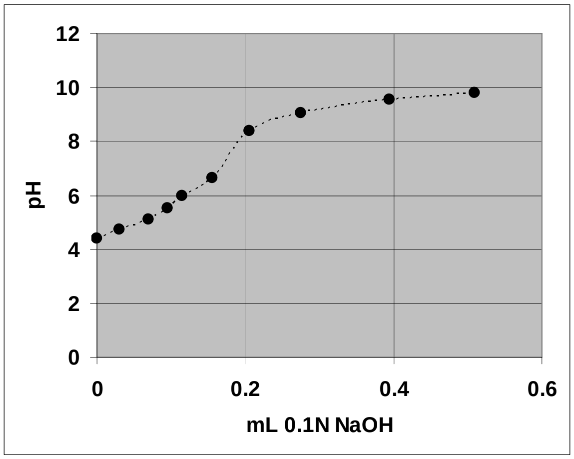

Figure 17: Free acidity determination—pH titration curve for sample I.

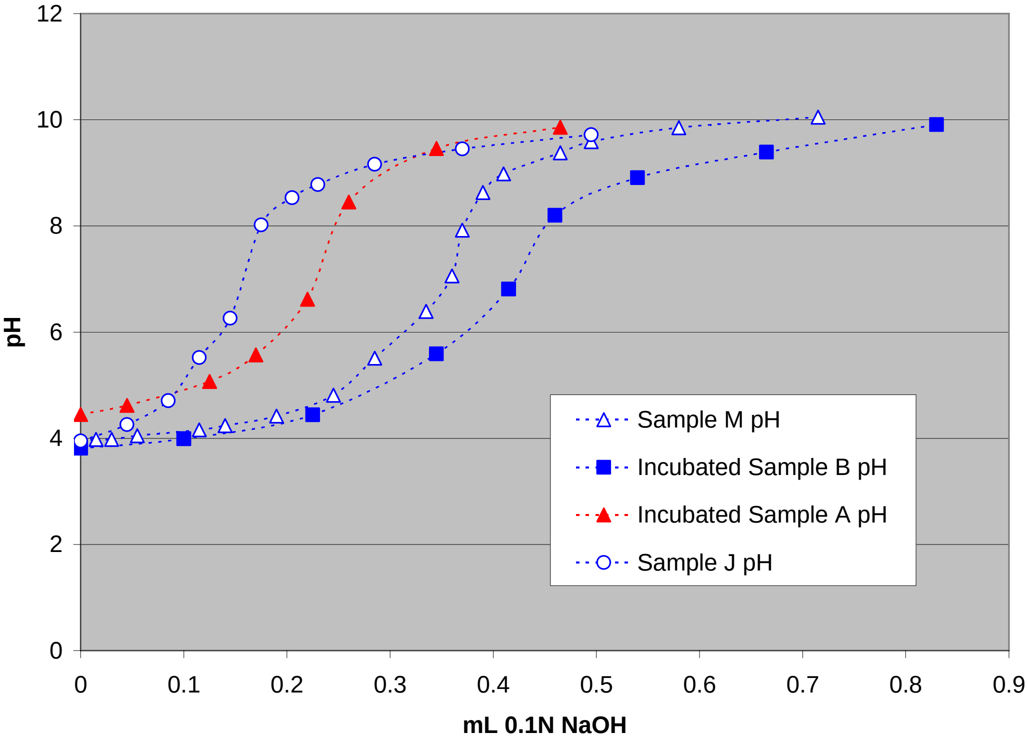

Figure 18: Free acidity determination—pH titration curve comparison for four magnetic tape samples.

Friction Test

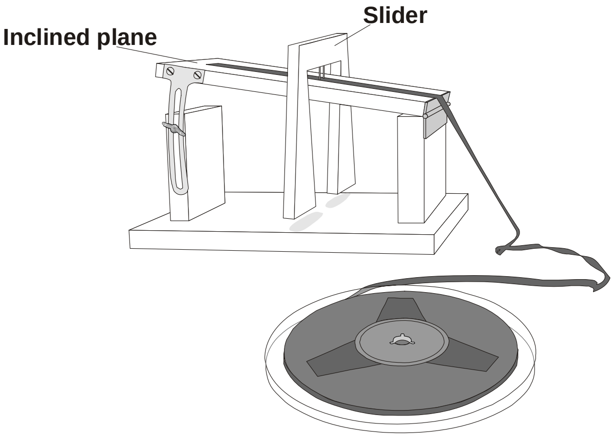

Figure 19: Apparatus for friction test.

In addition to the measurement of acetone extractable and the free-acidity test, a physical test was tried, which was aimed at detecting the changes in the tape binder over time. Binder degradation is a major problem in the prevention of information loss. As the binder deteriorates, it becomes sticky and may cause tape failure during playback. It is believed that binder decay leads to increased friction along the tape. Scientists at Eastman Kodak Company developed a nondestructive friction test over thirty years ago.[67] The test's wide utility for motion-picture film resulted in its being standardized by ISO.[68] IPI evaluated the method's usefulness with magnetic tape. Figure 19 illustrates the friction test apparatus. The test involves placing a length of the tape sample on the surface of an inclined plane. A rider is placed on top of the sample strip that has point contact with the surface. The inclined plane is raised until the rider slides. The idea behind this application of the friction test was that binder degradation increases the stickiness of the tape surface, and increased stickiness, in turn, necessitates raising the device plane higher in order to initiate the sliding of the rider. The coefficient of sliding friction is measured as a tangent of the inclined plane to the horizontal. The test is nondestructive.

Experimental

Magnetic Tape Samples

Five different types of tape were tested further during the study using accelerated aging. The magnetic tapes tested are described in Table VI. These tapes were donated to IPI for testing. The series include several magnetic media formats ranging in width from 2" to ½".

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[67] T. Anvelt, J. F. Carroll, and L. J. Sugden, "Processed Film Lubrication: Measurement by Paper-clip Friction Test and Improvement of Projection Life," *Journal of the Society of Motion Picture and Television Engineers*, Vol. 80, No. 9, Sept. 1971, pp. 734-739.

[68] ISO 18904:2000 (E), *Imaging materials—Processed films—Method for determining lubrication*, (Geneva: International Organization for Standardization, 2000).

Table VI: Magnetic tape sample formats.

Tape	Format
A	2" digital data tape (3M)
B	1" video tape (Fuji H621)
C	¾" U-matic video tape (Scotch UCA30)
D	½" VHS video tape (3M)
E	1" video tape (Ampex 196)

Sample Preparation

Prior to incubation, all tape samples were moisture-preconditioned. The main objective of this step was to bring all samples to specific levels of moisture content, which is essential for obtaining reproducible results. The method consisted of conditioning the tapes inside a temperature- and RH-controlled walk-in chamber. The hygroscopic properties of magnetic tape have been investigated in earlier studies. Cuddihy [69] demonstrated that magnetic tapes absorbed or desorbed water depending on the direction of change of relative humidity. Moisture equilibrium curves obtained at 25°C indicate that the moisture content of tapes depends essentially upon the relative humidity level. Data reported by Cuddihy indicated that tape in equilibrium at 75% RH contains more than 3.5 wt.% of water compared to about 1.0 wt.% at 20% RH. Although the study indicated that the age of the tape may alter the moisture equilibrium curve, at a given temperature different equilibrium RH levels lead to different tape moisture content. Previous data developed at IPI on the rate of moisture equilibration of magnetic tape were also used to finalize the preconditioning approach.[70] These results indicate that moisture conditioning can take weeks or months to reach equilibrium with the ambient RH. Based on these earlier results, a set of the five types of tape was conditioned for five consecutive weeks to high RH (25°C, 75% RH) and another set to low RH (25°C, 20% RH). Using this procedure, two sets of materials with different tape moisture content were prepared. After preconditioning, each set of samples was bagged in the climate-controlled chamber in order to maintain consistent moisture content in the material. This procedure involved stacking strips of each type of tape, wrapping them in a Teflon sheet, and double-bagging them in heat-sealable aluminum-foil bags.

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[69] E. F. Cuddihy, “Hygroscopic Properties of Magnetic Recording Tape,” *IEEE Transactions on Magnetics*, Vol. Mag-12, No. 2, March 1976, pp. 126-135.

[70] J.-L. Bigourdan, J. M. Reilly, and K. A. Santoro, *Effects of Fluctuating Environments on Library and Archives Materials*, Final Report to NEH, Division of Preservation and Access, NEH Grant#PA-23159-98, February 15, 2003.

Incubation Procedure

The bagged materials were incubated at 60°C and 80°C for various periods of time up to eight months. Incubation conditions were chosen based on earlier studies and preliminary tests conducted at IPI. Early studies on tape binder stability reported by Cuddihy[71] and Bertram[72] involved incubation temperatures ranging from 36°C to 75°C and a wide range of humidity levels from 0% to 100% RH. Based on the results reported earlier, it was expected that aging at 60°C and 80°C would lead to significant levels of binder hydrolysis in the tape samples. The sealed-bag approach chosen for the current research made possible the incubation of test samples at constant moisture content. Therefore, for each set of materials initially moisture-conditioned at either high RH (25°C, 75% RH) or low RH (25°C, 20% RH), it was expected that the rate of binder deterioration would be governed solely by thermal effect. The main objective of the incubation procedure was to produce a series of tape samples that would be representative of various tape binder conditions. A series of six sample bags was prepared for each set of tapes and incubation temperatures. A total of 96 bags were used for the research.

Property Measurements

All three detection tests were evaluated based on their ability to quantify various degrees of binder deterioration created through accelerated aging, as described above. Over time, sample bags were removed from the oven and examined. Each sample pull was tested based on four measurements, using free acidity, acetone extraction, and friction tests. The approach called for conducting more than 1,150 laboratory tests in all. Results are reported and discussed in the following sections.

Results

The data developed during the project are grouped according to test method. The main objective of this part of the project was to evaluate three test methods: two that would serve for laboratory testing only, because they are destructive (i.e., acetone extraction and acidity test), and one that might eventually be used in the field for condition assessment (i.e., friction test). Measurable free acidity changes could eventually lead to the development of a nondestructive diagnostic tool for assessing the condition of magnetic

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[71] E. F. Cuddihy, "Aging of Magnetic Recording Tape," *IEEE Transactions on Magnetics*, Vol. Mag-16, No. 4, July 1980, pp. 558-568.

[72] H. N. Bertram, and E. F. Cuddihy, "Kinetics of the Humid Aging of Magnetic Recording Tape," *IEEE Transactions on Magnetics*, Vol. 18, No. 5, September 1982, pp. 993-999.

tape. All magnetic tape samples were incubated at 60°C. In addition, tapes A, B, and E were incubated at 80°C.

Incubation at 60°C

All samples were incubated at 60°C inside moisture-proof packaging. One set of samples had been moisture-preconditioned to 25°C, 75% RH (high moisture content), and another set had been moisture-preconditioned to 25°C, 20% RH (low moisture content).

Free Acidity

Acidity measurements were conducted prior to and during incubation over a period of 20 weeks for materials preconditioned to high moisture content, and 32 weeks for the materials preconditioned to low moisture content. Free acidity values are reported in Figures 20 and 21 for both series of test samples (i.e., samples conditioned to either high or low moisture content). Free acidity levels are expressed in milliliters of 0.1N sodium hydroxide solution per gram of tape. Results did not indicate significant property changes. Free acidity levels remained lower than 0.1mL 0.1N NaOH/gram for both sets of test samples despite the difference in moisture content. Incubation at 60°C did not produce material changes significant enough to be conclusively detected by free acidity measurement.

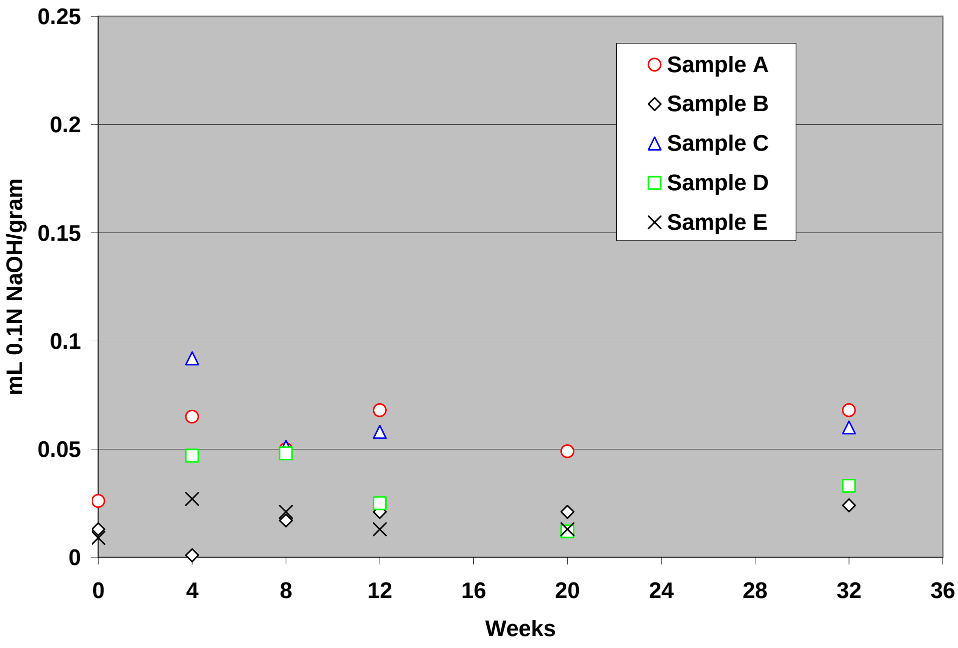

Figure 20: Free acidity versus incubation time at 60°C inside sealed bags. Samples were initially moisture-conditioned to 25°C, 20% RH.

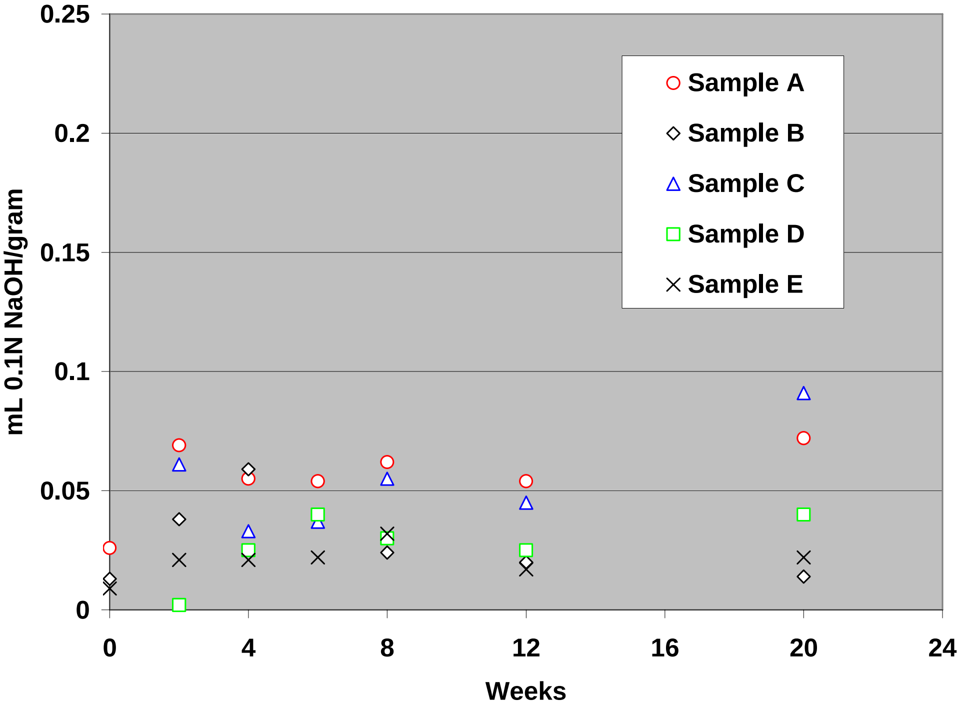

Figure 21: Free acidity versus incubation time at 60°C inside sealed bags. Samples were initially moisture-conditioned to 25°C, 75% RH.

Acetone Extraction

The acetone extraction test was conducted on all samples following the procedure described in Table III. Acetone extraction results are expressed in wt.% of acetone extractables. Each determination was conducted on four samples. The average value is reported in Tables VII and VIII. The test results indicate that the initial percentage of acetone extractables varied by a factor greater than 5 depending on the test samples. Tests were conducted prior to incubation. Tape A (2" digital data tape) displayed the highest value (3.85 wt.%), and tape E (1" videotape) displayed the lowest value (0.75 wt.%). These differences are illustrated in Figures 22 and 23. Based on the fact that these materials were obtained from several sources, and that the production dates and previous storage climate conditions were unknown, these differences are only indicative of the wide range of binder conditions that can be encountered, even when dealing with a relatively small number of materials. Data obtained during the incubation at 60°C provided some evidence that the determination of the percentage of extractable compounds might serve as a marker of binder property changes. A significant increase in the percentage of acetone extractables was observed for tapes A, C, and E. This behavior was marked, in particular for the samples initially conditioned at the higher humidity level—i.e., at 75% RH. The effect of initial moisture conditioning on property changes is further discussed later in this report. However, data obtained at 60°C indicate that the acetone extraction test was able (1) to detect differences between materials prior to aging, and (2) to monitor property change during incubation. Tapes B and D did not, however, display significant property changes, even those samples preconditioned to 75% RH at 25°C.

Table VII: Percent of acetone extractables determined over time at 60°C in sealed bags. Materials initially moisture-conditioned to 25°C, 20% RH.

Time (in weeks)	**Wt. % acetone extractables**				
	Tape A	**Tape B**	**Tape C**	**Tape D**	**Tape E**
0	3.85	1.57	1.98	1.51	0.75
4	3.81	1.26	2.05	—	0.7
8	4.05	1.15	2.3	1.27	0.78
12	3.89	1.22	2.35	1.38	1.15
20	4.14	1.41	2.53	1.35	1.23
32	4.35	1.31	2.99	1.45	1.67

Table VIII: Percent of acetone extractables determined over time at 60°C in sealed bags. Materials initially moisture-conditioned to 25°C, 75% RH.

Time (in weeks)	**Wt. % acetone extractables**				
	Tape A	**Tape B**	**Tape C**	**Tape D**	**Tape E**
0	3.85	1.57	1.98	1.51	0.75
2	3.94	1.31	2.46	1.52	0.78
4	4.32	1.3	2.89	1.61	0.92
6	4.7	1.36	3.08	1.73	1.21
8	4.94	1.25	3.11	1.54	1.18
12	4.7	1.41	3.69	1.57	1.82

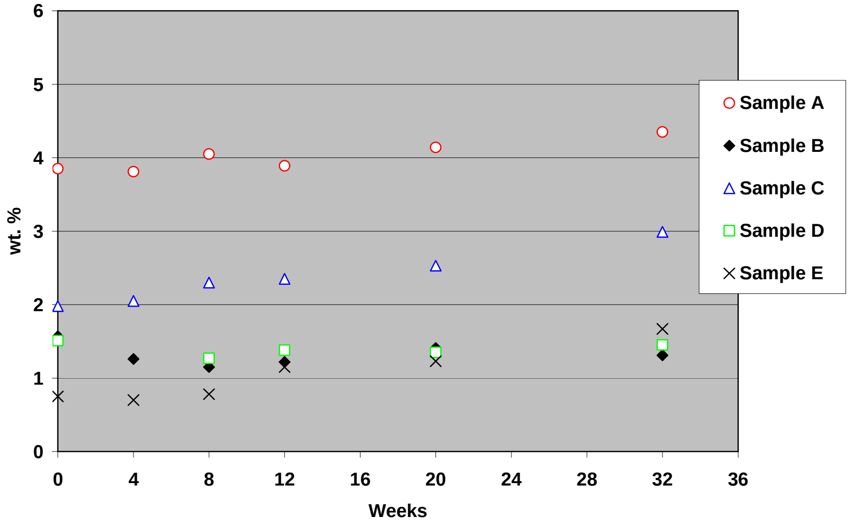

Figure 22: Percent acetone extractables versus incubation time at 60°C in sealed bags. Samples were initially moisture-conditioned to 25°C, 20% RH.

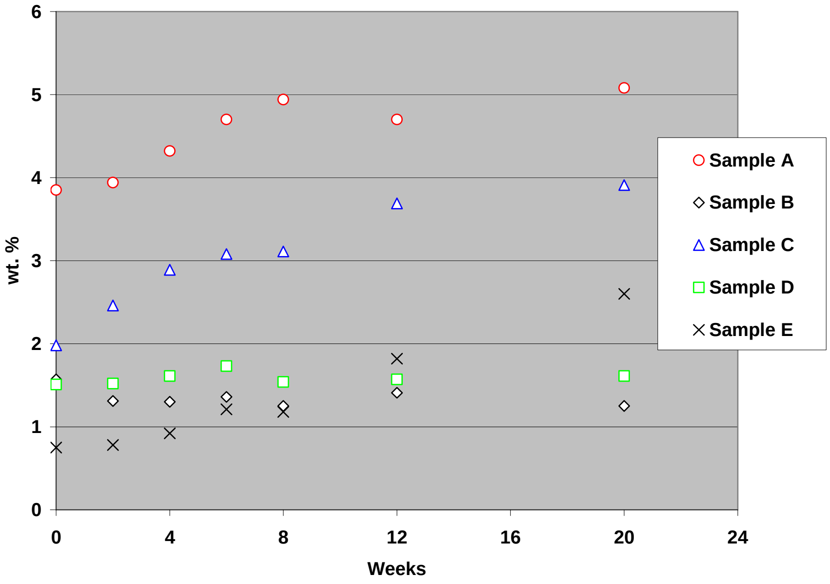

Figure 23: Percent acetone extractable versus incubation time at 60°C in sealed bags. Samples were initially moisture-conditioned to 25°C, 75% RH.

Friction Test

The results of the friction test, as reported in Table IX, provided no conclusive information. The data obtained from the friction test did not reveal significant differences between the five tapes and did not detect property changes during incubation at 60°C. No correlation was found between the friction test determinations and the data obtained from the acetone extraction test. Tapes A, C, and E displayed some property changes in terms of percent of acetone extraction. However, these indications of binder deterioration were not detected using the friction test device illustrated in Figure 16. If binder hydrolysis took place during aging, the device was not able to measure it.

Table IX: Friction test results obtained during incubation at 60°C for samples A, B, C, D, and E. Results are reported for each tape sample and sorted by % RH conditioning at 25°C.

Time (in weeks)	**Friction test results**									
	Tape A		**Tape B**		**Tape C**		**Tape D**		**Tape E**	
	20% RH	**75% RH**	**20% RH**	**75% RH**	**20% RH**	**75% RH**	**20% RH**	**75% RH**	**20% RH**	**75% RH**
0	4.0	4.0	4.0	4.0	4.0	4.0	4.5	4.5	4.5	4.5
2	—	4.0	4.0	4.0	—	4.0	—	4.5	—	4.5
4	4.0	4.0	4.0	4.0	4.0	4.0	4.5	4.5	4.5	4.5
6	—	4.0	4.0	4.0	—	4.0	—	4.5	—	4.5
8	4.0	4.0	4.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5
12	4.0	4.0	4.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5
20	4.0	4.0	4.0	4.0	—	4.5	4.5	4.5	4.5	4.5
32	4.0	4.5	—	—	4.0	—	4.5	—	4.5	—

Incubation at 60°C—Results

This set of data obtained by accelerated aging at 60°C prompted several observations:

> Free acidity measurements did not detect significant property changes within the framework of the experiment. All free acidity values were less than 0.1mL 0.1N sodium hydroxide solution.
>
> Acetone extraction measurements conducted prior to incubation indicated the approach could differentiate several tapes based on the percent of acetone extractables. Test values varied by a factor greater than 5.
>
> Significant differences exist among naturally aged tapes.
>
> Acetone extraction determinations displayed significant property changes during the incubation period for three test samples (tapes A, C, and E). Tapes B and D did not display any significant property changes.
>
> Moisture-preconditioning at higher humidity promoted faster increases in percent of acetone extraction for tapes A, C, and E.
>
> Measurements obtained with the friction test did not display significant property changes. The apparatus used for the test did not detect signs of deteriorated binder.

Incubation at 80°C—Effect of Temperature

Tapes A, B, and E were also incubated at 80°C. Two sets of samples were prepared for each tape. One was moisture-preconditioned at 25°C to 20% RH and the other at 75% RH. The following section reports results documenting the effect of temperature and moisture-preconditioning on free acidity, acetone extraction, and friction test evaluations. Experimental data are reported in the following sections.

Free Acidity

Figures 24-26 compare free acidity levels obtained through accelerated aging at 60°C and 80°C. All related tape samples were moisture-preconditioned to 25°C, 75% RH. Determinations conducted on tapes A, B, and E during the incubation at 80°C indicate increasing acidity levels over time (Table X). Free acidity of the tapes remained low after an incubation period greater than four months. However, acidity values indicate a definite trend toward higher tape acid content. While that behavior was observed for most of the tape series, the rate of acidity increase was faster for the samples moisture-preconditioned at higher RH. Within the time-frame of the experiment, samples preconditioned to 25°C, 20% RH displayed either a small acidity increase (tape B) or insignificant changes (tapes A and E). The impact of tape moisture content on property change during incubation is discussed later in this report. The comparison between data obtained at 60°C and 80°C demonstrates that higher temperature increases the rate of tape deterioration and that the decay process produces increasing levels of acidic compounds. That behavior was observed for tapes A, B, and E (Figures 24-26).

Table X: Free acidity determined over time at 80°C in sealed bags. Materials initially moisture-conditioned at 25°C to 20% and 75% RH.

Time (in days)	**mL 0.1 NaOH/gram**					
	Tape A		**Tape B**		**Tape E**	
	20% RH	**75% RH**	**20% RH**	**75% RH**	**20% RH**	**75% RH**
0	0.03	0.03	0.01	0.01	0.01	0.01
15	0.06	0.07	0.02	0.02	0.02	0.03
30	0.07	0.06	0.13	0.09	0.03	0.02
57	0.07	0.12	0.23	0.35	0.02	0.03
90	0.09	0.17	0.29	0.40	0.02	0.10
118	0.07	0.18	0.36	0.60	0.02	0.13

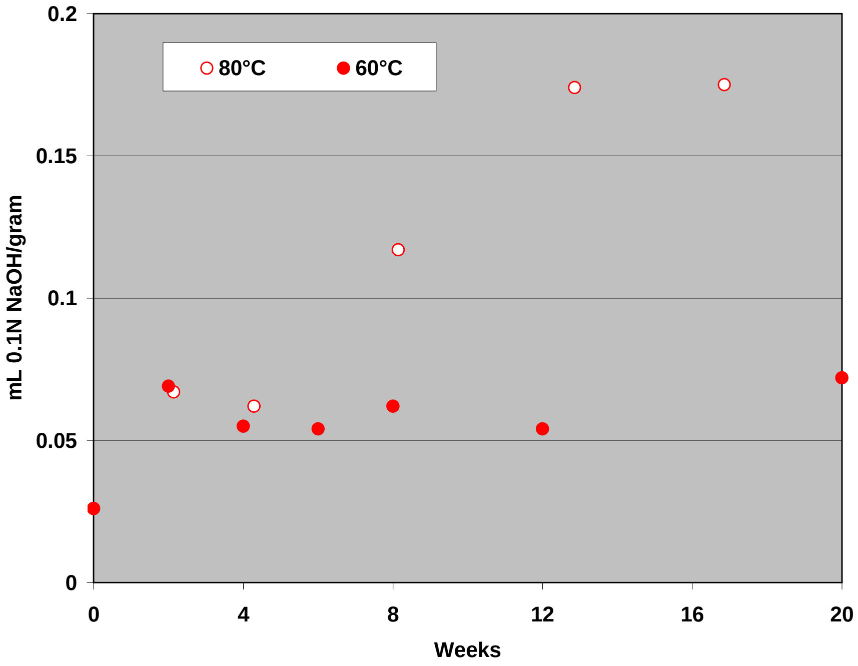

Figure 24: Effect of incubation temperature on free acidity for tape A. Initial moisture conditioning to 25°C, 75% RH. Incubation at 60°C and 80°C in sealed bags.

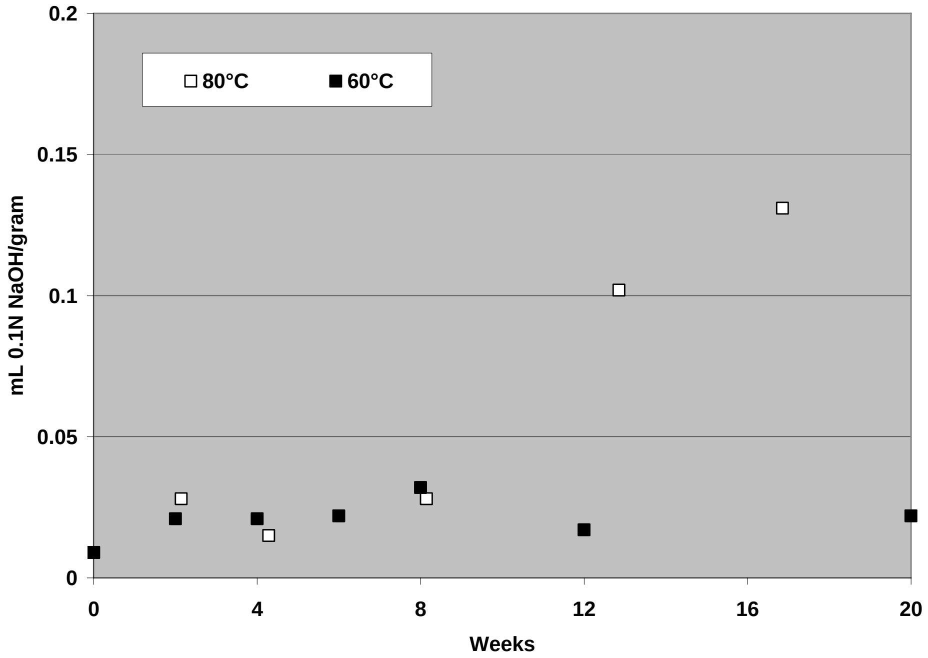

Figure 25: Effect of incubation temperature on free acidity for tape B. Initial moisture conditioning to 25°C, 75% RH. Incubation at 60°C and 80°C in sealed bags.

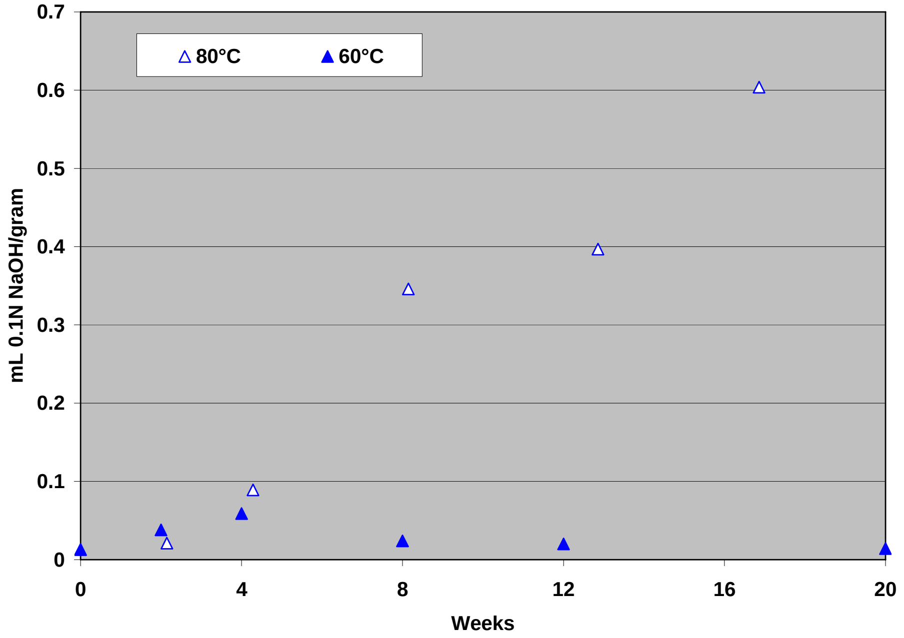

Figure 26: Effect of incubation temperature on free acidity for tape E. Initial moisture conditioning to 25°C, 75% RH. Incubation at 60°C and 80°C in sealed bags.

Acetone Extraction

Table XI reports the results from the acetone extraction test. The data are illustrated in Figures 27-29. As previously mentioned, tapes A, B, and E were incubated at 80°C in sealed moisture-proof bags after they had been moisture-preconditioned at 25°C to 20% and 75% RH. Results for the three types of tape tested indicate that acetone extractable increased faster at 80°C than at 60°C. That behavior was particularly marked for tape E. The increase in temperature from 60°C to 80°C had a lesser effect on the behavior of tape A. Initial values for these tapes differ significantly. While tape E displayed an initial proportion of acetone extractable of less than 1%, tape A displayed an initial test value of about 4%. These values underscore the lack of homogeneity in the results regarding the initial condition of the tapes, but they also show different behavior during incubation as monitored through the acetone extraction test. After about four months of incubation at 80°C, test results for tape E were greater by a factor of 4. The data reported in Table XI indicate smaller property changes for tapes A and B. It can be argued that the initial test results obtained for tapes A and B reflect a more advanced state of deterioration. In fact, earlier studies have indicated that above 1.5 wt.% acetone extractables, tape may encounter operational problems due to excessive binder hydrolysis.[73] In any case, it appears that, at a given temperature, initial test values do not necessarily reflect the behavior of the tape over time. The proportion of extractable compounds in tape E was initially less than 1 wt.%, but it increased to above 3 wt.% after a four-month incubation period at 80°C. During the same period, tape B displayed slower property changes despite an higher initial level of about 1.6 wt.%. Such behavior may indicate that within a certain range, which is yet to be determined, a higher initial percent of extractable materials does not necessary translate into greater instability of the tape binder.

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[73] H. N. Bertram, and E. F. Cuddihy, "Kinetics of the Humid Aging of Magnetic Recording Tape," *IEEE Transactions on Magnetics*, Vol. 18, No. 5, September 1982, pp. 993-999.

Table XI: Percent of acetone extractables determined over time at 80°C in sealed bags. Materials initially moisture-conditioned to 20% and 75% RH at 25°C.

Time (in days)	**Wt.% acetone extractables**					
	Tape A		**Tape B**		**Tape E**	
	20% RH	75% RH	20% RH	75% RH	20% RH	75% RH
0	3.85	3.85	1.57	1.57	0.75	0.75
15	3.92	4.42	1.23	1.28	0.71	1.08
30	4.32	4.93	1.26	1.39	0.92	2.03
57	4.35	5.47	1.37	1.68	1.32	2.87
90	—	5.18	1.36	1.76	1.75	3.16
118	4.74	5.37	1.65	2.11	2.32	3.30

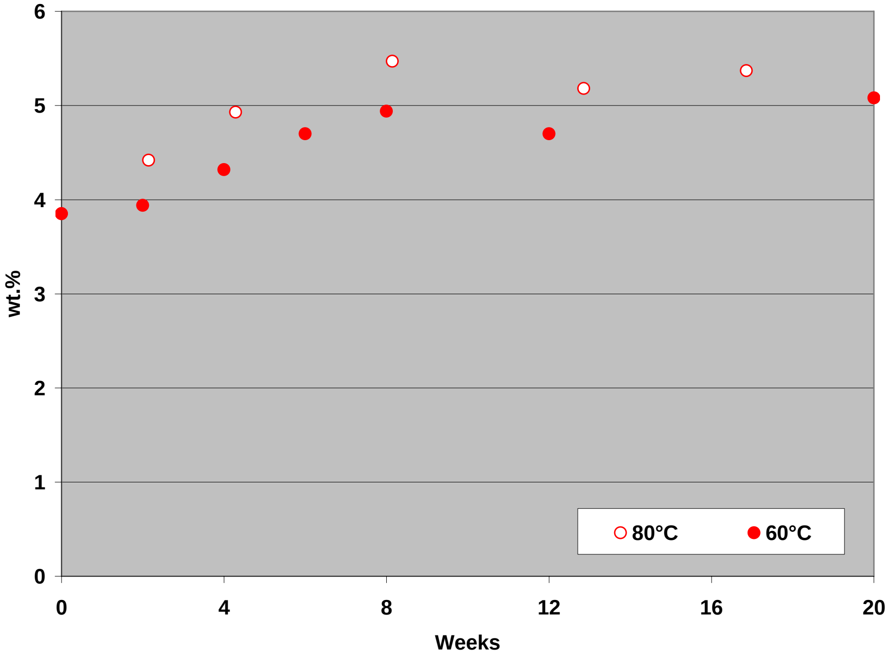

Figure 27: Effect of incubation temperature on acetone extractable (in wt.%) for tape A. Sample initially conditioned to 25°C, 75% RH. Incubation at 60°C and 80°C in sealed bags.

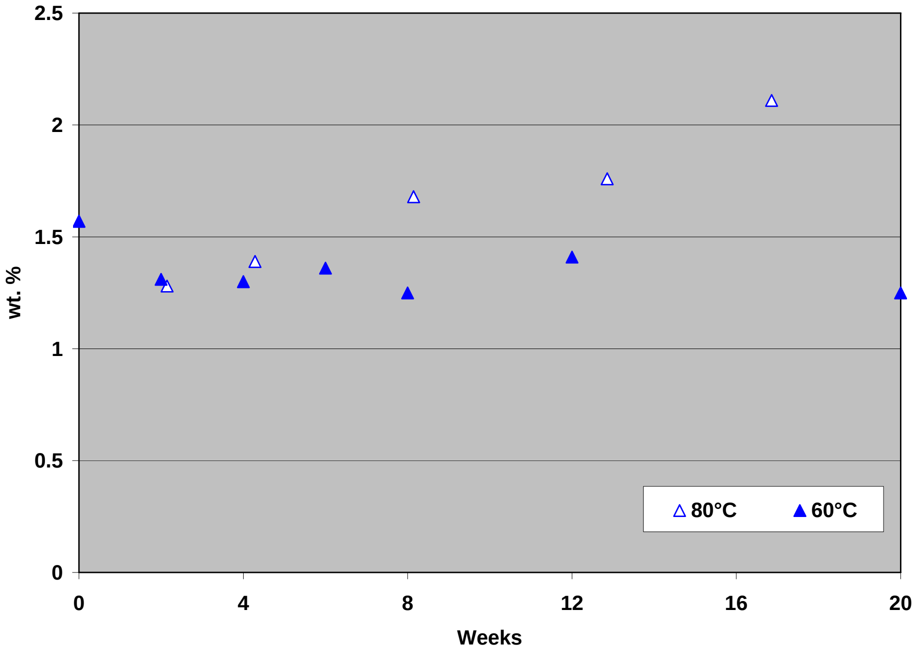

Figure 28: Effect of incubation temperature on acetone extractable (in wt.%) for tape B. Sample initially conditioned to 25°C, 75% RH. Incubation at 60°C and 80°C in sealed bags.

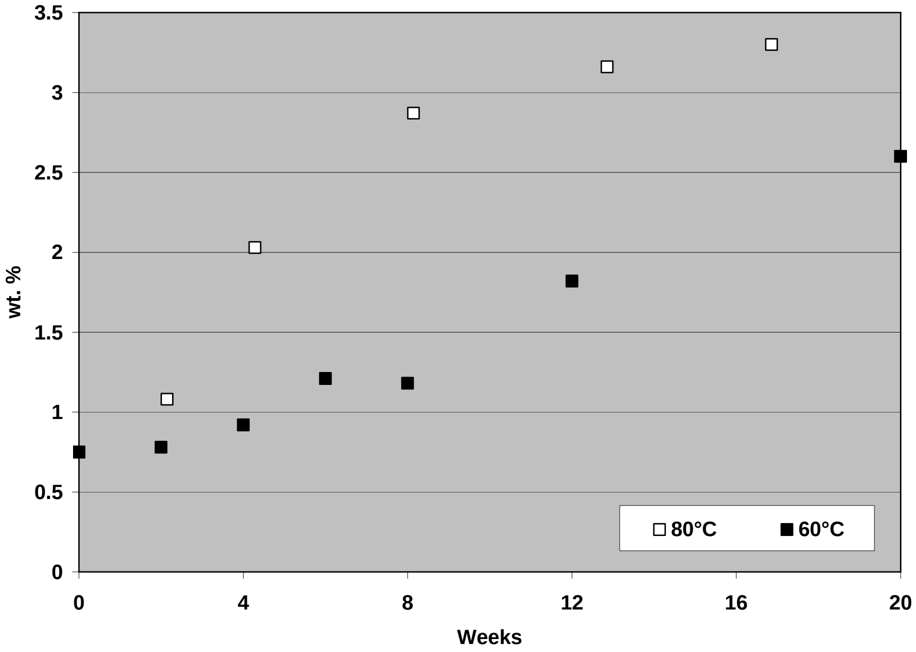

Figure 29: Effect of incubation temperature on acetone extractable (in wt.%) for tape E. Sample initially conditioned to 25°C, 75% RH. Incubation at 60°C and 80°C in sealed bags.

<u>Friction Test</u>

Although friction test determinations were carried out during the incubations, the results did not provide conclusive data. The data reported in Table XII were obtained at 80°C.

Test values are similar to those obtained at 60°C. The friction test did not provide a way for detecting any significant tape property changes.

Table XII: Friction test results obtained during incubation at 80°C for Samples A, B, and E. Results are reported for each tape sample and sorted by % RH conditioning at 25°C.

Time (in days)	**Wt. % acetone extractables**					
	Tape A		**Tape B**		**Tape E**	
	20% RH	75% RH	20% RH	75% RH	20% RH	75% RH
0	4	4	4	4	4.5	4.5
15	4	4.5	4	4	4.5	4.5
30	4	4.5	4	4	4.5	4.5
57	4	4.5	4	4	4.5	4.5
90	—	4.5	4.5	4.5	4.5	4.5
118	4.5	4	4	3.5	4.5	4.5

Incubation at 80°C—Results

Data developed by conducting accelerated aging at 60°C and 80°C prompted the following observations:

Free acidity determinations indicated a significant acidity increase during accelerated aging at 80°C. No measurable effect was detected when incubation was conducted at 60°C.

The thermal effect on acidity buildup in tape samples was further promoted by higher moisture content. Moisture-preconditioning to 75% RH at 25°C promoted faster increases in acidity than when the tapes were conditioned to 20% RH.

Increase in percent acetone extractables was greater at 80°C than at 60°C. A higher temperature led to a faster increase in acetone extraction values for each tape tested.

Friction test results did not provide any useful information regarding the evolution of tape condition during incubation at 80°C.

Results developed using free acidity and acetone extraction tests indicated that a higher temperature promotes a greater percentage of hydrolyzed tape binder and a small amount of acidic degradation byproducts that could be detected by measuring free acidity.

Free acidity and acetone extraction tests provided useful insights into tape property changes when tape was incubated at 80°C.

Effect of Tape Moisture Content

The moisture-preconditioning procedure involved exposing the tape over a five-week period to 20% RH and 75% RH at 25°C. Early research on the hygroscopic behavior of magnetic tape demonstrated that this range of conditioning RH may cause the amount of water present in the tape to vary by a factor of almost 4.[74] Although it was observed that moisture content might also depend on the materials' age, it was assumed that the preconditioning procedure would lead to significantly different moisture content levels. The following sections examine the experimental results from that perspective.

Acidity Test

Figures 30-32 illustrate data obtained at 80°C for tapes A, B, and E and compare results obtained by varying the moisture-preconditioning procedure. Incubating the tape samples at 60°C for eight months produced insignificant changes in acidity measurements. The data illustrated in Figures 30-32 indicate an acidity increase at 80°C during a four-month incubation period. The level of acidity detected after incubation is not very high, however. Compared with acidity levels recorded during nitrate and acetate film base stability studies, these levels are very low, especially considering the adverse incubation conditions chosen for the study. After a four-month incubation at 80°C and moisture-preconditioning to 25°C, 75% RH, tapes A and E displayed a free acidity level lower than 0.2 mL 0.1 N NaOH/gram of tape. The acidity level of tape B reached only 0.6 (a value comparable to the acidity level characterizing the onset of vinegar syndrome for acetate film). The acidity changes illustrated in Figures 30-32 are small overall. However, free acidity values obtained at 80°C indicate that higher tape moisture content promotes tape decay. At 80°C, according to the acidity test, tapes A and E preconditioned to 75% RH became more acidic over time, while tapes A and E preconditioned to 20% RH did not display any acidity change during the same incubation period. The acidity of both tape B series increased over time, but samples preconditioned to 75% RH showed a faster increase than those preconditioned to 20% RH.

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[74] E. F. Cuddihy, "Hygroscopic Properties of Magnetic Recording Tape," *IEEE Transactions on Magnetics*, Vol. Mag-12, No. 2, March 1976, pp. 126-135.

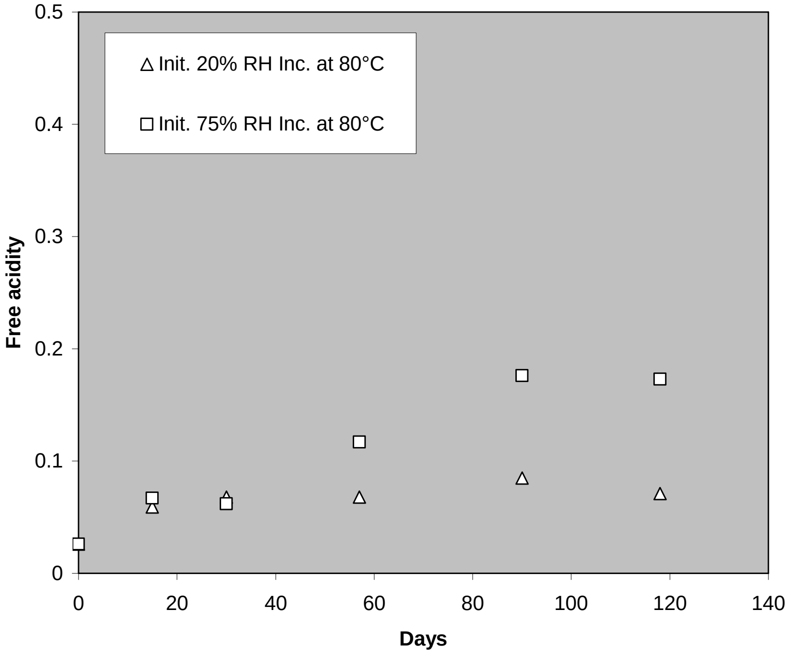

Figure 30: Acidity test results expressed in mL 0.1N NaOH/gram of tape for tape A. Incubation at 80°C in sealed bags. Tape initially conditioned to 20% and 75% RH at 25°C.

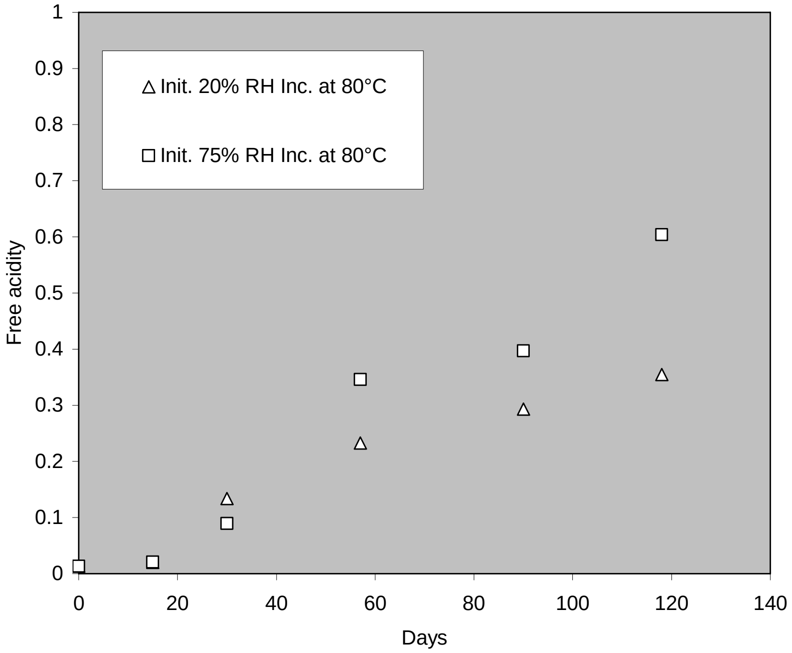

Figure 31: Acidity test results expressed in mL 0.1N NaOH/gram of tape for tape B. Incubation at 80°C in sealed bags. Tape initially conditioned to 20% and 75% RH at 25°C.

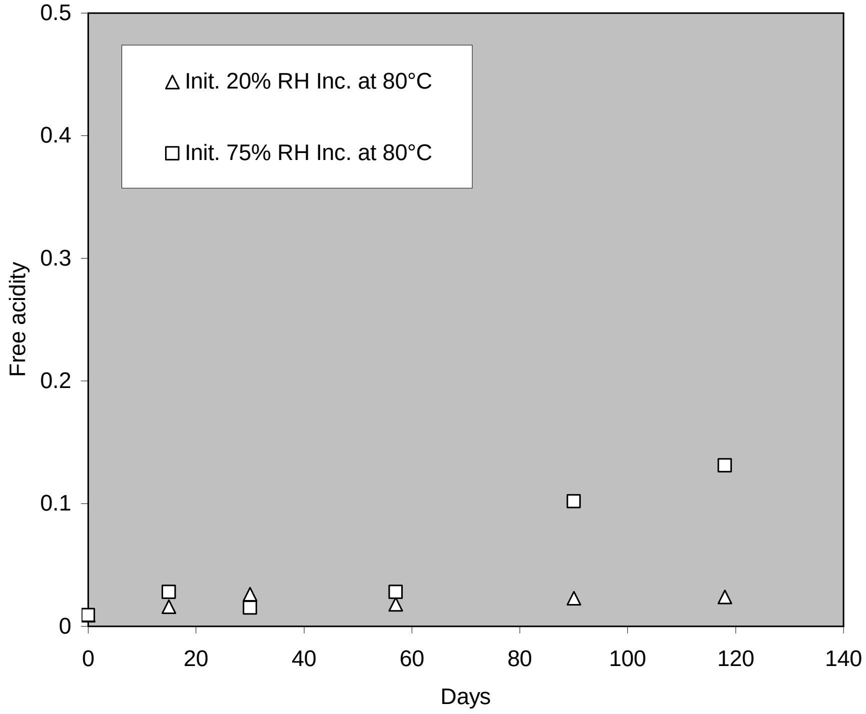

Figure 32: Acidity test results expressed in mL 0.1N NaOH/gram of tape for tape E. Incubation at 80°C in sealed bags. Tape initially conditioned to 20% and 75% RH at 25°C.

Acetone Extraction

Figures 33-40 illustrate the effect of varying the initial tape moisture content on the proportion of acetone extractable. Two sets of samples were prepared for each type of tape included in the study, one with low moisture content (preconditioned at 25°C, 20% RH) and one with higher moisture content (preconditioned at 25°C, 75% RH). Both sets were incubated at 60°C. In addition, tapes A, B, and E from both sets were incubated at 80°C.

Figures 33-40 report the change in acetone extractable expressed in wt.% over time. At 60°C, the results indicated different behavior depending on the type of tape. Tapes A, C, and E, as expected, showed an increase in acetone extractable associated with higher moisture content. However, tapes B and D did not display significant property changes. Initial test values do not correlate with these observations. The level of acetone extractables determined for tapes B and D (i.e., around 1.5 wt.%) falls within the range of the other tape samples. This indicates that initial test results may not be helpful in predicting tape behavior during aging. At 80°C, acetone extraction test results showed that extractable compounds are generated at a faster pace over time. These results are consistent with those of earlier studies, which indicated that higher humidity levels promote tape binder degradation. These studies also indicated that acetone extraction provides a way to monitor the rate of tape decay in laboratory studies. Acetone extraction levels determined for tape A, the behavior of which is illustrated in Figures 33 and 38, display a plateau after eights weeks of incubation at both temperatures. Such behavior was also illustrated in early research. The fact that tape A's initial test value was rather high (i.e., almost 4 wt.%) may have limited the magnitude of property change during the incubations. Nevertheless, the effect of higher preconditioning RH on property change was measurable.

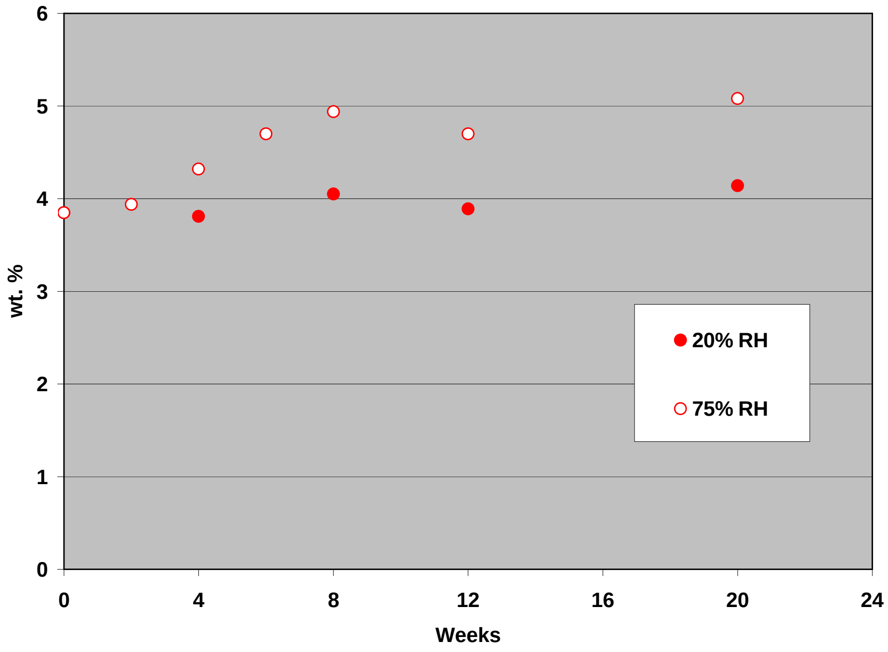

Figure 33: Percent acetone extractables versus incubation time for sample A. Incubation in sealed bags at 60°C. Materials initially moisture-conditioned to 75% RH and 20% RH at 25°C.

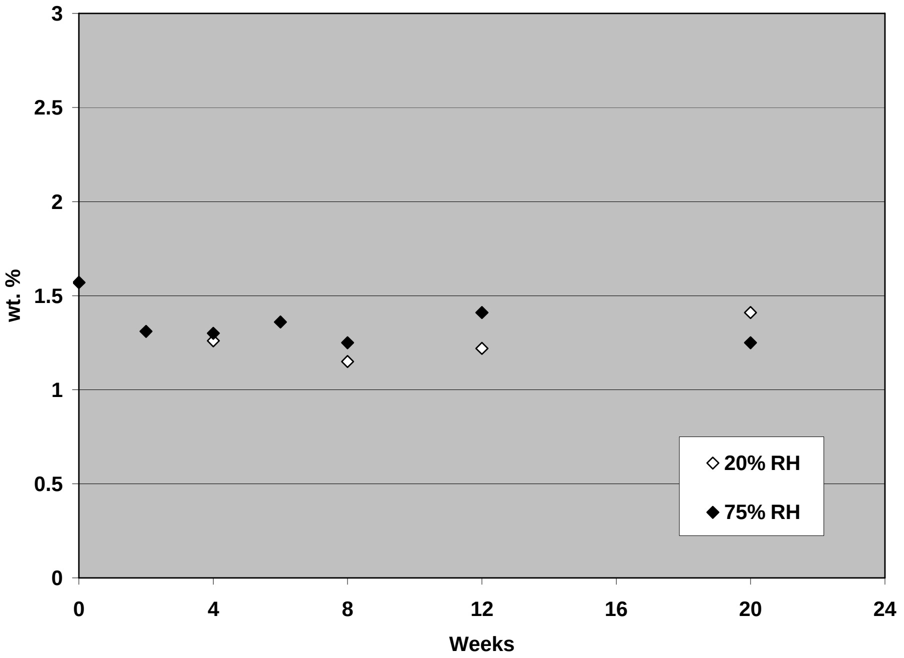

Figure 34: Percent acetone extractables versus incubation time for sample B. Incubation in sealed bags at 60°C. Materials initially moisture-conditioned to 75% RH and 20% RH at 25°C.

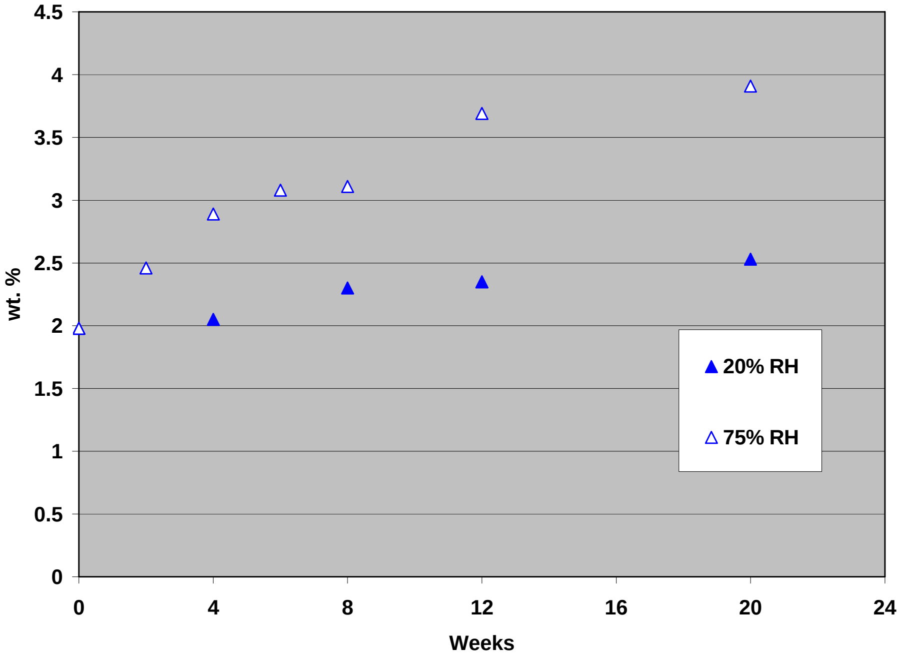

Figure 35: Percent acetone extractables versus incubation time for sample C. Incubation in sealed bags at 60°C. Materials initially moisture-conditioned to 75% RH and 20% RH at 25°C.

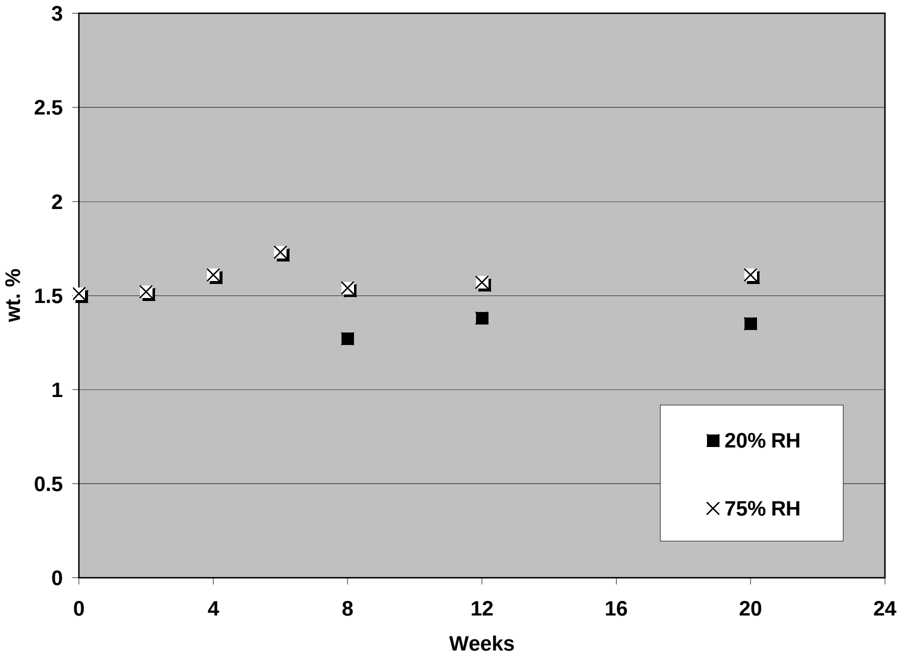

Figure 36: Percent acetone extractables versus incubation time for sample D. Incubation in sealed bags at 60°C. Materials initially moisture-conditioned to 75% RH and 20% RH at 25°C.

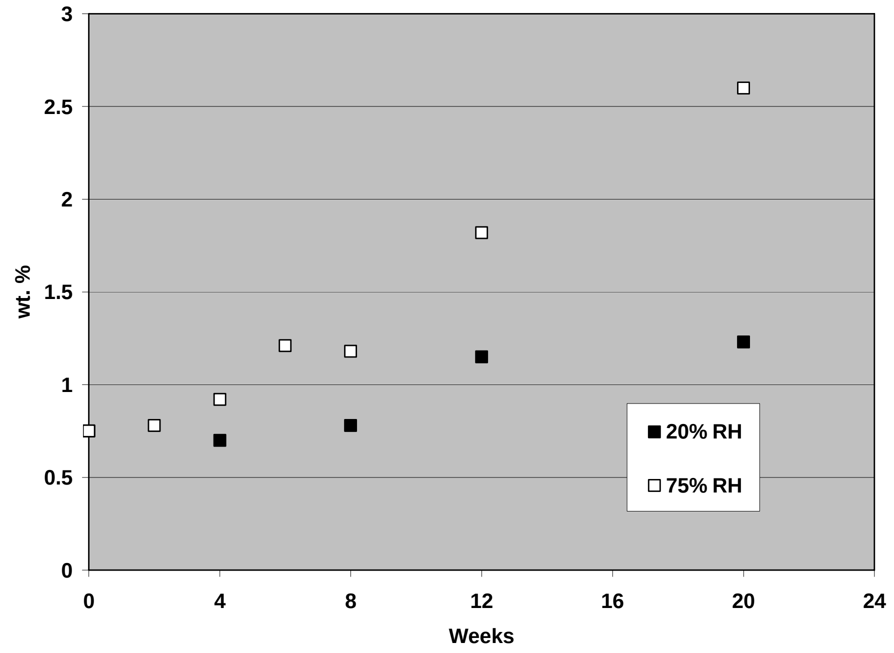

Figure 37: Percent acetone extractables versus incubation time for sample E. Incubation in sealed bags at 60°C. Materials initially moisture-conditioned to 75% RH and 20% RH at 25°C.

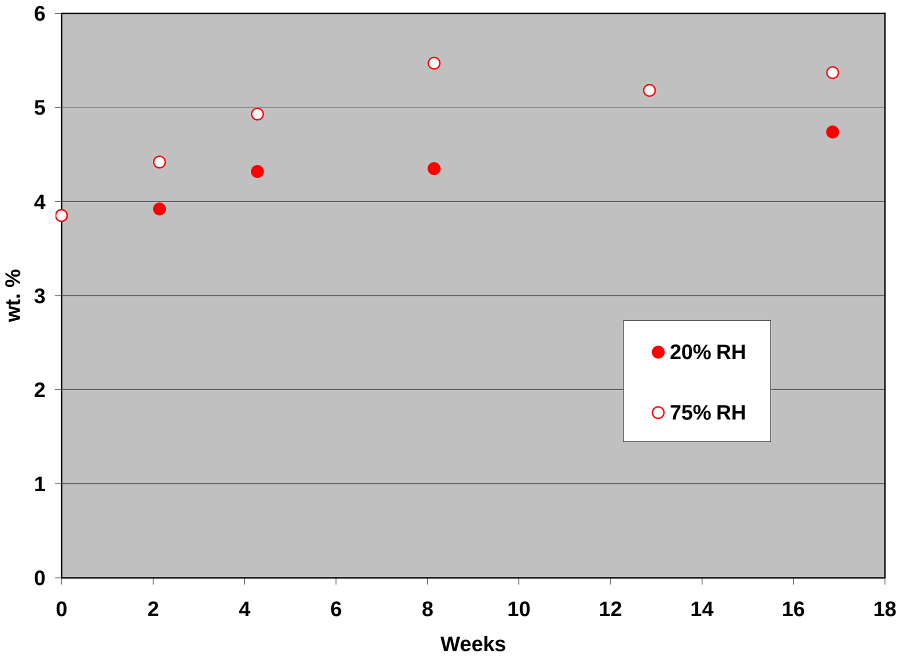

Figure 38: Effect of moisture content on acetone extractable (in wt.%) for tape A. Samples initially conditioned to 25°C, 75% RH and 25°C, 20% RH. Incubation at 80°C in sealed bags.

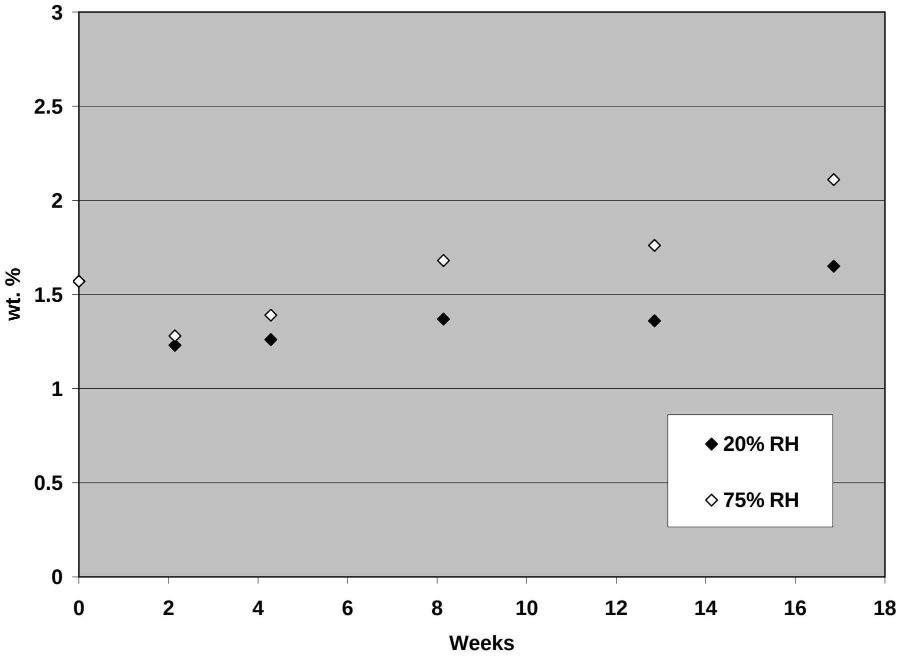

Figure 39: Effect of moisture content on acetone extractable (in wt.%) for tape B. Samples initially conditioned to 25°C, 75% RH and 25°C, 20% RH. Incubation at 80°C in sealed bags.

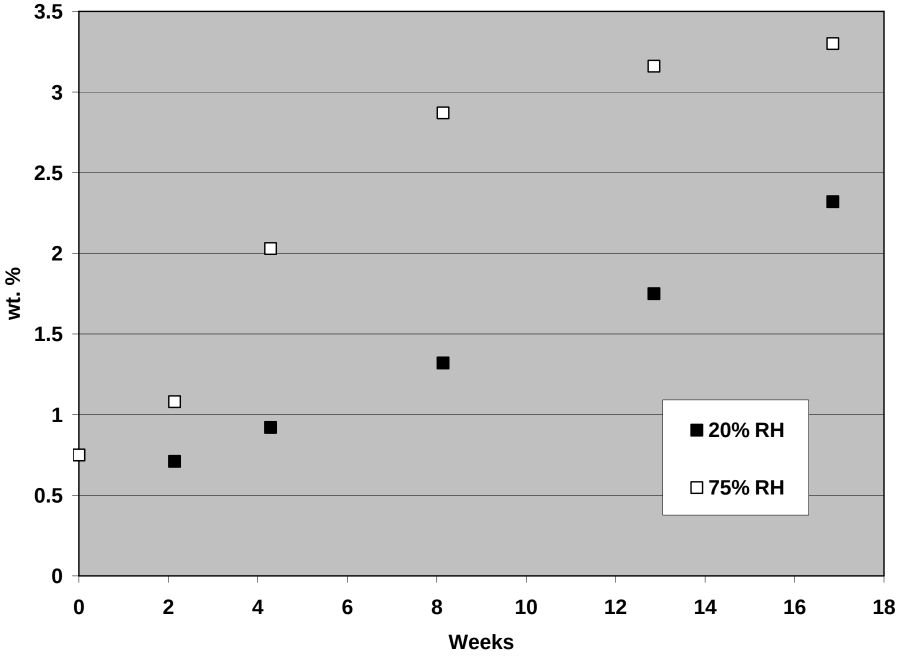

Figure 40: Effect of moisture content on acetone extractable (in wt.%) for tape E. Samples initially conditioned to 25°C, 75% RH and 25°C, 20% RH. Incubation at 80°C in sealed bags.

Friction Test

Tables IX and XII report the friction test results obtained by testing the tape samples incubated at 60°C and 80°C. The data indicate no significant property changes in any of the tapes at any of the incubation conditions used. Although the friction test is an easy and rapid test, it failed to detect any significant surface property change on the tape samples. Changes that were detected by the acetone extraction test were not detected by the friction test.

Evaluation of Naturally Aged Tape

Because the free acidity test could potentially become a nondestructive diagnostic tool, further acidity tests were conducted in the laboratory on a series of samples obtained from the field. These samples were not submitted to accelerated aging or tested prior to incubation (like tapes A, B, C, D, and E). Early in the study, the need for tape samples with known history or documentation regarding their playability was recognized to be critical.

Early research aimed to link tape behavior during playback to laboratory test results. Bertram[75] and Van Bogart[76] estimated the life span of tape based on the proportion of hydrolyzed binder as determined by acetone extraction. Both chose an end-of-life test result value above which tapes were likely to experience problems when played. Although it was recognized that the deterioration process causes an increase in acid content in the tape, its relationship with potential operational problems has not been documented. For that reason, and to enhance the interpretation of the research results, IPI had requested from the archival community tapes for laboratory testing that presented problems when played. Although the answers to that request were few, IPI received a series of eight tapes that were either unplayable (tapes F to L) or had caused problems when played, such as squealing (tape N). Tape M originates from a batch that had presented sticky shed problems. Free acidity, acetone extraction, and friction tests were conducted. Table XIII summarizes any available information provided by the donors on each sample and reports the test results.

Free Acidity versus Acetone Extraction

The acidity levels of the donated problematic tapes were found to be higher than those recorded during the study on tapes A to E prior to incubation. While tapes A to E displayed free acidity values lower than 0.05, the acidities determined for the donated tapes ranged from 0.15 to 0.35. In addition, these acidity levels were often greater than those determined for tapes A and E after months of accelerated aging at 80°C in sealed bags after moisture preconditioning at 25°C, 75% RH.

Acetone Extraction

The ratio of acetone extractables determined on the problematic tapes ranged from 1.5 to 4.1 wt.%. This result is consistent with observations made in early research. It was determined that tapes producing above 1.3 wt.% acetone extractables were likely to display playback problems.[78] These results agree with the behavior reported by the tape donors. High levels of extractables reflect binder deterioration that manifests as heavy residue on the tape surface, separation of the magnetic layer from the base, or head-clogging or squealing during playback.

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[75] H. N. Bertram, and E. F. Cuddihy, “Kinetics of the Humid Aging of Magnetic Recording Tape,” *IEEE Transactions on Magnetics*, Vol. 18, No. 5, September 1982, pp. 993-999.

[76] J. Van Bogart, *Magnetic Storage and Handling, A Guide for Libraries and Archives*. (Washington DC: National Media Lab, and The Commission on Preservation and Access, June 1995).

Free Acidity versus Acetone Extraction

Figure 41 illustrates results obtained on problematic tapes using free acidity and acetone extraction test procedures. Although the free acid content was measurable on each tape, test values remained at a low level (i.e., 0.35 and below). These acidity values did not agree with acetone extraction results, which displayed high values. In addition, it must be noted that free acidity values determined on tapes A to E prior to incubation were lower than 0.05, and, despite that, the percentages of acetone extractables were above 1.5 wt.% for four tapes (tapes A, B, C, and D displayed percentages within the range of 1.5 to 4 wt.%). The results indicate that significantly low free acidity levels may be measured when binder deterioration is already in an advanced state (e.g., acetone extractables greater than 1.5 wt.%). However, the results also indicate that acidity values can be lower than 0.05 for tape with already hydrolyzed binder (Tables X and XI). Thus, despite the fact that it was demonstrated during the research that free acidity increases as binder ages, extremely low acidity values (i.e., lower than 0.05) did not provide telling results regarding tape behavior. The data led to the conclusion that free acidity is not the first and best indicator of binder deterioration.

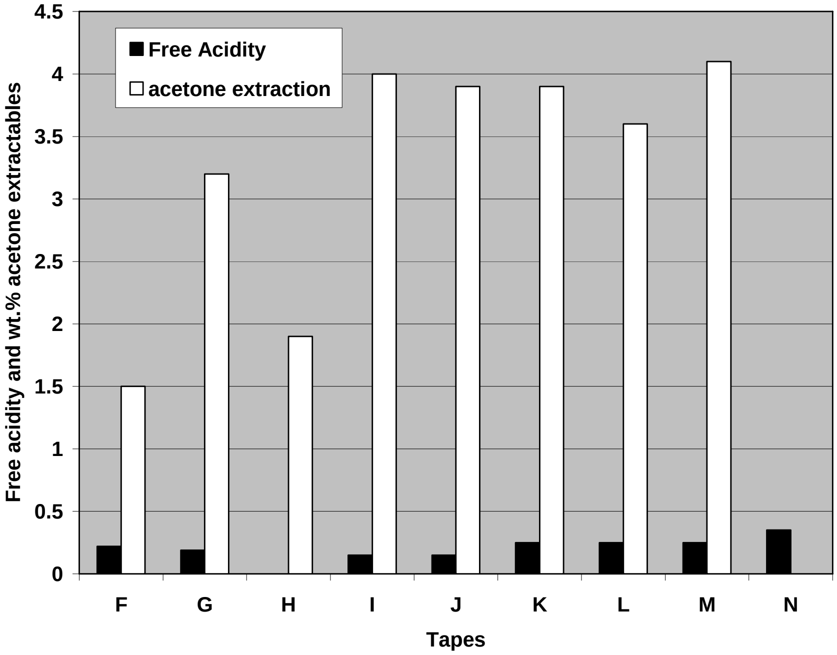

Figure 41: Free acidity and acetone extraction results determined on tapes that were either unplayable or that displayed operational problems after natural aging. Free acidity is expressed in mL 0.1N NaOH/gram. Acetone extraction results are expressed in wt.%.

Friction Test

The friction test was also performed on the unreadable tapes submitted to IPI for testing. Results are illustrated in Figure 42. The data were obtained by using two points of contact on the tape: a paper clip and a metal cup. The former is part of the standardized device. The cup was used to increase the contact area on the tape and therefore to reduce the pressure per square inch. Figure 42 indicates that changing the size of the point of contact did not lead to different results. The data ranged from 3.5 to 4.5 and were not consistently correlated to lower or higher values obtained from acidity and acetone extraction tests.[77]

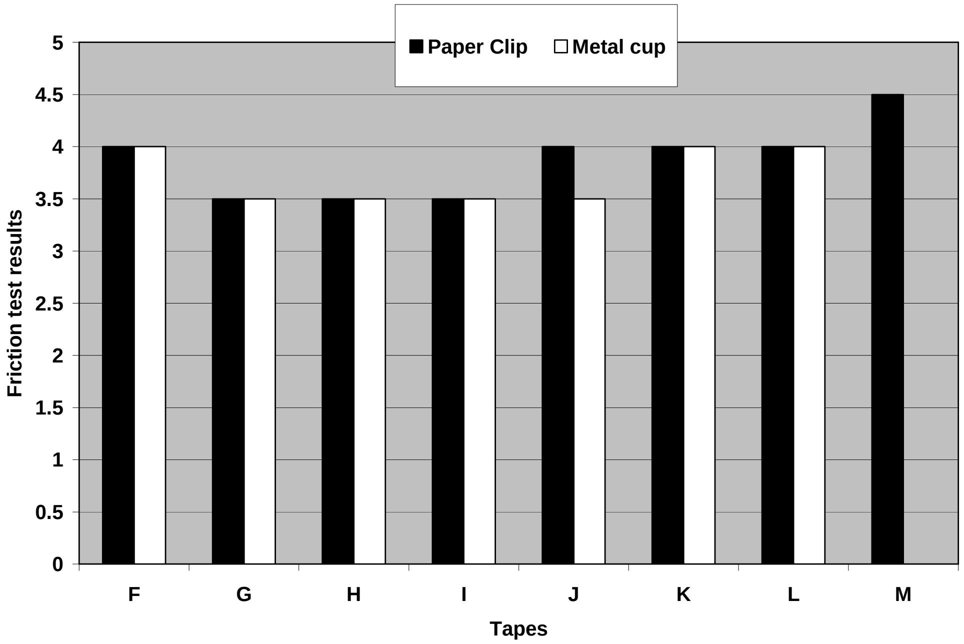

Figure 42: Friction test results determined on tapes that were unplayable or that displayed operational problems after natural aging. Procedure used two different points of contact: a paper clip and a small metal cup.

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[77] *Friction test results are expressed as the tangent of the inclined plane to the horizontal. Higher friction is reflected by higher test values.*

Table XIII: Free acidity and acetone extraction test results conducted on a series of naturally aged tapes. Free acidity expressed in mL 0.1N NaOH/gram of tape. Acetone extraction tests results in wt.%.

Tape	Width	Manufacturer and type	Problems	Acidity	Acetone extraction	Friction
F	2"	Ampex 175 Quad videotape (record date: 9/20/1980)	Hydrolyzed	0.22	1.5	4
G	2"	Scotch 400 Quad videotape (record date: 12/17/1977)	Heavy white powder residue	0.19	3.2	3.5
H	½"	VHS, no identified manufactured (record year: 1988).	Magnetic layer-support failure	—	1.9	3.5
I	2"	Scotch Quad videotape (record date: 11/20/1971)	Hydrolyzed	0.15	4.0	3.5
J	2"	Scotch Quad videotape (record date:9/25/1071)	Hydrolyzed. Heavy residue visible on tape surface	0.15	3.9	4
K	2"	Scotch 400 Quad videotape (record date: 9/16/1978)	Hydrolyzed	0.25	3.9	4
L	2"	Scotch 400 Quad videotape (record date: 4/11/1976)	Heavy white powder residue	0.25	3.6	4
M	¼"	Ampex 406 audiotape	Prone to playback failure	0.25	4.1	4.5
N	¼"	Sony PR-150 audiotape	Squealing	0.35	—	—

EVALUATION OF DETECTION TESTS

The information developed during the research is summarized in Table XIV. The data are organized into three main categories based on the experimental program, which addressed (1) the evaluation of tape condition prior to incubation, (2) the effect of temperature on binder stability, and (3) the effect of humidity on binder stability. The information gained is reported in relation to the evaluation method used to measure and monitor property changes over time. This presentation aims to identify the best indicator for assessing tape condition among the three laboratory tests: free acidity, acetone extraction, and friction. All three procedures were discussed earlier in this report. The information presented in Table XIV leads to the considerations presented in Table XV. The research has led to mixed conclusions. Although both methods—i.e., free acidity and acetone extraction tests—provided a way to follow property changes during accelerated aging tests, experimental results were not always consistent. The tapes did not appear to display similar behavior. At 80°C, according to the acidity test, tape B displayed a faster rate of decay than tapes A and E. Under the same incubation conditions, according to the acetone extraction test, tape E seemed to degrade at the fastest rate. These comparisons show some of the contradictions and dissimilarities present in the results. Other studies have often noted that inconsistencies in tape behavior make predictions difficult. Earlier research projects have shown that experimental results obtained through accelerated aging do not necessary provide satisfactory LE predictions.[78] These unexpected differences have been imputed to manufacturing procedures in the formulation of the magnetic layer of the tape. Current analytical research conducted at the CRCDG[79] provides invaluable insights into that domain.

The free acidity test was less sensitive than the acetone extraction test, based on the observation that at 60°C no property changes, or only very small ones, were measured, while an increase in the percentage of deterioration byproducts soluble in acetone was observed. Overall, free acidity values remained low. This was also observed by testing tapes known to be in an advanced state of decay. Therefore, acidity data are difficult to use as an indicator of binder deterioration. In fact, it seems that when a low level of free acidity was measured, the acetone extraction test indicated a high percentage of acetone extractables (i.e., above 1.5 wt.%). This casts doubt on the likelihood that a diagnostic tool comparable to A-D Strips for acetate-based material can be developed for tape condition assessment. If it can be assumed that acidity measurement is relevant for tape testing, the development of such test would require a considerable research effort to investigate other methods of acid detection. Such a possibility is currently being investigated through the development of a system capable of evaluating the surface acidity of the magnetic coating.[80]

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[78] M. T. Baker, “Lifetime Predictions for Polyurethane-based Recording Media Binders: Determination of the “Shelf-Life of Videotape Collections.” In: *Resins: Ancient and Modern*, edited by M. M. Wright and J. H. Townsend, Edinburgh: The Scottish Society for Conservation and Restoration, 1995, pp. 106-110.

[79] *Centre de Recherches sur la Conservation des Documents Graphiques* (CRCDG), Paris, France.

[80] *Appendix 9: Surface Acidity Evaluation for Magnetic Coating by Contact Angle Titration.* In: B. Thiebault, L. B. Vilmont, B. Lavedrine, *PrestoSpace, D6.1: Report on video and audiotape deterioration mechanisms and considerations about implementation of a collection condition assessment method*, 2006.

Table XIV: Comparison between free acidity, acetone extraction, and friction test evaluation methods. Summary of the data developed during the research.

	Samples		**Acidity**	**Acetone extraction**	**Friction**
Initial property values	Tape A		<0.05	3.85 wt. %	4
	Tape B		<0.05	1.57 wt. %	4
	Tape C		<0.05	1.98 wt. %	4
	Tape D		<0.05	1.51 wt. %	4.5
	Tape E		<0.05	0.75 wt. %	4.5
Effect of temperature (moisture preconditioned to 25°C, 75% RH)	Tape A	60°C	No change	Increase up to 4.7 wt.%	No change
		80°C	Increase up to 0.2	Increase up to 5.4 wt.%	
	Tape B	60°C	No change	No change	
		80°C	Increase up to 0.6	Increase up to 2.1 wt.%	
	Tape C	60°C	No change	Increase up to 3.7 wt.%	
	Tape D	60°C	No change	No change	
	Tape E	60°C	No change	Increase up to 1.8 wt.%	
		80°C	Increase up to 0.1	Increase up to 3.3 wt.%	
Effect of moisture content (incubation at 80°C)	Tape A	20% RH	Increase up to 0.1	Increase up to 4.7 wt.%	No change
		75% RH	Slight increase up to 0.2	Increase up to 5.4 wt.%	
	Tape B	20% RH	Increase up to 0.4	Increase up to 1.65 wt.%	
		75% RH	Increase up to 0.6	Increase up to 2.1 wt.%	
	Tape E	20% RH	No change	Increase up to 2.3 wt.%	
		75% RH	Slight increase up to 0.1	Increase up to 3.3 wt.%	

Table XV: Comparison between free acidity, acetone extraction, and friction test evaluation method. Conclusions.

	Acidity	Acetone extraction	Friction
Initial property values	No significant difference was detected among the samples. Low free acidity levels (less than 0.05) despite high levels of % acetone extractables determined on the same tapes.	Results provide an initial characterization of tape condition. Test results range from 0.75 to 3.85 wt.%.	Results were similar for all tapes.
Property changes during accelerated aging	No acidity change was noticeable during incubation at 60°C. Small acidity increase during incubation at 80°C. Combined effect of higher temperature and higher moisture content had limited effect on tape acidity increase.	Test results indicate property change even when no acidity increase had been detected. No correlation was found between initial test values and tape behavior. Lower initial test values did not translate into slower rate of deterioration during accelerated aging.	Results did not provide useful information to monitor tape condition during accelerated aging.
Testing on problematic tapes	Free acidity values ranged from 0.15 to 0.35. High acidities did not correlate consistently with other test results.	Test results ranged from 1.5 to 4.1 wt.%. Test results did not always correlate to acidity values.	Test results ranged from 3.5 to 4.5.
Conclusions and practical significance	Free acidity values display no changes, or only small ones, while acetone extraction did indicate significant changes. Free acidity test as performed in the study is destructive. If acidity measurement could lead to the development of a diagnostic tool, a more sensitive approach would be required. Free acidity measurement did not appear to have great potential as an indicator for tape condition monitoring.	Results confirmed that acetone extraction has potential for studying tape binder decay. During accelerated aging, however, tapes displayed behaviors that did not reflect their initial condition, characterized by acetone extraction test. Test is destructive and cannot be the basis for a diagnostic tool.	Although the method was nondestructive, the results did not demonstrate any promise.

CONCLUSION

The research project has shed new light on the numerous challenges that exist in the preservation of magnetic tape collections. The survey, in which 17 institutions participated, provided useful information about the tape preservation field. In particular, it underscored the need for greater knowledge about what materials the collections hold, how to care for them, how to manage their preservation, and how to decide which groups among them most urgently need reformatting. Answers to the survey projected a sense that magnetic tape collections are not under strategic preservation control. It was significant that only a small proportion of the collections currently benefit from special storage. The survey also confirmed the lack of quantitative data on the state of preservation of tape collections throughout the participating institutions. This situation is explained by the fact that, so far, no easy-to-use diagnostic tool or handy procedure has been provided to the field. Visual examination, machine tape cleaning, and playback analysis have been the only available methods by which to attempt tape condition assessment. Information gained during tape cleaning and playback analysis are part of new developments toward an automated system for tape transfer today. Unfortunately, the approach taken in this research project has cast doubt on the feasibility of developing a simple diagnostic tool for tape collections for one major reason: tape behavior was shown to vary widely.

IPI research focused on investigating three indicators of tape decay. They involved the assessment of tape condition using three laboratory testing procedures: free acidity, acetone extraction, and friction tests. The research was designed as a primary step in the development of a simple diagnostic tool. The acidity test and the acetone extraction test confirmed that temperature and humidity promote property change. At the same time, the only nondestructive test used in the study did not detect any significant property changes. In addition, the data failed to indicate a general pattern in terms of tape behavior. Some tapes displayed changes in the percentage of acetone extractable, while others incubated under the same conditions did not. Similar variations were observed in the free acidity measurements of the tapes prior to and during incubation. In addition, the level of free acidity remained consistently low, even after a long incubation at high temperature, and despite significant increase in binder hydrolysis as determined by the acetone extraction test. This tells us that it will be difficult to design a diagnostic tool for magnetic tape that is analogous to A-D Strips for acetate-based film.

At the end of this research project, IPI believes that extensive laboratory testing supported by analytical equipment, which is outside the current capability of IPI, would be required to explore new approaches to the development of a simple diagnostic tool for tape. It is believed that the chances for success are elusive at best, due to the nature of the problem and the need for a diagnostic device that is easy to use in the field. Magnetic tapes display considerable differences, and the property change that might lead to the development of a nondestructive test has not been identified yet. At the same time, IPI believes that it would be advantageous at this point to reconsider the specific problems associated with the preservation of magnetic tape collections.

It is striking that, today, magnetic tape collections are not expected to remain in their original form. This sets magnetic tape holdings apart from photographic film collections and makes new preservation strategies necessary. At the minimum, preserving original materials is an accepted strategy for film preservation, and often it is the most important thing that must be done. Therefore environment-based storage strategy has become the backbone for preserving photographic materials, both still and moving images. A simple diagnostic tool such as A-D Strips for acetate-based film has become an invaluable asset for choosing the best-fit preservation strategy for film collections. Such an approach was possible for film because stability studies had demonstrated that the behavior of the materials was sufficiently predictable to allow for the development of management tools. Although there may be differences in chemical stability among manufactured color photographic materials, or within the family of acetate supports, the behavior of these manufactured products was similar enough that generic aging models and tools could be developed. These tools have been enabling archivists to deal with the physical preservation of large photographic collections. One important thing about photographic film is that under the proper storage environment the medium can last for centuries, and the demise of a particular format has not been an unsolvable problem.

By contrast, preserving magnetic tapes has been mostly a matter of moving further away from the original materials. The idea of preserving information content by transferring indefinitely has even been accepted. In fact, this process becomes a necessity in order to retain the information. In this context, the types of tools that have proved to be extremely useful for the preservation of film may be less useful for preserving tape collections. For instance, the impact of a simple diagnostic tool, if one were available, might not offer the same benefits for tape collection management that existing diagnostic tools have had on film collection management. The main reason for this could be that the preservation of magnetic tapes might be managed better on the basis of format obsolescence than on the basis of condition, assuming that suitable storage environments could be provided. Media stability studies have demonstrated that proper storage is an essential part of minimizing decay. It is believed that proper storage, which is not always implemented for tape collections, would greatly benefit magnetic tape stability. Although the data developed by IPI was not directed at making predictions of tape life span, they did confirm that higher temperatures and higher moisture content promote further decay of tape. The study provided a perspective on the preservation of magnetic media, which is summarized in Table XVI. It is believed that tape preservation should be approached from three different directions: (1) improvement of the storage environment, (2) support of new initiatives toward automated transfer systems, and (3) creation of a tool for prioritizing tape transfer.

*Table XVI: Conclusions and perspectives on magnetic tape preservation strategies***.**

Strategy	Expected benefits, limitations, and requirements
Improve storage environments	Proper storage is the single most important factor for preventing media decay throughout large collections. Providing cooler and drier storage conditions would increase the life span of tape collections while they await transfer. Evaluation of the benefit versus the risk of storing magnetic tapes at cold/subfreezing temperatures may lead to storage practices that would further optimize media stability until information transfer becomes possible.
Support developments toward automated tape transfer	Since information content must eventually be transferred from one tape format to another, the development of automated systems is critical.
Prioritize transfer	A prioritized reformatting plan is key to the optimal use of available findings. Defining criteria on which the plan should be based is critical. Criteria that cannot be quantified or easily determined are of limited interest for planning a large project. Due to the lack of a simple diagnostic tool for tape evaluation, prioritization based on condition is not reliable. Current research into the development of an information database on magnetic tape media may provide a way to identify the tape families to act on first. However, such a source does not yet exist. Storage environment evaluation provides an assessment of the current risk for tape damage. The creation of an evaluation tool to rank the urgency for tape transfer based primarily on format obsolescence may have benefit for archivists who are planning reformatting programs. Such a tool could be developed only with the cooperation of manufacturers, tape experts, and archivists, and should be in a form that could evolve along with changes in technology.

The perspective described here highlights the necessity of providing suitable storage environments for tape collections. ISO recommendations[81] further stress that proper storage and handling practices are key for physical preservation. Storage environment is the single most important factor for stability; it benefits large collections and single objects as well until they can receive attention. For that reason, it is suggested that an

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[81] ISO 18933: 2006—*Imaging materials—Magnetic Tape—Care and handling practices for extended usage* (Geneva: International Standard Organization), 2006.

investigation of the benefit of colder storage temperatures versus the risk for tape damage be investigated. It is believed that the development of automated techniques for facilitating tape transfer will have an increasing value for preventing information losses. In most cases, tape transfer programs will have to be prioritized to be doable and affordable. No one criterion can be conclusively singled out. Suitability of storage environment, tape condition, risk of format obsolescence, or known tape vulnerability can all be regarded as legitimate decision factors. Considering the general acceptance of preserving tapes contents by transferring them to new formats, a “mass” strategy would be more effective than an item-by-item evaluation. Thus, formats with high risk of obsolescence that are being stored under poor conditions must be the first priority. In this context the creation of a decision-making tool for planning large-scale reformatting would benefit archives with large holdings. Such a project would require the cooperation of manufacturers, tape specialist, and archivists.

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