"HONEY, I BURNT THE TAPES!" A STUDY ON THERMAL TREATMENT FOR THE RECOVERY OF MAGNETIC TAPES AFFECTED BY SOFT BINDER SYNDROME-STICKY SHED SYNDROME

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"*I often receive questions on baking reels from archivists — how to do it, when to do it, and if it should be done at all. I would not be surprised if there are portions of collections out there that were accidentally destroyed by a well meaning archivist.*"[75]

Magnetic tape is an important medium in the capturing of information and has had widespread use in audio, video, and computer applications over the past 60 years. Libraries, archives, museums, government agencies, and commercial organisations have relied on magnetic tape for storing a considerable part of their information. The critical concern is primarily the change in physical properties of the magnetic tape, rather than the loss of magnetic characteristics[76]: magnetic tapes have proved to be rather stable in this aspect, and if a significant loss of magnetic characteristics is present, it is usually due to careless exposure to magnetic charges.

The lack of diagnostic tools to assess the state of preservation of tape collections forces the inspections to rely mainly on visual examinations and evaluators' expertise[77], while recovery methods are still subject to intuitive expedients and trial-and-error approaches. The lack of scientific knowledge on the optimal recovery methods leaves the way open to ill effects that might unintentionally damage the audio documents. In particular, the treatment discussed in this article is recognised to be "an invasive procedure that is not fully understood."[78]

By presenting a set of exploratory analyses conducted on magnetic tapes, this articles aims at raising awareness of the risks entailed by the treatment commonly used for the recovery of damaged tapes. On a higher level, it confirms that the field of audio preservation is still open to scientific research[79], and that knowledge advancement is better achieved in collaboration with disciplines such as chemistry, materials science, and engineering.

Most tape is made by coating the surface of a plastic film base or backing with a paint or "ink" containing magnetic particles homogenized in a binder that adheres to the film and dries by evaporation. The coating is usually so thin that it is only a small fraction of the over-all tape thickness.[80] Although the base is magnetically inert, it must meet stringent requirements of thickness, strength, and stability, in order to give a reasonable playing time in a compact reel. A tape about 50µm thick fills an 18 cm diameter reel with 365 meters of tape, which equals to a half hour at 7.5 inch/s. In addition to the base and binder, most tapes produced since the early 1980s show a back coating that acts as an aid to tape packing on the hub and reel.[81]

75 AES, 2008, p. 24.
76 Ibid.
77 Bigourdan, J., Reilly, J.M., Santoro, K., Salesin, G., "The preservation of magnetic tape collections: A perspective," IPI, 2006.
78 Casey, M., "Facet (field audio collection evaluation tool) — format characteristics and preservation problems, version 1.0," Indiana University, 2008, p.32.
79 Schüller, D., "Magnetic tape stability: talking to experts of former tape manufacturers," IASA Journal (42), 2014.
80 Camras, M., "Magnetic recording handbook," Van Nostrand Reinhold Company, 1988, P. 97.
81 Gibson, G.D., "Magnetic tape deterioration: Recognition, recovery and prevention," in Proceedings of the IASA annual Conference, 1996.

Figure 1. Sticky residue of a magnetic tape affected by SBS-SSS. Source: Centro di Sonologia Computazionale (CSC), University of Padova.

The degradation of all types of audio media is mainly due to their intrinsic chemical instability[82], aggravated by inadequate handling, storage conditions, and poor manufacture. The effects of the process of degradation are diverse and carrier-dependent: "degradation of magnetic tape is complex and not yet well understood."[83] One of the problems most often observed in magnetic tapes is characterised by undesirable shed, stickiness, or squeal, usually treated with prolonged exposure to heat. The authors embrace the terminology proposed by Hess[84], where the broad term "soft binder syndrome" (SBS) is applied "to all tapes that show stickiness, shedding, and/or squealing, whether they respond to baking or not."[85] The authors also agree with the additional subdivision proposed by Casey[86], where tapes that squeal but do not shed nor respond to treatment are classified as tapes with "unidentified problems" (SBS-UP) as opposed to "sticky shed syndrome" (SBS-SSS). This article focuses on tapes affected by SBS-SSS. Figure 1 shows a close-up of replay heads with sticky residue from a tape affected by SBS-SSS.

1. Motivation

Thermal treatment is a popular procedure that can temporarily revert the effects of the SBS-SSS. The procedure was first introduced in 1993 by the Ampex Systems Corporation[87] with the US Patent describing "a method of heat treating magnetic recording media comprising maintaining the magnetic recording media at a sufficiently elevated temperature for a sufficient time to overcome the adverse consequences of undesirable shed, stickiness or squeal." The patent recommends "a temperature of at least 50°C for at least 8 hours," however "lower temperatures and/or shorter times can restore media sufficiently to enable play-back." The factor that determines the temperature and the duration of the treatment is the state of deterioration of the audio document, but the patent does not provide indications on how to relate this information.

82 Schüller, D., "The ethics of preserving audio and video documents," UNESCO, 2006.
83 Casey, M., Gordon, B., "Sound Directions: Best Practices for Audio Preservation," Harvard University and Indiana University, 2007, p. 29.
84 Hess, R., "Tape degradation factors and challenges in predicting tape life," ARSC Journal 39(2), 2008, pp. 240–274.
85 Ibid., p. 251.
86 Casey, M., 2008, p. 33.
87 Medeiros, D., Curtis, J.L.S., Parry, R., Underwood, J., "Restored magnetic recording media and method of producing same," United States Patent, 1993.

The patent refers to its own results as "unexpected"[88] and "surprising,"[89] besides admitting that the theory behind it is not ascertained: "*it is believed* that the heat restoration process according to this invention, to some extent, may reverse certain hydrolysis" (italics of the authors). According to this "belief," more recent sources claim that thermal treatment is aimed at "removing the moisture that has accumulated in the binder" — although apparently this is only "thought" to happen.[90]

Despite this controversial scenario, thermal treatment continues to be largely applied and rightly so, considering that it is effective in most cases — although the reason is not known. Nevertheless, the careful archivist should be aware that the knowledge about thermal treatment "is merely anecdotal and will require further study."[91] Fortunately, further studies are in fact being carried out[92] and the care that the archival community has for novel solutions in the documents' best interest clearly shows at conferences, in journals, and mailing lists.

In the authors' experience, most tapes respond to "baking", but some do not, and a few are even damaged by it (an example is shown in Figure 1). The authors decided to plan a first set of chemical analyses during a research project aimed at the digitisation of unique audio documents with a great historical and economic value[93], for which no risk could be taken. The ultimate goal of this study is the definition of a scientific protocol for the treatment of SBS-SSS, which may spare many recordings from the consequences of unaware treatments — in terms of temperature, duration, and equipment (instead of a precision incubator such as the one shown in Figure 2, relatively expensive, "the most common equipment is the American Harvest Snackmaster Pro FD50 Food Dehydrator"[94]; even the home made solution of the hair-dryer-in-a-cardboard-box is said to "work well"[95] — sic!).

Other moot questions on thermal treatment are: the recommendable humidity level in the incubator during the treatment, which is not indicated in any of the sources; the duration of the benefits ("incubating the tape returns the tape to a playable condition for weeks or months after treatment"[96]; "this remedy is temporary; the tape will revert over time."[97]); and the risks involved with the treatment. "Although some report having 20-or-more successful 'bakes', there is no published or documented information on how many times a tape can be baked, cycling back and forth between the sticky-firm-sticky succession before it fails completely or before the signal is distorted or altered beyond use."[98] In fact, there is "little knowledge about how exposure to increased heat may impact the tape artifact itself."[99]

88 Medeiros, D., et al., 1993. "In this invention it has been unexpectedly found that deteriorated magnetic recording media [. . .] can be restored to playable and excellent quality media by heat treatment at a sufficiently elevated temperature for a sufficiently long time [. . .]."

89 Medeiros, D., et al., 1993. "It has also surprisingly been found that the heat treatment according to this invention can be carried out with the magnetic recording media such as tape in its cassette, on its reel, or retained by other tape housings [. . .]."

90 Medeiros, D., et al., 1993. "It is commonly thought that baking a tape will temporarily remove the moisture that has accumulated in the binder" (italics of the authors), from http://en.wikipedia.org/wiki/Sticky-shed_syndrome (last visited December 8th, 2014).

91 Gallegos, C., "And the survey says. . . ok! but the data says!," IASA Journal 38, 2012, p. 24.

92 Schüller, D., 2014.

93 Audiovisual archive of the Fondazione Arena di Verona, Italy (2009-2011). See: Bressan, F., Canazza, S., "Towards a procedure for quality control over large collections of digitized audio data: The case of the Fondazione Arena di Verona," in C. Grana, R. Cucchiara (eds.) Multimedia for Cultural Heritage, Springer, 2012.

94 Norris, S., "Tape baking" (contribution to Stanford University's audio preservation manual, "Introduction to Audio Preservation"), Stanford University, 2007.

95 Rivers, M., "Baking magnetic tape to overcome Sticky-Shed Syndrome," 2000.

96 Hess, R., 2008.

97 National Recording Preservation Board, "Capturing analog sound for digital preservation: Report of a roundtable discussion of best practices for transferring analog discs and tapes," 2006.

98 Gibson, G.D., 1996.

99 Norris, S., 2007.

Figure 2. Precision incubator suitable for the thermal treatment of magnetic tapes. The model shown in the picture is a Memmert INP 400 with natural convection. Source: Centro di Sonologia Computazionale (CSC), University of Padova.

2. Description of the analyses

The chemical analyses described in this section are not particularly innovative in the chemical field, but they had never been used to study audio magnetic tapes and the effects of thermal treatment. This shows that the collaboration with other well-established scientific disciplines can still significantly benefit the field of audio preservation and the methods adopted in this field.

The main goal of the analyses was to characterize the tapes, i.e., to understand their exact physical composition, in order to plan recovery methods that take into account the behaviour of each different material at varying environmental conditions including time (aging). Magnetic tapes are a complex case in this study, because they are made of several materials (substrate, etc.), whereas chemical characterization is usually performed on individual materials.

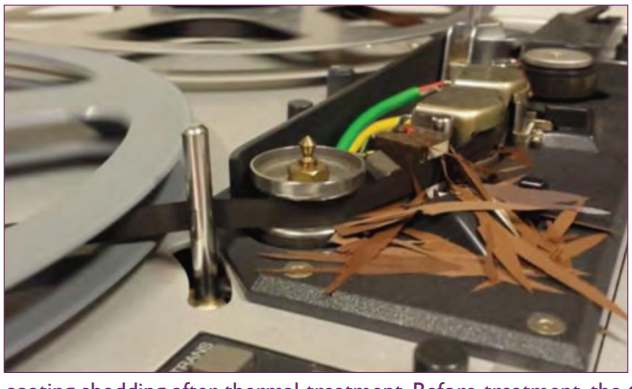


Figure 3. Magnetic coating shedding after thermal treatment. Before treatment, the tape showed some stickiness and shedding. After treatment the shedding was gone, but the magnetic coating was coming off in flakes as shown in the picture. Source: Centro di Sonologia Computazionale (CSC), University of Padova.

2.1 FTIR spectroscopic analysis in ATR

Infrared spectroscopy is a widely used technique that for many years has been an important tool for investigating chemical processes and structure. The combination of infrared spectroscopy with the theories of reflection has made advances in surface analysis possible. The fundamentals of Attenuated Total Reflection (ATR) spectroscopy are based on the evanescent wave

and how it is related to the concept of internal reflection. The concept of internal reflection spectroscopy originates from the fact that radiation propagating in an optically dense medium of refractive index n1 undergoes total internal reflection at an interface of an adjacent medium of lower optical density (refractive index n2 < n1). This wave is termed evanescent and is derived from the Latin root evanescere, meaning "to tend to vanish or pass away like a vapor." The above phenomenon occurs only when the angle of incidence exceeds a critical angle θ_c determined by $\sin\theta_c = n1/n2$. Samples are examined directly, without preparation. Infrared radiation internally reflects through a crystal (ZeSe Diamond) penetrating the sample by only a few microns. The absorbing / scattering of the light is collected and measured to produce a spectrum which is characteristic for the compound being analised. The instrument used for the analyses is a Nicolet Nexus 5700.

2.2 ThermoGravimetric analysis

Thermogravimetric Analysis (TGA) measures the amount and rate of change in the weight of a material as a function of temperature or time in a controlled atmosphere. Measurements are used primarily to determine the composition of materials and to predict their thermal stability at temperatures up to 1000°C. The technique can characterise materials that exhibit weight loss or gain due to decomposition, oxidation, or dehydration.

The analysis has been carried out with a linear temperature increase with a rate of 15°C per minute. The instrument used for the analysis is a TA Instruments SDT 2960 Simultaneous DSC-TGA. The analysis has been carried out under nitrogen atmosphere.

2.3 Electronic microscopy

The Scanning Electron Microscope (SEM) is considered to be a non-destructive type of analysis.[100] It uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens which are subsequently collected by a detector. The signals that derive from electron-sample interactions include secondary electrons (that produce SEM images), backscattered electrons (BSE), diffracted backscattered electrons (EBSD), photons (characteristic X-rays), visible light (cathodoluminescence–CL), and heat.

These signals reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample or a selected area of the surface of the sample (areas ranging from approximately 1 cm to 5 microns). A 2-dimensional image is generated with magnification ranging from X20 to approximately X30,000 and spatial resolution of 50 to 100 nm.

Samples must be solid and they must fit into the microscope chamber that undergoes into a stable vacuum on the order of 10^{-5} - 10^{-6} torr. (Samples likely to outgas at low pressures are usually analysed by "low vacuum" and "environmental" SEMs or ESEM). The instrument used for the analysis is a Philips XL30 TMP Microanalisi XRF-EDS.

2.4 Acetone extraction test

The acetone extraction test is able to provide valuable information on tape binder stability. 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

100 In this field, non-destructive means that the analysis can be repeated on the same sample more than once. But from the viewpoint of audio preservation, this test is destructive because it requires that the sample is prepared (i.e., gold coating), which is an irreversible modification of the tape. The fact alone that a small piece of tape must be cut to obtain the sample (approximately 1 cm) would not make the test destructive.

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. However, other components such as lubricants might also be soluble in acetone, and this may alter the results: for this reason, the authors have planned a study to analyse the composition of the residue. 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, besides a number of tape samples that were completely destroyed after the test, preventing any further measure of the weigh. The number of tapes on which the test could not be performed due to this behaviour are significant (about half of them): this fact was not reported in the previous study[101] that inspired the one presented by the authors, which makes it even more important to find alternative tests, such as the acidity test (extraction in water), which will be performed in the future precisely on the tapes that degrade completely in acetone.

Sample	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 1/2" 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 (±0.0001 gram).
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.

Table 1. Acetone extraction method used by Bigourdan, et al., for testing magnetic tapes.[102]

101 Bigourdan, J., et al., 2006, p. 25.
102 Bigourdan, J., et al., 2006, p. 27.

Extraction time. Bigourdan, et al.,[103] reports that some preliminary tests show 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 provides repeatable results. Shorter extraction times lead to inconsistent results, and longer extraction times do not significantly increase the amount of extractable compounds. 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.

Previous works[104] also suggest a 20-minutes extraction time, but in the present study a 30-minute extraction time was adopted.

Based on the preliminary tests, Bigourdan, et al.,[105] finalised an acetone extraction method to be used in the research, which the authors replicated herein. The method provides reproducible results within an acceptable range. The data discussed in the following sections were determined following the procedure described in Table 1.

It is worth mentioning that a different physical test (friction test) is suggested by Bigourdan, et al.,[106] aimed at "detecting the changes in the tape binder over time" and which was inspired by the work of the Eastman Kodak Company on motion-picture films in 1971.[107] 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 is 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 was measured as a tangent of the inclined plane to the horizontal. Contrary to the test conducted in the present work, the friction test just described is non-destructive. The author has not been able to try this test yet.

3. Results and discussion

Ten tape samples (labeled from A to L) have been analysed with the techniques described in the previous section. Some tapes came from the sound archive of the Arena di Verona, Italy[108] and some from the Centro di Sonologia Computazionale (CSC) of the University of Padova, Italy. All of them contained audio recordings (i.e., were not blank/new) and dated back to the 1980s or earlier. The brand was not always known due to missing box or explicit indication.

The combination of electronic microscopy and the FTIR in ATR allows for the determination of the chemical nature of the tape substrate, of the binder and of the magnetic material. The FTIR technique is fast, non-destructive, relatively inexpensive, and it allows for the identification of acetate tapes, the degradation of which is more accentuate and, most importantly, should never undergo thermal treatment. Acetates are thermolabile, and they would be irreversibly damaged. The most common rule of thumb to recognise acetate and polyester-based tapes is to "hold the tape up to the light and observe whether it appears translucent or opaque. If it appears translucent, it is acetate. If it appears opaque, it is polyester."[109] Another source claims that tapes are "easy to identify: hold the tape pack up to a strong

103 Bigourdan, J., et al., 2006.
104 Bertram, H.N., Cuddihy, E.F., "Kinetics of the humid aging of magnetic recording tape," IEEE Transactions on Magnetics 27, 1982, pp. 4388–4395.
105 Bigourdan, J., et al., 2006.
106 Bigourdan, J., et al., 2006, p. 33.
107 Anvelt, T., Carroll, J.F., Sugden, L.J., "Processed film lubrication: Measurement by paper clip friction test and improvement of projection life," Journal of the Society of Motion Picture and Television Engineers 80(9), 1971, pp. 734–739.
108 Bressan, F., Canazza, S., 2012.
109 Norris, S., 2007.

light and look through the pack itself. Acetate-based tapes are translucent, and light may be seen through the layers. Polyester tapes are opaque and no light is visible through the tape pack."[110] These rules of thumb are generally true but not infallible: the results of the FTIR Spectroscopic analysis in ATR shown in Table 2 revealed that the shiny side of tape samples A and B was made of cellulose acetate, despite their appearance which was not translucent. Failing to recognize acetate tapes can potentially destroy them irreversibly, hence the importance of 100% safe methods for their identification (possibly based on objective measurements and not on the human sensory system).

The large variety of materials shown in Table 2 is striking, even among the polyester-based tapes, and suggests that a "one size fits all" recipe for recovery is not optimal.
Another important observation about the FTIR analysis in ATR shows a negligible presence of water on the tapes' surface. This contradicts the popular sources that claim that thermal treatment is aimed at "drying" tapes, literally "extracting" the water that they have absorbed during years of storage in humid environments ("the binder [. . .] soaks up water and causes the urethane to rise to the tape's surface"[111]). Water is considered to be responsible for the stickiness exhibited by the tapes: "hydrolysis [is] the process by which the chemical that bonds the recording oxide to the polyester base absorbs moisture from the air."[112]

Sample	Brand	Shiny side	Matt side
Tape A	TEAC	cellulose acetate	polyvynil chloride - vynil alcohol
Tape B	AGFA	cellulose acetate	not identified[a]
Tape C	MAXELL	co-polymer (poly-vinyl butirrale - vinyl alcohol - vinyl acetate)	poliurethane
Tape D	TDK	polyester	polyester
Tape E	BASF	polyurethane	not identified[a]
Tape F	unknown	polyurethane	polyester (stearate)
Tape G	3M	PET	poliurethane
Tape H	BASF	polyurethane	co-polymer (tetrafuoloethylene - esafluoropropylene (TEFLON 100))
Tape I	unknown	polyurethane	not identified[a]
Tape L	unknown	polyurethane	not identified[a]

Table 2. The table summarizes the results of the FTIR spectroscopic analysis in ATR. The first column reports the tape samples. For each sample, the material composing the shiny side and the matt side is indicated. Tapes are identified only by the brand, because the model was unknown for all but three (Tape sample E: BASF SPR 50 LHL).
Table footnote a: The presence of degradation products or of a mixture of materials does not allow the identification solely on the basis of FTIR.

110 Casey, M., 2008, p. 5.
111 Kaltseis, S., Hubauer, A., "Tape dehydration as part of the 'journale' project: On dealing with sticky-shed syndrome," IASA Journal 38, 2012, p. 41.
112 National Recording Preservation Board, 2006, p. 2.

This belief is confirmed by the many web pages that propose food dehydrators in place of thermo-incubators for treating the syndrome. Food dehydrators use heat source and air flow to reduce the water content of foods: "dehydrating is a method of food preservation in which *moisture is removed* from the food"[113] (italics of the authors). Removing water from magnetic tapes, in whatever form, seems to be pointless, since the analyses showed that the presence of water was less than 1% in all tape samples. Hess and Casey had already pointed out that "the mechanism by which baking (also called incubation) renders a Sticky Shed Syndrome tape playable has been misunderstood."[114]

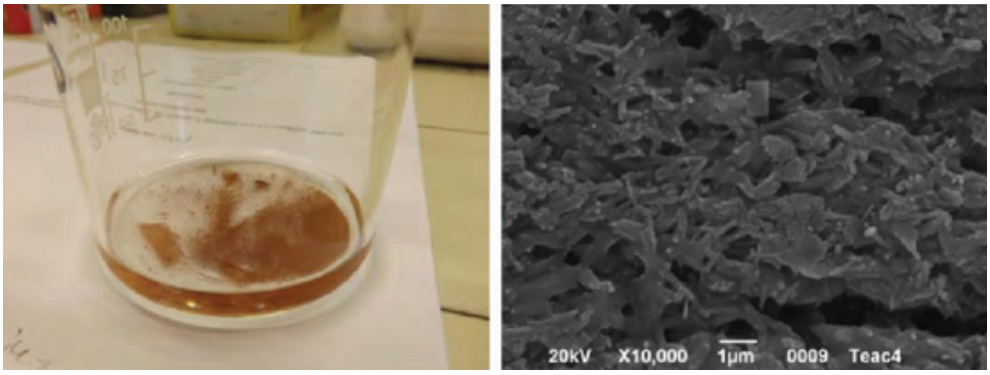
At the same time, the quality of some FTIR analyses was too poor to allow the characterisation of the materials (in particular, the matt side of the tape samples B, E, I, and L). The reason might be a mixture of components, some of which have probably originated from the process of hydrolysis, or which have been in the tape since manufacturing. This calls for further study on the chemical nature of the degradation products that can originate from the process of hydrolysis. The authors intend to conduct more studies on the residue of the acetone extraction test, namely on the tape samples that have completely melted or that have been destroyed in incubation. In fact, the acetone extraction test has been particularly interesting. The outcome was unexpected, as the source that inspired the test in this work does not report any case where the tapes melted or got destroyed, which was the case of tape samples A, B, and G (Figure 4(a)).[115] Another work on the experimental results of the acetone extraction test does not report similar cases either.[116] The test could not be performed on the melted/destroyed samples. The reasons might be the nature of the materials or the process of degradation involving the tapes.

Previous scientific literature does not report of works where audio magnetic tapes have been observed by means of electronic microscopy. The ESEM does not require the preparation of the samples (e.g., gold coating), but the SEM analysis — which does — reaches a greater magnification and allows to observe the different crystalline structures of the magnetic particles, such as in tape sample A (Figure 4(b)). Different structures suggest the presence of different types of iron oxides, corresponding to different chemical and magnetic properties. The types of iron oxides are at least four:

1. wüstite (FeO), crystallizes in cubes
2. magnetite (Fe_3O_4), crystallizes in octahedra
3. hematite (αFe_2O_3), crystallizes in the rhombohedral system
4. maghemite (γFe_2O_3), crystallizes in the tetragonal system

Figure 4(b) suggests the presence of two different types of iron oxide, since two different shapes are observed. In order to determine them accurately, future work might include an X-Ray Diffraction (XRD) analysis: the differences among the types of iron oxide is significant to the study on magnetic tapes in that it involves aging (behavior in time) and reactivity to water (hydrolysis).

113 Website of well-known producer of food dehydrators and roaster ovens: http://www.nesco.com/.
114 Casey, M., 2008, p. 30, and Casey, M., Gordon, B., 2007, p. 31.
115 Bigourdan, J., et al., 2006.
116 Cuddihy, E., "Aging of magnetic recording tape," IEEE Transactions on Magnetics MAG-16(4), 1980, pp. 558–568.



(a) Acetone extraction test (b) Electronic microspcopy

Figure 4. Tape sample A after the acetone extraction test (left) and observed by means of electronic microscopy (right). The first number from bottom left of the figure on the right is the power of the electron beam (20 kV); the second is the magnification rate (X10000); the third is the scale (the white segment above indicates the proportion, 1 µm); the progressive number in the analysis session; the sample identification number.

The ESEM also allows to determine which side of the tape carries the magnetic coating, which is not always easy to do with a visual inspection: the tape sides come in different colours (from light brown to black) and often with a shiny side and a matt side, but either can carry the magnetic coating. The ESEM allows analysing (i) the morphology of the tape, including damages of mechanical origin (gouges and hollows), and (ii) the distribution of the magnetic material on the tape surface.

The study of the thermal behaviour of the tapes by means of TGA measurements has been considered of great interest, since the initial motivation for this experience was the thermal treatment used for compensating the effects of the SBS-SSS. The results of the TGA showed that below 150°C the weight loss is extremely limited (less than 1%). Typically, this loss is due to adsorbed water, with more or less strength. These results suggest that the measurements might be repeated in the future with a slower heating ramp, with the aim of highlighting the liberation of adsorbed water or other volatile substances. Figure 5 shows an example of TGA graphics for a tape sample.

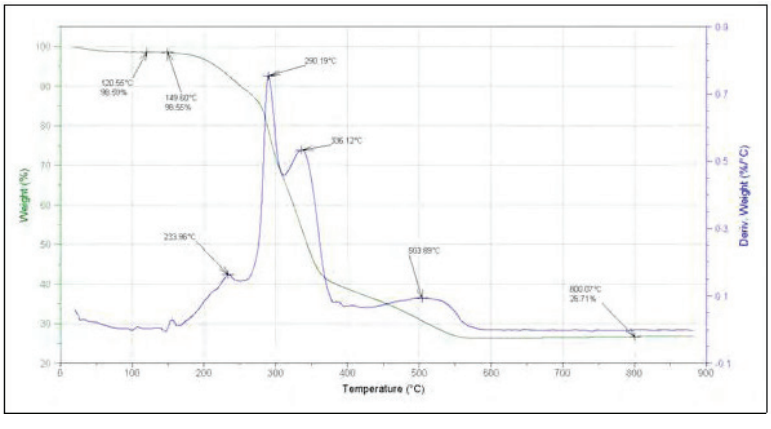


Figure 5. Example of TGA output. The green line indicates the tape sample weight (%), and the blue line the derivative tape sample weight (%/°C).

Two of the tape samples that have been analysed in this work were affected by SBS-SSS (samples I and L). The results indicate that the entity of their degradation was not severe, since the tapes were not melted nor destroyed during the acetone extraction test. However, the weight loss of the samples is consistent with the literature about damaged tapes (6.30% and 5.80%, against an average 1.35% of the samples in better condition). This indicates that the magnetic coating is not perfectly adherent to the substrate. Moreover, the residue that the tapes affected by SBS-SSS leave on the audio heads of the recorder has been analysed, and the presence of iron suggests that a portion of the information is physically detached from the coating. The entity of the modification on the audio signal induced by the detachment of the sticky residue is an interesting matter for future investigations.

4. Conclusions and further work

The aim of this article was to raise awareness in the archival community on the risks that are currently being taken when restoring magnetic tapes with thermal treatment due to the lack of a scientific understanding of the effects of said treatment. Nevertheless, the authors agree that the "lack of understanding of the sticky shed problem does not justify inaction on the part of audio archivists, since sticky shed grows gradually worse over the years."[117] Until further knowledge is gained, and precise recovery methods are devised, it is ok to keep "baking" tapes, but it is very important to be aware of the risks and, of course, to carry out the procedure with professional equipment (precision incubator).

The authors are currently conducting additional analyses to find out possible differences on tape samples before and after treatment, both at physical level and in the audio signal. The analyses are not only finalised at identifying the modifications that affect the tape during the treatment, but also to answer to this question: is the audio signal altered by the treatment? If so, how? If the treatment makes the tape playable again, then it is considered to be successful, but at what cost for the sound spectrum?

The authors also wish to keep investigating the products of tape degradation by means of the acidity tests, in order to determine hydrosoluble substances, generally of acid nature, produced by hydrolysis. Another aspect to explore is the acidity of the tape surfaces by means of a chemical method developed at the Department of Industrial Engineering of the University of Padova. The research schedule includes the Atomic Force Microscopy (AFM) analysis, finalised at studying the morphology of the surfaces; the Gas Chromatography-Mass Spectrometry (GC-MS); and the broadband dielectric relaxation spectroscopy.

5. References

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