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The impact of thermal treatment on the mechanical properties of magnetic tapes: Tensile test

Federica Bressan[1] and Roberta Bertani[2]

[1] *IPEM – Institute for Psychoacoustics and Electronic Music, Ghent University, Belgium*
[2] *Department of Industrial Engineering - Chemical Sector, University of Padua, Italy*

Correspondence should be addressed to Federica Bressan (federica.bressan@ugent.be)

ABSTRACT

This article presents the method and the results of a test aimed to determine the tensile properties of magnetic tape samples before and after thermal treatment. The goal is to investigate whether thermal treatment has an effect on the tapes mechanical properties. A tape showing no symptoms of degradation has been used. No modifications have been observed, which is in line with the hypothesis that thermal treatment has no effect on 'healthy' tapes. Thermal treatment is expected to restore the elasticity of damaged tapes, making them more resistant to mechanical stress and therefore less prone to break. This study contributes to the long-term goal of building a structured knowledge base about diagnostic tools and recovery methods for magnetic tapes.

1 Introduction

Magnetic tapes have had widespread use in audio, video, and computer applications over the past 70 years. An impressive technological evolution has occurred during this timespan, producing a variety of recording formats and equipment. Magnetic tapes come in different sizes and materials. In [1, 2], the authors have presented the results of a set of analyses aimed to characterize a pool of tape samples the materials of which were not known. The results of the analyses showed that tapes from different brands and production years are indeed made of different materials (both surface and substrate layers) and that they can hardly be identified with visual or olfactory inspections. The study was aimed to raise awareness on the fact that the tapes chemical composition matters when it comes to planning preventative measures or recovery methods against the destructive effects of ageing, and also to bring attention to the fact that some recovery methods are currently implemented without a complete understanding of the underlying processes (especially thermal treatment, see Subsec. 1.2). At the same time, the study marked the beginning of a series of tests and analyses on magnetic tapes, as part of a long-term commitment to contribute to the accumulation of a coherent body of work in the form of scientific literature and multimedia knowledge bases, to complement and unlock the *implicit knowledge* currently embodied by practitioners all around the world.

1.1 Motivation

In [3], the authors presented the methodology and the first results of a two-part experiment. The goal of the experiment was to determine the modifications that thermal treatment induces on magnetic tapes and on the audio signal memorized on the tapes. In order to do so, a tape was tested before and after treatment: a set of chemical analyses were conducted on tape samples, and audio analyses on the corresponding digitized signals. Besides chemical analyses, a mechanical analysis (tensile test) were presented in [3]. This article focuses on the mechanical analysis as a separate entity, offering a more extensive explanation of the motivation and the technique, along with the results obtained with a larger set of tape samples. This article is meant to be self-complete, but it could be useful to understand it in its connection with [3] especially in the light of the long-term vision about the scientific work described in the previous paragraph.

The hypothesis of the experiment described in [3] was that the treatment would induce no modification *on a 'healthy' tape*. Similarly, this study is concerned with modifications in mechanical properties before and after treatment, but differences between blank and recorded tape samples are not expected. Therefore the samples will be marked as blank and recorded only because they come from the same batch of the other experiment. The only hypothesis concerns the modifications in the tensile properties of the tape before and after treatment.

All the analytic methods and techniques that have been applied magnetic tapes in these studies are well established in the experts community. However they have not been systematically applied to magnetic tapes, a 'complex' case study from the chemical point of view because tapes are made of multiple materials together, which show different behaviors at varying temperature, humidity, etc. and which can also trigger interactions with each other. The fact that the analyses are established is a good thing because the audio community is provided with a repertoire of ready-made analyses to use, some of which are also relatively quick and inexpensive. At the same time, we believe that it is necessary to present these analyses in a language that can be understood by the audio community at large (from sound engineers to music archivists), and not for their generic use but in the light of their specific application to magnetic tapes. This is our intent and the approach behind this article.

1.2 Background

The critical concern about the physical degradation that affects all magnetic tapes with the passing of time is primarily the change in physical properties of the tape [4], not the loss of magnetic characteristics [5]. Magnetic tapes have proved to be rather stable in this aspect, and if a significant loss of magnetic characteristics occurs, it is usually due to careless exposure to magnetic charges.

Fig. 1: The instrument used for the tensile test: a dynamometer Galdabini SUN2500 with a load cell of 25,000N.

Organic materials are commonly prone to spontaneous chemical decay, and metallic particles in the presence of oxidizing compounds are subject to oxidation [6]. Oxidation is the chemical reaction believed to contribute to the appearance of undesired shed, stickiness and squeal in magnetic tapes (for a discussion on the aetiology of these symptoms, see [2]).

Thermal treatment is a popular procedure used to revert the effects caused by these symptoms. When effective, the treatment is expected to improve the playability of the tape, including the audio signal recorded on the tape. This corresponds to a modification in the chemical and mechanical properties of the tape. Speaking of mechanical properties, the tape is expected to gain elasticity, whereas an aged tape will break more easily especially during replay due to the stress to which it is subjected, and especially on a machine where suboptimal maintenance on the breaks system was performed. The tensile test described in this article is designed to reveal changes in the tape elasticity, before and after treatment.

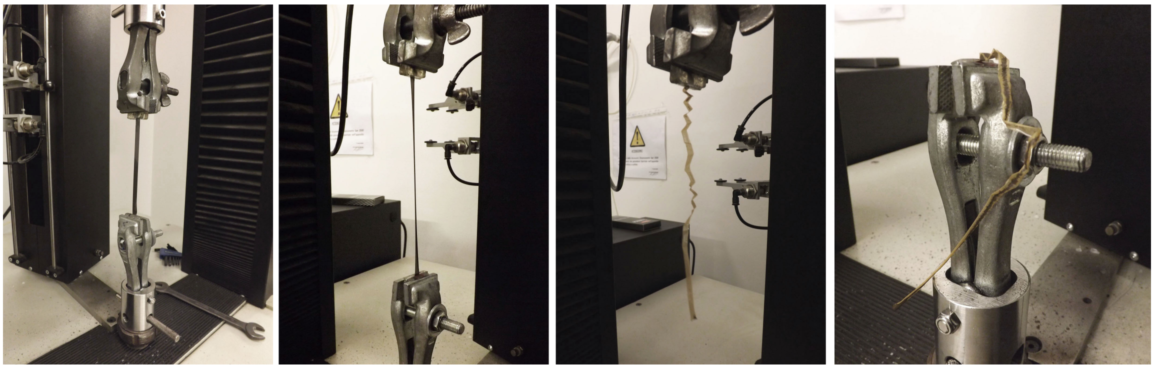

Fig. 2: The main phases of a tensile test. Details of the tape samples at different degrees of deformation are visible in Figure 3.

The article is structured as follows. Sec. 2 describes the experiment materials and the technique; Sec. 3 presents the results and the discussion. Sec. 4 summarises the conclusions and addresses some future work.

2 The experiment

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. A general cross section of a tape is shown in [3]. This is relevant to this experiment because the fact that different materials show different behaviors at varying temperature, humidity, etc. also means that they have different mechanical properties. Just as the stickiness is only caused by some components of the tape (but the entire tape is compromised as a consequence), so are its fragility or brittleness. The condition of every component of the tape must be good enough to allow playability. If one breaks too easily, it is of no use that the other(s) could resist higher levels of stress. It should be noted right upfront that during regular handling and usage, magnetic tapes are not subject to forces the entity of which is comparable to those applied in a tensile test. This test is only useful to reveal eventual differences in the mechanical properties of the same tape sample before and after thermal treatment – just like a Thermo-Gravimetric Analysis (TGA, see [2]) monitors the tape behaviour during an excursion from room temperature to 900°C in order to study its properties and not because thermal treatment for recovery purposes exposes the tape to a comparable heat.

2.1 Description of the technique

Tensile properties determined by this test method are of value for the identification and characterization of materials for control and specification purposes, often for industrial applications. The test covers the determination of tensile properties of plastics in the form of thin sheeting, including film (less than 1.0 mm in thickness). In this work the purpose is to compare the mechanical properties of magnetic tape samples before and after thermal treatment. The tape samples are progressively stretched by the dynamometer (see next paragraph, Subsec. 2.2) until failure is finally reached. The film base of the tape is obviously the part that elongates the most and that is easier to observe in this test. Two thresholds can be distinguished: until a certain level of stress, the deformation resulting from the stress is reversible, and the sample spontaneously resumes its original state as the stress is released; but after a certain stress level, the sample undergoes a deformation that is not reversible. However, the sample is still intact, i.e. it has not reached its breaking point. The breaking point is the measure of the maximum stress that the sample can endure. The thresholds are clearly visible in the so-called *stress-strain curve*, two examples of which are included in Section 3. Depending on the nature of the sample and on the end application of the test, these two thresholds may have different relevance or interpretations. In our case, not only the tape is compromised as soon as it passes the point of irreversible distortion, but it is the moment when the surface with the magnetic coating begins to fail that determines the upper limit of the stress that the tape can take. This threshold cannot be measured by means of this test method. During this test, it was observed that the surface does not break but slowly disintegrates until grains magnetic powder are literally detached from the film base. Details of the tape samples at different degrees of deformation are visible in Figure 3. Figure 1 schematizes the three main phases of the test: first the sample is anchored to the grips, then the grips separate until the sample breaks, and finally the sample is removed.

The instruments used for the analyses have been made available by the Department of Industrial Engineering of the University of Padua and by the Centro Universitario Grandi Apparecchiature Scientifiche (CUGAS) of the University of Padua.

2.2 Materials

The tape. The tape used for the experiment is a Maxell UD 50-60 coming from in the historical archive of the Centro di Sonologia Computazionale (CSC) in Padua. The tape was purchased in the late 1980s - early 1990s. It was stored in a sealed cardboard box with other brand new tapes until this experiment.
Two samples of blank tape before treatment, and three samples of recorded tape respectively before and after treatment were cut from the reel. The information about the tape total thickness, about 0.5 mm, is derived from the tape box (a picture of the box is included in [3]).
The treatment. The tape samples have been thermally treated with a precision incubator Memmert INP 400. For a description of the treatment cycle, see [3].
The instrument. The instrument used for the test is dynamometer Galdabini SUN2500 with a load cell of 25,000N (Figure 1). The rate of grip separation was set to 50 mm/min, according to the recommendation mentioned in the previous paragraph (Subsec. 2.1).
The procedure. For comparative purposes, the elastic module (E) and the yield strength (σ_s) have been determined. The tensile strength at break and the percent elongation at break have also been determined.
During the preparation of the test, the *Standard test method for tensile properties of thin plastic sheeting* has been considered [7]. For tensile modulus of elasticity determinations, a sample length of 250 mm is considered as standard, however a length as short as 100 mm is accepted. For the speed of testing (rate of grip separation), 50 mm/min are indicated for initial grip separations of 10 mm [7, Tab. 1 at p. 4].

Fig. 3: Different degrees of deformation of a magnetic tape during a tensile test.

3 Results and discussion

The values of the measurements for all tape sample are summarized in Table 1.
The results are consistent with the analyses described in [3]: the differences between the same samples before treatment or the same samples after treatment have the same order of magnitude of the differences between the samples before *and* after treatment. This suggests that the difference is not ascribable to the effects of the treatment. This is also consistent with that obtained in a similar test described in [6, p. 39]: "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".

It should be pointed out that this test has been conducted on a tape not showing symptoms such as shed, stickiness or squeal, therefore a tape on which the treatment is expected not to have any effect – unless the treatment has destructive effects, which in fact has been proven not to be the case in [3].

The samples before treatment reached an average elongation of 139.2% (recorded tape) and 135.4% (blank tape) before failing. The threshold of the acceptable deformation, equal to 5%, corresponds to a stress between 60 and 75 MPa. After 5%, the tape is considered useless because the magnetic coating starts detaching from the surface. The stress-strain curve in Figure 5 shows the strength of the film base of a sample (recorded tape) before treatment when subjected to a constant rate of elongation.

After treatment, the samples reached an average elongation of 138.8% before failing. The threshold of the acceptable deformation, equal to 5%, corresponds to a stress between 60 and 75 MPa. After 5%, the tape is considered useless because the magnetic coating starts detaching from the surface.

Fig. 4: Example of tape damaged during replay on a machine with bad breaks.

The threshold of permanent deformation of the substrate (5%) corresponds to a stress of about 60 MPa, however a much lower stress is sufficient to detach the magnetic coating from the tape surface. As a consequence, the tape as a whole can be considered compromised significantly below an elongation of 5%.

Below 5%, the film base elasticity would allow the sample to return to its initial length and shape, as it was before the tension was imposed. Beyond 5%, the tape is permanently distorted. In [8, p. 2], a typical polyester sample is reported to reach an elongation of 100%, while the figure of 5% for recording tapes is confirmed.

During normal usage and handling, magnetic tapes are not subject the the stress imposed by this test, although the stress caused by a sub-optimal condition of the recorder's breaks can cause the irreversible damage or the rupture of some aged tapes, especially at stop/start and during rewind at high speeds. Figure 4 shows an example of a damaged tape, deformed while being played on a machine with bad breaks. In this case the elongation was not sufficient to cause the detachment of the magnetic coating on the surface, and technically the tape is still readable because the film base did not break, but the original shape of the base has been permanently altered, with obvious negative effects on the acoustic information memorized in correspondence of damage. To learn more about the relation between the state of preservation of a tape and the stress caused by the recorder, it may be interesting to perform in the future a *shock tensile test*. This test is mentioned in a study conducted by the Scotch/3M tape manufacturer on polyester and acetate tape backings in 1969 [8, p. 4].

It is worth mentioning that a different physical test (*friction test*) is suggested in [6, p. 33], 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 [9]. The

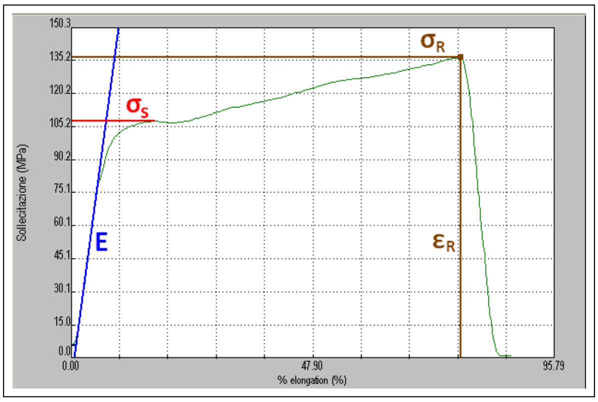

Fig. 5: Tensile testing on a tape sample before treatment. The figure shows the elastic module (E), the yield strength (σ_S), the tensile strength at break (σ_R) and the percent elongation at break (%). The percent elongation (%) is on the x-axis, the stress (in MPa) is on the y-axis. The values associated to all tape sample are summarized in Table 1.

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 this work, the friction test is non-destructive.

4 Conclusions and future work

The goal of this article was to present a mechanical test used to determine the tensile properties of plastics in the form of thin sheeting, including film. This test is suitable to identify tensile properties of magnetic tapes, and to detect eventual changes induced by thermal treatment. The results presented in this study are tightly connected to the experiment described in [3], where a more extensive description of the long-term plan to integrate the results of all the experiments is provided. The plan is about the systematic accumulation of knowledge about magnetic tapes and other audio carriers in the form of a coherent body of scientific

Tape sample		E (MPa)	σ_S (MPa)	σ_R (MPa)	ε_R (%)
Before treatment	Sample 1	1651	106.2	80.2	136.9
	Sample 2	1614	105.9	86.3	143.7
	Sample 3	1554	107.4	77.5	136.8
	Average	1606	106.5	81.3	139.2
After treatment	Sample 1	1596	106.7	93.3 6	142.7
	Sample 2	1733	105.7	88.1	138.8
	Sample 3	1704	106.8	88.4	134.8
	Average	1678	106.4	89.9	138.8
Blank tape	Sample 1	1681	106.7	74.16	136.1
	Sample 2	1680	106.9	76.6	134.7
	Average	1680	106.8	74.2	135.4

Table 1: The Table shows the results obtained with the tensile test on the tape samples. The columns represent the elastic module (E), the yield strength (σ_S), the tensile strength at break (σ_R) and the percent elongation at break (%).

work and its applications (e.g. interactive knowledge bases), contributing to and partially unlocking the implicit knowledge currently embodied by practitioners all around the world.

The results provided in this article have given an insight in the behaviour of magnetic tapes that are subject to an increasing tension up to the point of physical failure (breakage), showing that the point where the magnetic coating on the surface begins to disintegrate is what determines the upper limit of the stress that the tape as a whole can take, which is significantly lower than that indicated by the test for the tape base film. In any case the tapes on regular playback devices are not subject to the stress imposed during the test, however damages can occur on tapes that are particularly fragile due to ageing and/or due to defective devices. In the overall, the results have confirmed the hypothesis that no noticeable modification occurs during thermal treatment. Another test will be conducted during the second phase of the experiment described in [3], when a tape showing symptoms of degradation (e.g. undesired shed, stickiness and squeal) will be considered. It would also be very interesting to plan an experiment where modifications induced by *different thermal treatments* are investigated: in the present set of studies, only one type of treatment cycle is performed, with professional equipment. Plateau temperatures and durations may be varied, but also the instrument, including the food-dehydrator approach [10] to the creative “hair-drier-in-a-cardboard-box” approach [11]. It is a serious matter to consider these variations because they are consistently proposed by the rich and diverse repertoire of resources available on the internet and there is no reason to believe that they are not vastly applied – also considering the cost of professional equipment like a precision incubator. Although a clear picture of the real-world practices around the world is not available, due to the fragmented nature of this field, which we in fact wish to help decrease with the work presented in this article and with the future works included in the long-term plan mentioned above. A survey on the most popular devices to implement thermal treatment should most likely be included in the roadmap: the test results would be interpreted in direct connection with concrete experiences, thus increasing their usefulness and impact on real-world practices. Results of a thermal treatment performed with a precision incubator (ideal scenario) unfortunately do not inform the professional practice of an expert who uses a food-dehydrator (realistic scenario).

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