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► **To cite this version:**

Marie-Anne Loeper-Attia. Physical and Chemical Interactions between Metallic Instruments and Plastic Threads. Metal 2019 Proceedings of the Interim Meeting of the ICOM-CC Metals Working Group September 2-6, 2019 Neuchâtel, Switzerland, Sep 2019, Neuchatel, Switzerland. hal-04449341

HAL Id: hal-04449341

<https://hal.science/hal-04449341v1>

Submitted on 9 Feb 2024

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Physical and Chemical Interactions between Metallic Instruments and Plastic Threads

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Abstract

The collections at the Musée de la musique in Paris include several hundred brass, silver and silver-plated wind instruments that are often exhibited, loaned or played. For the museum's opening in 1997, special mountings were proposed and designed by Franck Hammoutène and various types of thread were used to hold the instruments by their cylindrical parts. These threads were regularly untied and re-tied, for instance, for loans to temporary exhibitions, studies and when the galleries were refurbished in 2009. They were also used for temporary reinforcement (instead of adhesives), mounting (sometimes in combination with foams) and for attaching labels. Various types of thread were used – rope, fishing line and sewing thread – composed of nylon, polyester, polyamide or polyethylene. The choice between these four materials depended on criteria such as the weight and nature of the instrument, colour of the surface it is attached to and the friction or tractive forces involved in the instrument's use. Over the years, various types of surface damage to the

metallic instruments have been noticed, including mechanical damage, such as scratches, and chemical damage, such as localised corrosion. After a short description of the collection of instruments and the degradation observed, this paper discusses the solutions now being applied at the Musée de la musique. The research addresses four points: 1) identification of the mechanical and chemical damage observed using visual and microscopic observations and XRF in situ; 2) the required specifications for choosing a new type of thread; 3) the types of plastic thread chosen and their various chemical and physical characteristics; and 4) corrosion tests in a humid chamber and Oddy tests with metallic sheets in contact with various types of plastic thread. The new solutions found will be introduced into the framework of the museum's global preventive conservation protocol.

Keywords

brass, exhibition, plastic thread, polypropylene

Introduction

In a museum setting, objects are subjected to a number of factors, such as climate, lighting and display method. The items in question, instruments, can be placed directly on a surface with a screen material that avoids any contamination with the support. The presentation can be more constrained if the instrument is mounted. The display method must be adapted to the materials the item is made of, taking into account any observed degradation or fragility. A material's corrosion resistance, especially in the case of a metallic material, is not merely an intrinsic property. The amount of corrosion depends greatly on the environment. It is therefore essential to set up sound storage and display protocols that correspond to an item's specific needs. This paper discusses the support and display of musical instruments in a museum setting, specifically at the Musée de la musique – Philharmonie de Paris at its opening in 1997 and during the various

stages of work in the exhibition areas, taking into account the constraints inherent to the materials, the location and the museographical approach.

Description of the museum and the particularity of the collections

The Institut national de musique was created by decree on 8 November 1793 to '[train] the artists needed to perform on national holidays' and included an 'instrument room' containing pieces confiscated from 'emigrants'. Under the terms of the Convention of 17 August 1795, the Institut became the Conservatoire de musique de Paris and included a collection of 'antique or foreign instruments, and those of our own customs, that can in their perfection serve as models'. Of the 316 items transferred to the Conservatoire in 1795, only a dozen remain today. In 1861,

the French government purchased for the Conservatoire the instrument collection of Louis Clapisson, a composer and member of the Institut. Two rooms were officially opened and, for the first time, a collection of instruments was made accessible to the public in Paris, marking the birth of the instrument museum. Clapisson was the first curator, followed by the composer Hector Berlioz and then Gustave Chouquet, who significantly developed the collections. The third major milestone occurred around 1960, thanks to the Countess Geneviève de Chambure (Getreau 1996). During this period, the role and purpose of a future Musée de la musique were defined in terms of conservation, restoration, inventory and documentation (Figure 1).



Figure 1. Musée instrumental in 1884. Engraving by Eugène Tradoné for the second edition of Chouquet's catalogue



Figure 2. Display case for 19th-century instruments

In 1978, with the founding of the Cité de la musique, the decision was made to hand the Conservatoire's national collections over to the state, leading to the creation of the Musée de la musique in 1995. An acquisition and

restoration campaign was launched and plans were made for a new museum, which officially opened at this new site in 1997. A redesign in 2009 introduced the latest museographical changes.

The major themes covered are the 17th century and opera, the music salon of the 18th century, the great inventions of the 19th century, the new sounds of the 20th century and, finally, the musical traditions of other continents (Figure 2).

Instrument mounting and display at the Musée de la musique – Philharmonie de Paris

The mounts created for the museum when it opened in 1997 were designed by architect Frank Hammoutène. Today, the museum is still required and obliged to use the same type of mount, based on the principle that the instruments are (generally) presented vertically or in playing position. A metal armature holds them up with half-rings covered in high-density polyethylene foam and threads encircling the instrument. These museographical constraints were included in the convention signed between Frank Hammoutène and the Musée de la musique. It explains why this display method is imperative and why it must continue to be used even today. Securing the instrument in a vertical position requires adjusted grips and a mounting perfectly adapted to the instrument. This often requires fastidious adjustments (Figures 3 and 4). There were, however, several exceptions to this rule when an instrument's configuration was particularly unusual and could not be made to fit the mounts designed by Frank Hammoutène.



Figures 3 and 4. Instrument mounting in a display case

Materials used and types of damage observed

To secure each instrument to its attachment ring, special threads were chosen, i.e. woven fishing line in two colours

Table 1. Composition of different fibres and threads

Woven fibres and threads		Non-woven fibres and threads	
Composition	Commercial name	Composition	commercial name
cotton		aromatic polyamide or aramid (PAA)	Kevlar, Technora, Twaron
non-aromatic polyamide (PA)	Rilsan, Technyl Nylon	aromatic polyester	Vectran
non-aromatic saturated polyester (PET)	Dacron, Tergal, Tetoron	carbon	
non-aromatic saturated polyester (PEN)	Pentex		
polypropylene	Prolene		
high-density polyethylene (HDPE)	Spectra, Dyneema, Nacrylan		

(grey and brown). The colour was selected to match the object. The brands used were either Caperlan thread (by Decathlon) or Nacrylan thread (by Tortue). Both types of fishing line are woven and made of Dyneema, the main component of which is high-density polyethylene (HDPE). The other types of fishing line are polyamide-based (nylon) or fluorocarbon. In addition to the main component, the threads also contain micro-pigments or abrasives that make the thread visible in water and ensure good grip in the reel during fishing. Unfortunately, the exact nature and concentration of these components were not provided by the manufacturers. Non-woven threads such as nylon (polyamide) or hemp (for the labels) were also sometimes used on the instruments. Table 1 indicates the type of fibres and their most common commercial names.

These threads, especially the woven ones, were chosen essentially for their strength. All of the data came from the supplier Kanirope (Table 2).

Table 2. Flexural strength of different threads

Composition	Type of fibre	Flexural strength daN (kg)
nylon (polyamide)	8-strand, 1 mm diameter	30
hemp	8-strand, 1 mm diameter	10
cotton	8-strand, 1 mm diameter	15
Dyneema (HDPE)	12-strand, 1 mm diameter	195

Even though the values for Dyneema are given for 12-strand weaves rather than the 8-strand weaves of the others, it is clear that this fibre is much stronger. Given the low values of hemp and cotton, it is suitable that they be used only to attach labels.

These threads were regularly cut and removed when an instrument was taken out of its display to be loaned, restored, consulted by researchers or played by musicians. Musical instruments are at once technical objects (products of science: acoustics, mechanics, etc.), objects

of use (producers of sound) and art objects (Barclay 2004). During remodelling work at the museum, all of the brass instruments (which are in fact instruments made of brass or silver- or gold-plated brass such as trumpets, saxophones and trombones) were removed from their mounts to be cleaned (Loeper-Attia 2007). It was then realised that a large number of the instruments were scratched and/or corroded where they touched the supporting threads. This damage was only visible on the metal objects; other instruments made from organic materials showed no sign of oxidation. Instruments with labels attached by old thread, as could be seen, also presented surface corrosion (Figures 5–7).



Figure 5. Silver corrosion due to a Nacrylan thread



Figure 6. Brass corrosion due to a hemp thread on a trumpet (E.734)

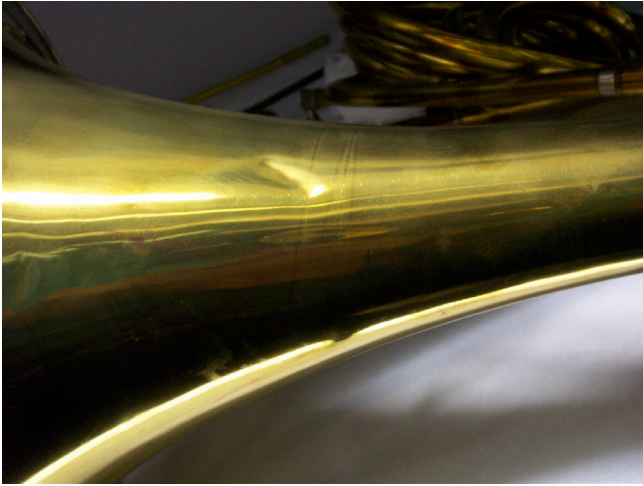


Figure 7. Stripe on a brass instrument due to a Caperlan thread

These traces were stubborn and often impossible to remove completely with chemical processes or mechanical cleaning with abrasive powders. It was decided not to attempt to remove the scratches observed because it would have required abrading a significant amount of material. Moreover, the intervention would have been clearly visible on these larger, polished areas and it would have been necessary to clean the entire surface. The Museum's team was therefore faced with the need to find an alternative to these threads to ensure the metal instruments were properly preserved.

Looking for other materials

Surveying other museums confirmed the regular use of nylon threads, fishing line and cotton threads to secure objects to mounts.

In order to choose the threads best suited to the conservation/restoration of cultural heritage objects, particularly those made of metal, the team first established appropriate specifications and then sought suitable products on the market and examined their composition. The threads selected had to meet the following specifications:

- product traceability
- chemical stability
- aesthetic unobtrusiveness
- no chemical or physical interaction with the contact material
- appropriate tensile strength
- zero hygroscopicity
- zero to low elongation
- no overt sensitivity to UV
- high melting temperature

The threads are made from crystalline polymer fibres. These polymers are elongated macromolecules arranged in straight, parallel filaments. Their hydrogen bonds hold the chains together and partly explain their high tensile strength. The particular positioning of the macromolecular chains occurs after the thread drawing phase following extrusion (Massardier 2001).

It should be noted that a polymer in its raw form generally lacks the properties required for the application in question. Additives need to be added to the plastic (Cavalier 2013) and these primarily affect the aesthetics, chemical stability, UV resistance, heat resistance, cost and plasticity. One function of additives is also to slow the polymers' oxidation, which causes yellowing, potential loss of transparency, the appearance of crazing and affects the mechanical properties by reducing potential flexibility and tensile strength. This oxidation is accelerated by temperature and UV rays. Additives trap formed radicals by reacting with them and/or absorbing UV energy. Common additives employed are inert composites, generally mineral-based, such as natural or precipitated calcium carbonate, talc and china clay, graphite, molybdenum disulfide and polytetrafluoroethylene. Phosphate-, phthalate- or benzoate-based plasticisers may also be present (Verrier 2013). Table 3 sets out the data collected on the primary fibres selected during the first phase of the investigation. All the values given and protocols of measurement are taken from the *Techniques de l'ingénieur* or mentioned reviews (see References).

It was decided to take into account only certain physical characteristics of these polymers, those that struck the team as most important to the specifications being drafted (Dossogne et al. 2010).

- **Modulus of elasticity:** the tensile stress required to obtain a given elongation. This is a value intrinsic to the material, defined as the ratio of stress to the elastic deformation caused by this stress. It is often called Young's modulus and its unit is the Mpa (megapascal).
- **Breaking strength:** also called stiffness or tensile strength. It is the resistance to deformation under the action of continuous stress and therefore corresponds to the tensile force under which a material reaches its breaking point. It must not be confused with stretch resistance: a material or fibre can be highly elastic yet have very high tensile strength (late rupture).
- **Loss of flexion** or resistance to flexural stress: loss of stiffness after 60 cycles of 180° folds.

Table 3. Mechanical characteristics of different fibres

Fibres	Elasticity modulus (MPa)	Flexural strength (g/denier)	Flexion resistance (60 cycles)	Resistance to UV (months)	Elongation %	T fusion (°C)
nylon	45	9.5	0	3 to 4	13	220
PEN	250	10.2	0	6	6	250
HDPE	1250	33	0	6 to 7	5	150
aramid	550 to 950	24 to 29	7 to 25%	2 to 3	1.5 to 4	NR
Vectran	510	23	15%	1 to 2	2	330
carbon	1350	60	22%	without effect	1.5	NR
polypropylene	1200 to 1700	31 to 42	0	6	1 to 6	160 to 170

- **UV resistance:** this is the resistance of the fibre to breaking under natural light, measured in months (Bohé et al. 2016).
- **Elongation at break** or percent elongation: this is a non-quantified characteristic of materials and defines a material's ability to stretch to its breaking point when under tensile stress.
- **Melting temperature.**

The results clearly show the significant differences in these fibres' behaviour. For example, polyethylene (PEN or HDPE) has a very high breaking strength, displays no loss of strength due to bending and has good UV resistance. Nylon is one of the most elastic fibres (it has high elongation at break), which allows it to absorb load peaks. Indeed, the higher a material's modulus of elasticity, the stiffer the material is; in other words, under equal stresses, a material with a high modulus of elasticity will stretch less than a material with a low modulus of elasticity.

For instrument-mounting purposes, it is therefore preferable to use a material with a high modulus of elasticity to ensure a support that is always adapted and adjusted. The loss of flexion must be low so that it can withstand bending and folding. The melting temperature must be high, as must be the breaking strength. It must also have good UV resistance. In the tests carried out, focus was therefore placed on polyethylene fibres – both with and without additives (Nacrylan, Dynema).

Comparative tests

Ageing tests

The goal was to demonstrate proper conservation of the threads chosen in a harsh environment in contact with metal. Rather than conducting an Oddy test which evaluates the gaseous effect of a composite on a metal plate, conditions closer to those in the museum setting

were created, i.e. thread and metal in direct contact, since the damage observed was only the result of direct contact and not a gaseous effect. The metal support chosen was a form of brass, similar to the alloys found in brass instruments, i.e. with a mass percentage of around 30% zinc. This content is close to that of alloys now referred to as 'cartridge brass', characterised by better ductility and higher corrosion resistance. Indeed, brasses containing up to 35% zinc are single-phase and reputed for their ductility and malleability when cold. Above 35%, hardness increases and ductility when cold is not as good, although malleability when hot is excellent. The maximum threshold for zinc content in brass is 42%, beyond which the alloys become too fragile. Two tubes and a rectangular-section rod were cleaned with abrasive powder (calcium carbonate), then rinsed and degreased with demineralised water, ethanol, acetone and cyclohexane. Various threads were then knotted to this assembly as shown on one of the tubes (Figure 8).



Figure 8. Brass tube with different threads

Each thread was previously weighed to evaluate whether there was any weight loss or gain after the experiment, to help quantify any potential transfer or loss of material. Each thread was weighed four times using a Mettler Toledo precision scale (0.0001 g accuracy) before and

after placing in the chamber. The tubes were placed in a climatic chamber for 30 days. The thermal cycles lasted 12 hours with a temperature variation of 18°C–22°C and relative humidity (RH) of 50%–80%.

These values corresponded to the possible variations inside the museum (one of the stores had suffered a climatic incident due to a failure in its air conditioning system and the RH had risen to 80%). After removal from the chamber, the tubes were examined and each wire was weighed. The weight variations were all consistent with the values indicated in the literature and, on average, were below 0.05%, except for the Nylon which was slightly more hygroscopic. Observation with the naked eye and a binocular magnifier revealed that every thread tested caused surface corrosion on the metal, except the polypropylene-based thread.

In phase two, tests were repeated with a thread made of polypropylene (the main component of Prolene). This material can be procured from textile manufacturers who produce these threads in large quantities. They come in various sizes, but those with diameters of less than 1 mm have ample strength. The thread tested here had a diameter of 0.25 mm and can withstand a load of 3 kg. The threads are naturally transparent up to a diameter of 1 mm and slightly opaque in larger diameters. Tests were also conducted with a monofilament thread compared to a woven or stranded thread to see if the presence of multiple strands might retain enough humidity to cause corrosion in the metal. Two polyethylene threads were tested: a monofilament thread and a thread woven from two filaments. The same protocol in the climatic chamber was applied and the same weight measurements were taken before and after the test. Other threads were knotted onto the brass plate to help characterise the corrosion products that formed on the surface of the metal. Their distribution is shown in Figure 9.

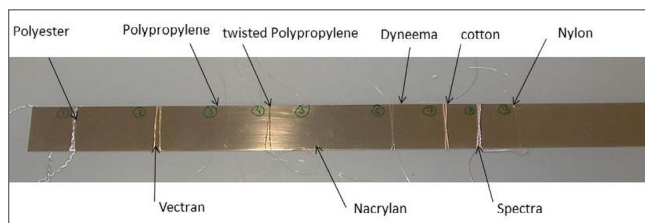


Figure 9. Brass plate with different threads

After spending time in the chamber, it was again evident that only the propylene threads (monofilament and woven) did not interact with the metal plate in any way. Table 4 sums up the results of these tests.

Table 4. Weight variations and effects of different threads on brass after oven testing

Commercial name	Chemical family	Weight variation (%)	Effect on metal
cotton	cellulose		X
nylon	polyamide	2	X
Prolene	polypropylene	0.02	
Spectra	high-density polyethylene	0.01	X
Spectra 148	high-density polyethylene	0.03	X
Nacrylan	high-density polyethylene	0.03	X
Dyneema	high-density polyethylene	0.03	X
Vectran	aromatic polyester	0.03	X
polypropylene	polypropylene	0.02	
polyester 1100/2/3	polyester	0.02	X

X-ray fluorescence spectroscopy of corrosion products in ageing tests

In an effort to better understand the corrosion these threads were causing on the alloys, analysis by x-ray fluorescence spectroscopy (XRF) was done on three corroded areas on one of the tubes after time in the oven and on a non-corroded area of the same tube. The corroded areas corresponded exactly to the position of the polyester 1100/2/3 Vectran and Spectra threads. Three shots were taken of the same area in order to obtain the most accurate possible results. The measurements were taken using an ArtTAX prototype II spectrofluorometer (Intax GmbH). The ArtTAX acquisition software connected to the spectrofluorometer allowed the spectra obtained to be processed. ArtTAX has an application that automatically identifies the elements present in each sample. This can be useful when analysing unknown samples, but it is important to maintain a critical eye with regard to the elements identified (Gomes 2013). Our analysis of the results did not provide any information on the nature of the corrosion products formed, given that the markings measured by the spectrometer and the respective spectra of the non-corroded tube and the corrosion products generated by the three threads are similar, and in fact identical to the naked eye. There are several possible explanations for this: the very small quantity of corrosion products formed and the limited range of use of the spectrofluorometer – it cannot determine elements below boron ($Z=5$) and above uranium ($Z=92$). In this case, a Coolidge tube with a molybdenum anode was used, furtherer limiting the range of use ($Z=13$ to $Z=92$). To determine the degradation product formed accurately, other analysis methods were needed.

What protocols must be adopted for metal instruments?

The conducted tests showed that most threads corrode metal sooner or later. It is highly probable that this is mainly related to the adjuvants and additives put into the fibre during manufacturing, given that Dyneema, Spectran and Nacrylan threads are made primarily of polyethylene, a material known to have no direct effect on metal (Lavédrine et al. 2012). The scratches observed on the metal sheets may be due to the abrasive effect of materials added to the threads, such as calcium carbonate, china clay and talc. It is therefore recommended that a thread containing no additives be used. Pure polypropylene thread also meets the other requirements stipulated in the specifications. Since 2006, we have been using two types of pure polyethylene thread, with a diameter of 0.25 mm or 0.53 mm. They are transparent or slightly opalescent (in the case of the thicker thread) and are used to secure adjusted mountings without risk of damage to the object. Thus far, no contact corrosion or scratching as previously observed has been noticed. Some of the other threads tested in this study are now being assessed for possible partial integration with woven threads or cords on musical instruments from outside Europe.

Conclusion

In developing an adapted protocol for the mounting and display of musical instruments at the museum, it was possible to select a fibre – polypropylene without additives – that is stable over time, has adequate mechanical properties and does not react with the metal in the instruments. A sound mounting protocol was therefore successfully established. We have since expanded the use of these types of thread, whose thinness and transparency make them ideal for use as supports and for seams in fabrics, or for reinforcement or partial integration with weakened woven fibres. Better understanding of the interactions of the other types of thread with metal is still needed.

Acknowledgements

The author would like to thank the entire team at the Cité de la musique – Philharmonie de Paris for making themselves available and providing assistance during this research.

Materials list

Dyneema:

Gremco Sarl, 1955 chemin de St Bernard,
06220 Vallauris, France
www.gremco-sarl.com

Polyester:

Cousin Trestec, 8 rue Abbé Bonpain, BP39,
Wervicq-Sud, 59558 Comines Cedex, France
www.cousin-trestec.com

Polypropylene:

Société Sagaert (département Zebulon), 58 rue d'Armentières, 59560 Comines Cedex, France
<http://sagaert.com/fr/textile/filature-de-polypropylene.html>

Prolene:

Ethicon, Johnson & Johnson Medical SAS,
1 rue Camille Desmoulins,
92 787 Issy-les-Moulineaux Cedex 9, France
<https://fr.ethicon.com/produit-catalogue-france/sutures-non-resorbables/prolene>

Spectra:

Honeywell
<http://www51.honeywell.com>

Vectran:

Laboderm, 12–16 rue Sarah Bernhardt, 92600 Asnières-sur-Seine, France
www.laboderm.fr

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