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Japanese Paper Threads as a Proposal for the Conservation of Pre-Hispanic Cordage. Evaluation of its Characteristics and Resistance

Ir a la versión en español

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ABSTRACT

The following paper presents the results from the physical characterization and subsequent application of yarns made from Japanese paper, whose features and properties in the field of conservation-restoration have proved useful for the intervention of archaeological objects of organic origin. This RESEARCH ARTICLE describes the process of thread elaboration as well as the evaluation of its physiomechanical properties through the analysis of mechanical traction, where the thickness of the thread is directly proportional to the force required to generate the thread's failure, meaning that the properties of the threads can be varied, depending on the specific conservation need.

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KEYWORDS

japanese paper threads, mechanical testing, threads, Candelaria cave, physical characterization of threads

INTRODUCTION

Candelaria Cave is in the Comarca Lagunera, South-West of the state of Coahuila, Mexico, at the foot of the Sierra de la Candelaria, in the Delicias Valley; its warm and dry conditions have favored the preservation of the extensive heritage found there (Figure 1). The cave opens about 30 m above the level of the cavern, whose chimney-like entrance, approximately 1 m in diameter, widens transversely and vertically reaching towards the highest chamber, the site where most of the anthropological materials were found (Figure 2) (Aveleyra, 1956).

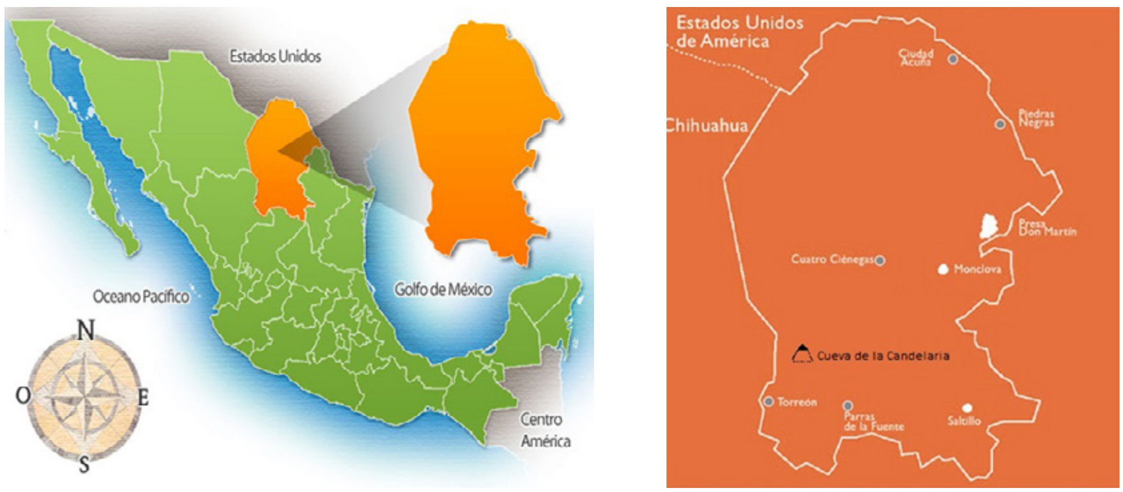
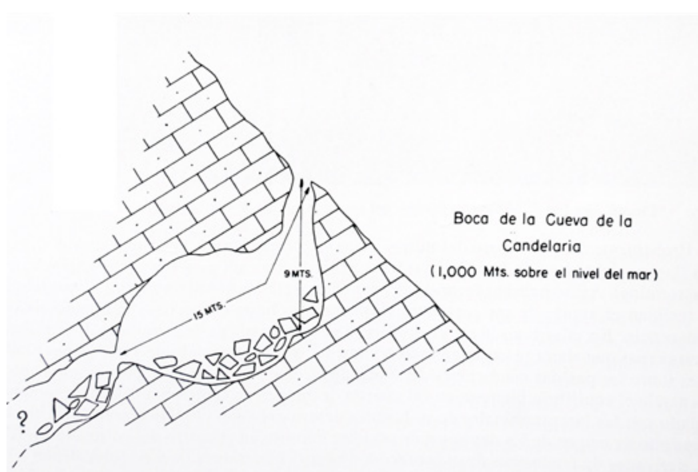


FIGURE 1. The location of the state of Coahuila and the Cueva de la Candelaria in the state of Coahuila (Sources: travelbymexico.com & Sánchez, 2017, p. 408).

FIGURE 2. The Cueva de la Candelaria entrance is a chimney-type structure (Source: Aveleyra, 1956, p. 49).



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The cave's discovery happened by chance in the 1950s, when a native from the region found it along with several corpses and other objects whose relevance, due to the large amount of organic materials deposited there (more than 2 000 well-preserved objects including skeletal remains, textiles, fabrics, ornaments, utilitarian elements, among others), led to a joint project between the state government and the Instituto Nacional de Antropología e Historia (INAH, National Institute of Anthropology and History) for the exploration and proper transmission of the importance of the site (Aveleyra, 1956).

Thus, in 1953, the first formal research project executed by INAH in northern Mexico began, led by Dr. Pablo Martínez del Río, director of the area of prehistoric studies. It spanned various seasons and involved different specialists, such as Manuel Maldonado Koerdell (geologist and paleontologist), Arturo Romano (physical anthropologist), Francisco González Rul, Martínez del Río himself, Luis Aveleyra (archaeologists), and Ignacio Bernal (historian), among others (González, 1998, p. 62), who all devoted themselves to the cave's exploration, recovering a large number of commonly used objects that belonged to the deceased and that were then placed alongside their remains (Aveleyra, 1956).

The chamber's floor was largely concealed both by collapsed materials and by several scattered mortuary bundles, most partially opened, with their contents all over the place because of pilferers and the impact from falling rocks from the cave's ceiling that had come loose and fallen on the bundles, as well as the natural decomposition of the corpses and intrusions made by smaller animals. Perhaps the most destructive of all of these was the activity from previous looters. The remains deposited there show that they were the product of a desert culture, where the settlers must have developed physiological features as an adaptive response to the environment. Although their apparent condition as 'hunter-gatherers' seems to place them in the category of nomads, it is inferred, from the remarkable cultural attire associated with the recovered funerary bundles, that such nomadism was relative, since they had to have prolonged settlements in one place to obtain the fibers and threads that permitted the manufacture of derived elements, such as shawls, baskets, sandals, etc. (Weitlaner-Johnson, 1977, p. 5).

The preservation of goods of organic origin was possible thanks to the dry atmospheric conditions, a constant temperature and relative humidity (RH), as well as the absence of light; all these factors helped to prevent the degradation of the plant and animal fibers. The preservation of these artifacts constituted a great rarity at the

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time and would continue to be so were it not for the excellent research work developed by the multidisciplinary team of 1953, as is evident from Aveleyra (1956), Weitlaner-Johnson (1977), and the reports stored in the archeology technical archive (INAH), which stimulated a group of sponsors from La Laguna to raise funds in order to build an adequate space to house the rescued material, so that on November 22, 1976, the first phase of the Museo Regional de la Laguna (Murel, Regional Museum of La Laguna) in Torreon was inaugurated.

According to archaeologist Luis Aveleyra Arroyo de Anda, first director of the Centro INAH Coahuila, once the objects had been studied the collection was divided in two. The first, based in the old Museo Nacional de Antropología e Historia (National Museum of Anthropology) located in downtown Mexico City, partially formed the display in the Chichimeca Room before being moved to its current location in the Northern Room, with the unused parts from this first lot stored in the Museum's warehouse; the second half of the collection was entrusted to a local museum, located in the building of the Preparatoria Venustiano Carranza (PVC, Venustiano Carranza High School) in Torreón, Coahuila.

Since then, although some of the recovered goods have undergone several conservation processes, the experience in treating this type of objects is limited since in most archaeological excavations there is usually very little recovery of these sort of materials and, in many cases, only fragments or incomplete pieces are found. In any case, this collection has allowed the development of various intervention proposals, according to the methodologies and materials of the time and the experience and criteria of the conservator in charge.

At the end of 2013, the Murel requested from the Coordinación Nacional de Conservación del Patrimonio Cultural (CNCPC, National Coordination for the Conservation of Cultural Heritage, Mexico) a diagnosis of the pieces recovered under the custody of the PVC to determine both their state of conservation and, if necessary, the interventions that the materials would require. During this process, and the development of this project, the main objective was to show and preserve the materialistic culture of hunter-gatherers in northern Mexico, stabilizing and conserving archaeological materials of organic origin belonging to the Candelaria Cave collection through recognizable and reversible structural and aesthetic interventions that would allow the materials to be re-treatable.

Among the materials recovered, cordage thread has a great impact on the collection due to the diversity of objects in whose elab-

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oration it is a constituent, either as a structural support (in nets, skirts and bags) or as a decorative element (in Yahuales, earrings and other objects).

In general, the collection's cordage bears several alterations that are detrimental to its preservation since they impede its handling, alter its potential unity as a cultural object, and hinder its exhibition. Much of the deterioration was generated in the archaeological context due to the deposition of sediment remains from the site, as well as the contact with decomposing organic matter and the dust that accumulated on the pieces since the time of excavation until the time of storage, not excluding previous interventions.

A major problem is the generalized rigidity of the vegetable fiber cords, which show loss of weave and considerable dryness, which is expected due to the aging of organic material in this type of archaeological context. It should also be noted that there are multiple splits in the cordage, with the consequent loss of original material that affects the object's functionality.

In each of the cases of intervention on cordage-based objects, a specific proposal was made, depending on factors such as: dimensions, percentage of original material present, original manufacturing techniques, deterioration, use and function in its original context, stability and its possible museum exhibition potential.

However, it was still necessary to establish a methodology and develop an intervention technique that could be standardized and adaptable to accommodate the many variations in the characteristics of the objects to be worked on. The methodologies commonly used for the conservation of textiles and fabrics were evaluated, advice was sought, and the idea of using Japanese paper arose thanks to the guidance of professor Marie Vander Mereen,[1] who brought our attention to the material's benefits and its versatility in Japan. From there the plan arose to elaborate threads of Japanese paper to make grafts and reinforcements in the archaeological items found in Candelaria Cave that presented loss of the pre-Hispanic cordage fabric, thus recovering the structural functionality of each object, staying true to its original characteristics, denoting the intervention, and giving the cultural good an aesthetic unity; an innovative proposal for the conservation of this type of cultural patrimony.

[1] Expert restorer at the CNCPC-INAH, Laboratory of graphic documents and, since 2011, coordinator of the International Course on Paper Conservation in Latin America. An Encounter with the Orient, in collaboration with the International Center for the Study of the Conservation and Restoration of Cultural Properties (ICCROM) and the Tokyo National Research Institute for Cultural Properties in Japan.

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When this experimental phase was carried out, the technique called *Shifu*, which refers precisely to the elaboration of Japanese paper yarns, was unknown, so it was carried out in the Laboratory for the Conservation of Archaeological Materials of Organic Origin at the CNCPC, using the Mesoamerican thigh-twisting technique to get as close as possible to the original characteristics of the cultural property. Describing the Shifu before going into our study is important since it serves as a frame of reference to support our proposal.

JAPANESE PAPER YARNS OR *SHIFU*

Shifu is a Japanese word that literally means 'paper cloth' (*shi*, paper, and *fu*, cloth); it is the result of a process that basically consists of twisting moistened strips of *washi* or traditional Japanese paper until they are as thin as thread and then weaving them on a loom (Larrea, 2017, p. 4).

According to Hiroko Karuno (2016, pp. 252-253), the history of textiles in Japan began in the Jamon period (between the XIII and X centuries B.C.) with the incipient elaboration of nets and braids based on fibers obtained from the bark of trees or from the fibers in tall grasses; it wasn't until the end of that period, moving into the beginning of the Yayoi period (600 B.C. -200 A.D.), that silk was introduced and the first silk fabrics appeared, which for a long time had been exclusively reserved for the the upper classes. During the Momoyama period (1573-1603), cotton seeds were introduced, giving rise to the cultivation of cotton in Japan. It wasn't until the middle of the Edo period (1603-1868) when the crop spread throughout Japan and became readily available for use across the land.

According to Kunio Yanagida, before cotton was well known to the entire population (commoners), in the XVII century, they wore fabrics made from bast fibers, such as hemp, ramie, *kaju* (paper mulberry), among others. They served the people well for a few thousand years, yet very little is known about this type of material. However, in ancient image scrolls there are some references to the attire of commoners which, it can be assumed, were made from bast fibers. Similarly, in books of poems from the mid-eighth century and even the X century there is mention of the use of headbands made from paper threads (which has the advantage of being able to absorb sweat better than cotton, which gets wet); however, few physical examples survive. It is believed that many of the common-

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er's pieces of clothing were used as fuel for fireplaces, and that their use overall was discontinued with the advent of the industrial revolution, in the Meiji period (1868-1912), when machine-made clothing started to be produced (Karuno, 2016, p. 253).

According to Larrea (2017), after World War II there was a cotton shortage, which led the descendants of the Katakura family to resume the *shifu* technique for cloth making.

Nowadays very few people know the art of making yarns with Japanese paper, and the garments that are produced are very expensive because of the type of work it involves: Firstly, the making of good quality paper, then its transformation into yarn and, finally, its elaboration into a textile or fabric.

As we can see, the production of paper yarns in Japan has a millenary tradition that, according to references, is little known to the rest of the world. These fabrics are very resistant and possess the properties of Japanese paper, such as: good resistance and flexibility, lack of fillers and sizing agents, homogeneous distribution of fibers - which provides surface uniformity, it is translucent, highly absorbent, and can be dyed, pressed, torn, stretched, sewn, hung and folded, diversifying the possibilities for its use (Gear, 2007; Álvarez, 2018), and whose characteristics are very useful for conservation purposes.

Thus, it was decided to elaborate threads from Japanese paper, since they function as a good aesthetic and structural option for the replacement of missing pieces. In order to do this, it was first decided to carry out resistance tests, as a way of expanding our knowledge of this technique which, although already applied on several pieces in the collection, was something that we kept improving with every passing intervention so that the technique was perfected, achieving an almost imperceptible visual appearance and a high level of restoration on the finished piece.

As mentioned above, when we decided to use Japanese paper to make yarns, we were not familiar with the *shifu* technique, so to successfully work with it, we began with an experimental phase to test how to use it across the different items in the collection; strips of varying widths were cut and then twisted to obtain yarn. Intuitively, the twisting was done following the Mesoamerican system of thigh twisting. The case study is presented below, as well as the tests used to verify the mechanical resistance of the paper yarns produced by manual twisting.

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BACKGROUND OF THE CORDAGE OF THE CAVE OF LA CANDELARIA

Cordage is the art form that teaches how to make ropes or threads. This action is called *spinning*; a process in which a set of continuous or discontinuous fibers are grouped, stretching and twisting them together until they reach a greater length and thickness comparable to the individual fibers. The stretching consists of arranging the fibers longitudinally, in a somewhat parallel way, to be able to carry out the twisting, which is the moment in which the fibers are "adhered" or compacted; giving elasticity, firmness and resistance to the yarn, which will allow for its manipulation when manufacturing a new object (Bastiand, 2000, p. 134).

Initially, the spinning process did not require tools: the fibers were twisted using one's fingers against the palm of the hand, with one hand on the thigh or on the cheek. Ethnographic studies report that, to this day, there are groups that still preserve these spinning techniques (Mirambel, & Sanchez, 1986, p. 52).

As previously mentioned, the cordage from the Candelaria Cave collection was used for the elaboration of a great variety of artifacts using diverse techniques where the raw material, the fiber, was provided by plants from the region.

Among the materials recovered were skeins of untwisted fibers as well as balls of finely spun yarn, portions of cordage, nets and woven cloth; also, some piles of fibers, arranged somewhat parallel, evidently ready to be twisted and made into yarn (Weitlaner-Johnson, 1977, p. 11). Following identification by Howard Arnott (University of California, 1954), Dr. Weitlaner-Johnson concluded that the Laguneros used yucca fibers (*Yucca carnerosana*, *Yucca treculeana*) almost exclusively for the manufacture of loom-made textiles such as narrow bands and large cloaks, while *Agave lechuguilla* fibers were used mainly in the manufacturing of fine and coarse cordage, sewing thread, nets, "flowers",[2] and other objects. It was also observed that the direction of twisting and the number of strands used is exceptionally uniform in each of the groups (Weitlaner-Johnson, 1977, p. 12).

As it has also been mentioned before, all yarns are spun as single strands, and if greater size and strength is required, then two single strands are twisted together (but this time in the opposite direction) to form two-ply yarns. Yarns can be spun in two directions, yarn spirals can be made either up and to the left, giving an *S-twist*, or up and to the right, forming a *Z-twist* (Weitlan-

[2] Made with threads and beads, forming a flower-shaped bouquet used as—earflaps—, ear ornaments. Known as such by Luis Aveleyra Arroyo (1956, p. 12).

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er-Johnson, 1977, p. 13). The threads are characterized by both the direction and the degree of twist —loose, medium or strong— on which the angle formed by the spiral in relation to the vertical or axis depends.

According to the analysis of Dr. Irmgard Weitlaner-Johnson, it is very likely that the Candelaria yarns were twisted with the system of winding fiber bundles under the palm of the hand and over the naked thigh of the spinner. Those made from Lechuguilla are predominantly two-ply, *Z-twisted*, while single-ply yarns are *S-twisted.* Many of the yarns are finely and evenly spun, with a high degree of twist, which provides great strength and elasticity (Weitlaner-Johnson, 1977, p. 15).

Several kinds of netting fabrics and warp-bonded fabrics were made with cordage, distinguishing three main types of nets: *(a)* knotless, or simple gauze technique (used in the creation of long bands with designs, nets stretched over wooden frames, soft and flexible bags, and fabrics made with one or more gauzes); *(b)* with knots (several fragments could have been part of a large fishing net used for carrying things or as animal traps), and *(c)* of linked warps: only fragments have been recovered so far, some pertaining to a loincloth (Weitlaner-Johnson, 1977, p. 91).

The intervention of the collection enabled us to know and understand the manufacturing technique used in different objects; its study and analysis was based on documentary sources, an organoleptic analysis, and a thorough observation that then enabled us to replicate the technique. By making samples, we were able to better understand the structure and manufacturing process, from obtaining the raw material through to the step-by-step elaboration of each process, estimating the approximate time required for production, which allowed us to elaborate a better-informed intervention proposal focusing on the restitution of missing parts to provide structural stability to the cultural goods.

General state of conservation of the goods made with cordage

The main deterioration found in the pieces of cordage in the collection came from the loss of the fiber's resistance, caused by the natural deterioration of cellulose, as well as the physical wear and tear of use prior to burial, all this, together with the deterioration factors generated during the burial context and its extraction. Among the objects studied, some have been found without any previous intervention, whilst others were found partially intervened, mainly using sewing threads to hold the fabric together, others showed signs of

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some cleaning processes, where mainly soil was removed from the context.

The most important affectations generally come from dust, dirt, impurities, rigidity, disintegration of the fibers, bad odor, stains, breakage and missing pieces. As for the latter, three types can be distinguished: Firstly, there are missing pieces that show modifications of the time period, which indicate that they were made before the funerary context; secondly, there are the missing and broken pieces associated with stains or areas of wear; and, finally, those generated by contact with the decomposing bodies, which are distinguished from the cracks in cleaner areas, since the leachates cause dense stains that stiffen the fibers and over time generate loss or missing pieces, causing fraying around the fabric, which leaves loose threads that can lead to the loss of even more fabric.

Characteristics of the cordage pieces in the collection

In the collection exists a diverse range of objects crafted from twine, including net bags, textiles, fragments of knotted nets, nets with gauzes, sandal ties, Yahuales, and others. These objects are distinguished by their physical characteristics, which can be measured or evaluated through physical and mechanical tests. These properties are related to the thread structure and have a greater direct influence on the internal quality and state of conservation of the twine. Regarding the archaeological cultural property, these tests cannot be performed since they are destructive mechanical tests that require sacrificing a large amount of sample;[3] however, to evaluate the characteristics of the collection's yarns, non-destructive tests were used, which were performed on the fabric considering the thickness of the yarn, the direction of the twist, the number of strands, and limit of manual resistance.

The analysis of each of the goods in the collection made it possible to accurately reproduce the missing strings with Japanese paper, considering the characteristics described below.

Yarn thickness

A vernier was used to measure the thickness of the twisted strands, we found that the twine in the collection has a wide variety

[3] To carry out this type of tensile or elongation test on the thread, a minimum length of 100 mm is required, allowing the gripping in the clamps, where a thread break will be generated later. This would imply having archaeological samples of considerable size that could be damaged or broken, which is not feasible here.

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of dimensions, ranging from two-strand twines with a thickness of approximately 1 mm to three-strand twines with a thickness of approximately 1 cm.

Direction of torsion

Through plain observation or by using a stereoscopic microscope, it is possible to identify the direction of the thread's twist, whether it has been formed using the S or Z directional twist, depending on whether the twist follows the direction of the inclination to the right or to the left. In the collection overall, S directional threads were more present in simple threads, whilst Z direction threads were found more commonly amongst twisted threads, corroborating the observations made by Dr. Weitlaner-Johnson.

Quantity of elements used during manufacturing

The number of strands is identified by performing a counter-twisting movement in order to observe the number of individual elements present. One, two, and three strand yarns have been identified in the collection.

Resistance

Deteriorations observed on the pieces—cracks, missing pieces, fiber degradation, fraying—, as well as disintegration or pulverization on the objects in the collection indicate that the fibers from which they are composed have low resistance, which is attributed to the high deterioration of the rigidity and friability in the fibers due to the loss of natural humidity within them.

PROCEDURE FOR THE PRODUCTION OF JAPANESE PAPER YARNS FOR RESTORATION PURPOSES

Yarns manufactured with Japanese paper are made by means of strips of Kozo paper which, due to their long fibers and physical characteristics, can be manipulated in order to twist the strips without breaking them. Figure 3 shows the characteristics of the paper chosen for yarn manufacture.[4]

[4] Information on Japanese Kozo fiber paper was provided by the staff of the CNCPC's Graphic Documents Conservation Laboratory and by supplier Jorge Montaño.

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Characteristics of Japanese paper used in the elaboration of yarn							
Common name	**Fiber color**	**Fiber length**	**Fiber shape**	**Fiber type**	**Fiber termination**	**Grammage**	**Characteristics**
“A” cream	Reddish dark brown	Long	Flat	100% Kozo	Natural	19 g/m^2	Prepared using handmade caustic soda ash

FIGURE 3. Characteristics of Japanese paper used in the production of yarns (Table: Miriam Elizabeth Castro Rodríguez, 2019; courtesy: Physical Chemistry Laboratory of the Coordinación Nacional de Conservación del Patrimonio Cultural [CNCPC]).

The procedure for the manufacture of the threads is described below, following the original intention for most of the cultural assets to be restored. In this case, two-strand *Z-twisted* yarns were made; the thickness of the strip was modified according to the thickness of the yarn to be reproduced.

Prior to using the Japanese paper threads for the restoration of the missing threads in the cordage found in Candelaria cave, tests were carried out using different thicknesses of paper strips, starting from 1 mm and increasing millimeter by millimeter until the thickness was the same as the original threads that were to be restored; when 10 mm was reached, it was corroborated that the physical characteristics of this paper, when twisted, gave, as the total thickness of the resulting thread, a tenth of the width of the strip (10 mm = 1 mm), so the search process was accelerated to achieve the necessary thickness in each case.

The first step consists of cutting the paper strips lengthwise from the sheet (to optimize the resource by obtaining longer yarns) and of the width corresponding to the thickness of the yarn to be obtained; in this research seven groups were determined, ranging from 3 to 20 mm in width,[5] which correspond to the thickness of the yarns within the collection.

Once the strips have been cut, the process of twisting begins by taking one of the ends between the fingers and twisting it until a thread of approximately 2 cm in length is obtained; once in this twisted state, this end is placed against the thigh and pressed with the palm of the hand, which slides towards the knee, achieving a S-type twist. One the strip has been fully twisted, it is grabbed by the center with both hands, which generates a stronger twist, until a ring is formed; this process begins retwisting the strip. Then, the twist is generated at each end and at the point of unison forming a thread of two ends; the direction of the thread changing from an *S*

[5] By twisting the strip in each of the established widths, it was confirmed that they replicate characteristics of the yarns from the collection.

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directional twist to a *Z* directional twist since, when this process is carried out, the direction of the twist is always inverted. By making twisted yarns, a better balance is achieved between the component yarn and the torsion of the resulting yarn.

After the yarns have been manufactured, they can then be dyed to match the exact chromatic palette of the original piece. Yet, for most of the pieces, it was decided to dye the yarns to a base color that would allow for the identification of the intervention, since an important part of what is sought with the reweaving is structural stability, more than the exact mimicry of original material. For this type of dyeing, natural dyes[6] were used in different proportions until the required color was achieved.

Tensile strength tests on the yarns

Mechanical tests, which consist of measuring different physical properties such as traction, compression, bending and abrasion; i.e., the capacity of materials to resist physical stresses applied to them equates to separating or generating a division or fracture on the material to be tested.

Tensile strength tests applied to yarns provide a valid and reliable standard, indispensable in the characterization of the material for its application in restorative operations, better ensuring the expected results at a medium and long term (Contreras, Mainou, & Antuna, 2012, p. 31). According to Lockuán (2012, p. 116), this property is a characteristic that determines the quality of a thread, so it becomes a basic test that provides relevant and comparative information with other materials (López, Romano, & Guinea, 2018, p. 26). The factors that directly influence the tensile strength of yarns are the following (Lockuán, 2012, p. 116):

- Fiber characteristics
- Thread construction
- Subsequent processes

In the experimental approach, the main variable within our samples is the way the yarns are made since the paper strips present different widths. In addition, Lagada (1952, p. 13) mentions that tensile strength depends on the quality of the fiber, the length taken for the test, the diameter, the level of maturity, its contortions, the existence of weak points, and the humidity it contains, as well

[6] Blend of *Camellia sinensis* and *Coffea arabica* at different concentrations, depending on the desired tone to be obtained.

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as the way in which the traction is made: gradual or instantaneous. The fact that the thickness or diameter of the yarn is the only variable factor allows for them to be directly related to the tensile strength results described below.

Tensile strength tests are performed with machines designed to elongate the material at a constant speed (Charrier & Hanser, 1991, p. 219) where the tensile force is applied along the length of its axis giving us the tensile stress and which when stretched gives us its deformation stress (Horie, 2013, pp. 27-28). The sample is mounted by its ends, which hold onto grips of the test apparatus, and then elongated by a movable crossbeam. The load cell measures the magnitude of the force applied to the sample, and the extensometer records the elongation. During the test, the deformation occurred in the central region of the sample length (Stuart, 2007, pp. 358-359). These were the properties analyzed and compared to verify the efficiency of the reinforcing materials: *1)* the mechanical resistance of the material to physical breaking when a progressive force is applied and *2)* the elasticity or property of recovering its original shape and dimension when the force that alters it ceases to be applied; properties that are linked to the analysis that validate the intervention proposal. Specifically, the properties analyzed and compared were as follows.

Breaking strength

The breaking strength is the maximum force that a sample withstands in the tensile strength test up until the breaking point of individual wires (single, bent or wired); the measurement is taken directly from the machine, and the result is expressed in *newton* (N).

Lengthening

Elongation is the increase in the length of a sample subjected to a tensile force and is expressed in millimeters (mm). If the test is carried to rupture, it is called *elongation at rupture*.

Modulus of elasticity

The proportional relationship between stress and elongation is called *elastic deformation and is* observed as a linear graph, the slope of which gives the Young's modulus of the material (also known as *modulus of elasticity* or *traction modulus*), *E*, which is a

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constant of proportionality that is related to the flexibility or rigidity of the material. The modulus of elasticity is expressed in units of force per unit area.

Procedure and instruments used for the tensile test of yarns made from Japanese paper

The series of experimental tests were carried out on a set of seven groups of yarn samples made from Japanese paper, *only at differing levels of thickness*, which were used to compare the mechanical resistance to physical breakage offered by the material when a progressive force is applied. The tests aimed to obtain the corresponding force-elongation curves, for which they were subjected to an increasing axial tensile stress until it´s break. The load force and elongation were measured simultaneously and at each instant during the test.

EXPERIMENTAL PROCEDURE

The procedure was based on standards NMX-A-069-1990 (Secretaría de Comercio y Fomento a la Industria, 1991) and ASTM D 2256-02 (2002), which are methods for determining the tensile properties of short fibers and continuous filaments of natural, artificial or synthetic fibers (or blends of any of these), whether single, plied or cabled, with the exception of high tenacity yarns and cords for pneumatic tire structures and elastomeric yarns.

The tests were performed using a Lloyd Instruments digital universal testing machine, model LFplus (Figure 4). The load force was measured with a 1 kN load cell and a minimum resolution of 0.1 mN. The samples were clamped with manual bollard-type grips, which are specially designed for use on ropes and yarns, using a pulley that reduces the chances of premature failure within the sample. The length of the yarns was measured with a Fowler Sylac digital vernier with a resolution of 0.01 mm. Parameter settings and data analysis of each measurement was done using Nexygen Plus software. An initial tension of 0.05 N (preload) was used, with a speed of 65.0 mm/min and a length of 10 cm. The tests were performed using two-strand twisted yarn samples with Japanese paper with the procedure repeated several times for each group, allowing for the precision of results to be considered from the standard deviation and the mean values calculated from the experimental data (Rubinson & Rubinson, 2001, p. 23).

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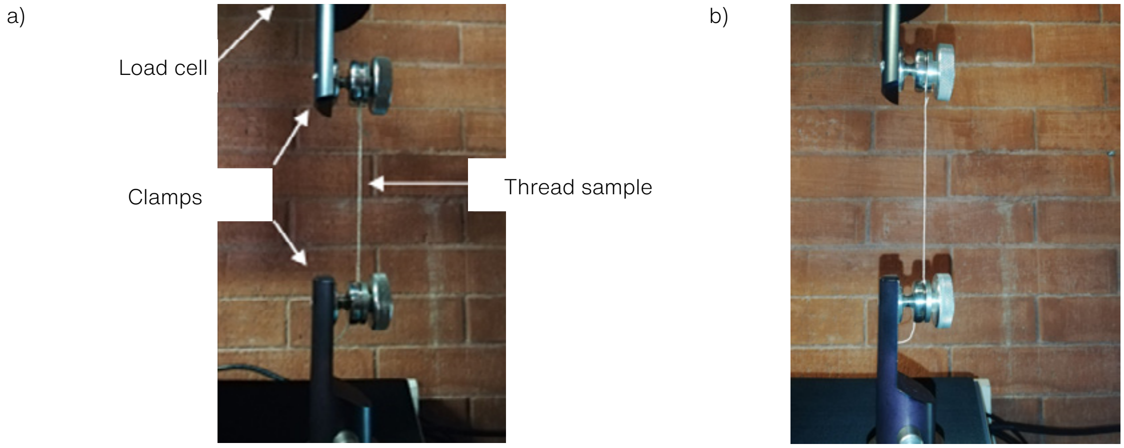

FIGURE 4. Tensile strength testing system with the main components of the equipment: *a*) Lloyd instruments universal testing equipment, model LFplus, *b*) clamp for thread testing (Photograph: Miriam Elizabeth Castro Rodríguez y Orlando Martínez Zapata, 2022; courtesy: Physical Chemistry Laboratory of the Escuela Nacional de Conservación, Restauración y Museografía [ENCRyM]).

Samples were obtained by cutting paper strips to widths of 3 mm, 5 mm, 8 mm, 10 mm, 12 mm, 15 mm and 20 mm lengths. They were cut along the longitudinal direction of the sheet, making them 62 cm long. When the strips were twisted, the lengths of the resulting threads varied according to the width of the strip; i.e., the thicker the strip, the shorter the resulting length.

Prior to performing the tensile test, the samples were prepared in accordance with standard practice, including having the same humidity conditions (Secretaría de Comercio y Fomento a la Industria, 1991, p. 3). The control was made with mass measurements, taken at the beginning and after the drying process, in a muffle at 105° C (221° F) for 45 min, and immediately kept inside a desiccator until the moment of the test. The results obtained from the tests, the analysis, and the main observations are presented below.

RESULTS

Physical properties of yarns

The torsion applied when braiding the yarns has an influence on the observed physical features; the detected properties were grouped in Figure 5.

When the yarns were made with strips of different thicknesses and braided with two strands, it was noticed that the thickness of the resulting yarn is one tenth of the width of the strip used, a pattern that is repeated for each sample (Figure 6).

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Resistance	The higher the torsion, the greater the resistance
Elasticity	The higher the torsion, the greater the elasticity
Appearance	More torsion means a smaller diameter (because of greater compaction). Since the yarns are handmade, the diameter can differ as a consequence of the variation of strength applied in each hand movement
Contraction	The stronger the torsion of the yarn, the more it shrinks, which results in a shorter length than that of the acquired yarn
Length	The length of the acquired yarns also depends on the paper strip's width; those made with thinner strips are longer than those made with thicker strips

FIGURE 5. Differences observed in Japanese paper yarns (Table: Miriam Elizabeth Castro Rodríguez, 2019; courtesy: CNCPC).

FIGURE 6. Relationship between the width of the paper strips and the thickness of the threads (Table: Orlando Martínez Zapata y Miriam Elizabeth Castro Rodríguez, 2019; courtesy: ENCRyM y CNCPC).

Strips width (mm)	Acquired yarns thickness (mm)	Acquired yarns lenght (cm)
3	0.3	25
5	0.5	21.5
8	0.8	20.5
10	1.0	20
12	1.2	20
15	1.5	19
20	2.0	19

FIGURE 7. Statistical results of the mean values of breaking strength, elongation at breaking and Young's modulus in tensile strength tests for Japanese paper yarns. Standard deviation values are shown in parentheses (Table: Orlando Martínez Zapata, 2022; courtesy: Physical Chemistry Laboratory of the ENCRyM).

Paper strips width (mm)	Breaking strength (N)	Break lengthening (mm)	Young's modulus (MPa)
3	3.8 (0.8)	9.0 (1.5)	800.93 (231.79)
5	5.8 (0.7)	11.2 (3.3)	373.52 (127.89)
8	8.6 (1.6)	12.6 (3.6)	183.29 (11.90)
10	11.2 (3.1)	14.6 (2.6)	154.77 (20.93)
12	16.5 (2.2)	15.4 (2.8)	153.76 (54.59)
15	23.1 (1.4)	20.6 (2.9)	143.74 (24.52)
20	28.2 (1.7	21.3 (2.4)	60.52 (16.55)

Tensile strength test results

The tests were carried out at an ambient temperature of 23°C (73,4° F) and at a relative humidity of 39%. The length of the yarns varied between 19 and 25 cm, which allowed tests to be carried out at a spacing of 10 cm between grips, while the rest of the sample was used for restraining purposes.

Figures 7 and 8 show the results of tensile strength tests performed on yarns of different thicknesses.

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Using the results of the tension and resistance tests, we see that the degree of resistance of the yarns increases as the width of the strands increases. That is, the yarns made with paper strips of narrower width have the lowest breaking strength, a factor which increases as the width of the paper strips increases (Figure 7). This makes it possible to grade yarn strength from this factor. The same occurs with the results from the elongation to rupture test, with higher values recorded as the width of the paper strip used increases.

Specifically, the values of the breaking strength of yarns between 8-10 mm and 10-12 mm have an overlapping standard devi-

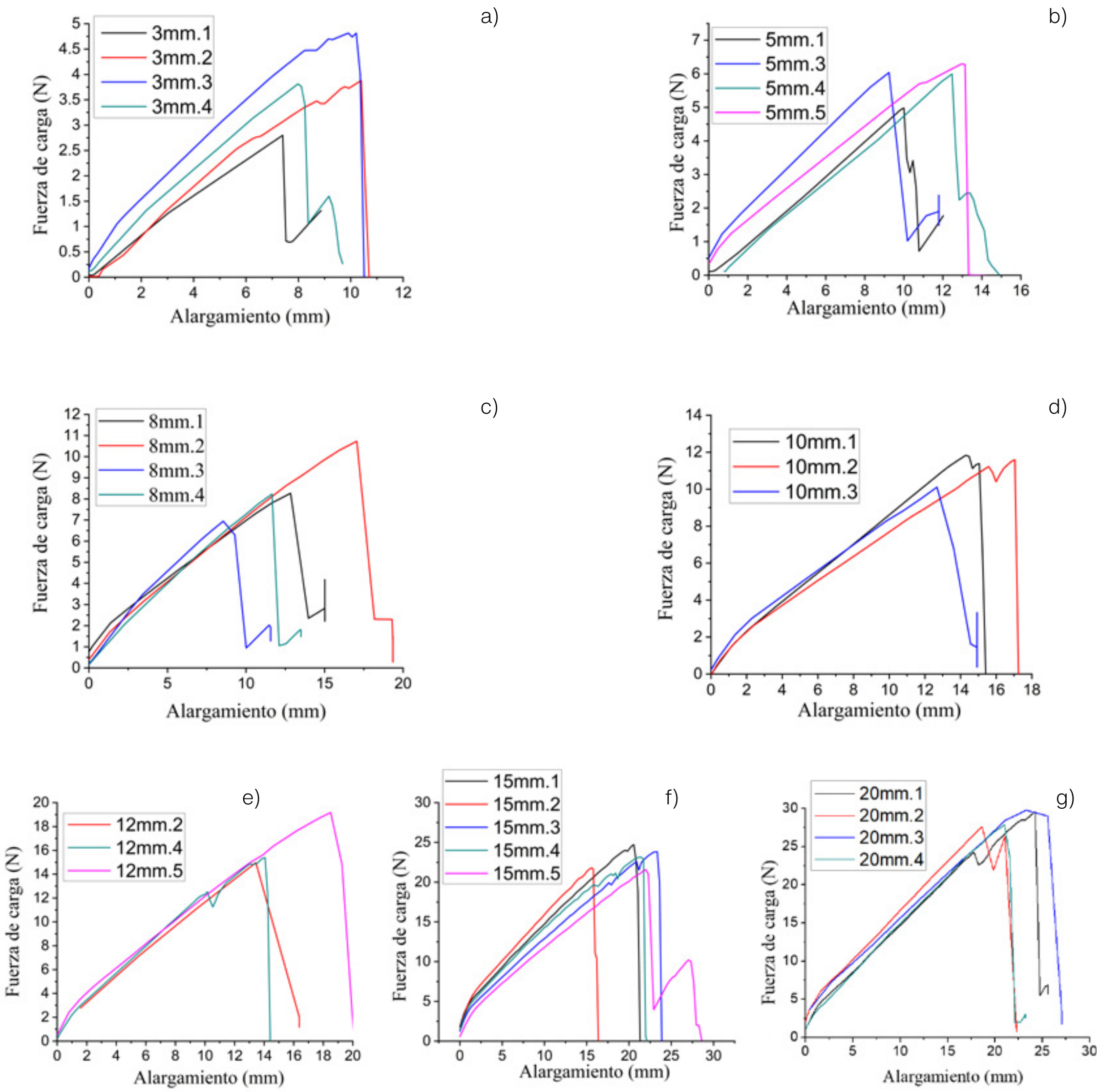

FIGURE 8. Tensile test results for the different yarns: *a)* 3 mm, *b)* 5 mm, *c)* 8 mm, *d)* 10 mm, *e)* 12 mm, *f)* 15 mm and *g)* 20 mm (Analysis and interpretation: Orlando Martínez Zapata, 2022; courtesy: Physical Chemistry Laboratory of the ENCRYM).

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ation, indicating that there is no statistically significant difference between them, so they are considered equivalent in terms of this mechanical property. Therefore, yarns made from 10 mm wide strips could be omitted.

In the moduli of elasticity (E) of the different groups of samples, we observed an inversely proportional relationship between the width of the paper strip or yarn thickness and the calculated values. Those yarns exhibit values that present lower rigidity values as the yarn thickness increases meaning that, according to the different groups of samples analyzed, yarns made with 20 mm wide strips correspond to yarns with more elastic deformation capacity or, since they have lower E, more flexibility.

Formal reintegration

The proposal to intervene for the replacement of missing pieces was made individually for each piece, considering that the objects belong to a museum collection and that they will be part of an exhibition at some point. Therefore, the main objective was to achieve structural stability and conditioning of the fibers, allowing for proper handling and preservation.

In cases where there were missing fibers, the percentage of original material preserved, and the number of references present were considered to achieve an accurate reproduction of the original fabric. In cases where they were sufficient, we used compatible materials that would allow for future re-treatment, achieving structural stabilization through formal reintegration through reweaving the missing sections.

We found structural flaws in some of the fabrics, causing instability and leading to the collapse of the piece, which were subsequently restored using yarns manufactured with Japanese paper; similar to those that were used in the previously mentioned resistance tests. Such threads are produced by matching to the thickness of the original piece, following the methodology mentioned above.

The considerable deterioration of the fibers in the collection's cordage can be seen by the large number of tears in the yarn or cordage, which may or may not be part of a breakage. In either case, splices must be made between:

1. Original material and original material: that is to say, in many instances, there isn't a loss of fabric since the thread or cord breaks slightly and separates, but there is no absence of extension; this means that it is only necessary to join the frac-

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tured ends to restore the fabric's continuity so that the resulting union between both ends is clean.

2. Original material and replacement material: In this case, there is a breakage in the thread, and with the passage of time and due to various other contributing factors of deterioration, there is a loss of the extension of the cord that forms the fabric, generating gaps and a decrease in the number of loops that deform the cultural property.

To make the joints for the first case, a natural adhesive and a small piece of Japanese paper were used to reinforce the joint, secure both ends and give the yarn continuity. For the second case, to replicate the original yarn's features, Japanese paper threads were made, the extension of which allowed the weaving of the missing gap. Once the paper yarns were made, they were joined to the edges of the original yarns, thus achieving an extension of the twine that allowed us to reproduce the weave used in each piece, following up the missing weave and fixing the fibers that were still preserved, as shown in Figure 10.

Each reweaving was carried out following the technique of the original piece (Figure 10), so it is essential to make a detailed record of the manufacturing technique used for each piece, in addition to preparing test tubes that will allow for the exact reproduction of the fabric in question.

CONCLUSIONS

As we have seen, Japanese paper has many properties that make it highly useful for conservation. Being made of long fibers, containing over 90% cellulose content in its natural structure, and not requiring fillers or adhesives in its creation makes it very stable against deterioration factors, besides its benefit of having high flexibility and resistance, allowing it to be spun whilst still preserving its primary properties and characteristics. This versatility of spinning permits the reproduction of any yarn or twine required to make any fabric replacement.

Tensile strength testing of yarns is essential to determine their quality and characteristics, especially if their use in conservation-restoration operations depends on this property.

The fact that the samples were made by varying only the width of the strips made it possible to determine their dependence on tensile strength, elongation at breaking, and modulus of elasticity.

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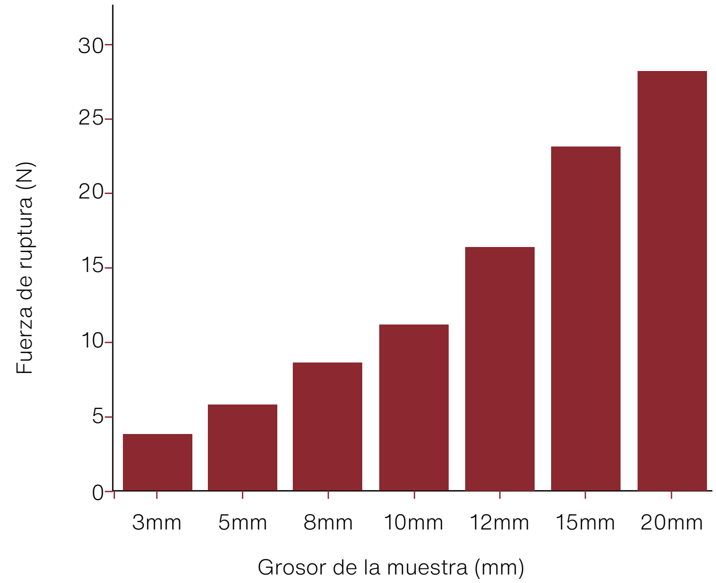

FIGURE 9. A comparison graph shows the mean values and standard deviations of breaking strength regarding the thread thickness. The height of the bars corresponds to the breaking force measured in Newton, and the standard deviation is presented as intervals at the top of each bar. Upon analyzing the graph from left to right, it is evident that there exists a direct correlation between the thickness of the yarn and the breaking force. This implies that the greater the thickness of the thread, the greater the force required to break it. The standard deviation intervals allow for the identification of significant differences between the thread thickness and its associated breaking force (Analysis and interpretation: Orlando Martínez Zapata, 2022; courtesy: Physical Chemistry Laboratory of the ENCRyM).

FIGURE 10. Detail of reintegration (rewoven with base-tone dyed Japanese paper) of the lagoon in EPVC V4 net bag, pza. 43, Cueva de la Candelaria, Torreón, Coahuila (Photograph: Julio Martínez Bronimann, 2017; courtesy: CNCPC).

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The desired yarn thickness will depend on the width at which the paper strips are cut, where strength and flexibility are directly proportional to the thickness and degree of twist, features that allow the yarn to be manipulated to make a fabric, reintegrating the structural unity of the cultural property.

In accordance with the principles of conservation, using a type of fiber different from that of the original piece allows us to denote our intervention in an anatomical structural analysis. Its behavior will be similar to the object without causing greater deterioration in the future since the Japanese paper threads will have a lower mechanical resistance than that of any new threads or cords with fibers equal to those of the original. It is more harmonious and compatible with fibers that are already deteriorated and have lost part of their mechanical resistance, returning their structural functionality, but without causing tensions to the original fibers. Additionally, the versatility of this material allows a chromatic reintegration (by various methods, thanks to the paper's great dyeability) giving the cultural property visual unity, besides having the advantage of being re-treatable and completely reversible.

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SIDEBAR IMAGE. Observation of twine under the Motic SMZ-171 stereo microscope (Micrograph: Amaranta González Hurtado, 2019; courtesy: CNCPC).