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Contribution Of Mechanical Tests: Assessing Vulnerability And Risks Of Degradation In Paintings

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Résumés

Français English
La conservation des œuvres peintes sur toile est intimement liée à la connaissance de leurs propriétés physico-mécaniques. Pour développer des outils d'évaluation tels que « le degré de vulnérabilité et les risques de dégradation mécaniques des peintures », l'usage d'essais mécaniques est inévitable. Ce travail regroupe une série d'études qui met en évidence l'importance de cette approche systémique.

The conservation of paintings on canvas is closely associated with the understanding of their physico-mechanical properties. Using mechanical testing is essential when developing tools to assess the level of vulnerability and risks of mechanical degradation in paintings. This paper addresses a series of studies highlighting the need of a systemic approach to decision-making for structural treatments.

Entrées d'index

Mots-clés : essai, mécanique, contrainte, rupture, fluage, relaxation, diagramme, sensibilité, hydrophile, hydrophobe, propriétés, physico-mécaniques, vulnérabilité, risques, dégradation
Keywords: testing, mechanics, strain, breaking point, creep, stress-relaxation, diagram, sensitivity, hydrophilic, hydrophobic, properties physico-mechanics, vulnerability, risks, degradation

Texte intégral

Introduction

1 Several studies have shown that environmental climatic conditions are a major factor of mechanical degradation in paintings.[1] Artworks are constantly subjected to these conditions, and the development of ensuing forces as an effect of climatic fluctuations, regardless of their locations and context. The actuality of temperature and humidity changes is not an illusion but a reality.[2] Works of art are subjected to these fluctuating conditions at every moment of the day.

2 A collection care conservation manager, from a pragmatic viewpoint, needs tools to assess the degree of vulnerability of paintings and the potential risks of mechanical damage in order to create a risk-assessment report for each work.

3 *The degree of vulnerability to environmental conditions* of a painting can be quantified on a scale of severity of damage after being subjected to fluctuating environmental conditions. This scale is influenced by two criteria:

- **The brittleness** which is represented by the breaking point of a paint film.
- **The sensitivity to moisture or temperature** can be described in a diagram.

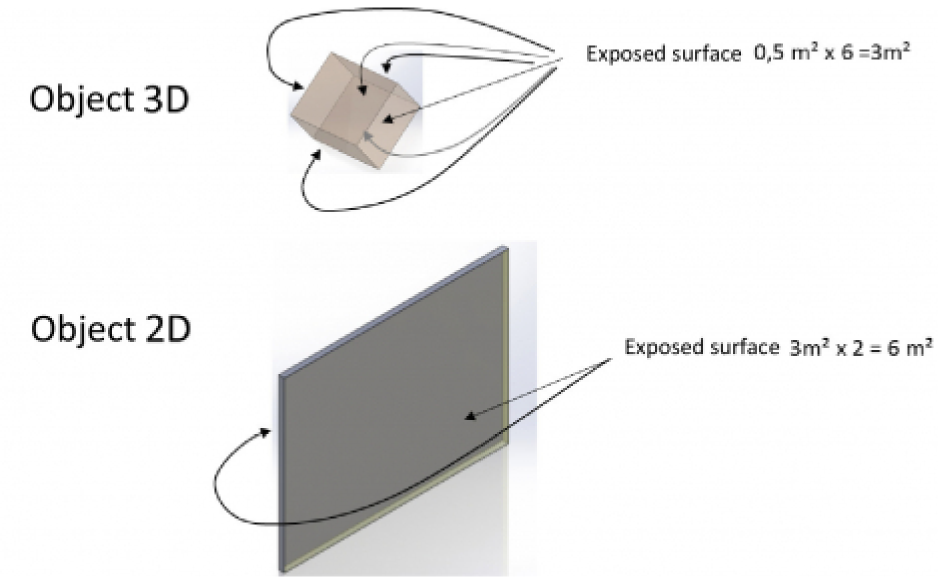
4 Thus, the degree of vulnerability could be used to rank the risk to paintings.

5 *A risk-assessment of mechanical damage* mostly relies on the existing relationship between the physico-mechanical properties of a painting in a given climate and its endurance limit in mechanical fatigue which sets a tolerance interval to the failure of paintings in conditions of fluctuating stress. Both notions use the physical and mechanical properties of paintings. Those can only be characterised through mechanical testing.

Paintings as case study

6 In a collection, paintings can be described as two-dimensional objects, if their depth is negated in relation to the other two dimensions. As opposed to 3D objects, 2D objects have a greater exposed surface area. For example, a cubic object with a side of 0.71m has an exposed surface area of 3m2 whereas a painting measuring 1.5 m x 2 m has an exposed surface area of 6m2 (Figure 1).

Fig.1: Exposed surface of a 3D and 2D objects



Representation of 3D and 2D objects

Credits © LARCROA

7 Thus, 2D objects, such as paintings, drawings and engravings, have a greater exposure to environmental conditions.

8 Physical and mechanical properties of materials are related to their chemical composition. Paintings are composed of hydrophilic and hydrophobic materials. Therefore, they are sensitive to moisture and temperature, absorbing and releasing water content as the climatic conditions fluctuate. The reactivity and fragility of paintings can be evaluated through their physico-mechanical properties in relation to moisture and temperature.

Equipement

9 Mechanical engineering laboratories are equipped with tools and machines specifically created to measure certain physico-mechanical properties of materials. Series of trials and tests exist in order to characterise mechanical properties. This field of research is complex as international standards used for testing are not designed to the study of the behaviour of paintings. Therefore, testing has to adapt to the materials and experimental protocols have to take into account the specificity of each painting technique. To match real-life conditions, new experimental devices were developed at the *Laboratoire d'Analyse et de Recherche pour la Conservation-Restauration des OEuvres d'Art* (LARCROA) by modifying existing equipment.

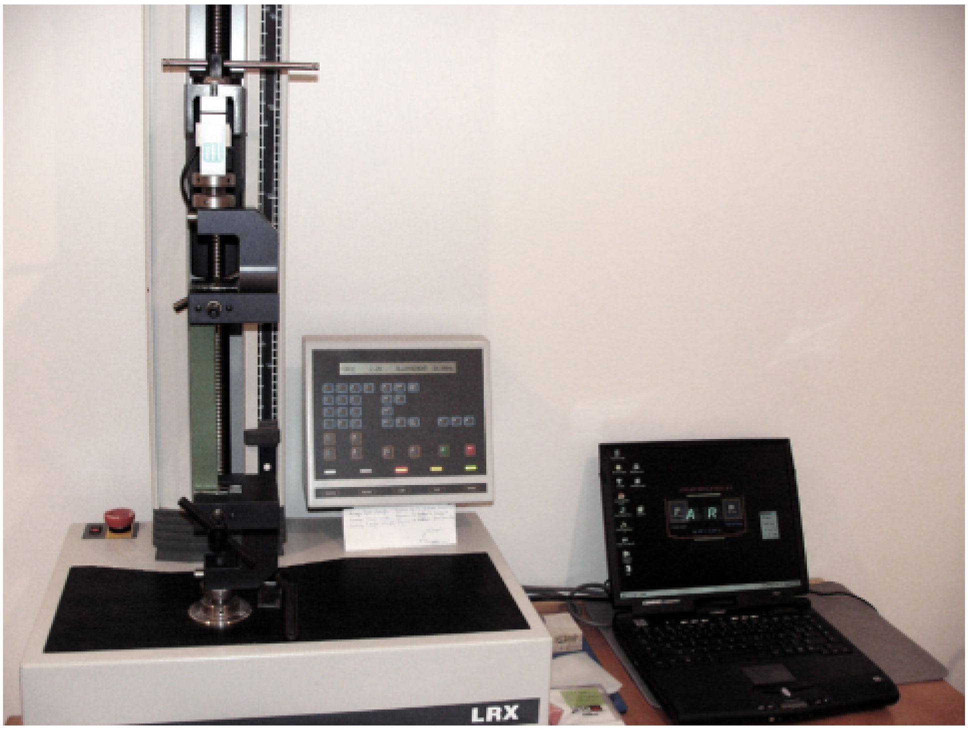
10 The interpretation of results is carried out based on mathematical tools or analytical methods. This interpretation is limited given the variety and singularity of each painting. Physical and mechanical characterisation, not widely in use for works of art in the field of art conservation, is in France confronted with a lack of interest from conservation scientists.

11 This paper presents the principle tests developed over the course of the past 20 years for the study of paintings at LARCROA. Our goal is to gather results which can be used in the field of art conservation. Each test is described simply and results of the physico-mechanical values obtained are listed. Case studies are given as illustrations for the potentiality of these tests.

Tensile Test

12 The tensile test is done on a Universal Testing Machine (UTM) (Figure2). It measures the fracture toughness of a material. The sample consists of a vertical narrow strip of test material, cut to specific standard dimensions. Gripping jaws are placed at the extremities of the sample. The vertical clamp is connected to a movable crosshead on the framework of the instrument. Testing is performed in stable environmental conditions (21°C, 50% RH). The mobile crosshead moves regularly at a predetermined set speed.

Fig.2 : Universal Testing Machine (UTM)



LLYORD LRX 2500

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13 Tests are performed on five samples from the same painting batch in order to obtain representative results. The tensile stress is applied to the sample at a constant deformation rate under specific loading conditions until failure occurs.

14 Tensile testing measures the following mechanical variables:

- Ultimate strength (N)
- Stress at ultimate strength of the painting and its support (MPa)
- Breaking stress of the paint film (MPa)
- Yield point (MPa)
- Percentage (%) of elongation at ultimate strength
- Zero-point Young's modulus of elasticity or at any given percentage elongation.

15 Curves present several parts. Their interpretation highlights the various behaviours of paint layers applied to canvas supports subjected to mechanical forces:

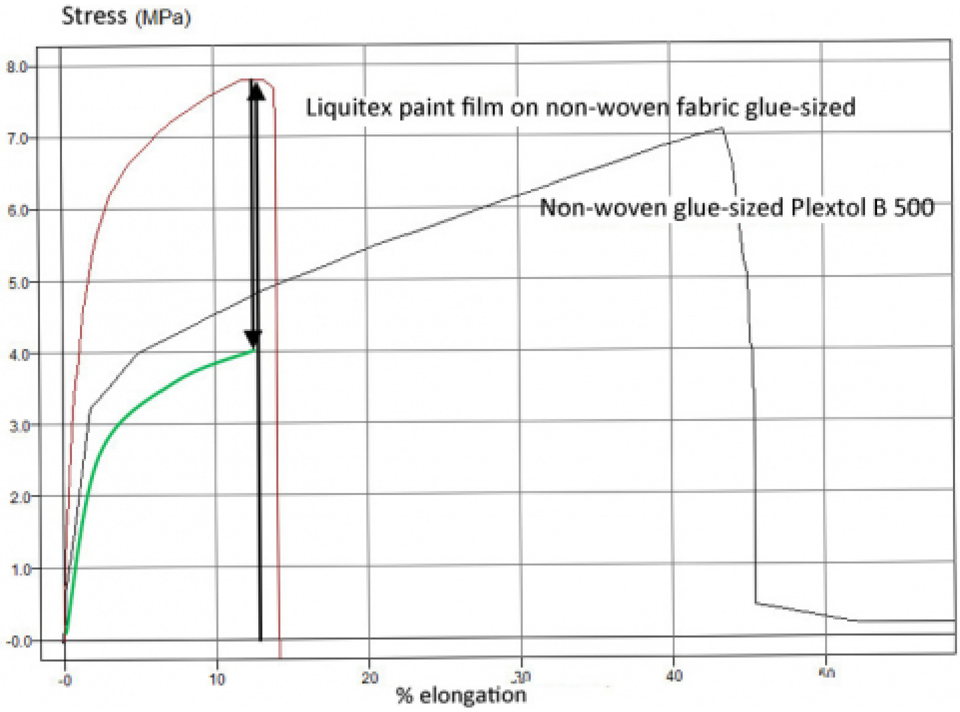
- Elastic, viscoelastic and visco-plastic properties of the paint film
- Speed of crack propagation
- Behaviour of the canvas or support
- Type of failure of the paint – ductile film, brittle film
- Type of failure of the support – clean, breaking with fraying

16 A painting can be understood as a sequence of adhesive layers which form a complex laminate. Each material has a specific modulus of elasticity. The material which has the highest modulus will dictate the overall behaviour. This principle is admitted and several types of cases are possible.

17 Type 1: *The support is stiffer than the paint film.* This is the case of a painting on metal, stone, wall, wood, glass. The material of the support is very resistant, and deformation is limited in comparison to the paint film. When the support abruptly breaks the paint layer follows. The tensile test only measures the mechanical properties of the support.

18 Type 2: *The support is as elastic as the paint layer, however, it is more resistant.* This is the case when a recent paint film (oil, acrylic, vinylic…) is applied to a canvas support and to non-woven materials. This can be illustrated by the tensile curve of a Liquitex® paint film on a non-woven polyester fabric (Figure 3).

Fig. 3 : Tensile curve of: (1) a Liquitex® paint film applied to a non-woven fabric, glue-sized with Plextol® B500, (2) a non-woven fabric sized with Plextol® B500 without a paint film, and (3) the theoretical curve of the Liquitex® paint film



Software NEXYGEN (version 3). Tensile failure procedure (40/060)

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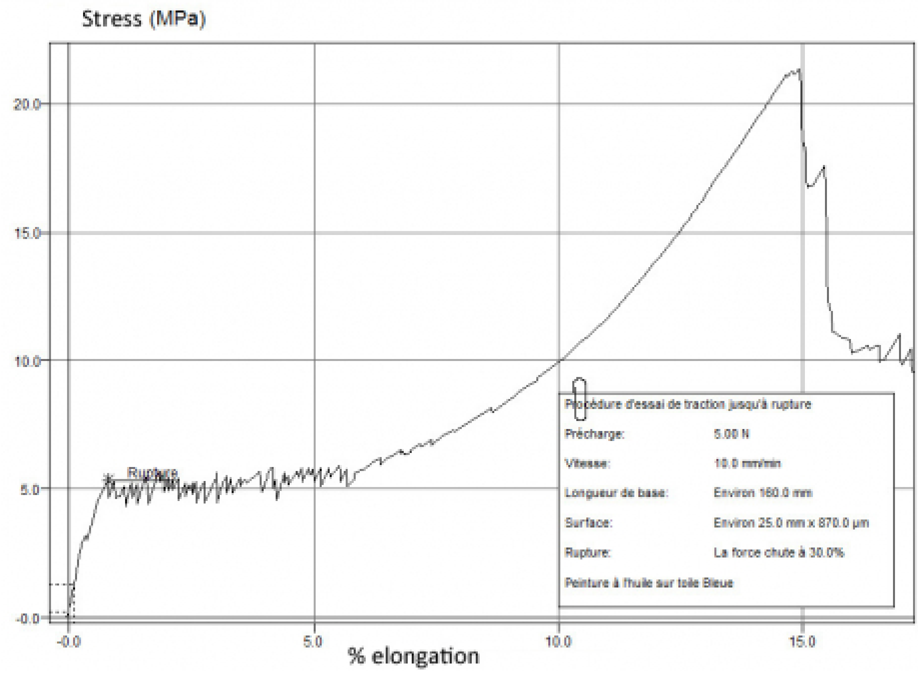
19 The graph on Figure 3 shows the tensile curves of a Liquitex® paint film applied to a non-woven polyester fabric, glue-sized with Plextol® B500 and of a non-woven polyester fabric, glue-sized with the same acrylic resin but without the paint film. The modulus of elasticity of the paint on non-women woven fabric is higher and the breaking point of the non-woven fabric alone is lower. When applying the law of additivity [4], the strength of the paint film can be measured by subtracting from the breaking point of the paint on non-woven fabric the value of the stress required for an equal strain on the now-woven fabric alone. In this case, the green curve is the theoretical curve of the Liquitex® paint film. Its breaking point is around 4 MPa.

20 Type 3: *the paint layer has a modulus of elasticity higher than the support*. This is the case for distempers, casein, based paints and old oil paint films which have lost their elasticity. The point-of-failure marks the moment after which the support will carry the load until its own failure. In this example, the break-point of the oil paint film applied to the canvas support is easily demonstrated on the graph. (Figure 4).

Fig. 4 : Stress-strain curve of oil paint



SofwareNexygen (version 3). Tensile failure procedure (40/0640)

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21 The stress-strain curve shows 3 different parts:

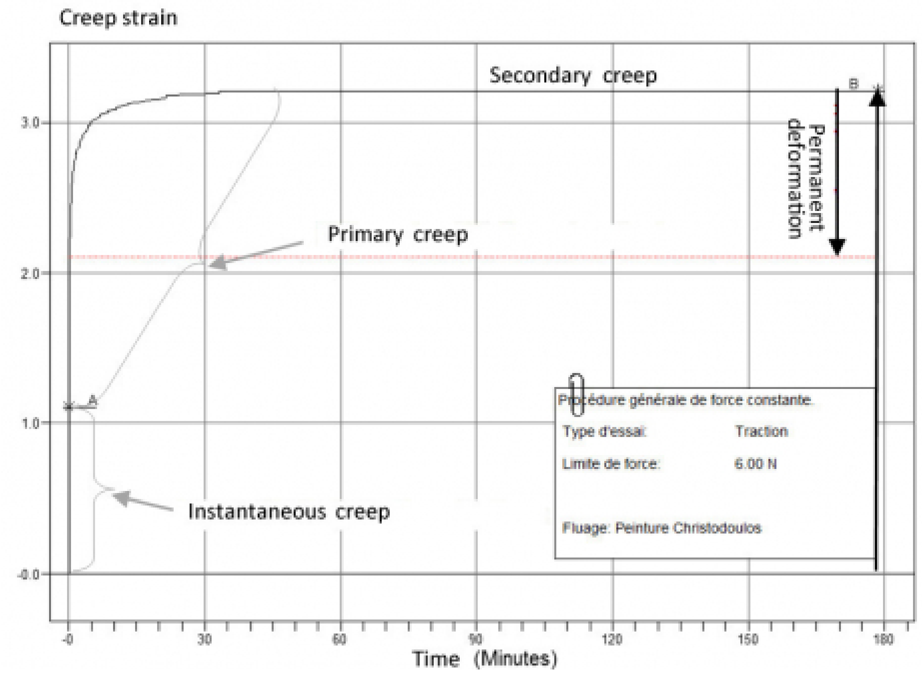
- The paint film has a high Young's modulus and dictates the overall behaviour. The linear start of the curve is known as the elastic region of the paint.
- A series of peaks are detected around 5 MPa from 1.6% to 6 % elongation. They attest to the formation of cracks. The breaking stress of the paint is given by the average value of the recorded peaks.
- From this point on the curve flattens. The canvas starts to expand. The increase in stress causes a 6 to 15% uniform elongation to the canvas until its failure.

22 The mechanical properties of the paint film and support are assessed by analysing this curve.

Creep Test

23 Creep is a physical phenomenon. A creep test consists in measuring the elongation of a material when submitted to a constant load as a function of time for a long enough duration. It is performed in tension using an Universal Testing Machine (UTM). The sample is attached between both the gripping jaws at the extremities. The mobile crosshead moves until the set load (N) is reached. The duration of the test is chosen prior to performing the test. (Figure 5).

Fig. 5 : Creep curve of a paint film on cotton canvas



Software Nexygen (version 3). Creep procédure (40/0642)

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24 Creep tests can characterise the following mechanical properties:

- The elastic deformation (reversibility) and the yield point.
- The delayed deformation (visco-elasticity)
- The residual deformation

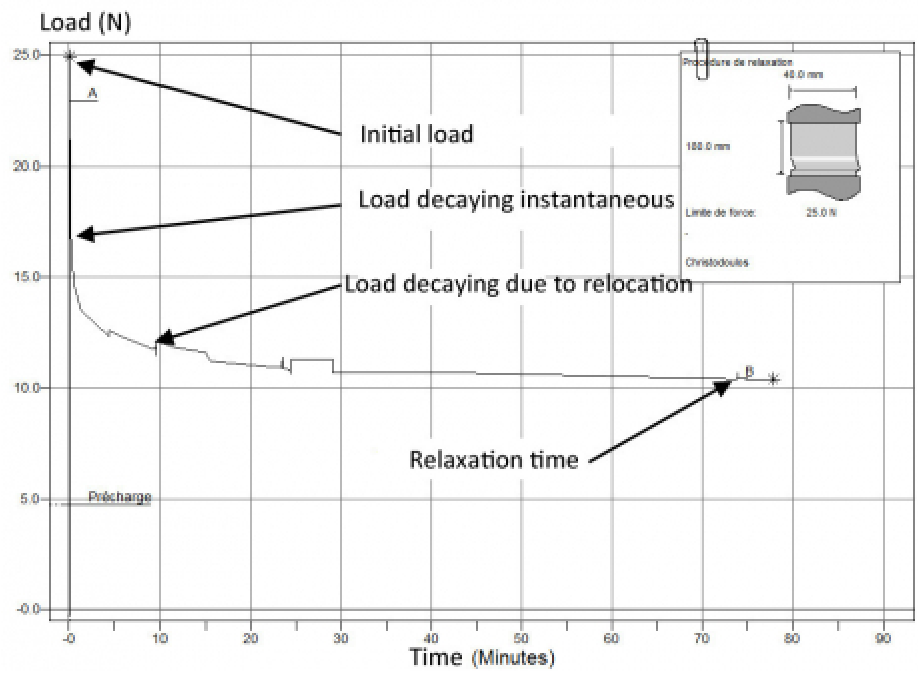
25 The elastic, visco-elastic and visco-plastic properties of paint are clearly clarified. This test can be performed under stable or fluctuating moisture and temperature conditions.

Stress Relaxation Test

26 Stress relaxation is a physical phenomenon. A stress relaxation test consists of measuring the decrease in stress of a material when subjected to a constant load as a function of time.

27 A relaxation test is performed in tension using an Universal Testing Machine (UTM). The sample is attached between both the gripping jaws of the tensile machine at the extremities. A mobile crosshead is moved until an initial determined load is exerted on the sample. The duration of the test is chosen prior to performing the test (Figure 6).

Fig. 6 : Stress relaxation curve of a paint film on cotton canvas



Software Nexygen (version 3). Relaxation procédure (40/0644)

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28 Stress relaxation tests can characterise the following values:

- Instantaneous drop in load due to elastic behaviour
- Load decaying due to visco-elastic behaviour
- Relaxation Time

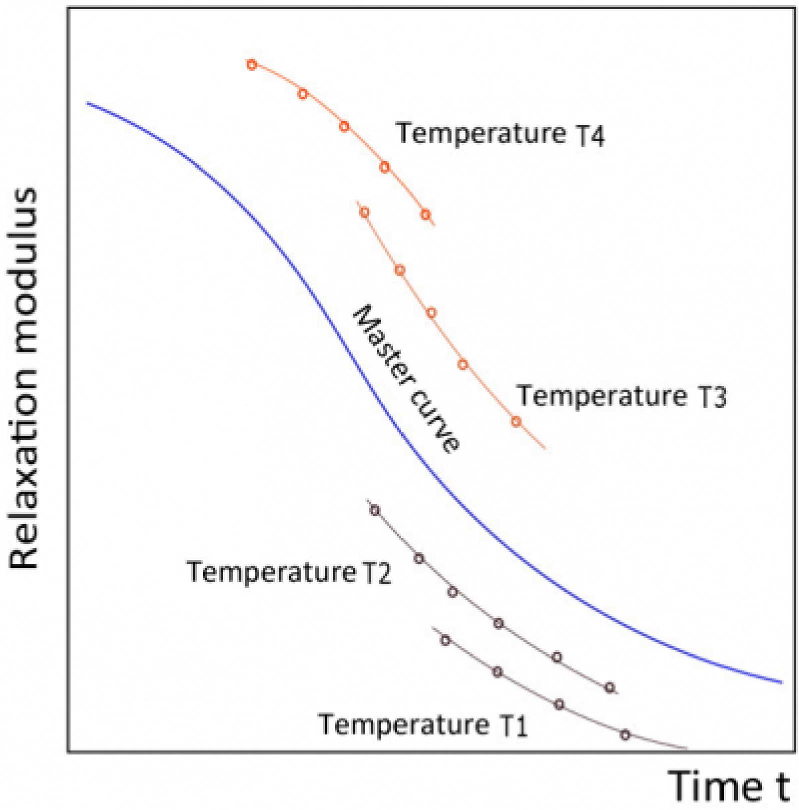
29 At stable moisture and temperature conditions, the stress relaxation tests can measure the rate of relaxation, that is to say the decrease of the load as a function of time.

Time-temperature superposition, temperature-moisture relationship, hydrophobic and hydrophilic properties of materials

30 To assess the impact of time, temperature and moisture on the overall behaviour of paintings, the analysis of results relies on the time-temperature superposition principle, the temperature-moisture relationship and the properties of hydrophobic and hydrophilic materials.

31 *The time/temperature superposition principle* [6]: The variation of the relaxation modulus obtained at a constant-speed, loading rate and variable temperatures has the same profile as at constant temperature and variable-speed loading rates. In this case, the time-temperature equivalence makes it possible to superimpose the response of the material as a function of the temperature on a reference curve by translation. The four relaxation curves of the same material at temperatures such as T1> T2> T3> T4 are translated to form a master curve (Figure 7).

Fig. 7 : Stress relaxation graphs of the same material at 4 different temperatures



Translation of the 4 graphs into a single curve as a function of time

John D.Ferry, *Op cit* 180 p.283

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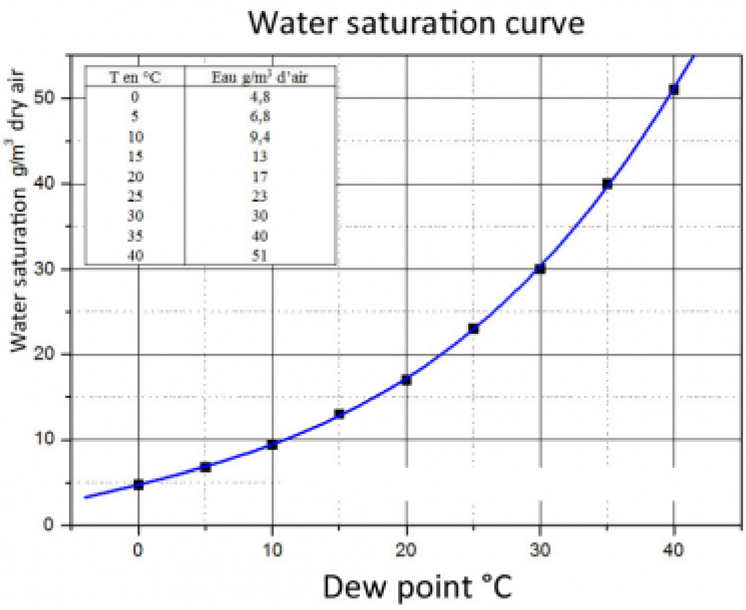
32 This principle shows that properties such as the Young's modulus, and consequently the breaking stress, depends on the speed of loading and temperature. When subjected to a very high-speed loading rate, the modulus of elasticity of a material corresponds with the modulus of elasticity at low temperature, and vice versa.

33 Temperature-moisture relationship: saturating water-vapour pressure (S) is a function of increasing temperature. This phenomenon is illustrated by the curve of saturation in airborne water-vapour at different temperatures (Figure 8).

Fig. 8 : Graph of water-vapour saturation



Moisture content and absolute humidity. Roche. A., 2016, p.47.

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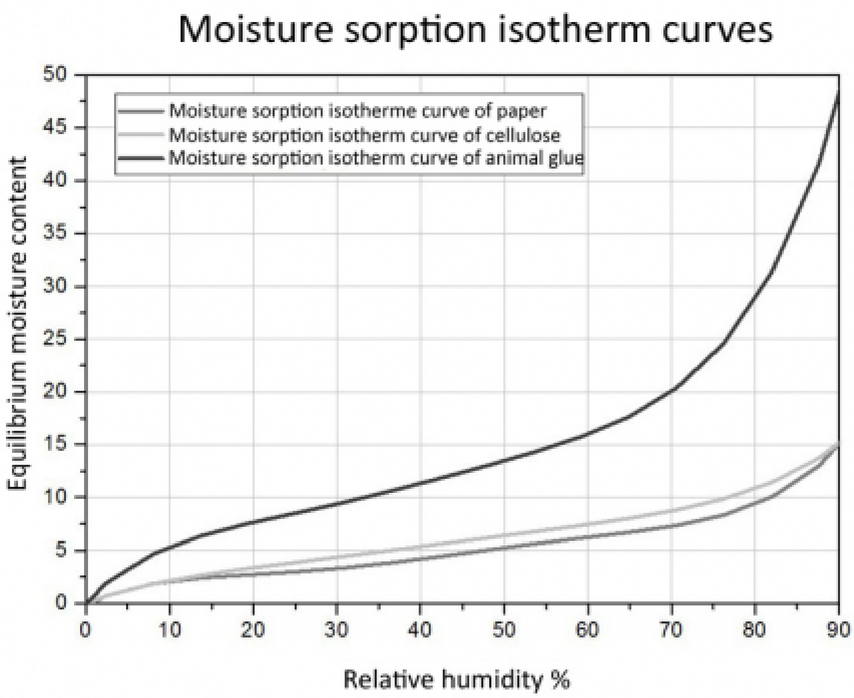
34 For an equal absolute amount of airborne water-vapour (AH) hot air will have a lower relative humidity than cold air. Relative humidity (RH) is measured by the following relation:

$$RH = \frac{AH}{S} \times 100$$

35 Hydrophilic materials absorb air humidity partially. At equilibrium, water molecules are constantly exchanged between hydrophilic materials and the surrounding air. Hydrophilic materials are characterised by their – Equilibrium Moisture Content (EMC). This ability to absorb and release water is given by the adsorption isotherm (Figure 9).

Fig. 9 : Adsorption isotherms of water – paper, cellulose, gelatin



Water-vapour balance between humid air and hydrophilic materials. Roche A., 2016, p.51.

Credits © LARCROA

36 *Properties of hydrophobic and hydrophilic materials :* Paintings are composed of hydrophilic (canvas, papers, woods, glues) and hydrophobic (fresh oil, acrylic and vinylic resins, polyester fibres) materials. The hydrophilic or hydrophobic tendency of painting components depends on their respective volume within the structure. The physico-mechanical properties of materials change according to their relationship to temperature and humidity.

37 Hydrophilic materials are sensitive to moisture. High relative humidity will cause swelling of the material and vice versa. Hydrophobic materials are sensitive to temperature. An increase in temperature will cause an expansion of the material and vice versa. Therefore, at each given humidity or temperature, materials are subjected to internal changing stresses.

38 The glass transition temperature (Tg) of a visco-elastic material varies depending on the relative humidity. This proves the existence of a temperature/humidity relation. By association, the time/temperature superposition principle could be applied to a time/humidity relationship.

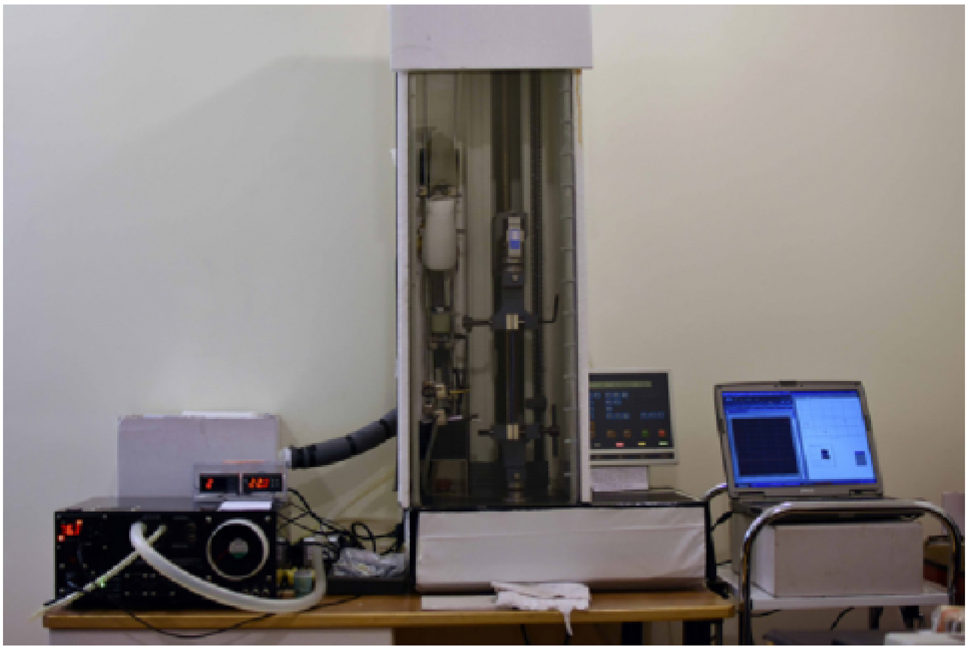
Assessing the sensitivity to moisture and temperature of a painting

39 Two methods have been used to check the influence of fluctuating environmental factors in paintings and assess their consequences. To illustrate both methods, an oil paint applied to a cotton canvas (vinylic size and priming layers) – entitled «Croisé RBV» dating from 2018 was used.

40 The first set up on a UTM (Figure 10) is composed of:

- A climatic chamber made of PMMA/polystyrene
- A humidity generator that can be programmed. It can produce stable or cyclic moisture conditions inside the climatic chamber.
- Temperature regulation is done by pulsating hot air and monitored by electronic regulators.
- Climatic data are recorded with a data logger (thermo-hygrometer) placed inside the chamber.
- A computer to control the UTM and save measured data.

Fig. 10 : First experimental set with a sample of paint from the « Croisé RBV » canvas



LLOYD LRX 2500 and climatic chamber

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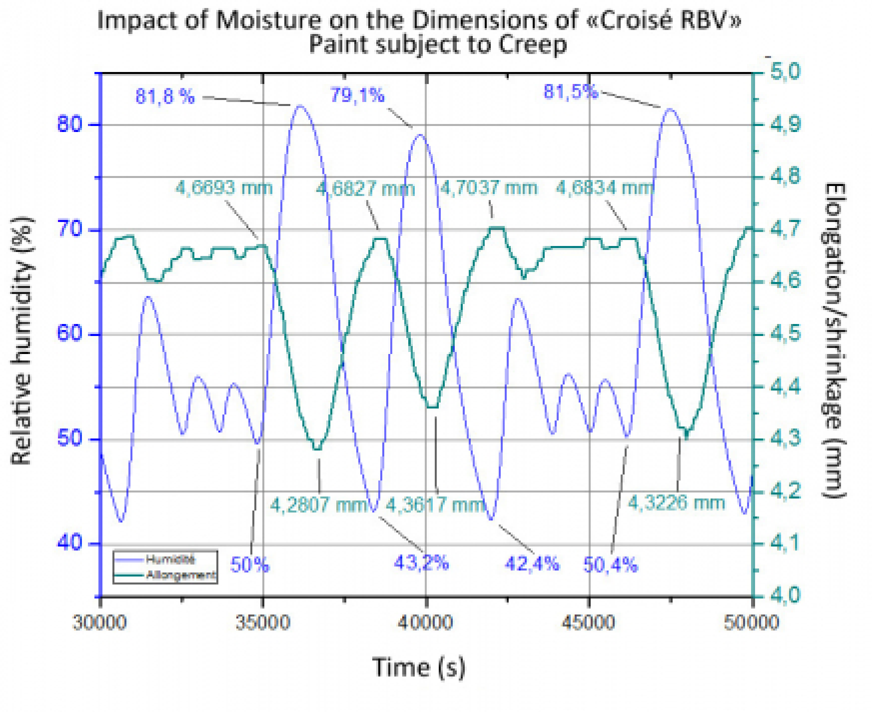
41 This experimental setup can perform mono-axial creep tests (at a constant load) in cyclic humidity. The sample of paint on canvas, which is attached between the two gripping jaws of the machine, acts as a painting without applied strain. Relative humidity cycles will cause dimensional variations which are recorded by the machine. The data obtained for "Croisé RVB" sample is plotted in the following graph (Figure 11).

Fig.11 : Recorded measurements from the first experimental setup of humidity and dimensional variations on « Croisé RBV » sample



Data processing Origin 2015 software (vers. VE)

Credits © LARCROA

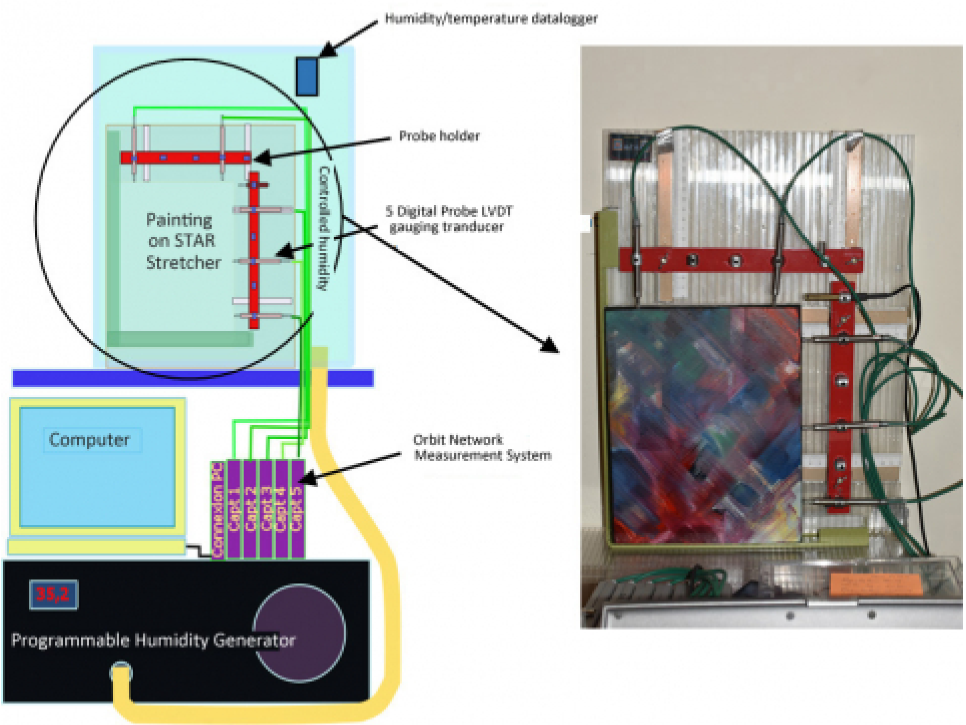
42 Dimensional variations – elongation and shrinkage of the sample – correspond with cycles of RH. For an RH variation higher than 38%, the dimensional variation measured in the painting is around 0.22%. Thus, for a 1 m long painting, the dimensional variation will slightly more than 2 mm. This variation cannot be ignored and demonstrates the sensitivity of the painting to humidity.

43 The second experimental setup, called a metrological frame, is composed of:

- The tested painting is mounted on a stretcher equipped with Auto-Regulated Tensioning System (Système de Tension Auto-Régulée : STAR).
- An adjustable metallic frame on which 5 LVDT[3] sensors are attached and linked to a computer connected to ORBIT[4].
- A small climatic chamber connected to the humidity generator which produces cycles of dry and humid air. A data logger, for temperature and for RH, records the climatic conditions.

44 The sensors are placed on the two edges of the painting mounted on the STAR stretcher (Figure 12).

Fig. 12 : Second experimental setup, the metrological frame and oil painting on cotton canvas «Croisé RBV » sample



Experimental device developed at LARCROA 2018

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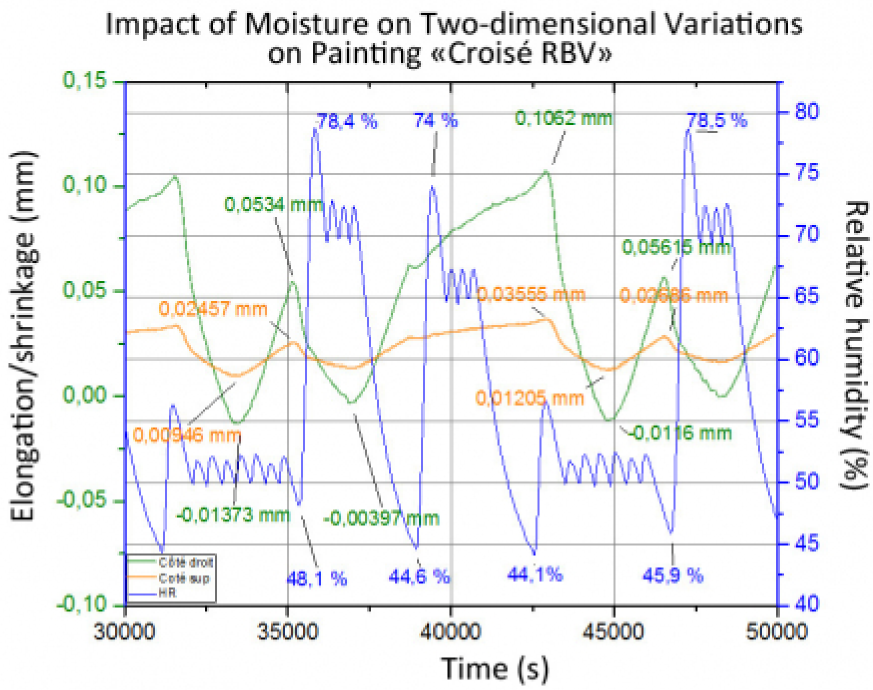
45 «Croisé RBV » canvas mounted on a STAR stretcher was tested. This experimental method can determine biaxial variations of elongation/shrinkage of the painting. It takes into account friction forces related to the tension of the painting on the stretcher. The recorded data are shown on the graph (Figure 13).

Fig. 13 : Measurements with the second experimental setup of the moisture and dimensional variations in the painting «Croisé RBV»



Data processing Origin 2015 software (vers. VE)

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46 Data analysis can also be used to assess the moisture sensitivity of the painting "Croisé RBV". For example, a 30% change in RH will cause dimensional variations of 0.24% in the warp and 0.04% in the weft of the painting.

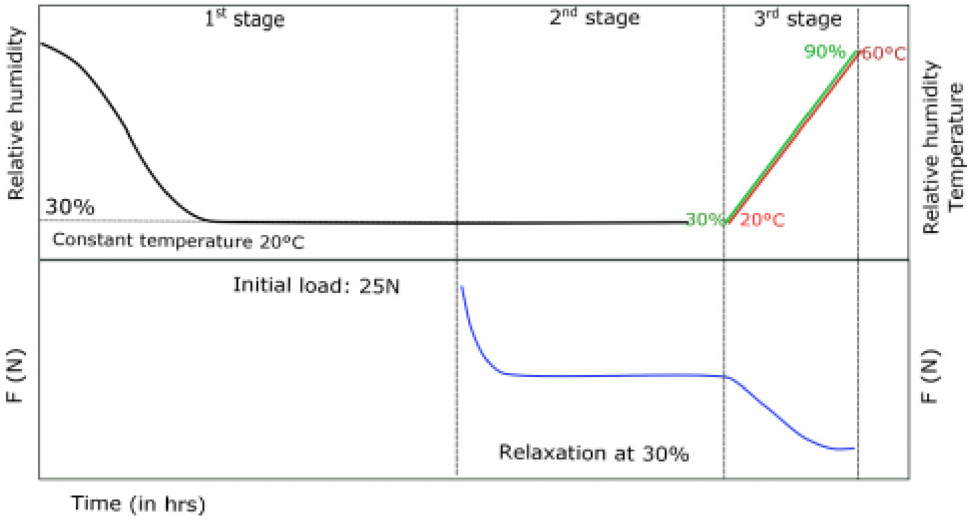
47 Both these tests show that hygrometric changes have a major impact on the overall behaviour of paintings.

48 The first experimental setup is used to produce a sensitivity diagram. The diagram is constructed by following three steps protocol that were devised by the author (Figure 14):

- The stress-relaxation test is performed under stabilised 30% RH conditions. A 25 N load is applied to the sample.
- Stress relaxation occurs within the sample and reaches a constant value.
- Modification of climatic conditions : *Humidity:* the generator is programmed to gradually increase moisture content from 30% to 90% RH. Temperature is kept constant at 20°C. *Temperature*: a temperature regulator triggers or stops the hot air fan in the chamber. The temperature will gradually reach the preset 60°C whilst the RH is kept at 30%. Changes in forces within the samples are recorded during moisture and temperature changes every 10 seconds.

49 After this, the environmental and mechanical data saved are processed in Excel and Origin software in order to produce the diagram of sensitivity to moisture or to temperature.

Fig.14: Three steps testing protocol



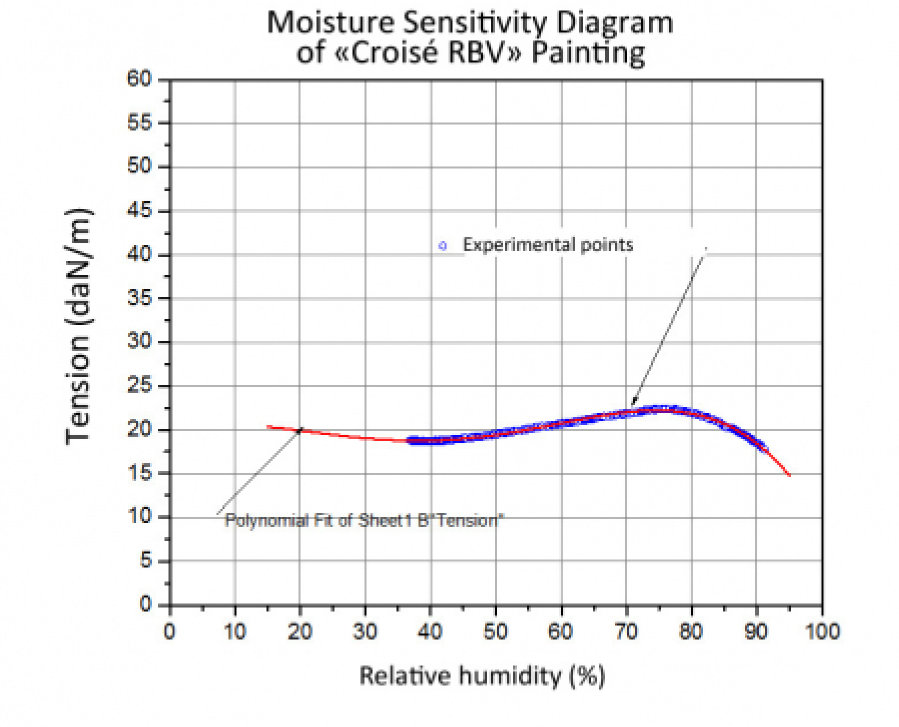
Graphic representation of the 3 stages of the test protocol

Credits © LARCROA

Mathematical Modelling of the Behaviour of a Painting

50 Experimental data, measured on the UTM, gives a series of experimental data points. The curve obtained closest to each of the experimental data points on the graph represent the regression polynomial function. It is obtained by a statistical analysis which describes changes in the random variable RH or T called polynomial regression (Figure 15).

Fig. 15 : Construction of a sensitive diagram



Data processing Origin 2015 software (vers. VE).

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51 Therefore, the sensitivity diagram is a mathematically defined curve by a 4th degree polynomial function.

$$t(RH,T) = a + b(RH,T) + c(RH,T)^2 + d(RH,T)^3 + d(RH,T)^4$$

52 This diagram shows the sensitivity of the painting to moisture or to temperature.

Mechanical Fatigue and Endurance of a Paint Film $V_{mini}t$

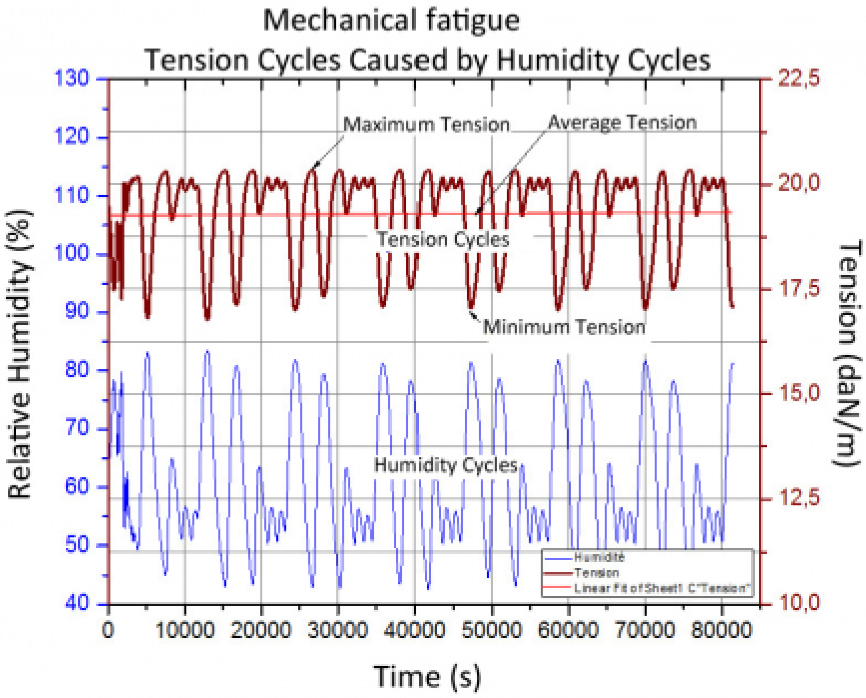
53 Mechanical fatigue can be the result of moisture induced stress variations. It is defined by alternating:

- Maximum stresses (drop in RH)
- Minimum stresses (rise in RH)

54 Stress variation is defined by the difference between the maximum and minimal stress, oscillating around an average stress.

55 In a painting on canvas mounted on a stretcher, stress variations caused by climatic cycles create changes in tension (Figure 16).

Fig. 16 : The graph shows variations in tension caused by cycles of humidity



Data processing Origin 2015 software (vers. VE).

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56 In dynamic fatigue, a material can fail under cyclic fluctuations of stresses much lower than its breaking stress.

57 In the field of material strength, different theories have been developed to determine the endurance limit of materials *(σD)*. Metals and certain plastics have been widely studied in this context. To the author's knowledge, no studies have addressed the endurance limit of paint films. The author's research is mainly based on the studies of Griffith A, Irwin G. and Wöhler A. who contributed to finding solutions to structural problems.

58 However, paintings on canvas mounted on standard stretchers are continuously subjected to tension fluctuations caused by unstable environmental conditions and vibrations. Measuring the endurance limit of a paint film is essential to assess the risks of mechanical damage to paintings.

59 The mechanical properties of a painting, composed of a polymeric matrix, in which particles or stiff defects are suspended, are related to their microscopic scale. When a change in tension occurs, the polymeric film, the particles or defects do not have the same response. This heterogeneous system binder/particle or defects cause stress concentrations in various zones, characterised by the stress concentration factor Kt. If the endurance limit of a painting σDp is related to both the breaking stress of the polymeric film and the factor of stress concentration, it can be written as the ratio between σ_{rupt} and Kt.

$$\sigma Dp = \frac{\sigma_{rupt}}{Kt}$$

60 The numerical analytic method of finite elements (FEA) served to demonstrate that Kt = 100 [8] that best meets conservation conditions for a painting. When using it in the expression of the endurance limit, it is proportionally related to the ultimate stress of a paint film.

$$\sigma Dp = \frac{\sigma_{rupt}}{100}$$

61 This mathematical expression gives a satisfying approximation of the endurance limit. The value is explicit enough and correct to use it in assessment calculations of damage risks for complex and heterogeneous objects such as paintings.

62 The endurance limit for paintings can also be defined as the minimum tension variation $V_{mini}t$.

$$V_{mini}t = \sigma Dp \times e$$

63 where *(e)* is the thickness of the paint film. The higher $V_{mini}t$ is, the more resistant the painting will be to fluctuating cycles of humidity and temperature.

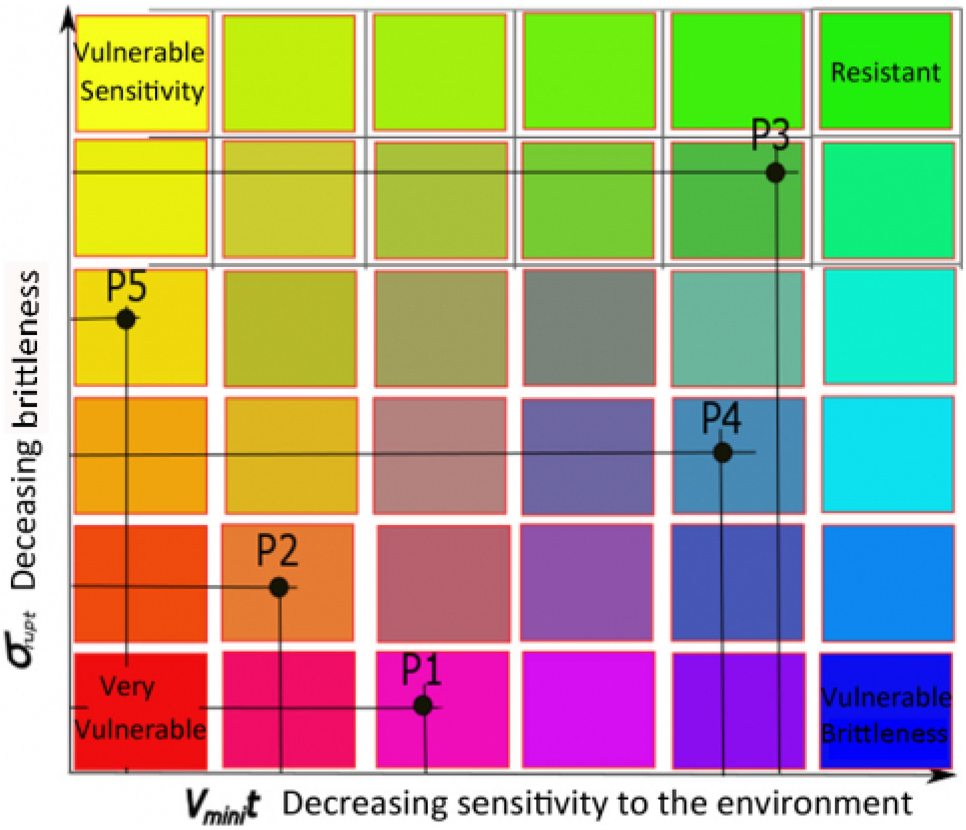
The Degree of Vulnerability of a Painting

64 The degree of vulnerability of a painting implies two physico-mechanical properties:

- Brittleness: This is defined by the breaking stress, that is to say its tensile strength. The lower it is, the more brittle the painting.
- Sensitivity: This is determined by the minimum tension variation $V_{mini}t$. In other words, its ability to withstand cycles of fluctuating tensions induced by environmental changes. The lower $V_{mini}t$, is, the greater the sensitivity to *RH* or *T*.

65 From these two properties, the degree of vulnerability of a painting can be plotted onto a graph. By locating the value of the stress value at failure σ_{rupt}, and the minimum stress variation $V_{mini}t$, on the graph, the position of the resulting curve will allow the degree of vulnerability of the painting to be assessed (Figure 17).

Fig. 17 : Graph of the degree of vulnerability of a painting



Graphic representation of the degree of vulnerability of a painting.

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66 In figure 17, five paintings are included in the graph. From their position it can be said that:

- P1 : very brittle and sensitive to environmental conditions – very vulnerable
- P2 : brittle and sensitive to environmental conditions – vulnerable
- P5 : very sensitive to environmental conditions and moderately brittle – vulnerable
- P4 : Moderate brittle and low sensitivity to environmental condition – low vulnerability

- P3 : Low brittle and low sensitivity to environmental conditions – very low vulnerability / strong /resistant

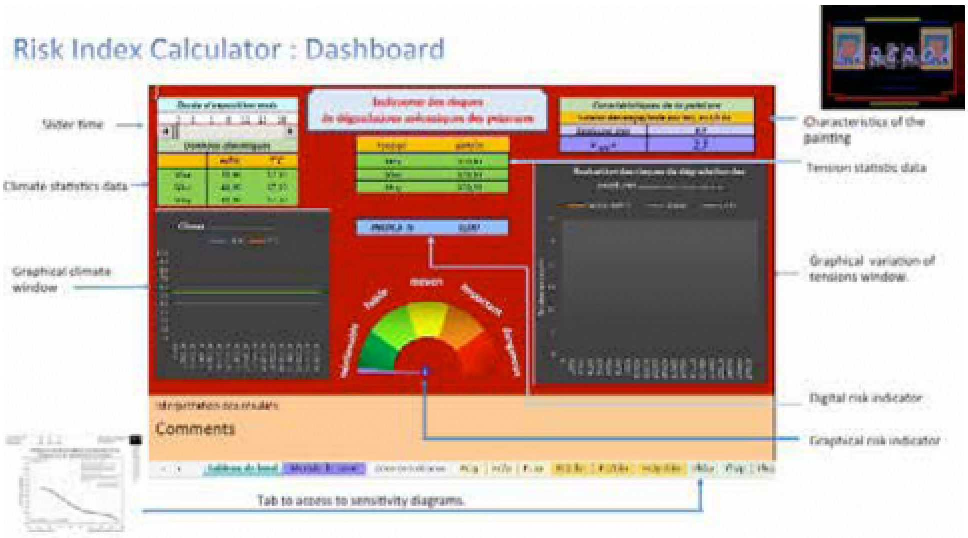
67 A classification can be drawn from this, which will allow the art collection manager to take actions in a case-by-case situation. During a loan, an exhibition or any other event in which a painting can be involved, stricter preventive conservation measures could be applied as the case dictates. In this example, stricter conservation measures should be applied to paintings P1, P2, P5 rather than P3 and P4.

Assessing Risks of Mechanical Damage to Paintings

68 Using the polynomial function from the mathematical modelling of a painting's behaviour, it is possible to translate environmental data – humidity and temperature – into mechanical data such as tension. The endurance limit of fatigue, which is defined as the minimal tension variation, sets the tolerance interval in which there is no risk of degradation.

69 From this data, a calculation module is used to assess the risks a painting is likely to be subjected to during transport or an exhibition in a more or less stable environment. Results from this calculation are given in the dashboard, Figure 18.

Fig. 18 : Dashboard of the calculation module « risks indicator»



Dashboard of the Excel- software calculation module.

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70 Risks can be tempered as a function of time – length of an exhibition, transport duration, etc. This risk-assessment tool takes into account the physical and mechanical properties of paintings, as well as the environmental conditions in which they are placed.

Conclusion

71 Using results from mechanical tests performed with specific equipment and environmental protocols allowed for a better understanding of the physico-mechanical properties of paintings. These results helped in developing new solutions. These Assessment Tools (AT) can be used in combination with Decision Making Tools (DMT). AT rely on calculations modules which integrating the physico-mechanical properties of paintings, as opposed to DMT which are mostly based on algorithms. These functional tools provide collection managers multiple options to organise their collections depending on their content and environmental conditions. This would also enable them

to consider a more secured planning for exhibition loans or events, to take greater care of works of art classified as vulnerable and to subject them to more frequent checks.

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Notes

1 MECKLENBURG, M.F., *Micro Climates and Moisture Induced Damage to Paintings*. Smithsonian Museum Conservation Institute Washington, D.C., Copenhagen, November. 19-23, 2007, p.19-25 ; BRATASZ, L, AKOGLU, K.G., KÉKICHEFF, P., *Fracture saturation in paintings makes them less vulnerable to environmental variations in museums*, Heritage Science, 2020; LIGTERINK F.J, DI PIETRO, G., : *Canvas paintings on cold walls: relative humidity differences near the stretcher*, Copenhagen 2007, p. 27-38.

2 BICHLMAIR, S., HOLL, K., AND KILIAN, R., "The moving fluctuation range – a new analytical method for evaluation of climate fluctuations in historic buildings", *Climate for collections standards and uncertainties,* Munich, 2012, p.439–450.

3 LVDT – Linear Variable Differential Transformer

4 ORBIT - Network of digital measurements.

Table des illustrations

Titre	Fig.1: Exposed surface of a 3D and 2D objects
Légende	Representation of 3D and 2D objects
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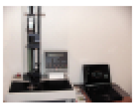

Titre	Fig.2 : Universal Testing Machine (UTM)
Légende	LLYORD LRX 2500
Crédits	Credits © LARCROA
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	URL	
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	**Titre**	Fig. 3 : Tensile curve of: (1) a Liquitex® paint film applied to a non-woven fabric, glue-sized with Plextol® B500, (2) a non-woven fabric sized with Plextol® B500 without a paint film, and (3) the theoretical curve of the Liquitex® paint film
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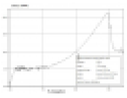	**Titre**	Fig. 4 : Stress-strain curve of oil paint
	Légende	SofwareNexygen (version 3). Tensile failure procedure (40/0640)
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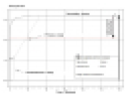	**Titre**	Fig. 5 : Creep curve of a paint film on cotton canvas
	Légende	Software Nexygen (version 3). Creep procédure (40/0642)
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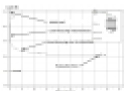	**Titre**	Fig. 6 : Stress relaxation curve of a paint film on cotton canvas
	Légende	Software Nexygen (version 3). Relaxation procédure (40/0644)
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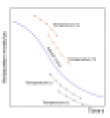	**Titre**	Fig. 7 : Stress relaxation graphs of the same material at 4 different temperatures
	Légende	Translation of the 4 graphs into a single curve as a function of time
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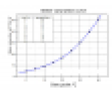	**Titre**	Fig. 8 : Graph of water-vapour saturation
	Légende	Moisture content and absolute humidity. Roche. A., 2016, p.47.
	Crédits	Credits © LARCROA
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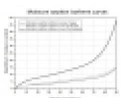	**Titre**	Fig. 9 : Adsorption isotherms of water – paper, cellulose, gelatin
	Légende	Water-vapour balance between humid air and hydrophilic materials. Roche A., 2016, p.51.
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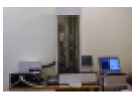	**Titre**	Fig. 10 : First experimental set with a sample of paint from the « Croisé RBV » canvas
	Légende	LLOYD LRX 2500 and climatic chamber
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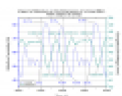	**Titre**	Fig.11 : Recorded measurements from the first experimental setup of humidity and dimensional variations on « Croisé RBV » sample
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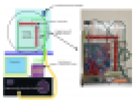	**Titre**	Fig. 12 : Second experimental setup, the metrological frame and oil painting on cotton canvas «Croisé RBV » sample
	Crédits	Experimental device developed at LARCROA 2018
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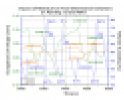	**Titre**	Fig. 13 : Measurements with the second experimental setup of the moisture and dimensional variations in the painting «Croisé RBV»
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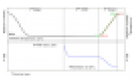	**Titre**	Fig.14: Three steps testing protocol
	Légende	Graphic representation of the 3 stages of the test protocol
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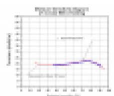	**Titre**	Fig. 15 : Construction of a sensitive diagram
	Légende	Data processing Origin 2015 software (vers. VE).
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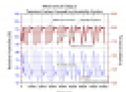	**Titre**	Fig. 16 : The graph shows variations in tension caused by cycles of humidity
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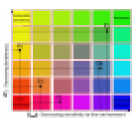	**Titre**	Fig. 17 : Graph of the degree of vulnerability of a painting
	Légende	Graphic representation of the degree of vulnerability of a painting.
	Crédits	Credits © LARCROA
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	**Titre**	Fig. 18 : Dashboard of the calculation module « risks indicator»
	Légende	Dashboard of the Excel- software calculation module.
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