

Technical assessment of cultural objects in the planning of transport

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ABSTRACT Assessing a cultural object's ability to withstand transport hazards such as shock, vibration, and changes in temperature and relative humidity (RH) requires both a detailed examination as well as some understanding of the materials used in construction and prior conservation treatments. This paper discusses some aspects of the object's construction, materials and conservation treatment in terms of their influence on the ability to respond to the external stimulus. New research has shown that low temperature can have a severe effect on paint films. Certain pigments can make paint films brittle regardless of temperature and RH conditions. Current research indicates that rapid RH fluctuations may not be a significant problem in unrestrained wood panel paintings.

KEYWORDS temperature, relative humidity, shock, vibration, brittleness, restraint, moisture diffusion

Introduction

Historically, the technical examination of any object has been cursory at best. Artefacts were assessed mainly in terms of their fragility, i.e. the damage that might result from impact (shock) or vibration. The technical examination usually comprised an assessment of the loose paint or inlays, weak construction joints or poor basic construction. When these conditions were encountered some form of conservation would generally be carried out prior to transport and in most cases the artefact was then conveyed successfully to its new destination. In 1991, a systematic study was made of the transport environment and the effects of shock, vibration, temperature and relative humidity (RH) for the transport of paintings (Mecklenburg and Tumosa 1991a,b). The study had certain limitations in that it focused on paintings and lacked a comprehensive examination of cultural materials. Nevertheless, it did make a considerable contribution in terms of assessing the effects of shock and vibration, temperature and RH on objects. For example, the research determined passive methods to stabilise RH and temperature during transit. But in the last two decades, there has been a marked increase in the amount of information available concerning the mechanical and dimensional properties of cultural materials. There have been significant advances in the understanding of environmental consequences of conservation treatments as well as in the development of numerical or computer modelling of cultural objects. Consequently, and in view of new research, a reassessment of our basic understanding of the effects of external stimuli on cultural materials is in order.

Back to basics

There is excellent information available regarding shock, vibration and the transit environment so a further review here is not necessary (Marcon 1991a). Furthermore, Saunders (1991) has published a useful summary of temperature and the RH environment encountered in transportation. There are some fundamental issues that need further discussion, however, including the mechanical and dimensional properties of materials. The mechanical properties are important since external stimuli such as shock and vibration induce failure in objects by the development of excessive displacements and forces. Changes in temperature and RH induce forces (actually stresses) in restrained materials so both the dimensional and mechanical properties are important. The significant improvements in our understanding since 1991 have been achieved as a result of research conducted on material properties, assessing conservation treatments and numerical modelling of cultural materials and objects. Careful examinations of objects and determining the materials used in their construction will considerably assist the assessment of their possible vulnerability during transport. If the potential hazards are clearly understood then it is possible to take steps to mitigate them.

Shock and vibration

The single most important factor in stabilising an object against the effects of shock and vibration is preventing relative motion of the component parts of the object. For example, shipping objects with cantilevered components such as the



Figure 1 Robert Baeumler, American, late 1950s. This illustration shows a detail of cracks generated from the exposure to low temperature. As a matter of interest, the owner of this painting witnessed this damage occurring while carrying the painting from her home to her car in the winter. (Photo: James Hamm. Courtesy of the owner, Sandra Kelberlau.)

arms of a marble sculpture or legs of a fragile table represent a potential hazard. Shock- and vibration-induced deflections of those components relative to the rest of the object can generate very high bending moments and internal stresses. So the solution is the restraint and support of the entire object in such a manner that no component moves relative to another. Packing such objects for transportation requires an examination of the object's geometry. In addition, the weight of the object should be determined in order to provide an estimate of the impact of dropping and an evaluation of the proper cushioning material. Marcon (1991b: 107) summarised the issues very succinctly when he stated that the design of protective packaging involves three considerations:

- (a) the sensitivity of an object to the conditions that occur during shipment;
- (b) the severity of the conditions that are expected during shipment;
- (c) the performance characteristics of packaging materials.

It might be added here that these considerations are valid for all objects not just paintings, and there is a need to consider the abrasion potential of packing materials. However, it is worth exploring further the 'sensitivity' aspects of an object, which also includes the mechanical properties of the materials used in its construction. For example, it is widely recognised that glass is a very brittle material and easily damaged by impact. But what is not often discussed is that both temperature and RH alter the mechanical properties of many materials, making them fragile.

Temperature effects on materials

To begin this discussion, it is worth commenting that the dimensional response of cultural materials to changes in temperature is very low (Mecklenburg 2007b). This means that forces in an object resulting from internal stresses in its materials are going to be low even with fairly significant changes in temperature. But more importantly, higher temperatures can 'soften' – or more accurately increase – the flexibility of a material. Lower temperatures can 'stiffen' or even cause many cultural materials to become brittle (Mecklenburg 2005). While steps are often taken to protect materials from

low temperature, these measures are normally passive and offer protection only for a limited time period. For example, a well-insulated packing case with 10 cm of rigid polyester urethane foam has a temperature half-life of about 8 hours, which means that in 8 hours there can be a temperature depression inside the case that is half the difference between the interior and exterior temperatures. If the temperature inside is 20°C and the outside 0°C, within 8 hours the inside of the case will be 10°C (Richard 1991). It is not uncommon for objects to be left outside on airport tarmacs in cold weather during transit. Equally important is that aircraft cargo holds are often kept cool as perishable materials such as fruits and flowers are shipped at the same time as artworks. On long flights, there can be a significant drop in the temperature inside the case.

With a depression of temperature, artists' paints can pass through their glass transition temperature (T_g), which is the range whereby materials transition from flexible or ductile to brittle. For example, the T_g for oil paints is around -10°C , for alkyd paints it is approximately 0°C and for acrylic paints, it is around 10°C (Mecklenburg 2007b). For paintings made with oil, alkyd, acrylic emulsion or solvent-based acrylic paints, the hazards caused by low temperature are very real, especially in a vibration or impact environment.

For example, figure 1 shows a damaged painting where the design layer was a mixture of Bocour (solvent-based acrylic) and oil paints. The delamination of the white paint layer is the result of the presence of zinc oxide pigment which promotes poor interlayer bonding of the design layers. The delamination continued even after the painting was returned to room temperature.

As can be seen in figure 1, the combination of low temperature and vibration can be detrimental. Most other cultural materials are already below the T_g when at room temperature; however, they can still become brittle. For example, gesso can become brittle at low temperature (Lopez 2006) but there are other occasions where materials are brittle even at room temperature.

Materials issues and artists' paints

Historically, research on the effects of pigments on paint film formation has been considerably less extensive and with good reason – it takes a long time to assess the effects of the pigments on the durability of the paint made with them. Over the last 30 years, a systematic study of the effects of pigment on the natural drying of oil paints was conducted. For the last 20 years, the paint study at the Museum Conservation Institute of the Smithsonian Institution (Washington, DC) included 'control paints' specifically manufactured with known pigments, oils and driers. Some paints are still undergoing modification after 20 years. Some of the results are of interest to those concerned with the preservation of objects containing oil paints.

Pigments, when used in making oil paint, have a profound effect on the ultimate durability of the paint (Mecklenburg 2005, 2008; Tumosa and Mecklenburg 2005). This is a result of the drying oil's ability to partially dissolve the pigments of some metallic compounds and form ions that react with the oil (Mecklenburg *et al.* 2012; Tumosa and Mecklenburg 2012). Oil paints made with pigments having no metallic ions, such

as the organic pigments and synthetic dyes, tend to have very poor 'drying' characteristics and are prone to damage from high RH. This can include alizarin crimson.

Other pigments with similar and poor drying characteristics (considered 'slow driers') include the earth colours (containing iron oxide). In these cases, the iron compounds do not readily dissolve in the drying oil. The reason that these paints form poor films is that they hydrolyse even in benign environments (Mecklenburg *et al.* 2005). In general, the pigments that are poor film formers when used alone in drying oils include: yellow ochre, red iron oxide, burnt and raw sienna, burnt and raw umber, terre verte, alizarin madder lake, lamp, ivory and vine blacks, Van Dyke brown, the cadmium pigments, lapis ultramarine, synthetic ultramarine, cobalt blue and yellow, and smalt. Note the curious contradiction in that cobalt has long been considered to be a 'drier'. The hazard here is that new paintings present the risk of wrapping material adhering to the paint surface or even distorting it.

In reality relatively few pigments, when used alone in drying oils, form durable paint films. These include basic lead carbonate and most of the copper compound pigments. Titanium dioxide white forms a weak paint film whereas zinc oxide and lead tin yellow form extremely brittle paint films.

It is possible to see the effects of different pigments in paintings when examined closely. For example, those paintings that have true earth colour grounds such as red iron oxide tend to be particularly prone to damage in higher humidity environments and the upper layers of paint can easily separate from the ground. Equally important is that they are liable to damage from cleaning solvents. Conversely, those paintings with white lead grounds tend to be remarkably durable irrespective of the pigments used in the final design layers. Research has shown that white lead grounds provide metallic ions that migrate through the upper paint layers stabilising them (Mecklenburg *et al.* 2012).

Contemporary paintings of the mid-20th century and later can present special difficulties. Since basic lead carbonate has been found to be a toxic pigment, alternative white pigments have been used in the commercial manufacture of artists' oil paints; these typically include titanium dioxide or zinc white or a mixture of both. When used alone as a white pigment, titanium dioxide will result in a very weak oil paint. Commercially prepared artists' canvases made with titanium white oil grounds will not remain durable. Knowing this, many manufacturers have changed to titanium white alkyd ground preparations which are far more resistant to environmental factors. Zinc oxide as a pigment will produce a very brittle oil paint with the particular problem of delamination of the paint layers. Figure 2 shows a detail of a painting by Henry Cliffe (1959). The paint shown in this detail is lead white containing zinc. Note the severe cracking and interlayer cleavage – this is mechanical damage due to rolling and not to moisture or temperature effects. Paintings with this combination of paints are prone to damage from basic handling and surface abrasion.

In post-World War II America, there was a group of important painters known as the Abstract Expressionists that included artists such as Willem de Kooning, Jackson Pollack, Franz Kline, Hans Hoffmann and Richard Diebenkorn among others. Many of these painters such as Kline, Hoffmann and Diebenkorn incorporated zinc white grounds in their paintings



Figure 2 Detail of a painting by Henry Cliffe (1959). The paint shown in this detail is lead white containing zinc. Note the severe cracking and interlayer cleavage. This is mechanical damage due to rolling and not to moisture or temperature effects. (Photo: Steve Gayler. Courtesy of the owner, Richard Saltoun.)

and the results have been problematic (Maines *et al.* 2012; Rogala *et al.* 2010a,b). These paintings with zinc grounds have become brittle, are cracking and are starting to delaminate. Furthermore, upper paint layers that would typically remain flexible are also becoming brittle as a result of ion migration of the zinc. It is important to note that the conditions brought about by the use of zinc oxide are independent of temperature and RH and these paintings are particularly vulnerable to impact and vibration. It is also important to point out that these paintings were made in the 1950s, 1960s and later so the effects of the zinc have become apparent in a relatively short time. One of the real difficulties with these types of paintings is that conservation treatments tend to be temporary measures as the chemical reactions in these paints are ongoing and impossible to inhibit.

Mixing zinc oxide with titanium dioxide will still produce a brittle paint even though the percentage of zinc is only about 15%. Naturally occurring manganese dioxide sometimes found in burnt umber can also cause oil paint to become brittle.

In the United States, artists' alkyd paints have been used more and more as an alternative to oil paints. Alkyd paints do contain a fairly high percentage of oil and as such they respond to pigments in a manner similar to drying oil paint. The big difference is that they tend to be considerably stronger. Nevertheless, pigments such as basic lead carbonate and zinc oxide will produce remarkably brittle alkyd paints (Mecklenburg *et al.* 2012).

Relative humidity: effects on materials

Where the dimensional response of cultural materials to changes in temperature is low, for many materials their response to changes in RH can be extremely high. This includes most woods (in the tangential and radial directions) as well as many 'slow-drying' paints, ivory and hide glues. As a consequence, many cultural artefacts made from these materials are vulnerable to changes in RH if restrained in any way. For example, when pieces of wood are glued together with their grains perpendicular to each other, each piece is restrained by the other because the longitudinal direction of the wood has a low dimensional response to RH. This is often the case in furniture, especially where wood veneers or inlays have been used. Another example is found on paintings on copper. Clearly copper is not responsive to changes in RH but the paint layers are to some degree. However, most other cases of restraint are not so obvious.

Traditional panel paintings and polychrome sculpture, typically constructed with wood gesso and either tempera or oil paints, are of special interest. Most research has focused on the dimensional response of the wood, and the gesso and paint layers rarely enter into the discussion. The gesso layers in such objects tend to be brittle (particularly at low RH) and while they are not significantly responsive to dimensional changes in RH, they do exhibit some response. If that response is restrained, as it is by the longitudinal grain of its wood support, the gesso will crack if the RH changes are sufficiently great. That is why cracks perpendicular to the grain of the supporting wood can be seen in so many panel paintings and gilded frames. Furthermore, the gesso layer of a panel acts as a structural restraint to the wood in the radial and tangential directions. This is one of the primary reasons why panels warp due to changes in RH (Mecklenburg 2007a).

The all-important question is: how much change in RH is safe? A fairly accurate estimate can be found if both the mechanical and dimensional behaviour of materials are determined. For example, the mechanical behaviour of cottonwood (also known as European poplar) in tension is shown in figure 3. This figure shows the tensile stress-strain tests for cottonwood in the tangential direction at different levels of RH. The tangential direction of any wood is the most dimensionally responsive to RH and it is also the weakest. The yield point is indicated by the arrow at a strain of 0.005. This is considerably lower than the strain required to cause the wood to actually fail.

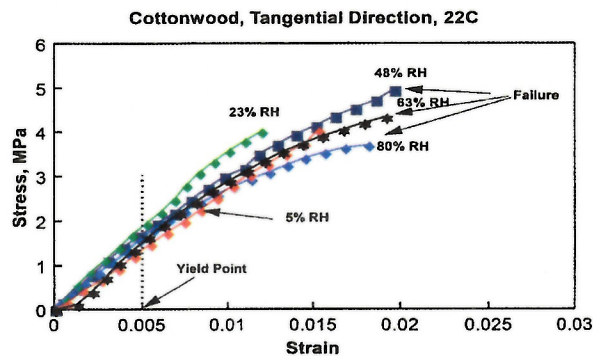


Figure 3 Tensile stress-strain tests at different RH levels for cottonwood in the tangential direction. The tangential direction of any wood is the most dimensionally responsive to RH and it is also the weakest. The yield point is indicated by the arrow at a strain of 0.005. This is considerably lower than the strain required to cause the wood to actually fail.

This is the boundary strain between fully elastic (reversible) behaviour and plastic behaviour where deformations become permanent. The yield strain is also considerably lower than the strains required, causing the wood to actually break. In looking at the individual curves from figure 3, it should be noted that the wood is getting weaker at 23% RH and 5% RH. This is fairly typical of most woods when the RH is below 30%.¹ So it is clear that maintaining an environment above 30% RH is of some importance.

Therefore using the yield point as a failure criterion in assessing the allowable changes in RH is both practical and conservative. It now remains to link the strains found in the mechanical tests to those strains determined from the dimensional properties induced by changes in RH. This is possible by showing the relationship between the two sources of strain (Mecklenburg and Tumosa 1996). Once that link is established, then it is a fairly simple matter to determine the allowable RH for any material when restrained.

Figure 4 shows the dimensional response of tangentially cut cottonwood to both large and intermediate changes in RH. The intermediate RH ranges are still fairly large and easily exceed the current recommended museum control RH ranges of $50\% \pm 5\%$. There is actually a family of the intermediate dimensional response ranges, two of which are shown in this figure. Also shown are the allowable RH fluctuations if the yield point of 0.005 had been used as the criterion for environmental RH limits. In addition, it is assumed that within this range the material can go into either tension or compression (using a strain range of ± 0.005) and still be within the elastic range.

The allowable RH fluctuations are then shown to range between 32% RH and 62% RH as compared to the current Smithsonian environment guideline recommendations of 37% RH and 53% RH. This means that the wood is behaving in a fully elastic and reversible manner in a RH range greater than the recommended museum guidelines. It also means that the change in RH has to be even greater to cause the wood to actually break.

One other important criterion that should be mentioned is that this analysis technique assumes that in all of the materials there are no existing cracks. If an object has cracks, then they act as expansion joints and release stresses developed by environmental stimulus. This infers that the object can be safely subjected to even greater environmental changes than indicated by the analysis discussed.

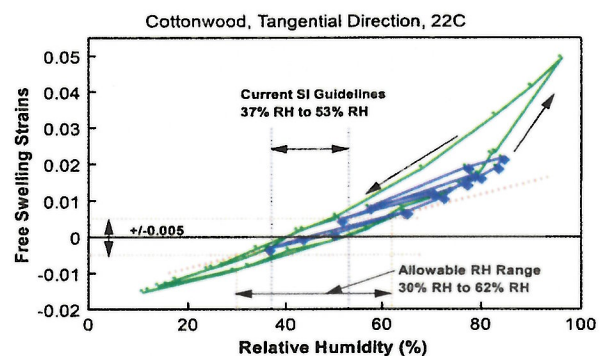


Figure 4 Allowable RH fluctuations if the yield point of 0.005 had been used as the criterion for environmental RH limits. These fluctuations range between 32% RH and 62% RH as compared to the recommended Smithsonian Institution guidelines of 37% RH and 53% RH.

Table 1 Assessing materials for their allowable RH ranges when restrained.

Material	From	To
Woods in general	30–32%	62%
Hide glue	30%	60%
Ivory	26%	67%
White lead paint	0%	100%
Titanium white paint	28%	66%
Zinc white paint	16%	63%
Earth colour paints	30%	64%

Assessing other materials for their allowable RH ranges when restrained is done in a very similar manner and leads to the following results shown in table 1. An average but conservative boundary between 30% RH and 60% RH can be assumed for the allowable range of most materials. This can also be viewed as saying that the materials can withstand RH fluctuations of $50\% \pm 15\%$. But it is useful to examine if this is true for cultural objects, which are composites of many cultural materials.

Gesso and wood panel paintings

Current research conducted at the Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences (Polska Akademia Nauk) is proving to be most interesting regarding the allowable climate variations for cultural objects. The researchers have carefully examined the mechanical, absorptive and dimensional properties of lime wood and gesso. Furthermore, they have developed one of the most sophisticated computer model systems for modelling wood panel paintings and polychrome sculpture (Kozłowski *et al.* 2011; Bratasz *et al.* 2011).

In the gesso studies, it was found that due to its brittleness, cyclic fatigue at very small strains would result in slow crack growth. But there are some interesting observations to be made. If the strain in the gesso was 0.0035, cracks would grow but after about 60,000 cycles there was no further crack growth. At a strain of 0.0025, cracks would grow but the crack growth ceases after about 22,000 cycles. If the strain was reduced to 0.0015 then no crack growth occurred even after 36,500 cycles. This suggested that there was critical strain of about 0.002. Furthermore, that the cracks eventually stop growing when the strains are 0.0035 and 0.0025 reinforces the idea that existing cracks begin to act as expansion joints, relieving further stresses and strains.

This research established a criterion for limiting the allowable RH cycle by using the critical strain of 0.002. In other words, what would be the RH fluctuation required to attain a critical strain of 0.002 in the gesso. The computer model developed in Poland uses a basic finite element analysis (FEA) technique whereby stresses, strains and deflections can be calculated throughout the object being modelled. But the new analysis technique goes further in that it calculates these quantities as moisture is diffusing through the object. So as the ambient RH is changing, the wood panel being modelled is dimensionally and mechanically responding to these changes.

The researchers in Poland used as an experimental model a simple, unrestrained 10 mm thick lime wood panel with a

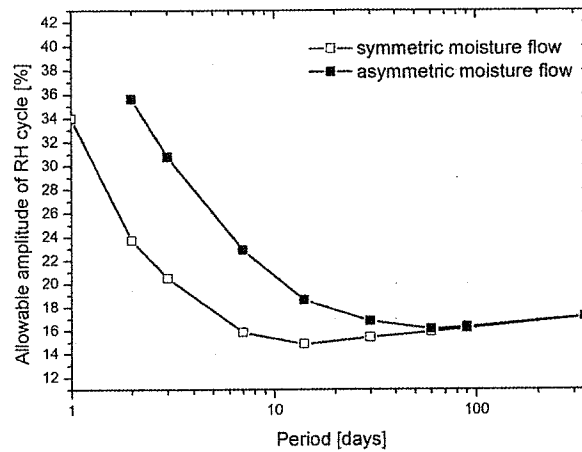


Figure 5 Allowable amplitude of the sinusoidal RH cycles as a function of the cycle duration (period of sine function) for a 10 mm single wood panel coated with a 0.5 mm thick gesso layer for a symmetric and asymmetric moisture flow at 20°C. Amplitude of RH variation was calculated assuming a starting point of 50% RH (Kozłowski 2012).

gesso coating. It was this experimental panel that assisted in carefully determining and calibrating all of the mechanical, dimensional and moisture diffusion properties of the materials used in the computer model. Since deflection of the model (in this case warping) is the primary solution to the analysis, it was important that the computer model deflections should match the deflections of the actual experimental panel with changes in RH and temperature. The results show the deflections in both the model and experimental panel to be remarkably consistent. Well-developed computer models can be used as diagnostic as well as predictive tools. In one sense, the model can help determine the cause of past damages (in the diagnostic mode) to an object and, in another it can be used to determine the consequences of environmental changes in advance (in the predictive mode). It is possible to illustrate both modes here.

Moisture diffusion in wood (and most materials) is fairly slow and it takes time for wood panels to fully respond to changes in RH. This is reflected in the low values of moisture diffusion coefficients for wood and as a consequence rapid changes in ambient RH will have less of an influence than slower changes. It now remains to determine both the speed of a RH cycle and the amplitude of that cycle, which will cause the strains in the gesso to reach the critical strain of 0.002.

Figure 5 shows the allowable amplitude of the sinusoidal RH cycles as a function of the cycle duration (period of sine function) for a 10 mm single wood panel coated with a 0.5 mm thick gesso layer for a symmetric and asymmetric moisture flow at 20°C. The amplitude of the RH variation was calculated assuming a starting point of 50% RH. Symmetric moisture flow reflects a panel painting with a gesso coating and no paint layer that can act as a vapour barrier slowing down moisture penetration. Asymmetric moisture flow reflects the presence of a vapour barrier such as paint or another moisture-resistant coating. Figure 5 plots the period of the RH cycle versus the amplitude of the RH cycle (allowable amplitude of the RH cycle [%] to be read as $50\% \text{ RH} \pm$ the value shown).

In figure 5, the data show that for the symmetric moisture flow the minimum allowable RH amplitude is about $50\% \pm 15\%$ and this occurs for RH cycles that take at least 10 days.

Table 2 Worst-case duration of sinusoidal RH cycles and their corresponding allowable amplitudes for varying thickness of unrestrained, single panels coated with a 0.5 mm thick gesso layer, and free moisture flow through both faces.

Panel thickness (mm)	Allowable amplitude (%)	Cycle duration (days)
2	15.26	3
5	15.31	7
10	14.87	14
30	13.19	90
40	13.41	365*

* 40 mm thick panel does not fully respond to a sinusoidal RH variation with period of 365 days (Kozłowski 2012).

If the RH cycles occur faster, the allowable RH amplitude increases dramatically. For example, an RH cycle of one day has an allowable RH amplitude of $50\% \pm 34\%$. If the panel has an asymmetric moisture flow the minimum allowable RH amplitude is even greater – about $50\% \pm 16\%$ – and this only occurs at RH cycles of 60 days. That short-term RH cycles have a limited effect on the stability of panel paintings certainly contradicts current thinking. Using the computer model in a predictive mode makes it possible to conduct a parametric study on the environmental effects when the panel thickness is changed.

Table 2 shows the worst case scenario for different thicknesses of a model panel painting where the wood is completely tangential or the most dimensionally responsive. In general, the minimum allowable RH amplitude does not change significantly but as the thickness increases the duration of the RH cycle required to meet the minimum allowable RH increases dramatically. A panel of only 2 mm thick still requires a RH cycle lasting three days and a panel of 40 mm thickness requires a RH cycle lasting over a year.

If a panel painting is treated and restrained with either battens glued across the grain on the reverse or with a cradle

that is locked, the stresses in the wood panel itself become the concern. This is because RH changes can increase the stresses in the wood tenfold or greater than they would be in an unrestrained panel (Hagan *et al.* 2005).

Effects of cycling canvas paintings in large ranges of relative humidity

If a traditional canvas painting is exposed to cycling of large changes in RH then corner cracks can occur. This can be demonstrated by constructing a 'mock' painting of canvas, a size layer of hide glue and a 'design layer' composed of a hard gesso film having the mechanical properties of an old brittle oil paint film. This is shown in figure 6 (Mecklenburg 2007a).

This mock painting was cycled from 90% RH to 35% RH and then back to 90% RH. Each half-cycle (from high to low RH or low to high RH) required just less than 24 hours for full equilibration. Periodically, the test painting was examined to see what cracking might have occurred. It was observed that with one small exception, all of the cracks occurred at the corners of the painting. At the ends of selected cycles (#4,

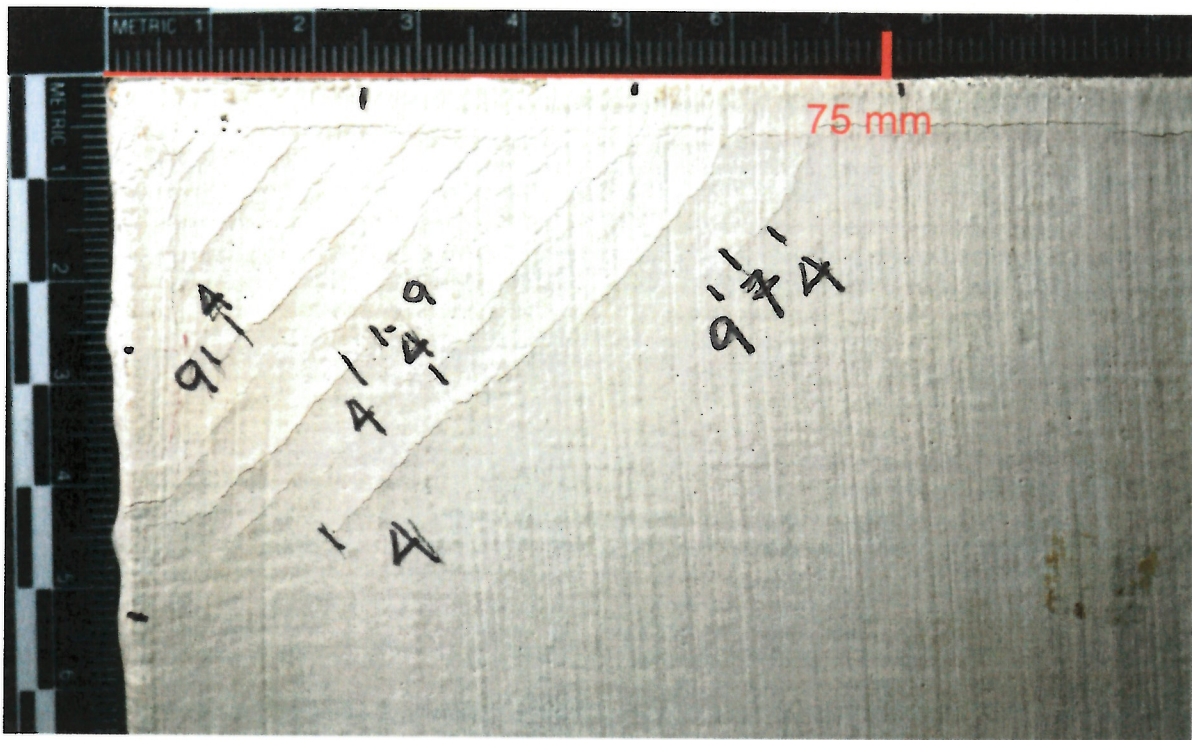


Figure 6 Results of cycling an experimental 'mock' painting from 90% RH to 35% RH and back to 90% RH. Additional cycling beyond the initial nine cycles did no further damage as the cracks that occurred relieved the stresses due to the initial RH cycles. This model painting was constructed with a stretched canvas, a hide glue size and a stiff gesso acting as a design layer. (Photo: Marion F. Mecklenburg.)

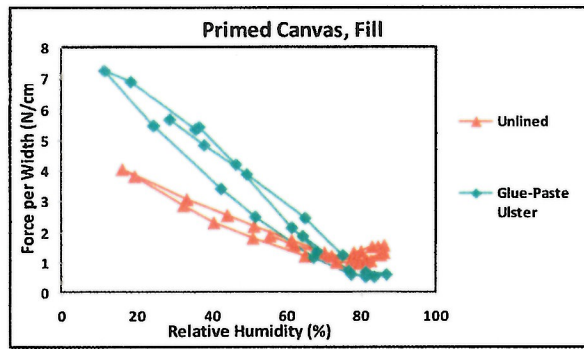


Figure 7 Increase in the low RH forces in a glue-paste lined painting when compared to an unlined painting. The glue layers, both the original size and the lining adhesive are responsible for cracking paintings (Andersen 2012).

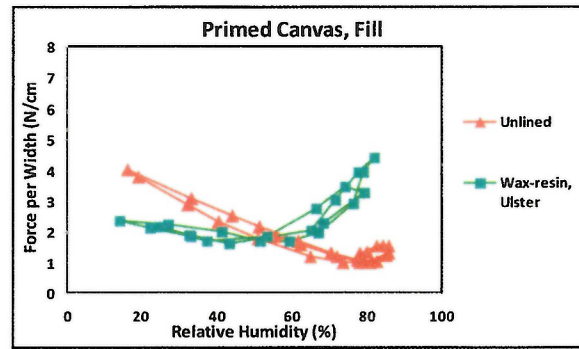


Figure 8 Increase in the high RH forces in a wax resin-lined painting when compared to an unlined painting. The canvas shrinkage in both the original and the lined paintings can induce cleavage of the paint films (Andersen 2012).

#7, and #9), the ends of the cracks were noted and marked. For example, a crack with a line and a '4' marked next to it indicated the maximum extension of the crack after four complete cycles from 90% RH to 35% RH and back to 90% RH. After nine cycles, no further cracking develops and this again suggests that the cracks are stress release mechanisms. This means that a cracked painting is able to withstand greater RH fluctuations than a painting with no cracks.

This occurs with many traditional paintings and, as seen, the cracks tend to be limited to the corners. This differs from the effects of low temperature where crack can occur throughout the painting. The primary cause of the corner cracking in these paintings is the response of the glue size layer to dramatic changes in RH (Hedley 1988; Mecklenburg 1982).

The effects of linings on canvas paintings

If a strip of a traditional painting is restrained and subjected to large RH cycles, the response of the painting can be seen in terms of the forces that developed in the painting at each step of the RH cycle. Figure 7 shows this force at different levels of RH for an unlined and glue-lined model painting. The 'painting' is a commercially primed linen canvas with animal glue size and a white lead ground.

The lined painting is the same as the unlined one but with a glue-paste lining adhesive and a secondary canvas support. Both plots show the fill direction of the canvases. At low RH levels, the force in both the lined and unlined 'paintings' increases, particularly in the lined painting. The very high level of the force in the lined painting is due to the addition of the glue-paste adhesive. Since the glue size in a traditional painting has the potential for cracking a painting at low RH levels, that hazard increases significantly with glue-paste lined paintings.

At high RH levels, the canvas develops higher forces as the canvas tries to shrink but is restrained by the stretcher. This is also shown in figure 7. Canvas shrinkage at high RH levels has the ability to cause paint layers to cleave away from the painting. Interestingly, other lining techniques can actually increase this behaviour.

Figure 8 shows the forces developed in both lined and unlined model paintings at high humidity. In this case, the lining adhesive was wax resin and the lining canvas was linen. As can be seen, the wax resin-lined painting develops

significant force at high RH. This force is a combination of the original and lining canvases attempting to shrink when restrained at these RH levels. It is worth noting that the wax resin adhesive does not prevent water vapour penetration. The reason that the shrinkage is aggravated is that the wax resin adhesive fills in all gaps in the linens where, without the wax resin, open spaces in the linens would have acted to relieve the forces.

Clearly, conservation treatments such as the lining techniques shown have the potential to make paintings considerably more responsive to changes in the ambient environment.

Conclusions

Research conducted since 1991 has helped to provide a clearer picture of the influence of the environment on cultural objects. Low temperatures not only cause cracking in paint films but because they induce brittleness, they represent an increased risk from shock and vibration. Twentieth-century oil paintings, due to the possible presence of zinc oxide, represent real shock and vibration hazards even at room temperature due to the inherent behaviour of the materials.

While RH has long been considered to be the primary cause of damage to many cultural objects, new research is showing that slow moisture diffusion considerably reduces the effects of rapid RH cycles in wood objects including panel paintings, polychrome sculpture and furniture. It is now evident that traditional conservation treatments can have a major adverse effect on the stability of many objects. Certain lining techniques make some paintings more responsive to RH and restraining panel paintings with battens or cradles can have severe consequences.

Inspecting objects prior to transportation for unstable or temperature-sensitive materials and prior conservation treatments will help to assess the safety of these objects.

Note

1. Unpublished data for the testing of woods in the cross-grain direction. It has been observed that both the strength and stiffness is considerably reduced for most woods when the RH drops below 30%. This is contrary to current thinking that low RH stiffens and strengthens the wood in the tangential and radial directions.

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Moving Collections

Processes and Consequences

Flytting av samlinger prosesser og konsekvenser

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