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MECHANICAL BEHAVIOR OF ARTIST'S ACRYLIC EMULSION PAINTS UNDER EQUILIBRIUM CONDITIONS

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INTRODUCTION

The response of materials to the environment is of considerable interest to those who care for cultural collections. These include objects made from contemporary as well as traditional materials. One class of material that has gained wide acceptance as a painting medium is acrylic. Acrylics are a fast drying paint that has considerable flexibility in terms of painting techniques and artist's manipulation. Paintings by a large number of artists are routinely shown in every museum in the world. The concern for a painting's longevity is prompting a systematic examination of paints and their mechanical response to different environmental conditions. Clearly the two biggest environmental concerns are changes in temperature and relative humidity (RH). Of special concern are those objects having constitutive materials that are restrained in their dimensional movement by changes in temperature and RH. This restraint can result from the object's construction or its mounting, such as a stretched painting. If restrained and either cooled or desiccated, materials will develop stresses in place of contraction and damage is a real possibility. The stresses in the materials, $\sigma(T)$ and $\sigma(RH)$, from restrained cooling or desiccation can be both measured and calculated. The basic equations for calculating the stresses are:

$$\sigma(T) = E(T)/\epsilon(T) \qquad \text{Eq. 1}$$
$$\sigma(RH) = E(RH)/\epsilon(RH) \qquad \text{Eq. 2}$$

where: E(T) and E(RH) are the equilibrium modulus as functions of temperature and RH and, $\epsilon(T)$ and $\epsilon(RH)$ are the strains induced in the materials as functions of temperature and RH. The strains, $\epsilon(T)$ and $\epsilon(RH)$ are calculated from the thermal, γ, and moisture, α, coefficients of expansions of the materials where:

$$\epsilon(T) = -(\int \gamma dT)/(1 + \int \gamma dT) \qquad \text{Eq. 3}$$
$$\epsilon(RH) = -(\int \alpha dRH)/(1 + \int \alpha dRH) \qquad \text{Eq. 4}$$

EXPERIMENTAL

The equilibrium modulus can be determined by taking the initial slope of a stress-strain curve with an extremely low loading rate. This process can take an excessively long time. For example, figure 1 shows the equilibrium stress-strain curves of several samples of three different acrylic emulsion paints. These are burnt sienna, titanium white and cadmium yellow. These tests took up to 18 months to conduct. The apparent scatter is induced by temperature fluctuations of as little as 1°C where the stress can vary as much as 8 PSI per degree C. In the case of these three paints, the equilibrium modulus are 9000 PSI for burnt sienna, 12000 PSI for titanium dioxide, and 3000 PSI for cadmium yellow. There are other ways of determining the stiffening effects of the environment.

The thermal and moisture coefficients were determined by measuring the dimensional changes occurring when different paints were subjected to changes in temperature or relative humidity. Typical examples of these coefficients are shown in figures 2 and 3. This data was used in computing the changes in the modulus of the paints resulting from environmental changes.

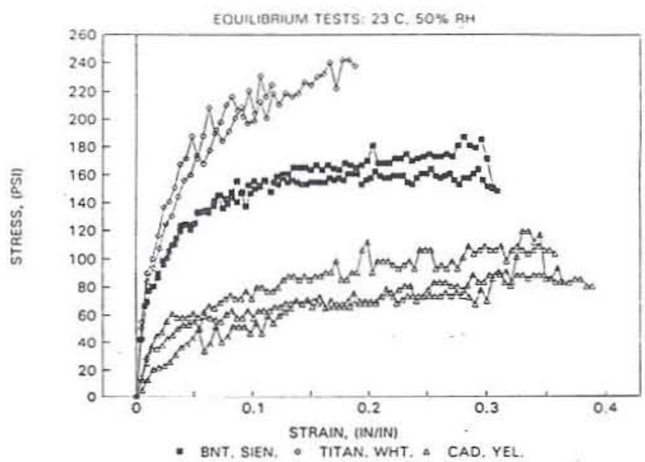

Figure 1. Eqúlibrium stress-strain plots ot acrylic paints taking nearly 18 months to complete at a constant RH.

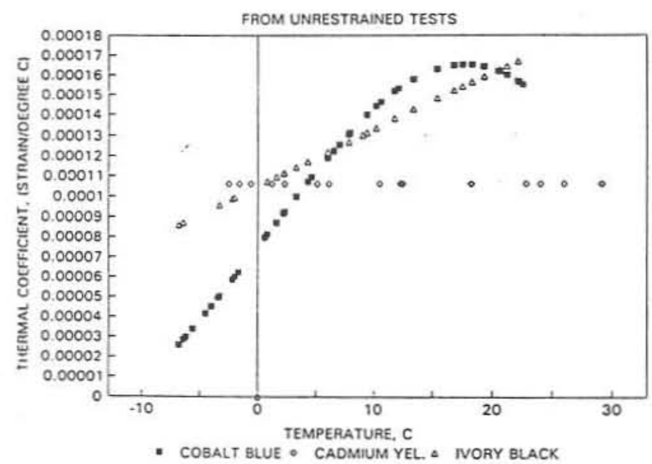

Figure 2. The measured thermal coefficients of expansion for three acrylic paints.

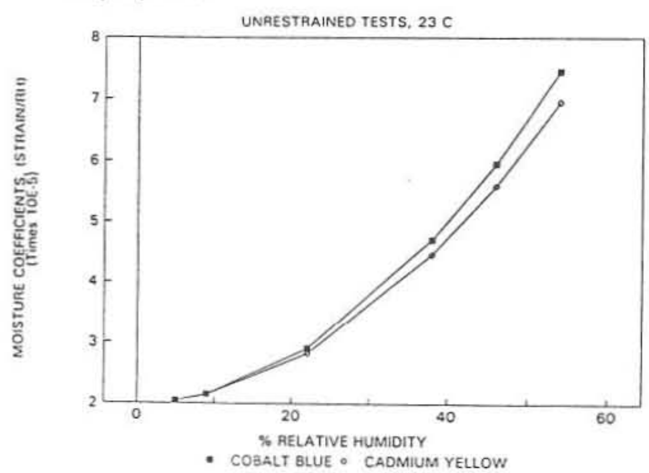

Figure 3. The measured moisture coefficients of expansion for two acrylic paints.

The modulus can be calculated by:

$$E(T) = \sigma(T)/\epsilon(T) \qquad \text{Eq. 5}$$
$$E(RH) = \sigma(RH)/\epsilon(RH) \qquad \text{Eq. 6}$$

where $\sigma(T)$ and $\sigma(RH)$ are the stresses resulting from restrained tests. To obtain this data, sample specimens of 13 year-old, unsupported, acrylic paints were restrained and the temperature varied at 5% RH and restrained and desiccated at 23°C. The results of these tests are shown in figures 4 and 5. The paints restrained and cooled developed significantly higher stresses than those restrained and desiccated. The stresses developed under restrained desiccation are nominal, particularly when compared to the ultimate strengths determined from constant environment equilibrium tensile tests. These stresses reach, at a minimum, the 50% equilibrium ultimate strength values or significantly higher. The ultimate strength at 50%RH for cobalt blue is 130 PSI, for cadmium yellow is 90 PSI, and for ivory black, around 50 PSI. The real concern, then, is the stress levels reached with restrained cooling. These stresses are potentially damaging when considering that the T_g of these paints is around 5° to 10° C,(1) and the paints lose ductility and become stiffer.

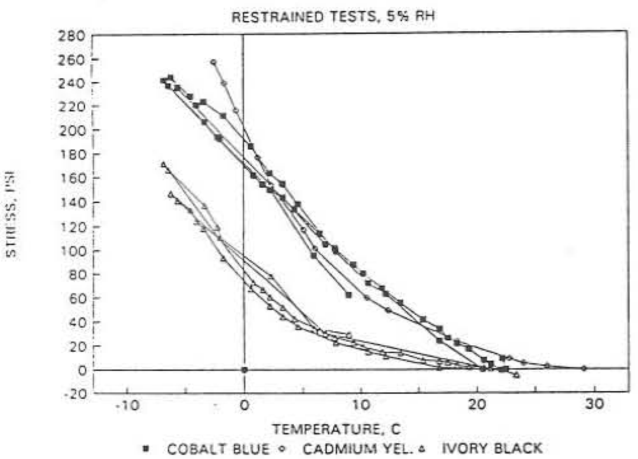

Figure 4. Stresses developed in restrained acrylic paint samples subjected to temperature changes.

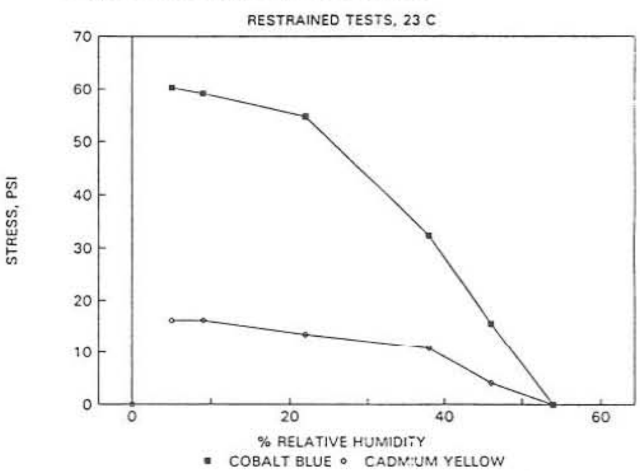

Figure 5. Stresses developed in restrained acrylic paint samples subjected to changes in relative humidity.

A measure of the increased stiffness is the increase in the modulus with cooling. This was calculated using eq. 5 and the results are shown in figure 6. The three paints illustrated are cobalt blue, cadmium yellow, and ivory black. The increase in stiffness with cooling is dramatic, nearly 10 times, with a temperature change of about 30°C. At sub-freezing temperature these paints are susceptible to damage from impact.

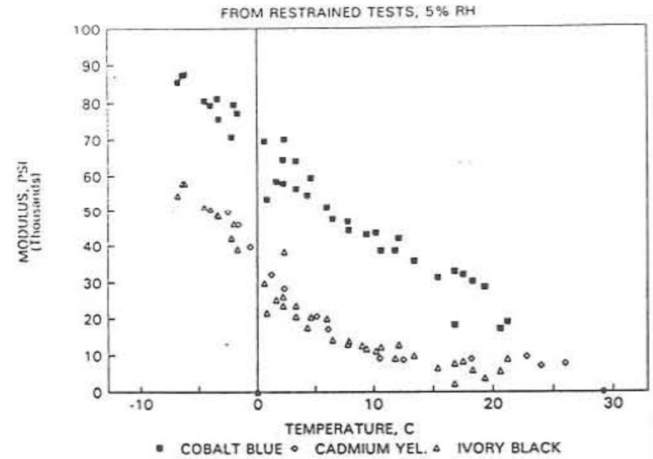

Figure 6. The calculated equilibrium modulus of acrylic paint samples using the thermal coefficients of expansion and the results from the restrained cooling tests.

CONCLUSION

The plastic region of the equilibrium stress-strain curves at 50% RH and 23°C is extensive. Some of the acrylic paints can extend nearly 40%. Similar testing at lower temperatures show considerable loss of this plastic region. The restrained desiccation tests showed that the stress development was relatively low. This implies that deep drops in relative humidity will not have the damage potential that is evident in other artists materials such as hide glue (2). The effects of cooling, however, cause significant stress development in restrained paint samples. This is not an unusual condition, since paint layers are often restrained by their substrates or stretchers as found in stretched canvas paintings. The increase in stiffness, the modulus, that accompanies cooling is of concern also since it demonstrates the even minor displacements to acrylic paint films will result in high stresses. This makes the objects using such paints quite prone to handling and impact damage.

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