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THE MECHANICAL BEHAVIOR OF ARTISTS' ACRYLIC PAINTS WITH CHANGING TEMPERATURE AND RELATIVE HUMIDITY

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ABSTRACT

Acrylic paints are commonly found in modern art. The mechanical properties of strength, modulus, and ability to elongate of a large sampling of artists' acrylic paints were studied in the temperature range of -8° C to 33° C, and from 5% to 50% relative humidity (RH). Data derived from the stress-strain curves suggests that acrylic paints lose the ability to plastically deform in response to applied force below temperatures of 5° C at 50% RH, and below 11° C at 5% RH. The brittle behavior of acrylic paints below these temperatures suggests a glass transition temperature that is RH dependent.

INTRODUCTION

Acrylic paints have been commonly found in modern art since their introduction slightly over fifty years ago. The widespread use of these paints makes the chemical and mechanical properties of acrylic paints important to study so that one can avoid conditions that might make paintings using these paints prone to damage from impact or vibration.[1]

Acrylic paints are polymer emulsions in water. Pigment particles, or dyes bound to transparent carriers, are suspended in the emulsion. The most commonly used emulsion in contemporary acrylic paints is a copolymer of methyl methacrylate and ethyl acrylate marketed under the brand name Rhoplex AC-33 or Rhoplex AC-34.[2] The properties of artists' paints can differ significantly from industrially used paints because, in general, they have larger pigment to volume concentrations (PVC). The properties of the acrylic polymer emulsions may also be altered by the addition of dryers, plasticizers, and fillers by individual manufacturers.

The dynamic mechanical properties of acrylic paints were studied in a temperature range from -8° C to 33° C and in a relative humidity (RH) range from 5% RH to 90% RH. These properties are useful in the analyzing the risk of transporting and handling modern acrylic paintings. The research indicates that the risks at certain environments can be considerable.

EXPERIMENTAL

The mechanical properties of strength, modulus, and ability to stretch of artists' acrylic paints were found through tensile testing in sealed environmental chambers. The paint test samples were 10-12 years old. The strength of a material is the magnitude of stress required to break it. The modulus of a material is a measure of its stiffness. The stretch or strain is a measure of the materials ability to deform prior to breaking. If a material has an increasing stiffness and a decreasing ability to stretch when loaded, it is said to become increasingly brittle. Relative humidity was maintained for each testing chamber by buffering the environment with conditioned silica gel. Loading rates ranged from 0.001 to 0.01 in/in/sec. and these are in the range of rates commonly experienced by art objects during transit or handling.

THE EFFECT OF RELATIVE HUMIDITY OF THE MECHANICAL PROPERTIES OF ACRYLIC PAINTS AT 23° C

Figures 1 and 2 show the relative strength and stiffness of nine acrylic paints at 5% RH and 50% RH, at 23° C. At 5% RH all acrylic paints were found to be significantly stiffer and stronger. Figure 3 shows the comparative ability of acrylic paints to stretch at 5% RH and at 50% RH. Acrylic paints, in general, are much more flexible than other commonly used artists' paints. For example, traditional artists' oil paints are rarely able to stretch over 10% under the ambient conditions of 23° C, 50% RH. All tested acrylic paints, however, were able to stretch over 50% at 50% RH, and four of nine tested types of acrylic paint stretched well over 200%.

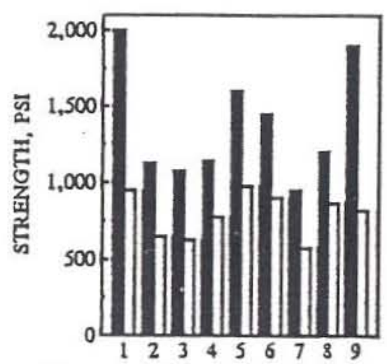

Figure 1. Strength of acrylic paint at 23° C.

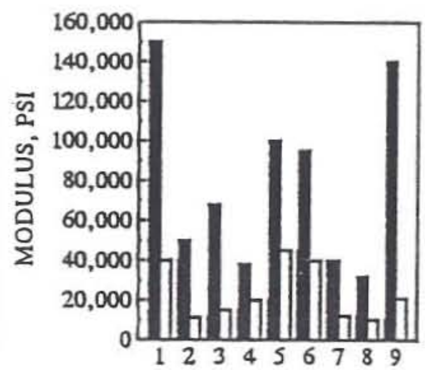

Figure 2. Stiffness of acrylic paint at 23° C.

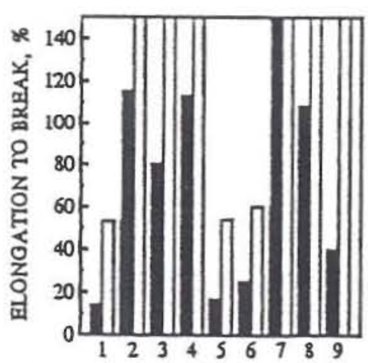

Figure 3. Ability of acyrlic paints to stretch at 23° C.

■ 5% RELATIVE HUMIDITY
□ 50% RELATIVE HUMIDITY

1 BURNT SIENNA
2 BURNT UMBER
3 CADMIUM YELLOW
4 CERULEAN BLUE
5 COBALT BLUE
6 IRON OXIDE RED
7 IVORY BLACK
8 RAW SIENNA
9 TITANIUM WHITE

At 5% RH there is a dramatic loss of the acrylic paint's ability to stretch at 5% RH when compared to 50% RH. This trend is dramatically exemplified by an acrylic titanium white that stretched 255% at 50% RH, with strength and modulus of 820 psi and 21,000 psi respectively. At 5% RH this same paint stretched only 40%, but had correspondingly large increases in strength and stiffness to 1900 psi and 140,000 psi. While it is important that the acrylics are getting stronger with desiccation, the loss of their ability to deform demonstrates their trend to glass like behavior. This should be taken as an indication of probable damage resulting from impacts, both on their edge and on their surface.

THE EFFECTS OF TEMPERATURE ON THE MECHANICAL PROPERTIES OF ACRYLIC PAINTS AT 5% RH AND AT 50% RH

Temperature can have an even greater effect on the mechanical properties of artist materials than relative humidity. The strength and stiffness of acrylic paints was found to be higher at lower temperatures than at 23° C. Figures 4 and 5 show the variation in strength with temperature at 50% RH and 5% RH. At temperatures below 5° at 5% RH and below 11° C at 50% RH many of the acrylic paints exhibited only elastic deformation, deforming nearly linearly until failure.

At lower temperatures, below approximately -1.5° C at 50% RH, and below 5° C at 5% RH acrylic paints often seemed to break early, failures were often catastrophic, with samples shattering into multiple pieces. These observations indicate that at low temperatures acrylic paints may become fracture sensitive, that is, rather than distributing stress evenly across the volume of the sample, the stress is concentrated around impurities or defects within the sample. Multiple areas with stress concentrations greater than the materials' strength can lead to multiple failure points.

Figures 6 and 7 show the variation in stiffness (modulus) with temperature of acrylic paints at 50% RH and at 5% RH. At 50% RH, the modulus of acrylic paints is relatively constant between 15° C and 23° C, and drops to zero near 33° C. As temperatures drop below 15° C, the stiffness of acrylic paints rises rapidly. At 5% RH, the modulus begins to rise at the same rapid rate beginning near 23° C. Referring to Figures 4 and 5, it is seen that these rises in modulus are accompanied by similar rises in strength under 15° C at 50% RH, and under 23° C at 5% RH.

Larger strengths and stiffnesses in acrylic paints at low temperatures are accompanied by their decreased ability to stretch, shown in Figure 8. At temperatures of 5° C at 50% RH, and of 11° C at 5% RH, some types of acrylic paints are brittle. By brittle is meant that acrylic paint samples showed no plastic deformation before failure. When brittle, acrylic paints generally stretched less than only 1% before breaking. All the acrylic paints tested were brittle below -1.4° C at 50% RH and 5° C at 5% RH, the same temperatures at which fracture sensitivity was seen for certain types of acrylic paint.

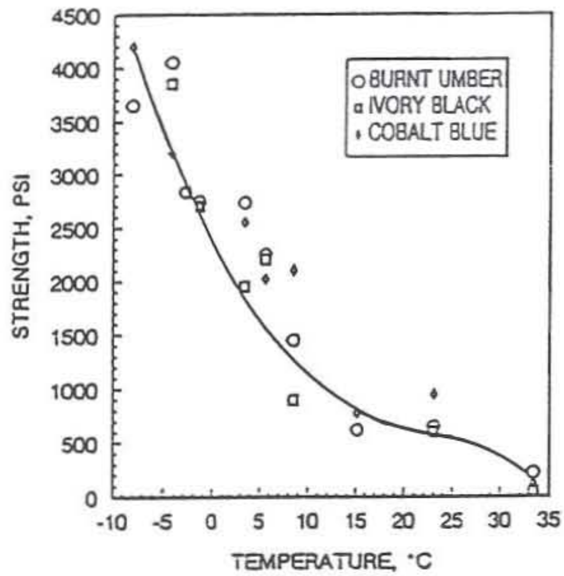

Figure 4. The strength of acrylic paints at 50% RH.

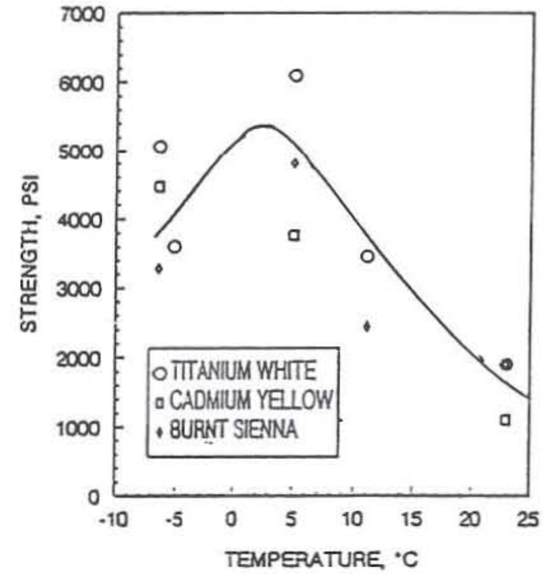

Figure 5. The strength of acrylic paints at 5% RH.

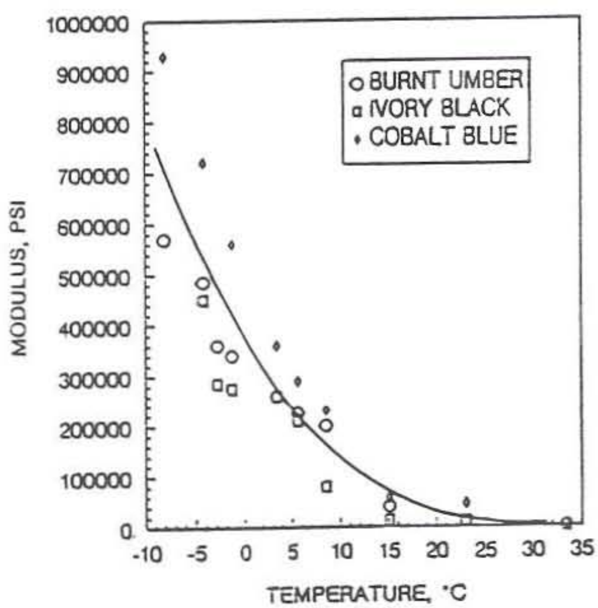

Figure 6. The stiffness of acrylic paints at 50% RH.

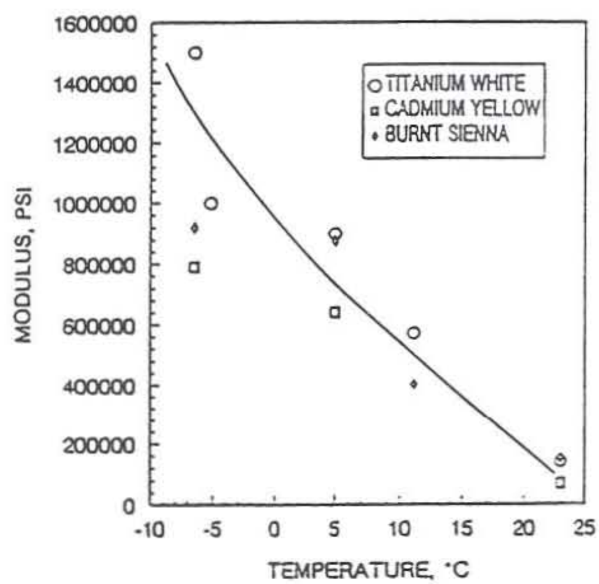

Figure 7. The stiffness of acrylic paints at 5% RH.

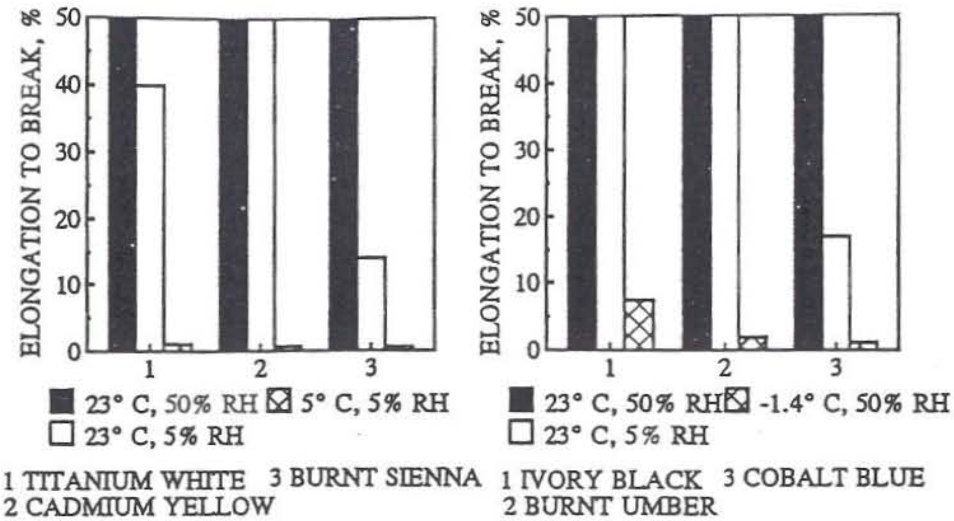

Figure 8. Elongation to break of acrylic paints at different temperature and relative humidities.

The examination of the temperature at which acrylic paints become brittle may be an examination of the glass transition temperature (T_g) in mechanical rather than thermal terms. In fact, the T_g of both Rhoplex AC-33 and Rhoplex AC-34 is calculated to be about 9° C.[3] Both of these T_g's are near the measured temperature at which acrylic paints are brittle. The addition of plasticizers to a polymeric system is thought in most cases to lower the T_g. The temperature at which acrylic paints are brittle at 5% RH, ≈5° C, is less than the calculated T_g for the co-polymers, possibly due to the addition of plasticizers by the manufacturers. The T_g of Ivory Black acrylic and cobalt Blue acrylic as measured by differential scanning calorimetry (DSC) was found to be 4.7 and 5.5 °C respectively.

The results indicate that acrylic paints become brittle at higher temperatures in low RH environments than at 50% RH. This suggests that the addition of atmospheric water to the environment of the acrylic paint samples (which may be considered thin films) lowers the T_g of these samples from approximately 5° C to -1.5° C. In this case, water is acting as a plasticizer. This type of phenomenon is found in many polar polymeric systems, nylon being an example.[4]

CONCLUSION

Acrylic paints were found to be significantly stronger and stiffer at 5% RH than at 50% RH, at 23° C. Although the ability of acrylic paints to stretch at 5% RH is less than at 50% RH, all tested samples still stretched over 20% of their original length at 5% RH.

The modulus and strength of acrylic paints rise with decreasing temperature. At 50% some acrylic paints became brittle at 5° C, and all acrylic paint types were brittle below -1.4° C. At 5% RH, some acrylic paint types became brittle at 11° C, and all had become brittle below 5° C.

Correlation of the brittleness of acrylic paints with the T_g of acrylic paints perhaps indicates that acrylic paints pass through a T_g near 5° at 50% RH and 10° C at 5% RH. Atmospheric water would then be acting like a plasticizer and would lower the T_g.

The test results indicate that temperature and relative humidity play a more important part in the behavior of acrylic paintings and painted objects than previously believed. Low temperatures, especially, may be hazardous environments during the transportation of acrylic painted objects.

Acknowledgements

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