## 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 5% to 50% relative humidity (RH). Data from 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 at 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 their deterioration can be prevented or slowed.[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 modern acrylic paintings, some of which may be quite large.

### EXPERIMENTAL

The mechanical properties of strength, modulus, and ability to stretch of artists' acrylic paints were found through tensile testing in plastic environmental chambers of 10-12 year old paint samples. 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, in the range of loading 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. In particular, 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%.

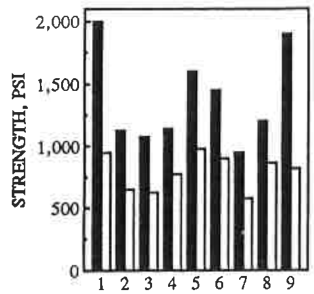


Figure 1. Strength of acrylic paint at 23° C.

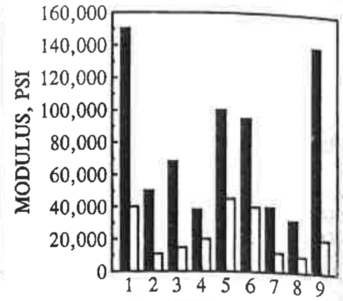


Figure 2. Stiffness of acrylic paint at 23° C.

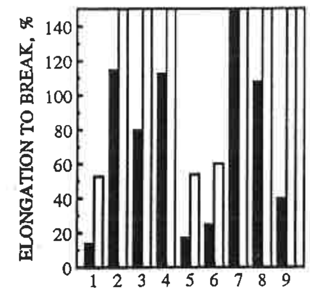


Figure 3. Ability of acrylic paints to stretch at 23° C.

■ 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

A smaller ability to stretch at 5% RH versus 50% RH was accompanied in all cases by greater strength and stiffness. 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.

The shape of acrylic paint stress-strain curves at 23° C, 50% RH can only be qualitatively divided into elastic and plastic zones. Plastic regions of the curves were generally level with a stress equal to or near the particular paints' strength. In some cases, full recovery of acrylic paint morphology was found after unloading samples from 100% elongations. At 90% RH, 23°, acrylic paints lost almost all of their stiffness, and plastic deformation of acrylic paints was made with little applied stress.

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

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.

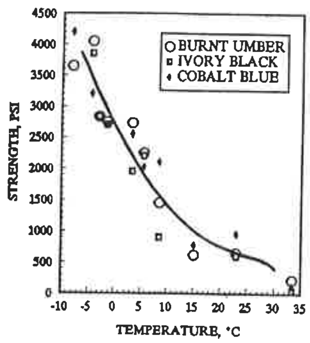


Figure 4. Strength of acrylic paint at 50% RH.

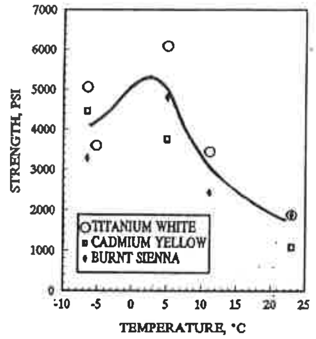


Figure 5. Strength of acrylic paint at 5% RH.

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.

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.

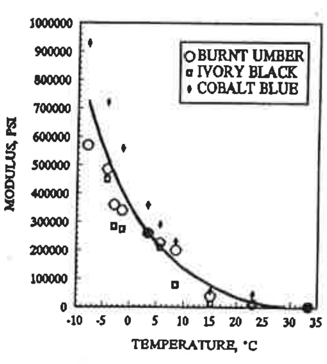


Figure 6. Stiffness of acrylic paints at 50% RH.

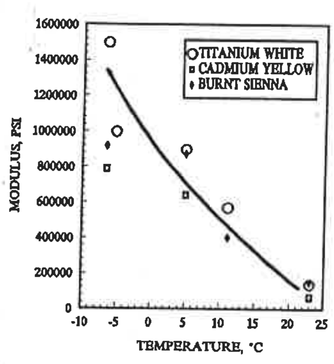


Figure 7. Stiffness of acrylic paints acrylic paints at 5% RH.

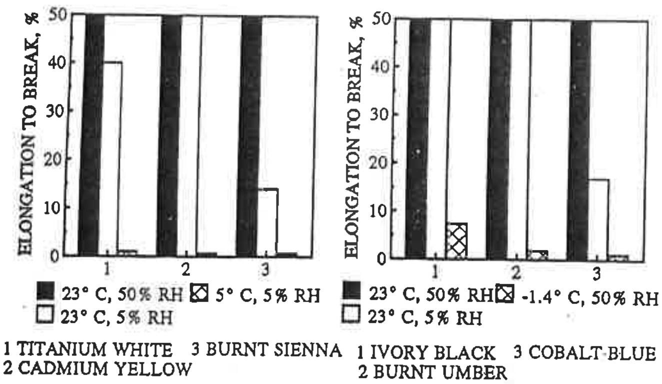


Figure 8. Elongation to break of acrylic paints at different temperatures and relative humidities.

The results indicate that acrylic paints become brittle at higher temperatures in low RH environments than at 50% RH. This perhaps indicates 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 at -1.4° C. At 5% RH, some acrylic paint types became brittle at 11° C, and all were brittle at 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 is acting like a plasticizer and lowering 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.

## REFERENCES


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4. J.J. Alkonis, W.J. MacKnight, Introduction to Polymer Viscoelasticity, John Wiley and Sons, (1983) 77.