# Mechanical properties of tempera paints

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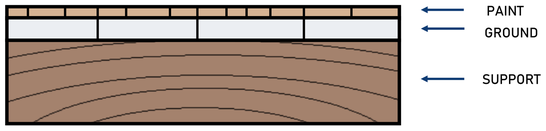
## Introduction

Paintings are, on the one hand, the category of most valuable objects in museums and, on the other, they are the most vulnerable relative humidity (RH) variations.

Differences in the change of its dimensions in response to humidity variations result mechanical stresses in the painting, which can cause of cracks.



Model of panel painting

Numerical modelling of moisture response of historic materials is one of the tools used to determine the environmental specifications for museums and to ensure safe preservation of vulnerable objects.

So far, computer models of historic panel paintings were typically considered a glue-based ground layer on a wooden substrate, whithout paint.


Virgin and Child' by unknown author (XV century) from St. Mary's Basilica in Krakow, [Microscopic scan done by Sergei Antropov]


Enlarged part of the painting 'Virgin and Child'

To overcome above simplification and model the formation of cracks in the paint layer, material properties of paints are necessary.

Tempera paints were commonly used in early Renaissance Italian paintings, but their mechanical properties are unknown contrary to other types of paints.

## Objectives

- Filling the gap in knowledge regarding mechanical properties of tempera paints.
- Developing 3D model of panel painting with developed craquelure pattern.
- …and through it contribute to the develkopement of environemntal guidelines for museums.

## Materials

PIGMENTS representative series uses in traditional painting practice with various chemical characteristics:


lead white
$2PbCO_3{\cdot}Pb(OH)_2$


azurite
$2CuCO_3{\cdot}Cu(OH)_2$


yellow ochre
FeO(OH))

BINDER – historical recipe C. Cennini ca. 1400

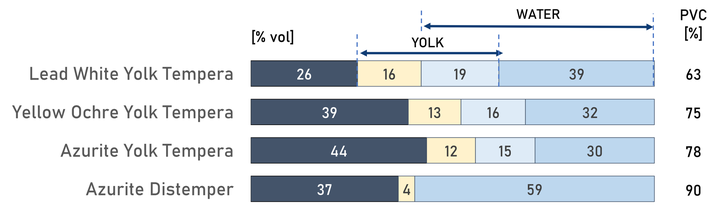
1. YOLK TEMPERA: yolk + water (1:1)

2. DISTEMPER: 7% wt water solution of rabbit skin glue
according to Cennini used in the case of blue pigments

### Proportions of pigment and binder

adopted by a practicing conservator to reach the required workability


[www.kremer-pigmente.com]



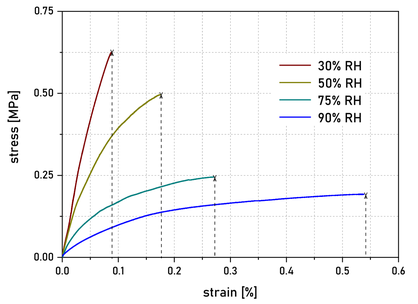


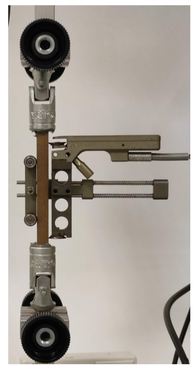
6 mm x 6 mm x 80 mm

## Mechanical properties

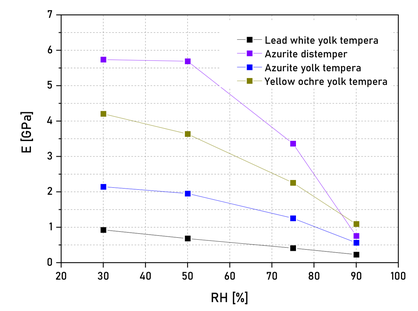
Tensile properties were performed in a Universal Testing Machine with humidity and temperature controlled by a climatic chamber.

Stress-strain curve for lead white tempera



Moduli of elasticity

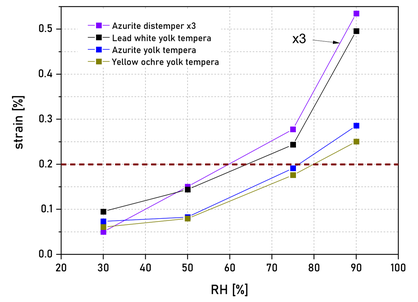



Moduli of elasticity of 30-year oil paints

| Oil paint | Moduli of elasticity [GPa] |
|---|---|
| Lead white in CPLO | 0.99 |
| Lead white in CPLO with litharge | 2.90 |
| Zinc white in CPLO | 2.10 |
| Sap green in CPLO | 0.71 |
| Verdigris in CPLO | 1.90 |
| Red iron oxide in CPLO | 0.05 |
| Winsor & Newton aklyd cobalt blue + 654 | 0.62 |
| Malachite in CPLO | 3.30 |
| Synthetic ultramarine in CPLO | 1.40 |

Moduli of elasticity shows a dependence on RH : decrease with increasing RH

Critical strain



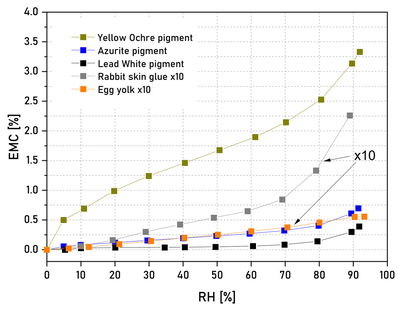

Damage criterion
(critical strain of gesso)

Critical strain varied with RH levels, increase with increasing RH
In low RH critical strain of tempera is below criterion of damage

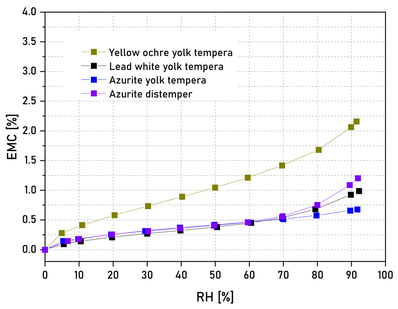
## Moisture sorption

Water vapour sorption isotherms measured with a vacuum microbalance

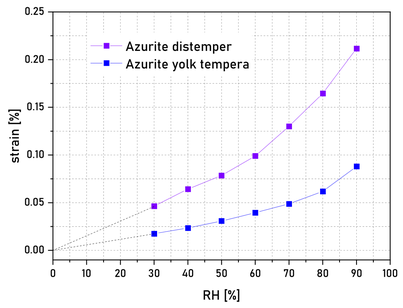
Sorption isotherm of pigments and binders




Sorption isotherm of paints




Swelling isotherm




The differences in the moisture sorption of tempera correspond to the sorption of the pigment used.

Swelling isotherms measured with an optical extensometer

## Conclusions

- In this study for the first time mechanical properties of tempera paints, such as moduli of elasticity, strain at break and swelling isotherm were determined.
- Mechanical properties of the paint depend on the pigment, the binder and relative humidity.
- The tempera paints is significantly more brittle than the ground and other paints.

## Acknowledgments

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