Simple method for evaluation of wood consolidant materials

Farmakalidis Helen Veronika

Conservation department of Benaki Museum
Koumbari 1, Athens
farmakalidis@benaki.gr

Introduction

When a conservator has to conserve an object he/she usually first apply the method on samples and test their properties, then the samples examined and the method can be evaluated, so the conservator can safely proceed to the final application of the method on the object.

Many times the conservators choose a consolidant material just because they are more familiar with this material and also because of years experience. But is every project similar with the previous one, is the experience the only factor that should follow when we choose a method and a conservation material? The conservator have to estimate all the parameters for choosing the most applicable method and this can be done after examining the object, its technology and preservation condition, it is important to reconsider the environmental conditions that the object is exhibited or stored and then he/she proceed evaluating the rage of materials that can be used for the conservation treatment.

Today conservators have a wide range of consolidation materials which are used for conservation, but very few of them are manufacture especially for conservation needs. For choosing the applicable material is important to know materials properties which can be collected from the technical data sheets and information which can be obtain after testing and those materials. Since the materials are produce for specific industries, they appear to have little relevance to the requirements of the conservators, also the information on the technical data are results of British, American or German standards which are usually on different units not easily comparison and some times its difficult to understand. *(Blackshaw M, Ward E, 1982)*

There are many analytical techniques for characterizing a polymer such as spectroscopic techniques, ultraviolet, infra red and Raman spectroscopy, nuclear and magnetic, electron spin spectroscopy, X-ray diffraction, transmission electron microscopy, scanning electron microscopy, thermal analysis and chemical techniques. *(Campbell D, White J. 1994)* But most of the conservators do not have a chemist background for applying or understanding analytical methods, but they have the theoretical knowledge and the practical skills to assess the materials by simple tests and evaluate their applicability as conservation materials.

Picture 1: Deposition of Christ

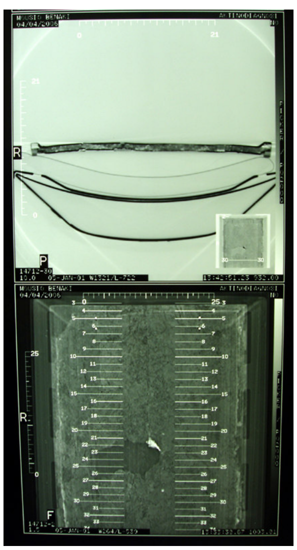
This speech has a target to study some of the consolidant materials which are used for the consolidation of wood objects in Greece and examine them by using simple tests and methods which can be used in the conservation laboratory. The most important issue is the simplicity of the tests, which allowed the assessing process of the materials and the evaluation of the results by a conservator. I am going to introduce you the method by using a case study of an icon which was the motive for producing this series of tests.

Picture 2: Back side of the wood support.

The icon: "The Deposition of Christ"

During the year of 2006 an icon came in Benaki Museum laboratory for conservation treatment. *(Picture 1)* The icon had an accident, after mechanical damage some areas the painted surface with a thin wood layer were detached. The icon was "The Deposition of Christ" which belongs to Renas Andreadis collection. Icon's technology is egg tempera on wood, priming on textile, size 50,5X37,5X2cm and its from Western Macedonia, c. 1400. (*Dranadaki A, 2002)*

Picture 3: Ultra Violet photograph of the back side.



Picture 4: Tomography.

The icon has been conserved on past treatment probably during 1960. The wood had been consolidated (with unknown consolidant) and damaged areas of the wood panel were replaced with new pieces of wood. *(Picture 2)* But the structure was not in stable condition and during handling the texture of the wooden support was coming off and it was a danger of further damage. The examination of the icon revel that the wooden support had been consolidated as we can see on Ultra violet photograph the treated part of the wood fluoresce differently than the new pieces of wood. *(Picture 3)* The icon was also examined by tomography which was applied to the entire surface by sections on every 5 cm and as we can see on tomography photograph between the wood and the painted surface where was a gap of air, which makes as wonder why on these areas there is no stable texture to support the painted surface. After making an investigative cross section on the back side of the icon, by removing a new piece of wood it was discovered the conservator had firstly applied a layer of polyurethane foam between the painted surface and areas that the original wood, which was destroyed after wood eating insects attack. As we known polyurethane foam has a sort life and by the time it becomes spongy and inapplicable to improve the cohesion and support the deteriorated areas. On the tomography all the areas which have polyurethane are marked on the film as gaps with air. Today we have been asked to conserve the icon and stabilize its condition by consolidating the wood structure. *(Picture 4)* The first thought was to remove the new pieces of wood and the polyurethane foam and then try to consolidate the original wooden support. But the old wooden support is badly deteriorated and the new pieces of wood have been attached by epoxy adhesive. Epoxy is very strong adhesive (with good mechanical properties) and it's not reversible on organic solvent, so if we try to remove the new pieces of wood by mechanical method part of the icon's wood will be removed and damaged. Considering the danger of damaging the wooden support, the consolidation of the entire structure was probably more appropriate. The project had as a target to make an actions plan for choosing the right method and material for the consolidation of a wooden object.

Consolidation treatment

The purpose of consolidation treatment is to establish the cohesion of the deteriorated material, by improving its mechanical characteristics and also achieving the cohesion between poor and healthy areas. With consolidant treatment we regard to conserve the deteriorated areas and at the same time to preserve and stabilize the healthy parts. This can be done by slowing down or even suspend the deterioration process.

Consolidation can be successful when:

- You have first study the deterioration mechanism of the poor material.
- You have knowledge of consolidant's characteristics.
- You choose a consolidant by following material's recommendations and not your preference on that material.
- When you have firstly study the compatibility of the deteriorated material with the consolidant.
- You first apply the method on lab samples.
- And then you apply the method on a certain area of the object and evaluate the results.
- You need to estimate the easiness of the application method, compatibility of the material, reversibility and also heath and safety during and after consolidation.

Choice of consolidant

There is a wide spectrum of consolidants which can be used which are natural, traditional materials, semisynthetics and synthetics. The properties of natural and traditional consolidants such as proteinaceous glues, drying oils, waxes and natural resins are well know because of their long period of use. The disadvantages of natural consolidants should not be ignored; they have poor penetration and low degree of strengthening, the sensitivity to changes in moisture content of the treated wood and the increasing embrittlement and reduce the reversibility by ageing. *(Unger A, Schniewind A, Unger W, 2001)*

Wood consolidation includes all treatment of reestablishing cohesion and for the stabilization of objects which have been damaged by biological, mechanical or chemical agents. An ideal consolidant should recover wood structure to its original properties.

The ideal consolidant should:

- Should have long-term lasting stability.
- The consolidant should have good penetration and distribution in the wood through its small particle size and low viscosity.
- Dimensional stability of the object.
- Should not change the appearance of the object, by discoloration, surface film, or glozing patches.
- Produce shrinkage or swelling of wood during consolidation.
- The consolidant should be compatible with the preservatives materials.
- Compatible with other conservation materials, adhesives, paints, gilding.
- Protect the consolidated object from insects and fungi.
- Not increase flammability of the wood.
- Should be no toxic.
- The consolidant material should be reversible.

To collect those properties in only one consolidant material, it's too optimistic for today's technology. But conservators can estimate the priorities and the requirements and choose the most appropriate consolidant. *(Unger A, Schniewind A, Unger W, 2001)*

During the twentieth century synthetic consolidants were introduce to conservation. Most of the consolidants that we use today are organic consolidant material.

Organic consolidant materials are mainly copolymers. The structure of an organic polymer can be compare to a chain, made by linking the monomers together. The reaction to make a polymer out of the monomers is called polymerization. Polymers perform very good characteristics and good penetration in the structure. Most of the organic consolidants are reversible materials. *(De Witte, 1982)* Organic consolidants can be divided into thermoplastic resins, elastomers and thermosetting resins. Thermoplastic resins soften when heated and become formable, but after cooling become solid again. Thermosetting resins are soft or liquid and become hard and brittle with curing and irreversible and that's because they form three dimensional network which can not be dissolved.

For the consolidation of a wood with soluble polymers, the choice of a suitable solvent is important for achieved a good solubility and successful consolidation of the deteriorate texture. The following parameters are important for method's success.

- Ease to penetrate.
- Small molecule size for good penetration.
- Evaporation of the solvent.
- Behavior of the wood to the solvent by shrinking and swelling.
- Retention of solvent on the texture.
- Migration behavior.
- Toxicity levels.

Solvents can be divided into polar and nonpolar liquids. Polar solvents have a greater affinity for wood than nonpolar, which is based on physicochemical interactions with wood. Nonpolar solvents should be preferred over polar solvents for wood consolidation.
(Unger A, Schniewind A, Unger W, 2001, Marcus Y, 2004)
Many properties of solvent are effected from the polarity such as: nonpolar solvent have better penetration because of low surface tension and electrostactic attraction with object's surface, so water as polar solvent has low penetration ability. For reducing object's surface tension you can first apply a nonpolar solvent on the surface and then the consolidant. For deeper penetration, acrylic emulsions can be dissolved in a solution of Ethanol-water, for reducing surface tension and water's polarity.
Another factor that influences the success of the treatment is the consolidation method that the conservator follows, which have different results and it depends of object's degree of deterioration.

- Immersion in the consolidant
- Immersion in the consolidant in low vacuum atmosphere
- Application on the surface by brush
- Application on certain areas of the surface by brush or pipette
- Application by air brush or spray method
- Application by poultice
- Injection of the consolidant with or with out pressure.

Principles and Criteria for choosing the applicable Consolidant Material

From the technical data sheet the conservator can find most of material's properties that need to know, but he/she can not be certain about consolidant's action during application and after application.
Have you ever consider how many information a conservator would like to know before choosing the applicable consolidant?

- Market name of the consolidant
- Company which produce the consolidant
- Country that the company is located
- Mail address of website
- Package or form of the material
- Type of the material (consolidant)
- Chemical composition
- Solubility in water
- Solids content %
- Gel time during polymerization
- Solvent that is used or can mixed
- Relative density
- Viscosity 25 ^{o}C, mPa.s
- Flash Point ^{o}C
- Glass Transition Temperature Tg ^{o}C
- Catalyst
- Minimum Polymerization temperature ^{o}C
- Freeze Point ^{o}C
- Softening Point ^{o}C
- Specific Gravity
- Hardness
- Polymerization time
- Workability
- Appearance
- Application method
- Humidity and Air Temperature during application
- Substrate that is recommended to used on
- Effectiveness
- Compatibility
- Penetration
- Change of surface colour

- Method that the consolidation adhieved by
- Durability on environmental conditions
- Storage time
- Reversibility
- Incompatibility (materials to avoid with)
- Health and Safety
- Cost

From my experience I have never found all this properties gathered in a technical data sheet. Some companies or conservation suppliers are very good on providing some information but not all that we would like to know. So the solution is to apply a series of simple to tests which can ensure that the material is suitable to be used in conservation. We can test consolidant properties of reversibility, flexibility, shrinkage, heat ageing, light ageing, penetration, hardness test and also pH measurement can be made by pH indicator papers.

Picture 5: Samples before testing

Picture 6: Samples during consolidation

Testing preparation

For the needs of testing I used a badly deteriorated wood which was cut on 8 pieces as many as the tested consolidants were and one was kept untreated for comparison result. The wooden samples marked by a number (1 to 7) and their weight before treatment was recorded. *(Pictures 5, 6)* The choice of the consolidants was with criteria of conservator's preferences and also trying to cover the spectrum of organic polymers even with consolidants that I do not prefer to use. Paraloid B67 (ethyl methacrylate copolymer) 15% in White Spirit

1. Paraloid B72 (ethyl methacrylate copolymer) 15% in Toluene
2. Paraloid N48 (ethyl methacrylate copolymer) 15% in Toluene
3. Epoxy resin 103 with catalyst HY956
4. Hydroprimer (acrylic emulsion) 15% in water.
5. Hydrowood (acrylic emulsion) 15% in water.
6. Epoxy resin 103 with catalyst HY956 in 20% Toluene.

The choice of the solvent was with criteria the small molecule size and low evaporation rate the solvents so we can have best penetration, toluene (diameter of molecule 0,568 and B.P. 110) which dissolves Paraloid B72 and N48 and white spirit (diameter of molecule 0,596 and B.P. 150-196) which dissolves Paraloid B67. *(Marcus, 2004, Torraca 1990)*

Penetration ability

Picture 7: Samples after the first hour of consolidation treatment.

The wood samples were consolidated with the previous materials by the method of partly immersion in consolidant for 2 hours (in metal containers). After 1 hour the only sample that the consolidant which had migration behavior and had cover the top side of the wood sample was Paraloid B67 then Paraloid B72 was in the half and the others ¼ of the wood sample. *(Picture 7)* After 2 hours the samples that were completely consolidated were Paraloid B67, Paraloid B72 and Paraloid N48, the other samples were consolidated up to the middle high of the wood samples. The observation of the first part of the test was about the deep and fast penetration of the consolidants which as was expected the consolidants with solvents with small molecule size had better penetration. The acrylic emulsion had poor penetration because of larger molecule size and also water is a polar solvent which has low penetration ability.

Picture 8: Samples No1 after consolidation

The samples were removed from the consolidants and they left to dry on room temperature. The excess consolidant was left to polymerize in the metallic container for producing a film which was going to be used for further testing. The left over consolidants on the metallic container of the Hydroprimer and Hydrowood were coloured brownish after consolidation treatment and that because the water emulsions dissolve part of the wood texture which was dispersed in the solution. That made the film unsuitable for light ageing test, so it was produced new film for this testing method.

Picture 9: Samples No 2 after consolidation

Picture 10: Samples No 3 after consolidation

Picture 11: Samples No 4 after consolidation

Picture 12: Samples No 5 after consolidation

Picture 13: Samples No 6 after consolidation

The samples were left to dry for 10 days and then were weighted after consolidation. All the samples had increased their weight satisfactory and after an optical examination samples condition was recorded.

1. Paraloid B67 (ethyl methacrylate copolymer) 15% in White Spirit

Original weight 135,7 gr. Weight after treatment 201 gr. so the sample had increased its weight by 50%, its texture had a very good cohesion between poor and healthy parts. The sample was slightly discoloured and on the top side of the sample had a glossy effect. *(Picture 8)*

2. Paraloid B72 (ethyl methacrylate copolymer) 15% in Toluene

Original weight 112 gr. Weight after treatment 120 gr. The sample had increased its weight by 10%, its texture had a good cohesion between poor and healthy parts. No colour change. *(Picture 9)*

3. Paraloid N48 (ethyl methacrylate copolymer) 15% in Toluene

Original weight 117,5 gr. Weight after treatment 142 gr. The sample had increased its weight by 25%, its texture had a good cohesion between poor and healthy parts. No colour change. *(Picture 10)*

4. Epoxy resin 103 with catalyst HY956

Original weight 106 gr. Weight after treatment 118 gr. The sample had increased its weight by 15%, its texture had a good cohesion between poor and healthy parts but only on the area which was immersed in the consolidant. The sample was very discoloured and with glossy effect. *(Picture 11)*

5. Hydroprimer (acrylic emultion) 15% in water.

Original weight 123 gr. Weight after treatment 142 gr. The sample had increased its weight by 20%, its texture had a bad cohesion and between the poor and healthy parts and cracking between them was produced, and also biological attack was visible on the base of the sample. No colour change. *(Picture 12)*

6. Hydrowood (acrylic emulsion) 15% in water.

Original weight 124,7 gr. Weight after treatment 185,2 gr. The sample had increased its weight by 45%, its texture had a bad cohesion and

Picture 14: Samples No 7 after consolidation

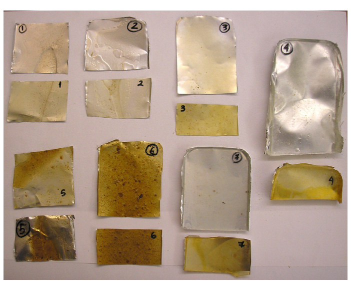
between poor and healthy parts cracking between them was produced. No colour change. *(Picture 13)*

<u>7. Epoxy resin 103 with catalyst HY956 in 20% Toluene.</u>

Original weight 126 gr. Weight after treatment 160 gr. The sample had increased its weight by 25%, its texture had a good cohesion between poor and healthy parts but only on the areas that were immersed in the consolidant. The sample's color was very discoloured and with glossy effect. *(Picture 8)*

Light ageing test

Picture 15: Close box with Ultra Violer light source.



Picture 16: Polymers sample films, after light ageing test.

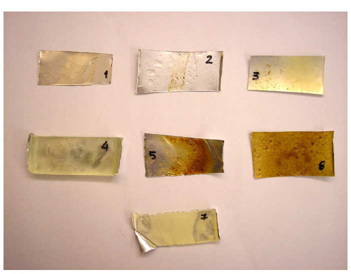
For the light ageing test were used samples from the polymers films which have been produced. It was also tried to test wooden samples on which was firstly applied a polymer, but during the testing it was recorded that the wood was changing colour so it was not possible to evaluate the results.

The method was easy and simple. In a close box with two Ultra Violet light sources type OSRAM HNS 15 Watt OFR, the samples where exposed in Ultra Violet radiation (similar to day light) for 6 days. The reaction of the samples on ultra violet radiation was recorded after 1 day, 2 days and then after 6 days. *(Picture 15)*

After 6 days almost all the samples have change colour but comparing them together the best reactions to day light was from Paraloid B67 and Paraloid B72. *(Picture 16)* If this equipment is not available in the laboratory the conservator can place the samples on a widow glass so the polymers can be exposed to the sunlight.

Light Ageing Test				
No	**Consolidant**	**1 day**	**2 days**	**6 days**
1	Paraloid B67	No change	No change	Slightly yellow
2	Paraloid B72	No change	No change	Slightly yellow
3	Paraloid N48	Slightly yellow	Slightly yellow	Yellow
4	Epoxy resin	Slightly yellow	Slightly yellow	Very Yellow
5	Hydroprimer	Slightly yellow	Slightly yellow	Yellow
6	Hydrowood	No change	No change	Fogy and yellowish
7	Epoxy resin + 20% toluene	Slightly yellow	Slightly yellow	Very Yellow

Picture 17: Samples in the oven, during the heat ageing test.



Picture 18: Polymers sample films, after heating ageing test.

Heat ageing test

For this test the samples of polymers films were placed in an oven on 60 ^oC for 6 days and then when they removed from the oven they immediately placed in a freezer -18 ^oC for 1 day. The idea of this test is to produce a thermal shock to the film and record its reaction to this drastic temperature changes. *(Picture 17)* When the samples removed from the freezer they left to room temperature for 1 day and then where examined by optical observation and their properties were tested. *(Picture 18)* The best results were on Paraloid B72 and Paraloid N48 which had no change on colour and flexibility, reversibility, hardness *(Look on tables Flexibility test, Reversibility test and Hardness test)*.

Flexibility test

Flexibility is one of the properties that a consolidant and an adhesive need to have. The method of assessing mechanical properties of a polymer is with highly specified standard tests, such as ISO/R527 which used for commercial evaluation. I try to evaluate the flexibility of the polymer film by bending the film; and repeating the bending until the film cracked or break. If the film cracked on the first bending then it is brittle, if it cracks over 20 times then the film is flexible, if it is not possible to bend the film then its recorded as no flexible. This method was applied on the film samples before testing and after light and heating tests. As we can see on the following table with the results the series of Paraloid copolymers had the best performance, from the results we can conclude that all the polymers after ageing have become less flexible.

Flexibility Test				
No	**Consolidant**	**Before ageing**	**After light ageing**	**After heat ageing**
1	Paraloid B67	Very flexible	Brittle	Brittle as thin film
2	Paraloid B72	Very flexible	Very flexible	Flexible
3	Paraloid N48	Flexible	Flexible	flexible
4	Epoxy resin	No flexible	No flexible	No flexible
5	Hydroprimer	Brittle	Brittle	Brittle
6	Hydrowood	Very flexible	Very flexible	Very flexible
7	Epoxy resin + 20% toluene	No flexible	No flexible	No flexible

Reversibility test

The materials which used in conservation have to be reversible, but are we usually examine materials reversibility before use and after a time period that they have exposed to the environmental conditions? The conservators can not forget shellac which have been used as consolidant and adhesive for many years and today its not easily removable and also Soluble Nylon which was the "Paraloid" of 1960 and by ageing it produce a cross linking and becomes insoluble.

For reversibility test were used five solvents which were with different solubility parameters. The following solvents were applied on polymer's surface by cotton wool, the assessment of how reversible a polymer was depend from the range of solvents that dissolve the film and by estimating the time that it takes. The test was applied on polymer's film before and after ageing.

The solvent which were used were:

1. Water, N 18
2. White Spirit, N 90
3. Toluene, N 80
4. Acetone, N 47
5. Ethanol, N 36

The results of the reversibility test before ageing tests were the follow:

<u>1. Paraloid B67 (ethyl methacrylate copolymer) 15% in White Spirit</u>

1. Water: No soluble
2. White Spirit: Very Good
3. Toluene: Very Good
4. Acetone: Very Good
5. Ethanol: Average

<u>2. Paraloid B 72(ethyl methacrylate copolymer) 15% in Toluene</u>

1. Water: No soluble
2. White Spirit: No soluble
3. Toluene: Very Good
4. Acetone: Very Good
5. Ethanol: Good

<u>3. Paraloid N48 (ethyl methacrylate copolymer) 15% in Toluene</u>

1. Water: No soluble
2. White Spirit: No soluble
3. Toluene: Very Good
4. Acetone: Very Good
5. Ethanol: Poor

4. Epoxy resin 103 with catalyst HY956

1. Water: No soluble
2. White Spirit: No soluble
3. Toluene: No soluble
4. Acetone: No soluble
5. Ethanol: No soluble

5. Hydroprimer (acrylic emulsion)15% in water.

1. Water: No soluble
2. White Spirit: No soluble
3. Toluene: Good/Average
4. Acetone: Good
5. Ethanol: Average

6. Hydrowood (acrylic emulsion)15% in water.

1. Water: No soluble
2. White Spirit: No soluble
3. Toluene: Average
4. Acetone: Average
5. Ethanol: Poor

7. Epoxy resin 103 with catalyst HY956 in 20% Toluene.

1. Water: No soluble
2. White Spirit: No soluble
3. Toluene: No soluble
4. Acetone: No soluble
5. Ethanol: No soluble

As you can see from the results most of the polymers were dissolved on organic solvents with exception of the epoxy resin which is well know that it produce cross linking with curing. The surprise of the test was the Hydrowood which was expected to have better solubility properties as an acrylic emulsion, so this material is a clear example that some of materials which used in conservation do not follow the criteria.

The polymers were tested by the same method after ageing and as you see from the following table that their reversibility on organic solvents has slightly reduced.

Reversibility tests				
No	**Consolidant**	**Before ageing**	**After light ageing**	**After heat ageing**
1	Paraloid B67	Very Good	Very Good	Good
2	Paraloid B72	Very Good	Very Good	Good
3	Paraloid N48	Very Good	Very Good	Very good
4	Epoxy resin	Swelling	No reversible	No reversible
5	Hydroprimer	Good	Good	Average
6	Hydrowood	Average	Average	Average
7	Epoxy resin + 20% toluene	Swelling	No reversible	No reversible

Hardness test

This test was applied on the surface of polymers films before and after ageing. For the test were used pencils of difference hardness and try to scratch of penetrated the surface; the hardness of the surface is represented by the hardest pencil that was not scratched the surface. The pencils which were used where Faber Castell pencils from softest to hardest as follows: 6B, 5B, 4B, 3B, 2B, B, HB, F, H, 2H, 3H, 4H, 5H, 6H. *(Odegaard, Carroll, Zimmt, 2000)* By this test was observed that the polymers by ageing become harder and less stretchable as we can see on the following table.

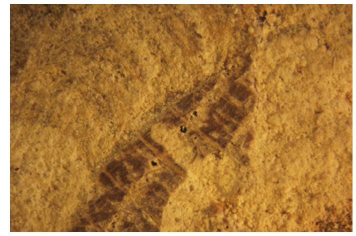
Hardness Test				
No	**Consolidant**	**Before ageing**	**After light ageing**	**After heat ageing**
1	Paraloid B67	HB	HB	2H
2	Paraloid B72	3B	2B	F
3	Paraloid N48	B	HB	6H
4	Epoxy resin	5H	5H	No scratched
5	Hydroprimer	F	H	5H
6	Hydrowood	4B	2B	HB
7	Epoxy resin + 20% toluene	F	H	6H

Microscopic observation

The wood samples which were consolidated on the chosen polymers were left to dry and then were cut on half so a cross section of the consolidated texture could be exposed and examined. Most of the samples were satisfactory consolidated especially if you consider who badly deteriorated the wood was, the only two samples that the consolidation was not sufficient was Hydroprimer and Hydrowood; and that's because the texture of the wood has poor cohesion between poor and health parts and cracks had been produced between those two areas.

Picture 19: 1st sample after consolidation.

Picture 20: Cross section of the sample after consolidation.



Picture 21: Photo of wood's texture through the optical microscope 10X magnification.

Picture 22: Paraloid B67 film.

Picture 23: After light ageing test.

1. Paraloid B67 (ethyl methacrylate copolymer) 15% in White Spirit

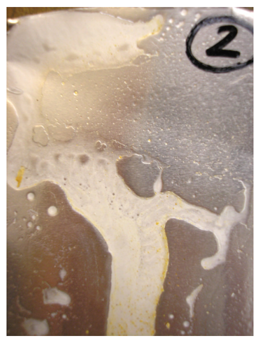
The sample had increased its weight by 50% and its texture had very good cohesion between poor and healthy parts, the structure was very stable after consolidation and by handling the wood sample no surface of the wood was coming off. As you can see on the photo thought optical microscope 10X magnification the deteriorated parts of wood had been successfully consolidated. Slightly colour change.

The polymer film was clear transparent with very good properties of flexibility and reversibility before ageing. After light ageing the polymer was slightly yellow, but after heat ageing cracking of the polymer was recorded.

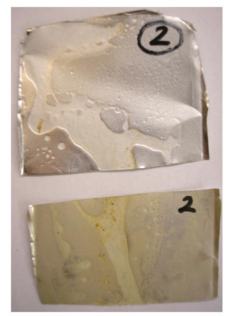
Picture 24: 2nd sample after consolidation.

Picture 25: Cross section of the sample after consolidation.

Picture 26: Photo of wood's texture through the optical microscope 10X magnification.



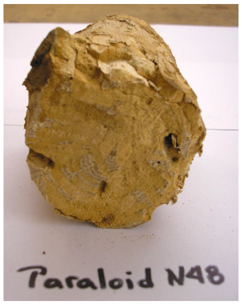
Picture 27: Paraloid B72 film.



Picture 28: After light ageing test.

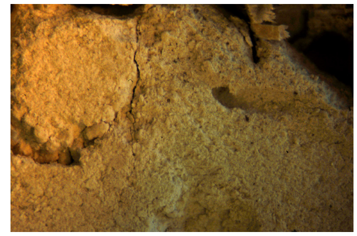
<u>2. Paraloid B72 (ethyl methacrylate copolymer) 15% in Toluene</u>

The sample had increased its weight by 10% after consolidation. Its texture had very good cohesion between the poor and healthy parts, the structure was stable after consolidation and you can safely handle the wood but the structure was too light for a wood sample. As you can see on the photo thought optical microscope 10X magnification the deteriorated parts of wood had been successfully consolidated. No colour change. The polymer film was slightly milky colour before testing, with very good properties of flexibility and reversibility. The polymer after light ageing was slightly yellowed but it preserved the other properties as before ageing.



Picture 29: 3rd sample after consolidation.

Picture 30: Cross section of the sample after consolidation.



Picture 31: Photo of wood's texture through the optical microscope 10X magnification.

Picture 32: Paraloid N48 film.

Picture 33: After light ageing test.

<u>3. Paraloid N48 (ethyl methacrylate copolymer) 15% in Toluene</u>

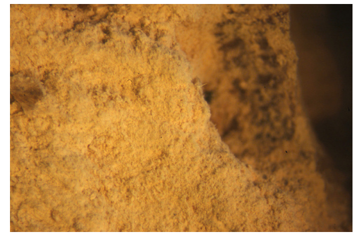
The sample had increased its weight 25% after consolidation. Its texture had very good cohesion between poor and healthy parts, the structure was stable after consolidation and you can safely handle the wood but again it was very light for a wood sample. As you can see on the photo thought optical microscope 10X magnification the deteriorated parts of wood had been successfully consolidated.

No colour change.

The polymer film was clear and transparent before ageing and had very good reversibility and flexibility properties. After light ageing the film became yellow but the other properties were preserved as before ageing tests.

Picture 34: 4th sample after consolidation.

Picture 35: Cross section of the sample after consolidation.



Picture 36: Photo of wood's texture through the optical microscope 10X magnification.

Picture 37: Epoxy resin film.

Picture 38: After light ageing test.

4. Epoxy resin 103 with catalyst HY956

The sample had increased its weight 15% and the texture had a good cohesion between poor and healthy parts on the areas of wood that was immersed in the consolidant. The color was very darken and with glossy effect after consolidation. As you can see on the photo thought optical microscope 10X magnification the deteriorated parts of wood had been successfully consolidated.

Colour change.

The polymer film was very clear and transparent after curing, but it was not flexible and not reversible. By light ageing it become very yellow.

Picture 39: 5th sample after consolidation.

Picture 40: Cross section of the sample after consolidation.

Picture 41: Photo of wood's texture through the optical microscope 10X magnification.

Picture 42: Hydroprimer film.

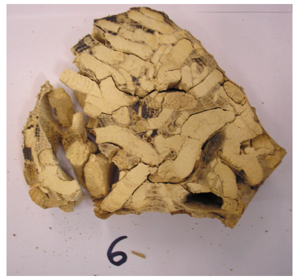
Picture 43: After light ageing test.

<u>5. Hydroprimer (acrylic emulsion)15% in</u> water.

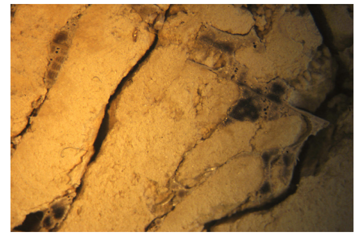
The sample had increased its weight 20% but it's the texture after consolidation had bad cohesion between poor and healthy parts also cracking of those areas were produced after curing because of shrinkage of wood texture. As you can see on the photo thought optical microscope 10X magnification the cracking is visible with or with out microscope and biological attack on the base of the sample. No colour change.

The polymer film was clear and transparent before ageing but it was brittle and cracks were recorded after curing, the polymer was not easily removable. After ageing test the film was slightly yellow, and more brittle and shrinkage of the film was recorded after heat ageing test.

Picture 44: 6th sample after consolidation.



Picture 45: Cross section of the sample after consolidation.



Picture 46: Photo of wood's texture through the optical microscope 10X magnification.

Picture 47: Hydrowood film.

Picture 48: After light ageing

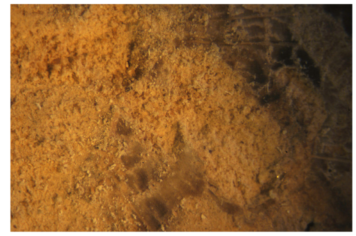
<u>6. Hydrowood (acrylic emulsion) 15% in water.</u>

The sample had increased its weight by 45% after consolidation but its texture had a very bad cohesion and between poor and healthy parts and was produced cracking because of shrinkage of wood texture. You can see on the photo thought optical microscope 10X magnification the cracking is visible with or with out microscope. No colour change.

The polymer film was very clear and transparent before ageing but some bubbles produced with curing, the film was flexible but not easily reversible. After light ageing test the film was slightly yellow.

Picture 49: 7th sample after consolidation.

Picture 50: Cross section of the sample after consolidation.



Picture 51: Photo of wood's texture through the optical microscope 10X magnification.

Picture 52: Epoxy resin film.

Picture 53: After light ageing test.

<u>7. Epoxy resin 103 with catalyst HY956 in 20% Toluene.</u>

The sample had increased its weight by 25% after consolidation; its texture had a good cohesion between poor and healthy parts only on the areas of the sample which was immersed in the consolidant. The color was very darken and with glossy effect. As you can see on the photo thought optical microscope 10X magnification the texture have been successfully consolidated. Colour change

The polymer film was clear and transparent but not flexible and not reversible before ageing tests. After light ageing the film become very yellow.

Conclusions

The main conclusion is that by simple testing methods we can assess the materials of conservation before we apply them to the object. Usually conservation suppliers do not test the materials that they sale, so they recommend a material through the technical data (which some times are not available from the produced companies).

From the seven material what were tested the series of Paraloid copolymers had the best results; the better cohesion on the wood samples was with Paraloid B67 15% in white spirit which can be preferred also because of low toxicity solvent.

The epoxy resin is better to be avoided used as consolidant because its no reversible it can badly discolour the surface, gives a plastic effect to the texture and also it's not a compatible material.

The acrylic emulsions which were tested also gave a poor coherence to the wood texture, had biological attack during drying and produce shrinking, splitting and cracking of the wood structure after curing and finally they had poor reversible properties.

Future work

The materials which can be further examined are Paraloid B67 and Paraloid B72. It will be first examined their application on the polyurethane foam and if they can consolidate the foam and improve its properties. After that the best one will be applied on two concentrations (15% and 20%) as spot tests on the wooden support of the icon for evaluating the results of which one have deeper penetration and gives better cohesion to the wooden support.

Acknowledgment

I would like to thank my friend and colleague Charis Grammatikos for providing me this wonderfully deteriorated wood sample and also for helping me during the experimental work.

Also I wish to thank the Head of the Conservation Department of Benaki Museum Mr. Stergios Stassinopoulos who is always positively thinking about examining the materials before use them for the conservation of art objects.

Finally I would like to thank, conservation supplier Ananiadis Company for provide me some of the material that I use for testing.

References

1. Ashley-Smith J., 1990. A Consistent Approach to a varied collection, in Oddy A. (ed). *Restoration: Is it Acceptable?* Occasional Paper 99, Department of Conservation. 89-93. London: British Museum.
2. Bennett H., 1986. *Concise Chemical and Technical Dictionary.* United Kingdom: Edward Arnold.
3. Blackshaw S., Ward S., 1983. Simple tests for assessing materials for use in conservation, in Tate J.O., Tennent N.H., Townsend J.H. (eds). *The Proceedings of the symposium "Resins in Conservation" held at the University of Edinburgh, Edinburgh, U.K. 21-22 May 1982.* 2-1 to 2-15. Edinburgh: Scottish Society for Conservation and Restoration.
4. Campbell D. and White J.R, *Polymer Characterization, Physical techniques*. London: Chapman & Hall.
5. Ciabach J., 1983. Investigation of cross-linking of thermoplastic resins by ultraviolet radiation, in Tate J.O., Tennent N.H., Townsend J.H. (eds). *The Proceedings of the symposium "Resins in Conservation" held at the University of Edinburgh, Edinburgh,*

U.K. 21-22 May 1982. 5-1 to 5-8. Edinburgh : Scottish Society for Conservation and Restoration.

6. De Witte E., 1983. Resin in conservation: Introduction to their properties and applications, in Tate J.O., Tennent N.H., Townsend J.H. (eds). *The Proceedings of the symposium "Resins in Conservation" held at the University of Edinburgh, Edinburgh, UK 21-22 May 1982.* 1-1 to 1-6. Edinburgh : Scottish Society for Conservation and Restoration.
7. Down J.L. Macdonald M.A. Tetreault J. Williams R.S. 1996. Adhesive testing at the Canadian Conservation Institute - an evaluation of selected poly(vinyl acetate) and acrylic adhesives. *In Studies in Conservation*. Vol. 41, p.p. 19-44.
8. Dranadaki A., 2002, *Greek Icons 14th – 18th century The Rena Andreadis Collection*, Milan: Skira and Benaki Museum publications.
9. Farmakalidis H.V., 2003, *Recommendations of Compatible Consolidant Materials,* MSc dissertation on National Technical University of Athens.
10. Ferretti M., 1993. *Scientific Investigations of Works of Art.* Rome : ICCROM
11. Fieser L.F., & Fieser M., 1961. *Advanced Organic Chemistry.* London: Reinhold Publishing Corporation.
12. Horie C.V., 1987. *Materials for Conservation: Organic consolidants, adhesives and coatings.* London: Butterworth-Heinemann.
13. Horie C.V., 1983. Reversibility of polymer treatment, in Tate J O, Tennent N.H., Townsend J.H. (eds). *The Proceedings of the symposium "Resins in Conservation" held at the University of Edinburgh, Edinburgh, UK 21-22 May 1982.* 3-3 to 3-5. Edinburgh: Scottish Society for Conservation and Restoration.

14. Houwink R. & Salomon G., 1965. *Adhesion and Adhesives. Volume 1 Adhesives.* Netherlands: Elsevier publishing company.
15. Marcus Y, 2004, *The properties of Solvents.* New York: John Wiley & Sons.
16. Mills J S & White R, 1987. *The Organic Chemistry of Museum Objects.* London: Butterworths.
17. Nicholsom J W, 1991. *The Chemistry of polymers.* Great Britain : The Royal Society of Chemistry.
18. Obegaard N., Carroll S. and Zimmt W., 2000, *Material characterization tests for objects of art and archeology.* London: Arcehtype publications.
19. Packard-Chairman E, 1992. *Directory – Code of Ethics & Standards of Practice*, Washington: The American Institute for Conservation of Historic & Artistic Works.
20. Torraca G. 1990. Solubility and Solvents for Conservation Problems. Rome: IICROM .
21. Unger A., Schniewing A.P., Unger W. 2001, *Conservation of Wood Artifacts.* Berlin: Springer.
22. Urbani G, 1996. The Science and Art of Conservation of Cultural Property, in Price N.S, Tally M.K, Vaccano A.M. (eds). *"Readings in Conservation" Historical and Philosophical Issues in the Conservation of Cultural Heritage.* 445-450. Los Angeles: The Getty Conservation Institute.
23. Ward P, 1989. *The Nature of Conservation. A Race Against Time*. Los Angeles: Getty Conservation Institute. 9-11.