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# COMPATIBILITY INDICATORS IN DEVELOPING CONSOLIDATION MATERIALS WITH NANOPARTICLE INSERTIONS FOR OLD WOODEN OBJECTS

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***Abstract***

*The conservation of old wooden objects is a complex domain that encapsulates science, aesthetics and art. A priority in wood conservation is the operation of consolidation. Historical wooden objects are frail and present different forms of degradation, often active infestation being present. Maintaining physical integrity and authenticity are thus priorities for the object in question. A consolidation material should not only impart sufficient mechanical strength to the object, but be compatible with all the materials that are part of the object. A myriad of new potential materials and technologies are worth special attention in solving major problems in wood consolidation. Aiming to develop new nanotechnologic consolidation materials for old wood, we conducted several researches. Before testing the benefits of adding nanoparticles into the recipe of consolidation materials for old wood, one has firstly to establish compatibility criteria and indicators between the matrix and the insertion in each case. That is the topic of the present paper. The results obtained, namely a list of compatibility indicators, represent the starting point in developing innovative consolidation materials with nanoparticle insertions.*

***Keywords:*** *consolidation; wood; nanoparticles; compatibility indicators.*

## Introduction

From the beginning of civilisation, wood played an indispensable role in human life mainly due to its aesthetic value, its availability and its processing properties. It is, therefore, not a surprise that wood has an important place in our cultural heritage, either as structural beams, painted or gilded panels, furniture items, as shown by Timar in [1 - 3], statues and icons of both artistic and religious value etc. The use of wood, however, is not without pitfalls. It requires understanding of its complex anatomical structure [4], its physical and mechanical properties; wood is also dimensionally unstable and continuously vulnerable to deterioration caused by fungi and insects.

Most often, old wooden objects present evidence of active infestation, besides historical biological degradation by insects or fungi, who affect their structural integrity, physical and mechanical properties. The authenticity of the object threatened. Conservation of wooden objects is a complex activity because of wood's faulty defects that occur in time, conservators being confronted with a myriad of puzzling issues.

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By and large, any treatment in conservation should follow several principles, internationally established so that any attempt to develop new materials is founded on those principles, as noted by several authors in [5 - 13]:

- any material in the conservation treatment must not alter the integrity and authenticity of the object;
- any material/treatment must present potential reversibility and allow further interventions of restoration, whenever necessary;
- any material/treatment must be compatible with all the materials encapsulated by the object; the "artistic" materials are to be treated as a whole and not separately.

A consolidation treatment is usually necessary when the wooden object is seriously altered, its integrity and authenticity no longer being ensured. It is meant to provide the object with physical and mechanical resistances and properties. Once the necessity for consolidation is determined, a number of decisions must be made in regard to materials and methodology. These decisions include the choice of a consolidant, the solvent type, the solution concentration and a suitable method of application. Those choices mostly depend on the nature of the object to be treated, the type and condition of the materials, and the functional requirements of the object as shown in [14] and [15].

The general requirements of wood consolidation materials include, apart from *reversibility*, *compatibility* and *re-treatability* [12, 16], specific technical aspects related to the wood swelling and shrinking phenomena, penetration depth, uniformity of distribution, consolidant retention and toxicity levels.

A consolidation material should impart sufficient strength to the object to be conserved while also ensuring some cohesion of the disrupted structure [7, 8, 17]. In other words, a consolidation material is required to have two main properties *adhesion* and *cohesion* to finally provide the object with mechanical strength and physical properties. That is why high molecular weight organic compounds are preferred, due to their physical and chemical stability and, implicitly, resistance to weathering and aging. Such materials include natural resins, oils, waxes, collagen glues and synthetic thermoplastic or thermosetting polymers as shown by Timar *et al*. in [16].

The most recent treatment of consolidation uses soluble resins, thermoplastic synthetic polymers in solvent solution, due to its ease of application and the reversibility of the consolidation product - the polymer fixed in the wood remaining soluble in the initial solvent [11, 12, 18, 19] – its increased mechanical strength and scratch resistance, as well as its possible resistance to biological attack.

The present paper refers to a theoretical approach to develop new consolidation products with nanoparticle insertions based on compatibility indicators and constitutes a major step in choosing and testing new consolidation materials. Compatibility indicators constitute a further experimental approach, a study about the influence of nanoparticles added to current consolidation materials and, finally, to the treated wooden support.

## Experimental

A theoretical analysis was carried out on the advantages and disadvantages of the currently used consolidation materials, as well as the properties of several nano-materials which may be used as fillers in the newly developed consolidation products.

Based on general and specific requirements, a consolidation material should have, and similar to the model presented by Rodrigues and Grossi in [20], specific compatibility criteria and indicators between the nano-insertions and the wooden support were established as shown in figure 1.

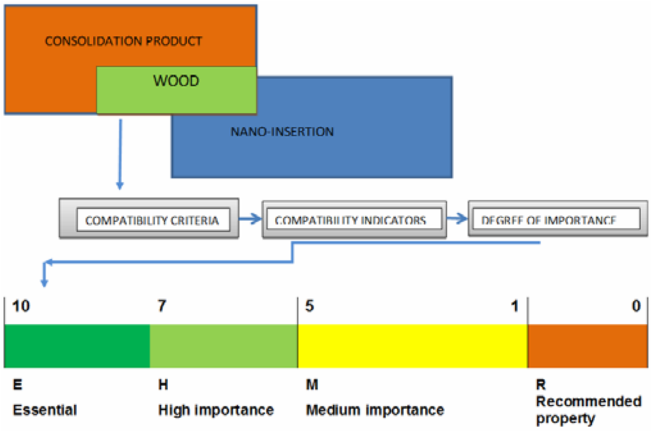


**Fig. 1**: Compatibility criteria and indicators between nano-insertions and the wooden support

Those compatibility criteria and indicators are in fact performance parameters relevant to the properties of consolidation materials. The quantifiable indicators were rated according to their importance in the wood conservation field, in a ratio scale from 0 to 10 and were given the codes E, essential property, H, important property, M for medium importance and R recommended properties (Fig. 1).

## Results and discussions

According to the advantages and disadvantages of currently used consolidation products (Table 1) and the technical performances of nanomaterials (Table 2), the opportunities to develop new potential products with superior properties were highlighted in tables, in order to be adjusted and for further testing.

**Table 1.** Natural and synthetic consolidation materials used for wooden supports: advantages and disadvantages

| Type of consolidant | Application method | Advantages [18], [22], [9] | Disadvantages [22], [9] | Opportunities by nano-insertion |
|---|---|---|---|---|
| (0) | (1) | (2) | (3) | (4) |
| *Animal glues* [12], [14], [7] | Soaking in hot mixtures | Reversible, Non-toxic, Compatibility, Good adhesion Do not stain wood Gilded and painted wood | Not resistant to moisture and heat (shrinkage and swelling) May become brittle over time Poor penetration into wood | *Moisture resistance Bio protection Dimensional stability Elasticity, Increased penetrability* |
| *Waxes, beeswax and paraffin* [21], [7], [12] | Melted wax/ hot mixtures with resins Saponified wax | Resistant to moisture, Reversible, Non-toxic Resistant to organic solvents, No change of colour in time, Chemical stability , (macromolecular compound) | Dust accumulation Darken in time Reversible to heat Poor mechanical resistance UV transparency Partial elasticity | *Anti-dirt properties Fire resistance, UV resistance Increased mechanical properties Improved elasticity* |
| *Vegetable oils,* mainly linseed oil, tung oil and colophony [14], [12] | Hot baths Cold mixtures with turpentine and phenol | May be used as plasticizers Resistant to water Non-toxic | Softening of support Darkening Sticky surfaces Poor straightening | *Anti-dirt properties Bio-protection UV resistance* |
| *Natural resins* [14] | Mixtures / solutions | Solvent soluble – reversible Good adhesion, Heat reversibility, Transparency, Chemical stability (macromolecular compound) | Exudation / Softening, Easily deformable, Partially reversible, Moderate straightening, Brittle / reduced elasticity, Change of colour | *Improved mechanical resistance UV resistance Resistance to solvents Anti-dirt surfaces* |
| *Cellulose derivatives* [14], [22] | Mixtures/ solutions | Fixatives Good adhesion Soluble in acetone, esters | Poor penetration, Brittle in time, Discoloration Poor film formation Prone to fissures and cracks Yellowing in time | *Improved elasticity Colour stability* |

| (0) | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| *Synthetic adhesives* [9] | Mixtures /solutions | Good penetration (low molecular weight), Reversibility<br>Resistance to UV light | Dust accumulation<br>Brittleness | *Anti-dirt properties Bio-protection, Increased mechanical properties*<br>*Improved elasticity* |
| *Thermoplastic resins* [9] | Mixtures/ solutions | Ease of use, Increased mechanical strength, Adhesion<br>Resistance to water, alcohol, acids<br>Partially reversible<br>Compatible to plenty of materials<br>Penetrability to porous substrates<br>Soluble in organic solvent | Partial reversibility<br>Toxic<br>Possible yellowing in time<br>Plastic like appearance<br>Glossy surfaces<br>No bio-protection<br>No fire-resistance | *UV resistance*<br>*Water resistance*<br>*Bio-protection*<br>*Improved mechanical strength* |
| *Thermosetting resins* [9] | Mixtures/ solutions | Not soluble in organic solvents<br>Good adhesion<br>Increased strength (structural consolidation)<br>Durability | Not soluble in organic solvents<br>Totally irreversible, Discoloration in time, Poor penetration, Darkening / Shrinkage, (melamine formaldehyde) | *Bio-protection*<br>*Fire-resistance*<br>*Improved mechanical strength* |
| Monomers that polymerise *in situ* | Mixtures/ solutions | No solvent, Durability, Increased strength, Structural consolidation, Abrasion resistance, Water resistance, Resistance to bio-degradation | Irreversible treatment<br>Expensive technology | *Bio-protection*<br>*Fire-resistance* |

**Table 2.** Nanomaterial possible fillers for wood consolidation products

| **Nano-insertion** | **Support material** | ***Property*** | **Application method** |
|---|---|---|---|
| *Lignin fibrils / cellulose whiskers* [23] | Textile<br>Rubber<br>Other materials (wood included) | *Hydrophobicity*<br>*Fire resistance*<br>*Smart-materials*<br>*Consolidation of plastic objects* | Brushing<br><br>Micelle growth<br>Composite technology |
| *Au, Ag* [24 ], [25] | Wood | *Bio-protection* | Deposition techniques in aqueous/polymer solution |
| *Metal oxides* [26] | Wood | *Self-cleaning surfaces*<br>*Scratch resistance*<br>*Resistance to ageing*<br>*Fissure reduction*<br>*Resistance to chemical substances*<br>*Increased adhesion*<br>*Durability*<br>*Dimensional stability*<br>*Resistance to natural weathering*<br>*Reduction of free water absorption* | Polymer matrix with metal oxides insertion<br>Vacuum deposition |
| *Alumina* [27] | Wood | *Self-cleaning surfaces*<br>*Scratch resistance*<br>*Fire resistance* | Sol-gel<br>Spraying<br>Polymer matrix |
| $TiO_2$ [28], [29] | Wood | *UV protection*<br>*Fire resistance*<br>*Self-cleaning*<br>*Water resistance (super-hydrophobic surfaces)*<br>*Bio-protection* | Sol-gel<br>CVD<br>Sputtering<br>Dispersions in acrylic polymers |
| *ZnO* [29], [30] | Wood | *Bio-protection*<br>*Fire-resistance*<br>*UV resistance*<br>*Water resistance* | Sol-gel<br>Emulsion in acrylic copolymers |
| $SiO_2$ [31] | Wood | *Scratch resistance*<br>*Good adhesion*<br>*Fire-resistance*<br>*Water-resistance*<br>*Self-cleaning* | Sol-gel<br>Impregnation |
| *MgO* [26] | | *Bio-protection*<br>*Hydrophobicity* | <br>Sol-gel |
| *FeO* [32] | Wood | *UV protection*<br>*Bio-protection* | Liquid organic media |
| *Cu* [33] | Wood | *Bio-protection* | In polymer matrix |

Due to the improved properties they offer to wood, the selected nano-insertions that are to be further tested are $TiO_2$, ZnO and $Fe_2O_3$. Nanoparticles like $Fe_2O_3$ are ideal from the technical performance point of view, but not entirely valid for conservation treatments since colour modifications may occur. However, further tests will outline that issue.

Table 2 synthesizes the results obtained by different authors in regard to the combination of various nano-insertions (*e.g.* cellulose whiskers, metal oxides) with different supporting materials (*e.g.* wood, textiles, rubber) focusing on the increased performances obtained by using those combinations.

The theoretical analysis led to the selection of several specific compatibility criteria and indicators between the wooden matrix and the consolidant (Table 3).

**Table 3**. Theoretical compatibility criteria and indicators for wood consolidants with nanoparticle insertion

| Nano-insertion | Consolidation product | Compatibility criteria | Compatibility indicators | Rating scale |
|---|---|---|---|---|
| $TiO_2$ | Wax | *Chemical and physical properties*: | *Consolidant retention* | E[a] 10 |
| | | | *Penetration depth* | |
| ZnO | Oils | affinity to wood wood | | E 10 |
| | | impregnation capacity | *Uniformity of* | |
| $Fe_2O_3$ | Thermoplastic synthetic resins | cohesion | *distribution* | E 10 |
| | | adhesion | *Microscopic structure* | |
| | | | | E 8-10 |
| | | *Mechanical properties (treated wood)* | *Bending strength* | |
| | | | *Compression strength* | |
| | | | *Modulus of elasticity* | H[b] 7 |
| | | | *Scratch resistance* | |
| | | | | H 7 |
| | | | *Water absorption* | |
| | | *Hydrophobic behaviour* | | H 5 |
| | | | *Swelling* | M[c] 5 |
| | | *Visual properties* | *Colour difference (ΔE)* | E8/H 7 |
| | | | *Resistance to fire* | E8/H 7 |
| | | *Thermal properties* | | |
| | | | | E 8 |
| | | | *Resistance to insects* | |
| | | *Bio-protection* | *and fungal attack* | |
| | | | | H 7 |
| | | | *Toxic emissions* | |
| | | *Environmental impact* | | |
| | | | | E 10 |
| | | | | H 7 |

[a] *= essential,* [b]*= high importance,* [c] *= medium importance*

## Conclusions

We took a theoretical approach focused on the development of new consolidation products with nanoparticle insertion, based on a critical analysis of the currently employed wood consolidation products and the opportunities offered by some nano-insertions. The results we obtained allowed us to propose an original set of compatibility criteria, corresponding to practical quantifiable indicators and an importance rating scale for old wood consolidation products.

The selected compatibility criteria and indicators require further experiments to establish the technical performances of newly engineered consolidation materials with nanoparticle insertions applied in old wood conservation. Such researches are already being conducted and the results will be published at a later date.

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