A brief critical review on the behavior of historical timber structures affected by biological agents and other external factors

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ABSTRACT

The durability of the historical timber structures is significantly influenced by the quality of the timber used for its construction, by its physical and mechanical properties, but also by the negative action of various biological agents (xylophage insects and fungal rot) as well as that of external factors (climatic or technologically-resulted humidity, air temperature, chemical compounds, radiations, etc.).

The paper highlights the effects of the most noteworthy biological agents present in the temperate climate onto historical timber, as well as the effects of moisture (with an emphasis on the provisions of Eurocode 5 and EN 335-1 in regard to the matter), those of high temperature, of aggressive chemical compounds and of various radiations (ultraviolet, infrared, gamma, etc.).

As a final point, the paper briefly describes the main courses of action required to counter the effects of the action of biological agents and of other external factors on the historical timber structures.

INTRODUCTION

An important spot in the attention of specialists in our country but also in the rest of developed countries occupy the efficient construction of buildings in all categories, to meet the requirements of increasingly diverse users.

After the ‘90s, increasingly more emphasis was poised on developing the qualitative aspects of construction, which considers also the conditions of comfort, not only the structural soundness (strength, stability).

In most cases, the current state of wooden buildings, both historic and modern, is concerning, on the one hand due to lack of maintenance, improper operation or the lack of timely repair, and on the other hand due to the more polluting, aggressive environment. These factors may cause harm to the community in equal measure as to the owner of the building.

Thus, the monitoring of the building’s evolution in time must be undertaken with all the emphasis, taking into account both age and state of degradation.

CAUSES AND EFFECTS OF DEGRADATION FOR WOOD STRUCTURAL. SOME PROTECTIVE MEASURES.

Timber, the oldest building materials known, while organic and having many advantages (cheap, easily worked and shaped, biodegradable, low apparent density to high relative strength, low weight, can be shaped in custom forms and sizes that are difficult or even impossible to build with other building materials, favorable thermal properties, durability of wooden buildings, timber reuse possibility, the possibility of associating wood with steel or concrete and efficient formation of mixed structures, etc..) has proven its qualities as a material suitable for construction, and therefore, especially for the structures of historic roofs.

The conditions of proper use of timber for these frameworks are those of 'dry, covered conditions' where very durable species (oak, larch, locust, etc.) can fulfill their role as long as 500-1000 years, similarly to that of long-lasting species (white pine, Scots pine) whose duration of service is drastically reduced while used outdoors. Low durability species can withstand 120-700 years, and the short-lived ones can last for 60-70 years in sheltered, dry places, while not attacked by any harmful factor.

Apart from the action of fire, which, throughout history, has been the biggest threat to wooden buildings, timber lifetime can be significantly reduced by biological pests. It is likely to be attacked mainly by two types of biological agents (insects and fungi), but in particular situations can be attacked by marine organisms, too. Fungi attack is determined by the existence of favorable conditions related mainly to the presence of water and oxygen, while insects can attack all types of wood.

We know that without water there is no life, and even if in some cases this does not seem to be clear, humidity is a basic condition for fungi and boring insects.

Timber should be set only when properly dried, with humidity near to the estimated equilibrium point, which is the usual state of humidity of wood in the specific climatic conditions of a country or climate zone. The corresponding moisture to this equilibrium point for our country is approx. 15%.

Humidity is the main factor that influences all physical and mechanical characteristics of wood and, implicitly, its durability, by fostering the development of agents for biological degradation. The humidity present within structures has a significant effect on metal components used in joints, as well.

Wood structural design must consider, besides the effect of environmental conditions operating on timber moisture, other situations that may cause a significant increase in timber moisture, such as:

- contact between wood and soil or between wood and other parts of the building;
- presence of timber in a warm atmosphere and humid;
- vapor condensation inside elements;
- significant accumulation of snow in some areas and ingress of water in damp areas;
- water penetration during storage on site or during installation of parts before covering.

Regarding the level of exposure to moisture, Eurocode 5 rules and regulation differentiate three classes of service and 5 classes of risk.

European Standards EN 335-1 on,, Durability of wood and wood-derived materials. The definition of classes of risks to biological attacks - General specifications"and the national norm EN 335-1 define the following classes of risk:

Risk class 1 - Situations in which wood or wood products are sheltered, covered, fully protected from weather and all possibilities of dampening;

Risk class 2 - Situations in which wood or wood products are sheltered, covered, fully protected from the weather but where high humidity environment can lead to occasional but non persistent dampening;

Risk class 3 - Situations in which wood or wood-based products are on the outside, unsheltered, but not in direct contact with the ground, continuously exposed to weather or protected from the weather but can be exposed to frequent dampening;

Risk class 4 - Situations in which wood or wood-based products are in contact with the ground or fresh water, and constantly exposed to moisture;

Risk Class 5 - Situations in which wood or wood-based products are constantly exposed to salt water.

Classes 1 and 2 require a low level of natural durability and relatively simple treatments.

Classes 3, 4 and 5 correspond to the highest risk of biological attack and require measures to keep the pieces as much as possible in the lowest risk class.

Under Rule / 45 / wood undergoes biodegradation four levels of risk, namely:

Level 1 - wood used inside buildings, where there is no danger of dampening which favors decay fungi installation and development;

Level 2 - wood used in buildings where there are minimum conditions of degradation under the attack of decay fungi (wood used as roof elements: rafters, beams, columns, roof decking, moldings, interior walls);

Level 3 - wood used in buildings at risk of degradation by wood decay fungi, in situations in which it can achieve humidity of 30% and the alternation with dry moisture;

Level 4 - wood used in buildings with favorable conditions for biodegradation: in permanent contact with the ground, or constantly exposed to weathering without film-forming finish (roofing shingles and tiles).

Newly felled green timber contains between 40-50% moisture content, of which approx. 50% is free water and about. 50% water hygroscopic. Chemically bound water is approx. 1%. The limit between free water and the water wettability is between 25-30% moisture and is called saturation point. Over that limit shrinkage and swelling are not affected, but below this limit it is very harmful.

Swelling and shrinkage are natural phenomena that can not be stopped, they can be attenuated at best, this being one of the main drawbacks of wood as a construction material.

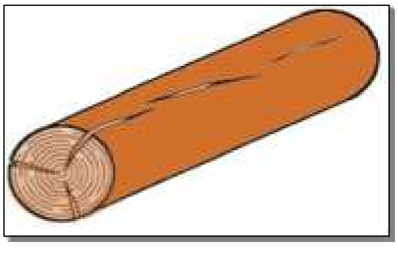
Therefore, due to the anisotropy of wood, these phenomena are not uniform and vary by the characteristics of cross-sectional directions: axial - approx. 1% radial - approx. 5-6% or tangential - approx. 10-12% (Fig. 1). Linear dimensional changes are not uniform in the three directions of structural orientation in neither size nor dynamic.

Radial swelling is on average 50% of the tangential and radial swelling dynamics is 10-15% lower than tangential. Longitudinal swelling is insignificant in size and dynamics.

The unevenness of the swelling phenomenon is determined by species, structure, size and composition of the anatomical parts of wood (medullary rays and cell membranes).

Shrinkage, the opposite of the swelling phenomenon, occurs simultaneously with desorption (removal) of water from the cell membrane. Timber with very little shrinkage (pine, poplar, fir), low (chestnut, lime) and middle (cherry, maple, birch) is considered good for use in solid wood works.

In general, wood undergoes shrinkage after being assembled as well, as it continues to dry. Therefore, the formation of cracks (Fig. 2) does not typically affect the resistance structure because these defects are predictable, and are taken into account when assessing the admissible efforts.



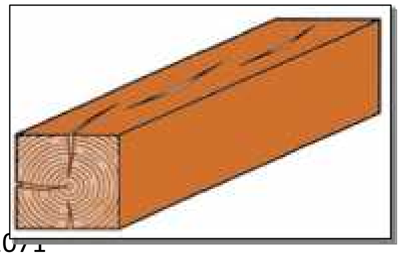


Fig. 1. Uncontrolled cracking

During the first years of operation, the sudden drying of wood, especially if it was not dried or conditioned before being set, cause cracks or crevices of considerable size which can lead to decreased bearing capacity and rigidity, with serious consequences if these defects occur in hazardous areas (zone of maximum torque and so on). As well, they make way to larvae of insects, fungi spores, water accumulation, ultimately favoring degradation. In this case, appropriate measures will be taken to correct and eliminate the consequences of these defects.

Fungal development occurs when moisture content exceeds 20%, and sometimes in the absence of light, poor ventilation and alkaline environments.

For each situation the risk according to use and placement must be assesed. Depending on the risk appropriate preventive and protective measures must be provided.

Lower fungi do not affect timber strength; they produce only color defects (eg red heart in beech or blue in softwood) as opposed to higher fungi (fungi parasitic forest), which, depending on the species, can attack lignin (eg, white rot, which attacks standing trees). Timber attacked by these crack along the annual rings, medullary rays and fibers, breaking into strips.

Other higher fungi which attack timber pulp and cause rot in the forest or in the warehouse, are the saprophytic fungi and mushrooms; they are called warehouse fungi – eg. Stereum, Leuzites and Paniophora.

The most dangerous fungi that cause wood rot are Merulius lacrymans and Poliporus vaporarius which attack the hidden parts of wood.

Decay rate depends on the type of fungus, the climate, the conditions of use of the building and the nature of the timber used. To grow, fungi need moisture content, air, adequate temperature and food. In the absence of either of these conditions, their development stops, but spores can become active as soon as conditions become favorable again.

Suppression of humidity, avoiding condensation moisture due to water seepage etc., prevents fungal invasions. Wood containing max. 20% moisture content (timber dried outdoors) is protected from the destructive effects of fungi.

Special attention must be given to the bearing zones of the structural elements of wood, especially beams or pillars, resting or embedded in closing elements or foundations, in places closed, unventilated (eaves, valleys, ends of beams, slabs, blind floors, hidden). All contact surfaces must be ventilated and allowed to dry.

If and when fungal invasions and rot occurs, it must be documented in regard to the scale of the phenomenon, the type of mushroom, the causes of the phenomenon, noting the corrective actions, where appropriate.

For roofs, the physical condition of wood is determined primarily by the waterproofing qualities of the cover, which set the conditions for the frame, either favorable or unfavorable to fungi and hydrophilic boring insects. Even when continuous maintenance is provided and the covering remains watertight, insects that survive in dry wood may invade.

Some species of beetles, ants, caterpillars and even some insects attack and degrade wood joinery seeking shelter in the galleries they dig, reducing the structural strength to some extent. Other species of boring beetles such as the bark beetle, attack the timber heart with very serious consequences.

The consequence and the risk of insect invasions on timber varies greatly, depending on temperature conditions. Insect activity is favored by high temperature allowing their development and reproduction; the attack occurs usually on dry wood, but there are insects that can tolerate a certain percentage of moisture.

The main insects that attack coniferous wood are xiloterus lineatus, sirex gigas (Fig. 2) (mason bee), Anobium domesticum (Fig. 3), camponotus herculeanus (Fig. 5) and camponotus ligniperda (Fig. 6) (two species of ants that live in coniferous stems), hylecoetes dermestoides (Fig. 7), Hylotrupes bajulus (Fig. 4).



Fig. 2. Sirex gigas **Fig. 3.** Anobium domesticum **Fig. 4.** Hylotrupes bajulus



Fig. 5. Camponotus herculeanus **Fig. 6.** Camponotus ligniperda **Fig. 7.** Hylecoetes dermestoides

The main insects that preferably attack hardwood are cerambyx cerdo (Fig. 8), lymexylon ship (Fig. 11), xyleborus monographus (Fig. 9), platypus cylindriformis (Fig. 12), ptilinus pectinicornis (Fig. 10), zeuzera pyrina (Fig. 13).



Fig. 8. Cerambyx cerdo **Fig. 9.** Xyleborus monographus **Fig. 10.** Ptilinus pectinicornis

Fig. 11. Lymexylon navale

Fig. 12. Platypus cylindriformis

Fig. 13. Zeuzera pyrina

The finding of an insect invasion on structural or non-structural construction wood requires identifying the species, the damage, the effects of the aggresion and the appropriate treatment measures.

Under normal conditions timber is fairly resistant to chemical agents. Its chemical and anatomical structure causes it to present a good resistance in aggressive environments compared to steel or concrete under the same conditions. While metal structures need periodical protective treatment and concrete structures require permanent verification of their condition, to avoid cracks that can lead to corrosion of the reinforcements, wooden structures used in aggressive environments require very little maintenance, localized mainly in the fastening areas.

The natural resistance of wood is sufficient to avoid chemical attack and special conservation measures are not required; sometimes, it is recommended that the clean surface of the wood used in aggressive environments not be covered with protective products which, by cracking, create conditions for aggressive chemical agents.

If a surface chemical attack (corrosion) occurs, it reduces the strength in timber 10 ... 20 mm deep, while the rest of the section remains untouched.

Corrosive agents primarily attack lignin and hemicelluloses and never cellulose, therefore resinous wood that has a higher amount of lignin has generally lower corrosion resistance than hardwood.

Cellulose, which is prevalent in the timber composition, is insoluble in water, ether, acetone, alcohol etc. Corrosive gases such as ammonia and formaldehyde have no effect on timber, but wood sulfur dioxide can attack when its action is combined with moisture and high temperatures. Mineral acids (sulfuric acid, nitric, hydrochloric) carbonize cellulose; organic acids have a lower action. Concentrated alkali have a swelling effect on cellulose. Dissolved alkali oxidants- chromium, bromine, have an impact on lignin and cellulose, reducing mechanical resistance of wood. Antiseptics and flame retardant salts reduce resistance when introduced by impregnation into wood, especially in regard to dynamic loads. The effect of various chemicals on the timber depends on the wood species, product aggression and exposure time and temperature.

Thus it was found that environments with average values of pH = 3 ... 10 and salt solutions have no effect on timber and that alkaline environments destroy timber especially in the presence of high temperatures.

Due to the thermal characteristics and internal structure of timber, it can be said that high temperatures do not particularly affect its properties and its behavior. For temperatures under the 60oC effect on timber strength can be ignored and temperatures around 100oC, although leading to a change of color to brown, do not affect timber strength.

Under the influence of temperatures above 105 ° C, the wood begins to decay gradually (Fig. 14), releasing flammable gases (hydrogen, methane, ethane). The timber decomposition in the absence of air is called dry distillation. In the presence of air and under the action of direct flame wood begins to burn.

The process is as follows:

- At a temperature of 225-250 ° C, the flash point is reached - small explosions of flue gases formed by thermal decomposition of wood take place;
- At a temperature of 260-290oC a continuous flame is formed.

In the absence of direct flame, timber auto-ignition occurs at a temperature of 330-470oC. These characteristic points of the timber fire behavior differs from one species to another, flammability and burning rate increasing with a lower density.

Simultaneous action of high temperatures and humidity favors reducing resistance and rigidity.

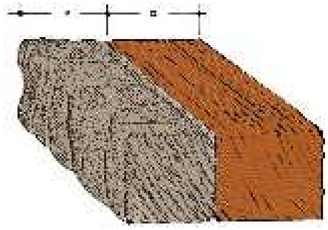


Fig. 14. Section of wood attacked by fire: a) charred area b) protected area

Timber can not be made to become incombustible, but it can be made hardly flammable through appropriate measures.

Defense against the action of fire is achieved by the treatment of timber with substances, called fireproofing or antipyrine, aimed to increase the resistance of wood materials to burning. The organic nature of these materials makes them flammable, and by fireproofing this feature is not eliminated. Fireproofing only leads to a delayed ignition and a slower burning process by suppressing flame after ignition and, if possible, by a quick extinguishing of the embers. The effect of the delayed combustion process is limited. The estinguishing of the open flame has great impact on the spread of fire.

A particular aspect isthat of the composite elements, made by gluing, as their resistance in aggressive environments is influenced by the type of additive used.

A particular chemical action which effects on the mechanical behavior of timber may occur where there is direct contact between wood and metal parts (fasteners) on a large area. It is recommended that metal parts are galvanized, coated with protective substances or be made of stainless steel.

Also, wood exposed to solar radiation and generally under UV changes its structure at the surface (max.1 mm thick) with a gray surface color, thus achieving a pseudo - carbonization.

The effect of solar radiation can occur but by heating the wood, which generates moisture content variations which result in the appearance of deformation.

Other types of radiation like gamma rays, X or micro-wave may lead to changes in the internal structure of the wood but only at high levels of radiation, not normally meet.

CONCLUSIONS

The natural durability of the different types of wood and wooden structures is determined by the quality of wood used and by the environmental factors that can support the installation of biological organisms.

It is obvious that the quality of wood and permanent maintenance of the waterproof providing cover (for roofs), excludes the installation of most pests. Wood can be protected against Xerofile boring insects (which attack dry wood) using chemical insecticides. The general deterrence treatments are effective where old structures are concerned, especially against insects and less against fungal attack. A basic condition for any repair, consolidation or restoration work is the preliminary chemical treatment of wood elements to be included in the structure, providing increased resistance against fungi and timber.

Many buildings, and especially heritage ones, have wooden parts, which, due to an age of even hundreds of years sometimes, are weakened, even if they had no direct contact with moisture, wood decay fungi or insects, so the wood needs to be protected.

Today, there are new materials and methods of protection and conservation for wooden structures designed protect it from weathering, fungal and insect attack, fire, etc. Generally, protection and conservation treatments consist of wood coating with a waterproof, incombustible, insulating layer or impregnation of antiseptics and flame retardant substances.

Even if manufacturers are trying to provide the least harmful substances on the environment, all of them are, to a lesser or greater extent, still toxic.

The best, cheapest and most environmentally friendly wood preservation method is protection by its design, despite all attempts of the chemical industry to forward the idea of the chemical and synthetic protection.

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