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Nanostructured materials for protection and reinforcement of timber structures: A review and future challenges

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HIGHLIGHTS

- Nanostructured materials offer potential applications in timber structures.
- Recent nano-materials for reinforcement and protection of timber are examined.
- Innovative nano-coatings and their wood surface protection functions are reviewed.
- Next-generation application fields have also been analysed.
- Research on reinforcement of timber structures with carbon nanotubes is presented.

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ABSTRACT

The latest technological innovations in nanostructured materials for reinforcement and protection of timber structures are presented. Starting from the definition of nanotechnologies applied in the construction field, the paper briefly describes nano-materials already existing on the market, nano-coatings and their wood surface protection functions, classification and compatibility with the different wood species, focusing on their potential usage and their application in the fields of architecture, civil engineering and cultural heritage.

Next-generation application fields are reviewed with a special focus on an experimental research on reinforcement of historic timber structures with the application of a polymeric resin reinforced with carbon nanotubes.

1. Introduction

Nanosciences and nanotechnologies represent a new scientific and technological approach for manipulating material structure and behaviour at the atomic and molecular scales, where properties differ significantly from those observed at a larger scale. Descending from the normal scale to the infinitely small (the prefix "nano" means 10^{-9}), we enter the domain of quantum physics: the use of nano-particles makes it possible to obtain materials with new chemical, physical and mechanical properties and to increase the original performance of conventional materials (e.g. carbon atoms connected to form nanotubes, can produce materials that are stronger than steel) [1]. Since 1959, when nanotechnologies were firstly introduced by Richard P. Feynman during the famous lecture "There's plenty of room at the bottom" [2] there have been revolutionary developments and nowadays nanotechnology involves multidisciplinary areas of investigation, which in recent years have affected all sectors of industry with significant economic implications.

For the European Union, nanotechnologies represent one of the major fields of scientific development for the near future and have been identified as priority areas for European economic and industrial development. The growing interest in the potential applications of nanotechnology is confirmed at international level in the strategic documents for the planning of scientific research and technological innovation funding. In 2008, the European Commission also adopted the "Code of Conduct for responsible research in the field of nanotechnology." In the absence of comprehensive structured legislation, this voluntary code aims at promoting integrated, safe, ethical and responsible research, recalling some principles (i.e. "sustainability" and "precaution") on which the EU States are invited to take concrete action. As nanotechnology is an emerging research field, there is great debate regarding to what extent nanotechnology will benefit or pose risks for human health and environment and many research projects at international level are specifically focusing on these issues.

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Hundreds of products containing nano-materials are already in use in many sectors of life (including health, information society, industry, energy, transport and space). In particular, in the field of construction and cultural heritage, nanotechnologies are providing a significant boost to innovation in traditional processes and products. Some applications in relevant international architecture are contributing to their diffusion. At present, the most promising applications relate to nano-structured coatings. Together with the common performance requirements (long term stability, durability and weather resistance, good adhesion to the substrate, transparency, sustainability of the production process, etc.), they introduce additional functionality such as self-cleaning, photocatalysis, water resistance, fire resistance, scratch resistance, graffiti resistance and antibacterial properties [3,4].

Currently, the nanotechnology industry is rapidly developing in the field of construction and cultural heritage [5]. However, it should be highlighted that most research has been directed at materials such as concrete and metal. To date, several ready-to-use nano-products for wood protection are available on the market but very little research has focused on the reinforcement of timber structures. The last part of this paper focuses on this specific topic, presenting also results of experimental research on the application of a polymeric resin reinforced with carbon nanotubes on historic timber structures. The research addressed the definition and assessment of a methodology for preparation and application of the nano-composite. The aim was to verify whether there was an increased mechanical resistance in comparison with traditional reinforcement methods.

2. Nanotechnology and wood

2.1. Wood: a natural nano-structured material

Due to its anatomical features, wood is considered a natural nano-structured composite material, anatomically similar to strong piping bonded with a thermoplastic matrix, the lignin, and equipped with strong dissipative capacity with regard to fracture energy (Fig. 1). It can be seen as a polymeric composite of cellulose, hemicellulose, protein and lignin, as well as, at the nanoscale level, a cellulosic fibrillar composite [6]. This natural nano-composite can potentially offer important applications in the field of nanotechnologies mainly as nano-materials derived from forest products (i.e. nano-cellulose, cellulose nano-composites) or as nanotechnology incorporated into traditional forest-based products (i.e. nano-coating to enhance wood durability) [7].

2.2. Nanotechnologies for wood in construction field

The use of wood as construction and building material is widespread, with different formal, colour and structural features that make it unique. Architectural heritage built in wood is an important sector of our cultural heritage, including different typologies (such as floors, roof trusses, bridges, etc.). On the topic of their conservation it has become widely accepted that such structures should be maintained and preserved, with interventions respectful of their original conception, but also of their material [8,9].

Wood discolours as a result of exposure to ultraviolet (UV) light, moisture and bio-organisms. Treatments introduced by nanotechnologies can improve its durability or stability, which are negative factors associated with timber exposure to the environment. Despite the highly innovative character of these techniques (some still experimental), in recent international case studies it is possible to find out applications of nano-structured materials on relevant new architectures as well as on historic timber structures belonging to cultural heritage (Fig. 2).

3. Nano-coatings for timber protection

Nanocomposite coatings can improve the performance and functionality of wood, extending its stability, which is often a factor that limits its use. On the other hand, it is noted that traditional products and treatments available on the market, aimed at maintaining wood durability, are often highly toxic for humans and for the environment. There is therefore the need for new non-toxic products. Nano-materials are usually incorporated into coatings, in an aqueous, organic or polymeric medium and different nano-impregnation of timber is possible. An essential aspect is that nano-particles are well dispersed in a suitable medium to avoid aggregation. Nano-particles are less than 100 nm in size and they protect or enhance the properties of the substrate. Their high ratio of surface area to mass ensures that a loading of only a few percent by weight in coatings can significantly enhance chemical, thermal and physical properties [12].

Nanotechnology applications in coatings have shown remarkable growth in recent years. This is a result of an increased

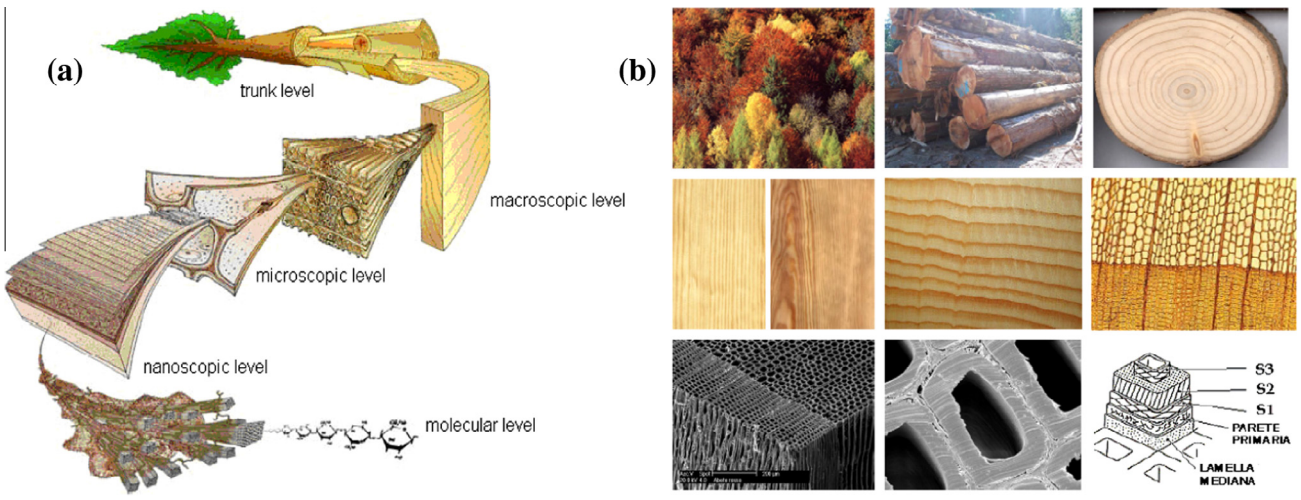

Fig. 1. Different levels of observation of wood (a) (artwork by Mark Harrington, ©University of Canterbury, 1996) and variability of wood structure at different scales of observation (b) (re-elaborated from R. Zanuttini).