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Environmentally friendly wooden-based coatings for thermal insulation: Design, manufacturing and performances

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ABSTRACT

The design of an innovative protective and thermal insulating coating is investigated. The coating is composed of two superimposed layers; the innermost layer consists of dried beech dust dispersed in a diluted polyurethane binder, while the outermost layer is a conventional decorative hybrid epoxy-polyester powder coating. Each layer was sprayed on a metal substrate and baked at moderate temperature to consolidate the coatings and establish their full properties. The morphological features, mechanical response, protective and thermal insulating performance of the coatings were experimentally analysed by varying their structure and dried beech dust concentration in the binder. These coatings exhibit high potential in terms of thermal insulation and also show remarkable behaviour in terms of visual appearance, adhesion to the substrate and long lasting.

1. Introduction

Buildings in the continental United States account for roughly 35% of the primary energy and 65% of the total electricity used each year. They also generate 35% of the US and nearly 10% of the global carbon dioxide (CO_2) emissions. Energy-efficient and, even better, low-energy building design has therefore become increasingly important in the conception of modern buildings and construction, especially in light of the growing environmental concerns related to global warming [1,2]. Due to the limited availability of non-renewable energy resources and their increasing costs, a common challenge among scientists and practitioners is to find novel and viable solutions to reduce energy consumption and waste. In the building industry, energy savings often relate to thermal insulation from severely hot or cold climates [3]. Thermal insulation is usually pursued with a conformal design of the outermost surface of the building (i.e., envelopes), proper choice of raw materials and their combined usage. Glass and mineral fibres, polyurethane foam boards, in situ foamed products and expanded and extruded polystyrene abound in the conception of architectural, engineering and technical applications in the design of new buildings [4]. Similarly, binding of these materials to one or more enclosed air spaces allows for further improvement of the energy-efficient design of building facilities. Energy-efficient windows are an important part of the high levels of insulation required by low-energy buildings. The prevention of air infiltration and the reduction of heat exchange are usually pursued with double- or triple-glazed windows, weather-proof sealing and insulating frames with complex shaped profiles in laminated wood or aluminium as well as with the development of highly effective spacers and/or thermal breaks [5]. Little importance is usually ascribed to the role of the paint, apart from its specific role of protecting the window frames from ageing. However, the true interface between any segment of the building envelopes and the external environment is the paint, and thus, it does play a major role. Energy-saving or reflective paints can achieve a decrease in energy consumption of up to 50% [6–9], thus actively contributing to reducing both resource depletion and the adverse environmental impacts of pollution generated by energy production, which is often considered to be the cornerstone of sustainable design. Accordingly, the role of paint can be crucial to the surface of the window frame as well. Beyond reducing the need for frame maintenance, paint can also be designed to reduce heat exchange, thus increasing the overall efficiency of the window and, at the same time, allowing for a significant simplification of the design of the wooden or metal profile. An increased insulation capability of the paints would reduce the need for complex-shaped insulating profiles in the design of window frames. Shape simplification results

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in reduced costs and maintenance with increased reliability of the end-product.

There are several methods by which a paint can be made thermally insulating. For example, energy-saving paints, manufactured by the addition of mineral insulators, are widely diffusing into the building market. Their efficiency has been demonstrated in several experimental analyses in which mineral insulators have been found to act as obstacles to heat transmission, thus significantly contributing to a reduced heat loss [10,11]. Similarly, reflective paints are manufactured by dispersing metal flakes within organic binders, which, once deposited, can generate low-emittance surfaces. In this respect, their implementation in home attics, on flat and sloped roofs and in wall systems of building envelopes in snowy environments or in the hottest deserts has proven to be highly efficient in reducing energy consumption and has established new standards in low-energy building design [12,13]. Further alternatives to the manufacturing of energy-saving paints can involve the use of natural materials, such as a mixture of cotton fibres dispersed in an organic binder and deposited by fibre spraying [14], which have displayed great potential in the field of construction (pipelines, boilers, heat exchangers, etc.) and can conjugate their thermal insulating properties to high mechanical performance.

The present manuscript investigates the potential of a low impacting insulating material for the design of a novel paint formulation for the protection and decoration of window frames. The design of these coatings was studied as a function of their structure and composition. Dried beech dust was chosen as an eco-friendly thermal insulator, and an improved method for dispersing the dusts in a polyurethane-based binder as well as the spraying and curing process were investigated. The morphological features, mechanical response and protective and thermal insulating performance of the coating systems were experimentally analysed by varying the coating structure and wood dust concentrations. Most of the designed coatings exhibited high potential in terms of thermal insulation and demonstrated a notable visual appearance, adhesion to the substrate and chemical endurance. These properties make the resulting paint an ideal candidate not only for energy savings in the manufacture of window frames but also for decorative and protective purposes.

2. Materials and methods

2.1. Materials

Dried beech powder (La.So.Le. est, Percoto UD, Italy), 20 μm in diameter, was dispersed in a diluted polyurethane-based binder (Desmophen 651 MPA/X, Bayer, Leverkusen, Germany) at concentrations of 40, 60 and 80 wt.% to achieve a homogenous suspension designed for thermal insulation purposes. Appropriate levels and types of dispersants, thickeners and defoamers ensure good

Table 1
Coating systems investigated and corresponding average thicknesses.

Coating type	Coating material	Wood dust concentration (wt.%)	Coating thickness ± SD (μm)
A	Insulating layer +decorative layer (interlayer + topcoat)	0	109 ± 4
B		40	113 ± 5
C		60	124 ± 7
D		80	156 ± 4
B*	Insulating layer (interlayer alone)	40	76 ± 4
C*		60	89 ± 6
D*		80	123 ± 6
Ref.	Decorative layer (topcoat alone)		111 ± 6

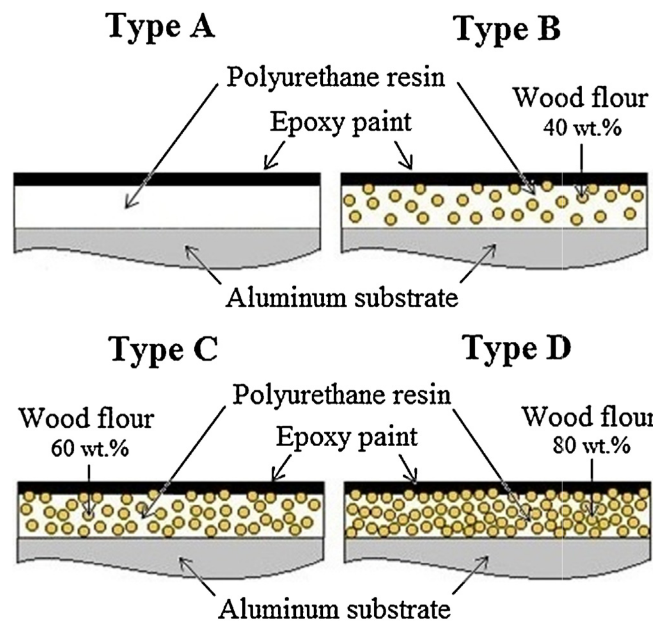

Fig. 1. Design of the coatings.

dispersion of the filler in the binder and proper rheology of the formulations. A hybrid epoxy-polyester thermosetting powder, specifically designed for powder coating (20 μm diameter, 0.80 shape factor, Interpon 100-AN8061 Akzo Nobel, Sassenheim, the Netherlands), was selected for the formulation of the decorative layer. The material is based on bisphenol-A type epoxy and carboxylic acid-terminated polyester resins. Catalysts, flowing agents (silica and aluminium oxides), promoters (applied after melting) and UV stabilisers (titanium oxides) complete the formulation.

The formulations were deposited on aluminium substrates (EN AW-6081 T6, 50 mm × 40 mm × 6 mm). This alloy is representative of a large class of materials widely used in the manufacturing of window frames.

2.2. Processing

Multi-layered coatings were deposited on aluminium substrates by spraying with a high-volume low-pressure (HVLP) gun. The deposition process involved multiple steps: (i) the aluminium substrates were washed in an ultrasonic bath of isopropyl alcohol and blow dried; (ii) the liquid formulation based on the dispersion of wood powders in polyurethane-based binders (i.e., the insulating interlayer) was deposited (300-mm stand-off distance, 0.8-mm nozzle, 1.75-bar feeding pressure) on the aluminium surface; (iii) after a short pre-drying step, another layer (i.e., the decorative topcoat) consisting of dry epoxy-polyester powders was deposited (300-mm stand-off distance, 1.4-mm nozzle, 2.5-bar feeding pressure); (iv) the sample was then baked in a convection oven at 160 °C for 20 min. Table 1 summarises the different coatings that were manufactured and corresponding thicknesses. Samples A–D (Fig. 1) featured both the insulating interlayer and decorative topcoat, with different concentrations of wood powder (0–80 wt.%) in the innermost insulating layer. Samples B* to D* featured only the insulating interlayer with different concentrations of wood powder (40, 60 and 80 wt.%). The interlayers were also left as-deposited for comparative purposes and to investigate the role of the decorative topcoat in terms of visual appearance, mechanical performance and thermal insulation. Finally, a coating (i.e., Ref.) consisting only of the epoxy-polyester decorative layer deposited on an aluminium substrate without the insulating interlayer was also studied. The average coating thicknesses varied from