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Standard-compliant development of a design value for wood–plastic composite cladding: An application-oriented perspective

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ABSTRACT

Bio-based materials, such as wood–plastic composites (WPC), have gained the interest of the resource-intensive building industry. Presently, this novel composite is being used in decking and cladding. The structural design of façades made from WPC compounds, however, has been difficult in the past due to a lack of design principles and experience.

In this case study a design concept is developed, which combines material attributes describing the strength loss of the material due to different weathering processes on façades. Although this approach is widely used for approvals of cladding kits in Central Europe, it has not yet been used for WPCs. This paper is unique because for the first time research findings taken from a literature review on WPC attributes are used to obtain a realistic WPC design value for engineered façades. Simulations of WPC aging in three main categories predicted a strength loss of approximately 50% compared to the virgin material. Nevertheless, a WPC material design value which includes the effects of material aging is still useful for a façade planner's practical work in view of the mandatory codes and standards in this field.

1. Introduction

Wood–plastic composites (WPC) are an example of a novel highly sustainable building material. They consist of wood fibers embedded in a petrochemical plastics matrix. Main applications are decking and cladding. There is an emerging body of literature concerning the use of bio-fiber reinforced plastics instead of pure petrochemical polymers, which relieves the pressure on scarce resources such as fossil fuels. However, their use in "green" façades is still in its infancy because their development constitutes a challenge, particularly for the medium-sized industry. The global WPC production has experienced an overwhelming boost in the past years. In 2012, 1.5 million tons of WPC were produced worldwide, and this was mainly driven by decking and the North-American market. The production volume of WPC decking in Europe was 174,000 tons in 2012, whereas only 16,000 tons of WPC cladding were produced [1]. According to literature reviews on WPC technology, recent research mostly focuses on single aspects of compound properties rather than on multiple attributes

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and the extent of their mutual interaction. Despite a growing market, WPC investigations are generally not very application oriented.

The literature review revealed that WPC producers publish very little information about technical properties, certificates and approval documents. It appears that current WPC cladding products in particular are marketed at private house owners rather than architects and engineers who are in charge of material selection within a building project and assess products under technical aspects. It can be theorized that by not disclosing specific product details, the WPC industry is overlooking a potential market segment which is continuously increasing.

In view of the current research deficiencies, this paper aims to develop and apply a method for deriving a WPC-cladding material design value. The following approach agrees well with engineering methods because it is mainly based on material and building design codes. This could motivate façade planners to not only choose WPC cladding because of its sustainability but also because available performance data supports their design process.

2. Concept for deriving a design value from test results: EN 1990

"Eurocode EN 1990: Basis of structural design" [2] is a standard that regulates how calculations for engineering structures should be carried out. Whenever design checks for a building element or a material are carried out, this standard specifies how to deal with material-related properties derived from performance tests. This is necessary because such tests only reflect the properties of a particular series of test samples and could hardly serve as a reference for all imaginable cases where the material is used in practice. A 30-year-old WPC product in a façade, for example, exhibits significantly different properties than the originally tested specimens in the laboratory. Therefore, results from the tests must be translated from the characteristic values representing the virgin material state into the design values for the design codes. Obviously, the design value of the material resistance is smaller than the characteristic value, as it takes into account any distortion effects within the test procedure and, in particular, the material degradation due to aging within the relevant time frame. In EN 1990 [2], these material-related aspects are taken into account with the following factor:

$$\text{Conversion factor}: \eta \leq 1.0 \tag{1}$$

Besides the influence of testing conditions and aging, further corrections are necessary to account for uncertainties within the cladding product system, such as size effects resulting from small test samples, and future large-scale applications. Therefore, a partial safety factor is defined as follows:

$$\text{Safety factor}: \gamma_M = \{\gamma_m \times \gamma_{Rd}\} \geq 1.0, \tag{2}$$

where γ_M can be subdivided into two partial factors:

$$\text{Material safety factor}: \gamma_m \geq 1.0 \tag{2.1}$$

$$\text{Construction safety factor}: \gamma_{Rd} \geq 1.0 \tag{2.2}$$

The resulting design material property is:

$$\text{Material design strength}: R_d = \eta \times \left(\frac{X_k}{\gamma_M}\right) \tag{3}$$

where X_k is the material property according to EN 1990 [2], expressed as 5th-percentile. This value was calculated from the arithmetic mean of a test series. Based on normal distribution and unexpected variation, the mean value is additionally reduced by the k_n-fold variation coefficient. If, as usually recommended in approval documents for cladding, ten individual tests on virgin specimens were run within a series, the k_n-factor is 1.92. With a higher number of tests k_n decreases and X_k becomes more precise.

Whenever a structural engineer wants to perform a design check for WPC cladding under a particular load, the material design value R_d must be superior to the wind load E_d:

$$\text{Design requirement for WPC wall cladding}: E_d \leq R_d \tag{4}$$

The capacity of cladding under a given load is thus assessed for the ultimate limited state, which is marked by the subscript "d". The wind loads are taken from national standards and the material design value is given either by the relevant material-related standards or the approval documents. The latter should further provide information about the bending strength of the WPC panel and the pull-out resistance of the fasteners used for attaching it. If the strength values have the subscript "d", a façade planner can be sure that any uncertainties regarding the material or its application are already taken into account.

However, there are still no approvals for WPC wall cladding, which is why a strategy for the standard-compliant design of such cladding is presented in this paper. It is essential to focus on the previously introduced coefficients, which requires a deeper knowledge of testing statistics and engineering design. Further information on this topic is given in EN 1990 [2]. The parameter X_k can be determined from tables given in Appendix D, which can be used to calculate the 5th-percentile value for a given test series. The parameter γ_M takes into account material and particularly construction-related deviations from the results of laboratory tests. Their assessment demands a high level of experience with similar, well-established materials. From a review of product approval documents of various façade products it was found that the value of γ_M generally ranges