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Fire resistance of inorganic sawdust biocomposite

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Abstract

The objective of this study was to manufacture fire-resistant biocomposite sandwich plates using waste sawdust as filler and an inorganic potassium aluminosilicate binder. Using binder contents of 29% and 34%, twelve biocomposite plates were fabricated without using any specialized equipment, heat, or pressure, thus producing an environmentally conscious biocomposite material. Several of the plates were strengthened with carbon and glass fiber reinforcements to create a more durable sandwich structure. The influence of binder content and reinforcement type on the heat release rate and smoke emission characteristics were investigated using the OSU heat calorimeter and the NBS smoke chamber, respectively. All specimens passed the Federal Aviation Administration requirements for heat release and smoke emission, the criteria used for evaluation of the test results in this study. Relative to 15 other wood plastic composites that utilize organic polymers, the inorganic biocomposite showed superior heat release rates during 5 min of fire exposure.

Keywords: A. Wood; A. Recycling; C. Sandwich; B. High-temperature properties; E. Casting

1. Introduction

1.1. Biocomposites

Wood plastic composites (WPC) or biocomposites are relatively new categories of materials that cover a broad range of composite materials utilizing an organic resin binder (matrix) and fillers composed of cellulose materials. The new and rapidly developing biocomposite materials are high technology products, which have one unique advantage – the wood filler can include sawdust and scrap wood products. Consequently, no additional wood resources are needed to manufacture biocomposites. Waste products that would traditionally cost money for proper disposal, now become a beneficial resource, allowing recycling to be both profitable and environmentally conscious. The use of biocomposites and WPC has increased rapidly all over the world, with the end users for these composites in the construction, motor vehicle, and furniture industries [1–7].

One of the primary problems related to the use of biocomposites is the flammability of the two main components (organic binder and cellulose-based filler). If a flame retardant were added, this would require the adhesion between fiber and matrix not be disturbed by the retardant. The challenge is to develop a fire-resistant biocomposite that will maintain its level of mechanical performance [8–10]. In lieu of organic matrix compounds, inorganic matrices can be utilized to improve the fire resistance. Inorganic-based wood composites are those that consist of a mineral mix as the binder system. Such inorganic binder systems include gypsum and Portland cement, both of which are highly resistant to fire and insects [2]. The main disadvantage with these systems is the maximum amount of sawdust or fibers that can be incorporated are low. This drawback stems from the inherently high viscosity of the inorganic resin, which reduces the ability of the sawdust particles to become fully saturated with resin during the mixing

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process. In addition, chemical sizings placed on reinforcing fibers are specifically engineered to improve the bond between fiber and organic resin. Since the chemical make-up of organic and inorganic resins differ considerably, these sizings often interfere with bonding between fibers and inorganic resin. As a result, less fiber can be successfully incorporated in the composite.

1.2. Potassium aluminosilicate matrix

One relatively new type of inorganic matrix is potassium aluminosilicate, an environmentally friendly compound made from naturally occurring materials. This matrix is a two-part system consisting of an alumina liquid and a silica powder that cures at a reasonably low temperature of 150 °C (302 °F). In addition, hardeners can be added to facilitate room-temperature curing. The Federal Aviation Administration has investigated the feasibility of using this matrix in commercial aircraft due to its ability to resist temperatures of up to 1000 °C without generating smoke, and its ability to enable carbon composites to withstand temperatures of 800 °C and maintain 63% of their original flexural strength [11]. Potassium aluminosilicate matrices are compatible with many common building materials including clay brick, masonry, concrete, steel, titanium, balsa, oak, pine, and particleboard [12–15]. Processing requirements and mechanical properties of carbon/carbon composites, ceramic matrix composites made with silicon carbide, silicon nitride and alumina fibers, and carbon/potassium aluminosilicate composites were compiled by Papakonstantinou et al. to study the relative performance of potassium aluminosilicate composites [16]. The extensive study indicated that carbon/potassium aluminosilicate composites have mechanical properties that are better than most fire-resistant composites.

1.3. Flammability parameters

The fire behavior of a material is commonly characterized using two parameters, the heat release rate (HRR), and the specific optical smoke density (D_s). The heat release rate (HRR) is the rate at which heat energy is evolved by a material when burned and is used to measure how large and how quickly a fire environment grows. Recently, advances in fire research and fire dynamics have emphasized the importance of the heat release rate as the primary fire hazard indicator of a material. The rate of heat release, especially the peak HRR, is the primary characteristic determining the size, growth, and suppression requirements of a fire environment. To quantify the heat release properties of any material, the Ohio State University (OSU) Rate of Heat Release Test is utilized in accordance with ASTM test method E906 [17]. The heat release rate is expressed in terms of power per unit area (kW/m^2) and reaches maximum value when a material is burning most intensely. In contrast, the heat release of a burning material is the amount of heat energy evolved and is expressed in terms of energy per unit area (kW-min/m^2) [17–19]. The Federal Aviation Administration standards for heat release are commonly referred as the "65·65" acceptance criteria and are set forth in Federal Aviation Requirement (FAR) 25, Amendment 25–61 (FAR 25.853[a-1]) [20]:

- The maximum heat release rate during the 5-min fire test cannot exceed 65 kW/m^2.
- The total heat released during the first 2 min cannot exceed 65 kW min/m^2.

The specific optical smoke density, D_s, is a dimensionless measure of the amount of smoke produced per unit area when a material is exposed to both flaming and radiant heat sources. To determine this smoke-generating characteristic, the NBS Smoke Test is employed in which a material is burned in the NBS (National Bureau of Standards) Smoke Chamber. The maximum value of D_s that occurs during the first 4 min of the test, ${}^4D_m$, is the most important parameter measured [19–21]. According to Federal Aviation Requirement (FAR) 25.853(c-1) Amendment 25–72, ${}^4D_m$ during the 4-min test cannot exceed 200 [20].

The primary objective of the research reported in this paper was to fabricate fire-resistant biocomposite sandwich plates by combining the aforementioned potassium aluminosilicate matrix with waste sawdust. Earlier research by the authors [22] found that the compressive and flexural strengths of this biocomposite were approximately 39 and 1.79 MPa, respectively, while increases of 265% in flexural capacity were achievable with one tow of carbon fiber reinforcement on the tension face of a biocomposite beam. Using similar formulations of the biocomposite used to establish these mechanical properties, the authors investigated the fire response of the material in this paper. Small plates of this biocomposite material were reinforced with glass and carbon fibers to examine the effect of reinforcement type on heat release rate and smoke emission of the resulting sandwich plate.

2. Experimental investigation

The two major variables investigated in this experimental study were sawdust content used in the biocomposite mix and type of reinforcement used on the exterior faces of the sandwich plate. The two primary response variables included heat release rate and optical smoke density, which were measured experimentally using the OSU and NBS test methods, respectively. These methods were utilized since they are standard tests used to evaluate the fire response of most materials. The specimens were categorized into two separate sets based upon the test method used to evaluate them, as shown in Tables 1 and 2. The average thickness of the plates was 11.9 mm. Specimens for OSU heat release testing measured 150 × 150 mm while NBS specimens measured 74 × 74 mm.

Six sandwich plates were manufactured by hand for each set of specimens (OSU and NBS), resulting in a total