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Char Valorization into Sustainable and Performant Polyurethane Insulating Panels

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River maintenance is required for environmental risk management; however, the resulting vegetable biomass owns poor properties that preclude its treatment in an energy power plant. Nevertheless, the large availability of river biomass and a possible valorization of the by product from the gasification process (namely char, a fine-grained vegetable carbon) can encourage and make this operation more sustainable. If the use of char as soil or substrate improver has been widely studied in the last 15 years, the application of this substance for construction materials or composites is starting to gain more attention recently. Indeed, in addition to the great advantage of carbon sequestration, the use of char can reduce the energy associated with the production process of such materials by decreasing the consumption of raw materials. In this work, char deriving from the gasification process of local river biomasses is fully characterized and used in different ratios in polyurethane panels for insulating purpose. Remarkably, polyurethane panels show an enhancement in thermal insulating power and electric conductivity by increasing the char content. Enhancements in terms of mechanical properties are also observed for maximum char content up to 1 wt%. In contrast, higher content results in preventing a good development of polymerization and consequently of good properties. Precisely, the char use significantly increases the maximum load in stress-relaxation tests and improves the load recovery after 10 min, whereas higher elastic modulus and compressive strength values are observed in compressive tests. The char effectiveness toward more sustainable and performant insulating materials is demonstrated.

1. Introduction

River maintenance is a vital operation to ensure embankments' safety and prevent ruinous floods. However, the large amount of biomass deriving from this operation is still not widely exploited for bioenergy production mainly due to its poor quality related to high moisture and ash content and the variable size distribution. So, compared to wood chips or pellets, it is less valorized into power plants.[1] Nonetheless, the significant availability of this type of biomass justifies the optimization of a dedicated power plant. Apart from the energy production, this process generates an interesting by product which is a fine-grained vegetable carbon: char from Energetic Recover of River Biomass. Char use as soil improver has been well established during the last 15 years. Moreover, recently it is starting to gain more attention as a promising secondary raw material for construction materials and composites, so toward sustainability of the construction sector. For instance, char addition might contribute to energy reduction related to the production process of construction materials, carbon sequestration, reduction of the firing temperature, reduction of raw materials exploitation, and properties optimization.[2–6] Applications into polyurethane products provide interesting filtering and antipollutant properties,[7–9] although no further studies have focused on the mechanical, thermal, and electrical properties of polyurethanes for insulating panels real applications. In this work, the char deriving from the gasification of Secchia River Biomass (Emilia Romagna, Northern Italy) was considered as a viable secondary raw material for insulating construction materials and as a possible solution toward economic and environmental sustainability of the river maintenance process. Char, characterized by a fine grain size (<4 mm), was added in different content in polyurethane mix aiming at conferring sustainability and performance optimization to insulating panels. Chemical, physical, and thermal analyses were conducted for char and polyurethane panels to fully characterize the by-product properties and its influence on the final composite material.

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2. Results and Discussion

2.1. Char

Char resulted in a strongly alkaline pH value; remarkably, this could affect the material acceptability for specific applications but

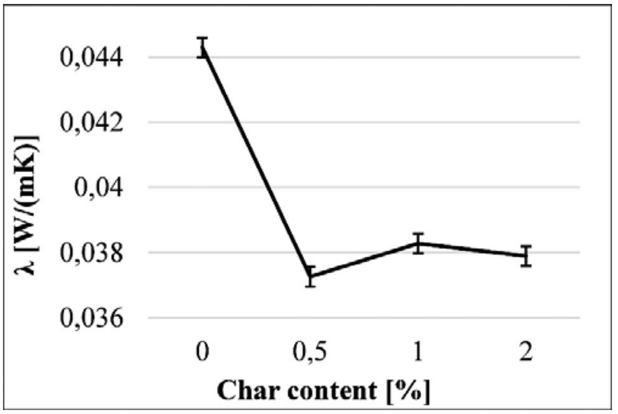

Figure 1. Thermal conductivity (λ) of polyurethane panels as a function of char content.

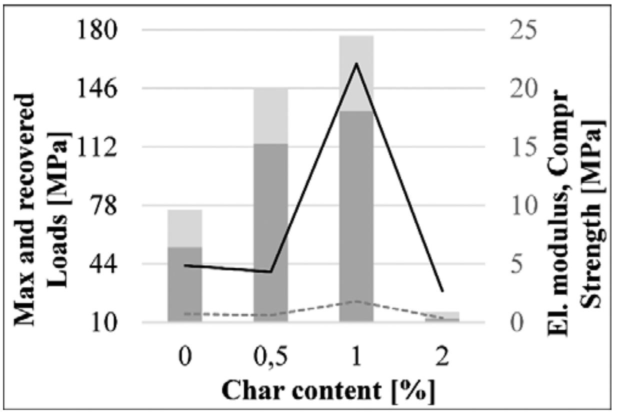

Figure 2. Mechanical test results as a function of char content. Stress-relaxation test in the bar chart: maximum load at 5% deformation (Dark gray), recovered load after 10 min relaxation (clear gray). Compressive test: elastic modulus (black line), compressive strength (gray dotted line).

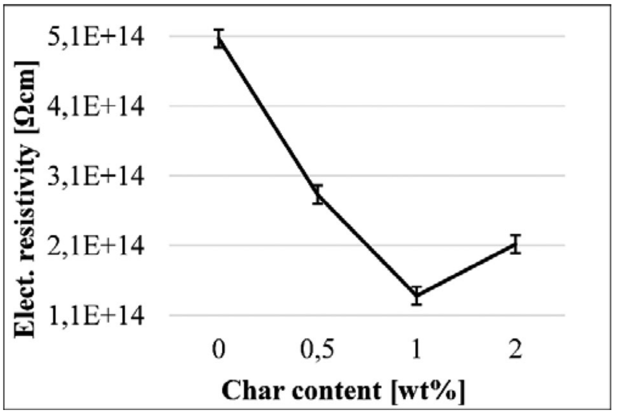

Figure 3. Electric resistivity of polyurethane panels as a function of char content.

not for polyurethanes. In addition, the evidence from calcimeter, EDS, and XRD analyses displayed a significant presence of calcium carbonate. Indeed, a linear correlation between alkalinity and carbonate content is established in literature,[10] although also carboxyl and hydroxyl groups may contribute to char pH. According to literature data on char deriving from different feedstocks and processes, a total carbon from 45% to 85% is assessed by EDS chemical analysis. Similarly, elemental analysis detected carbon content by 54%, while other contents were: Hydrogen 1%, Nitrogen 0.33%, Sulphur 0%. XRD displayed a predominant amorphous nature with only calcite and quartz traces as crystalline phases. Finally, the Electric conductivity (Ec) value for char was computed around 5–6 mS cm^{-1}.

2.2. Polyurethane Panels Containing Char

The addition of increasing char content further decreased the low thermal conductivity of polyurethane, that stands as one of the best thermal insulating materials for constructions. Indeed, by adding up to 2 wt% of char to polyurethane mix, a sensible reduction of the reference sample value (0.044 W (m K)$^{-1}$) is promoted till the range 0.037–0.038 W (m K)$^{-1}$, see **Figure 1**. The results obtained from mechanical tests are summarized in **Figure 2**. In the stress-relaxation test, the reference sample displayed a maximum load of 53.5 kg and a load recovery of 22 kg. On the other hand, the addition up to 1 wt% of char positively promoted an increase of these values to around 133 and 44 kg, respectively. Elastic modulus increased in samples with additions up to 1 wt% of char too. However, for char content greater than 1 wt%, the polyurethane displayed a rapid loss of mechanical properties attributable to a noncomplete polymerization occurrence of the polymeric matrix. SEM-EDS investigation supported this theory by highlighting a denser structure where char particles filled the polyurethane porosity. As shown in **Figure 3**, an electric conductivity reduction was also promoted by the addition of 0.5, 1, and 2 wt% of char compared to the reference panel (5×10^{14} Ω cm).

3. Conclusions

Promising results concerning the reuse of char in polyurethane panels for insulating purposes emerged from this work. A significant reduction in terms of both thermal and electrical conductivity occurred thanks to a graphite-like behavior of char in reflecting IR and conducting electricity. Moreover, a maximum char content of 1 wt% was outlined for mechanical properties optimization. Indeed, the polyurethane panels containing up to 1 wt% of char displayed better elastic and viscoelastic properties than the reference samples without char. Whereas, higher content affected the correct polymerization of the polymeric matrix, so precluded the development of good mechanical properties.

In conclusion, char use in construction field applications appeared a feasible solution toward more environmental and economic sustainability for the river maintenance and biomass gasification processes. Moreover, due to the polyurethane properties optimization, char addition in the mix might lead to a reduction of raw materials exploitation, benefits in avoiding the accumulation of electrostatic charges and reduction of carbon dioxide related to construction materials. So, the char addition in polyurethane insulating panels might promote the construction sector sustainability and good practice to counter global warming.

4. Experimental Section

Char Characterization: Char was fully characterized to understand better its properties that, as for char in general, strictly depended on the process that generated it. The char involved in this work derived from the gasification of a local River Biomass (Secchia River, Emilia Romagna, Northern Italy). The grain size distribution was determined through a mechanical sieving test that was conducted by involving 2, 1, 0.500, 0.250, and 0.125 mm sieve sizes and 15 min vibration. The particle structure and surface morphology of char was examined by Environmental Scanning Electron Microscope ("ESEM-Quanta 200 FEI"), whereas Energy Dispersive Spectroscopy (EDS) identified the atomic elements and their relative percentual proportions in char. Additionally, an elemental analyzer (CHNS-O Thermo Finnigan Elementary Analyzer Flash EA 1112) was involved in detecting the content of C, H, N, S. Electric Conductivity, and pH measurements were performed following the standards UNI EN 13038:2012 and UNI EN 13037:2012, respectively. Finally, crystalline phases and carbonates were revealed using an X-Ray Diffractometer (Phillips PANalyticalPW3710) and a Dietrich–Fruhling calcimeter.

Polyurethane Panels Preparation and Characterization: Char was dried at 105 °C for 24 h and ground (<125 μm), then mixed with two different polyols, isocyanate, water, catalyst, and silane agents. Char ratios by 0.5, 1, and 2 wt% of polyol content were considered. The mixture was poured into a mould (20 × 20 × 2 cm) and thermally maintained at 40 °C by a cryostat. A thermal conductivity test was performed through a Heat Flow Meters (HFM 436 Lambda) to highlight the possible effects of char addition on the power insulating of polyurethane panels. Additionally, since polyurethane panels might find applications also in structural elements, some mechanical tests were performed. A stress-relaxation test was carried out to compare the viscoelastic behavior of panels containing increasing char content and the reference one (without char). For this purpose, a constant deformation by 0.1 mm s^{-1} up to the maximum load (5% of deformation) was considered, then the relaxing (deformation recovery) behavior after 10 min was observed. Additionally, a compressive strength test was performed following UNI EN ISO 604 and involving a Universal testing machine (Instron 5567) equipped with a 30 kN maximum load. Finally, electric resistivity measurements were performed through Keithley 6517a instrument.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Keywords

char, construction materials, electrical conductivity, insulating materials, polyurethane

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