Environmental Impact of Waste Wood Ash

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Waste wood ash (WWA) is used with other waste materials in geopolymer production and is found in pulp and paper, wood-burning industrial facilities, and wood-fired plants.

Keywords: geopolymer concrete ; waste wood ash ; environmental impact mechanical properties

1. Introduction

Globally, 0.74 kg of solid waste is generated per capita per day, with national rates varying between 0.11 and 4.54 kg per capita per day depending on urbanization rates and income levels [1][2][3]. The Europe and Central Asia regions, with 20% (392 million tons per year), rank second in solid waste generation [4][5][6]. The overall composition of waste mainly corresponds to organic and green waste (44%); paper and cardboard (19%); other materials (14%); plastics (12%); glass (5%), metal (4%); wood (2%); and rubber and leather (2%). As for waste treatment, it mainly focuses on recycling (20%) and incineration (17.8%), providing the possibility of giving a new useful life to the materials after their use and ensuring adequate final disposal [7]. This is in line with the adaptation of a circular economy as a novelty and eco-friendly production model. In the specific case of the construction industry, part of the environmental impact is due to the demolition of structures, which generates different types of solid waste. On the other hand, the use of cement in the production of bricks/block and concrete, which is used in the latter to make it more resistant [8], implies a significant anthropic emission of carbon dioxide (CO_2) of 5–8% worldwide, which could increase, according to projections, to 27% by the year 2050, especially taking into account that one cubic meter of concrete is produced annually per person [8][9][10][11]. Based on this reality and the projected scenario, the cement and concrete industry has been developing a series of strategies and innovations to reduce CO_2 emissions. One of these innovations is the production of geopolymers to be used as alternative materials to replace all or part of the ordinary Portland cement used in construction, which is obtained either from metakaolin or from industrial, forestry, and agricultural waste with a high aluminosilicates content [12][13][14][15]. A geopolymer is a binder of mineral origin (inorganic) obtained from the dissolution [16][17][18][19] and subsequent polycondensation of ashes rich in aluminosilicates in the presence of an alkaline solution (hydroxides and silicates of alkali metals, Na and K) [13][20][21]. Additionally, the use of mixed geopolymers, which are generated by the combination of two or more types of chemically stabilized industrial wastes or ashes, has been considered [22]. The use of this type of materials can reduce CO_2 production by up to 90%, while preserving or even improving their mechanical properties (e.g., porosity, structure, compressive strength, water absorption, and durability) [12][23].

Several researchers have devoted themselves to using different raw materials for the production of concrete, for example, agricultural residues such as rice husk ash and palm oil ash [24], sugar cane bagasse [25][26], and corn cob ash [27], finding good results in the properties of concrete [28]. On the other hand, wood waste ashes [29][30] have emerged as a good option for the fractional replacement of binder and kaolin used in the formation of geopolymers, since in addition to increasing workability, porosity, and drying shrinkage, these wastes are given an alternative use, and potential environmental pollution [29][30][31][32][33] is reduced by their entry into the environment, contributing directly to sustainable development [34][35]. Ekaputri reported [36] obtaining a concrete (geopolymer) with high compressive strength (48.5 MPa to 48.5 MPa) from class F ash with 10 mol/L NaOH due to the generation of hydroxide ions that significantly influence the dissolution of the Si and Al atoms of the source material. Despite the advantages of using high concentrations of alkali (NaOH, between 8–10 M) to obtain a high compression strength product of 104.5 MPa and 71 MPa for the paste and mortar, as well as a lower change in length due to temperature and water evaporation that have the lowest shrinkage percentage [37], it has been proven that the use of ashes from forest biomass (wood) can decrease the requirements of alkaline activators by up to 20% without the loss of properties [38][39][40][41]. However, when the substitution level of these ashes is higher than 10% by mass, the mechanical properties of the geopolymer are affected [42][43][44][45], proportionally reducing the compressive and flexural strength of the mortars, for all curing times [35]. Likewise, it is highlighted that different conditions can be used during the process of obtaining geopolymers, such as the type of curing, humidity control, temperature, concentration and proportions of alkaline activators, type and quantity of raw material or proportions of starting materials (in case of mixtures), which will influence the properties of the final product. Among the findings, it can be mentioned that the increase in SiO_2/Al_2O_3 ratios positively influences the mechanical compressive strength of geopolymers [15], and it was found that the inclusion of 5–15% wood ash in the process can generate greater strength and durability depending on the age (aging time) of 3–7 days as a consequence of the formation of gels and minerals that increase alkalinity [12]. Research has also been conducted on the effects of the solid–liquid ratio and the alkaline activator in the synthesis of pure geopolymers. Alves et al. [46] used as precursor material ground blast furnace slag with a solid–liquid ratio between 1.5 and 2.2, and as activator solutions (a) a sodium hydroxide/sodium silicate/water mixture and (b) a potassium hydroxide/potassium silicate/water mixture, finding that the resulting geopolymer possessed high compressive strength depending on the solid–liquid ratio and the percentage of water added to the mixture, which is further impacted by the composition of the activating solution. They also noticed that the strength increases with aging [46]. Currently, the addition of plastics to the optimized wood ash-based geopolymer is being tested; for example, in the case of polypropylene (PP), it has been reported that the addition of 1% PP fiber generates an increase in compressive, tensile, and flexural strength by 3.7%, 15.6%, and 10%, respectively [47]. Other types of materials are also being developed. Kristály et al. [48] produced a composite of geopolymer foam and glass to obtain a lightweight and environmentally friendly concrete from waste materials (secondary raw material), which is a valuable building material useful for thermal and acoustic insulation of walls that is also heat-, fire-, and acid-resistant [48].

2. Environmental Impact of WWA

2.1. Air Pollution

Energy extracted from burning the wood results in the formation of WWA. WWA is very fine, which results in the ease of pollution causing respiratory problems for human beings and animals around the site of WWA production [49]. Loose ash has a high possibility for harmful influence on ground vegetation [50], predominantly to the cover and certain kinds of moss groups [51].

2.2. Land Pollution

WWA is problematic if spread regularly and requires slow delivery rates from spreaders [50]. Because of the huge variety of WWA quality, reliance on the sort of chemical structure of WWA is needed before demonstrating the direction of management as agricultural or forest-related systems [52]. WWA recycling to agricultural or forests appears a decent environmental solution, but there are a lot of possible difficulties related to its use in systems, which are more multifaceted [50].

2.3. pH Increase

The topsoil of the system is affected by pH differences and its blocks the crop or tree to obtain enough amount of nutrition from the soil. The delivery rate of calcium to soils is reliant on the primary shape of the ash, with loose ash such as WWA possibly instigating a temporary quick increase in pH in the soil [53]. For the first 7 years, the soil under 100 mm depth had a very minor change in pH value after WWA application, but after 16 years, an increase in pH value was observed [50]. The land dumping of WWA results in the slow transfer of pH from the topsoil to bottom soil, which can be observed over time. There is an increase in the pH of runoff water over the same period where WWA is applied, as observed by Fransman et al. [54].

2.4. Higher Production Rate

Approximately 2.5 kilo-tons of WWA are annually discarded in lands, as of 2006 [50], but it may increase at a high rate and a decrease in forest land has been observed. In several countries across the globe, 90% of WWA is sent to landfill and the balance part goes as land applied purpose, co-composed with sewage sludge [50]. Apart from the several environmental effects discussed above, Pitman et al. (2006) [50] studied specifically soil properties and soil vegetation.

2.5. PH Affects the Nutrition (Phosphorus, Nitrogen, and Potassium) Addition of Soil

When WWA is in contact with water, the pH solution becomes higher as the hydroxides and oxides in the WWA are dissolved and hydroxide ions are developed. WWA has a liming impact when introduced into soils and could be utilized to neutralize acidity. Three tons of WWA have a liming effect equal to one ton of quicklime. The solubility of different nutrition elements in the WWA varies considerably. Generally, the solubility of the nutrients elements are in the order of potassium > magnesium > calcium oxide > phosphorus [55].

2.6. Heavy Metal Contamination of Soil

pH, organic material content, and hydrous oxide play the main roles in the adsorption of heavy metals from the soil [56]. When WWA dissolves in an acid environment such as soils in forests, the alkalinity of WWA is consumed and the metals are exposed to a pH far lower than that of the ash, causing higher solubility [55]. WWA could also have high concentrations of heavy metals due to the fuel, which is contaminated. Wood from and wood preservers and demolition in waste wood generally comprise higher proportions of heavy metals. As a result of the relatively low volatilization temperatures for many of the heavy metals, they become enhanced by WWA. In the combustion of untreated wood [57], the concentrations of lead and antimony are one order of magnitude higher, while the concentrations of arsenic, cadmium, chromium, copper, nickel, and zinc are approximately twice as high.

2.7. Soil Water Leachate

Williams et al. (1996) [58] observed that there are amplified concentrations of both calcium and potassium in groundwaters and soils, with some movement of aluminum and magnesium in it. In a long-term experiment, soil leachate at a 20 cm depth taken from mineral soils displayed elevated levels of calcium, magnesium, and potassium, but no significant impact on nitrate concentration, pH or Cd, Cu, Cr, and Pb levels [50]. The storage of moistened WWA in the air led to an adverse effect: it increased potassium leaching. The leaching of phosphorous, magnesium, and metal species from the ash matrix is generally low with a high pH prevailing in the water phase during short-term leaching [59].

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