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A review on use of recycled municipal and construction solid wastes for manufacturing sustainable construction materials.

Una revisión sobre el uso de residuos sólidos de construcción y municipales reciclados para la fabricación de materiales de construcción sostenibles.

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ABSTRACT

Huge amount of wastes are being generated, and even though the incineration process reduce the mass of wastes to a large extent, large amount of residues are still remain. The sustainable development of the system should decrease the waste-to-energy ratio continuously through the planned reuse of materials. This paper reviews the existing studies on recycling municipal and construction solid waste for the manufacture of Geo polymer composites. The principal findings of this work reveal that municipal and construction solid waste could be successfully used into Geo polymer composites as an alternative in the forms of precursor, aggregate, additive, reinforcement fibres, or filling material. Additionally, the results indicate that although the inclusion of such waste might depress some attributes of Geo polymer composites, proper proportion design and suitable treatment technique could solve these detrimental effects. Finally, a brief discussion is provided to identify the important needs in the future research and development for promoting the utilization of solid waste materials in the forthcoming sustainable geo polymer industry. In summary, this work offers guidance for a greener approach to building – scoring favourably in environmental performance for being relevant to resource conservation, landfill diversion, and waste recycling.

Keywords: Construction materials, Geo polymer composite, Municipal solid waste, Construction solid waste, Sustainability.

RESUMEN

Se están generando enormes cantidades de desechos y, aunque el proceso de incineración reduce en gran medida la masa de desechos, aún quedan gran cantidad de residuos. El desarrollo sostenible del sistema debería reducir la relación entre residuos y energía de forma continua mediante la reutilización planificada de materiales. Este artículo revisa los estudios existentes sobre el reciclaje de residuos sólidos urbanos y de la construcción para la fabricación de compuestos poliméricos geo. Los principales hallazgos de este trabajo revelan que los desechos sólidos municipales y de construcción podrían usarse con éxito en compuestos de polímeros geo como una alternativa en forma de precursores, agregados, aditivos, fibras de refuerzo o material de relleno. Además, los resultados indican que, aunque la inclusión de tales residuos podría deprimir algunos atributos de los compuestos poliméricos de Geo, el diseño de la proporción adecuada y la técnica de tratamiento adecuada podrían resolver estos efectos perjudiciales. Finalmente, se proporciona una breve discusión para identificar las necesidades importantes en la investigación y el desarrollo futuros para promover la utilización de materiales de desecho sólidos en la próxima industria de geopolímeros sostenibles. En resumen, este trabajo ofrece una guía para un enfoque más ecológico de la construcción, con una puntuación favorable en el desempeño ambiental por ser relevante para la conservación de recursos, la desviación de vertederos y el reciclaje de desechos.

Palabras clave: Materiales de construcción, Compuesto geopolimérico, Residuos sólidos urbanos, Residuos sólidos de la construcción, Sostenibilidad.

INTRODUCTION

Population growth, booming economy, and rapid urbanization have greatly influenced in the increase of solid waste generation all around the world. This issue is of piercing concern to the nations, municipalities, and individuals, as it can cause significant damages to human health, natural resources, and ecosystems. Therefore, the concept of adopting green technologies for environmental sustainability has been increasingly recognized and included in recent years. Most notably, the traditional concept, in which waste is regarded as pollution, has been progressively changing towards the new perspective that waste can be treated as a resource. This can be led societies to become more sustainable.

One of the attracting inventions have been made in recycling solid waste materials for the manufacture of Geo polymer composites. Geo polymer, namely alkali-activated material, is usually derived from the chemical reaction between alumina silicate precursor materials and alkaline activators, being widely regarded as an alternative to ordinary

Portland cement (OPC) [Provis et al, 2013]. The past three decades has witnessed the rapid development of Geo polymer, because of its excellent performance in various fields. The geo polymer composite exhibits excellent mechanical properties and other inherent properties such as superior durability, immobilization of toxic contaminants, etc. [Provis et al, 2013] Furthermore, Geo polymer composite is featured with low greenhouse-gas emissions, less energy consumption, and reuse of waste materials, which is considered as an essential for the future sustainability of the building and construction industry [Habert et al, 2011, Hassan et al, 2019]. Thus, by exploiting the potential use of solid waste materials as a component in Geo polymer composites will definitely contribute to a sustainable and eco-friendly construction material. Overall, this work hopes to help in the upcoming development of Geo polymer composites, which is featured with high eco-friendliness.

LITERATURE REVIEW

MUNICIPAL SOLID WASTE

Municipal solid waste (MSW) generally refers to domestic and commercial waste generated within a municipal authority. Researchers have attempted to utilize this waste for the preparation of geo polymer composites. Therefore, this section deals with the emerging research studies on recycling MSW into geo polymer composites, including municipal solid waste incinerator ash and construction solid wastes.

MUNICIPAL SOLID WASTE INCINERATION ASH

Currently, incineration is commonly used practice to reduce MSW. Incineration can reduce waste volume and mass by up to 90 % and 70 %, respectively [Silva et al, 2019]. Additionally, incineration allows for producing energy from waste. While after the incineration process, two types of ashes are generated, namely municipal solid waste incineration bottom ash (MIBA) and municipal solid waste incineration fly ash (MIFA). MIBA is the residue with large particles, which is found at the bed of the incinerator, whereas MIFA corresponds to the very fine particles collected by the air pollution control system [Sarmiento et al, 2019]. As different characteristics of MIBA and MIFA, their utilization in geo polymer composites is discussed below separately.

MIBA

MIBA accounts for about 80 % of the waste combustion residues and contains much less toxic organic substances in comparison with MIFA. Thus, there exists a great potential for the utilization of MIBA rather than sending it to a landfill. Although there have been considerable effort to make this waste valuable through using it as raw material for cement production or as filler for road construction, several significant drawbacks limit the wide applications of MIBA, especially the leach of heavy metals [Siddique et al, 2010].

Obviously, MIBA can potentially be utilized as a geo polymer precursor, due to the presence of both amorphous fraction, and high content silica and aluminium oxide. Initially, MIBA was used as a partial replacement for the precursors during the synthesis of geo polymer composites [Lancellotti et al 2013]. The follow-up studies then examined the feasibility of using MIBA as the only geo polymer precursor [Chen et al, 2016, Lancellotti et al, 2015]. For instance, through microstructure analysis and composition characterization, [Chen et al, 2016] have identified the successful geo polymerization of MIBA, and the formation of new crystal phase consisting of silica, aluminium, and sodium. Similar results have also been observed in the studies by [Lancellotti et al, 2015] and [Zhu et al, 2019]. It is consistently believed that geo polymerization is able to immobilize the majority of hazardous elements in MIBA effectively, and the produced geo polymer composites can be characterized as non-hazardous materials [Chen et al, 2016] [Zhu et al, 2019].

It should, however, be noted that the resulting MIBA-based geo polymer composites usually possess low mechanical performance and highly porous structure [Lancellotti et al, 2015]. This is mainly due to that the metallic aluminium presented in MIBA can react with alkaline solution and then generate hydrogen gas [Chen et al, 2016]. Besides, in comparison with the traditional aerated concrete, the production of aerated geo polymer concrete had less spherical air voids and wider air-void size distribution [Xuan et al, 2019]. The test results also showed that the resulted geo polymer composites possessed satisfactory compressive strength and durability due to the high degree of geo polymerization and dense microstructure [Huang et al, 2018, Huang et al, 2019]. More to the point of utilizing MIBA as a precursor, researchers have evaluated the feasibility of the application of MIBA as substitute for aggregate in geo polymer composites. The study of [Gao et al, 2017] was on this aspect. Here, MIBA was employed as a substitute for a maximum of 50 % fine aggregate (by volume) in geo polymer mortar. Although MIBA negatively affected the strength for its porous and fragile structure, no expansion and cracking was observed due to the metallic aluminate from MIBA. Eventually, the compressive strength of 35–56 MPa can be achieved, suggesting wide application potentials and high reuse rates of MIBA in geo polymer composites.

MIFA

MIFA is a fine powder extracted from the combustion gas by using the air pollution control devices. MIFA contains high amounts of heavy metals such as chromium, cadmium, lead, and zinc, etc., and therefore, it is considered as hazardous waste [Ashraf et al, 2019]. In addition to the heavy metals, several types of soluble salts are the other cause of concern [Siddique et al, 2010]. Therefore, a method that can solve this harm and effectively utilize MIFA is urgently needed. It was found that the leaching concentration of heavy metals (e.g., chromium, copper, lead, zinc, mercury, and cadmium) still remained relatively low after being immersed in aqueous alkali or leached by acid rain.

The partial replacement of geo polymer composites by MIFA usually resulted in a decrease in mechanical strength [Diaz-Loya et al, 2012, Liu et al, 2019]. However, there also exist studies demonstrating that MIFA exhibited good reactivity in alkaline medium, and thus good mechanical strength for construction purposes [Diaz-Loya et al, 2012, Liu et al, 2019, Zhao et al, 2019]. For instance, compressive strength up to 18.8 MPa at 14 days was obtained in geo polymer pastes based on neat MIFA by [Diaz-Loya et al, 2012]. [Zheng et al, 2016] Synthesized geo polymer concrete by the gradual introduction of MIFA from 20 % to 100 %. The achieved compressive strength and flexural strength varied from 10.1 MPa to 34.3 MPa and from 1.0 MPa to 3.5 MPa, respectively, after curing for 7 days at 100 °C.

As the contents of chlorides and sulphates are commonly high in MIFA the negative effects of these compounds on geo polymerization kinetic cannot be ignored. [Zheng et al, 2011] Utilized the water-wash pre-treatment to eliminate the inorganic slat from MIFA and then investigated the geo polymerization of MIFA to determine the benefit of use of water-wash pre-treatment. It was found that water-wash pre-treatment considerably promoted the early strength and also resulted in a higher ultimate strength (22.7 MPa at 28 days) in comparison with the counterpart without water-wash pre-treatment. Meanwhile, a better immobilization efficiency of heavy metal was identified in the geo polymer composites based on water-washed MIFA. Therefore, a viable and practical pre-treatment is essential for the use of MIFA as the raw material for geo polymer composites in civil construction applications.

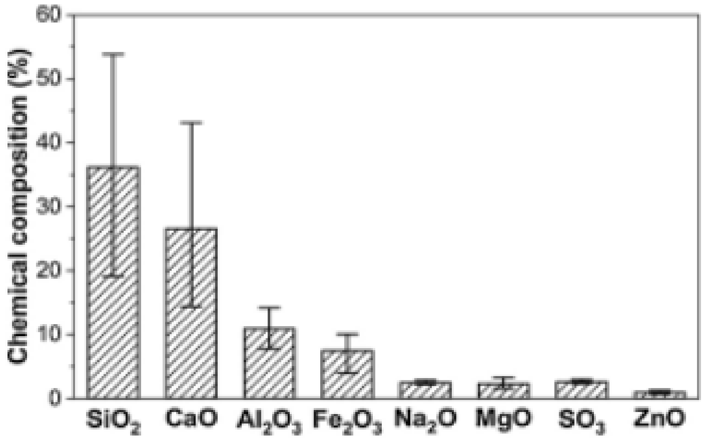

Fig1.Chemical composition of MIBA [Chen et al, 2016; Gao et al, 2017; Xuan et al, 2019; Huang et al, 2018

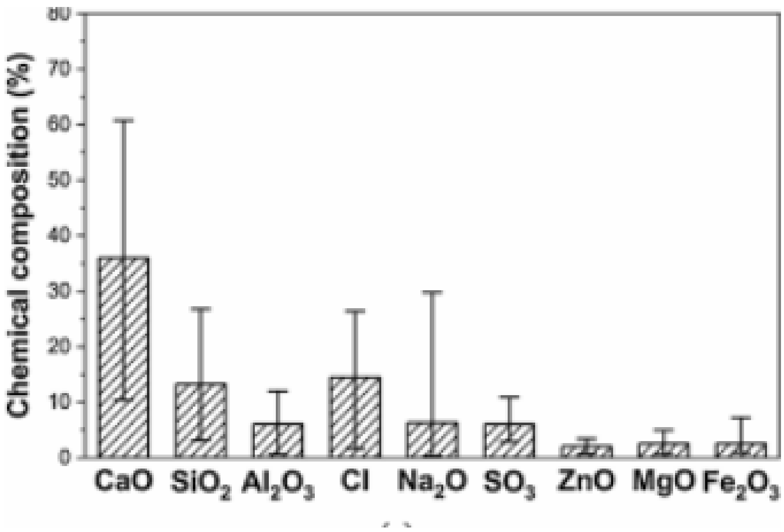

Fig2.Chemical Composition of MIFA [Diaz-Loya et al, 2012; Liu et al, 2019; Zhao et al, 2019; Zheng et al, 2011]

CONSTRUCTION SOLID WASTE

Construction solid waste (CSW), an inescapable by-product of the construction, renovation, or demolition activities, comprises a wide array of materials, including concrete, metals, bricks, timber, ceramics, asphalt, soil, plaster and polymers. This waste accounts for the largest source of the solid waste stream in most countries around the world. As a result, how to solve this CSW problem has raised great concerns from economic, environmental perspectives. In recent decades, numerous studies have been devoted to increasing the recycling rate and reducing landfill rate of CSW. This section provides a thorough review of the achievement in recycling CSW in geo polymer composites, including concrete waste, waste clay brick, ceramic waste, etc.

CONCRETE WASTE

Concrete is the most widely used building material as its relatively low cost, availability of raw materials, and good mechanical and durability properties. Accordingly, it has been reported that approximately one-third of CSW consists of concrete. This concrete waste was once routinely trucked to landfills for disposal, but recycling has plentiful benefits that make it an alternative in this age of more environmental laws, greater environmental conscious, and the desire to reduce construction costs. Consequently, reuse and recycling of concrete have received a great deal of attention, from the late 1980s or early 1990s [Xu et al, 2017, Tang et al, 2020]. Concrete waste was initially reused in the new concrete based on OPC [Tang et al, 2020], and then has strived for the application in geo polymer composites, with the booming development in geo polymer technology [Khedmati et al, 2018].

Most efforts making use of concrete waste in geo polymer composites are through using it as recycled aggregates, including coarse and fine aggregates. In literature, the attention has been mostly focused on the influences of various factors (e.g., chemical activators, raw materials, curing regimes, and replacement ratio) on the performance of geo polymer composites containing recycled concrete aggregates, with regards to the mechanical, durability, and microstructural properties. Also, the lower autogenous and drying shrinkage could be detected in the geo polymer mortars after the inclusion of recycled concrete aggregates, which was related to the function of recycled concrete aggregate as an internal curing agent. Recently, [Sata et al, 2013] reported that utilizing recycled concrete aggregates boosted the resistance of geo polymer composites to elevated temperatures, up to 800 °C.

WASTE CLAY BRICK

Clay bricks are respected to be the second most common construction material after concrete. The waste clay brick (WCB) originates not only from demolition activities, but also from the rejected bricks during the manufacturing, transporting, and construction processes. Clay bricks are produced by mixing ground clay with water, forming the clay into the desired shape, and then drying and firing. In particular, clay brick contains high levels of SiO_2 and Al_2O_3 and therefore is considered to have great potential as a geo polymer precursor. It is concluded that WCB could provide a valid alternative to the precursor material for geo polymer composites.

In the study of [Huang et al, 2019], high strength geo polymer pastes using a high volume of WCB as source materials were developed under ambient temperature curing. There also exist other studies concentrating on the use of crushed clay brick as coarse or fine aggregates in geo polymer products [Reig et al, 2017, Tuyan et al, 2018]. As brick aggregate is comparatively weaker and more porous than virgin aggregate, the significant reduction in the mechanical strength has been observed when the recycled brick was used as aggregate substitute in geo polymer concrete and mortar [Reig et al, 2017, Tuyan et al, 2018]. The test results also demonstrated that the use of crushed clay brick as coarse aggregate could equip geo polymer concrete with excellent thermal insulation, and thermal resistance under the temperatures of 400–800 °C. In another study, pervious geo polymer concrete was successfully developed using crush clay brick aggregate, which contained continuous voids and possessed high water permeability [Reig et al, 2017].

CERAMIC WASTE

Ceramic materials and products are often applied in building decoration projects, such as floor-wall tiles, garden ceramic, terracotta products, and sanitary ceramic. The production of ceramics is similar to that of clay brick: normally starts from raw material, mixing, moulding, burning, polishing, and glazing. The chemical composition of ceramic, along with highly amorphous alumino-silicate, makes it possible to manufacture geo polymer composites. Therefore, utilizing CWP as the precursor materials in geo polymer formulation has gained great academic interest. Afterwards, further research has been done aiming to understand the geo polymerization process of CWP, and to enrich the technical data on the effect of particle size, curing condition, and alkaline solution properties on the performance of final products [Huseien et al, 2018]. In short, CWP exhibits high geo polymerization potential, which is even better compared with waste bricks and concrete [Huseien et al, 2018]. The findings suggested that high volume CWP could produce geo polymer composites with compressive strength over 70 MPa. Also, the developed geo polymer composites exhibited enhanced resistance to elevated temperature with the increase of CWP content, which also has been verified by [Sun et al, 2018]. Similarly, researchers blended CWP with metakaolin and even waste glass powder to synthesize geo polymer composites, and the resulted products also exhibited satisfactory performance In addition to utilizing ceramic waste as the precursor materials, the other possible application of ceramic waste is using as aggregate replacement in geo polymer mortar and concrete [Tuyan et al, 2018]. Particularly, in the studies by [Reig et al, 2017], the ceramic waste was used as both a precursor and recycled aggregate.

CONCLUSION

Accumulation of unmanaged municipal and construction solid waste has been an increasing environmental concern. Recycling of such solid waste into sustainable and energy-efficient construction materials is a viable approach to relieve the stress of pollution and meantime to conserve virgin resources for the next generation. This study has critically reviewed the potential applications of diverse municipal and construction solid waste as substitute materials in the manufacturing of sustainable geo polymer composites, specifically, in the form of partial or even fully substitution of precursors or aggregates, reinforcement fibers, or additives. Conclusively, even though the incorporation of the studied waste materials into geo polymer composites adversely affects their few attributes, such as strength, workability, and durability, satisfactory performance can be still maintained through controlling its quantity percentage in accordance with the outcomes of the current work.

Additionally, these waste materials could be recycled in geo polymer composites with a high rate if proper treatment is carried out or suitable proportion design is adopted, attributing to the improved mechanical and durable performance of the final products. Finally, there are still a number of areas that require additional attention, especially from the scientific and technological perspectives in the field of geo polymer, as well as, the alternative for the disposal of municipal and construction solid waste by recycling it into manufacturing sustainable construction materials, advance in the solid waste management plans and strategies.

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