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SOLID WASTE GENERATED FROM CERAMIC/PORCELAIN INSULATORS VERSUS POLYMER/COMPOSITE LONG ROD INSULATORS/SILICON RUBBER INSULATORS: RECYCLING ASPECTS - A COMPREHENSIVE REVIEW

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ABSTRACT

In this comprehensive review, we emphasized to evaluate the comparative analysis regarding recyclability of porcelain or ceramic insulators wastes versus polymeric or composite insulators' wastes, which could be used as raw materials for other industrial activities. Interestingly, many studies reported better efficacy of the porcelain or ceramic insulators as concrete for building materials while polymeric or composite insulators wastes to make raw materials are costly affair and sometimes hazardous to the environment. The insulators made up of ceramic or porcelain has many advantages as compared to polymeric or composite insulators. In conclusion, recyclable products could easily be obtained from the wastes of porcelain or ceramic insulators as compared to polymeric or composite insulators. This study may be helpful for industries, academician and authorities to work on future research for waste to wealth concept and circular economy.

KEY WORDS: Ceramic insulator, Composite insulator, Environmental impact, Loss of biodegradation, Recycle and reuse, Insulator wastes.

INTRODUCTION

After the completion of lifetime any product leaves some solid waste (SW). In view of the environmental concerns and landfills constraints SW disposal is becoming a major challenge. Otherwise, the improper disposal of this SW hampers the environment especially the contamination/pollution of soil, water and air (Mugoni *et al*., 2015). It was also recorded that industrial SW disposal is a global problem (Khoshsepehr *et al*., 2023).

It is important to note that the conversion from wastes to raw materials as resources can only be achieved through investment in SW management as this depends on a synchronised set of actions for developing markets and maximize recovery of reusable/recyclable components (Sridevi *et al*., 2012).

Besides several SW, there are two types of SW viz. porcelain or ceramic insulators versus polymer or composite long rod insulator or silicon rubber generated from the electrical insulators which have already been documented (Abdel Salam, 2019; Jiang *et al*., 2020).

Abdel Salam (2019) did an interesting work for the replacement of sand by ground electric porcelain waste in cement mortars, which is tried for the first step in subsequent application to concrete mixes. Jiang *et al.* (2020) reported that the content of organic components in scrapped composite insulators are

(*Regional Head, [2]Former Member (Power Systems)) found to be reduced <40.0%, while the proportion of inorganic components are found to have increased >60.0%.

Ultimately, there are four common classes of recycling techniques for SW (Insulators, 2023)

1. Primary recycling, which states that the conversion of SW into raw materials, which is having properties equivalent to those of the original components.
2. Secondary recycling, which defines the conversion of SW into raw materials, which is having properties inferior to those of the original components.
3. Tertiary recycling, which means the conversion of SW into chemicals or fuels?
4. Quaternary recycling, which explains the conversion of SW into energy.

According to the "European Parliament" issued instructions on waste electrical and electronic equipment (WEEE) generating that all such equipment should be recycled and effectively banned for the disposal into landfills. Moreover, greater constraints on electrical waste, presently and in the near future, which propose that producers as well as utilizers of high voltage apparatus would increasingly be identified the alternative waste-management practices (Insulators, 2023).

The present study has been compiled through review of available literature based on the quantum of solid waste generation from electrical insulators viz. porcelain/ceramic insulators as well as polymer/composite long rod insulator/silicon rubber insulator to recognize the waste to wealth concept.

Solid waste generation from ceramic/porcelain insulators

In recent decades, clay-based ceramics such as porcelain, are suitable and attractive systems due to their characteristics to becoming hostess, involving some industrial wastes during their production but these are heterogeneous materials that could allow discrepancies in their composition, production methods, or sintering temperatures (López-Perales *et al.*, 2024). It was reported that the mechanical resistance accomplished by the experimental sample, which is containing 15 wt% of chamotte (also known as grog, fires and, or fireclay, is a calcined clay (often high in alumina) used in ceramics and refractories to enhance strength, reduce shrinkage, and improve crack resistance.) waste means six-folds the value procured through the control sample (0 wt% of chamotte addition) and was accredited to a higher mullite phase content and well-dispersed crystals (primary and secondary mullite - any of a type of rare mineral consisting of aluminium silicate ($3Al_2O_3 \cdot 2SiO_2$). It is formed upon firing aluminosilicate raw materials and is the most important constituent of ceramic whiteware, porcelains, and high-temperature insulating and refractory materials) in the ceramic body (López-Perales *et al.*, 2024).

Mantovani *et al.* (2013) reported that the discarded ceramic material obtained high thermal stability, which is an interesting characteristic feature to use as chamotte. This can also be reused to replace gravel for the usable materials in substations.

Zimbili *et al.* (2014) investigated the usage of ceramic insulator waste in construction based on concrete. The results proved that the temperature benefited in the manufacturing of ceramic tiles (about 900 °C) that are sufficient to activate pozzolanic properties of clay (The actual firing step runs from about 800 °C to the programmed peak temperature, typically between 850 °C and 1350 °C, which depends on the product being made. The main physio-chemical transformations take place in this step. These reduce the ceramic material's porosity). The investigation also observed that after optimization (11-14% substitution), the cement blend performed suitable with no morphological difference between the cement blended ceramic waste and that blended with other pozzolanic materials.

Campos *et al.* (2018) studied that ceramic insulator waste could be similar tocommon aggregates in concrete and mortar when coupled with a granulometric control. This study examined the grinding methods for and succeeding use of porcelain insulator waste for the replacement of fine aggregates in concrete, which is verified for the improvement with this substitution provided as per the mechanical properties and durability of the concrete through scanning electron microscopic analysis.

Rodríguez *et al.* (2019) reported that fired porcelain scrap has been recycled as filler for procuring a sustainable high voltage porcelain insulator. Quartz was also gradually replaced by 5, 10, 15 and 25/wt% of porcelain scraps in an accepted siliceous porcelain composition.

Belhouchet *et al.* (2019) studied to know the usage of scrap and broken insulators after firing, which is commonly known as porcelain chamotte in their porcelain body compositions that is a very interesting technological and environmental concept. After the burning process, some chemical reactions take place to constitute the final microstructure of the porcelain, which is formed by quartz grains and mullite needles (Mullite needles, or acicular mullite, are a form of the mineral mullite ($3Al_2O_3{\cdot}2SiO_2$) that are needle-shaped and form during the firing of certain ceramic bodies, particularly porcelain, contributing to its strength and thermal shock resistance) implanted in an amorphous matrix. In this context, porcelain insulator scrap material is chemically same as the porcelain, hence its incorporation as raw material in original insulator composition could be technologically viable.

Meena *et al.* (2022) reviewed the recyclable properties of ceramic insulators wastes and it was obtained that some new aggregates like ceramic insulators wastes are used to create sustainable new concrete. They mentioned thatthese materials are workable, durable, hard, strong, and highly resistant to physical, chemical, and biological weathering where a proper solution is applyingceramic insulators wastes as binder content.

Pereira *et al.* (2022) evaluated self-levelling mortar (SLM) for building materials from porcelain insulator waste (PIW), which replaced the sand partially and totally. Their finding stated that PIW presented pozzolanic characteristics and increased the compressive strength of mortars as per XRD analysis [X-ray diffraction (XRD) analysis is a non-destructive technique that analyzes the structure of crystalline materials. It can be used to identify materials, determine their chemical composition, and more.]. They reported that SLM containing PIW presented compressive andflexural strength of 24.11 MPa and 7.07 MPa, respectively.

Jwaida *et al*. (2024) reviewed to document the usage of ceramic insulators wastes, which is used as a replacement for concrete constituents, viz. cement and aggregates. According to them, this technique offers a promising boulevard (road ahead) for reducing the environmental impact and promoting sustainable construction practices by reducing the amount of energy consumed and resources required for concrete production, as well as the minimization for quantity of ceramic insulator waste to landfills.

Solid waste generation from polymer/composite long rod insulator/silicon rubber

Mantovani *et al.* (2013) reported that the polymeric insulatorwasteshave little recycling potential due to thermogravimetry, differential scanning calorimetry and relative density as per test results, which suggested degradation of used material compared to new one.

Medina *et al.* (2018) mentioned that polymer decomposition (biodegradation) takes a long time and causes hazardous environmental impacts. Therefore, polymer wastes' disposal is a serious environmental issue. Tires containing almost 50% rubber are polymeric materials. The global production of rubber materials in 2017 was about 26.7 Mtons divided into 12.31 Mtons of natural rubber (NR) and 14.46 Mtons of synthetic rubber (SR).

Jiang *et al*. (2020) documented that a large number of composite insulators are scrapped on reaching the end of their lifetime every year. Due to the exceptional chemical unresponsiveness of the silicone rubber within the insulators, these have poor self-degradation features and ultimately reach to landfills and occupying a lot of space, which unintentionally hampers the ecological environment. They also reported that there has not been any efficient means to recycle composite insulators.

Fazli and Rodrigue (2020) evaluated the main approaches to recycling silicone materials from composite electrical insulators through chemical depolymerization, automated grinding, solid fuel, and thermal degradation. They also documented that combustion and landfilling as conventional methods of polymer waste elimination, which have reported several disadvantages such as the creation of dust, fumes, and toxic gases in the air, as well as underground water pollution.

Mei *et al.* (2021) reported that silicone materials cannot easily biodegrade or decompose. Specifically, it may take 50-500 years for the silicone materials to decompose as per environmental conditions. They mentioned that each recycling approach has its limitations. Firstly, chemical depolymerization, especially acid-catalysed depolymerization, is the most mature method widely used in treating waste insulators. Therefore, the composite insulator wastes are reaching to landfills and damage the environment.

Shang *et al.* (2024) examined an effective method for recycling the waste generated from silicone rubber insulators by pyrolysis to obtain mullite ($3Al_2O_3 \cdot 2SiO_2$) with high purity and compact construct. The recycling process did not generate toxic products. They also investigated thermal degradation process of housing material by analysing its degradation products as per the generation of the gas and residues. The experimental results indicated that the colorant agent Fe_2O_3 inside the housing material is beneficial for the generation of mullite by reducing the temperature of mullitization. Besides, since the transitional alumina formed by the dehydration of aluminum hydroxide [ATH: Aluminium trihydroxide (ATH), also known as aluminum hydroxide, is a widely used, inorganic, halogen-free flame retardant and smoke suppressant, particularly in polymers and coatings, due to its ability to absorb heat and release water during combustion], which has a smaller diameter and could better dissolute into the silica phases and ATH is a better choice as the additional aluminium resource. By comparing the materials, structure, and particle size of grains constituted at different calcination temperatures, the proposed pyrolysis temperatures of the two stages are 1400 ^oC and 1600 ^oC, respectively.

CONCLUSION

In this comprehensive narrative review, it is well understood that porcelain or ceramic insulators wastes are easily converted to recyclable products as raw materials for concrete substitutions compared to polymer or composite long rod insulator or silicon rubber. Moreover, some international studies reported the recycle methods for polymer or composite long rod insulator or silicon rubber wastes but this may be costly affair and required another technology to implement. Regarding environmental hazards, as such no impact was recorded on the porcelain or ceramic insulators wastes in comparison with polymer or composite long rod insulator or silicon rubber. This study may be helpful for industries, academician and authorities to work on future research for waste to wealth.

This study is emphasizing an avenue regarding the solid waste generation from both types of electrical insulators. But the major health concerns are from polymeric electrical insulators due to its polyethylene nature of wastes. When plastics like polyethylene, polyvinyl and polystyrene are burned, toxic substances such as benzene, toluene, and xylene are released into the air, and then inhaled by animals and humans, thus causing different types of cancer, lung disease, immune disorders, etc. (Khandare *et al*., 2021). The toxicity study from electrical insulator wastes among the animals from terrestrial and aquatic environment is scanty.

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