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Ceramic waste reuse and valorization alternatives: A review

Mayra Alejandra Arias Ocampo[1]
Andrés Felipe Rojas González[1]

1. Universidad Nacional de Colombia - Sede Manizales

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Autor de correspondencia:

Ingeniería Ambiental, Universidad Nacional de Colombia - Sede Palmira
Correo electrónico: maariaso@unal.edu.co

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Summary

Ceramic materials account for the largest percentage of waste generated in the construction and demolition of concrete structures. Currently, this ceramic waste is disposed of in landfills, due to the lack of alternative disposal options and the lack of awareness of options for the reuse of these materials. This study aims to identify the existing alternatives and establish the potential for the reuse and valorization of ceramic waste. This analysis of alternatives for the reuse and valorization of ceramic waste is carried out through a bibliographic review focused on identifying the existing options for the reuse and valorization of ceramic waste. For each existing alternative, a brief description of the methodology used is made and the main results achieved in each study are highlighted. Based on the bibliographic review, some alternatives for the reuse of ceramic materials are presented. It was established that ceramic waste is currently used mainly in the formulation of concrete, manufacture of electrical insulators, extraction of alumina, and as a geological barrier to contain nuclear waste. In addition, based on the properties of ceramic materials, it was concluded that the potential applications for reuse include obtaining thermal insulators, abrasive materials, coral reef regeneration, and the elaboration of structures using additive manufacturing techniques. It was found that the most economically profitable option for the reuse and valorization of ceramic waste is the manufacture of concrete, while the most viable option is the manufacture of abrasive materials.

Keywords: Ceramic materials, porcelain wastes, reuse and valorization of waste, concrete formulation, manufacture of electrical insulators, alumina extraction, thermal insulators, abrasive materials, coral reef regeneration, ceramic additive manufacturing.

Alternativas de reutilización y valorización de residuos cerámicos: una revisión

1. Introduction

Environmental issues have become one of the most critical issues of our generation, as global environmental problems are increasingly serious. In the current world, civilization is asked to reduce the negative environmental effects of their industrial and commercial operations (Tikul, 2014). Recently, there are new environmental regulations and strategies that focus on mitigating the environmental impacts generated by the accelerated increase in waste from the industrial and commercial sectors. (Sepehri & Sarrafzadeh, 2018). In addition to environmental regulations, the need to incorporate green technologies and implement integrated waste management have become some of the most important commitments of our time. The implementation of these efforts, to reduce the environmental impact, requires specific measures to prevent the generation of waste and promote reuse and recycling practices (Lassinantti *et al*., 2018; Sepehri & Sarrafzadeh, 2018; Owoeye *et al*., 2019).

In the search for alternatives to mitigate the environmental impacts caused by human activity, many countries in the world are working to minimize the pollution/contamination generated by their solid wastes by using them in a more productive way. In the case of the ceramic industry, it is estimated that waste generation corresponds to one-third of global ceramic production (Awoyera *et al.,* 2018; Belhouchet *et al.,* 2019; Tikul, 2014). For the most part, this waste cannot be incorporated back into the production line at the factory, due to the level of transformation that the raw materials undergo as they are subjected to rigorous firing processes during manufacturing (Blackett *et al.,* 2008). The difficulty in recycling these materials means they are disposed off in the environment as waste materials without any additional treatment. These solid wastes are mainly taken to dumps or landfills (Rodriguez *et al.,* 2019). Moreover, these waste materials result in severe pollution and significant landfill occupation (Tam *et al.,* 2018).

One example of an industrial sector where the amount of ceramic waste has increased is the electrical industry. In this sector, ceramic waste is generated from the use and disposal of porcelain or ceramic

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electrical insulators. The global demand for this resource has expanded considerably due to the fast development of energy sector, and this has led to an increase in the utilization of raw materials used in their manufacture (Cicek *et al.,* 2018). Electrical insulators that are rejected by quality control and those that reach the end of their useful life are disposed off and become ceramic waste. Most of this waste is not recycled. The stock of waste electrical insulators increases by millions of tons per year. This situation causes important environmental problems and is a waste of resources (Meng *et al.,* 2012). Due to the environmental issues generated using electrical insulators, the search and research of alternatives for the reuse of this material have become a major concern in many countries (Tam *et al*., 2018; Cicek *et al*., 2018).

By recycling ceramic waste, the useful life of landfills is increased, since the amount of material disposed of in them is reduced, and natural resources are preserved (Keleştemur *et al.,* 2014). The most widely studied ceramic waste reuse alternative consists of its incorporation as an aggregate in the production of concrete (Awoyera *et al.,* 2018). In these concrete compositions, the feasibility of using ceramic waste as fine aggregate (Piyaphanuwat & Asavapisit, 2017), coarse aggregate (El-Dieb & Kanaan, 2018), or as a replacement for a percentage of cement (Kannan *et al.,* 2017) has been identified.

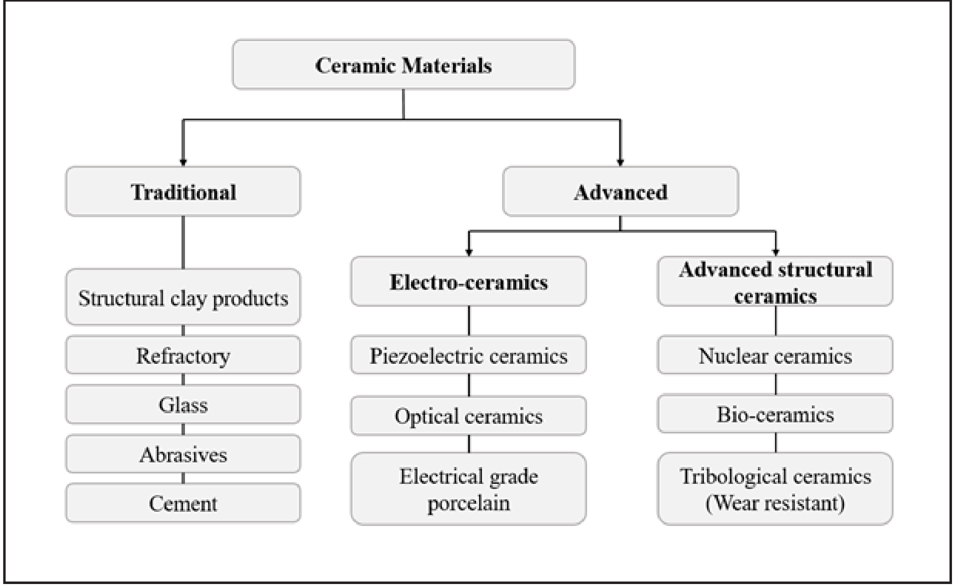
Other less well-explored alternatives for the reuse of ceramic waste have been discovered. One of these alternatives is the reuse of damaged porcelain electrical insulators in the manufacture of new insulators, in such a way that a fraction of the raw material is replaced by the recycled porcelain/ceramic of these damaged insulators (Rodriguez *et al.,* 2019). The addition of waste materials (produce by the manufacture of ceramics or discarded by the industry) into the production cycle is an attractive option that provides economic benefits, protection of natural resources, and a decrease in environmental pollution (Zengrong *et al.,* 2013). Another alternative for the reuse of this ceramic waste that has not been investigated a lot is the extraction of valuable materials such as alumina (Al_2O_3) (Henao & Lopéz, 2017; Khalil, 2014).

The objective of this study is to identify the current and future alternatives for the reuse and valorization of ceramic waste generated in the construction industry, the sanitary industry, and the electrical industry, among others. The identification of the current alternatives is done through a bibliographic review focused on describing the processes, operating conditions, and findings of the main reuses of ceramic wastes. The reuse prospects are established based on the properties of ceramic materials found in published literature.

2. Ceramic materials

The term ceramic is used to describe inorganic materials (although some organic matter may be present), consisting of non-metallic compounds, and whose manufacture includes a firing process (Shah & Huseien, 2020). A general classification of ceramic materials is presented in Figure 1. This figure demonstrates that ceramic materials can be divided into two major groups, traditional ceramics, and advanced ceramics. Traditional ceramics are mainly made up of three basic components: clay, silica, and feldspar (Bhattacharyya *et al.,* 2005). Examples are bricks, tiles, and certain types of cement. On the other hand, advanced ceramics are made of high-purity compounds of alumina (Al_2O_3), silicon oxide (SiO_2), and other compounds, which give them properties with technical and industrial applications in various fields such as electronic, electrical, nuclear, medicine, and magnetic, among others (Matteucci *et al.,* 2002).

Figure 1. Classification of ceramic materials
Source: Authors



A specific example of advanced ceramic materials is electrical-grade porcelain, which is used in the manufacture of electrical components for high, medium, and low-voltage applications, such as insulators for distribution and transmission lines. One of the essential parts of the electrical system is the porcelain insulator, which gives electric power systems operating safety and efficiency. (Papailiou & Schmuck, 2013). Power grid insulators must meet electrical, mechanical, and chemical requirements, which enable

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them to efficiently insulate electricity and withstand high voltages and temperatures without suffering fractures (Morocutti *et al.,* 2012). Porcelain has historically and traditionally been the most extensively used material for the construction of electrical insulators because it is a ceramic with good features in terms of hardness and mechanical strength, resistance to high temperatures, and corrosion, heat, and water resistance (Liebermann, 2012).

Porcelain insulators have been used successfully since the early days of power transmission and distribution, beginning in the 19th century (INMR, 2021). The high mechanical and dielectric strength of porcelain, combined with its inertness to the environment, has long made it the most widely used electrical insulating material (Merga *et al.,* 2019). However, the specific composition of electrical porcelain can vary significantly depending on the application, with several porcelain categories including C110, C111, C112, C120, and C130 as presented in Table 1. Category C110 is primarily silica-rich clay (SiO_2), while C112 contains cristobalite, a SiO_2 variant with a different crystal structure. The widely used categories for medium voltage (MT) and high voltage (HV) insulators are C110, C120, and C130. The latter two porcelain types are characterized by having a relatively high alumina (Al_2O_3) content (Contreras, 2014).

Table 1. Classification and typical composition of electrical grade porcelains.
Source: (Contreras, 2014)

Category	Name	Typical chemical composition (% by weight)					
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO+MgO	K_2O+Na_2O
C110	Silica porcelain, plastic processing	68–72	20–24	< 1,0	< 0,5	< 1,2	4,0–5,5
C111	Pressed silica porcelain	68–72	20–24	< 1,0	< 0,5	< 1,2	4,0–5,5
C112	Cristobalite based porcelain	65–70	24–28	< 1,0	< 1,0	< 1,2	3,5–4,5
C120	Alumina porcelain	48–55	40–47	< 1,0	< 1,2	< 1,2	3,0–4,0
C130	High mechanical strength alumina porcelain	37–42	50–8	< 1,0	< 1,5	< 1,2	3,0–4,0

3. Ceramic waste reuse and valorization alternatives

Waste ceramic materials, which include brick walls, tiles, electrical insulators, and all other ceramic products, represent approximately 50% of construction waste (Juan *et al.,* 2010). Therefore, worldwide, ceramic materials manufacturers, consumers, and the scientific community have been concerned about finding strategies to reuse the waste produced using these materials. These strategies seek to reduce the environmental impacts caused by disposing of ceramic materials in landfills (Jain *et al.,* 2022). The following are some of the studies that have been conducted worldwide regarding the possibilities of using ceramic wastes in different processes.

Reuse of ceramic waste as a concrete aggregate

Portella et al. (2006) investigated the feasibility of incorporating electric porcelain ceramic waste to concrete mixes. This study showed the feasibility of reusing porcelain waste, by using between 20 to 50% in weight, and it was found to improve the mechanical strength and corrosion resistance in concrete structures. Sekar et al. (2011) analyzed the viability of using ceramic waste as coarse aggregates in mixtures to prepare concrete. The coarse aggregate in the mix, which traditionally is rock, was completely replaced by porcelain insulator waste using a mix weight ratio of 1:1,23,2.64, corresponding to cement: fine aggregate: coarse aggregate. In this study, Sekar et al. (2011) found that the compression strength of concrete prepared with ceramic insulator wastes was 16% lower than the compression strength of traditional concrete. The low strength of the concrete, prepared from the porcelain wastes was caused by the smooth surface of the ceramic aggregates and the lack of cohesion between the wastes and the other components of the concrete mix (Sekar *et al*., 2011).

Kannan et al*.* (2017) evaluated high-performance concrete (HPC) mixes, which contain of 10 to 40% mass of ceramic waste powder (CWP) as a replacement for Portland cement. CWP is the result of the porcelain waste-crushing process. This material is made up of fine particles smaller than 0.075 mm, and rich in silica and alumina. Table 2 shows the percentage of cement substitution by CWP. This table gives the percentage values by weight of cement, porcelain waste, water, and other aggregates, used for the preparation of five different concrete mixes. This study analyzed the microstructure, strength, mechanics, and durability of HPC mixes. Concrete containing CWP as a replacement for cement was found to have good strength and

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long durability. Furthermore, the microstructural analyzes indicated that the incorporation of CWP does not significantly affect the water adsorption properties of the concrete. The favorable characteristics of concrete are the result of the low water/cement ratio of the mix and the high surface area of CWP which allows the appearance of densely packed particles (Kannan. *et al.,* 2017).

In a similar study (El-Dieb & Kanaan, 2018), it was found that the use of 10% by weight of CWP as cement replacement is adequate to improve concrete strength. It was also found that replacement levels between 10% and 20% by weight could be used to improve the workability of the mix, while a replacement level of 40% is needed to improve concrete durability. Additionally, it was observed that varying replacement percentages of cement to CWP can benefit different mix quality criteria. An example of this is that, in a formulation where 10% to 20% of the cement is replaced by CWP, the workability and strength of the mix were optimized, while the use of 30% to 40% CWP improved, in combination, the compressive strength, drying shrinkage, chloride ion penetration, microstructure, and electrical resistivity.

Table 2. Proportions of CWP as a replacement for cement in concrete mixes.
Source: (Kannan. et al., 2017)

Mixture components	% by mass in the mixture				
	0%	**10%**	**20%**	**30%**	**40%**
Cement (kg/m^3)	485	437	388	340	291
Porcelain waste (kg/m^3)	0,0	48	97	145	194
Water (m^3/m^3)	0,21	0,21	0,21	0,21	0,21
Dune sand (kg/m^3)	662	658	654	650	646
Coarse aggregate (kg/m^3)	993	988	981	975	968
Volumetric Ratio (Water/Cement Materials)	0,43	0,43	0,43	0,43	0,43

Several studies were identified and highlighted the effects of using ceramic waste as a construction material (Siddique *et al.,* 2019, Keshavarz & Mostofinejad, 2019) and its inclusion in the manufacture of concrete (Bhogilal & Tejas, 2018; Huseien *et al.,* 2020). A summary of these studies is presented in table 3 with emphasis on the type of waste used, the percentage of replacement used, the properties evaluated, and the most important findings. In most of these studies, it is noted that the mechanical properties of concrete are improved when ceramic waste replaces conventional raw materials, such as cement, fine aggregates, and coarse aggregates.

Use of waste as raw material for the manufacture of electrical insulators

The manufacture of porcelain electrical insulators is a complex process that is carried out through several stages such as extrusion, pressing, turning, polishing, enamelling, and sintering (Rodríguez *et al*., 2019). Waste is produced throughout the production process as a result of production failures or the lack of efficient quality control for the final product, since due to its fragility it can break during processing or storage (Meng *et al.,* 2016).

Table 3. Recent research on the use of ceramic wastes in the production of concrete. **Source:** Modified from (Meena et al., 2022)

Concrete type	Ceramic type	Material and % of Replacement	Evaluated properties	Findings	References
Self-compacting concrete	Ceramic powder waste	Cement (0, 10 and 20%)	Compressive strength, and slump value	As the ceramic waste increases, the slump and strength value decreases	(Bhogilal & Tejas, 2018)
Self-compacting concrete	Ceramic powder waste	Cement (0, 28 and 57%)	Slump value, chloride ion permeability, compressive and segregation strength	With a 30% replacement rate, adequate values were obtained for the evaluated characteristics	(El-Dieb & Kanaan, 2018)
Self-compacting concrete	Ground clay brick waste	Cement (0, 20, 30 and 40%)	Compressive strength, water absorption, chloride attack, and electrochemical measurements	By using 20 and 30% clay brick waste as a cement substitute, mechanical and durability properties are increased.	(Jerônimo *et al.,* 2018)
Self-compacting alkaline-activated concrete	Ceramic tile dust waste	Ground furnace slag (0, 10, 20, 30, 40, 50, 60, 70 and 80 %)	Slump flow, compressive strength, flexural and tensile strength, water absorption, sulfuric acid attack	Strength and durability increased with increased percentages of ceramic waste	(Huseien *et al.,* 2020)

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Concrete type	Ceramic type	Material and % of Replacement	Evaluated properties	Findings	References
Concrete	Ceramic tile wall and floor tile waste	Fine and coarse aggregate (0, 25, 50, 75 and 100%)	Slump, compressive strength	The concrete made with 100% fine and coarse ceramic waste showed better compressive strength	(Awoyera *et al.,* 2018)
Concrete	Chinese porcelain ceramic wastes	Fine aggregate (0, 20, 40, 60, 80 and 100%)	Resistance to freezing and thawing, corrosion, and chloride penetration resistance	Increasing the ceramic waste content improved the measured properties of the concrete.	(Siddique *et al.,* 2019)
Concrete	Porcelain tile and red ceramic waste	Coarse aggregate (0, 25, 50, 75 and 100%)	Water absorption, compressive, flexural, and tensile strength	Mechanical strength and water absorption improved with the addition of 100% ceramic waste as coarse aggregate in the concrete	(Keshavarz & Mostofinejad, 2019)
Concrete	Brick waste	Coarse aggregate (0%, 10%, 30%, 50% and 75%)	Compressive and flexural strength, density, and slump values	Mechanical strength and density decreased as the substitution ratio increased, while the slump was similar	(Nepomuceno *et al.,* 2018)
Concrete	Chinese porcelain ceramic waste	Fine aggregate (0, 20, 40, 60, 80 and 100%)	Sulfate attack	Increasing the content of ceramic waste in concrete waste sulfate attack.	(Siddique *et al.,* 2018a)
Concrete	Ceramic tile waste	Coarse aggregate (0, 5, 10, 20 and 25%)	Compressive and flexural strength	At up to 20% of the use of ceramic wastes as coarse aggregate, the mechanical properties of the concrete increased	(Bommisetty *et al.,* 2019)

Concrete type	Ceramic type	Material and % of Replacement	Evaluated properties	Findings	References
Concrete	Chinese porcelain ceramic waste	Fine aggregate (0, 20, 40, 60, 80 and 100%)	Compressive, flexural, and impact strength, and rebound test	Increased use of ceramic wastes improves the mechanical properties of concrete	(Siddique *et al.,* 2018b)

For the electrical insulators industry, the use of fragmented insulators that have gone through a firing process as raw material in their porcelain tile mixes is an attractive technical and environmentally sustainable alternative. After the firing stage, several chemical reactions occur that promote the formation of the final porcelain microstructure, which is made up of quartz grains and mullite needles embedded in an amorphous matrix (Belhouchet *et al*., 2019). Therefore, porcelain electrical insulator wastes have the same chemical composition as the original porcelain. This indicates that the incorporation of these wastes as raw material for the manufacture of porcelain electrical insulators is technologically feasible (Rodriguez *et al.,* 2019).

There are some reports in the literature where they reuse fired ceramic wastes as raw material in their porcelain mixture to manufacture ceramic insulators (Gress & Leshchenko, 1969; Caligaris *et al.,* 2000; Fassbinder, 2002; Liu *et al.,* 2019). In 1969, Gress & Leshchenko carried out one of the earliest investigations into the use of porcelain waste in the production of high-voltage insulators. These researchers found that a 26% content of porcelain waste in the production of electrical insulators significantly improves their properties. With this waste content, the insulators meet the quality requirements concerning electrical, mechanical, and chemical characteristics, due to the higher alumina content (Gress & Leshchenko, 1969).

Fassbinder (2002) analyzed the use of ground waste from burned electrical insulators as a raw material for the manufacture of new alumina-rich porcelain insulators. The results showed that a higher supply of this waste added to the manufacturing process favors the mechanical strength of the resulting electrical insulator. Caligaris *et al.* (2000) studied the possibility of reusing porcelain waste generated in the manufacture of electrical insulators, with the purpose of reducing the disposal of this waste in the production chain and reducing the consumption of raw materials. They found that the use of porcelain waste improves the mechanical strength of sintered electrical insulators between 1250 °C - 1300 °C, because this waste has a higher mullite content (Caligaris *et al.,* 2000).

Alumina Al2O3 extraction

Alumina or aluminum oxide (Al_2O_3) is a ceramic material that is currently extracted from the mineral bauxite. Worldwide consumption of this ceramic compound is steadily increasing due to the fact that it is one of the most adaptable materials for a variety of uses. A few common applications of Al_2O_3 are related to the manufacture of ceramics (Burger & Kiefer, 2021), refractories (Ruys, 2019), catalyst and/or catalyst support (Said *et al.,* 2019), high-temperature thermal insulators (Mert & Mert, 2021), electronic substrates (Mavrič *et al.,* 2019), laboratory instruments and chemical sample holders (Khattab *et al.,* 2012; Matjie *et al.,* 2005). Despite the wide range of applications, bauxite reserves are limited, as only four countries in the world (Guinea, Jamaica, Australia, and British Guiana) are producers of this mineral (Khalil, 2014). These countries have an agreement, as does the Organization of Petroleum Exporting Countries (OPEC), to control global bauxite production and commercialization (Marciano *et al.,* 2006). Since there are few or no bauxite deposits in the majority of Arab countries, where Al_2O_3 production is still quite limited, there is a growing need for this ceramic material from various sources. This results in higher capital costs and subsequent global dependency. In light of this circumstance, it is essential to look for alternate Al_2O_3 sources (non-bauxite sources) (Hind *et al.,* 1999).

In 2014, Khalil evaluated the possibility of the reuse of ceramic waste to obtain Al_2O_3 through an extraction process using $KHSO_4$ as a fluxing medium. This work sought to analyze the feasibility of the reuse of ceramic waste from construction activities or generated in manufacturing processes, to obtain Al_2O_3. It was found that an efficiency of 99.06% could be obtained in the extraction of Al_2O_3 from ceramic waste, in addition, through the study of the mineralogical composition and the determination of the particle size, it was found that nano Al_2O_3 particles could be obtained with a pure of 99.37% and a particle diameter <50 nm (Khalil, 2014).

Henao & Lopéz (2017) evaluated the possibility of treating insulating porcelain ceramic waste, to extract alumina. In the characterization of this waste, it was found to contain about

26.36% w/w of alumina. These researchers evaluated the effect of sulfuric acid concentration and solids concentration as factors promoting alumina leaching in the porcelain waste. In this study, it was found that a 20% V/V concentration of sulfuric acid at a temperature of 90°C, for 3 h and with an agitation speed of 250 rpm, allows the extraction by leaching of a maximum alumina content of 23.57 % w/w. The product obtained, after calcining the leachate for 6 h at 1100°C, reached a purity of 97.90% α-alumina (Henao & Lopéz, 2017).

Ceramic waste as a geological barrier to contain nuclear waste

Devanathan et al. (2011) investigated the properties of ceramic wastes to determine if these wastes are apt to provide a stable geological layer with impermeable qualities. In this way, this waste can be used to produce a geological barrier to contain hazardous nuclear waste and prevent it from coming into contact with the subsoil. The authors found that ceramic waste has special characteristics that can provide a protected and stable environment for storing hazardous waste. One of the main challenges to solve was the deposition of toxic radioisotopes such as plutonium (239Pu), which has a half-life of 24,200 years. Half-life means the time it takes to decompose half of the material, this does not mean that all material takes twice as long to decompose. The authors conclude that ceramic waste has the potential to provide the stability that these toxic wastes require. However, further research is needed to confirm these results, as there are difficulties in modeling the behavior and degradation of ceramic waste over long periods of storage (Devanathan *et al.,* 2011).

4. Prospects for the reuse of ceramic waste

Ceramic waste to produce thermal insulating material

Thermal insulators are extremely important materials for improving energy efficiency and reducing environmental impacts in the building sector (Alhabeeb *et al.,* 2021). Energy consumption in European households accounts for 40% of the total energy supply, with this sector being the largest energy consumer (European Commission, 2018). Therefore, proper insulation of buildings is a critical issue that allows for minimizing the transmitted heat flux, saving heating

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energy, and reducing emissions associated with the use of fossil fuels for thermal energy production (Cozzarini *et al.,* 2020). Inorganic fiber materials like mineral wool and organic foam materials like expanded or extruded polystyrene and polyurethane foams dominate the market for materials used to make thermal insulation. (Kostadinović *et al.,* 2022).

Given the above, it is necessary to look for secondary raw material alternatives to produce thermal insulators. These alternatives must comply with environmental, public health, and sustainability requirements in the construction sector. Therefore, the reuse of ceramic waste for the manufacture of thermal insulators is being proposed as an alternative because it is a low-cost material, does not generate health problems like asbestos, is an abundant material, is available at any time of the year, and has a low thermal conductivity (0,0020 – 0,0039 (Moraes *et al.,* 2019). In addition, it is a refractory material, with high heat resistance, so it can be used in steam generation systems to avoid energy loss on the exterior.

Ceramic waste to produce abrasive material

Exploring secondary materials as raw materials for the manufacture of abrasive instruments has been motivated by rising resource demands and usage, creating a more sustainable environment (Palaniyappan *et al.,* 2021). In addition to being a sustainable material, compared to other types of abrasives, ceramic waste has a microcrystalline structure that allows it to degrade progressively, leading to a wide range of applications in the manufacture of bonded abrasives, coated abrasives, and other specialty abrasive tools (Sabaa & Fahad, 2019). Some characteristics that make ceramic waste a promising material as a raw material for manufacturing abrasive products (Sabaa & Fahad, 2018; Huang *et al.,* 2021):

- It is extremely strong, which means it has a long service life.
- The particles retain sharp edges for a longer periods of time.
- It is not brittle, and its cutting edges are not compromised when sanding other materials.
- It is ideal for grinding shapes and surfaces, or for smoothing.
- They do not generate toxics waste and are safe to use.

Ceramic wastes for coral reef regeneration

Thanks to their versatility for use as a construction material and their ability to build structures, porcelain electrical insulators are an attractive alternative as a substratum for the regeneration of coral reef colonies in coastal areas. Artificial structures made of porcelain insulators, these structures with varied geometric shapes are environmentally friendly and function as temporary homes for marine fauna. On top of these ceramic structures, algae are naturally attached so that polyps or coral seeds can settle and grow. These structures encourage the recovery of degraded sites while protecting natural reefs. Their presence benefits local fishing, increases local tourism, and promotes the creation of educational spaces for the protection of marine resources (El País, 2019). Based on this initiative, it is possible to develop conservation projects to restore the environmental benefits provided by marine biotopes and generate new marine ecosystems for the preservation of any endemic, threatened, or endangered species due to climate change and human activity (Garza, 2019). Beforehand, extensive research and laboratory tests must be carried out to ensure that the materials used do not generate any contamination that may affect life in the marine ecosystem.

Ceramic waste for making structures from additive manufacturing techniques

Addictive manufacturing (AM) is the elaboration of 3D prototypes by deposition of material in several layers, the prototypes are manufactured from computer-based digital models (Lakhdar *et al.,* 2021). AM has been of great importance for academia and industry during the last decades, thanks to AM, innovations have been generated in the manufacturing processes of various industries (Mitchell *et al.,* 2018). The ceramic industry has a need to manufacture advanced materials with complex structures, AM has the potential to meet these needs, and this is why the ceramic industry is one of the most promising areas to implement this technology (Hur *et al.,* 2022). Currently, ceramic additive manufacturing is used only for research and prototyping purposes. The reasons that have driven this technique for the fabrication of ceramic matrix products center on the possibility of creating highly customized, geometrically complex parts with improved properties of density, surface finish, and mechanical strength (Sun *et al.,* 2023).

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5. Conclusion

Four alternatives for the reuse and valorization of ceramic waste were identified in different literature. These alternatives were: the manufacture of concrete, the manufacture of electrical insulators, the extraction of alumina, and a geological barrier to contain nuclear waste. The viable option, both economically and in terms of its physicochemical properties, for the reuse and valorization of ceramic waste is the manufacture of concrete. Since this waste is suitable for substituting fine and coarse aggregates, and partial substitution in the production of cement. In terms of qualities like density, durability, permeability, and compressive strength, concrete made using ceramic waste outperforms regular concrete. Similarly, four possible applications of this waste were established using their main properties. In such a way the reuse perspectives were established as the production of thermal insulators, the manufacture of abrasive materials, the regeneration of coral reefs, and the elaboration of structures from additive manufacturing techniques. Of these possible applications, the manufacture of abrasive materials stands out, since this waste has a high density, durability, and toughness and is not brittle.

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