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Use of sargassum and other organic substitutes in the construction industry: a review

Uso del sargazo y de otros sustitutos orgánicos en la industria de la construcción: a review

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ABSTRACT

Currently, sargassum, due to the large quantities that have arrived on the coasts of Mexico and other parts of the world, has become an environmental, economic and health problem, which makes its study important to provide value. Sargassum has been used for the production of biofuels and bioremediation, however, to the large amount of this organic material, the construction industry has used it in its raw state as a cementitious substitute. The objective of this article is to know the potential use of sargassum ash as a cementitious substitute, comparing it with various organic biomasses that have been used for the same purpose, for which a bibliographic review of organic biomasses, their characteristics, substitution percentages has been carried out. and its application. The above will provide knowledge of the properties that ash must contain for its application either in mortars or pastes that improve long-term durability, to advance sustainable construction.

Keywords: *Organic cement substitutes, construction, sargassum, organic biomasses, mortar.*

RESUMEN

Actualmente el sargazo por las grandes cantidades que han arribado en las costas de México y en otras partes del mundo, se ha convertido en un problema ambiental, económico y de salud, lo que hace importante su estudio para proporcionarle una valorización. El sargazo ha sido utilizado para la elaboración de biocombustibles y biorremediación, sin embargo, por la gran cantidad de este material orgánico, la industria de la construcción lo ha utilizado en estado crudo como sustituto cementante. El objetivo de este artículo es conocer el potencial uso de la ceniza de sargazo como sustituto cementante comparándolo con diversas biomasas orgánicas que han sido utilizadas para el mismo fin, para lo cual se ha realizado una revisión bibliográfica sobre biomasas orgánicas, sus características, porcentajes de sustitución y su aplicación. Lo anterior proporcionará conocimiento de las propiedades que tiene que contener la ceniza para su aplicación ya sea en morteros o pastas que mejoren la durabilidad a largo plazo, para avanzar en la construcción sustentable.

Palabras clave: *Sustitutos orgánicos de cemento, construcción, sargazo, biomasa orgánica, mortero.*

1. INTRODUCTION

Due to population growth and the development of urban areas over time, the use of concrete has been on the rise, leading to an increase in cement production. Unfortunately, tied to the growth in cement demand, the disproportionate amount of greenhouse gas (GHG) emissions would also increase proportionally, with the construction industry being responsible for 37% of GHG emissions, while emissions from cement production fluctuate at an annual rate of 8%. (Zhang *et al.* 2022).). Among the strategies designed to tackle this issue, the implementation of supplementary cementitious materials (SCMs) derived from biomasses and their residual ashes has shown promise as a solution to ameliorate the environmental impact.

To date, various organic biomasses have been used (Figure 1) as SCMs. Given the considerable amount of sargassum beached in coastal zones in Mexico and other countries, its use as a potential material for the construction industry has gained attention. Sargassum is a type of macroalgae that inhabits shallow waters and serves as a habitat for a variety of species, participating in several biological cycles and sea connectivity. Its arrival on Mexican coasts dates back to 1960; however, in 2015, the first atypical arrival occurred, increasing annually from 2015 to 2018. It has been estimated that due to its rapid growth pattern, sargassum can double its volume in less than 20 days, explaining the quick proliferation of these macroalgae. Anthropogenic impacts on oceans have contributed to sargassum proliferation, surpassing authorities' capabilities to address it.

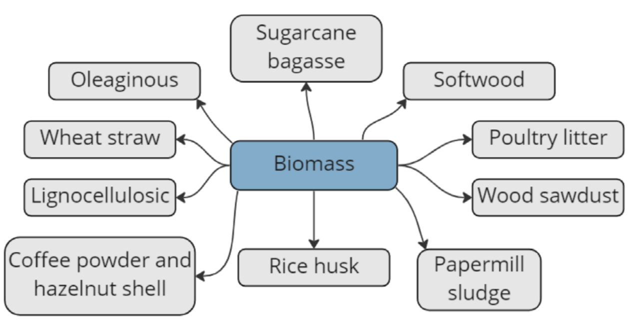

Figure 1. Biomasses commonly used as supplementary cementitious materials (SCM). Source: self made

These aforementioned problems have resulted in socio-economic, health, and environmental issues along the Caribbean coast and around the globe. Economic issues involve reduced tourism, diminished investment opportunities, and fishing activities. On the ecological front, sargassum decomposition produces hydrogen sulfide, which harshly affects biodiversity in marine environments (Martinez-Daranas *et al.* 2019) and also causes dermatitis, conjunctivitis, and respiratory tract infections. This has prompted authorities to adopt various hygiene and monitoring measures (Rodríguez-Martínez *et al.* 2019).

In environmental terms, residual ashes offer benefits when used as supplementary cementitious materials (SCMs) since greenhouse gas (GHG) emissions linked to the calcination process tend to be lower than conventional cement production. This results in enhanced composite performance, and, in some cases, certain ashes can even sequester CO2 to further the mitigation effect. Several authors have studied the sequestering effect of ashes from biomass; certain calcinated biomasses can sequester up to 870 kg of CO2-equivalent emissions for each ton of bulk dry biomass (Gupta *et al.* 2018; Maljaee *et al.* 2021; Roberts *et al.* 2010 and Woolf *et al.* 2010).

Numerous organic materials have been proposed as calcination stock to repurpose residual ashes as SCMs, including poultry litter (PL), sugarcane bagasse (SCB), sawdust, among others (Gupta *et al.* 2020; Choi *et al.* 2012; Zavala-Arceo *et al.* 2019 and Ahmad *et al.* 2020).

The present article aims to describe the properties of several biomasses used in previous studies and the potential of sargassum ashes as supplementary cementitious material, reviewing the benefits it could provide to the construction industry.

2. SELECTION CRITERIA

There are indeed investigations that utilize ashes of organic materials as cementitious substitutes; however, few provide comprehensive data on their composition and the specific characteristics in which they were employed, either in pastes or mortars.

The literature search was conducted across various databases and was limited to the period from January 2016 to December 2023. A combination of the following keywords, in conjunction with Boolean operators AND and OR, was used to narrow the scope of the search: ash, cementitious, construction, material, SCM, pastes, mortars.

The eligibility criteria were established based on the publication of the article in English, including discussions on the chemical composition of organic materials, as well as details regarding their use and the percentage of substitution, either in pastes or mortars. A total of 40 articles were selected for an extensive review, analyzed, and the results are presented in this article.

3. RESULTS AND DISCUSSION

Cement is a key ingredient in any construction-related project, whether it is a residential or commercial building. Consequently, substantial quantities of cement are produced annually, reaching around 25 billion tons. This equates to over 3.5 tons per person globally (Vassilev *et al.* 2010).

Cementitious composites are obtained through chemical and physical reactions between minerals present in raw cement and water, in the presence of lime and additives. The main hydration products of these reactions are calcium silicate hydrates, calcium hydroxide and sulfoaluminates, Eq. (1) (Barron 2010).

(1)

$$2\,(CaO)3.(SiO2) + 7H2O \rightarrow (CaO)3.(SiO2)2.4\,(H2O) + 3\,Ca(OH)2$$

To the present day, the cement production industry releases most of its greenhouse gas (GHG) emissions during the manufacturing and processing stages, posing a significant threat to the environment. Approximately 7% of global CO2-equivalent production corresponds to this industry (Oh *et al.* 2014). Thence, the need to replace cement with repurposed materials arises, primarily as supplementary cementitious materials (SCMs).

A type of SCM is derived from organic wastes, whether from livestock or the wood industry (see Fig. 1), conventionally known as biomasses. These materials have recently been valorized as construction industry materials, whereas in the past, biomasses were mainly used for biofuel production (Lee *et al.* 2019; Antar *et al.* 2021). The main advantage that SCMs from biomasses possess is the reduction of GHG emissions associated with cement production and the innovation of current technologies in cement composites.

When these materials were initially implemented, they were repurposed in their raw state, negatively affecting various parameters of both mortars and concretes, such as durability, hydration rate, and an increase in impurities in the cementitious matrix (Maljaee *et al.* 2021). Currently, the ashes from these biomasses are used as an alternative to fossil fuels due to their potential as a bio-renewable material. These pyrogenic ashes are obtained as a solid carbonaceous material occurring after the calcination process at temperatures ranging from 200°C to 800°C (pyrolysis) under limited oxygen conditions (Vigneshwaran *et al.* 2020; Cha *et al.* 2016).

3.1 Properties of materials used as SCMs.

Chemical composition of the biomasses and pyrogenic ashes is of uttermost importance when considered as SCM since certain chemical reactions are sought for; Hence, the origin of the biomass and its chemical composition play a crucial role (Table 1).

Determined by the type of biomass used and pyrolysis conditions, the most common elements found in pyrogenic ashes include carbon (C), oxygen (O), hydrogen (H), nitrogen (N), calcium (Ca), potassium (K), silicon (Si), magnesium (Mg), aluminum (Al), sulfur (S), iron (Fe), phosphorous (P), chloride (Cl), sodium (Na), manganese (Mn) and titanium (Ti) (18).

Table 1. Chemical composition of the biomass used as SCMs Source: self made									
Materials	**Chemical composition**								
	SiO_2	Al_2O_3	Fe_2O_3	CAO	MgO	Na_2O	K_2O	LOI	
CPO	20.8	4.3	2.2	65.3	2.17	-	0.63	0.91	Chand, 2021
Silica fume	87.5	0.5	1.53	1.27	1.01	-	1.14	5.92	Chand, 2021
Fly ash									
F Class	37.0-62.1	16.6-35.6	2.6-21.2	0.5-14.0	0.3-5.2	0.1-3.6	0.1-4.1	0.3-32.8	ASTM 618-17a, 2017
C Class	11.8-46.4	2.6-20.5	1.4-15.6	15.1-54.8	0.1-6.7	0.2-2.8	0.3-9.3	0.3-11.7	ASTM 618-17ª, 2017
Ash									
Sugarcane bagasse	55.49	4.92	8.29	8.74	7.96	0.93	8.34	5.4	Chand, 2021
Rice husk	15.77	0.03	0.05	0.19	0.04	-	0.88	-	Gupta et al. 2020c
Poiltry Litter	12.102	2.075	0.964	52.763	6.357	-	6.443	-	Castillo et al. 2022
Coconut shell	0.49	0.18	0.23	0.07	0.05	-	0.66	-	Gupta et al. 2020a
Softwood	0.45	1.35	1.82	0.65	0.51	-	0.42	-	Cosentino et al. 2019
Hazelnut shell	0.11	-	0.25	0.44	-	-	1.01	-	Restucia et al. 2016
Coffee Powder	0.3	-	-	4.74	1.35	-	9.15	-	Restucia et al. 2016

Three categories of SCMs can be distinguished: 1) pozzolanic potential, 2) hydraulic potential and, 3) filler potential. Ashes with moderate to high content of amorphous silica (Maljaee *et al.* 2021) enable the pozzolanic reaction, thus, being proposed as a cement replacement with equivalent properties. These properties include internal adherence with aggregates, production of hydrates, and acting as a corrosion protection agent by increasing the pH.

According to the ASTM C618-17a (2017) standard, an accumulated number of reactive oxides must be present in the ash chemical composition. Dicalcium silicate once hydrated turns into tobermorite gel -which is a calcium silicate hydrate mineral- and, to a lesser extent, calcium hydroxide (CH) Eq. (2):

$$2\,(2CaO.SiO2) + 6\,H20 \rightarrow 3CaO.2SiO2.3H20 + 3Ca(OH)2 \quad (2)$$

Calcium aluminate in conjunction with lime and water produces ettringite Eq. (3):

$$(3CaO.Al2O3) + 3CaSO4.2H20 + 15\,H20 \rightarrow 3CaO.Al2O3.\ 3CaSO4.\ 32H20 \quad (3)$$

Calcium aluminate in conjunction with ettringite and water turns into monosulfate Eq (4):

$$2\,(3CaO.Al2O3) + 3CaO.Al2O3.3CaSO4.32H20 + 4H20 \rightarrow 3\,(3CaO.Al2O3.CaSO4.12H20) \quad (4)$$

Calcium aluminate in conjunction with calcium hydroxide and water produces hydrated calcium aluminates Eq (5):

$$3CaO.Al2O3 + Ca(OH)2 + 12\,H20 \qquad 4CaO.Al2O3.13HO \quad (5)$$

According to the standard, for a material to be considered as pozzolanic, the sum of the aforementioned oxides must be over 50% of the total oxide composition.

3.2. Physical and chemical properties of pyrogenic ashes

Other key properties of pyrogenic ashes are the physical-chemical properties: specific area, cation exchange capacity, water retention, pore size and distribution (Maljaee *et al.* 2021). These properties determine the composite absorption, water retention, density, insulation and thermal regulation (Zhang *et al.* 2022), all key properties for cement hydration and strengthening.

Pyrogenic ashes porosity inversely affects the overall density of the composite, in other words, if the ash porosity is high, the resulting density tends to be lower and the resistance is also affected. Porosity is significantly influenced by the calcination temperature; higher temperatures result in higher porosity values, leading to lower density values (Weber and Quickr 2018)

3.3. Properties of cementitious composites

Hardened state properties

Hardened-state properties determine the quality of any produced mortar or concrete. The most important parameters for determining such quality include compressive strength, flexural strength, durability, porosity, and surface area (Figure 2). Compressive strength is strongly correlated with the water/binder ratio and porosity of the constituent materials. It plays a crucial role in the matrix binding between aggregates and the cementitious paste, representing the maximum uniaxial load a given mortar or concrete can withstand. This strength is normally expressed as force per unit surface in the shearing plane (Comite ACI 116, 2000).

Flexural strength refers to the ability to withstand bending forces. Therefore, cement and concrete have low flexural strength, so reinforcing steel is added to improve their ability to resist such loads. The durability of cementitious composites is characterized by the ability to withstand environmental forces, including wind loads, chemical and igneous forces, and other service-related forces. It is important to mention that parameters affecting durability, such as porosity and water absorption, play a crucial role. (Comite ACI 116, 2000).

Water absorption determines porosity by measuring the water uptake capacity (humidity) in cementitious composites. Through this pore network, deleterious compounds can ingress the matrix, such as chloride ions, with their effects further enhanced through carbonation. Additionally, porosity and surface area in materials determine the final mechanical and durability-related properties.

Thus, organic pyrogenic ashes possess features that could enhance these aforementioned properties, indicating its potential as SCM.

3.4. Pyrogenic ashes as supplementary cementitious material

As mentioned above, greenhouse gas emissions related to cement production represent an environmental concern. Therefore, there is a need to replace cement with more eco-efficient materials, such as pyrogenic ashes obtained after the calcination of biomasses. Numerous ashes have been tested in previous efforts to address this pressing environmental (Table 2).

Oxides like Si, Al, Fe and Ca are crucial for pozzolanic reaction -producing additional calcium silicate hydrate (C-S-H) in the cementitious matrix. Since pyrogenic ashes tend to possess these oxides as primary components, their use as SCM to enhance cementitious properties has been proposed.

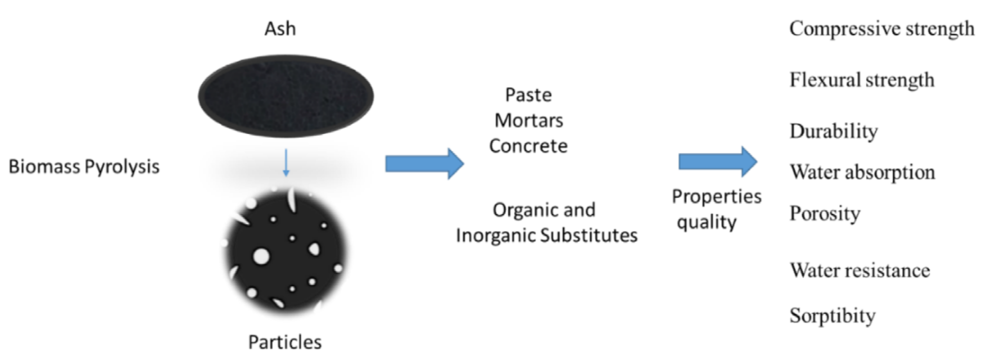

Figure 2. Properties of cementitious composites
Source: self made

Table 2. Organic biomass valorized as SCMs Source: self made					
Source	**Pyrolysis temperature (°C)**	**Substitution (%)**	**Application**	**Results**	**Reference**
Coffee powder and hazelnut shells	800	0.5-0.8	Cement paste	Increase in compressive strength and flexural strength Increase in fracture energy	(Restuccia and Ferro, 2016)
Sugarcane bagasse	200	2-4	Cement paste	Increase in cement hydration Increase in thermal conductivity	(Rodier *et al.*, 2019)
Softwood biochar	7000	0.8-1	Cement paste	Increase in flexural strength Increase in fracture energy	(Cosentino *et al.* 2019)
Poultry litter ash and enhanced poultry litter ash	450	10	Mortar	Achieve minimum compressive strength required Increase water uptake	(Roy *et al.* 2017)
Wood sawdust	300-500	1-2	Mortar	Increase in compressive strength Decrease water absorption and water uptake	(Gupta *et al.* 2018)
Wood sawdust (presoaked)	300-500	2	Mortar	Increase in compressive strength Decrease water absorption and water uptake	(Gupta *et al.* 2018a)
Rice husk	500	20	Mortar	Increase in compressive strength and brittleness Equal drying retraction as in control sample Decrease in water absorption. Increase in durability	(Muthukrishnan *et al.* 2019)
Lignocellulosic and non-lignocellulosic	210-600 500	2	Mortar	Increase in compressive strength, modulus of elasticity and toughness	(Gupta *et al.* 2020)
Oleaginous and softwood mix	700	4-8	Mortar	Increase in compressive strength Decrease in thermal conductivity and vapor resistance. Reduces energy consumption	(Park *et al.* 2021)
Poultry litter ash	800	10, 15, 20	Mortar	Increase in compressive strength	(Castillo *et al.* 2022)
Wheat straw ash	650	1.5	Mortar with MPC	Increase in compressive and flexural strength Decrease in water absorption	(Ahmad *et al.* 2020)
Rice husk	500	40	Mortar with cenospheres	Increase in surface area and water demand Enhances cement hydration while maintaining density. Increase in high temperature resistance	(Gupta *et al.* 2020c)
Coconut shell and wood residue	500	5	Mortar with silica fume	Enhances cement hydration Decrease in water absorption Decrease in autogenous shrinkage and drying shrinkage. Equal compressive strength	(Gupta *et al.* 2020a)
Papermill sludge, rice husk and poultry litter	800	0.1	Concrete	Increase in flexural and tensile strength Achieves minimum required compressive strength. Increase in water absorption	(Akhtar and Sarmah, 2018)
Rice husk, poultry litter and bentonite enhanced poultry litter	450-500	0.1	Recycled aggregate concrete	Increase in compressive and tensile strength Decrease in water absorption and permeability. Increase in durability	(Akhtar and Sarmah, 2018a)
Wood sawdust	500	0.5-2	Concrete with silica fume	Increase in compressive, flexural and tensile strength. Decrease in permeability Increase in high temperature resistance	(Gupta *et al.* 2020b)

3.5.Pyrogenic ashes in cementitious composites

Pyrogenic ashes in cement pastes

Three types of reaction can occur in the cementitious matrix between ashes and cement itself: pozzolanic, hydraulic or filler. Studies have been carried out where ratios of 0.5-0.8% of cement have been replaced with biocarbon retrieved after the calcination process of coffee powder and hazelnut shell, increasing flexural strength by 35-75% and 46-48%, respectively; compressive strength increased by 72-75% and 64-71%, respectively; and fracture energy by 33-62% and 72-100%, respectively. These results were obtained after 7 and 28 days of curing (Restuccia and Ferro., 2016). In another study, a 2% cement substitution with sugarcane bagasse improved cement hydration, however, in the 2-6% range the minimum required compressive strength was not achieved (Rodier *et al.* 2019). A substitution of cement with sawdust improves flexural strength and fracture energy by 20%, in contrast with control samples at 7 and 28 days of curing (Cosentino *et al.* 2019).

As indicated below, ashes from organic materials might improve cementitious properties but also decrease certain other properties at a certain ratio of replacement, hence, it is necessary to carry out further studies to determine the proper ratio at which substitution enhances these properties without affecting other aspects such as durability or strength.

Pyrogenic ashes in cement mortars

Ashes from different biomasses have also been studied as partial replacement of cement in mortars. In one study, wood dust replaced cement at a5% ratio, showing barely any effect on compressive strength while improving water retention properties (Choi *et al.* 2012). Similarly, replacing cement with poultry litter ash and enhanced poultry litter ash achieved the minimum required strength while also improving water uptake properties. However, bentonite-enhanced poultry litter achieved higher compressive strength values (Roy *et al.* 2017).

In another study, wood sawdust replaced 1-2% of cement in mortars enhancing compressive strength in early ages and decreasing absorption and water uptake by 58% and 65%, respectively. The same authors modified the addition process by implementing a wetting process before addition in the same ratio -1 to 2%-, resulting in increases for compressive strength and flexural strength by 40-50% while absorption and water uptake decrease by 55-60% (Gupta *et al.* 2018).

Rice husk ash replaced cement in mortars, at a 20% ratio in one study, resulting in increased compressive strength and durability (Muthukrishnan *et al.* 2019). When considering only the thermal treated ash, compressive strength and brittleness of control samples is matched in mortar specimens. However, in the case of untreated ashes, water uptake improves and thus, durability. Poultry litter ash has also been used as a SCM (Castillo *et al.* 2022) with replacement ratios of 10, 15 and 20%. The 10% ratio obtained best results in terms of compressive strength and durability at 7 and 90 days of curing.

Ashes from lignocellulose has been used in ratios of 2%. Even after two years compressive strength, modulus of elasticity and overall toughness increased by 10-12%, 16-20% and 30-40%, respectively (Gupta *et al.* 2020). In contrast with non-lignocellulosic (algae residue) there is a decrease in compressive strength by 15%. Mixes of sawdust and oleaginous as organic biomasses have been studied in replacement ratios of 4% increasing compressive strength. However, when considering hygrothermal effects with 8% replacement ratios, thermal conductivity and vapor resistance decrease in the case of these ashes, hence, optimizing energy performance even considering the low replacement ratio (Park *et al.* 2021).

Mortars with replacements and different types of cement and additives have been studied in the past, seeking to improve their compressive strength, increase their thermal stability at higher temperatures, hasten hardening, or make them lighter, among many other properties related to durability. Wheat straw ash replaced 1.5% magnesium phosphate cement in mortars, improving compressive strength by 17.3% and flexural strength by 10% while water absorption decreased from 5.7% a 4.7% (Ahmad *et al.* 2020).

Rice husk ash has been used in another study where it replaced silica fume in a 40% replacement ratio in modified mortars with cenospheres. In this study, results indicate an increase in surface area and water uptake with no effects on overall density, indicating its potential as lightweight mortar or concrete. In terms of compressive strength, an increase of 15-20% was observed after an increase in temperature compared with samples with silica fume (Gupta *et al.* 2020). A mixture of coconut fiber ash and sawdust replaced 5% of cement in mortars, resulting in an improvement of cement hydration, however, water absorption values decrease by 16%. Another interesting result from this study lies in the pretreatment process; when ashes was pretreated compressive strength increased by 20-30%.

In the aforementioned studies, ashes acted as fillers for most cases, due to their physical-chemical properties, acting more in filling pores than reacting in a pozzolanic or hydraulic manner.

Pyrogenic ashes in concrete

Ashes as SCMs have also been studied in concrete. Results indicate that substitutions of 0.1% biocarbon from three different sources -paper mill sludge, rice husk ash and poultry litter ash- increase strength by 12% -in the case of rice husk ash and paper mill sludge-, while poultry litter ash and rice husk ash increased flexural strength by 20%. It is worth noting that all three substitutions increased water absorption values.

In another study, rice husk ash and enhanced poultry litter were mixed with recycled aggregates resulting in increased compressive strength and tensile strength, by 17.5% and 3.7%, respectively. In terms of durability, water absorption experienced a decrease by 17% and 8%, respectively, thus, reducing permeability (Akhtar *et al.* 2018).

Concrete with modified properties through additives could also benefit from the inclusion of SCMs from calcinated biomasses. In one study (Gupta *et al.* 2018), biocarbon from wood sawdust replaced cement in a 0.5-2.0% ratio in a concrete mix with silica fume. Results indicate that in the 0.5-1.0% range compressive strength, flexural strength and tensile strength increase by 17% and 16%, at 7 and 28 days of curing, respectively. However, at 1% replacement absorption and water uptake decreases by 28% and 43% at 7 and 28 days of curing. At 2% replacement higher temperature resistance was achieved -550°C-, a 45% increase, compared with control samples.

3.6. Environmental, health and economic impact of sargassum

Currently, sargassum has been revalorized for various purposes, serving as food, fertilizer in agriculture, and in the health sector, primarily due to its composition (Buschmann *et al.* 2017). It is also widely used as source for biofuels (Gaurav *et al.* 2017) and bioremediation (Wang *et al.* 2020). However, its chemical composition must be considered in order to avoid health-related risks.

In environmental terms, sargassum can be considered as natural marine reservoir,as more than 145 invertebrates and 127 fish species have been associated with this alga (Freestone *et al.* 2017). Nevertheless, its accumulation in seas and shores has disrupted biodiversity. It was estimated that during sargassum decomposition, over 78 species perish due to hypoxia, as water quality diminishes, oxygen levels increase and the presence of organic materials, hydrogen sulfide, ammonia and phosphorous intensifies (Martinez-Daranas *et al.* 2019; Cabanillas-Teran *et al.* 2019). When sargassum reaches coastal zones, it must be promptly removed through a costly and laborious process, resulting in beach erosion and affecting biodiversity-destroying nests and turtles' offspring (Martinez-Daranas *et al.* 2019; Maurer *et al.* 2015).

3.7.Sargassum in the construction industry

Due to environmental, health and economic issues related to the increasing shoring of sargassum on the coasts of the Caribbean -considered as an invasive alga, a considerable number of studies have revalorized this hazardous residue in various areas. While this alga has been studied at macro and micro levels, there is still insufficient information regarding its use of this residue as SCM (Chávez *et al.* 2020). In the light of the lack of information in this respect, the paragraph explores potential uses for sargassum in the construction industry. (Figure 3).

Potential of sargassum in portland cement composition

As of late, sargassum has been studied as a fine aggregate in mortars. Several studies have shown that a 5% replacement ratio of fine aggregate achieves the minimum compressive strength (75kg/cm^3), along with improved thermal properties (Zavala-Arceo *et al.* 2019). In another study, pulverized sargassum replaced 10% cement in a paste, increasing compressive strength by 12.4% at 28 days of curing, in contrast with control sample (Chahbi *et al.* 2022).

Potential use in paving

Sargassum has been utilized as a replacement, at a 4% ratio, for styrene-butadiene-styrene rubber in a bio-bitumen mixture; the mixture was produced using marine algae oil modified with polystyrene with graphite oxide (20% ratio of bitumen mass). This modification achieves a higher softening point at elevated temperatures, enhanced ductility at low temperatures, and increased resistance to stress in harsh environments (Li *et al.* 2019).

Sargassum has also been studied as asphalt modifier, exploring its potential as synthetic elastomers to enhance pavement performance in highways, with replacement ratios ranging from of 0.5 to 4.0% in bitumen mass. Results indicate improvements in softening point, penetration index and an increase of 2.5% on resistance against deformations (Salazar-Cruz *et al.* 2021).

Figure 3. Upcycling of sargassum ash into construction materials.
Source: self made

Additionally, Posidonia Oceánica has been studied as reinforcement where rigidity and strength improved, ultimately enhancing the overall performance of the asphalt mix (Herráiz *et al.* 2016).

Raw sargassum in bricks

Sargassum has been used as a source for the production of bricks for the construction industry. SargaBLOCK™ has been manufacturing sargassum bricks since 2019 for sustainable house buildings. These bricks contain approximately 40-60% of raw sargassum, with industrial and artisanal compression of 112 Kg/cm^2 (Sargablock 2021). Several studies have demonstrated that alginate from algae contribute to soil stabilization and thus, have proven to be useful for brick production.

Researchers have studied soil stabilization with natural polymers and fibers from algae for sustainable construction materials and to assure non-hazardous materials (Galán-Marín *et al.* 2010). The addition of Alginate increased compressive strength up to 3.77 MPa, while the addition fiber increased it by up to 37%. The combination of both polymers and fibers doubled compressive strength of the soil. Sargassum (*S.natans and S. fluitans*) retrieved from coastal zones in Quintana Roo was used for brick production in a ratio of 40% of soil mass. The compressive strength ranged from 7.5 to 11 MPa, values considered on the high-end for raw sargassum replacement (Desrochers *et al.* 2020 a; b).

Facades and coatings

Marine algae has been studied as facades and coatings in the context of technological innovation in order to decrease energy consumption and increase thermal comfort, thus, reducing stress on the environment by decreasing GHG emissions associated with thermal comfort equipment. Also, these coverings isolate noise by creating a micro-climate with thermal control. Nevertheless, this alternative is still costly to implement, despite the numerous benefits in terms of sustainable energy production.

One research evaluated the potential of algae for facade boards in a photo-bioreactor system to revalorize biomass as a source of clean energy (Wilkinson *et al.* 2017). The results of this study, indicate that algae function as a bio-film with fireproof and anti-bacterial properties.

3.8. Potential of sargassum ash as supplementary cementitious composite.

The development of eco-efficient concrete has been prioritized in two ways: first, by reducing the depredation of natural resources and second, by improving production efficiency. The former focuses on the revalorization of residues as sources in a process -the main takeaway of the circular economy-, in the sense of developing more efficient environmental policies to benefit communities further (Busch *et al.* 2022). The latter centers more on the continuous improvement of the processes associated with clinker production and source material calcination (Fernández *et al.* 2017).

Sargassum possesses properties suitable for a supplementary cementitious material, such as its thermal insulation properties with a thermal conductivity of 0.045 W/mK and a specific heat of 2000 J/KgK (Fernández *et al.* 2017). For a material to be considered as thermal insulator the aforementioned values should remain lower than 0.07 W/mK and over 1400 J/KgK, respectively (Asdrubali *et al.* 2015). The valorization of algae through its properties points to its potential study as SCM, directly correlated with savings in economic terms, while simultaneaously addressing pressing environmental and health issues.

CONCLUSIONS

In the past, various organic biomasses have been used as additional materials, adding value to their core residual means and significantly impacting the environment, the health industry, and the economy overall. Favorable results have been obtained for construction, depending on the biomass used.

Sargassum ash emerges as a strong candidate for valorization as a supplementary cementitious material, thereby adding core value through the revalorization of this invasive alga.

It is crucial to accurately determine the substitution percentages with the ash to avoid affecting properties such as strength, porosity, and flowability.

To learn more about this organic material, it is important to conduct tests such as pozzolanic activity, as well as determining the ideal temperature for calcination and calorimetric tests to ascertain the application of this organic matter.

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REFERENCES

Ahmad M.R., Chen B, Duan H. (2020). Improvement effect of pyrolyzed agro-food biochar on the properties of magnesium phosphate cement. *Science of the Total Environment.* 1-13.

Akhtar A., Sarmah A. (2018). Novel biochar-concrete composites: Manufacturing, characterization and evaluation of the mechanical properties. *Science of the Total Environment*. 408-416.

Akhtar A., Sarmah A. (2018a). Strength improvement of recycled aggregate concrete through silicon rich char derived from organic waste . *Journal of Cleaner Production*. 411-423

American Society of Testing Materials ASTM C-618-17a. (2017). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete,.

Antar, M.; Lyu, D.; Nazari, M.; Shah, A.; Zhou, X.; Smith, D.L. (2021). Biomass for a sustainable bioeconomy: An overview of world biomass production and utilization. *Renew. Sustain. Energy Rev*. 139, 110691.

Asdrubali F., D'Alessandro F,. Schiavoni S. (2015). A review of unconventional sustainable building insulation materials. *Sustainable Materials and Technologies.* 4 1-17. https://doi.org/10.1016/j.susmat.2015.05.002

Barron, A. (2010). Hydration of Portland Cement [WWW Document]. OpenStax-CNX Modul. m16447. http://cnx.org/contents/Lbv3xcBF@11/Hydration-of-Portland- Cement#eip1411

Busch, T, Johnson, M, Pioch, T. (2022). Corporate carbon performance data: Quo vadis? *Journal Ind Ecol.* 26: 350– 363. https://doi.org/10.1111/jiec.13008

Buschmann, A.H., Camus, C., Infante, J., Neori, A., Israel, A., Hernández-Gonzalez, M.C., Pereda, S.V., Gomez-Pinchetti, J.L., Golberg, A., Tadmor-Shalev, N., Critchley, A.T. (2017). Seaweed production: overview of the global state of exploitation, farming and emerging research activity. *Eur. J. Phycol.* 52, 391–406. https://doi.org/10.1080/09670262.2017.1365175.

Cabanillas-Teran, N., Hernández-Arana, H., Ruiz-Zárate, M., Vega-Zepeda, A. Y Sanchez-Gonzalez, A. (2019). Sargassum blooms in the Caribbean alter the trophic structure of the sea urchin Diadema antillarum. *PeerJ 7:* e7589. https://doi.org/10.7717/peerj.7589.

Castillo, D., Cruz, J. C., Trejo-Arroyo, D. L., Muzquiz, E. M., Zarhri, Z., Gurrola, M. P., & Vega-Azamar, R. E. (2022). Characterization of poultry litter ashes as a supplementary cementitious material. *Case Studies in Construction Material.* 17. https://doi.org/10.1016/j.cscm.2022.e01278

Cha, J.S.; Park, S.H.; Jung, S.-C.; Ryu, C.; Jeon, J.-K.; Shin, M.-C.; Park, Y.-K. (2016). Production and utilization of biochar: A review. J. *Ind. Eng. Chem*. 40, 1–15.

Chahbi M., Mortadi A., El Moznine R., Monkade M., Zaim S., Nmila R. & Rchide H. (2022) A new approach to investigate the hydration process and the effect of algae powder on the strength properties of cement paste. *Australian Journal of Mechanical Engineering* 1-10.

Chávez V., Uribe-Martínez, A.; Cuevas, E.; Rodríguez-Martínez, R.E.; van Tussenbroek, B.I.; Francisco, V.; Estévez, M.; Celis, L.B.; Monroy-Velázquez, L.V.; Leal-Bautista, R.; Álvarez-Filip, L.; García-Sánchez, M.; Masia, L.; Silva, R. (2020). Massive Influx of Pelagic Sargassum spp. on the Coast if the Mexican Caribbean 2014-2020: Challenges and Opportunities. *Water* 1-24.

Comité ACI 116. (s.f.). (2000). Terminología del cemento y hormigón.

Cosentino I.,Restucccia L., Ferro G. Tulliani J. (2019). Type of materials, pyrolysis conditions, carbon content and size dimensions: The parameters that influence the mechanical properties of biochar cement-based composites. *Theoretical and Applied Fracture Mechanics*. 1-10. https://doi.org/10.1016/j.tafmec.2019.102261

Desrochers, Anne, Cox, Shelly-Ann, Oxenford, Hazel A., van Tussenbroek, Brigitta I. (2020a). Sargassum Uses Guide: A Resource for Caribbean Researchers, Entrepreneurs and Policy Makers. *CERMES Technical Report No. 97 Special Edition*.

Desrochers, Anne, Cox, Shelly, Oxenford, Hazel, Van Tussenbroek, Brigitta. (2020b). Sargassum uses guide: a resource for caribbean researchers, entrepreneurs and policy makers lead. *Food and Agriculture Organization of the United Nations (FAO) Produced* (97), 100.

Fernández,F, C. J. Boluda, J. Olivera, L. A. Guillermo, B. Gómez, E. Echavarría, A. M. Gómez. (2017). Análisis elemental prospectivo de la biomasa algal acumulada en las costas de la republica dominicana durante 2015. C*entro Azucar* 44 11-22.

Freestone, D., Roe, H., Laffoley, D., Morrison, K., Rice, J., Inniss, L., Trott, T.M. (2017). Sargasso Sea. In: United Nations (Ed.), The First Global Integrated Marine Assessment. *Cambridge University Press, Cambridge,* pp. 893–898. https://doi.org/10.1017/9781108186148.060.

Galán-Marín, C., Rivera-Gómez, C., Petric, J. (2010). Clay-based composite stabilized with natural polymer and fibre. *Construct. Build. Mater.* 24 (8), 1462–1468. https://doi.org/10.1016/j.conbuildmat.2010.01.008.

Gaurav, N., Sivasankari, S., Kiran, G., Ninawe, A., Selvin, J. (2017). Utilization of bioresources for sustainable biofuels: a Review. Renew. *Sustain. Energy Rev.* 73, 205–214. https://doi.org/10.1016/j.rser.2017.01.070.

Gupta S., Ewi-Kua H. (2020a). Application of rice husk biochar as filler in cenosphere modified mortar: Preparation, characterization and performance under elevated temperature. *Construction and Building Materials.* 1-16. https://doi.org/10.1016/j.conbuildmat.2020.119083

Gupta S., Ewi-Kua H y Sze-Dai P. (2020b). Effect of biochar on mechanical and permeability properties of concrete exposed to elevated temperature. *Construction and Building Materials.* 1-16. https://doi.org/10.1016/j.conbuildmat.2019.117338

Gupta S., Ewi-Kua H, Yang Low C. (2018a). Use of biochar as carbon sequestering additive in cement mortar. Cement and Concrete Composites. 1-63. https://doi.org/10.1016/j.cemconcomp.2017.12.009.

Gupta S., Krishnan P., Kashani A y Ewi-Kua H. (2020c). Application of biochar from coconut and wood waste to reduce shrinkage and improve physical properties of silica fume-cement mortar. *Construction and Building Materials*, 1-15.

Gupta S., Palansooriya K., Dissanayake P., Ok Y. Y Ewi-Kua H. (2020). Carbonaceous inserts from lingocellulosic and non-lignocellulosic sources in cement mortar: Preparation conditions and its effect on hydration kinetics and physical properties. *Construction and Building Materials.* 1-17. https://doi.org/10.1016/j.conbuildmat.2020.120214

Gupta S., Wei-Kua H., Pang S. Biochar-mortar composite: (2018) Manufacturing, evaluation and physical properties and economic viability. *Construction and Building Materials*. 874-889. https://doi.org/10.1016/j.conbuildmat..02.104

Herráiz, Teresa Real, Julia, I., Herráiz, Real, Domingo, Laura Montalbán, Domingo, Francisco Carrión. (2016). Posidonia oceanica used as a new natural fibre to enhance the performance of asphalt mixtures. *Construct. Build. Mater.* 102, 601–612. https://doi.org/10.1016/j.conbuildmat.2015.10.193.

Lee, S.Y.; Sankaran, R.; Chew, K.W.; Tan, C.H.; Krishnamoorthy, R.; Chu, D.-T.; Show, P.-L. (2019). Waste to bioenergy: A review on the recent conversion technologies. *BMC Energy,* 1, 4.

Li J., Zhang F., Muhammad Y., Liu Y., Wei Y. y Chen H. (2019). Fabrication and properties of wide temperature domain pavement seaweed modified bio-bitumen. *Construction and Building Materials*. 1-14. https://doi.org/10.1016/j.conbuildmat.2019.117079

Maljaee H.,Madadi R., Paiva H., Tarelho L y Ferreira V. (2021). Incorporation of biochar in cementitious materials: A roadmap of biochar selection . *Construction and Building Materials.* 1-18. https://doi.org/10.1016/j.conbuildmat.2021.122757

Martinez-Daranas B. y Suárez A. (2019). An overview of Cuban seagrasses. *Bull Mar Sci.* 94(2):269–282.

Maurer, A.S., Neef, E.D., Stapleton, S. (2015). Sargassum accumulation may spell trouble for nesting sea turtles. *Front. Ecol. Environ.* 13, 394–395. https://doi.org/10.1890/1540-9295-13.7.394.

Muthukrishnan S., Grupta S y Wei-Kua H. (2019). Application of rice husk biochar and thermally treated low silica rice husk ash to improve physical properties of cement mortar. *Theoretical and applied fracture mechanics*. 1-46. https://doi.org/10.1016/j.tafmec.2019.102376

Oh, D.-Y., Noguchi, T., Kitagaki, R., Park, W.-J. (2014). CO2 emission reduction by reuse of building material waste in the Japanese cement industry. *Renew. Sust. Energ. Rev.* 38:796–810. https://doi.org/10.1016/j.rser.2014.07.036.

Park J.H., Kim Y.U., Jeon J., Yun B.Y., Kang Y y Kim S. (2021). Analysis of biochar-mortar composite as humidity control material to improve the building energy and hygrothermal performance. *Science of the Total Environment*. 1-8. https://doi.org/10.1016/j.scitotenv.2021.145552

Restuccia L., y Ferro G. (2016). Promising low cost carbon-based materials to improve strength and toughness in cement composites. *Construction and Building Materials.* 1034-1043. https://doi.org/10.1016/j.conbuildmat.2016.09.101

Roberts K.G., Gloy B.A., Joseph S., Scott N. y Lehmann J. (2010). Life cycle assessment of biochar systems: Estimating the energetic, economic and climate change potential. *Environmental Science & Technology*, 827-833. https://doi.org/10.1021/es902266r

Rodier L., Bilba K. y Arsene M.A. (2019). Utilization of bio-chars from sugarcane bagasse pyrolysis in cement-based composites. *Industrial Crops & Products*. 1-9. https://doi.org/10.1016/j.indcrop.2019.111731.

Rodríguez-Martínez, R.E., Medina-Valmaseda, A.E., Blanchon, P., Monroy-Velazquez, L.V., Almazan-Becerril, A., Delgado-Pech, B., Vasquez-Yeomans, L., Francisco, V., García-Rivas, M.C.(2019). Faunal mortality associated with massive beaching and decomposition of pelagic Sargassum. *Mar. Pollut. Bull.* 146, 201–205. https://doi.org/10.1016/j.marpolbul.2019.06.015.

Roy K., Akhtar A., Sachdev S., Hsu M., Lim J. Y Sarmah A. (2017). Development and characterization of novel biochar-mortar composite utilizing waste derived pyrolysis biochar. *International Journal of Scientific and Engineering Research.* 8, 1912-1919.

Salazar-Cruz, B.A., Zapien-Castillo, S., Hernández-Zamora, G., Rivera-Armenta, J.L. (2021). Investigation of the performance of asphalt binder modified by sargassum. *Construct. Build. Mater.* 271, 121876. https://doi.org/10.1016/j.conbuildmat.2020.121876

Sargablock. (2021). *SargaBLOCK*. https://sargablock.com.mx/productos/

Vassilev S.V., Baxter D. Andersen L y Vassileva C. (2010). An overview of the chemical composition of biomass. *Fuel*. 913-933. https://doi.org/10.1016/j.fuel.2009.10.022

Vigneshwaran, S.; Sundarakannan, R.; John, K.M.; Joel Johnson, R.D.; Prasath, K.A.; Ajith, S.; Arumugaprabu, V.; Uthayakumar, M (2020). Recent advancement in the natural fiber polymer composites: A comprehensive review. *J. Clean. Prod.* 277, 124109. https://doi.org/10.1016/j.jclepro.2020.124109

Wang, S., Zhao, S., Uzoejinwa, B.B., Zheng, A., Wang, Q., Huang, J., Abomohra, A.E..(2020). A state-of-the-art review on dual purpose seaweeds utilization for wastewater treatment and crude bio-oil production. *Energy Convers. Manag.* 222, 113-253. https://doi.org/10.1016/j.enconman.2020.113253.

Weber K., y Quickr P. (2018). Properties of biochar. Fuel. 217, 240-261. https://doi.org/10.1016/j.fuel.2017.12.054

Wilkinson, S., Paul S., Ralph P., Hamdorf B., Navarro C., Laila K., Santana G. (2017) Exploring the feasibility of algae building technology in NSW. *Procedia Engineering.* 180, 1121-1130. https://doi.org/10.1016/j.proeng.2017.04.272

Woolf D., Amonette, J., Street-Perrott, F. (2010). Sustainable biochar to mitigate global climate change. *Nature Communications*, 1, 56.

Zavala-Arceo A., Cruz-Arguello J., Figueroa-Torres M.Z. y Yeladaqui-Tello A. (2019). Determinación de las propiedades térmicas de un mortero modificado con sargazo como material alternativo en construcción. *Revista de Ingeniería Civil*, 1-9. DOI:10.35429/JCE.2019.10.3.1.9

Zhang Y., He M., Wang L., Yan J., Zhu X., Ok Y., Machtcherine V. y Tsang Daniel. (2022) Biochar as construction materials for achieving carbon neutrality. *Biochar* 1-25.