EPS waste management from coastal cleaning actions: identification of contamination sources, collection, treatment, and re-use in cement-based materials

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Abstract Finding sustainable solutions to reduce plastic waste in response to today's global environmental challenges is a high priority for the scientific community. Collaboration among many scientists with diverse research interests is the key to success for integrated proposals for the collection, treatment, and reuse of recyclable waste. This study presents proposals for integrated EPS waste management, from identifying pollution hotspots to collection routes, especially on the coast where waste is more abundant and leaves a larger footprint, to reuse in cement-based materials. This paper discusses the various options for recycling low-grade EPS and the potential applications of mortar or concrete containing EPS collected on the coast. The multiple benefits are not limited to reducing EPS waste, but benefit the entire planet, from reducing aggregate consumption to improving building insulation.

Keywords: EPS, cement, circular economy, waste management, reclaiming, retrieval, recovering, recapturing

1. Introduction

Expanded polystyrene (also known as EPS or "Styrofoam") was first discovered in 1839. Its use increased rapidly during World War II, primarily because of its light weight and insulating properties and its use in military aircraft. Today, it is a widely used product in everything from energy-efficient building insulation and food packaging to disposable restaurant materials and soilless hydroponic horticulture. For many years, EPS was considered a "miracle product." That has changed, and it is now referred to as the "nightmare of waste" The reason EPS is referred as one of the most difficult wastes to dispose of is its properties. It is a non-biodegradable material that takes hundreds of years to decompose. It also takes up a lot of space in rubbish dump. EPS also contains toxic substances, styrene and benzene, and the polystyrene beads formed by polymerization are tiny and durable (Visvanathan et al., 2007).

The main sources of EPS pollution are municipal waste, but it is also an important source of marine pollution. Research shows that 80 % of all ocean pollution originates from the land, which points to toxic, land-based EPS trash as the primary culprit (Smith, 2015). Unfortunately, EPS packaging products end up in landfills after consumption, creating a significant amount of waste that is an environmental burden. It is important to note that polystyrene (PS) has accounted for about 10 % of all plastic waste in the last decade, ranking it as one of the most important post-consumer wastes. The main disadvantage of EPS is its very low recycling rate. The behavior of EPS in the ocean shows that it decomposes in seawater, is not biodegradable - and eventually enters the food chain via marine fauna (Consoli et al., 2018). Its properties as a lightweight, waterproof, and floating material combined with its insulating properties make it a popular choice for the marine materials industry. Major applications include fishing, aquaculture, floating buoys, food packaging, such as fish boxes, the interior of floating media, harbor platforms, and more. EPS space debris poses a chemical and physical hazard to marine life. Polystyrene foam poses a threat because it tends to quickly turn into microplastics, and microplastics pose a dual problem: First, it can be consumed by almost all marine life, and second, it can absorb large amounts of toxic chemicals due to its large surface-to-volume ratio, e.g., (Bakir et al., 2016; Consoli et al., 2018).

Global production forecast indicators of EPS are shown in Figure 1, which indicates that production is expected to increase through 2029 (Exactitude Consultancy, 2022), although environmental drawbacks have been pointed out. Global cumulative plastic production since 1950 is projected to increase from 9.2 billion tons in 2017 to 34 billion tons in 2050, as shown in Figure 2 (GRID-Arendal, 2021). There is therefore an urgent need to reduce the production of virgin plastics, reduce the amounts of uncontrolled or poorly managed waste entering the oceans, and increase the recycled content of plastic waste, currently estimated at less than 10 %.

EPS is technically recyclable, but due to its large volume relative to weight, it takes up a lot of space, is not properly managed, and is not recycled. This creates challenges for waste management centers. Transportation to recycling centers is not cost-effective, considering fuel and other transportation costs, as well as the low value of the material itself. The biggest challenge for recycling methods is the contaminated and low-quality EPS collected from the coast. Mechanical recycling is not the ideal option, and chemical recycling is not yet sustainable (Lau et al., 2020; Visvanathan et al., 2007).

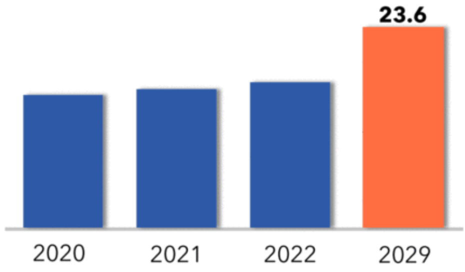

Figure 1. Expanded Polystyrene Market (Exactitude Consultancy, 2022)

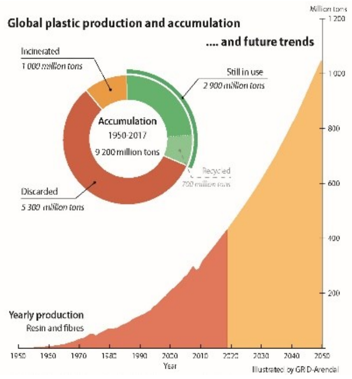

Figure 2. Global plastic production, accumulation and future trends (GRID-Arendal, 2021)

Recently, several technical publications have described the incorporation of EPS beads into cement-based materials. There are several applications for mortar or concrete made of EPS, aimed at reducing the structural weight of the material and producing new materials that improve thermal and acoustic insulation. In most applications, aggregates are partially replaced by expanded polystyrene-EPS, both coarse and fine aggregates. The results are optimistic for the use of this material in various areas of construction. In the search for solutions to reduce EPS waste and use it for other sustainable solutions, investigating the use of marine EPS waste in cement-based materials could be a viable solution for the management of coastal EPS waste.

2. Mapping of EPS waste

The Mediterranean Sea is the sea basin that connects Europe, Africa and Asia, has high levels of plastic waste and is one of the four most polluted seas. The amount of plastic waste generated by residents and visitors is over 24 million tons per year. Due to the increase in tourism in recent decades, the amount of waste has increased by up to one-third during the summer in some countries. Therefore, waste management by local institutions cannot be effective. Each year, 0.57 million tons of plastic enter the waters of the Mediterranean Sea, which is equivalent to 33,800 plastic bottles being discharged into the sea every minute. In regions directly linked to tourism, such as Greece, economic losses occur due to the impact on the blue economy (Dalberg Advisors, 2019; Julien Boucher et al., 2020).

Marine litter, particularly floating plastics such as EPS, has been found in the Mediterranean Sea in quantities comparable to those in the oceans. Studies based on global models show that the Mediterranean Sea is the sixth largest marine litter accumulation zone worldwide (Consoli et al., 2018). Marine litter and plastic pollution are a growing problem in the Adriatic and Ionian sub-basins (Arcangeli et al., 2018; Fortibuoni et al., 2019).

Due to the structure of the Mediterranean Sea, plastic fragments entering from the coast is naturally retained inside the basin (Danovaro et al., 2020). As has been studied, there is an influx of surface water from the Atlantic but no outflow along the coastline, resulting in accumulation in the interior (Zambianchi et al., 2017). When compared to the global ocean map and ocean behavior, the Mediterranean Sea shows an accumulation role of suspended particles of global origin, as reported by (Lebreton et al., 2012). Using a range of models and historical data, (Zambianchi et al., 2017) found that large amounts of fragments, including plastic waste, accumulate in the southeastern part of the Lebanon Basin and along the southern coast of the Mediterranean Sea. A long-term occurrence of litter was also observed in the southern Algerian basin and southeast of Crete. (Liubartseva et al., 2019)

3. Collection and transportation of EPS waste from marine (coastal areas)

Coastal surveys of the Saronic Gulf reveal that EPS foams have a wide yet uneven geographical distribution. Due to the nature and special characteristics of the material, polystyrene foam litter are transported over long distances by currents and wind and eventually become trapped by rocks, low dense coastal vegetation and other marine debris creating considerable material aggregations. The high collection, handling and transportation costs make locating EPS litter hotspots a crucial prerequisite to any retrieval effort. High resolution photographic surveys of large coastal areas (Papachistopoulou et al., 2020) can reveal these hotspots and help plan and execute efficient collection operations.

Photographic assessment methods can help identify litter sources and quantify EPS litter load along the coastline. Quantification of polystyrene foam litter can be achieved by determining the Average Weight per Standard Object Identified which will help place a weight-tag on objects identified on photographs. Furthermore, it is important to understand the relationship between visible and non-visible objects (those hidden behind rocks, dense vegetation etc.). This can only be achieved by comparison between photography and detailed physical sampling on site.

Recovering EPS litter from the coasts is a laborious and costly exercise. Sizeable material blocks such a buoy and floater fillings are difficult to handle and transport due to size and weight. Cutting to pieces of manageable size on site is time consuming, requires tools and releases large quantities of EPS beads and dust to the environment. Smaller objects like fish boxes are easier to handle, still effort must be put to avoid EPS bead and dust contamination during downsizing and cleaning from excess dirt. The abundance of small EPS fragments found on the investigated coasts present a real challenge for any debris collection effort and highlight the importance of early recovery before the abrasive forces of nature reduce them to small or minute pieces.

Transportation of high volume-low weight EPS from remote or inaccessible coasts is a cost determining factor. Collected material will have to be transported by boat or pick-up track or a combination of the two to a convenient transit facility where EPS litter can be further processed, packaged, and dispatched to the final processing facility. Careful monitoring of all steps in this supply chain can contribute to the understanding of costs and areas of improvement.

4. Uses of low-quality EPS waste in constructions

Lightweight expanded polystyrene concrete has been started to use in various applications, to reduce the structural weight of the material and to produce new materials, that improve thermal and sound insulation. In most applications, the aggregates are partially replaced by EPS polystyrene foam, both the coarse and fine aggregates. As is well known, natural coarse and fine aggregates, cement and water are the main components of concrete production. The processes of aggregates used for concrete production are very harmful for the environment and involve relatively high costs (e.g., mining, processing, transportation). In addition, many countries have introduced taxes on the extraction of primary materials. Numerous studies have shown that other materials such as waste, recycled materials, and low-energy materials can be used in concrete to replace natural aggregates (Dvorkin et al., 2018). The use of these materials reduces the need for natural resources and the amount of waste sent to landfills. In addition, the weight of 2400 kg/m^3 dense concrete is very high compared to the load it can carry, making it difficult for civil engineers to build high-rise buildings (Shafigh et al., 2012; Topçu et al., 2008). On the other hand, the need to produce efficient materials that meet building codes while minimizing cost and carbon footprint has led researchers to search for alternatives, including lightweight materials for concrete production (Nikbin et al., 2018a). The use of lightweight concrete made from various lightweight aggregates (LWA) is not a new concept. Typical examples are the dome of the Pantheon, the Colosseum in Rome, and the port of Cosa in Spain.

The use of mechanical, physical, and chemical methods to incorporate new aggregates into concrete is being intensively studied to produce lightweight concrete (LWC). The most used method to produce LWC is the partial or complete replacement of natural aggregates with lightweight aggregates (LWA) in concrete or mortar. These aggregates can be natural (e.g., pumice, biopolymers) or artificial (e.g., EPS waste) and used to produce lightweight mortar (Herki et al., 2017). The most important issue in using natural LWA is the high-water requirement to produce concrete with sufficient properties (Nikbin et al., 2018b). To solve the high material consumption, the use of modified or unmodified EPS raw materials or EPS waste is one way to produce LWC. The lightweight mortar or concrete is used for both load-bearing and non-load-bearing elements, and the thermal insulation of LWC is about twice that of concrete, which is in line with the global agenda to reduce CO_2 emissions and energy consumption in buildings (Nikbin et al., 2018b; Prasittisopin et al., 2022). Because of these advantages, research on LWC has intensified in the last two decades.

Applications of LWC include its use in buildings, e.g., walls and roofs, floating structures, long-span concrete structures (bridges), and in the fabrication of guardrails on highways to prevent traffic accidents. some of the applications mentioned are shown in Figure 3 (Herki et al., 2017; Prasittisopin et al., 2022).

Figure 3. Applications of EPS concrete (Prasittisopin et al., 2022)

5. Conclusions

Recovering EPS litter from the coasts is a laborious and costly exercise. The litter must be carefully processed for the appropriate exploitation in cement-based applications. This work corresponds to the wrap-up of the information that can be found at the literature enriched with the lessons learned from the first months of practice on the topic.

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