Original Scientific Paper/Originalni naučni rad
Paper Submitted/Rad primljen: 18. 1. 2023.
Paper Accepted/Rad prihvaćen: 22. 6. 2023.
DOI: 10.5937/SJEM2302020L

UDC/UDK: 628.477.6.036
666.972:665.944

Korišćenje otpada od rušenja u procesu proizvodnje polimernih betona

Luka Latinović [1], Aleksandar Banjac[2], Nemanja Stojić[3]

[1]School of Engineering Management, University Union - Nikola Tesla, Belgrade, Serbia, luka.latinovic@fim.rs
[2] Porsche AG, Stuttgart, Germany, aleksandar.banjac@gmx.de
[3] Auto-Moto Association of Serbia, nemanja.stojic@amss.org.rs

Apstrakt: Procenat otpada koji nastaje aktivnostima rušenja je značajan. Štaviše, postoji mali deo ovog otpada koji se podvrgava procesu reciklaže. Sa izuzetkom čelika, većina materijala, kao što je drobljeni beton, obično se odlaže na divlje deponije, što je uobičajen problem u Srbiji. Istovremeno, važno je napomenuti da konvencionalni betoni, koji se u velikoj meri koriste u građevinskom sektoru, pokazuju nekoliko nedostataka. Implementacija revolucionarnih tehnologija u oblasti hemije ima potencijal da značajno transformiše pristupe trajnom odlaganju građevinskog otpada, a istovremeno proširi obim potencijalnih primena otpadnih materijala. Ovaj rad predstavlja sveobuhvatnu analizu literature kako bi ponudio novu perspektivu o izvodljivosti korišćenja otpada od rušenja u procesu proizvodnje polimernih betona, veoma obećavajućih materijala za podzemne konstrukcije, zbog njihovog hemijskog sastava i sposobnosti da obezbede efikasnu hidroizolaciju. Nalazi ove studije sugerišu da otpad od rušenja ima značajan potencijal kao održiva sirovina za proizvodnju polimer betona. Međutim, očigledno je da je dalji napredak u tehnologiji reciklaže neophodan da bi se povećala konkurentnost polimer betona dobijenih od otpada od rušenja u poređenju sa konvencionalnim betonima.

Ključne reči: izgradnja i rušenje, C&D otpad, cirkularna ekonomija, zelena hemija, upravljanje otpadom.

The Utilization of Demolition Waste in the Manufacturing Process of Polymer Concretes

Abstract: The proportion of waste generated by demolition activities is substantial. Furthermore, there is a minuscule fraction of this waste that undergoes the process of recycling. With the exception of steel, the majority of materials, such as crushed concrete, are typically disposed of in wild landfills, a common problem in Serbia. Simultaneously, it is noteworthy that conventional concretes, extensively utilized in the construction sector, exhibit several shortcomings. The implementation of breakthrough technologies in the field of chemistry has the potential to significantly transform the approaches to permanent disposal of construction waste while also broadening the scope of potential applications for waste materials. This paper presents a comprehensive literature analysis to offer a novel perspective on the feasibility of utilising demolition waste in the manufacturing process of polymer concretes, a highly promising materials for underground constructions. This is due to its chemical composition and ability to provide effective waterproofing. The findings of this study suggest that demolition waste possesses significant potential as a viable raw material for the manufacturing of polymer concrete. However, it is evident that further advancements in recycling technology are necessary to enhance the cost competitiveness of polymer concrete derived from demolition waste in comparison to conventional concrete.

Keywords: construction and demolish, C&D waste, circular economy, green chemistry, waste management.

1. Introduction

The process of economic growth has resulted in significant alterations to the environment by human society. The impact of human activities on the environment is increasingly evident and has been considerably amplified in the context of the scientific and technological revolution, as well as rapid technological advancements.

The changes resulting from the intensified development of key sectors such as energy and processing industry, chemical industry, oil refining, mining, and metallurgy pose significant environmental hazards. The process of agricultural intensification, together with the expansion of transportation infrastructure including roads, waterways, and air routes, also plays a significant role in the exacerbation of environmental pollution. Anthropogenic activities have resulted in the pollution of various environmental components, including air, water, land, and agricultural resources.

Annually, significant quantities of aerosols, exhaust gases, and soot are emitted into the atmosphere by industrial and transportation activities. Every year, an enormous quantity of wastewater, amounting to billions of tons, is released into aquatic bodies. In major industrial hubs, the concentration of aerosols and other air pollutants frequently surpasses the established thresholds, resulting in adverse effects on human health such as respiratory disorders and allergies. Pollutants originating from water and air sources undergo long-distance transportation through the circulation of water and air pathways, subsequently reaching the soil. These pollutants tend to accumulate in plants and propagate throughout the food chain. Nutrients are present inside the physiological systems of both humans and animals. Heavy metals are considered to be highly hazardous carcinogens. The contaminants primarily focus on both surface and groundwater sources, subsequently accumulating in the food chain and organisms of humans and animals.

In order to address the issue of environmental pollution, it is important to do thorough study on technogenic environmental alterations at all levels, analyze and monitor these changes, and assess their influence on diverse ecosystems and human populations. The topic of discussion pertains to the field of health. In order to enhance the efficiency of the interaction between human society and the environment, it is imperative to prioritize the preservation of nature and the sustainable utilization of raw material resources (Ugrinov, Markov & Nikolić, 2021). Additionally, it is crucial to actively transition production processes towards innovative waste-free circular production technologies, while also adopting renewable energy sources for energy conversion purposes (Pavlović, Nestić & Bošković, 2021).

The disposal techniques of building waste play a crucial role in the overall amount of waste generated (Luangcharoenrat, Intrachooto, Peansupap et al., 2019; Latinović, Marjanović & Bajrović). This aspect holds particular importance (Park, Kim, Roh et al., 2020). The investigation of permanent disposal methods for construction waste and the complete eradication of waste through waste processing holds significance in its potential use across many manufacturing processes (Białko & Hoła, 2021). Contemporary waste management technologies contribute to the attainment of the green growth objectives outlined in the Green Agenda of the European Union, as well as the green economy advancement strategies within the Circular Economy in the Republic of Serbia. The use of innovative technologies in the field of Green Chemistry has the potential to significantly transform the approaches to permanent disposal of construction waste. Additionally, these advancements can broaden the scope of potential applications for waste materials, allowing them to be utilized as valuable resources in various industrial processes.

Simultaneously, it is noteworthy that classic concretes, which are extensively employed in the construction industry, possess several limitations including delayed hardening, inadequate tensile strength, the occurrence of cracks during the drying process, insufficient ductility, relatively high capillary porosity, and limited chemical resistance (Radonjanin, Malešev, Lukić & Milovanović, 2009). The majority of the faults described can be attributed to the inherent structural composition of traditional concrete. An endeavor to address the limitations of traditional concrete while enhancing its favorable characteristics involves investigating the potential for altering or modifying the internal composition of concrete through the application of polymers (Radonjanin et al., 2009). The evolution of polymer-concrete composites necessitated the integration of conventional cement concrete technology with novel polymer technology in the field of concrete. Consequently, following extensive research conducted in numerous laboratories worldwide, a diverse array of novel polymer concrete composites has commenced practical implementation in various everyday applications. Conversely, within urban settings, the demolition of structures results in a substantial accumulation of aged concrete, hence presenting a conspicuous environmental challenge in terms of its extraction and disposal. Hence, the examination of the feasibility of substituting natural aggregate with recycled materials, such as aged concrete, ceramic fragments, grout, shattered glass, chopped wood waste, and other similar substances, has gained significant attention in recent years (Radonjanin et al., 2009).

2. Polymer concretes

Polymer concrete refers to a type of concrete in which the binding agent is derived from an organic polymer. Polymer concrete is a construction and structural substance. The substance in question can be described as a composite material consisting of a high-molecular compound combined with a mineral filler. Furanic, polyephyrhic, epoxy, phenol-formaldehyde, and kumaro-indene polyvinyl resins, as well as bitumen, are utilized as binding agents. Chargers commonly employed in many applications include quartz sand, granite, basalt shredded gravel, and construction trash. Polymeric elements incorporated into cement concrete result in a composite material known as polymer-cement or cement-polymer concrete. The polymer serves as a constituent that enhances the characteristics of concrete. Polymers are introduced into the concrete mixture through the utilization of water dispersions, such as latex and emulsions, or solutions, as discussed by Alhazmi et al. (2021). Water-soluble monomers are additionally employed, wherein they undergo polymerization subsequent to their incorporation into the concrete mixture. The polymer content in polymer-cement concrete varies between 1-3% and 15-20% of the mass of cement, depending on its intended application. The aqueous dispersions of polyvinyl acetate are commonly utilized. In contrast to traditional cement concretes, polymer concretes and polymer-cement concretes have enhanced tensile strength, reduced brittleness, and increased deformability. According to Alhazmi et al. (2021), these materials exhibit enhanced waterproofing properties, increased resistance to frost, improved durability against abrasions, and heightened resilience against the effects of corrosive liquids and gases. Polymer concretes and polymer-cement concretes are commonly employed in the construction of flooring systems within industrial facilities, garages, and hospitals. These materials are utilized in the production of high-quality coatings for roadways and airport runways, as well as in the restoration of deteriorated concrete surfaces and the remediation of fissures. Polymer-cement composites and polymer concretes containing fine aggregate are commonly employed for their waterproofing and protective properties, as well as their application as finishing products, coatings, and mastics. Thermal insulation plates can be made from polymer concretes that use lightweight fillers such as expanded clay or perlite sand. Polymer concretes are utilized in the production of unreinforced items featuring slender walls, as well as models representing various architectural structures. These rods are utilized in subterranean buildings and facilities, including as the manufacturing of mining cladding and sewage collectors, among others.

Concrete-polymer composites refer to materials that involve the substitution of a polymer and reinforcement cement-based binder for the traditional cement binder mixed with water in conventional mortar and concrete. The application of polymers in concrete technology can be categorized into three primary classifications: Polymer-Portland-Cement concrete, polymer-impregnated concrete, and polymer concrete capillary cavities. Polymer concrete exhibits favourable characteristics as a constituent blend for subterranean constructions due to its chemical composition and inherent impermeability. Although cement-bonded mortars are not capable of withstanding acidic solutions due to the effects of chlorine and sulphate, polymer-based plasters exhibit resilience and can be used as repair mortar or coating materials. Polymer concretes are characterized by their favourable water resistance and notable hydraulic capacity, which can be attributed to their inherent smoothness. The adhesive property of these materials holds utmost significance. Hence, in practical applications, polymer concretes are mostly employed for the purposes of repair and adhesion (Asdollah-Tabar, Heidari-Rarani & Aliha, 2021).

One notable aspect of polymer concrete is its ability to mitigate the occurrence of shrinkage fractures commonly observed in conventional cement concrete, owing to the absence of water during its production process. Polymer concretes exhibit the desirable characteristic of frost and chemical resistance, rendering them suitable for construction applications that necessitate robust resistance against chemical agents. One notable characteristic of polymer concrete is its relatively low weight relative to its ultimate bearing capacity. Polymer concretes, possessing superior bending strength compared to conventional concrete, are employed as an additive material in Portland cement concrete.

This application serves to mitigate surface erosion in concrete, and finds utility in various domains including structural and decorative construction panels, sewage pipes, underground tunnel equipment, drainage channels, carbon coating, steel pipes in geothermal applications, and structures such as swimming pools. A considerable body of research has been conducted to ascertain the properties of various polymer concrete materials (Tawfik & Eskander, 2006; Sosoi et al., 2018; Alhazmi et al., 2021; Asdollah-Tabar, Heidari-Rarani & Aliha, 2021). One notable benefit is the utilization of diverse aggregates in the manufacturing process of polymer concrete, including construction waste. This practice aligns with the principles of the circular economy, thereby potentially contributing to the sustainability of the construction sector (Alhazmi et al., 2021; Asdollah-Tabar, Heidari-Rarani & Aliha, 2021).

3. Construction and demolish waste in the process of polymer concrete manufacturing

According to Cheyne (2002), waste can be described as any substance resulting from human and industrial actions that lacks any remaining value. Based on several sources, it has been determined that construction and demolition operations (C&D) account for a substantial proportion, approximately 40%, of the overall share. When considering the demolition of buildings, it is noteworthy that a considerable proportion of construction debris comprises black metals, wood, paper, packing material, and fractured concrete. Therefore, by increasing the share of recycling of these materials in C&D activities, unnecessary waste would be reduced and significant effects could be achieved in terms of reducing the production of virgin materials. Hence, the use of circular economy principles and the thorough management and disposal of construction waste should be prioritized across a wide range of construction sites (Białko & Hoła, 2021). Once the structure of construction waste has been identified, along with its underlying causes, it becomes imperative to explore strategies for its mitigation. We suggest implementing a requirement for every construction company to develop a customized construction waste management strategy that aligns with their unique business practices. This will ensure that all personnel, from management to operational workers, are working collectively towards the objective of effectively managing construction trash.

Furthermore, alongside the implementation of several tactics, the role of reductions and economic considerations in construction waste management is of considerable importance. Numerous suggested approaches for recycling materials exist, the practical implementation of C&D waste recycling is still restricted to a narrow range of solid waste categories. When evaluating materials for recyclability, it is crucial to examine three primary factors (Mindess et al., 2003):

- economic implications,
- its compatibility with other materials,
- and its inherent qualities.

From a strictly economic perspective, the attractiveness of C&D waste recycling is contingent upon the competitiveness of the recovered product in relation to natural resources, namely in terms of price and quantity. In places characterized by a scarcity of raw materials and limited landfill capacity, the utilization of recycled materials is expected to exhibit more competitiveness. Conversely, in areas where an abundance of building materials is readily accessible, the elevated costs associated with recycling procedures, stemming from their inefficiencies, are likely to result in higher pricing. Hence, it is imperative to closely monitor the technological advancements in recycling construction waste, with particular emphasis on the techniques employed to incorporate these reclaimed elements into the manufacturing processes of building materials for subsequent construction cycles. The subsequent enumeration shows a compilation of materials that exhibit significant potential for the application of circularity principles through the research of recycling and reuse technologies in the manufacturing of building materials:

- asphalt,
- brick,
- concrete,
- black steel,
- glass,
- walls,
- colored metals,
- paper and cardboard,

- plastics, and
- wood.

3.1 Saw dust and polyethylene terephthalate (PET)

In the process of polymer concrete fabrication, several agricultural, municipal, and industrial types of wastes can be used as supplementary cementitious materials. However, they need to exert adequate physical and chemical properties in terms of their pozzolanic properties for potential use in sustainable concrete.
In an experimental study, Sosoi Barbuta, Serbanoiu, Babor & Burlacu, (2018) prepared a control mix of polymer concrete and two mixes of polymer concrete with aggregate substitution. They prepared the control mix of polymer concrete (CPC) with 12.4 percent of epoxy resin, 12.8 % of fly ash filler, and two sorts of natural river aggregates in concentration of 37.4% both:

1. sort I (0-4 mm), and
2. sort II (4-8 mm).

The authors used Romanian POLICOLOR S.A. product from Bucuresti, which is activated by a hardener type ROPOXID P401. The fly ash was from Electric Power Plant Holboca Iasi, used by several other authors in previous experimental studies by Barbuta, Taranu & Harja, (2009), and Barbuta, Harja & Babor (2010). The two mixes with wastes were prepared with the same dosage of epoxy resin, fly ash and sort 4-8 mm, only the sort 0-4 mm were replaced by saw dust and pulverized PET bottles. PET packaging is a material from which it is relatively "ungrateful" to extract useful production raw material by recycling (Latinović, 2018). In the first mix the aggregate sort 0-4 mm was replaced with saw dust in dosages of 25%, 50%, 75% and 100% by (Sosoi et al., 2018). In the second mix the aggregate sort 0-4 mm was replaced with chopped PET bottle in dosages of 25%, 50%, 75% and 100% by. For preparing concrete the aggregates, fly ash and waste were mixed together; the epoxy resin was combined with hardener and was introduced in the mix. The sample cubes of 70 mm size were poured, and demolded after 24 hours, according to the European standard EN 12390-3 2010 (EN, 2010). After fourteen days, the authors measured, weighed and tested samples to the compression. The density of hardened concrete mixes and compressive strengths were determined on three samples for each test, according to standard prescription (Sosoi et al., 2018). The density of hardened polymer concrete with aggregate substitution in both cases (with saw dust and pulverized PET packaging) was under 2000 kg/m^3, indicating that a lightweight concrete and varied between 1919 and 1762 kg/m^3 for the mix with saw dust and between 1948 and 1703 kg/m^3 for the mix with pulverized PET, Fig. 1 (Sosoi et al., 2018). Except the first mix, all values of density of polymer concrete with PET were smaller than that of the polymer concrete with saw dust (Figure 1).

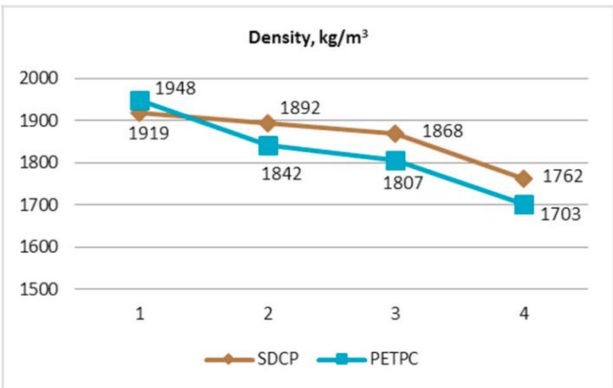

Figure. 1. Variation of density for polymer concrete (Sosoi et al., 2018).

The density of both mixes with substitution were smaller than that of the control mix, which had a density of 2117 kg/m^3. The authors also found out that the workability of fresh concrete increased with increasing PET concentrations (Sosoi et al., 2018). In the case of polymer concrete with saw dust, the workability was negatively correlated with the waste concentration (Sosoi et al., 2018). The highest value of compressive strength f c =56.6 MPa (Figure 2) was obtained for polymer concrete with saw dust substitution of aggregate (SDPC1), a value bigger than that of control mix with an increase of 18.1% (Sosoi et al., 2018).

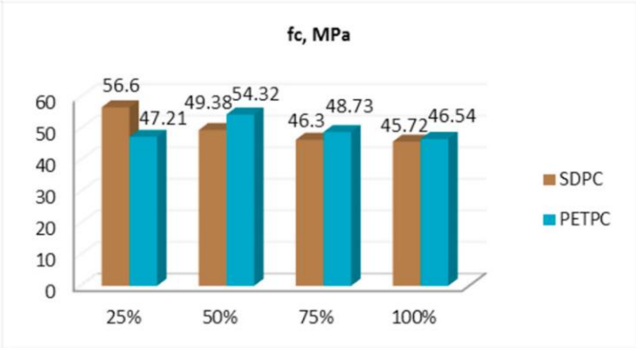

Figure. 2. Variation of compressive strength of polymer concrete (Sosoi et al., 2018).

3.2 Styrenated polyester (SP), Marble waste and PET

Tawfik & Eskander (2006) prepared polymer concrete from using marble wastes, and also, pulverized PET bottles as fillers. The polymer concrete was synthesized by mixing 12 wt% SP resin with 88 wt% filler. The high filler content, as authors noted, is important from an economic point of view, in order to improve the final properties and dimensional stability of the obtained materials (Tawfik & Eskander, 2006). The authors prepared polymer concrete and subjected cured casts to physical, mechanical, and chemical evaluations. Figure 3 shows the effect of changing basalt (mesh size 0.5–1.0 cm): marble powder (≥0.1 cm) ratio on the compressive strength with casting under pressure at 300 kg/cm^2.

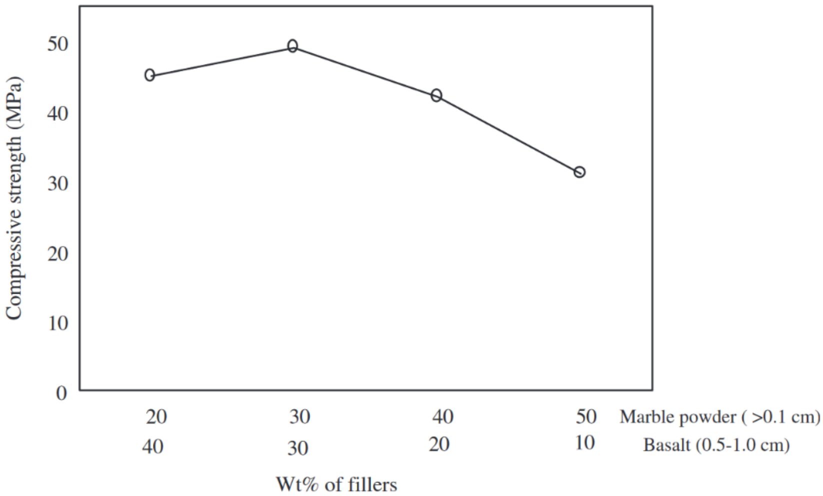

Figure 3. The effect of changing marble powder ratio on the compressive strength of polymer concrete under casting pressure 300 kg/cm^2 and constant marble ratio (Tawfik & Eskander, 2006)

The authors' findings indicated that the specimen, comprising 30 wt% basalt and 30 wt% marble powder, exhibited enhanced compressive strength under a pressure of 300 kg/cm2. The researchers also discovered that subjecting the polymer concrete to pressure during the casting process resulted in a noticeable improvement in the compressive strength of the resulting products. According to Tawfik and Eskander (2006), it is posited that the observed phenomenon can be ascribed to the influence of applied pressure on the expulsion of voids amidst the filler particles within the casted polymer concrete, resulting in enhanced compaction and rigidity of the blocks. However, authors also noted that increasing the applied pressure from 300 to 900 kg/cm^2 corresponded with slight changes in the compressive strength values of the casted polymer concrete. The mechanical properties for various polyester-filler composites depended on the type and amount of filler and also on the particle size of the filler used (Tawfik & Eskander, 2006). Finally, the authors concluded that a fast cured polymer concrete, with acceptable physical properties, good mechanical integrity, enhanced chemical characterization, and providing better heat and flame resistance, can be synthesized from the recycled PET soft drink bottles and marble waste materials. The production of the polymer concrete mentioned can be developed for semi-industrial and industrial scales for its economic advantages, as well as environmental benefits where its main raw materials are wastes.

3.3 Coarse Recycled Aggregates

Coarse Recycled Aggregates (CRA) are composed of several constituents and this is a natural consequence of the different types of waste present in construction & demolish waste (CDW). The European Standard EN 933-11 defines the following constituents of CRA (EN 933-11):

- Ru—unbound stone (in fact, natural aggregates);
- Rc—concrete and mortar;
- Rb—clay masonry, calcium-silicate masonry, aerated non-floating concrete;
- Ra—bituminous materials;
- Rg—glass;
- X—other materials (clay, soils, metals, non-floating wood, plastic, gypsum-based
- and rubber);
- FL—floating materials.

The components exhibit distinct qualities, and their appropriateness as aggregates for concrete varies. According to Silva, de Brito, and Dhir (2014), there is a positive correlation between the adequacy of a concrete recycling aggregate (CRA) and its water absorption and density. Specifically, a lower water absorption and higher density are indicative of a more suitable CRA for concrete applications. Ruthenium (Ru), which can be seen as a non-applicable (NA) element in practical contexts, is the most suitable component, followed by Rhodium (Rc) and Rubidium (Rb). It is advisable to exercise caution when considering the inclusion of other constituents, as standards and national specifications restrict the utilization of CRA based on constituent properties (Pacheco & de Brito, 2021). In general, it is ideal for CRA to possess a substantial number of constituents belonging to the categories of Ru and Rc. The primary rationale for favouring the use of crushed recycled aggregates (CRA) over fine recycled aggregates (FRA) is due to the presence of unwanted constituents in FRA, such as type X contents and disaggregated mortar, which are specific poor-quality constituents found in types Rc and Rb. According to Bravo, de Brito, Pontes, and Evangelista (2015), a comparison between CRA and FRA from the same source reveals notable disparities, indicating that CRA is a superior aggregate. As stated by Pacheco and de Brito (2021), the utilization of FRA is subject to more rigorous requirements and guidelines compared to the utilization of CRA.

To ensure that the CRA are of sufficient quality to be used in concrete, the production process includes preliminary separation and RA may be produced from two types of CDW (Pacheco & de Brito, 2021):

- Mixed CDW, which is achieved by removal of most unintended materials (e.g., wood, large plastics, soils);
- Concrete waste, since this type of waste is of good quality (mainly constituents of the type Ru and Rc, with a small content of contaminants since preliminary sorting is not perfect).
- Based on their results, Sáez del Bosque et al. (2017) argued that the production of good-quality CRA for concrete requires that the content of wood, plastic, glass and asphalt waste is as low as possible. This is achieved through preliminary sorting and removal of deleterious materials during the production of the CRA (Pacheco & de Brito, 2021). The typical composition of CRA produced with mixed CDW is as follows (Agrela et al., 2011):
- Content of Rc plus Ru of about 65% to 85%;
- Content of Rb in the region of 10% to 35%;
- Content of Rg and Ra between 0% and 2%, but in specific cases of up to 10%;
- Content of X below 2%.

Conversely, the contents of some types of CDW, namely, those that have commercial value (metals) and those that impair the properties of concrete the most (e.g., gypsum-based), are greatly reduced (Pacheco & de Brito, 2021). This is relevant because:

- Most properties of concrete are detrimentally affected by ceramics (Paine & Dhir, 2010). Ceramics are porous and weak and their presence decreases the aggregate crushing value of the CRA and results in larger number of trans-aggregate fractures in the mechanical failure mechanisms of concrete (Pacheco & de Brito, 2021).
- Clay has different detrimental effects. Fine particles of clay may cover the particles of CRA, weakening the bond between the aggregate and the cement paste. Furthermore, since these particles are smaller than those of cement, they may also adsorb to the cement particles, impairing a regular and homogeneous crystallization of the cement hydrates (Angjusheva,

Ducman, Fidancevska & Jovanov, 2021; Pacheco & de Brito, 2021). Other detrimental effects are due to their large water absorption, which may compromise workability if unaccounted for, and the possible influence on the setting and hardening of concrete. Clay may be present as agglomerated lumps of relatively large dimension (including within the coarse aggregate size range), especially when moist. These large clay particles tend to disaggregate during handling, transport and mixing (Pacheco & de Brito, 2021).

- Gypsum-based materials, including plasters, may induce sulphate reactions that influence setting and, most importantly, these materials can lead to sulphate attack of hardened concrete, resulting in expansion, cracking and spalling (Pacheco & de Brito, 2021).
- Glass and plastics bond poorly with the binder and metallic constituents are prone to corrosion. These types of constituents are typically poorly shaped for concrete (too flaky and/or elongated) (Pacheco & de Brito, 2021).

The specificities of the constituents of CRA, as Pacheco & de Brito (2021) argue, mean that, in comparison to NA (raw stone), CRA are weaker, more deformable, more porous and lighter, and have larger water absorption.

3.3.1 Processing of CDW into Recycled Aggregates

According to Silva, de Brito, and Dhir (2017), the effectiveness of a concrete recycling aggregate (CRA) is contingent upon the utilization of appropriate equipment and techniques during its production. There are several combinations of equipment and processes that are accessible for use. This section aims to provide a summary of these processes and their respective relevance. In addition to the imperative of waste removal, the manufacturing process of CRA bears substantial resemblance to that of NA. It involves the transportation of voluminous materials, followed by their crushing and subsequent screening based on size (Pacheco & de Brito, 2021). Furthermore, according to Pacheco and de Brito (2021), it is imperative for the production process to prioritize the manufacture of high-quality CRA that adhere to the necessary standards and specifications. According to the authors' proposition, it is recommended that CDW be transported to a licensed CDW facility via truck, where a first inspection and acceptance of the load should be conducted. According to their assertion, this inspection shall verify the compliance of CDW with the reported composition before to accepting the load at the CDW factory. The composition of construction and demolition waste (CDW) that is supplied is contingent upon the level of effort exerted at the construction or demolition site in terms of segregating various waste categories (Pacheco & de Brito, 2021). The cost of delivering loads of mixed construction and demolition waste (CDW) is higher compared to delivering different types of CDW, in order to encourage segregation by the contractor. In addition, it is recommended that contractors who fail to comply with the specified CDW type and/or regulatory obligations be prohibited from accessing the CDW facility. After acceptance of the load, CDW should be either:

- Immediately sent for processing into RA, whenever CDW is delivered with low contamination of unintended constituents; or
- Undergo preliminary removal of unintended constituents and sorting whenever a significant portion of such wastes is included. Figure 4 shows different types of construction and demolish waste. Only the fraction labelled as „CDW-suitable“ should be used to produce RA. This may be either mixed CDW or only concrete waste. The removal of unintended constituents is fundamental in order to ensure that the RA behave satisfactorily (Pacheco & de Brito, 2021).

*Figure 4. Separation of CDW by type(**a**) CDW requiring separation (**b**) Ongoing separation (**c**) Wood waste (**d**) Plasterboard waste (**e**) CDW—suitable (Pacheco & de Brito, 2021).*

4. Conclusion

The utilization of construction industry waste, including sawdust, crushed concrete waste resulting from demolition, broken glass, and other similar materials, has the potential to be employed as fillers in the production of polymer concrete. However, it is necessary to conduct further research in order to develop polymer concretes that are suitable for the specific use, as these ingredients alter the properties of polymer concrete. In addition, it is worth noting that recycling processes can exhibit inefficiencies, resulting in recycled aggregates being priced higher than their virgin raw material counterparts. The following points must be addressed in order to attain sustainability in the management of building waste within the framework of a circular economy. However, if this objective were to be attained, significant beneficial impacts would be exerted on both the environment and the economy. By using this approach, the objective of the circular economy can be realized, wherein trash is utilized as a valuable resource. Furthermore, this approach facilitates the creation of polymer concrete, a sophisticated material much sought after for constructing architectural structures. Simultaneously, the use of this approach would result in a decrease in spatial pressure exerted by voluminous building trash on landfills. Ultimately, the utilization of construction waste has the potential to decrease the expenses associated with the production of polymer concrete and enhance the market competitiveness of polymer concrete manufacturers.

Literature

1. Alhazmi, H., Shah, S. A. R., Anwar, M. K., Raza, A., Ullah, M. K., & Iqbal, F. (2021). Utilization of polymer concrete composites for a circular economy: A comparative review for assessment of recycling and waste utilization. *Polymers*, *13*(13). https://doi.org/10.3390/polym13132135
2. Agrela, F., Sánchez De Juan, M., Ayuso, J., Geraldes, V. L., & Jiménez, J. R. (2011). Limiting properties in the characterisation of mixed recycled aggregates for use in the manufacture of concrete. *Construction and Building Materials*, *25*(10). https://doi.org/10.1016/j.conbuildmat.2011.04.027
3. Asdollah-Tabar, M., Heidari-Rarani, M., & Aliha, M. R. M. (2021). The effect of recycled PET bottles on the fracture toughness of polymer concrete. *Composites Communications*, *25*. https://doi.org/10.1016/j.coco.2021.100684
4. Angjusheva, B., Ducman, V., Fidancevska, M., & Jovanov, V. (2021). Optimizing Process Parameters of Clay-Based Ceramics with Addition of Construction and Demolition Waste. *Advanced Technologies*, *10*(2), 61-65. https://doi.org/10.5937/savteh2102061A
5. Barbuta, M., Harja, M., & Babor, D. (2010). Polymer concrete with fly ash. Morphologic analysis based on scanning electron microscopic observation. *Revista Romana de Materiale*, *40*(1), 337-345.
6. Barbuta, M., Taranu, N., & Harja, M. (2009). Wastes used in obtaining polymer composite. *Environmental Engineering and Management Journal*, *8*(5), 1145-1150.
7. Białko, M., & Hoła, B. (2021). Identification of methods of reducing construction waste in construction enterprises based on surveys. *Sustainability (Switzerland)*, *13*(17). https://doi.org/10.3390/su13179888
8. Bravo, M., de Brito, J., Pontes, J., & Evangelista, L. (2015). Mechanical performance of concrete made with aggregates from construction and demolition waste recycling plants. *Journal of Cleaner Production*, *99*. https://doi.org/10.1016/j.jclepro.2015.03.012
9. Chandel, S. K., Goyal, R., & Singla, S. (2019). Utilization of construction waste as partial replacement of aggregates in cement concrete. *International Journal of Innovative Technology and Exploring Engineering*, *8*(9 Special Issue). https://doi.org/10.35940/ijitee.I1165.0789S19
10. Cheyne, I. (2002). The definition of waste in EC law. *Journal of Environmental Law*, *14*(1). https://doi.org/10.1093/jel/14.1.61
11. EN 12390-3:2010, Testing hardened concrete. Part 3: Compressive strength of test specimens
12. EN-933-11. Tests for Geometrical Properties of Aggregates. Classification Test. for the Constituents of Coarse Recycled Aggregate; CEN: Brussels, Belgium, 2009.
13. Latinović, L. (2018). A New Recycling Paradigm - an Innovative Approach to the Plastic Waste Recycling in Serbia. *Serbian Journal of Engineering Management*, *3*(2), 1-12. https://doi.org/10.5937/SJEM1802001L
14. Latinović, L., Marjanović, M., & Bajrović, H. (2023). Informal Recycling Sector in Serbia through a Health Perspective. *Serbian Journal of Engineering Management*, *8*(1), 14-22. https://doi.org/10.5937/SJEM2301014L

15. Luangcharoenrat, C., Intrachooto, S., Peansupap, V., & Sutthinarakorn, W. (2019). Factors influencing construction waste generation in building construction: Thailand's perspective. *Sustainability (Switzerland)*, *11*(13). https://doi.org/10.3390/su11133638
16. Osmani, M. (2011). *Construction Waste. Waste, 207–218.* doi:10.1016/b978-0-12-381475-3.1
17. Pacheco, J., & de Brito, J. (2021). Recycled aggregates produced from construction and demolition waste for structural concrete: Constituents, properties and production. *Materials*, *14*(19). https://doi.org/10.3390/ma14195748
18. Paine, K. A., & Dhir, R. K. (2010). Recycled aggregates in concrete: A performance-related approach. *Magazine of Concrete Research*, *62*(7). https://doi.org/10.1680/macr.2010.62.7.519
19. Park, W. J., Kim, R., Roh, S., & Ban, H. (2020). Identifying the major construction wastes in the building construction phase based on life cycle assessments. *Sustainability (Switzerland)*, *12*(19). https://doi.org/10.3390/su12198096
20. Pavlović, A., Nestić, S., & Bošković, G. (2021). Circular economy management in business organizations using digital technologies. *Serbian Journal of Engineering Management*, *6*(1), 22-29. https://doi.org/10.5937/SJEM2101022P
21. Radonjanin, V., Malešev, M., Lukić, I., & Milovanović, V. (2009). Polimer-betonski kompoziti na bazi recikliranog agregata. *Materijali i konstrukcije*, *52*(1), 91-107.
22. Sáez del Bosque, I. F., Zhu, W., Howind, T., Matías, A., Sánchez de Rojas, M. I., & Medina, C. (2017). Properties of interfacial transition zones (ITZs) in concrete containing recycled mixed aggregate. *Cement and Concrete Composites*, *81*. https://doi.org/10.1016/j.cemconcomp.2017.04.011
23. Saribiyik, M., Piskin, A., & Saribiyik, A. (2013). *The effects of waste glass powder usage on polymer concrete properties. Construction and Building Materials, 47, 840–844.* doi:10.1016/j.conbuildmat.2013
24. Silva, R. v., de Brito, J., & Dhir, R. K. (2014). Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. *Construction and Building Materials*, *65*. https://doi.org/10.1016/j.conbuildmat.2014.04.117
25. Silva, R. v., de Brito, J., & Dhir, R. K. (2017). Availability and processing of recycled aggregates within the construction and demolition supply chain: A review. In *Journal of Cleaner Production* (Vol. 143). https://doi.org/10.1016/j.jclepro.2016.12.070
26. Sosoi, G., Barbuta, M., Serbanoiu, A. A., Babor, D., & Burlacu, A. (2018). *Wastes as aggregate substitution in polymer concrete. Procedia Manufacturing, 22, 347–351.* doi:10.1016/j.promfg.2018.03.052
27. Tam, V. W. Y., & Tam, C. M. (2006). *A review on the viable technology for construction waste recycling. Resources, Conservation and Recycling, 47(3), 209–221.* doi:10.1016/j.resconrec.2005.1
28. Tawfik, M. E., & Eskander, S. B. (2006). Polymer Concrete from Marble Wastes and Recycled Polyethylene terephthalate. *Journal of Elastomers & Plastics*, *38*(1), 65–79. doi:10.1177/0095244306055569
29. Ugrinov, D., Markov, M., & Nikolić, M. (2021). Small-town Sustainable Development Opportunities. *Serbian Journal of Engineering Management*, *6*(2), 32-42. https://doi.org/10.5937/SJEM2102032U