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Potential Use of Post-Earthquake Concrete Construction Waste to Reduce Environmental Impact and Enhance Economic Value

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ABSTRACT: The increasing intensity and magnitude of earthquakes has given a rise to numerous problems. Beyond the loss of life and economic damage, environmental degradation occurs due to the vast amount of debris resulting from structural and infrastructure damage. With proper processing, concrete waste holds significant potential for reuse as recycled aggregate in new construction. This approach mitigates environmental impact by reducing the consumption of natural aggregates. Transforming concrete rubble into recycled aggregate involves several stages: demolition, cleaning, transportation, crushing, screening, and storage. The equipment employed ranges from simple tools—such as chisels and sledgehammers—to breakers, excavators, and industrial crushers. Research indicates that recycled concrete aggregate possesses different compared to natural aggregate, including specific properties regarding saturated-surface-dry density, water absorption, and crushing and impact values. Utilizing concrete waste to manufacture concrete bricks and paving blocks yields compressive strengths in the range of 10–20 M.Pa. When used as a partial replacement for coarse aggregate in concrete mixtures, it produces compressive strengths varying between 20 and 30 M.Pa; however, the incorporation of admixtures such as nano silica and meta kaolin can boost compressive strength to 40–60 M Pa. Repurposing concrete waste as recycled aggregate offers dual benefits: it reduces environmental impact while simultaneously enhancing the economic value of the waste material.

KEYWORDS: Earthquake, Concrete Waste, Recycling, Compressive Strength, Environmental Impact

1 INTRODUCTION

Over the past two decades, there has been an increase in the occurrence of major earthquakes causing massive damage in Indonesia (Aceh 2004; Nias 2005; Yogyakarta-Central Java 2006; Pangandaran 2006; Bengkulu 2007; Padang 2009; Lombok 2018; Palu 2018; Cianjur 2021; Mamuju 2021; and Flores 2026) https://www.usgs.gov/programs/earthquake-hazards/lists-maps-and-statistics. Such events have also occurred in other countries (Japan 2011 and 2026; Turkey and Syria 2023; Myanmar and Thailand 2025; Venezuela 2026; Italy 2026; and Colombia 2026), resulting in fatalities, economic losses, and environmental issues. https://www.kaggle.com/datasets/dhrubangtalukdar/200-years-of-global-major-earthquakes-18262026.

After the earthquakes, various material turned into rubble debris from infrastructure and structures—such as roads, bridges, and buildings for offices, education, healthcare, commerce, industry, and housing, as well as clean water, electrical, and telecommunications facilities—must be managed immediately[1]. Materials commonly encountered during the clearing process include wood, plastic, paper, concrete, bricks or concrete blocks, ceramics, asphalt, asbestos, glass, and excavated soil and rock; however, concrete is the predominant material found. The process of demolishing, transporting, and clearing this debris incurs costs amounting to approximately 3–5% of the structure's total construction cost.

Figure 1. Damages of Structural Building after the 2018 Palu Earthquake and Its Debris (Sources: Author's Documentation)

Concrete mixtures generally consist of approximately 15–20% cement, 60–80% aggregates, and 10–15% water, although these proportions can be adjusted to meet specific strength and flexibility requirements. While most concrete constituents are manufactured products or mined materials, cement accounts for the highest embodied energy within concrete; indeed, the cement industry is the most energy-intensive of all manufacturing sectors. As a crucial component of concrete, cement is not environmentally friendly; the cement industry is a leading contributor to the greenhouse effect and global warming.

Energy consumption associated with the production and construction processes for concrete is also higher than that for steel and timber building materials [2]. Utilizing waste concrete as a construction material serves both economic and environmental purposes—specifically, the mitigation of environmental damage. In terms of production and construction, concrete and steel structures consume approximately 16–17% more energy than timber structures. Similarly, the global warming potential of steel and concrete structures is about 25–30% higher than that of wood structures

Beyond its use in building construction, the utilization of concrete waste for road pavement materials has also been the subject of several studies [3]. Research has been conducted on utilizing concrete waste—specifically by adding metakaolin as a partial cement replacement—to achieve good compressive strength characteristics, yielding results with future development potential [4]. The use of concrete waste as coarse aggregate has also been investigated in various parts of the world [5], [6], [7], and [8]. Previous research indicates that recycled aggregates derived from concrete waste—both fine and coarse—possess physical properties suitable for use as construction materials. When used to manufacture paving blocks, recycled fine aggregates exhibit a higher bulk density than natural aggregates.

Furthermore, properties such as water absorption, silt content, moisture content, and abrasion resistance (tested via the Los Angeles machine) meet technical specifications for reuse in concrete and road pavement applications [8]. Test results regarding compressive strength, splitting tensile strength, and bending strength from prior studies also demonstrate characteristics that justify the use of concrete waste as a substitute for coarse aggregate.

Compressive strength tests—a primary property of concrete—yielded values ranging from 15 to 35 MPa, depending on the target mix design. Generally, concrete made with recycled aggregates exhibits a 20–25% reduction in compressive strength compared to concrete made with natural aggregates; however, some studies have reported contrasting results. Incorporating metakaolin as a partial cement replacement, along with other admixtures, holds significant potential for enhancing compressive strength.

The use of recycled concrete waste in building construction and road paving warrants further research and evaluation at both small and large scales. Implementing this practice on a massive, sustainable scale could significantly mitigate the growing environmental impact associated with global warming and climate change.

2 RESEARCH METHODS

This study employs a quantitative approach that is subsequently interpreted qualitatively in the discussion and conclusions. The data used are secondary, sourced from previous studies, national and international earthquake research centers, articles and journals, websites, and other sources valid and relevant to the research topic. Data processing and analysis were then conducted to generate new data supporting this research.

2.1 Demand of Recycled Aggregate

The utilization of concrete construction waste as aggregate is practiced worldwide. Asia, being the most populous continent, accounts for approximately 53.2% of the global total of such construction waste. China is the leading Asian nation in utilizing this waste, followed by India. Large structural elements—such as those from buildings, bridges, and other structures—are demolished and reduced to smaller sizes. A variety of tools and equipment are employed for this purpose, including chisels, hammers, breakers, excavators, and concrete crushers. The cost allocated for this entire process can range from 2% to 5% of the total contract value for a building's reconstruction. The process of converting post-earthquake concrete debris into aggregate—which is subsequently reused in concrete mixtures and road pavements—involves the following stages: sorting, dismantling, crushing, and screening [9].

Characteristic of Timber, Concrete and Steel as Materials Construction showed in Table 1.

Table 1. Characteristic Materials Construction

Material	Advantages	Undvantages
Timber	Renewable resources Insulation properties Aesthetic Lightweight	Susceptible to fire Required maintenance Limited loading
Concrete	High compressive Fire resistabt Durable Versatility	Low tensile strength Shrinkage & cracking High carbon footprint of cement
Steel	High strength Ductile Fire resistant Long life-span	Susceptible to corrosion Required fireproofing High initial cost

Source:https://www.strucompare.com/apps/compare/comparison.html

How wood structures compare to steel and concrete for carbon footprint. A life cycle analysis of the three major materials used as structural support for buildings - wood v concrete v steel - embodied carbon

Wood, steel and concrete each have specific structural advantages, each with their own characteristics. The following is a life-cycle comparison conducted by the Athena Sustainable Materials Institute (ASMI) of the materials only, and does not include any considerations of how they each affect thermal performance, vapour or air movement through wall assemblies.

a. **Concrete** makes it possible to design very robust and durable buildings, and taking advantage of its thermal mass by keeping it inside the building envelope can help regulate interior temperatures. There is also an increasing use of precast concrete in the building industry, which offers advantages in terms of environmental impact, cost and speed of construction - especially if choosing carbon negative concrete CMU blocks using Carbicrete and also low-carbon concrete from CarbonCure.
b. **Steel** stands out for its speed and efficiency in construction. It's relative light weight and ease of construction allows for a workforce about 10 to 20% smaller compared to a similar concrete-based structure being built. Steel structures also have excellent durability.
c. **Wood** is much lighter by volume than both concrete and steel, it is easy to work with and very adaptable on site. It is durable, results in less thermal bridging than its counterparts and easily incorporates prefabricated elements. Its structural performance is very high and its compressive strength is similar to that of concrete.

Table 2. The Impact of Concrete and Steel Compared to Wood

Environmental Impact Compared to Wood	Embodied Energy	Climate Impact	Negative Impact on Air Quality	Negative Impact on Water	Resources Impact by Weight	Waste Produced
Metal	+53%	+23%	+74%	+247%	+14%	-21%
Concrete	+120%	+50%	+115%	+114%	93%	+37%

Source:https://www.strucompare.com/apps/compare/comparison.html

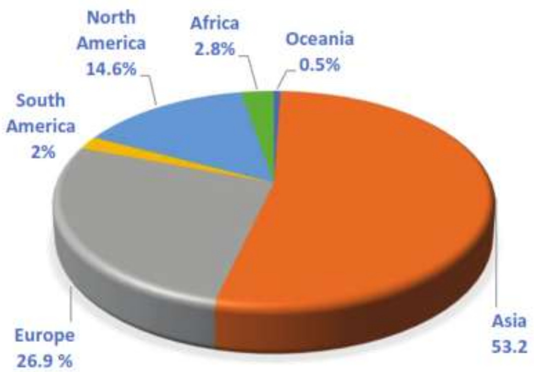

Figure 1. Annual Production of Construction and Demolish Wastes[10]

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2.2. Recycled Aggregate Production Process

The process of converting concrete rubble into recycled aggregate can be carried out using fully manual, semi-mechanical, or fully mechanical methods. Figure 2 illustrates several types of equipment used to process concrete rubble into aggregate.

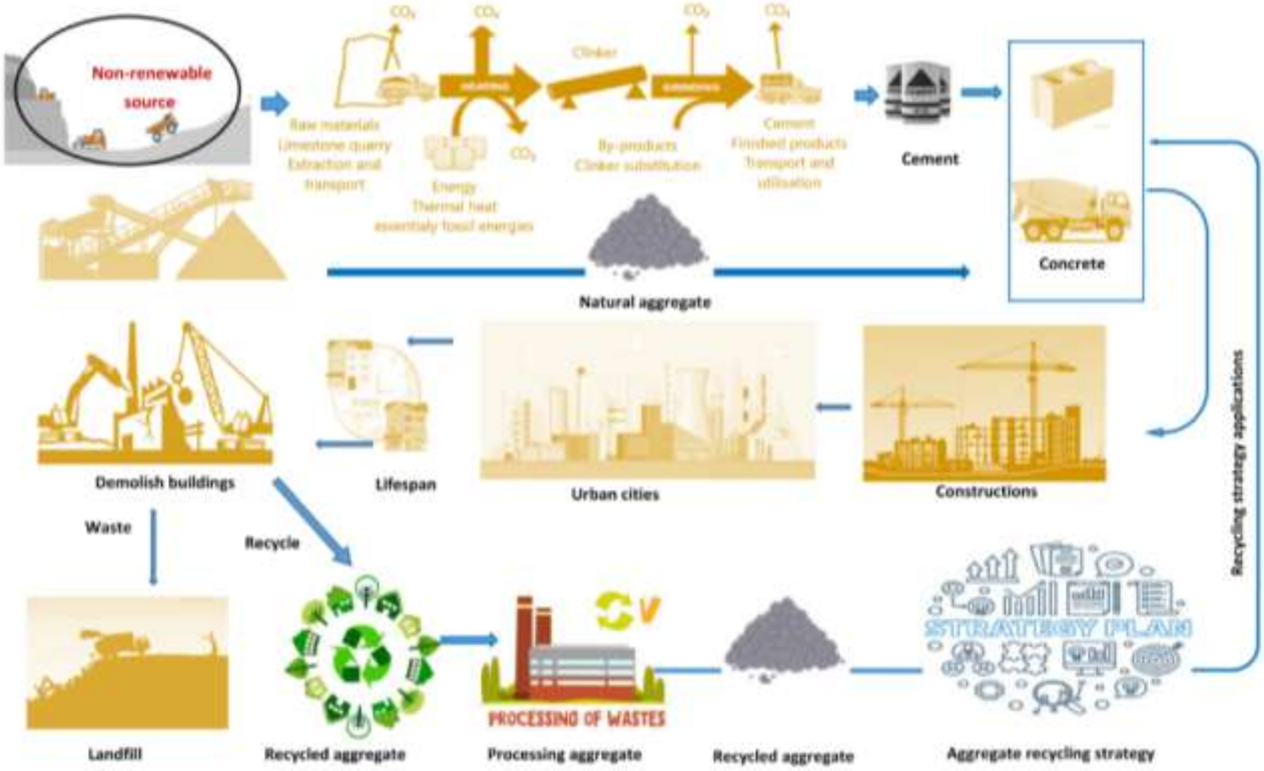

Figure 2. Principles of Designing A Strategy for Recycled Aggregate Concrete [11]

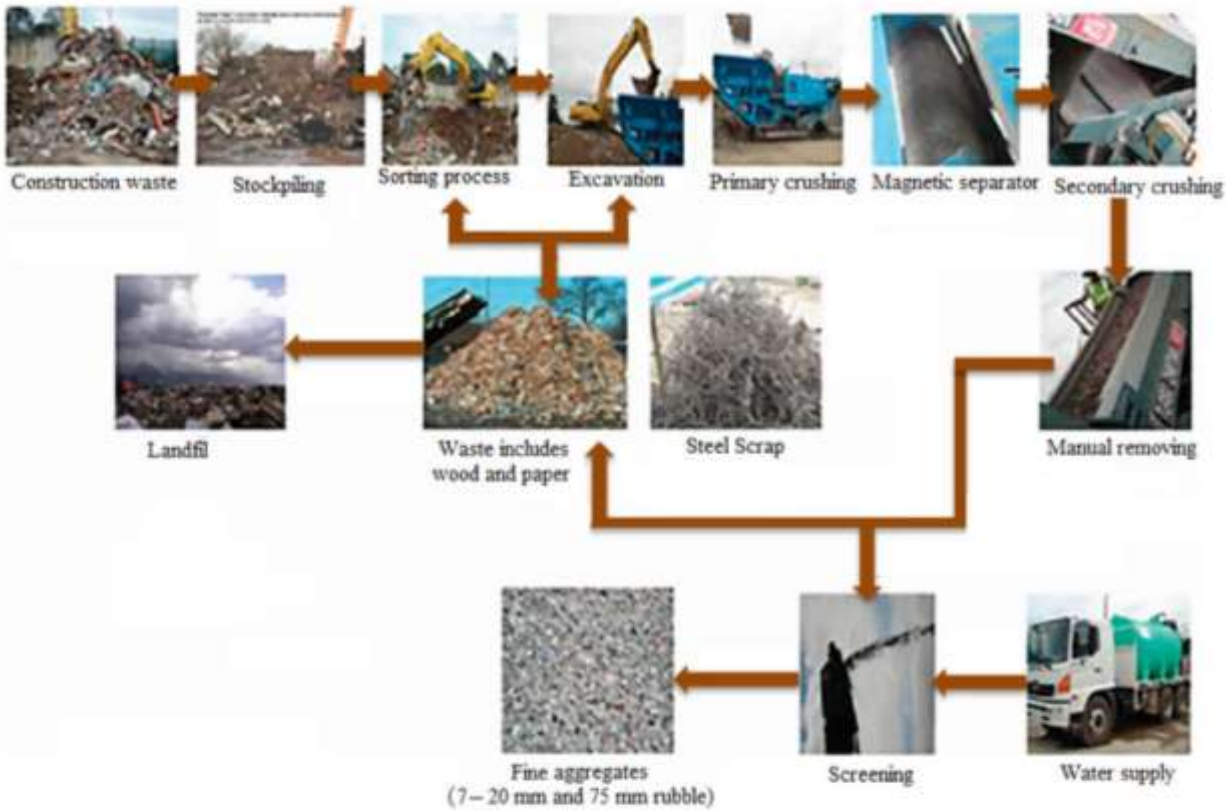

Figure 3. Current Recycling Process of Recycled Concrete Aggregates [11].

2.3. Recycled Concrete Mix Design

Recycled concrete aggregates exhibit higher bulk density, crushing and impact values, and water absorption rates compared to natural aggregates. As with concrete made from natural aggregates, producing concrete with recycled aggregates requires a mix design process to achieve the desired concrete quality. Several studies have investigated the partial replacement of natural aggregates with recycled aggregates, with replacement percentages ranging from 10% to 100% and target compressive strengths between 20 MPa and 35 MPa. The most comprehensive study was conducted by Sethia et al. (2022), utilizing replacement levels ranging from 10% to 100% in 20% increments. In addition to compressive strength, tests for splitting tensile strength and bending strength were also performed.

Tabel 3. Review on Recycled Aggregate Concrete

Literature	Percentage Substitution of Recycled Aggregates.	Compression Strength (MPa)	Treatment and Various of Testing
Naik & Ramakrisnaiah	20; 40; **60**; 80; 100	30	Compression, splitting and bending test
Sethia et al. 2022	**20**; 40; 60; 80; 100	32	With Metakaoline Admixture 1% and 3%
Nikhil et al.	10; 20; 30		Used to Bitumenous Pavement
Agarwal et al. 2020	20; 40; 60	60	With Nano Silika Admixture 1%, 3%, 5%
Wagih et al. 2013	**25**; 50; 75; 100	33	With Admixture
Pourghashti et al. 2018	Variasi 0.5 dan 0.6 water cement ratio	20	Bond Test
Algarni et al. 2021	33; 67; 100	28	With 3 variations treatment

3. RESULTS AND DISCUSSION

Based on data from previous studies, the potential for utilizing concrete waste as recycled construction material is presented here. Several key points derived and discussed are as follows: Concrete and mortar waste from buildings damaged or collapsed following earthquakes can be reused as fine and coarse aggregates through manual, semi-mechanical, or fully mechanical processing. Tests were conducted to determine the characteristics of aggregates derived from concrete waste, including bulk density, specific gravity, abrasion resistance, moisture content, silt content, and water absorption. Results indicated higher values—particularly for bulk density and water absorption—as well as higher crushing and impact values compared to natural aggregates.

Concrete waste can be utilized as fine aggregate in the production of paving blocks and concrete blocks. It is also used as coarse aggregate, specifically in concrete mixtures, and as road pavement layers (sub-base and base courses). Compressive strength tests on concrete utilizing recycled concrete coarse aggregates yielded widely varying results. When used to manufacture concrete blocks, the material achieved a compressive strength of approximately 10 MPa; when used for paving blocks, it achieved approximately 20 MPa. Concrete utilizing recycled concrete waste aggregates demonstrated compressive strengths ranging from 20 to 30 MPa—categorized as medium-strength concrete—with a replacement proportion of 20–40% for the coarse aggregate. To achieve higher compressive strengths, the use of admixtures such as nanosilica and metakaolin as partial replacements for a small fraction of cement (1–5%) can yield concrete compressive strengths in the range of 40–60 MPa.

Every year demand for recycled aggregates is increasing annually due to the growing scarcity of natural aggregates in various parts of the world. Beyond the issue of scarcity, there is a need to mitigate the environmental impact associated with natural aggregate mining and cement production—the latter being a major industrial contributor to global warming and extreme weather events. The recent increase in the frequency and magnitude of earthquakes across the globe has caused massive damage to concrete structures, resulting in vast amounts of concrete debris. A crucial requirement is the availability of modern concrete waste processing machinery with adequate capacity.

Beyond recovering aggregates, processing debris from buildings, bridges, and other concrete structures also yields reinforcing steel, which holds economic value.

3 CONCLUSIONS

a. There is immense potential for processing concrete waste into aggregate; the demand for recycled aggregate in 2030 is projected to reach approximately 16 million tons.
b. Tests on the characteristics of recycled concrete aggregate reveal higher bulk density, water absorption, and crushing and impact values compared to natural aggregate.
c. Concrete blocks and paving blocks made using concrete waste achieve compressive strengths that meet the standards required for construction materials.
d. Previous research indicates that concrete utilizing recycled aggregate can achieve compressive strengths of approximately 20–30 MPa; this range falls within the medium-strength category, which is most commonly used for low-rise building construction.
e. The use of admixtures such as nanosilica and metakaolin to replace a small portion of cement (1–5%) enables the concrete to achieve compressive strengths of approximately 20–60 MPa, even when recycled concrete aggregate is used.
f. Utilizing concrete waste helps reduce environmental impact while simultaneously enhancing the economic value of the waste material.

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