Enhancing Concrete Recycling in Iran: A Comprehensive Review of Strategies

Hesam Eshraghi
Khaje Nasir Toosi University of Technology

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Hesam Eshraghi[1], Yaghoub Alipouri[2]
1- Faculty of Civil Engineering, K. N. Toosi University of Technology, Tehran, Iran, hesam.eshraghi@email.kntu.ac.ir
2- Assistant Professor, Faculty of Civil Engineering, K. N. Toosi University of Technology, Tehran, Iran, y.alipouri@kntu.ac.ir

ABSTRACT

Concrete, the most-used construction material by weight, presents a significant environmental challenge due to its high production environmental footprint and huge quantities of demolition waste. Iran, with a thriving construction sector, faces escalating waste management issues. This paper provides a comprehensive review of strategies to increase concrete recycling in Iran. It explores the current state of concrete recycling practices, the environmental and economic benefits, and the existing barriers hindering wider adoption. The paper then analyzes various strategies across the concrete life cycle, including: demolition practices, collection and transportation systems, processing technologies, and market development for recycled concrete aggregates (RCAs). Several case studies are examined in order to identify best practices and strategies used by countries with successful concrete recycling programs that provide valuable insights about the factors contributing to their success which will be useful for implementation in Iran. Furthermore, the review concludes with recommendations tailored to the Iranian context, emphasizing the crucial role of collaboration between different stakeholders in Iran.

KEYWORDS: Concrete recycling, Construction waste, Recycled concrete aggregates, Concrete environmental footprint, Iran concrete recycling industry

1 INTRODUCTION

Concrete as the most prevalent construction material globally, plays a vital role in infrastructure development and urbanization. However, its production is highly energy-intensive and relies heavily on natural resources such as sand and gravel. Consequently, demolition of concrete structures generates massive quantities of waste that poses a significant environmental challenge. Landfilling concrete waste not only depletes valuable landfill space but also raises environmental concerns due to the potential leaching of pollutants. (Sivamani and Kamaleshwar, 2022)

Iran, with its rapidly expanding construction sector, faces a growing problem of construction and demolition (C&D) waste. As estimated by industry experts, Iran generates nearly 120 million tons of C&D waste annually, with concrete constituting a major portion, while landfilling remains the dominant method for C&D waste disposal in Iran. (Web-1)

Concrete recycling offers a promising solution to mitigate these environmental concerns. Recycled concrete aggregates (RCAs) obtained from demolition waste can partially replace raw aggregates in new concrete production. This approach reduces the environmental footprint of concrete by lowering energy consumption, raw material extraction, and waste generation, while providing a cost-effective source of aggregates in a circular economy context.

Concrete recycling in Iran is at an emergent stage as a limited infrastructure for processing and utilizing RCAs exists. Construction practices in Iran need improvement in terms of proper demolition techniques and efficient ways of waste segregation and recovery of concrete debris. (Broujeni et al, 2016)

Increasing awareness among stakeholders regarding the benefits and performance of RCAs is needed to increase the market acceptance as there are positive developments since several companies have started offering concrete recycling services in Iran, primarily focusing on crushing and size reduction.

2 BENEFITS OF CONCRETE RECYCLING

Concrete recycling offers a compelling solution to the environmental and economic challenges associated with conventional concrete production, the significant advantages of incorporating RCAs into the construction industry includes:

2.1 Environmental Benefits

Widespread adoption of concrete recycling leads to a significant decrease in demand of virgin aggregates (sand and gravel) which are essential natural resources often extracted through unsustainable practices that disrupt ecosystems (e.g. riverbed sand mining) and cause environmental damage through deforestation and soil erosion. Utilizing RCAs as a partial replacement for virgin aggregates conserves these resources and mitigates the environmental impact of their extraction. Studies demonstrate that incorporating RCAs in concrete mixtures can reduce virgin aggregate demand by 40% with minimal effects on concrete performance. (Jayasuriya et al., 2021) On a national scale, widespread concrete recycling can lead to the preservation of millions of tons of natural resources annually.

Virgin aggregate production is an energy-intensive process, requiring significant fossil fuels for extraction and transportation, leading to greenhouse gas emissions and contributing to climate change. Concrete recycling, in contrast, requires considerably less amount of energy. The process primarily involves crushing and sorting existing concrete debris, significantly reducing the need for energy-intensive extraction and processing of virgin materials. Sabau, et al (2021) concluded that concrete recycling can reduce the CO_2 emissions compared to using virgin aggregates entirely. At a larger scale, widespread concrete recycling can contribute to national efforts to reduce greenhouse gas emissions in the construction sector.

Landfilling concrete waste not only depletes valuable landfill spaces but also raises environmental concerns. Improperly managed concrete landfill can leach pollutants like heavy metals into surrounding soil and groundwater. These heavy metals disrupt plant growth, contaminate water sources, and pose health risks through bioaccumulation. Concrete recycling offers a compelling solution to these issues. By diverting concrete waste from landfills and processing it into recycled concrete aggregates (RCAs), the risk of heavy metal leaching is minimized and the overall burden on landfills is reduced. (Wu et al, 2022)

2.2 Economic benefits

The widespread adoption of concrete recycling offers a range of economic benefits for the construction industry. While due to high availability and accessibility to virgin aggregate in most regions of Iran the cost of virgin aggregate is generally cheaper than recycled concrete aggregates, RCAs can provide a more economical alternative to virgin aggregates by diverting concrete debris from landfills through recycling which eliminates landfill tipping fees and profit gains from resale value of the RCAs. This process also introduces a new market in Iran with vast employment opportunities and a global market value of 40 billion U.S. dollars. (Web-2)

3 CHARACTERISTICS COMPARISON

The use of RCAs in concrete mixtures can affect various fresh and hardened concrete properties. Virgin aggregates generally exhibit higher density and lower porosity compared to RCAs as they consist of the adhered mortar from the demolished concrete which has a more porous structure due to the presence of hydration products e.g. calcium silicate hydrate (CSH) gel.

The lower density and higher porosity of RCAs can influence various concrete properties. This results in a decrease in workability for RCA concrete compared to VA concrete with the same w/c ratio. To maintain desired workability for proper placement and compaction, RCA concrete may require additional mixing water or the use of superplasticizers. Optimizing the mix design through proper w/c ratio control is recommended to achieve a balance between workability and strength as the excessive water addition can negatively impact long-term strength and durability. (Pereira et al., 2012)

The rounded shape of RCAs, compared to the more angular shape of VAs, can increase the risk of segregation in concrete mixtures, especially for those with high RCA content. Mitigating segregation in RCA concrete requires careful mix design considerations. Using well-graded RCAs and employing proper casting techniques like controlled pouring and adequate vibration are essential to ensure a homogenous concrete mix can and reduce the risk of segregation. (Smith et al., 2018)

Concrete containing RCAs can exhibit slightly lower compressive and tensile strength compared to concrete with only VAs. The extent of this reduction depends on the quality of the original concrete used to produce RCAs, the amount of adhered mortar, and the overall RCA replacement level in the mixture. Hansen and Narud (1983) found that concrete made from RCA obtained approximately same compressive strengths and maximum 10% reduction in tensile strength as the original concrete they were made from. In another study Jayasuriya et al. (2021) showed that concrete containing up to 40% RCA replacement will result in only 3.2% reduction in compressive strength. However, for higher-strength structural applications, lower RCA replacement levels or the use of high-performance VAs may be necessary.

The durability of concrete with RCAs is a crucial aspect for long-term performance. The higher porosity of RCAs can potentially increase the risk of freeze-thaw damage in climates with frequent freezing and thawing cycles. However, Huda and Alam (2015) found that concrete made with different RCA replacement levels successfully passed the freeze-thaw durability test. The durability performance of RAC was satisfactory and for all the considered mixes it was more than 95% whereas the passing scale was only 60% of the initial value. Proper air entrainment techniques during mix design can also mitigate this issue by creating air voids within the concrete mixture that accommodate the expansion of water during freezing cycles to reduce internal stresses and prevent cracking. (Kolay et al, 2018)

The increased porosity of RCAs can also lead to higher permeability compared to concrete with only VAs. Hansen (1986) found that concrete made from RCAs and w/c of 0.5 to 0.7 has 2 to 5 times permeability of concrete made with VAs. This can affect the resistance to chloride ion penetration, which is a concern for reinforced concrete structures exposed to salts or marine environments. However, Rasheeduzzafar and Khan (1984) found that high water absorption for recycled concrete could be offset by lowering the w/c of the recycled concrete by 0.05 to 0.10.

The presence of reactive silica aggregates in the original concrete used to produce RCAs can also pose a risk of Alkali-Silica Reaction (ASR) in new concrete mixtures containing these RCAs. ASR is a deleterious reaction between the alkali hydroxides in the cement paste and the reactive silica in certain aggregates, leading to internal expansion and cracking. Careful selection of RCA source materials with minimal risk of ASR susceptibility is crucial to mitigate this potential issue.

Another important factor in corrosion studies is Half-cell potentials which is important due to the electrochemical reaction that leads to rust. Higher potential leads to higher the risk of corrosion. The Building Contractors Society of Japan (1978) concluded that the rate of carbonation of a recycled aggregate concrete made with concrete that had already suffered carbonation was 65% higher than the control concrete made with conventional aggregates, also reinforcement in recycled concrete may corrode faster than in conventional concrete. This accelerated corrosion, however, could be offset by reducing the w/c ratio of the recycled concrete. Hansen (1986) also concluded that a reduction in w/c reduces corrosion potential of recycled concrete.

Building Contractors Society of Japan (1978) investigated the change in modulus of elasticity of concrete made using recycled concrete aggregates. They concluded that the reductions in modulus of elasticity made with recycled coarse and fine aggregates varied from 25 to 40%. However, Silva et al. (2016) found that recycled aggregate concrete will generally have modulus of elasticity compliant with existing standards and specifications for virgin aggregate concrete.

Table 1 Summary of characteristics comparison

Property	Virgin Aggregates (VA)	Recycled Concrete Aggregates (RCA)
Workability	Higher for same w/c ratio	Lower due to higher water absorption
Segregation Risk	Lower due to angular shape	Higher due to rounded shape
Compressive Strength	Slightly higher	Depends on RCA quality and content
Freeze-Thaw Resistance	Normal	May require higher air content for similar performance
Permeability	Lower	Higher
Corrosion potential	Lower	Higher
Modulus of elasticity	Normal	Slightly lower

4 STRATEGIES FOR INCREASING CONCRETE RECYCLING IN IRAN

There are several different approaches for increasing concrete recycling which are practiced worldwide and can be utilized in Iran for addressing specific challenges within the country context.

4.1 Developing National Standards and Guidelines

Establishing clear and well-defined national standards and guidelines for the production, quality control, and use of RCAs is necessary. These guidelines should be based on international best practices (e.g., ACI CRC 18.517, AASHTO M 319-02, IRC 121-2017, ACI 555R-01) while considering the specific characteristics of Iranian concrete and construction practices. Standardization will provide confidence to engineers, contractors, and regulatory bodies regarding the performance and code-compliance of RCA.

4.2 Government Incentives and Financial Support

Government intervention is crucial to promote widespread concrete recycling. Targeted tax breaks and subsidies for utilizing recycled aggregates can offset the initial cost disadvantage. Grants can stimulate investment in recycling facilities, while regulations mandating minimum RCA content in public construction projects creates a guaranteed market. Implementing financial incentives such as preferential bidding opportunities for projects utilizing RCAs can encourage their adoption. Government funding for establishing local supply chains for concrete recycling can further increase the adaption.

Enacting landfill bans on specific concrete waste streams and introducing tipping fees for concrete debris disposal can incentivize recycling practices. California has established the 75% recycling goal through legislation with defined strategies and focus areas (Cal Recycle, 2016)

Vermont has gone further to define C&D waste including concrete waste as recyclable materials and mandate the recycling of certain C&D waste streams in the state law. (Vermont Department of Environmental Conservation, 2016)

Having a national association dedicated to promoting concrete recycling is also crucial. Some cities in Iran have already these associations (e.g. Employers' association of C&D waste recycling companies of Tehran province). A national association can facilitate communication between researchers, industry professionals, policymakers, and the public while promoting the development of national standards, disseminating best practices, and advocating for policies that support increased RCA utilization.

4.3 Infrastructure Development and Investment

A network of well-equipped recycling facilities strategically located across Iran is essential to ensure efficient and cost-effective processing of concrete debris. Public-private partnerships can be used for financing and operating these facilities. Mobile crushing plants also can be used in remote areas where establishing permanent facilities might not be feasible. Investing in advanced crushing and sorting technologies can also improve the quality and consistency of RCAs produced in Iran.

Technologies like impact crushers with adjustable settings and automated sorting systems based on size, density, and potential contaminants can optimize the RCA production process and minimize waste generation during processing. Hubert, et al. (2023) found that the impact crusher results in the production of aggregates possessing more spherical geometric characteristics, a broader spectrum of grain sizes and a relatively higher content of fine particles as compared to those obtained from the jaw crusher.

Developing a reliable and efficient logistics network for collecting and transporting concrete debris to recycling facilities is also crucial. Collaboration with construction companies and demolition contractors can establish clear collection protocols and ensure a steady supply of concrete debris for processing this can further close the loop and create a sustainable demand for RCAs.

Yu, et al. (2021) recommended that implementation of strict on-site waste classifications to ensure waste purity, establishing an information sharing platform to improve the business communication, and investment in up-cycling technology innovations, can enlarge the cooperation space for RCA industry.

4.4 Education and Training Programs

Enhancing awareness and knowledge about RCAs among stakeholders is crucial for wider adoption in Iran. Educational programs and workshops can be designed to address technical aspects of RCA utilization, including mix design considerations, performance characteristics, and potential challenges. Training programs focused on safe and efficient processing techniques, quality control procedures, and health and safety protocols for handling concrete debris can also significantly enhance the quality and efficiency of the RCA production process.

Availability of skilled personnel is also essential for the efficient operation of recycling facilities. Collaboration with established research institutions and industry leaders in countries with successful concrete recycling programs can facilitate knowledge transfer and accelerate the development of the Iranian RCA industry. Joint research projects, exchange programs, and technology transfer agreements can provide necessary expertise and practices for Iran.

Raising public awareness about the environmental benefits of concrete recycling is also necessary. Educational campaigns targeting policymakers, developers, and the general public can increase support for policies that promote sustainable construction practices.

Jain, et al. (2020) showed that sustainable waste management will require sustained awareness campaign and efforts to bring long-term behavioural changes towards industry.

4.5 Utilizing Innovative Technologies

Implementing advanced characterization methods to assess the quality and performance potential of RCAs produced from diverse sources within Iran is necessary. Techniques like X-ray diffraction, microstructural analysis, and alkali-silica reaction (ASR) susceptibility testing can contribute to a more comprehensive understanding of RCA behaviour and facilitate the development of customized mix designs for optimal performance. While RCAs are well-suited for non-structural and low-strength structural applications, investigating advanced processing and pre-treatment techniques to modify the properties of RCAs can ease the way for wider utilization in demanding construction projects.

Carriço, et al. (2021) introduced a novel separation method for obtaining RCAs from hardened concrete which resulted in a cleaner recycled fine aggregate with minimal cement paste contamination and obtain a recycled binder with up to about 80% cement content by weight.

Utilizing similar novel methods can increase the yield and performance of RCAs in Iran. Figure 1 and Figure 2 respectively show the novel and conventional method in RCA industry.

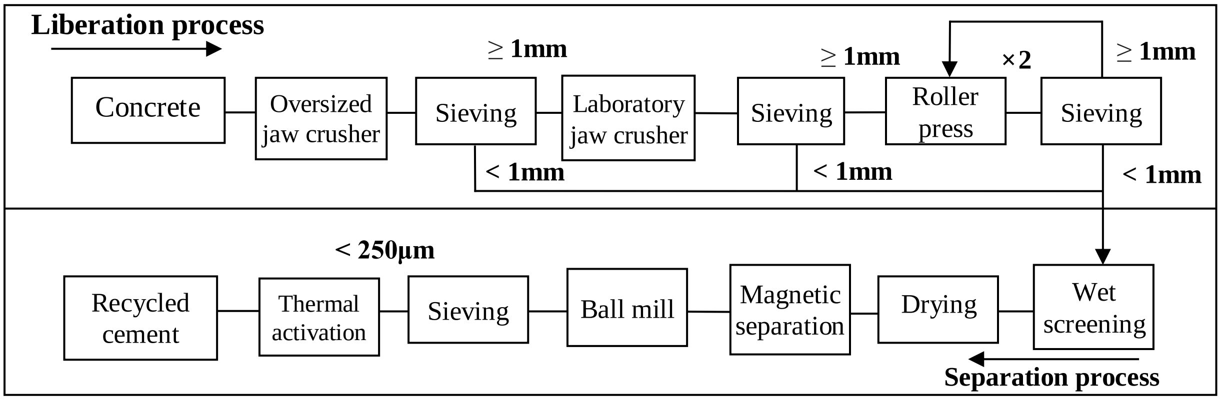

Figure 1: Flowchart of the novel liberation and separation method. (Carriço, et al., 2021)

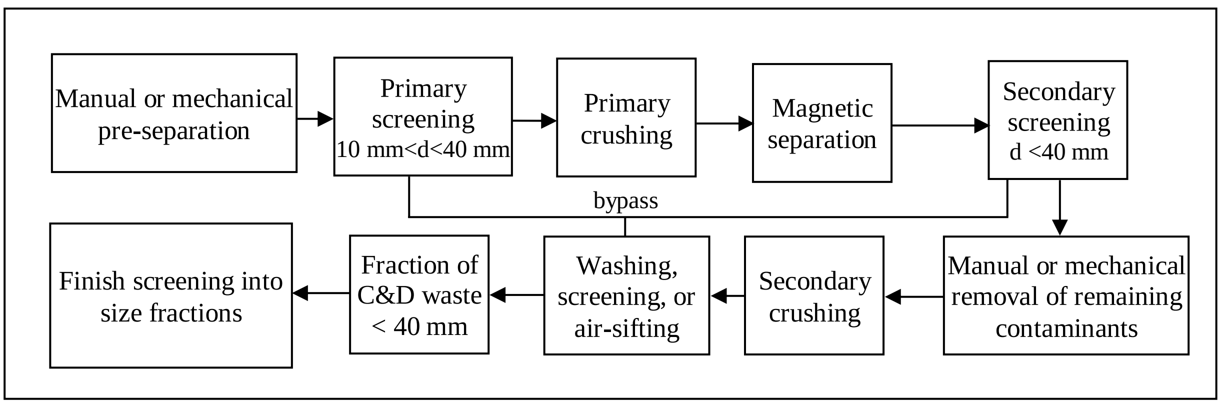

Figure 2: Flowchart of the conventional liberation and separation method. (ACI 555R-01)

5 CASE STUDIES

Utilizing valuable insights and experiences of countries with successful concrete recycling programs and analyzing the factors contributing to their success and implementation of them in Iran can benefit the Iranian RCA industry. Countries with high Human Development Index tend to have high C&D waste recycling rate and have set well-established frameworks for improving their performance.

5.1 European Union

European parliament's waste framework directive 2008/98/EC set 70% goal for construction and demolition recycling rate for year 2020 while achieved 74% rate in that year (Williams, et al., 2020). The EU is currently revising the waste framework directive, with a focus on potentially increasing the C&D waste recycling target further. Additionally, revisions might introduce specific requirements for concrete recycling rates within the overall C&D waste target.

Directorate-General for Internal Market, Industry, Entrepreneurship of EU also published C&D waste protocol as a non-binding guideline for member countries through their 2020 construction strategy.

Figure 3 shows C&D recycling rate in select European countries with high recycling rate.

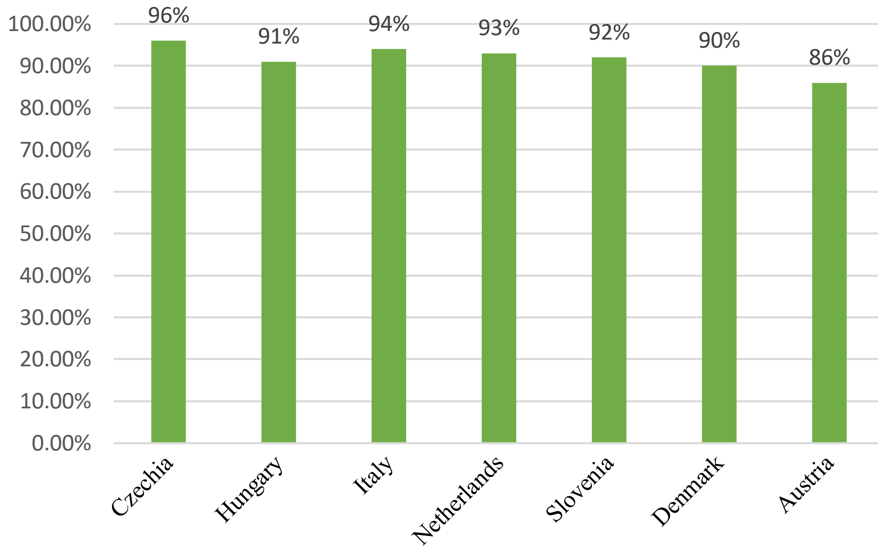

Figure 3: Construction and demolition waste recycling rate of select European countries (Eurostat, 2019)

Netherlands as a global leader in C&D waste recycling has utilized several effective strategies for achieving high recycling rate. Their strategy consists a combination of innovative practices and supportive government policies. The Dutch government launched in 2016 the national program of 'Circular Netherlands in 2050' with aim of reaching 100% circular raw construction materials by 2050 which more than 325 companies, financial institutions, universities and non-profit organisations have signed for it. Another agreement was signed on 2018 by a joint venture of 4 Dutch ministries and 50 companies in the construction sector with the goal of cooperation and transparency in the concrete value chain shall in order to foster the demand for 'green' concrete. Following this agreement, sustainability criteria shall be included in tenders and the target of 100 percent high-quality recycled concrete shall be met in 2030, and CO_2 emissions shall be significantly reduced. Consequently, all stakeholders in Netherlands started to introduce measures and monitored their progress. (Web-3)

Netherlands boasts a well-developed network of recycling facilities equipped with modern technology for efficient concrete processing and high-quality RCA production while the Dutch governments imposes high landfill taxes for C&D waste. This strategy makes recycling a more economical option and diverting market forces to this section.

Research organizations in Netherlands have also supported researches in new technologies such as Laser-Induced Breakdown Spectroscopy (LIBS) for continuous quality assessment and RFID tags for contactless identification and tracking of aggregate recycling process in order to increase transparency, access valuable information, and optimize new concrete design mixes.

Reliable regulations and certifications for RCAs also exist in Netherlands in order to achieve desired performance and pass the code requirements. RCA usage in Netherlands is subject to NEN-5905 regulation and non-mandatory BRL-2506 certification.

5.2 United States

Construction and demolition waste recycling rate stands at 76% nationwide (EPA, 2018). Federal agencies advocate use of RCA in wide range of projects, e.g. Federal Highway Administration encourages the use of recycled materials in federal highway projects through its Sustainable Materials and Practices Initiative, this initiative promotes using RCAs in federally funded transportation projects whenever feasible. American Association of State Highway and Transportation Officials has also issued AASHTO M 319-02, standard specification for reclaimed concrete aggregate for unbound soil-aggregate base course, which ease the usage of RCAs in infrastructure projects.

Local state governments practice different strategies for increasing concrete recycling. California as a pioneer state in C&D waste management has implemented several policies in this regard. Construction and Demolition Waste Disposal Control Law enacted in 1990, along with current codes and legislatives, requires that at least 65 percent of waste tonnage from construction, demolition, and renovation waste shall be diverted from disposal, while a new policy enacted in 2016 requires 75% recycling rate. California Department of Resources Recycling and Recovery, also offers grant programs that provide financial assistance for establishing and upgrading recycling facilities, promoting investment in the RCA infrastructure.

California has also statewide criteria for plan review and construction inspection of projects within the jurisdiction of division of state architect. DSA IR 19-3 states that RCA may be used for concrete base, pipe bedding, landscape, exposed minor concrete applications such as, sidewalk, curb, gutter, parking strip, and pavement while they are not permitted for structural concrete, provided all the following requirements are met:

- Source of recycled aggregates are identified
- Use of recycled coarse aggregates from salt contaminated concrete pavements is prohibited.
- Thoroughly cleaned and washed before use.
- Contain no deleterious materials.
- Meet the requirements of the California Building Code and its referenced standards, e.g. ASTM C33
- Satisfy specific project requirements
- When used in minor concrete, the amount shall be limited to no more than 50% of the total dry aggregate mass.

U.S. Green Building Council, the organization responsible for Leadership in Energy and Environmental Design (LEED) certification of building projects, also states that projects are required to develop and implement a waste management plan, quantifying material diversion goals and recycle and/or salvage at least 50% of construction, demolition and land clearing waste (LEED NC-MR cr. 2.1 & 2.2).

5.3 Japan

Japan, another pioneer country in concrete recycling has robust strategies and plans for achieving near-complete recycling rate of concrete waste. Construction Material Recycling Law enacted in 2000, mandates the recycling of construction waste including concrete, with new provisions, targeting recycling rate of 95% in 2010 and final disposal amount of specified construction material wastes generated in works ordered by the Government to be zero in 2005.

Japan has also established clear and comprehensive quality control guidelines for RCAs that define the physical and mechanical properties of RCAs for use in different construction applications. There are three classifications of recycled aggregate: "L, M, and H", and the applicable range is determined by Japanese Industrial Standards (JIS) guidelines.

Recycled aggregate L is used in areas where durability and strength are not required. Specifically, it can be applied to backfill/soil concrete where strength is not required.

Recycled aggregate M has intermediate durability and strength among recycled aggregates. It can be used as a reinforced concrete product or an unreinforced concrete product. Specifically, it can be applied to concrete pipes, box culverts, manholes, retaining walls, flat plates and gutters.

Recycled aggregate H has the highest durability and strength among recycled aggregates. Specifically, it can be used in the main structures of buildings, including reinforced concrete buildings, and can be used in the same way as ordinary concrete, while it cannot be used as high-strength concrete.

JIS A 5021, JIS A 5022 and JIS A 5023 provide dedicated specifications respectively for H, M and L classifications of recycled aggregate. Ministry of Land, Infrastructure, Transport and Tourism has also issued ‘Model specifications for recycled concrete aggregate’ and ‘Handbook for promoting the use of recycled concrete aggregate’ which provide recommendations for the use of RCAs in concrete mixes for different construction projects.

6 CONCLUSION

Widespread adoption of concrete recycling in Iran offers significant environmental and economic benefits. Landfill diversion, reduced energy consumption, and minimized environmental impact from virgin aggregate extraction are among some of the advantages this practice holds. However, the Iranian concrete recycling industry currently faces challenges that hinder its full potential. Limited infrastructure for processing and utilizing recycled concrete aggregates, coupled with a lack of widespread awareness about their benefits and performance among the industry, pose significant obstacles.

The establishment of clear and well-defined national standards and guidelines in Iran for the production, quality control, and use of RCAs is a necessary step, while funding for creating local supply chains for concrete debris collection and transportation will also be essential. Introducing preferential bidding opportunities for projects utilizing RCAs and mandating minimum RCA content in public construction can further increase their adoption in Iran.

Case studies showed the main factor in achieving higher concrete recycling rate are the Governments that can utilize their authority for enacting legislations, providing nationwide regulations and diverting construction taxes into C&D waste management in order to driving market forces into the RCA industry.

Fortunately, by implementing targeted strategies and learning from successful international models, Iran can overcome these hurdles and establish a robust concrete recycling industry.

Ultimately, by fostering a collaborative framework and working towards a shared vision, all stakeholders in Iranian construction industry can contribute to a thriving concrete recycling industry, paving the way for a more sustainable and resource-efficient construction sector.

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