

Analyzing the Use of Recycled Materials in Sustainable Concrete in the GCC Countries

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Abstract. The modern construction industry is based on the development of concrete structures and concrete is the most commonly used building material for the construction industry. Concrete manufacturing involves development of a mixture containing different natural resources like stone, clay, sand, water, and cement. These natural resources are extracted and transported to the construction site to create concrete (Ahmad et al., 2022). On the other side, concrete waste poses a significant environmental and economic challenge for the global construction industry. The present study is based on analyzing the use of recycled material for the development of sustainable concrete mix. Recycled materials involve the recycling of construction waste that provides the best alternative for natural resources and helps to prevent the environment. The present study is based on qualitative data analysis and surveys to highlight the usage of recycled materials to develop sustainable concrete. The survey results demonstrate that recycled materials are significantly important for the development of concrete mix and it is cost-effective and also protect the environment. The present research provides a deep insight into the usage of recycled materials for sustainable concrete manufacturing.

Keywords: Sustainable building, Construction, Recycled materials, Green Building, GCC

1. Introduction

Concrete is playing an essential role in the global construction industry and it is the most commonly used structural and construction material. Modern construction is depending upon concrete to develop modern infrastructures. Concrete is widely used in the construction industry including underground, on the earth's surface, and underwater construction. Concrete provides a promising solution to develop structures according to people's desires and proves it's sustainable for development in human society. The concrete mixture contains different substances including stones, cement, water, sand, clay, etc (Vishwakarma & Ramachandran, 2018). The raw material for the development of concrete mixture includes natural resources and extraction of natural crushed stone is more energy-consuming. Due to the development of concrete structures, the natural resources for the development of concrete are getting lesser and increasing construction and concrete waste. The carbon footprints of concrete development are

mainly associated with the cement industry. Humans are developing concrete for construction since the 20th century and the increasing demand for concrete is posing environmental and sustainability issues. According to Shukla, Gupta & Gupta, (2020), the annual volume of concrete scrap in 2000 was more than 360 million tons all over the world (Shukla, Gupta & Gupta, 2020). To address the increasing demand and environmental issues, scientists are focused on developing sustainable concrete by using recycled material. It is studied that recycled stone extracted for concrete waste needs 8 times less energy than the extraction of natural stone.

The construction industry is a major contributor to the GCC economies and UAE is specifically focused on developing modern infrastructure and the use of recycled material for the development of sustainable concrete. According to studies 70 to 80 thousand tons of concrete waste is utilized by UAE to get crushed stone and the remaining concrete waste is used in landfills and unauthorized dumps (Najaf & Abbasi, 2022). Recycling concrete waste leaves a positive impact on the environmental, technological, and economic aspects of the modern world. For a sustainable construction business, it is effective to develop sustainable concrete by using recycled construction materials (Vishwakarma & Ramachandran, 2018). At present, the world is moving to advancements and innovative construction with higher demand for recycled materials and environmental concerns. The properties and durability of the concrete mixture vary according to the material used for the development of the concrete. It is demonstrated that minimizing the use of natural resources is a way to protect the environment and it is significantly important to shape the modern construction industry (Al-Mansour et al., 2019). The use of recycled material not only contributes to the environment but is also important for cost reduction and economical aspects. The properties and durability of the concrete mix involve technical aspects and recycled material poses different physical and chemical properties as compared to natural resources. The technical aspects are important for the sustainable development of recycled concrete mixtures that could be used for future construction projects (Al-Mansour et al., 2019).

Recently, many researchers were focused to develop sustainable concrete for commercial use by using recycled material. With rapidly changing global conditions, it is important to recycle construction materials. The present study is based on addressing the problem of using recycled materials and the development of sustainable concrete for future construction projects in GCC countries. The use of different recycled materials is important for the strength and quality of recycled concrete. The understanding and use of different materials in concrete mixtures are part of the present research. The paper is aimed to address the following research questions.

- How to use construction waste to develop recycled materials for concrete manufacturing?
- How using recycled material in construction, and industry limits the use of natural resources.
- What are the differences in properties between conventional concrete and concrete developed by using recycled material?
- What are the technical aspects of using recycled material in the development of sustainable concrete?
- What are the environmental aspects of using recycled materials for the development of sustainable concrete?

2. Literature Review

2.1 Concrete and its importance in the world

During the construction of a structure, concrete is utilized to give strength, durability, and versatility. Concrete's exceptional characteristics have made it a dependable and long-lasting choice of construction businesses for both commercial and residential structures. Sand, cement, gravel, or crushed stone from natural sources are adhered (fastened) together to form a mixed, monolithic mixture that is known as concrete (Sandanyake et al., 2020). The substance that binds the grains of natural stone together is different in different types of concrete. The most common type uses cement as a binder and is known as cement concrete. In the production of asphalt concrete and tar concrete, bitumen and tar are employed as a binder. Other varieties of concrete exist, including gypsum and lime concrete. Concrete is a common component of construction (Marvila et al., 2022). On the highways, it frequently has construction. A concrete construction, such as a bridge abutment, culvert, or the concrete pavement of a road, appears to be constructed of grey stone. Typically, "stone," is a substance that is dead and inert and whose qualities don't change for decades or centuries.

Concrete is highly resistant to natural influences like cooling, heating, dryness, moisture, abrasion, and erosion. Concrete materials exist for hundreds of years and at present concrete is widely used in the world for the construction and development of infrastructure. Most of the materials used for concrete manufacturing include natural resources and it is studied that only one-tenth of concrete is using artificial materials (Shukla, Gupta & Gupta, 2020). The other nine-tenth part of the concrete includes natural stone, sand, and water that need to be mined at the construction site. According to studies, concrete is highly used for the construction of bridges, retaining walls, culverts, and viaducts. It is studied that concrete infrastructure is inextricably linked to modern society. It is important to develop housing, medical centers, transportation infrastructure, hospitals, buildings, and roads (Likes et al., 2022). Concrete is a necessary component for the development and survival of human societies. Concrete has exceptional performance in social, economic, and environmental aspects as a foundation and building block of long-lasting and reliable infrastructure. It would become impossible to offer affordable, low-maintenance infrastructure to enormous cities. Furthermore, concrete is durable, inexpensive, and widely available. Concrete may be molded into any shape, allowing for the creation of inventive and innovative buildings. While infrastructure is necessary for modern society to grow, concrete is the best building material for creating long-term infrastructure (Al-Mansour et al., 2019).

2.2 Concrete mixtures and their properties

Different concrete mixtures are studied by researchers. However, cement concrete is one of the most common and important concrete mixes. The key to diverse concrete mixtures is varying the amount of cement in them to achieve the desired qualities. Normal concrete takes 30 to 90 minutes to set. It takes around 7 days for the cement to begin hardening and another 28 days to reach 80% of its ultimate strength (Marvila et al., 2022). It has a strong compressive strength but a low tensile strength (Mohammadhosseini, Tahir & Sam, 2018). It is useful in locations with typical weather, but it cannot withstand strong conditions like freezing and high temperature without being treated on the outside. Researchers also highlighted high-performance concrete. High-performance concrete is made by carefully selecting and preparing cement combinations, with plasticizers added to improve the properties of concrete. It has high strength, is easy to work with, has a high density, builds strength quickly, has good permeability, and is exceedingly durable. By including air-entraining agents in the concrete mix, they can be made to resist temperature. To achieve high strength, the cement-to-water

ratio in the concrete mixture is reduced, and silica is added to avoid strength loss during the hardening process (Mohammadhosseini, Tahir & Sam, 2018). High-strength concrete is slightly more difficult to work with due to the lower cement-to-water ratio, but it has incredibly high strength, making it suited for skyscraper and sidewalk construction. A careful selection of aggregates is required to preserve its strength throughout time (Likes et al, 2022). Lightweight concrete is substantially lighter than other concrete combinations and has a lower mass per unit volume. They have limited strength and density as well. The inclusion of air-entraining admixtures protects them against freezing. They are utilized in situations where they are subjected to less stress, such as sidewalk linings, road linings, decorative constructions, parapet walls, and so on (Sandanayake et al., 2020).

2.3 Materials used in concrete mixtures

Ready concrete (factory-prepared concrete mix) is made up of four major components. These are cement, sand, crushed stone, and water, which are kneaded in a specific proportion (Amin, & Abdelsalam, 2019). Without crushed stone, the combination will be called cement mortar or sand concrete, with the main difference being that sand with a bigger particle size module is used in sand concrete. Concrete is made by combining the following components in the following weight ratio:

- Cement - 1 share;
- Sand - 2 shares;
- Crushed stone - 4 shares;
- Water - 0.5 shares.

Water and cement are the primary components of concrete, and they serve the primary purpose of binding all of the mixture's components into a single integral structure. One of the most important jobs in the manufacture of concrete is achieving the proper water-cement ratio (Vishwakarma & Ramachandran, 2018). Different studies are focused to analyze factors like the humidity of the crushed stone and sand utilized, the degree of moisture absorption, and other comparable ones. The cement can set and harden during the hydration phase (contact with water), resulting in the production of a cement stone (Amin, & Abdelsalam, 2019). Cement stone, in reality, is prone to distortion. It has a volumetric shrinkage of up to 2 mm/m. Despite the low rate, shrinkage processes cause internal strains and the production of tiny cracks, which are not apparent but harm the cement stone's strength and service life (Amin, & Abdelsalam, 2019). To reduce such deformations, aggregates might be added to the resulting mixture's composition. The finished concrete mixture has a certain alphanumeric index and is described with the obligatory indication of the brand (M) and class (B) for strength, mobility (P), water resistance (W), and frost resistance (F) (Mohammadhosseini, Tahir & Sam, 2018).

2.4 The effect of concrete on the environment

Concrete, from an environmental standpoint, is one of the most serious risks to the earth and climate at every stage of its manufacturing, usage, and even for many years after construction (Collivignarelli et al, 2020). Cement, crushed stone, sand, and water are the primary components of concrete. All of this appears to be abundant on Earth. However, the volume of concrete produced puts numerous resources in danger. The truth is that desert sand is unsuitable for concrete; only the marine variety is required (Hossain, Shahjalal, Tiznobaik, & Alam, 2019). Humanity consumes sea sand quicker than the ocean's waves can restore resources, resulting in a deficit over time. In 2012, the manufacturing of concrete consumed 9% of all water utilized by humanity. According to the journal *Nature Sustainability*, emerging countries would consume 75% of all water required for concrete manufacturing by 2050. (Hossain, Shahjalal, Tiznobaik, & Alam, 2019).

Grinding clinker and gypsum produces cement for concrete manufacturing. Clay and limestone must be heated to 1400°C to be converted into clinker. Such temperatures necessitate a lot of energy, which implies a lot of carbon dioxide enters the environment (Hossain, Shahjalal, Tiznobaik, & Alam, 2019). In 2015, clinker manufacturing accounted for 8% of all CO₂ emissions released by humans. If concrete were a country, it would be the third largest emitter, trailing only the United States and China. On hot days, concrete cities heat up faster than villages where this material is rarely used. Geographers and urbanists have extensively researched the phenomenon known as the urban heat island (Siddique, Singh, & Singh, 2018). It is well known that temperature differences in cities with populations of over a million people and beyond can exceed 5°C. This causes health difficulties for residents, a decrease in drinking water quality, and increased electricity use for fans and air conditioning. One of the most visible effects of global warming is the growing frequency of natural disasters such as earthquakes, tsunamis, floods, and tornadoes (Marvila et al., 2022). The list is extensive, but in the case of concrete, floods should be our primary concern. Concrete roads and highways prevent incoming water from quickly entering the ground (Kirthika, Singh, & Chourasia, 2020). As a result, floods become more damaging. They do more economic damage, take more human lives, and make it difficult to restore destroyed cities.

2.5 Recycled concrete

As a result of the annual destruction of old buildings. In total, a considerable amount of solid waste is produced, from which scientists are attempting to create a secondary material - recycled concrete, which is also suitable for construction. However, the ultimate result is a less durable, but ecologically beneficial, material: recycled concrete is 40% less durable than regular concrete on average (Shukla, & Gupta, 2020). To strengthen the recycled concrete, the scientists used a new method of producing it under high pressure and added other elements to the original mixture (Lokes et al, 2022). Pressure can be used to fix the shape of concrete, and chemicals can be used to boost flexibility and strength. Concrete recycling is the process of reusing concrete stones as a building material for a variety of uses. The secondary raw material produced has a lower crushing strength and dynamic loads, as well as a lower specific gravity (Shukla, & Gupta, 2020). At the same time, it has a higher absorption capacity as compared to new concrete and sustainable concrete products/structures. However, disposal is less desirable because it disregards the value of these wastes, as well as their potential as secondary raw materials (Lokes et al, 2022). Concrete recycling is critical for the environment because it is one of the most commonly used materials on the planet (Makul, 2020). The primary benefits of recycled concrete include decreased transportation costs, reduced environmental effects, reduced usage of natural aggregate stocks, and reduced environmental impact due to reduced pollution created by building waste (Sivakrishna, Adesina, Awoyera, & Kumar, 2020). The usage of recycled concrete involves the replacement of road base units, the creation of hard containment barriers, and the addition of a considerable fraction of fresh concrete. Crushed concrete is delivered to a recycling plant where it is crushed to make recycled concrete (Makul, 2020). To function properly, recycling machines require that the crushed concrete be free of contaminants such as wood or brick (Brannick, & Roche, 1996).

2.6 Recycling material and development of sustainable concrete

Waste concrete products (concrete products) are big and relatively small bits of concrete construction created during building deconstruction. This form of bulky garbage is also generated during the construction of new structures and certain industrial processes (Merli et al, 2020). The primary suppliers of sustainable concrete trash are construction companies and businesses that manufacture sustainable concrete goods. Furthermore, regular persons who deconstruct various structures on their sites contribute to the accumulation of such rubbish.

Each source of concrete waste faces the difficulty of disposal (Merli et al, 2020). The primary method of recycling and developing sustainable concrete products is through processing, which results in the manufacture of secondary crushed stones with fraction sizes ranging from 30 to 70 mm (Vishwakarma & Ramachandran, 2018). Manufactured products are widely utilized in road construction, other sorts of land development activity, and the manufacturing of heavy concrete as a huge aggregate (Mohammadhosseini, Tahir, & Sam, 2018). This crushed stone is not inferior in quality to the primary stone, but it is less expensive. Concrete and metal reinforcement are used to make sustainable concrete products (Najaf, & Abbasi, 2022). Concrete slabs and other similar products can be processed not only on the premises of the processing facility using stationary equipment. A mobile plant, which is a mobile crusher and screening complex, is prevalent today. Such an installation serves the same purpose as a factory's manufacturing line (Mohammadhosseini, Tahir, & Sam, 2018). Sustainable concrete can be created by crushing and grinding building debris, then adding additives and placing it under pressure and temperature to achieve strength comparable to or greater than regular concrete. It has been discovered that polymer additions play an important role in increasing the strength of recycled concrete and providing sustainability to constructions (Najaf, & Abbasi, 2022).

3. Methodology

A research method is a systematic approach that demonstrates the complete processes and methods to conduct the research. The present study is based philosophy of interpretivism that advocates qualitative research methods. The qualitative method of research devises to collect the data from sources that can be interrogatable. The qualitative research method is acceptable for the study by comparing with other methods and findings of different researchers. The research design of the study is based on a survey questionnaire. The present study is based on both primary and secondary data collection and provides analysis to get the answers to research questions. The secondary data is collected from past literature relevant to the topic of study and primary data collection is based on a survey questionnaire. The survey questionnaire method provides an easy outline of the topic and sums up the results. The sampling of the population for the present study involves targeting the participants and inviting them to fill out the questionnaire. The sampling is done through an online survey. The participants are shortlisted based on their association with the construction industry and the development of concrete mixtures. Online platforms like LinkedIn and Twitter are used to get the professional profile of the participants. The survey include a sample size of 40 participants and only 33 participants responded to the questionnaire. The participants are professionals from different backgrounds and experiences in the construction industry. The participants were invited to fill out the survey questionnaire through email which is a convenient method for researchers to collect the responses. The collected data is further subjected to cleaning as the result formulation is depending upon the responses and data collected. The limitation of the research method is that older literature on the topic is not valid as the development of sustainable concrete using recycled materials is associated with recent developments. The present study only includes data from previous studies that are not older than 5 years. The survey is specifically focused on the construction industry of GCC countries and participants include professionals from GCC countries. The present research adopts research ethics and does not include any personal information, working preferences, and job-related information. Collected data will not be shared with the third party and avoid biased opinions and personal likeliness.

4. Results and Discussion

The results of the research are based on qualitative analysis of primary and secondary data that evaluate the key findings of the study. Only 33 participants responded to the questionnaire survey and the results are presented. The demographic characteristics of the participants are important to highlight the association and diversity of the participants. The results revealed that 46% of participants are between 31-40 years of age, 15% of respondents were between 41-50 years, 27% of participants are 18-30 years old and only 12% of respondents are above 50 years. The qualification of respondents is an important factor that demonstrates the working and learning capabilities of the individuals. It is observed that a maximum number of respondents are holding a Bachelor’s degree while 27% hold a master’s degree. Most of the respondents have working experience in the construction industry and 34% have 4 years of experience, only 18% of respondents have more than 5 years of experience. All the participants are working in the construction industry and qualifications and working experience are important to determine the validity of the findings. The following figure demonstrates the qualification and working experience of participants.

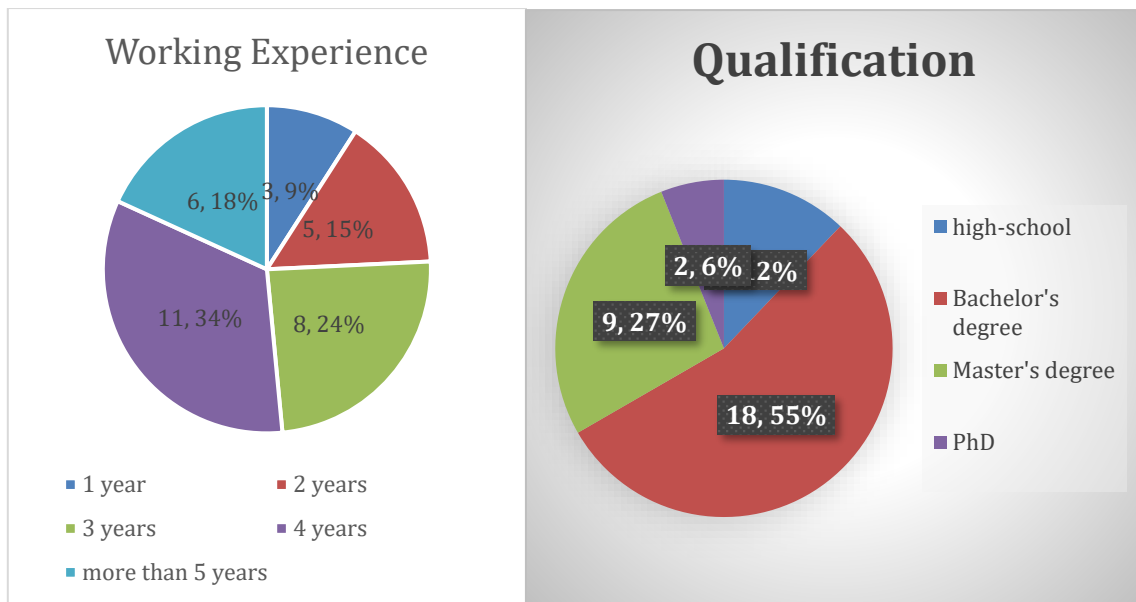


Figure01: a) working experience b) Qualification

Concrete is used in different construction projects including Buildings, roadways, infrastructure, and others. The material and composition of concrete materials are different for different types of construction projects. The survey questions the participants about the sector where they are providing concrete mixture. Depending upon the demand and usage of concrete mix in different sectors, the study demonstrates the development of sustainable concrete for each sector by using recycled material. It is observed that 55% of the concrete manufacturers are providing a mixture to roadways and minimum concrete is provided to the building sector. The demand for concrete in the building sector is significantly high and it is important to understand that building projects require high strength to construct complex structures that is why the building sector is least focused on the use of recycled materials for the development of concrete. On the other hand, road construction projects are based on paving the roads on the earth's surface. Recycled concrete is highly used in road projects and the demand for recycled concrete is increasing in this construction sector. The following figure demonstrates the percentage of responses for each sector to provide concrete.

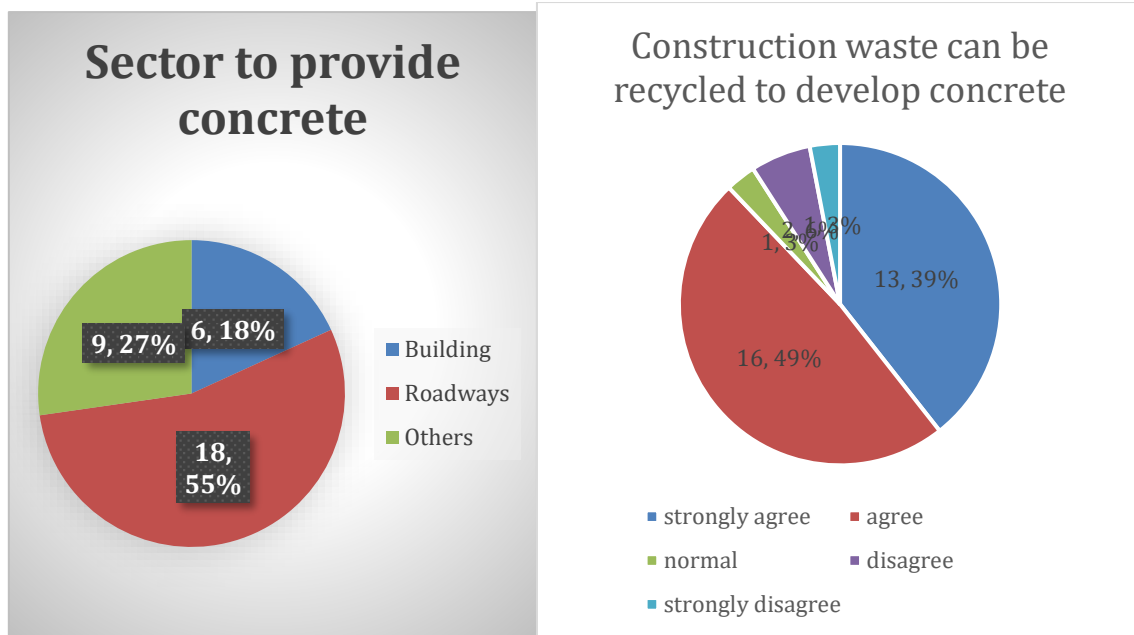


Figure02: a) sector to provide concrete b) recycling of construction waste

The respondents were asked about the strength of concrete developed by using recycled material, it is observed that 73% of respondents advocate that recycled concrete can provide similar strength as traditional concrete. The strength of concrete is an important characteristic of the use of concrete in different projects. The research finding highlights that strength of recycled concrete can be enhanced by creating the right mixture and addition of different additives. Many additives like tire rubber can be used to enhance the strength of recycled concrete. The finding highlights that most concrete manufacturing companies are involved in using recycled material for construction projects. 64% of respondents stated that their companies are using recycled material whereas only 36% of companies are using traditional methods and rely on natural resources to manufacture concrete mix. It is studied that recycled concrete mostly includes recycled stone and this kind of concrete mix is most suitable for paving roadways.

The present research is focused to determine the advantages and disadvantages of using recycled concrete. The respondents highlight different barriers and advantages of using recycled material for concrete mix. The most important advantage of using recycled concrete is it improves the concrete properties and makes it less reactive to external factors. Other advantages of using recycled concrete include the local availability of recycled concrete materials, the cost-effectiveness of using recycled materials, improve the production of concrete, and recycled concrete is sustainable for the construction industry. The advantages of using recycled materials are highlighted in the figure below. The use of recycled material for concrete manufacturing is beneficial for the construction industry in several ways but there are some disadvantages to using recycled materials for concrete mix. Its findings highlighted that lower qualities of recycled concrete are major disadvantages while the other disadvantages include lack of specifications, restrictions from authorities, local availability of natural resources, slower production, increased cost of extracting materials from waste, and others.

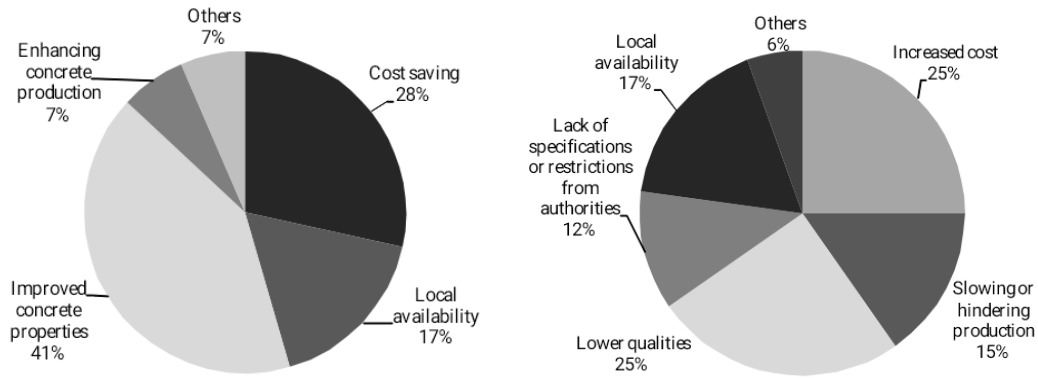


Figure 03 Advantages and disadvantages of using recycled materials

As highlighted in the literature that concrete mix includes different ingredients like sand, water, stone, and cement. The designing of concrete mix is significantly important to get the desired results and strength. The use of recycled material for the development of sustainable concrete does not follow any standard and the mixture is designed by different companies. The respondents were asked about how they are creating concrete mix. Most of the respondents argue that they are using company history to design the concrete mix. The company manufacturing recycled concrete worked for years to have a sustainable concrete mix. Each company develops its composition and provides recycled concrete to different industries. The second majority of the respondents are following standards to create the concrete mix. The standards are developed by construction regulatory authorities that provide details about the usage of different components for the development of sustainable concrete. The third way of designing concrete mix is to use industry specifications. The industry specifications are requirements provided by companies that require concrete mix for a construction project. Different specifications are provided depending on the nature of the project.

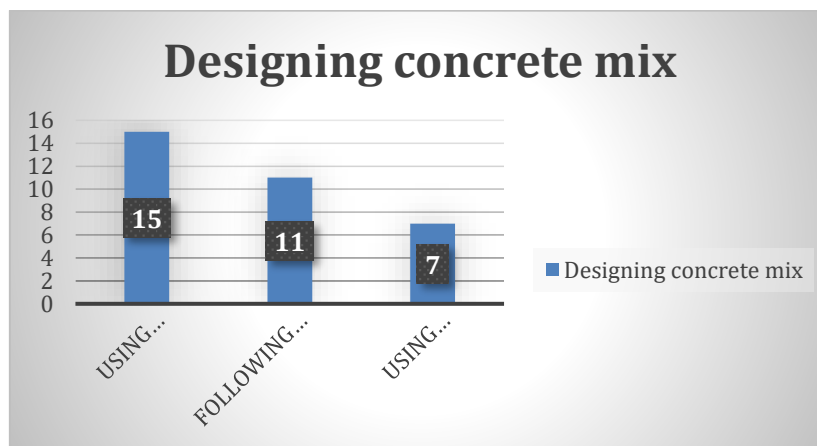


Figure04: Designing concrete mix

The results show that different recycled materials can be used to develop sustainable concrete. The composition of concrete mix varies according to industry specifications. The respondents were asked about the usage of different pre-specific concrete mixes and it is observed that 67% of companies are using Fly Ash Class F, fly ash class C is used by 58% of companies, and PLC and other concrete mixes are rarely used. The specifications are directly associated with an aggregate mix of concrete. The aggregate mix is significantly important for the construction industry and aggregate mix is used to develop sustainable concrete mix. Different raw materials are used to create aggregate mix and the aggregate mix is important to determine the overall strength of the concrete. The research results demonstrate that RCA and

lightweight aggregate are the most commonly used materials. The research also reveals that it is difficult to understand the properties of old concrete and extract the materials with the required properties. The strength and temperature tolerance of the recycled material is different from the concrete made of natural resources. It has been studied that RCA exhibits inferior engineering properties and water absorption is high for RCA. These changing properties made RCA less feasible to be used as recycled material for sustainable concrete development. 83% of respondents prefer to use lightweight aggregate as raw material for sustainable concrete development. The recycled materials that could be used in the development of concrete include lightweight aggregate, RCA, tire rubber, crushed glass, plastics, brick rubble, slag, crushed ceramics, foundry sand, and waste expanded polystyrene.

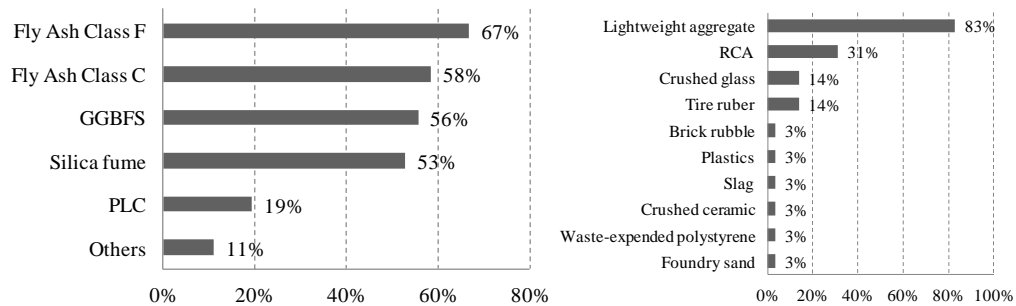


Figure 05: a) use of different specific concrete mix. b) recycled materials used for concrete manufacturing

The use of recycled material for the creation of concrete is significantly important to protect the environment. It was studied that construction waste and the usage of natural resources for the creation of concrete pose a harmful environmental threat to the global community. To reduce industrial and construction waste, the recycling of waste material is necessary. The carbon prints of the construction industry highlight that maximum energy is consumed for the extraction and crushing of natural resources and due to the usage of recycled materials global waste can be reduced which is pleasant for the environment. The respondents were asked about the impact of using recycled material in concrete on the environment. 55% of respondents argued that the usage of recycled concrete is environmentally friendly and it is crucial to prevent the usage of natural resources that maintain an equilibrium in a natural system. Several environmental factors are identified as the environmental problems of the construction industry. The environmental factors include water consumption, CO2 emission, global warming, land pollution, change in global temperature, and chemical pollution. The results highlighted that recycled concrete contributes very little to address the global environmental concern. However, it is helpful to keep the earth clean. The following diagram shows the responses of participants toward the environmental contribution of recycled materials for concrete mix.

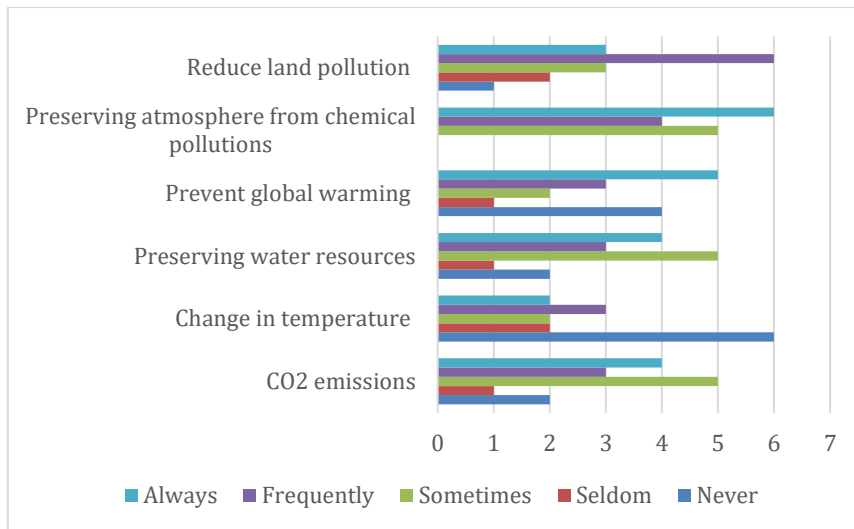


Figure 06: environmental impact of using recycled material for concrete development.

The results are based on highlighting the key findings of the study. It is found that the use of recycled material for the development of concrete is significantly important and it is necessary to adopt recycled material for the sustainable construction industry in the future. The recycled material for the concrete mix is cost-effective and provides an opportunity to handle economic challenges. The use of recycled material also contributes to the environment and attracts people working for environmental sustainability.

5. Conclusion

The present study provides a qualitative analysis that is focused on the development of sustainable concrete by using recycled material. The study provides a detailed literature review that highlights the importance of using concrete for construction projects and the use of recycled material for the development of concrete. The study concludes that concrete mixtures contain different components and usage of recycled materials for concrete manufacturing is important in terms of environmental and economic sustainability. Recycled concrete provides cost-effective solutions and provides extra strength to the building structure. The use of recycled material for concrete manufacturing involves the addition of different substances like tire rubber to improve the properties of concrete. The findings indicate that concrete is extensively used in building and road projects and recycled concrete is highly used for road projects because strength is not a question for road projects. The survey results demonstrate that different concrete manufacturing companies are at different levels of recognition and utilization of recycled concrete. Most of the companies are using company history for the development of concrete mix while the other companies are based on following the specifications provided by the industry. The construction waste can be effectively used as raw material to develop a sustainable concrete mix.

For future work, the study recommended expanding the knowledge base by considering the construction industry of different countries other than GCC and UAE. The accuracy of results can also be expanded by improving the sample size. The present study serves as the starting point for the development of sustainable concrete through using recycled material. It is also important for the researchers to analyze the industrial prospect and perceptions of the companies operating in the construction industry toward the usage of recycled materials for the development of sustainable concrete.

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