Chapter 1

Introduction

1.1 General

In a global review of solid waste management by the World Bank, it is estimated that by 2050 the number of people living in cities will be approximately equal to the population of the whole world was in year 2000, as a result of the increasing rate of the urbanization [5]. 53% of the population in India is projected to reside in urban agglomerations within the next 30 years. Ministry of urban development (2015) estimated the need of redevelopment of around 202.3 million m^2 of old structures [6]. In order to fulfil the requirements of the increasing population and its urbanization, infrastructure facilities have to be improved. Development of infrastructural facilities is accompanied by construction, remodeling, and demolition of buildings, roads, bridges, flyovers, subways, runways, factories, and other similar establishments [7]. Growth in the construction industry puts direct pressure on natural resources, which are already depleting day by day. In the process of infrastructural development, a large amount of construction and demolition (C&D) waste is also produced. Waste production is largely due to the demolition activities carried out on existing structures on completion of their service life or for restructuring. According to the Danish Environmental Protection Agency (DEPA), in 2003, 30% of the total waste generated was C&D waste [8]. The Environmental Protection Agency (EPA) defines C&D debris as the waste material produced in the process of construction, renovation, or demolition of structures (both buildings and roads). In addition, it includes the materials generated as a result of natural disasters [9]. 70-75% the waste generated was from demolition activity, 20-25% from renovation, and the remaining 5-10% from new building developments.

1.2 Background

C&D waste consists mainly of inert and non-biodegradable materials such as concrete, plastics, wood, metal, broken tiles, marbles, bricks, etc. A maximum of those materials have sufficient market value in the recycling industry, except concrete and brick waste, which account for about 80% of the total [9]. Concrete and brick waste are bulky, heavy and inert as well, due to which it is a very challenging job to handle these wastes. These waste are used to be disposed of on farm land, low-lying areas, prime residential areas and pits. This method of improper disposal has very adverse effects on the environment, like groundwater contamination and an increment in carbon footprints. Environmental issues such as increased flood levels due to the illegal dumping of C&D waste into the rivers, resource depletion, shortage of landfill and illegal dumping on hill slopes are evident [4]. The best way to handle C&D waste is to either reuse or recycle it. The difficulties in disposing of the concrete rubble and demolition waste, together with the developing scarcity of natural aggregate, have prompted an urge to recycle the concrete waste. The philosophy of the three R's, i.e., reduce, reuse, and recycle, can change the future of this construction industry and can help us achieve sustainable goals for a better future. The image of C&D waste is shown in Fig. 1.1 in which it can be observed that all types of connstruction materials like concrete, bricks, marbles, tiles etc. The concrete waste strictly contains old concrete, shown in Fig. 1.2. The percentage of waste production varies considerably among different sectors and waste categories, reflecting different socio-economic factors. C&D wastes account for the majority (48%) while municipal wastes account for only 12% [10].

As aggregates account for 60 –70% of concrete by volume, using concrete waste as recycled aggregate will not only solve the resource problem, but will also save soil. Effective use of recycled concrete aggregates (RCA) in the concrete industry can help in both ways of reducing the environmental impact and preserving resources [11]. For the sustainable development of every sector, the reuse and reduction of waste produced is the most fundamental requirement. For RCA to work well in regular concrete, it needs to be used in different ways depending on its properties (low-quality aggregates for low-quality

Figure 1.1: Construction and demolition waste (C&D waste)

Figure 1.2: Concrete waste

concrete and high-quality aggregates for high-quality concrete) [12].

1.3 C&D waste management: (Global perspective)

Globally, cities generate about 1.3 billion tonnes of solid waste per year. The world generates 0.74 kg of waste per capita per day. An estimated 2.01 billion tonnes of municipal solid waste were generated in 2016, and this number is expected to grow to 3.40 billion tonnes by 2050 under a business-as-usual scenario [5]. Amount of C&D waste generation in million tonne around the world till 2018 is shown in Fig. 1.3, and amount C&D waste generation per capita in the different part of world is shown in Fig. 1.4 [3]. The largest producer of C&D waste is China of around 2360 million tonnes, United States (US) is the second largest producer (around 600 million tonnes), and with 530 million tonnes, India is spots the third largest generator of C&D waste. France and Germany also heavily contributes by producing of 240 and 225 million tonnes of waste, followed by United Kingdom (UK) and Netherlands. Countries like Italy, Austria, Brazil and Spain generated comparatively less amount of C&D waste (38 to 61 million tonnes). Other countries like Belgium, Russia, Australia, Poland, Finland and Sweden produced C&D waste under 25 million tonne. When watse generation in tonne per capita was analysed for countries around the world, European countries leads the list. Netherlands (5.9 tonne per capita) followed by Austria, France, Finland, Germany UK and Belgium. Contrarily, China and US being the top two countries around the world for total production of construction waste, their per capita C&D waste generation was lower than 2 tonne per capita. India's per capita generation of C&D waste was 0.4 tonne.

Countries have employed the legal process to maximize the reuse of C&D waste in construction. In many countries, like Japan, the United States, and the United Kingdom, various recycling techniques are being used and returning good results. The process of recycling C&D waste includes storage, sorting, collection, transportation, recycling, and disposal. Singapore, a land-constrained country, recycles 98 per cent of its C&D waste. Hong Kong, which also has serious land constraints and therefore cannot afford landfills, has very stringent controls over C&D waste. In 2019, only 8% (7% C&D waste and 1% concrete waste) of the total C&D waste produced were disposed to the landfills, in 2020 it reduced to 6% [13]. The revenue generated is used to maintain and subsidize C&D

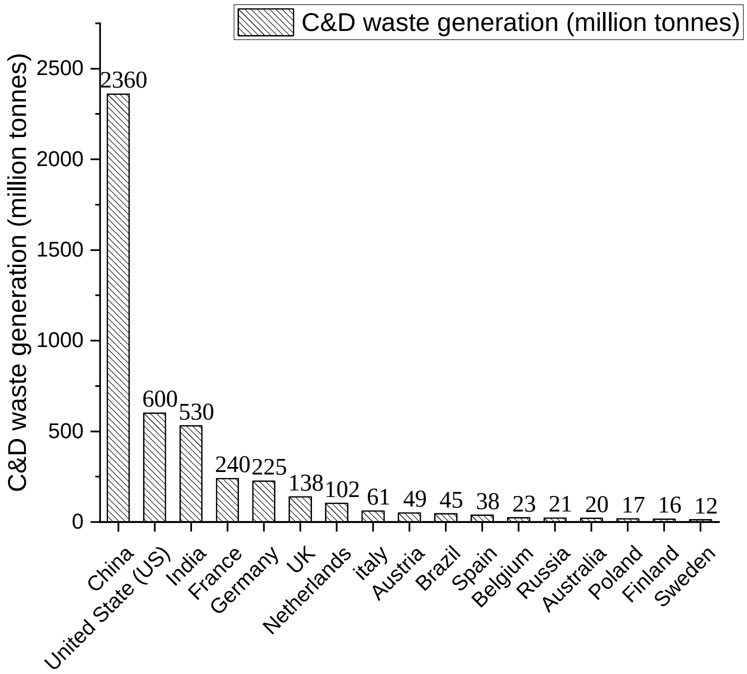

Figure 1.3: C&D waste generation around the word in 2018 [3]

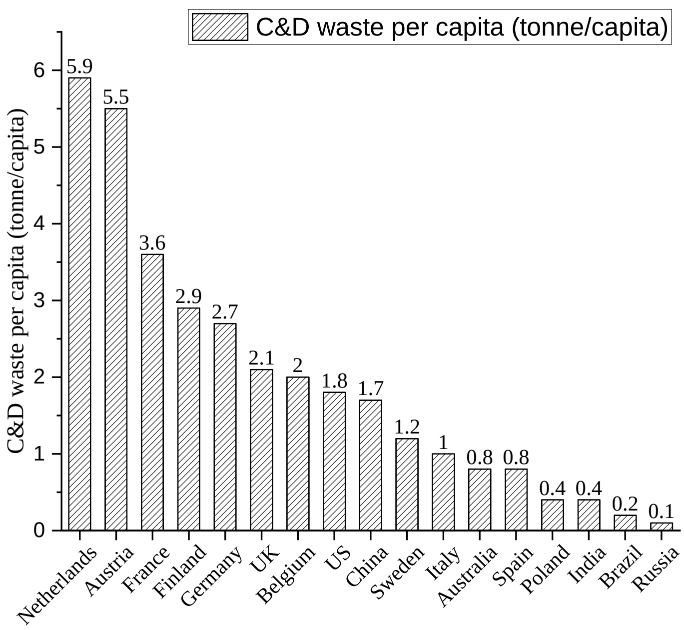

Figure 1.4: C&D waste generation (tonne per capita) around the word in 2018 [3]

waste recycling centers. This has created incentives for reuse and also for very efficient construction practice that minimize the generation of construction debris. Instead of demolishing structures, Hong Kong dismantles systematically. It also offers tax concessions to C&D recycling centers. South Korea has one of the most extensive and oldest recycling policies for C&D waste. C&D waste management is part of its low carbon green growth strategy. The country passed a law on acceleration of C&D waste reuse and recycling in 2005 that provides for step-by-step demolition and the utilization of recycled aggregates. It has adopted separate building codes for recycled asphalt concrete aggregates, recycled concrete aggregates, and road pavements. The Architectural Institute of Korea's Standard Building Construction Specifications recommend increased use of recycled C&D material. Although, C&D waste generation increased from 45.9% (2009) to 51.2% (2019), Korea has recycled almost all the waste (more than 99% of concrete waste, 99% of asphalt waste, more than 97% of masonry, and more than 85% of stone and dust waste) [14]. In the European Union, there are clear rules regarding the use of recycled materials in buildings. The EU 2004 regulations in the form of European Standards for Aggregates explicitly provide for aggregates made from natural, recycled, and manufactured materials. They focus on fitness of use and do not discriminate between resources. While C&D waste is not used in the structural and foundation frames in the EU, it is extensively used in non-structural frameworks. Some member countries have reported that over 20 per cent of their national consumption is from recycled materials. In the United Kingdom, the Northern Ireland Environment Agency has published "The Quality Protocol for the Production of Aggregates from Inert Waste" in 2004. This has helped to promote use of recycled and secondary aggregates. Almost 280 million tonnes of aggregates are used every year, which is 28% of the total C&D waste generated. In the US, New York has stringent measures for C&D waste as it is land-locked and has limited space for disposal. Its disposal practices are more efficient than the rest of the US. It forces the developers to segregate waste on site, dismantle and not demolish it, in addition to other measures. A 2010 review of global best practices by an MoEF appointed committee shows that in Scotland, about 63 per cent of waste was recycled in the year 2000. Denmark and the Netherlands have aggressive reuse strategies for C&D waste; the Netherlands discovered that 80 per cent of its C&D waste is bricks and concrete that can be recycled to reduce land pressure. In Japan, way back in 2000, about 95 per cent of waste concrete was

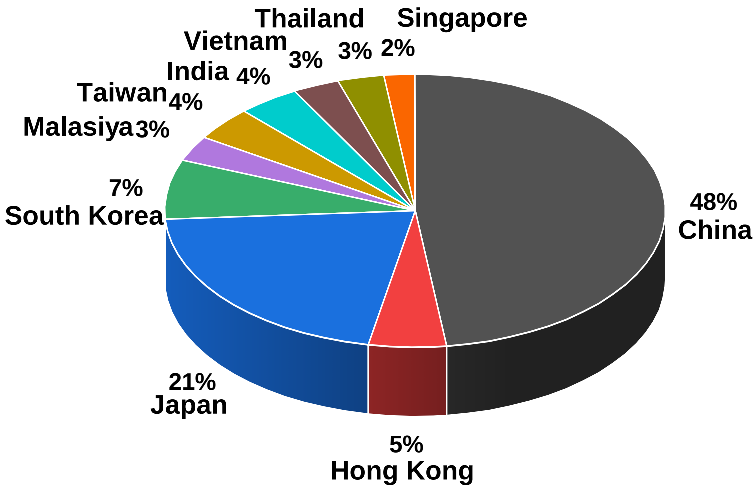

Figure 1.5: Estimates of C&D Wastes in Some Asian countries (Asian Institute of Technology, 'Report on reduce, reuse and recycle (3R) practices in C&D waste management in Asia' [4]

crushed and reused as roadbed and backfilling material, while 98 per cent of asphalt and concrete and 35 per cent of sludge were recycled . Recycling methods used in Japan are heating and rubbing methods; eccentric-shaft rotor method; and the mechanical grinding method. The Asian institute of Technology, Thailand conducted a survey in various Asian countries and prepared a report regarding C&D waste management in May 2008. The study includes Asian countries like Bhutan, Japan, Hong-Kong SAR, China, Thailand, and others including India. The following pie chart shows the status of C&D waste in Asian countries. Fig. 1.5 shows the status of construction waste in Asian countries.

1.4 C&D waste management: (Indian perspective)

Developed countries have already included the philosophy of 3 R's to counteract the problem of disposing off C&D waste. But developing countries like India are still focusing on disposing of this waste.

India is emerging as one of the leading countries among developing ones. With

Table 1.1: Constituents of C&D waste generated per year in India [1]

Constituent	million tonnes/year
Soil, Sand and gravel	4.20 to 5.14
Bricks and masonry	3.60 to 4.40
Concrete	2.40 to 3.67
Metals	0.60 to 0.73
Bitumen	0.25 to 0.30
Wood	0.25 to 0.30
Others	0.10 to 0.15

the speed of economic growth, the construction sector in India is achieving its new high. According to the 11th 5 year plan of Goverenment of India, construction industry is second after the agriculture in terms of magnitude [1,8]. Investment in the construction industry accounts for around 11% of India's GDP. According to TIFAC (Technology, Information, Forecasting, and Assessment Council -2000), the total construction work in the country for the 5 years during 2006-2011 has been estimated to be 847 billion dollars [15]. With the growth in the construction sector, the generation of C&D waste is equally substantial.

There is no systematic data base on C&D wastes, according to union ministry of forest and environment (MoFE) [2]. Despite the fact that C&D waste is the greatest component of the waste stream, it has been overlooked historically. In 2000, TIFAC did a comprehensive study for C&D waste was estimated at 14.69 million tons. Waste generation during construction and renovation/repair work was $40 - 60$ kg/m^2 and $40 - 50$ kg/m^2 respectively. The highest contribution to waste generation was from demolition of buildings, which yielded on average $4 - 5$ kg/m^2. According to center for science and environment (CSE), since 2005 India has newly constructed 5.75 billion m^2 of additional floor space with almost 1 billion m^2 in 2013 itself. If this is taken into account with data from TIFAC, then around 50 million tonnes of C&D waste were generated only in 2013 and, over the period of 2005 to 2013, C&D waste generation would have been around 287 million tonnes, because of demolition. From 2013 to 2015 an average of 193 million tonnes of C&D waste would have been generated from repair and renovations. If TIFAC

Table 1.2: Estimates of quantity of C&D waste from various agencies [2]

Name of the Agency	Estimation Year	CD waste (Million MT /year)
Ministry of Environment Forest (MoEFCC)	2010	10 to 12
Technology Information, Forecasting and Assessment council (TIFAC)	2001	12 to 15
Central Pollution Control Board (CPCB)	2017	12
Building Material Promotion Council (BMTC)	2013	165 to 175
Centre for Science and Environment (CSE)*	2014	530

and CSE data are combined, India produced 530 million ton of C&D waste only in 2013, nearly 44 times more than the data provided by TIFAC, in which waste generated by infrastructure projects such as dam and roads is not included. If C&D waste in India is properly quantified it will surely surpass the total quantity of other solid waste generated. A lot of it is being used by land sharks to illegally fill up water bodies and wetlands around urban centers for real estate development. The rest is just being dumped into rivers and open spaces [16].

Constituents in C&D waste generated is provided in Table 1.1 and estimates of quantity of C&D waste from various agencies is shown in Table 1.2. Due to the lack of emphasis, the annual estimates of total C&D trash created at the local level and nation-wide range from 15 million to 625 million tonnes [17]. Lack of C&D waste management facilities appears to have greatly contributed to many sorts of environmental degradation during the past two decades. For instance, C&D waste placed beside roadways contributes to an increase in suspended particulate matter (SPM) as it degrades over time. In recent years, PM 2.5 levels have increased in metropolitan areas, which has been a hub of building activity for the past two decades. In certain years, it exceeds to 150 g/m^3 in the summer, and about 200 g/m^3 in the winter, compared to the tolerable limit of 60 g/m^3 [18]. According to CAG (Citizen Consumer and Civic Action Group) (2016) [19], the mishandling of C&D waste contributed to the 2015 flooding in Chennai. Increasing pressure from the judiciary, think tanks, and citizen organisations in 2016 contributed to the passage of the C&D Water Management Rules.

One of the main reasons for the paucity of authentic data has been the absence of regulatory compulsions. There is no separate body for regulating and estimating C&D waste generation in India untill 2016. There is no separate codal provision available in India. In addition to the C&D Rules 2016, two supplementary regulatory requirements have been implemented. Both pertain to the criteria that permit the use of recycled materials for a variety of applications. In 2016, the Bureau of Indian Standards revised the IS 383:2016 [20] standard for coarse and fine aggregate for concrete (third version). The updated standard allows the use of manufactured aggregates derived from sources other than nature in the manufacturing of concrete for conventional structural applications, including mass concrete works. The amended IS 383 [20] permits the use of up to 20 percent recycled concrete aggregates as coarse or fine aggregate in Reinforced Concrete (M 25 grade) and up to 100 percent in Lean Concrete (M 15 grade). This alteration is compliant with the National Buildings Code (NBC-CED 46) of India, 2005: Part 11 [21], which permits up to 30 percent of natural aggregates to be replaced with recycled concrete aggregates.

1.5 Benefits of C&D waste recycling

Recycling of C&D waste reduces the production and emission of greenhouse gases and other pollutants. It reduces the need for new landfills and the costs involved in them. Recycling saves energy and also reduces the environmental impact. It creates employment opportunities in recycling industries. A lot of money can be saved by reducing the project disposal costs, transportation costs, and the cost of new construction materials by recycling old materials onsite [8].

- The environmental benefits of recycling C&D waste are considerable. By assessing carbon dioxide and energy use at a large scale recycling plant, researchers have shown that, over its 60-year life span, the carbon dioxide emissions prevented will be ten times as much as those produced, and eight times as much energy will be saved as that which is used.

- Recycling of C&D Waste: C&D waste management can be defined as the process related to the proper storage, collection, and transportation, recovery and recycling, processing, reusing, and disposal of C&D waste in a manner that is in consensus with the principles of human well being, economic, engineering, and other environmental considerations.

- Recycling and reuse: Reuse and recycling are important strategies for the management of waste. Other reasons that support the adoption of these strategies are reduced extraction of raw materials, reduced transportation costs, improved profits, and reduced environmental impact. To save conventional natural aggregate for other important projects, all rapidly depleting conventional natural aggregate sources have demanded the use of recycling/ reuse technology.

By using life cycle assessment, it was reported that recycled concrete presented the best environmental behavior followed by mixed concrete and traditional concrete [22].

1.6 Recycling process of C&D waste

Concrete wastes are first separated from the C&D wastes. Large debris of concrete wastes is then crushed into smaller pieces with the help of a primary crusher. Steel, glass, wood, plastic, and other contaminants are then sorted out. Secondary crushers are then utilized to convert concrete waste into the desired size of aggregates for different purposes. As secondary crushers Jaw, cone, hammer and impact crusher are used. Jaw crushers provide the best grain size distribution. The cone crusher is suitable for use as a secondary crusher with a 200 mm maximum feed size. Swing hammer mills are seldom used. Impact crushers provide a better grain size distribution of aggregate for the road construction process. When it comes to other properties of recycled concrete aggregate than grain size distribution, the jaw crusher performs better than impact crusher because in the jaw crusher opening size can be set at 1.2-1.5 times the maximum size of original aggregate, that crush only a small portion of the original aggregate particles in the old concrete. Impact crusher, on the other hand, crush old mortar and original aggregate particles alike and thus produce a coarse aggregate of lower density. Another disadvantage of impact crushers is high wear and tear, and therefore they have relatively high maintenance costs [23] . Regarding the influence of the recycling process, the number of processing stages is an aspect to be taken into account since the density of RCA depends on the amount of adhered mortar. Using jaw crushers and impact crushers, the rate of recovery of coarse aggregates was 60%, decreasing to 35% for further processing (material crushed twice with the mechanical equipment) [24]. The RCA obtained after both primary and secondary crushing produces stronger concrete than the RCA with only primary crushing [24]. Including all the original concretes, only crushing by the jaw crusher and then followed by the impact crusher to reduce adhered mortar (level 1) resulted in 52-55% adhered mortar content. This result indicates that even though original concretes are different types or have different qualities, the amount of adhered mortar may be approximately the same at level 1 [25]. The investigation of crusher efficiencies carried out by BCSJ showed that except for grain size distribution, the physical properties of recycled concrete aggregates such as specific gravity, water absorption, sulphate resistance, and Los Angeles abrasion loss were not significantly affected by different types of crushers and crusher settings.

1.7 Recycled concrete aggregates

RCA obtained has a very similar appearance to crushed natural aggregate, but the physical and mechanical properties of aggregates obtained through crushed concrete are different from those of natural aggregates (NA). RCA has been found to be more porous, rougher, and equi-dimensional than NA [26]. From the literature, it has been observed that RCA has two major differences against NA; i.e., the presence of adhered mortar [27], due to which there is the formation of a new interfacial transition zone (ITZ) between the original aggregate and old mortar [28]. Due to this adhered mortar, RCA have low density/specific gravity, high water absorption, higher abrasion loss, and lower toughness compared to NA [29]. The quality of RCA is highly dependent on the processing technique as well as the quality of the source concrete.

1.8 Research Objectives

The objectives of the thesis are as follows:

- The best possible way to maximize the utilisation of RCA in mainstream concrete.
- To create a cost-effective method of reducing adhered mortar content in C-RCA and thus improving its properties.
- To develop a mix-design approach for producing a mix of RCA concrete that can take care of the adversaries of RCA.
- To investigate the fresh and hardened concrete properties of RCA-concrete treated with two different types of methods against NA-concrete.
- To investigate the mineralogical properties of RCA and the micro-structural properties of RCA-concrete.

1.9 Thesis Outline

The research conducted to accomplish the above-stated goals is presented in seven different chapters. The board content of various chapters of the thesis are as follows:

Chapter 1 addresses the description about the generation of waste from the construction and demolition activities. It discusses in briefly the impact of C&D waste generation on the environment. It details the amount C&D waste generation around the world and in India. In this chapter, definition of recycled concrete aggregate (RCA) is provided, along with the importance of using RCA in concrete. Recycling process of C&D waste into RCA is also discussed.

Chapter 2 discussed a detailed literature review on use of RCA in production of new concrete. Various physical and mechanical properties of coarse as well as fine RCA in comparison to natural aggregates are extensively discussed. The focus of literature review is drawn towards the quality improvement of RCA using various treatment methods. An in-depth discussion of various techniques employed to improve the physical and mechanical properties of concrete produced with RCA has been brought out.

Chapter 3 outlines the details of materials and methodologies used in the present study. The procedures involved in finding out the properties of aggregate and concrete for the present study are briefly discussed in this chapter. Aggregate sample preparation and methodology adopted for the experimental study are also detailed. A brief discussion on the preparation of concrete samples and the procedure of frsh and hardened concrete tests along with the XRF, XRD and SEM analysis are also mentioned in this chapter.

Chapter 4 elucidates the process of recycling the concrete waste to produce RCA. Effect of parent concrete on the properties of produced RCA is highlighted in this chapter. Treatment methods that are mechanical in nature are compared against each other for the capacity of reducing adhered mortar. The sampling of RCA required for various study is one of the important part of this chapter.

Chapter 5 in this chapter an attempt has been made to explore the impact of old concrete strength on the coarse-RCA (C-RCA) as well as on the new concrete produced from it. Concrete samples were categorised according the source of C-RCA and studied for the various fresh and hardened properties.

Chapter 6 discussed the potential of C-RCA as well as F-RCA in the production of new concrete. In this chapter, compatibility of all four type of aggregate (C-RCA, F-RCA, C-NA and F-NA) was analysed with their varying percentage in the concrete mix. For all the replacement combination of RCA, various properties (fresh and hardened) of concrete was analyzed along with the micro-structural differences.

Chapter 7 the summary of all the results presented in various chapters along with the major conclusions is presented in this chapter. The limitations of present research and its future scope are also presented in this chapter.