CHAPTER 1

INTRODUCTION

1.1 General

Protection of environment, conservation of natural resources, and sustainable constructions are the three important essences of any modern development [Jianzhuang and Falkner (2007)]. Today, sustainable development has been advocated throughout the world [Tam (2005), Wengui et al. (2012)]. Construction industry is a massive consumer of natural resources and a huge construction and demolition (C&D) waste producer as well [Wai et al. (2012)]. Generally, C&D waste coming from construction industry consists mostly of inert and non-biodegradable material. Furthermore, concrete rubble has been found to be a major portion consisting around 40% present in C&D waste [Kawano (1995), Oikonomou (2005)].

The C&D waste, normally dumped on the roadside, causes problems to traffic and environment. Moreover, it is an additional workload to the local administration. On the other hand, the resources of natural coarse aggregates are scarce and depleting very fast as the construction activities are increasing day by day. Therefore, these two important issues have to be sorted out very urgently. Both problems can be mitigated by utilizing the concrete rubble obtained from C&D waste as recycled aggregate (RA) in concrete and implemented all over the world.

Now-a-days, sustainable constructions, environmental problems and protection of natural aggregate resources are the crucial issues in the construction industry. Therefore, the present research work aims to utilize the maximum possible extent of recycled aggregate (RA) obtained from C&D waste in high-strength concrete production. The use of recycled aggregate in concrete will be an important step towards sustainable construction and the conservation of natural resources as well.
1.2 Construction and demolition (C&D) waste scenario

Construction by nature is not an environmental-friendly activity [Tam et al. (2005)]. Construction and demolition (C&D) waste has been generated whenever any construction, demolition, renovation activities and natural disasters like Tsunami, earthquake, war, and cyclones takes place [Oikonomou (2005)]. A part of this C&D waste comes from the municipal stream also. In India, the total quantum of waste from the construction industry has been estimated to be between 12 million to 14.7 million tonnes per annum out of which seven to eight million tonnes are concrete and brick waste [Waste Management World, (2012)]. Table 1 shows the quantity and make up of C&D waste per annum in India.

**Table 1.1:** Quantity and make up of C&D waste per annum in India*.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Quantity generated in million tonnes per annum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil, sand and gravel</td>
<td>4.20 to 5.14</td>
</tr>
<tr>
<td>Bricks and masonry</td>
<td>3.60 to 4.40</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.40 to 3.67</td>
</tr>
<tr>
<td>Metals</td>
<td>0.60 to 0.73</td>
</tr>
<tr>
<td>Bitumen</td>
<td>0.25 to 0.30</td>
</tr>
<tr>
<td>Wood</td>
<td>0.25 to 0.30</td>
</tr>
<tr>
<td>Others</td>
<td>0.10 to 0.15</td>
</tr>
</tbody>
</table>

(*Source: Technology information, forecasting and assessment council (TIFAC), Department of science and technology, Government of India)

The huge quantities of C&D waste, coming from different sources creating many impacts on the environment. However, some waste management options namely: i) reduce, ii) reuse, iii) recycle, iv) compost, v) incinerate and vi) landfill are most popular and widely utilized worldwide to reduce impacts on the environment [Peng et al. (1997)]. Even though, so many methods are practiced all over the world, ‘recycling’ is one of the best and most suitable strategy for protection of natural resources, environment and sustainable constructions as well. The materials like wood, plastic, steel, paper, brick, soil, thermo coal, leaves, ashes, glass etc are present in the C&D waste. Therefore, the final quality and performance of RA has been changing rapidly from source to source [Valerie and Tegguer
Hence, the RA obtained from C&D wastes have been limited to lower grade concrete applications only [Liam Butler et al. (2014)].

The quality and performance of recycled aggregate obtained from C&D waste generally depends on their separation process and condition of the separated material. The final quality and performance of RA are mainly dependent on many factors like i) the properties of parental rock, ii) source of C&D collected, iii) the age of demolished structure, iv) water cement (w/c) ratio and grade of old concrete used, v) type of cement and admixtures used, vi) the quality and quantity of adhered cement mortar present on the surface of RA, vii) the presence of other material and viii) method of separation of RA from C&D waste. However, the said factors are not that easy to predict always. These are the major weaknesses of C&D waste for utilization in concrete. Hence, researchers are utilizing RA as a partial replacement of natural aggregates in concrete.

In India, nearly 50% of Construction & Demolition (C&D) waste is being re-used and recycled while the remainder is mostly land filled because the construction industry is not aware of the effective recycling techniques and recycling possibilities [Waste Management World (2012)]. Furthermore, the Bureau of Indian Standards (BIS) does not provide any specifications or standards for practicing the recycled aggregate in construction activities. However, some countries like China, U.K, USA, France, Denmark, Germany, Singapore, Greece, Japan etc have developed some standards and specifications to practice RA in concrete.

1.3 Utilization of recycled aggregate in concrete

The utilization of RA in concrete is an effective method to conserve natural resources and save money. The utilization of RA in recycled aggregate concrete (RAC) is beneficial in all aspects. However, some issues of RA, namely: high water absorption, presence of transverse cracks, sulphate and chloride contents, impurities, adhered cement mortar, poor grading and variations in quality from source to source etc are causing problems to utilize RA in concrete [Tam et al. (2008)²]. Similarly, some drawbacks have also been found in recycled aggregate concrete (RAC). They are i) limited slump and mechanical strengths and ii) higher water absorption, sorpitivity, chloride-ion penetration, drying shrinkage, abrasion loss, creep [Kou and Poon (2012)³]. Therefore, RA is often limited its utilization in lower-grade concretes and as filling materials.
The properties of recycled aggregate are mainly dependent on the quality and quantity of adhered cement mortar present on its surface [Poon et al. (2004)\textsuperscript{a}, Etxeberria et al. (2007), Evangelista and Brito (2010)]. The crushing procedure and the dimensions of the RA have an influence on the amount of adhered mortar [Hansen and Begh (1985)]. Literature reports also conform that the cement mortar attached on the surface of recycled aggregate primarily influences the final performance of concrete in both fresh and hardened states [Neville (2009), Ryu (2002), Ajdukiewicz and Kliszczewicz (2002), Poon et al. (2004)\textsuperscript{b}]. Good quality of aggregate is one of the primary requirements of high-strength concrete [Dhir and Paine (2010)]. In literature, some of the researchers utilized RA in high-strength concrete also. However, they restricted the dosage of recycled aggregate as 20-30\% only [Limbachiya et al. (2000), Tam (2005), Dhir and Paine (2010), Kou and Poon (2012)\textsuperscript{a}].

1.4 Necessity for the present work

Concrete is one of the most important building materials [Shetty (2005)]. Concrete is mouldable, adoptable, relatively fire resistant, generally available and affordable. The properly designed and produced concrete has an excellent workability, mechanical and durability properties. Globally, 10 billion tonnes of concrete is required for construction industry in every year [Meyer (2009)]. Coarse aggregates comprises (approximately)70-80\% of the volume of concrete and exert significant influence on the properties of concrete [Dhir and Paine (2010)]. Hence, there is a need to search for an alternative coarse aggregate material to protect the natural aggregates. In this context, the utilization of recycled aggregate (RA) in concrete has been very popular method and encouraging by many countries in recent years. So far, most of the researchers utilized recycled aggregate (RA) for lower-grade concrete applications and for un-important works because of variations in quality of RA from source to source and the presence of adherent cement mortar on its periphery [Marios et al. (2011)\textsuperscript{a}].

The utilization of RA in high-strength concrete has been reported very rarely because of the problems associated with recycled aggregates. Some of the eminent researchers utilized RA for high-strength concrete also. Majority of the past researchers have utilized un-processed recycled aggregate widely in high-strength concrete production. Because of this reason, the replacement level of natural aggregates with RA has been limited to 20\% only [Limbachiya et.al (2000)]. Some authors utilized processed recycled aggregates (PRA) also, but they used
normal mixing approach [Shima (2004)]. Hence, the results are not that much impressive. Some researchers produced high-strength concrete with un-processed recycled aggregate by utilizing two-stage mixing approach [Tam (2005)]. However, the dosages of RA in concrete was limited to 30% only.


Similarly, some more processing techniques have suggested in literature to improve the performance of RAC. They are i) straight-forward mechanical grinding [Dhir and Paine (2010)], ii) heating and rubbing [Tateyashiki et al. (2002), Muller and Linss (2004)] and iii) eccentric–shaft rotor method etc. However, some initial trials at the University of Dundee, U.K., have shown that these do indeed improve RA performance, but these techniques are not yet practiced in full-scale experimentation of RAC [Dhir and Paine (2010)].

Majority of researchers utilized un-processed recycled aggregate in various mixing techniques namely i) single-stage mixing [Dhir and Jappy (1999), Ali Abd Elhakam et al. (2012)], ii) two-stage mixing [Otsuki et al. (2003), Tam (2005), Poon and Dixon (2007), Kou et al.(2011)b] and iii) three-stage mixing [Deyu Kong et al. (2010)]. It was also found that, the two-stage mixing approach is better method than normal mixing approach to produce high-strength concrete with RA [Otsuki et al. (2003), Tam (2005), Deyu Kong et al. (2010). The research studies undertaken by Tam (2005) have concluded that, the two-stage mixing approach can also be modified further to improve the performance of recycled aggregate concrete (RAC). In this context, another ten more new variants of existing two-stage mixing approach (which was initially developed by Tam Wing Yan Vivian in 2005) have been tried in the present study to produce high-strength concrete by using processed recycled aggregate.
So far, most of the past researchers including Tam V.W.Y. have been used ordinary Portland cement. Now a day, almost 70-80% of the cement usage or production is blended cements (PPC & PSC) only in the construction industry [Indian cement review (2013)]. In literature, some researchers have also reported that, the utilization of mineral and chemical admixtures can improve the final performance of high-strength concrete with RA [Dhir et al. (1999), Li et al (2009), Deyu Kong et al. (2010)].

Furthermore, in literature, the combined procedure of both two-stage mixing approach and processing techniques to produce high-strength concrete with RA is scarce. Therefore, in this work, the processing technique (straight-forward mechanical grinding) and two-stage mixing approach (TSMA) were jointly used to improve the final performance of resultant high-strength RAC by using PPC. In this work main efforts are used, to produce high-strength concrete by using more dosages of recycled aggregate (RA) obtained from C&D waste.

1.5 Research objectives

The present research has been carried out with the objective, to utilize maximum possible quantity of recycled aggregate obtained from construction and demolition (C&D) waste for producing high-strength concrete and to decide the process/method of RAC making to achieve the aim.

The entire work is divided into two phases namely: i) influence of processing technique on RAC and ii) influence of mixing approaches on RAC with the following objectives.

- To produce high-strength concrete utilizing recycled aggregate obtained from construction and demolition (C&D) waste.
- To decide the maximum possible replacement level of recycled aggregate (RA) for producing the high-strength concrete by adopting combined processing technique and two-stage mixing approach.
- To study the influence of processing technique on the properties of high-strength RAC, to select the suitable degree of processing.
- To study the influence of two-stage mixing approaches on the properties of high-strength RAC for selecting the most appropriate variant of two-stage mixing approach.
- To solve the problems of environmental pollution, achieve sustainable construction, and conservation of natural resources of aggregates.
1.6 Research methodologies

The main purpose of the work is to utilize more quantity of recycled aggregate for the production of high-strength concrete. To achieve the main aim, first of all, the existing problems associated with recycled aggregate (RA) and recycled aggregate concrete (RAC) were studied thoroughly to understand the basic scenario of both RA and RAC. Next step, the available techniques of processing and mixing have been investigated to improve the final performance of RAC. Finally, the various properties of recycled aggregate concrete in both fresh and hardened states have been investigated by adopting both processing and mixing techniques jointly.

The information on recycled aggregate is still insufficient. The quality of RA varies from source to source. So many factors are controlling the final quality of RA. Hence, based on the extensive literature survey, a processing technique called ‘straight forward mechanical grinding’ and ‘modified two-stage mixing approaches’ have been selected to use jointly to overcome the difficulties encountered by RA and RAC in the production of high-strength concrete.

In this study, the experimental work has been carried out into two phases namely i) Influence of processing technique on the properties of RAC and ii) Influence of mixing approaches on the properties of RAC. The mix proportion of M75 grade has been kept constant in both phases. However, each time, a new mix has been prepared by replacing virgin coarse aggregates with recycled aggregates (both processed and un-processed). The percentage replacement of virgin coarse aggregate (VCA) with recycled aggregate (PRA) varies from 0 to 100% in 10 equal steps.

In the first phase, the adherent cement mortar and loose particles have been removed from RA by using straight-forward mechanical grinding technique such that, the final quality or performance of RA can be improved. Once the adhered cement mortar has been removed, then the dosages of RA can be increased in high-strength concrete. In this phase, the influence of processing technique on the various properties of high-strength RAC has been studied to select the most suitable processed recycled aggregate for making high-strength concrete.
In the second phase, the modified two stage mixing approaches have been used to improve the final performance of resultant high-strength recycled aggregate concrete (RAC). In the second phase, the influence of modified two-stage mixing approaches on the properties of high-strength RAC has been studied to select the most appropriate two-stage mixing approach.

In order to investigate the properties of recycled aggregate concrete, extensive experimentation has been planned. The various properties of concrete namely, slump, density, compressive strength, flexural strength, split tensile strength, modulus of elasticity, ultrasonic pulse velocity, water absorption, sorptivity, chloride ion penetration, drying shrinkage and abrasion resistance, SEM were studied. These innovative combined techniques of both processing and mixing may be helpful to replace natural aggregates fully or partially with processed recycled aggregates in high-strength concrete.

1.7 Lay out of the thesis

The chapter wise summary is given below

Chapter 1 describes the general introduction, construction and demolition(C&D) waste scenario, necessity of utilization of recycled aggregate (RA) in concrete are highlighted. The research objectives, research methodologies and layout of the thesis have been presented.

Chapter 2 deals with the literature related to C&D waste and its utilization in concrete, utilization of un-processed and processed recycled aggregates for making low-strength and high-strength concrete with their advantages and disadvantages. The various processing techniques and mixing approaches adopted by past researchers have been reviewed. Based on the review of literature, the objectives of the research have been formulated/decided.

Chapter 3 describes the processing technique and two-stage mixing approaches used in this work. A processing technique called ‘straight-forward mechanical grinding’ has been introduced to produce processed recycled aggregates (PRAs). The production process of four varieties of PRAs by using Los Angeles abrasion drum has been described. They are termed as PRA (0-RVS), PRA (200RVS), PRA (500RVS) and PRA (700RVS). Furthermore, ten new variants of two-stage mixing approach (i.e., TSMAs) adopted in the present work have been discussed in this chapter elaborately.
Chapter 4 includes the experimental planning and testing consisting of determination of material properties, mix proportion, casting, and curing details of concrete specimens of different shapes are described in this chapter.

Chapter 5 presents the experimental results and discussions of processing technique. The influence of processing technique on the properties [viz: workability, mechanical and durability] of RAC has been discussed. The results of scanning electron microscopy (SEM) of RAC have been presented and discussed. Processed recycled aggregate [PRA (500RVS)] has been found as most appropriate processed recycled aggregate (PRA) for making high-strength concrete in this chapter.

Chapter 6 presents the results and discussions of two-stage mixing approaches. The influence of two-stage mixing approaches (TSMAs) on the properties [viz: workability, mechanical and durability] of RAC has been discussed. All the tests have been conducted by using PRA (500RVS) only. Based on the results, the TSMA-2 has been found as the most appropriate two-stage mixing approach. The experiments of all ten two-stage mixing approaches (TSMAs) have been compared with the result of RAC produced by normal mixing approach (NMA).

Chapter 7 summarizes the general conclusions. Part (a) of the chapter presents the conclusion with respect to ‘influence of processing technique on the properties of RAC’. Whereas the conclusions with respect to Influence of mixing approaches on the properties of RAC have given in part (b). Moreover, the recommendations from this work and scope of future work have been presented in this chapter.