IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 5 Ver. VII (Sep. - Oct. 2016), PP 39-45
www.iosrjournals.org

Fabrication of Green Bricks Utilizing Sustainable Recycled Fine Aggregates

Neeraj Jain*, A. K. Minocha and Mridul Garg
EST Division, CSIR-Central Building Research Institute, Roorkee-247667, India

Abstract: *The objective of the present research is fabrication of bricks by the incorporation of recycled fine aggregate obtained from crushing of waste concrete and evaluation of the physical and mechanical properties of bricks. The natural fine aggregate and stone dust were replaced by recycled fine aggregate at a level of 50, 75 and 100 % for fabrication of bricks. Properties like Bulk density, water absorption and compressive strength were evaluated after a period of 28 days of curing and discussed. At 50 % replacement, maximum compressive strength of 6.37 and 7.68 MPa has been observed for natural fine aggregate and stone dust respectively and it is 8.7 and 25.6 % higher than respective controls. The results of compressive strength are encouraging using stone dust as fine aggregate as compared to river sand. Further, it has also been observed that the compressive strength and bulk density of all the bricks fabricated using recycled fine aggregates meets the 28-day target strength as per IS: 1077 and was not less than 5.0 MPa in any case.*
Keywords: *Recycled fine aggregates, molded bricks, compressive strength, stone dust, water absorption, bulk density*

I. Introduction

Demand of natural resources and energy has increased many folds with exponential increase in population and urbanization. Construction industry is the major source of solid waste production which consists of about 50 % of the total waste generated and consumes about 40 % of the natural aggregates [1-2]. Preservation of the environment and conservation of the rapidly diminishing natural resources should be the essence of sustainable development. The disposal of this waste has become a severe social and environmental problem all over the world. The possibility of recycling the waste from the construction sector is thus of increasing importance [3-5]. Besides benefits like environmental protection and conservation of natural resources, shortage of land for waste disposal and increasing cost of waste treatment are the principal factors driving the recycling concept [6]. Construction and demolition (C & D) wastes are normally composed of concrete rubble, bricks and tiles, sand and dust, timber, plastics, cardboard and paper and metals. Concrete rubble usually constitutes the largest proportion of C & D waste which after separation, crushing and grading can be utilized for as a substitute for natural coarse aggregate in concrete or as a sub base layer in pavements. This type of recycled material is called recycled aggregates [4]. The recycled aggregate has been successfully utilized in some European and American countries for production of environmental friendly concrete for construction having similar mechanical and durability properties to those of conventional concrete [7].

Production and utilization of recycled aggregate are common practice in construction industries of countries like USA [8], Australia [9], and Japan [10]. According to 2010 European Aggregate Association Annual Review report [11], Germany is the greatest producer of recycled aggregate recycled aggregate, with a production of about 60 million tonnes followed by UK, Netherlands and France with about 49, 20 and 17 million tonnes respectively. Extensive research has been carried out over past two decades on the viability of recycled aggregates in the production of structural concrete. Most of the work on using recycled aggregates in concrete has focused on replacing the coarse aggregate and the effect on mechanical strength and durability performance of concrete are now reasonably well known [12-17]. However, the fine fraction of these recycled aggregates has not been the subject of through studies because of their higher water absorption. This renders the control of free water-to-cement (w/c) ratio and results in a higher shrinkage and creep of the hardened concrete. Evangelista and de Brito [18-19] has reported that fine recycled concrete aggregates does not jeopardize the mechanical and durability of the concrete for replacement ratios up to 30 %. Khatib's results [20] indicate that once fine recycled aggregate introduce in to the mix, their effect on compressive strength remains constant for incorporation ratios between 25 % and 75 %.

Further, Poon et al. [21-22] suggested that the disadvantages of using recycled fine aggregates in structural concrete can be avoided making mechanized molded concrete blocks and bricks. This is because of combined vibrating and compaction action and a minimal amount of water is needed to make the mixture fluid enough to be fed in molding machine. Several workers conducted studies on the successful utilization of crushed brick fine aggregates for development of concrete [1, 23], solid cement bricks [24], paver blocks [25] for different levels for replacement.

In India, about 14.5 MT of solid wastes are generated annually from construction industries and about 25 % of it is recycled and utilized in building materials [26]. A few works has been carried out to explore the utilization of the remaining C & D waste for development of value added products. Presents laboratory investigations deals with the feasibility studies of fabrication of non modular bricks using fine recycled concrete aggregates as a replacement of natural fine aggregate (river sand) and stone dust used as fine aggregates.

II. Materials And Methods

Cement

Ordinary Portland Cement (OPC) of 43 Grade conforming to IS: 8112:1989 [27] was utilized as binder with surface area of 3220 cm^2/g and specific gravity of 3.14. Typical chemical composition of OPC analyzed by WDXRF (S8 Tiger, Brucker, Germany) and results are shown Table 1.

Table 1: Typical composition of ordinary Portland cement

Chemical Composition (%)											
CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	K_2O	Na_2O	TiO_2	BaO	P_2O_5	Others
64.34	19.90	4.30	4.24	2.88	2.04	1.05	0.31	0.33	0.25	0.13	0.23

Fine aggregates

Natural fine aggregate (NFA) and stone dust were used as fine aggregates for fabrication of bricks and collected from local resources. Samples of demolition waste were collected from sorting facility of Municipal Corporation of Delhi, India which consists of concrete, bricks, stones, gravel, silt etc. After sorting, concrete waste was crushed in a jaw crusher to obtain a well graded recycled coarse aggregate (RCA) for maximum 10 mm to 4.75 mm nominal size as per IS 383: 1970 [28]. The fine fraction passing from 4.75 mm sieve obtained during crushing of waste concrete was used as recycled fine aggregates (RFA) for replacement of natural fine aggregates (NFA) and stone dust. The particle size distribution of natural, recycled fine aggregates and stone dust have been shown in Fig. 1 along with minimum and maximum limits of grading specified in IS: 383: 1970. The physical properties of fine aggregates have been determined as per IS 2386: 1963 and are shown in Table 2 which indicate that RFA is coarser than NFA and stone dust. Sieve size of NFA is within the limit of IS: 373 and falls in Grading Zone II. The scanning electron micrograph (SEM) of NFA, RFA and stone dust are shown in Fig. 2a,2b and 2c respectively.

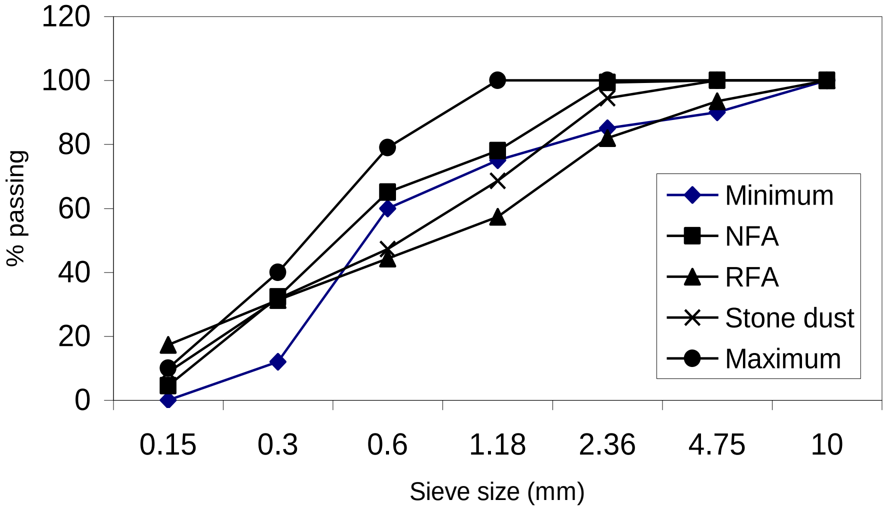

Fig.1: Particle size distribution curves of fine aggregate

Table 2: Physical properties of natural and recycled fine aggregates

Parameters	Natural fine aggregate	Recycled fine aggregate	Stone dust
Fineness modulus	2.38	4.10	2.48
Specific gravity	2.68	2.49	2.74
Water absorption (%)	0.62	5.90	4.50
Bulk Density (kg/m^3)	1490	1240	1510

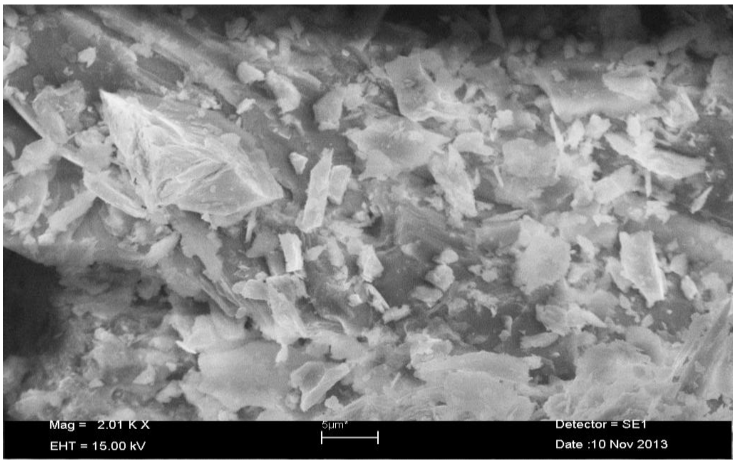

Fig. 2a: SEM of river sand (NFA)

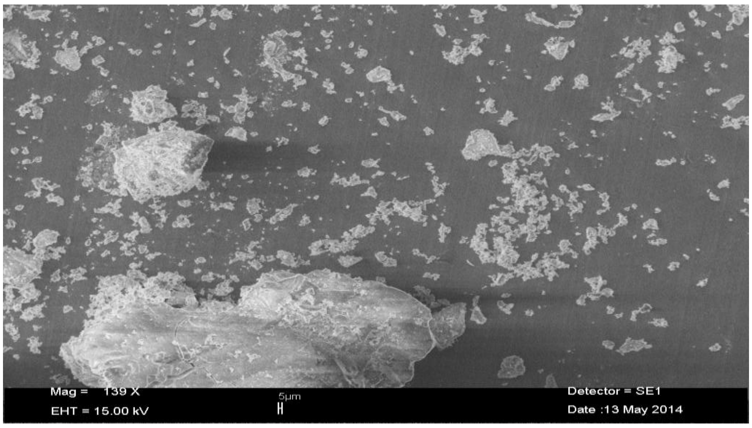

Fig. 2b: SEM of recycled fine aggregate (RFA)

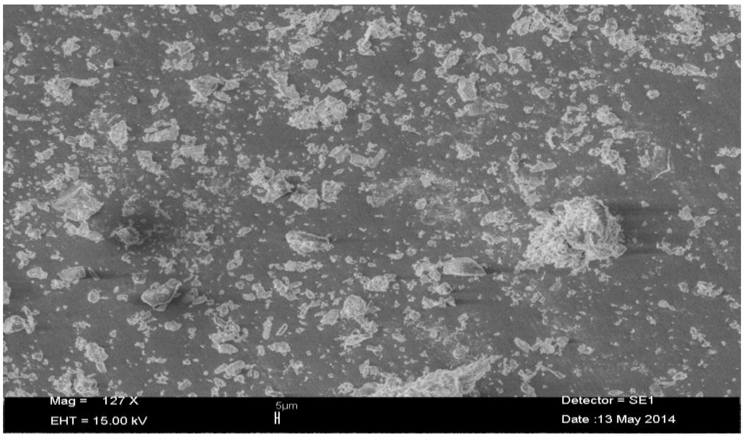

Fig. 2c: SEM of stone dust

Mix proportions

For fabrication of bricks, cement and fine aggregates were used in a proportion of 10 : 90 % by weight and fine aggregate was replaced to 50 and 75 and 100 % by recycled fine aggregate. The mix compositions and their designations used for controls, replacement of natural fine aggregate and stone dust at various level of replacement are shown in Tables 3. A perusal of Table 3 shows that control mixes prepared using 100 % natural fine aggregates and stone dust were designated as NFA100 and SD100 respectively, while the mix containing 100 % of recycled fine aggregate was designated as RFA100. The mixes having replacement of NFA and stone dust by 50 and 75 % of RFA are designated as NFAR50, NFAR75, SDR50 and SDR75 respectively. The proportion of cement, NFA and RFA for NFAR50 and NFAR75 10 : 45 : 45 and 10 : 22.5 : 67.5 % by weight. When stone dust was utilized as fine aggregate, the proportion of cement, stone dust and RFA was also same as in case of NFA. In all the mixes water was added equivalent to the consistency of the respective mix and is also shown in Table 3.

Fabrication of bricks and curing

The bricks of size 225 mm x 106 mm x 76 mm were fabricated as per specification of IS:1077 : 1992 [30] by mixing different proportions (Table 3) of cement and fine aggregates using vibration-compaction technique with a vibration time of 15 sec. Water was added equivalent to consistency. The bricks were removed from the mould, placed at room temperature for 24 h and then cured at a relative humidity of over 90 % at room temperature (25±2^{o}C) for 28 days. The cured bricks were tested for physical and mechanical properties as per procedure given in IS 3495 : 1992 [31]. A photograph of fabricated bricks using 100 % recycled fine aggregate has been shown in Fig. 3.

Physical and mechanical properties

The properties of bricks like water absorption and compressive strength were determined following the procedure laid down in IS: 3495 [31] for burnt clay bricks. Water absorption is the measure of permeability and porous nature of hardened specimen. The samples of brick were dried in a ventilated oven at a temperature of 105±2^{o}C till it attains substantially constant mass. After cooling the specimens to room temperature it was weighed and immerse in water for 24 hours. After removal from water, it was allowed to drain for 1 min by placing them on a 10 mm wire mesh, and visible water was removed with a damp cloth and immediately weighed. Water absorption, percent by mass is calculated and the average of three specimens was reported. The bulk density in g/cm^3 was also calculated by dividing the weight of the specimen by the overall volume.

Table 3: Mix proportion of bricks using natural fine aggregates, stone dust and recycled fine aggregates

Mix designation	Proportion (%) by weight				
	Cement	NFA	Stone dust	RFA	Consistency
River sand					
NFAR0 (control)	10	90	----	----	11.0
NFAR50	10	45	----	45	12.0
NFAR75	10	22.7	----	67.5	13.0
Stone dust					
SDR0 (control)	10	----	90	----	11.5
SDR50	10	----	45	45	12.5
SDR75	10	----	22.7	67.5	13.5
Recycled fine aggregate					
RFA100	10	----	----	90	14.5

Fig. 3: Fabricated bricks using 100 % recycled fine aggregate

Mechanical property like compressive strength was determined after 28 days curing and the average values of three specimens tested for each mix were reported in the results. Before determination of compressive strength, all the specimens were stored for 24 h in water at room temperature of 25±2^{o}C, air dried and tested. A compression testing machine for determination of compressive strength and the sample was placed horizontally. The upper face of the bricks was capped by 2 sheets of 3 mm thick plywood sheet of size larger than the blocks by a margin of 5 mm from all the edges. A compression load of 14 N/mm^2/min was applied to the face until no greater load sustained by the specimen. The maximum load applied was recorded and the compressive strength was calculated by dividing the maximum load by area of the brick.

III. Results And Discussion

Water absorption

Water absorption of bricks after 24 hours was calculated and results are shown plotted in Fig. 3. A perusal of Fig. 4 shows that percent water absorption increases with increase in replaced NFA and stone dust content by recycled fine aggregate. Maximum water adsorption of 8.87 % is shown by RFA100 mix at 100 % replacement while data reveals that the water absorption at 50 and 75 % replacement of NFA and stone dust varies 9.7 to 25 % and 8.3 to 22.6 % respectively as compared to respective controls.

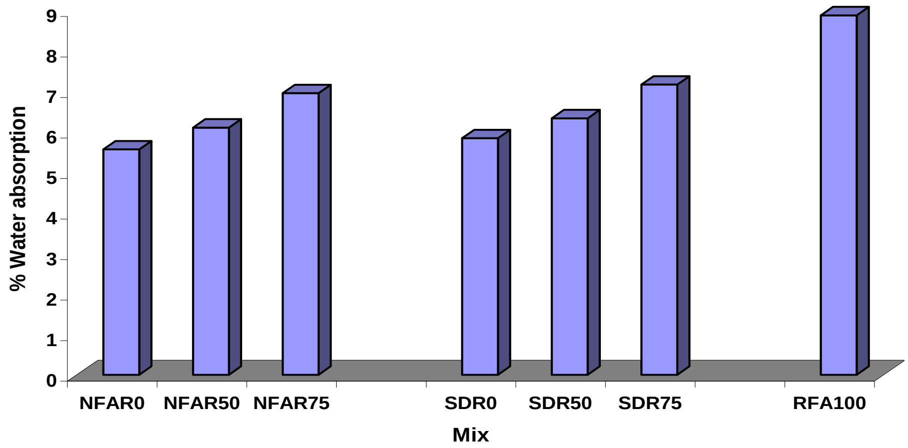

Fig. 4: Water absorption of Bricks

The high water adsorption capacity of RFA mixed samples is due to its porous nature than natural sand and stone dust and the same may be seen in SEM images (Fig. 2a to 2c). However, al the results of water absorption were in compliance to IS:1077 [31] and where water absorption shall not be more than 20 % by weight up to class 12.5 and 15 % for higher classes.

Bulk density

The test results for bulk density of bricks fabricated using NFA, stone dust and their replacement by RFA are shown in Fig. 5 which indicates linear decrease in density with increase in RFA content from 0 to 100 %. The results show that density of bricks using 50 % (NFAR50) and 75 % (NFAR75) decreases 2.5 and 4.4 % respectively as compared to control (NFAR0). The percent decrease in density of bricks using 50 % and 75 % of stone dust is 1.58 and 3.58 % respectively as compared to control (SDR0) which is slightly lower than samples prepared using NFA. Lowest Maximum density of bricks has been observed with 100 % replacement by RFA (RFA100) and it is 5.4 and 8.4 % as compared to controls (NFAR0 and SDR0 respectively). The reason for decrease in density with increase in RFA content may be explained by the substantially lower particle density of the fraction under 2.26 mm and also the increased water content. These results also corroborate previous studies carried out by Neno et al. [1] in which decrease in density has been observed with increase in content of recycled fine aggregates.

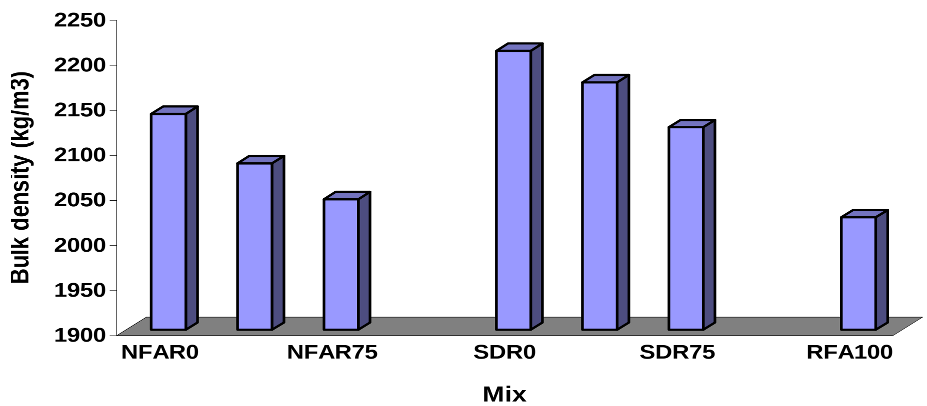

Fig. 5: Bulk density of bricks

DOI: 10.9790/1684-1305073945

Compressive strength

Fig. 6 shows the test results of the compressive strength of bricks after 28 days of curing. It has been observed that with the incorporation of recycled fine aggregate, enhancement in compressive strength takes place as compared to controls (NFAR0 and SDR0), but maximum strength is observed at 50 % replacement (6.37 and 7.68 MPa for NFAR50 and SDR50 respectively) and it is 8.7 and 25.6 % higher than control utilizing natural fine aggregate (NFAR0) and stone dust (SDR0) respectively. The strength increases slightly at 75 % and 100 % replacement of NFA (2.5 and 1 %) and stone dust (7.36 and 3 %) by RFA. In general, the results of compressive strength are encouraging by utilizing stone dust as compared to natural fine aggregate. Further, it has also been observed that the compressive strength of all the bricks prepared using recycled fine aggregates meet the 28-day target strength as per IS: 1077 and was not less than 5.0 MPa in any case.

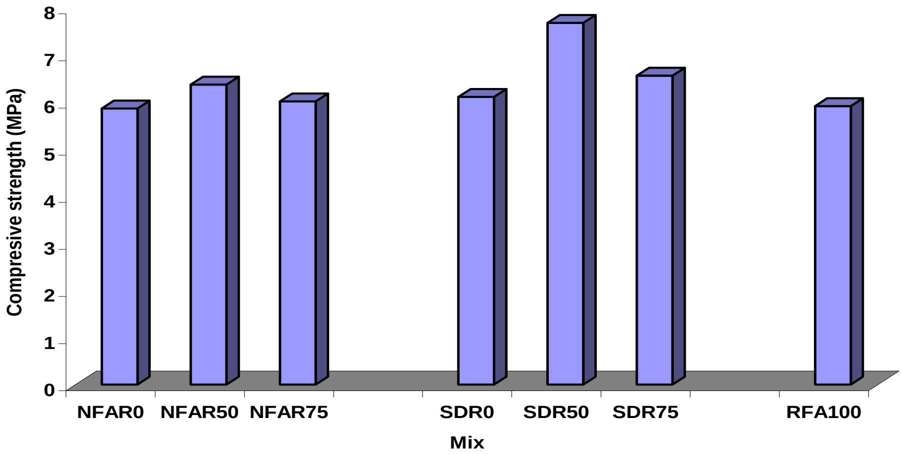

Fig. 6: Compressive strength of brricks

The increase in compressive strength with replacement of NFA and stone dust by RFA may be caused by various factors as explained by Sajedi and Razak [32]. The concrete particles have a higher specific surface and are sharper edged and more porous than natural fine aggregate (river sand), so the bond with the cement paste of the mix is better. Furthermore, this waste may contain non-hydrated cement that completes its hydraulic reactions and sets when in contact with water, leading to greater cohesion between particles and strength. Khatib [20] reported a systematic decrease in compressive strength as the fine aggregate content increases and were contrary to the present investigations. However few researchers obtained the results which were similar to the present studies. Lopez et al. [33] reported an increase in compressive strength with an increase in the replacement ratio. Hamassaki et al. [34] obtained the best compressive strength results for the mix with 100 % incorporation of concrete waste.

IV. Conclusions

Laboratory investigations carried out for fabrication of bricks using recycled fine aggregates as a replacement of natural fine aggregates and stone dust up to 100 % by weight. Based on physical and mechanical tests, the following conclusions can be drawn:

1. Water absorption of bricks after 24 hours shows that percent water absorption increases with increase in replaced NFA and stone dust content by recycled fine aggregate from 0 to 100 %. The high water adsorption capacity of RFA mixed samples is due to its porous nature than natural sand and stone dust.
2. Bulk density of bricks fabricated using replacement by RFA indicates linear decrease in density with increase in RFA content from 0 to 100 %. The reason for decrease in density with increase in RFA content may be explained by the substantially lower particle density of the fraction under 2.26 mm and also the increased water content.
3. The compressive strength of the bricks using NFA and stone dust increases at a replacement level of 50 %, 75 % and 100 % by RFA as compared to control. However, maximum increase was at 50 % replacement. It has also been observed that the compressive strength of all the bricks prepared using recycled fine aggregates meet the 28-day target strength as per IS: 1077 and was not less than 5.0 MPa in any case.
4. The higher compressive strength with replacement of NFA and stone dust by RFA may be due to higher specific surface, sharper edged and more porous nature of RFA than natural fine aggregate (river sand), so the bond with the cement paste of the mix is better. Furthermore, this waste may contain non-hydrated cement that completes its hydraulic reactions and sets when in contact with water, leading to greater cohesion between particles and strength.

5. Based on the results, it is recommended that recycled fine aggregate may be used for partial replacement of 50 and 75 and 100 %the natural sand in mortars for development of bricks. From mechanical performance point of view, a preliminary analysis gave very promising results for utilization of RFA. But for large scale applications, the studies must be fine tuned for performance of these modified mortars and more studies like susceptibility to wall cracking, water vapour permeability and water retentivity need to be find out.

Acknowledgements

The Authors are thankful to the Sh. Y. Pandey, Director, CSIR-CBRI, and Roorkee, India for his permission to publish the present work.

References

[1]. Neno C, Brito, J de, Veiga R. Using fine recycled concrete aggregate for mortar production. *Mat Res*. 2014;17(1):168-77.
[2]. Tam WYV,Gao XF, Tam CM, Ng KM. Physio-chemical reactions in recycle aggregate concrete. *J Hazard Mat* 2009;16390:823-28.
[3]. *RILEM Report 6*. Recycling of demolished concrete and masonry, Edited by TC Hansen, E & FN Spoon, UK 1992.
[4]. Poon CS, Kou SC, Lam L. Use of recycled aggregates in molded concrete bricks and blocks. *Constr Build Mat* 2002;16(5):281-89.
[5]. *RILEM Report 22*. Sustainable raw materials-construction and demolition wastes. Edited by Ch F Hendriks, HS Pietersen, The publishing Company of RILEM, 2000.
[6]. P K Mehta, Advances in concrete technology, *Concrete International*, June issue, 69-76, 1999.
[7]. Desmyster J, Vyncle J. Proceedings of the Ist ETNRecy,net/RILEM Workshop, on useof Recycled Materials as Aggregates in Construction Industry (posters). Paris: ETNRecy, net, 2000.
[8]. Construction Materials Recycling Association. Concrete Recycling.org; 2013.
[9]. Tam VWY. Comparing the implementation of concrete recycling in the Australian and Japanese construction industries. *J Cleaner Prod* 2009;17(7):688-702.
[10]. Dosho Y. Development of a sustainable concrete waste recycling system –application of recycled aggregate concrete produced by aggregate replacing method. *J Adv Concr Technol* 2007;5(1):27-42.
[11]. European Aggregates Association. Annual review 2011-2012. Brussels, Belgium; 2012.
[12]. Ismail S, Ramli M. Engineering properties of treated recycled concrete aggregate (RCA) for structural applications. *Constr Build Mater* 2013;44(7): 464-76.
[13]. Silva RV, Brito J de, Dhir RK. Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. *Constr Build Mat* 2014;65(Aug):201-17.
[14]. Rao A, Jha KN, Misra S. Use of aggregates from recycled construction and demolition waste in concrete. *Resour Conserv Recycl* 2007;50(1):71-81.
[15]. Huda SB, Alam MS. Mechanical behavior of three generations of 100% repeated recycled coarse aggregate concrete. *Constr Build Mat* 2014;65(Aug):574-82.
[16]. Rahal K. Mechanical properties of concrete with recycled coarse aggregates. *Builds & Environ* 2007;42(1):407-15.
[17]. Levy SM, Helene P. Durability of recycled aggregates concrete: a safe way to sustainable development. *Cem Concr Res* 2004;34(11):1975-80.
[18]. Evangelista L, de Brito J. Mechanical behaviour of concrete made with fine recycled concrete aggregates. *Cem Concr Comp* 2007;29(May):397-401.
[19]. Evangelista L, de Brito J. Durability performance of concrete made with fine recycled concrete aggregates. *Cem Concr Comp* 2010;32(1):9-14.
[20]. Khatib JM. Properteies of concrete incorporating fine recycled aggregate. *Cem Concr Res* 2005;35(4)763-69.
[21]. Poon CS, Kou SC, Lam L. Use of recycled aggregates in molded concrete bricks and blocks. *Constr Build Mat* 2002;16(5):281-89.
[22]. Poon Cs, Kou Sc, Wan HW, Etxeberria M. Properties of concrete blocks prepared with low grade recycled aggregates. 2009:29(9):2369-77.
[23]. Dedieb F, Kenai S. The use of coarse and fine crushed bricks as aggregate in concrete. *Constr Build Mat* 2008;22(5):886-93.
[24]. Sadak DM. Physico-mechanical properties of solid cement bricks containing recycled aggregates. *J Advanced Res* 2012;3(3):253-60
[25]. Poon CS, Dixon Chan. Paving blocks made with recycled concrete aggregate and crushed clay brick. *Constr Build Mat* 2006;20(8):569-77.
[26]. Pappu, A, Saxena M, Asolekar SR. 2007. Solid Waste Generation in India and Their Recycling Potential in Building Materials. *Build and Environ* 2007;42(6): 2311-20.
[27]. IS 8112: Specification for 43 grade ordinary Portland cement. India; *Bureau of Indian Standards*, 1989.
[28]. IS 383: Specification for coarse and fine aggregates from natural sources for concrete. India; *Bureau of Indian Standards*, 1970.
[29]. IS 2386: Methods of test for aggregates for concrete Part I-IV. India; *Bureau of Indian Standards*, 1963.
[30]. IS 1077: Common burnt clay building bricks-specifications. *Bureau of Indian Standards*, 1992.
[31]. IS 3495 : Methods of tests of burnt clay building bricks. *Bureau of Indian Standards*, 1992.
[32]. Sajedi F. and Razak H A. Effects of curing regimes and cement fineness on the compressive strength of ordinary Portland cement mortars. *Construction and Building Materials* 2011:25(4):2036-2045.
[33]. Lopez V, Llamas B, Juan A, Moran J M Guerra I, Eco-efficient concretes: impact of the use of white ceramic powder on the mechanical properties of concrete. *Biosyst Eng* 2007, 96(4): 559-64
[34]. Hamassaki L T, Sbrihhi N C and Florindo Mc. Use of rubble as aggregate for masonry mortars. In: *Proceedings of the workshop on "Recycling and reuse of waste as construction materials*." 1997: Sao Paulo:EPUSP/ANTAC:1997 107-115. In Portuguese.