UTILIZATION OF CERAMIC WASTE AS AGGREGATE IN CONCRETE: A REVIEW

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Abstract—India faces major challenges associated with waste generation due to rapid industrialization, urbanization, population growth, and this impacts on the environment and public health. In the recent era, there has been a growing trend in the utilization of crushed ceramic waste as an alternative aggregate for concrete especially in the construction industry. A huge quantity of ceramic waste is generated during processing, transportation and handling and using the said waste as aggregate in concrete production could prove as an emerging solution to maintain the environment and simultaneously increasing appreciably the compressive strength, split tensile strength and flexural strength as well as properties of concrete like resistance to the chemical attack such as sulphate attack and chloride attack. The ceramic waste aggregate (both fine & coarse) is hard and durable material than the conventional aggregates. It has good stability, thermal resistance, and mechanical & durability properties.

Keywords—Construction Aggregate, Construction & Demolition Waste, Ceramic Waste Aggregate, Compressive Strength, Split Tensile Strength, Flexural Strength, Water/Cement Ratio.

I. INTRODUCTION

In recent constructions, the consumption of ceramic materials is increasing day by day in the form of tiles, sanitary fittings, electrical insulators, etc., which changes into wastage due to its brittle nature, these waste materials are not reusable and recyclable due to the physical and chemical structure. Increased construction activity and continuous dependence on conventional materials of concrete making are leading to scarcity of natural aggregates and increased construction cost.

Ceramic waste is dumped away which results in environmental pollution, in addition to forming dust and threatening both agriculture and public health.

Ceramic Tile Aggregates [CTA] as it is easily available and cheaper than Natural Aggregates [NA], also the latter needs mining whereas no such process is required in case of CTA.

In addition to this, use of CTA is an effective economic measure in reducing cost of concrete, maintaining the environment clean, waste management i.e. safe disposal of Ceramic Waste, decreasing the consumption of natural raw materials alongwith improved concrete properties.

A. CONSTRUCTION AGGREGATE DEMAND:

World Construction Aggregate Demand (Million Metric Tonnes)					
				% Annual Growth	
Item	***2007***	***2012***	***2017***	***2007-2012***	***2012- 2017***
Construction Aggregate Demand	30300	40150	53200	5.8	5.8
North America	3800	3050	3750	-4.3	4.2
Western Europe	3275	2550	3000	-4.9	3.3
Asia/Pacific	17350	27000	36500	9.2	6.2
Other Regions	5875	7550	9950	5.1	5.7

Table: 1 World Construction Aggregate Demand

[Source: http://www.aggbusiness.com/]

B. CONSTRUCTION & DEMOLITION WASTE:

A large quantity of wastage is produced annually in all countries. In particular, Construction and Demolition (C&D) wastes contribute the highest percentage of wastes worldwide about 75%. Furthermore, ceramic materials contribute the highest percentage of wastes within the C&D wastes about 54%.

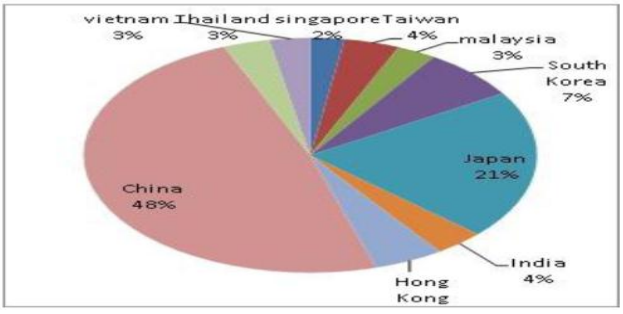

Figure: 1 Construction & Demolition Waste [Asian countries] [May 2008]

[Source :(Asian Institute of Technology, 'Report on reduce, reuse and recycle (3R) practices in construction and demolition waste management in Asia', Thailand, May 2008, 81 p.)]

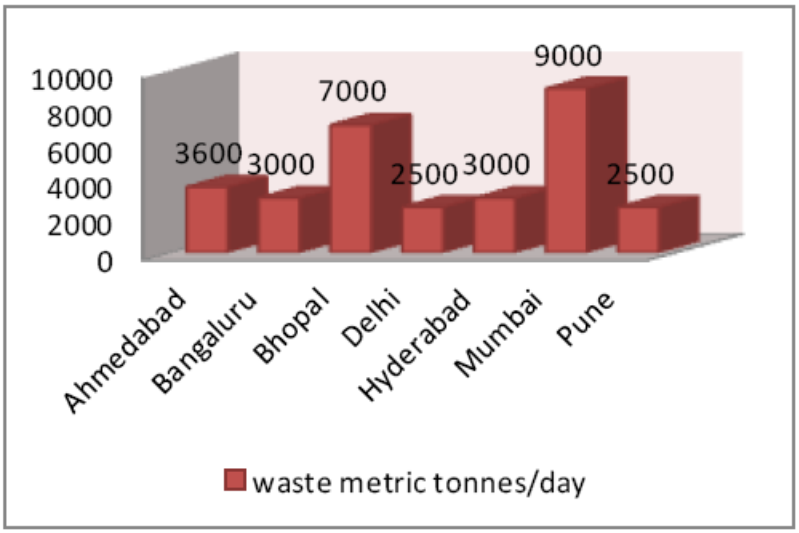

Figure: 2 C&D Waste production/day in Indian Cities [Year 2008]

[Source: http://www.nexusnovus.com]

C. CERAMIC WASTE:

About 30% of daily production of ceramic materials in India change into wastage and this amount reaches to millions tonnes per year. Presently this waste is not recycled in any form. Therefore, they are useless in practice and cause environmental and disposal problems. However, the ceramic waste is durable, hard and highly resistant to biological, chemical and physical degradation. The properties of these materials make them a good and suitable choice to be used in concrete. The use of waste ceramic tiles in concrete effects the properties of concrete, and makes it economical and also solves some of the disposal problems.

One of the worlds most consumed construction material is concrete. Manufacturing of concrete depends to a great extent on availability of cement, fine and coarse aggregate.

The cost of these raw materials required for concrete production has increased rapidly over time. The negative impact of the ever rising requirement for concrete involves ecological imbalance and environmental degradation. The utilization of waste materials like Ceramic waste will not only reduce the cost of construction and even improve safe disposal of waste materials. As of now ceramic waste is being disposed of by landfill. The main reason behind this is non-availability of standards, avoidance of risk, lack of information and knowledge in using ceramic wastes in construction.

D. WORLD PRODUCTION & CONSUMPTION OF CERAMIC TILES:

TOP MANUFACTURING COUNTRIES								
S.NO.	***COUNTRY***	***2012 (Sq.m Mill.)***	***2013 (Sq.m Mill.)***	***2014 (Sq.m Mill.)***	***2015 (Sq.m Mill.)***	***2016 (Sq.m Mill.)***	***% On 2016 World Production***	***% var. 16/15***
1	CHINA	5200	5700	6000	5790	6495	49.70%	8.80%
2	**INDIA**	**691**	**750**	**825**	**850**	**955**	**7.30%**	**12.40%**
3	BRAZIL	866	871	903	899	792	6.10%	-11.90%
4	SPAIN	404	420	425	440	492	3.80%	11.80%
5	VIETNAM	290	300	360	440	485	3.70%	10.20%
6	ITALY	367	363	382	395	416	3.20%	5.30%
7	INDONESIA	360	390	420	370	360	2.80%	-2.70%
8	IRAN	500	500	410	300	340	2.60%	13.30%
9	TURKEY	280	340	315	320	330	2.50%	3.10%
10	MEXICO	231	230	230	245	267	2.00%	9.00%
	TOTAL	9189	9864	10270	10229	10932	83.70%	6.90%
	TOTAL WORLD	11226	11961	12377	12357	13056	100.00%	5.70%

Table 2: Top Manufacturing Countries

[Source / Fonte: Acimac Research dept,"World production and consumption of ceramic tiles", 5th edition 2017]

The global production of ceramic tiles during 2016-17 in the world is about 13,056 million square meters. China is the largest ceramic tiles producer (6,495 million square meters) which is 49.70% of world production as well as consumer (5,475 million square meters) which is 42.80% of world consumption. Compared to China, India ranks 2nd; accounting for 955 million square meters tiles production which is 7.30% of world production and also ranks 2nd in terms of consumption accounting for 785 million square meters which is 6.10% of world consumption.

TOP CONSUMPTION COUNTRIES								
S.NO	***COUNTRY***	***2012 (Sq.m Mill.)***	***2013 (Sq.m Mill.)***	***2014 (Sq.m Mill.)***	***2015 (Sq.m Mill.)***	***2016 (Sq.m Mill.)***	***% ON 2016 WORLD CONSUMPTION***	***% var. 16/15***
1	CHINA	4250	4556	4894	4885	5475	42.80%	12.10%
2	**INDIA**	**681**	**718**	**756**	**763**	**785**	**6.10%**	**2.9**
3	BRAZIL	803	837	853	816	706	5.50%	-13.50%
4	VIETNAM	254	251	310	400	412	3.20%	3.00%
5	INDONESIA	340	360	407	357	369	2.90%	3.40%
6	USA	204	230	231	254	274	2.10%	7.90%
7	SAUDI AREBIA	230	235	244	263	248	1.90%	-5.70%
8	TURKEY	184	226	215	234	241	1.90%	3.00%
9	MEXICO	187	187	197	218	235	1.80%	7.80%
10	THAILAND	160	180	175	192	189	1.50%	-1.60%
	TOTAL	7293	7780	8282	8382	8934	69.90%	6.60%
	TOTAL WORLD	10964	11582	12081	12177	12783	100.00%	0.05

Table 3: Top Consumption Countries

[Source / Fonte: Acimac Research dept. "World production and consumption of ceramic tiles", 5th edition 2017]

TOP EXPORTING COUNTRIES										
COUNTRY		***2013 (Sq.m Mill.)***	***2014 (Sq.m Mill.)***	***2015 (Sq.m Mill.)***	***2016 (Sq.m Mill.)***	***% on 2016 national production***	***% on 2016 world exports***	***% var 16/15***	***value 2016 (million €)***	***average export price (€/sq.m)***
1.	CHINA	1,148	1,110	1,089	1,025	15.8%	36.7%	-5.9%	4,979	4.9
2.	SPAIN	318	339	378	395	80.3%	14.1%	4.5%	2,570	6.5
3.	ITALY	303	314	316	332	79.8%	11.9%	4.8%	4,588	13.8
4.	INDIA	55	102	134	186	19.5%	6.7%	38.8%	598	3.2
5.	IRAN	114	109	112	126	37.1%	4.5%	12.5%	328	2.6
6.	BRAZIL	63	69	77	94	11.9%	3.4%	22.1%	293	3.1
7.	TURKEY	88	85	77	81	24.5%	2.9%	4.8%	463	5.7
8.	MEXICO	64	62	61	56	21.0%	2.0%	-8.2%	289	5.2
9.	UAE	58	55	54	48	66.7%	1.7%	-11.1%	278	5.8
10.	POLAND	48	42	42	46	32.4%	1.6%	9.5%	246	5.3
TOTAL		2,259	2,287	2,340	2,389	23.2%	85.5%	2.1%		
TOTAL WORLD		2,670	2,705	2,746	2,794	21.4%	100.0%	1.7%		

Table 4: Top Exporting Countries

[Source / Fonte: Acimac Research dept. "World production and consumption of ceramic tiles", 5th edition 2017]

India is the 4th largest country in the World in exporting ceramic tiles and have exported 186 Mm^2, 19.5% of National Production & 6.7% of World Exports in the Year 2016-17.

Further, USA is the top importing country for ceramic tiles and had imported 194 Mm^2, 70.8% of National Consumption and 6.9% of World Imports in the Year 2016-17.

TOP IMPORTING COUNTRIES									
S.No	***COUNTRY***	***2012 (Sq.m Mill.)***	***2013 (Sq.m Mill.)***	***2014 (Sq.m Mill.)***	***2015 (Sq.m Mill.)***	***2016 (Sq.m Mill.)***	***% on 2016 national consumption***	***% on 2016 world imports***	***% var. 16/15***
1.	USA	147	165	164	179	194	70.8%	6.9%	8.4%
2.	SAUDI ARABIA	155	170	156	188	167	67.3%	6.0%	-11.2%
3.	GERMANY	89	89	95	100	115	91.3%	4.1%	15.0%
4.	IRAQ	105	121	102	106	112	98.2%	4.0%	5.7%
5.	FRANCE	107	96	99	99	104	87.4%	3.7%	5.1%
6.	SOUTH KOREA	61	65	76	72	75	60.0%	2.7%	4.2%
7.	PHILIPPINES	38	46	53	60	75	65.2%	2.7%	25.0%
8.	UAE	52	53	54	64	59	71.1%	2.1%	-7.8%
9.	INDONESIA	37	36	46	45	57	15.4%	2.0%	26.7%
10.	ISRAEL	43	48	44	52	57	91.9%	2.0%	9.6%

	TOTAL	834	889	889	965	1,015	62.1%	36.3%	5.2%
	TOTAL WORLD	2,524	2,670	2,705	2,746	2,794	21.3%	100.0%	1.7%

Table 5: Top Importing Countries

[Source / Fonte: Acimac Research dept. "World production and consumption of ceramic tiles", 5th edition 2017]

This huge amount of productions has caused them to be among the most commonly consumed materials in the world.

II. LITERATURE REVIEWS

Md Daniyal & Shakeel Ahmad (2015) in their study on Application of Waste Ceramic Tile Aggregates in Concrete found that substitution of crushed waste ceramic tiles in concrete for Natural Coarse Aggregates ranging from 10% to 50%, the optimum value with a Water Cement Ratio of 0.5 was about 30%. The compressive strength and flexural strength of optimal concrete was found 5% and 32% higher than reference concrete respectively. The analysis also revealed that using waste ceramic tile lead to enhancing the properties of concrete.
They also concluded that the workability of the concrete is inversely affected by the increase of Water Cement Ratio and the Slump Value decreases as the tile coarse aggregate % increases, this was attributed to higher water absorption and more angular shape of the latter. The workability of concrete was high for WC ratio of 0.6 and considered appropriate whereas for WC ratio 0.4 it was found to be very low & hence inappropriate. The workability of concrete with WC Ratio 0.5 is also low but considered appropriate generally.
It was also concluded that Mass density of the concrete was inversely affected by the increase of water cement ratio & the weight of the structure can be decreased upto 3.4%, 2.7% and 3.1% for water cement ratio of 0.4, 0.5, 0.6% respectively. [1]

Amitkumar D. Raval, Dr.Indrajit N. Patel, Prof. Jayeshkumar Pitroda (2013) in their research work on Ceramic Waste: Effective Replacement of Cement for Establishing Sustainable Concrete investigated that the compressive strength of concrete and optimum percentage of the partial replacement by replacing OPC cement by 0%, 10%, 20%, 30%, 40% and 50% of ceramic waste for concrete mix ratio of 1:1.80:3.84, the Compressive Strength of M 20 grade Concrete increases when the replacement of Cement with Ceramic Powder up to 30% replaces by weight of Cement and further replacement of Cement with Ceramic Powder decreases the Compressive Strength.
Concrete on 30% replacement of Cement with Ceramic Powder, Compressive Strength obtained is 22.98 N/mm2 and the cost of the cement is reduced up to 12.67% in M 20 grade and becomes more economical without compromising concrete strength than the standard concrete. [2]

P.Rajalakshmi, Dr.D.Suji, M. Perarasan, E.Niranjani (2016) in their project on "Studies on Strength Characteristics on Utilization of Waste Ceramic Tiles as Aggregate in Concrete" studied the fine aggregate replaced by ceramic tiles fine aggregate in the range of 10% and coarse aggregate in the range of 30%, 60%, 100% by weight of M-30 grade concrete. Due to higher water absorption and irregular shape of ceramic waste aggregate, workability of ceramic aggregate concrete decreases as the percentage of replacement of ceramic waste aggregate increased. Compressive strength achieved by ceramic tiles aggregate concrete was good. The ceramic waste aggregate concrete has shown good resistance to the chemical attack such as sulphate and chloride attack and concluded that waste ceramic tiles can be used as an alternate construction material to coarse and fine aggregate in concrete. [3]

Parminder Singh & Dr. Rakesh Kumar Singla (2015) studied "Utilization of Waste Ceramic Tiles as Coarse Aggregate in Concrete" and the results indicated that except M 30 mix there was no significant effect on compressive strength of concrete in M 20 and M 25 mixes up to 20% replacement of normal 20 mm coarse aggregates with tile aggregates but beyond that, strength started decreasing gradually with increase in the proportion of tile aggregates in concrete. Mechanical properties of ceramic aggregate are similar to the natural aggregate and its behavior is similar but not same, e.g. Water absorption, crushing value and impact value, are higher than natural coarse aggregate and lower by specific gravity i.e. 2.24 g/cm3. For all concrete mixes (M 20, M 25, M 30) compressive strength of concrete decreases with increase in the proportion of replacement of natural aggregates with tile aggregates which is due to low specific gravity & higher porosity of tile aggregates as compared to natural aggregates. Tile aggregate concrete is economical as compare to conventional concrete. As an estimate for making $1m^3$ of concrete by substituting 20% normal 20 mm aggregates with tile aggregates about 16% money can be saved on total amount of 20 mm aggregates. [4]

Prof. Shruthi. H. G, Prof. Gowtham Prasad, Samreen Taj & Syed Ruman Pasha (2016) investigated Reuse of Ceramic Waste as Aggregate in Concrete as a replacement for natural coarse aggregate with 0%, 10%, 20% and 30% of the substitution and M 20 grade concrete. The results indicated that, the maximum compressive strength & maximum split tensile strength was obtained for 30% replacement of ceramic tile aggregate with natural coarse aggregate. The compressive strength and split tensile strength for 10% and 20% replacement of Ceramic Tiles Aggregates is not increased. There is little variation in the strength when compared with normal concrete. The use of tile aggregates for partial replacement of coarse aggregate in concrete has positive impact on the environment and obtaining lower costs as tile aggregates are easily available & cheaper than natural aggregates & therefore, a prospective application in construction industry & an alternative to natural aggregates. [5]

Hemanth Kumar Ch ,Ananda Ramakrishna K, Sateesh Babu K, Guravaiah T, Naveen N, Jani Sk (2015), studied the "Effect of Waste Ceramic Tiles in Partial Replacement of Coarse and Fine Aggregate of Concrete" in which waste crushed tiles were used to partially replace the coarse aggregate by 10% and 20% and tiles powder was used to partially replace the fine aggregate by 10% and 20%. It was observed that increase in tiles powder leads to the increase in strength and workability of concrete, maximum compressive strength was obtained for the mix having 20% of tile powder. For the combinations compressive strength was increased for all mixes and maximum compressive strength obtained for the mix having 10% of crushed tiles and 20% of tiles powder. The optimum percentage of coarse aggregate that can be replaceable by crushed tiles was 10%.Tile powder behaving like admixtures, which can be used to produce RMC mix. There were minor increases in workability when crushed tiles were replaced in place of coarse aggregate. [6]

M. Sekar (2017) in "Partial Replacement of Coarse Aggregate by Waste Ceramic Tile in Concrete" observed that compressive strength increase with addition of ceramic waste of 15% and beyond which there appears to be no specific enhancement in strength. The specific gravity for ceramic waste is 2.65 whereas for crushed stone is 2.70. The water absorption for ceramic waste is 1.76% whereas for crushed stone is 1.53%. The properties of ceramic waste coarse aggregate are within the range of the values of concrete making aggregates. The surface hardness of ceramic waste concrete with 15% replacement of crushed stone aggregate is 6.6 % higher than control concrete. The velocity value of ceramic waste concrete with 15% replacement of crushed stone aggregate is 4.30% higher than control concrete. The compressive strength of ceramic waste concrete with 15% replacement of crushed stone aggregate is 6.4 % higher than control concrete. It concluded that the replacement of coarse aggregate with ceramic waste upto 15% replacement reaches optimum level. In the control concrete beam the ultimate load was 610 KN. After the replacement of coarse aggregate with 15% of ceramic wastage the ultimate load was found to

be 600 KN. But 30% and 45% replacement of ceramic scrap has reduced the ultimate load to 565 KN and 550 KN respectively. Hence the optimum percentage replacement of ceramic scrap should be at 15%. [7]

V. Giridhar, H. Sudarsana Rao, P. Suresh Praveen Kumar (2015) "Influence of ceramic waste aggregate properties on strength of ceramic waste aggregate concrete" (2015) concluded that Water absorption of ceramic waste aggregate is slightly higher than of natural coarse aggregate & Mechanical properties such as Impact value, Crushing Value and Abrasion value of ceramic waste aggregate are slightly higher than those for natural coarse aggregate. However all values are less than 30%, hence ceramic waste aggregate can be safely used in concrete composition as alternative material for coarse aggregate. It was concluded that 40% of replacement can be safely used in concrete composition without considerable loss of compressive strength. The split tensile strength of ceramic waste aggregate concrete decreased with increase of replacement level. However the decrease was only 6.2% up to 20% replacement, which was marginal, therefore, it was concluded that 20% replacement can be safely used in the M 20 grade concrete from tensile strength consideration. [8]

IV. CONCLUSION

From the in-depth investigation and study of the subject, it had been concluded that a constant research work is required on the utilization of waste materials viz. Construction and Demolition Waste (CDW) especially Ceramic Waste [CW].

The ceramic waste aggregate had the potential to replace Natural Coarse &/or Fine aggregate in concrete as its physical properties are well within the range specified by IS: 383-1970. Hence, the ceramic waste aggregate can be safely used in the concrete composition.

It had been concluded that Substitution of crushed waste ceramic tiles in concrete for Natural Coarse &/or Fine Aggregates lead to enhancing the properties of concrete. It causes a decrease in unit weight and helps in load bearing capacity of the structures. The ceramic tile aggregates didn't caused any remarkable negative effect on the properties of concrete in addition to cost effective and environment-friendly measure.

Finally, it can be concluded that Ceramic Tile Aggregates [CTA] is an appropriate concrete material for substitution into concrete composition based on its properties & associated benefits & might prove techno-economically feasible and viable solution for the construction industry.

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