Ceramic waste in concrete - A Review

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Abstract:- Use of hazardous waste in concrete will lead to green environment. The concrete made so is called sustainable concrete which can also be called as Green concrete. Production of by-products and waste are increasing rapidly which need proper disposal , it's recycling and reuse is necessary for protection of environment, reduction in dependency on natural materials, reduction in CO_2 and making concrete efficient and economical. The importance of sustainable concrete has become considerable for academia and industries. Ceramic industry in India has grown to approximately 750 million meter^2 production [1]. During manufacturing process and transpiration lots of ceramic product brake and ceramic waste generated every year. Ceramic products made of glazes, stains and clay which contains toxic metals like Antimony, vanadium, cadmium, copper, cobalt, lead, manganese, chromium, selenium and barium [2]. Ceramic wastes is mostly used for landfilling which makes neighboring land unfertile and contaminate groundwater. The objective of this investigation is to study and evaluation of the effects of the recycled ceramic as fine, coarse aggregate and ceramic fume as replacement for conventional material on the properties of concrete and cement matrix. In this study the effect of the replacement of conventional material with ceramic waste on the properties of concrete such as workability, Compressive strength, flexural strength, modulus of elasticity, split Tensile strength, Adhesive strength are studied in depth.

Keywords – Green Concrete, Ceramic waste, recycled ceramic aggregates, Ceramic fume, floor tile

I. Introduction

Construction industry play vital role in development of infrastructure of any region. Concrete is being used as prime material for construction which makes concrete most consumed manmade material on earth. Concrete consist natural aggregates (Fine and Coarse) and binder (mostly cement). Consumption of natural resources increasing proportionately to civilization development and unbalanced consumption of natural resources will lead to their exhaustion. Cement industry is one of the largest producer of greenhouse gases like CO_2. Cement industry contribute about 6% of Global CO_2 emission. For the production of per ton cement 1.57 tons of clinker consumed which contain mainly Limestone, clay and shale etc. and its source is nature [3]. Industrial wastes have continued to increase due to the continuous demand of resources use by humans for different activities. Some of these wastes are hazardous. Some wastes or by-product have been successfully utilized as alternative construction material. Ceramic waste have a potential to be utilized as a partial replacement of construction materials. The ceramic industry has a long history, the first instance of functional pottery vessels being used for storing water and food, to be around since 9,000 or 10,000 BC. In 2008 India was the 24th larger ceramic trading nation in the world and India imports ceramic of worth US$ 317.5 million [4]. India produced approx. 600 million square meters ceramic in 2011-12 [4] which increase to approx. 750 million square meters in 2015-16 [1].A ceramic is an inorganic, non-metallic, solid material it's raw material contains clay minerals such as kaolinite and alumina, modern ceramic materials contains silicon carbide and tungsten carbide. Ceramic materials have been used for a long time for multiple uses like making goods such as tableware (crockery, cutlery etc.), sanitary ware and high voltage electric insulators. Ceramics are normally used as a building materials too. Ceramic floor, tiles and various clay building brick are example of it. This paper presented a review of the use of ceramic materials in construction industry as partial replacement of conventional materials and cement focus on concrete making.

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II. Literature review

The general features of a few selected experiments researches related to the properties of recycled ceramic aggregates are discussed here in after.

Alves et al. [6] studied the replacement of 0%,20%,50% and 100 % of total natural aggregate volume with recycled aggregate (recycle brick and sanitary ware aggregate) for determination of its mechanical properties i.e. workability, Fresh density, compressive strength , split tensile strength, modulus of elasticity, abrasion resistance and influence of superplasticizers.

Wioletta et al. [7] Studied about the properties of cement matrix modified with ceramic waste by the addition of ceramic filler (10%, 15% and 20% of cement mass) with Mortar and tested its consistency retention, workability retention, shrinkage test, freeze-thaw resistance test, flexural and compressive test (2,7,14,28 and 56 days) .

Jiménez et al. [8] tested the replacement of natural fine aggregate with ceramic waste in masonry mortar with the replacement of fine aggregate (0%, 5%, 10%, 20% and 40%) of natural sand with ceramic recycled fine aggregate in a ratio of 1:7 volumetric cement-to-aggregate.

Katzer [9] did the strength performance comparison of mortar made with waste fine aggregate and ceramic fume with exchange of cement by ceramic fume

(0%,10%,20%,30%,40% and 50%) along with w/c ratio equal to 0.50, 0.55 and 0.60 for each % group of concrete and tested consistency of fresh mix, density, compressive strength and flexural strength.

Medina et al [10] tested sanitary ceramic wastes as coarse aggregate in eco-efficient concretes as partial replacement of natural coarse aggregate with ceramic coarse aggregate (15%, 20% and 25%) and performed consistency test and Hardened concrete properties (Mechanics and microstructures) like Compressive strength, X-ray Diffraction (XRD) and X-ray microanalyses (EDX).

Hunchate et.al [11] tested the Compressive strength and split tensile strength of concrete with ceramic waste aggregate as a replacement of natural coarse aggregate by ceramic waste aggregate at 0%, 20%, 40%, 60%, 80% and 100%.

Raval et al. [12] studied the replacement of OPC cement replaced by ceramic waste 0%, 10%, 20%, 30% 40%, & 50% by weight for M-30 grade concrete.

Tavakoli et al. [13] tested the properties of concrete made with ceramic waste as the substitute for coarse aggregates with 0 to 40 percent and for sand with 0 to 100 percent of substation.

Anderson et.al [14] tested the 20%, 25%, 35%, 50%, 65%,75%,80%, and 100% replacement of natural aggregate with ceramic coarse aggregate in 40 Mpa concrete mix.

Mandavi et.al [15] tested the 10%, 20%, 30%, 40% and 50% replacement of natural sand with waste ceramic tiles and prepared M25 grade concrete.

III. Aggregates' properties

Jiménez et al. [8] studied the properties of natural siliceous sand and rubble partition walls composed of red ceramic brick. It's reported that water absorption 0.79% for natural aggregate and 9% for recycled ceramic aggregate and dry density 2.14 gm/cm^3 of ceramic waste which was lower than natural fine aggregate (2.63 gm/cm^3). Medina et al [10] found that the natural coarse aggregate has lower water absorption than coarse sanitary ware aggregate. Bulk density is higher for coarse natural aggregate (2630 kg/m3) than for coarse recycled ceramic aggregate (2390 kg/m3). Hunchate et.al [11] studied the properties of natural fine aggregate and ceramic waste aggregate obtained from electric transformers which was used as insulator. It's reported that water absorption ceramic waste 0.18% and that of natural aggregate was 0.10%. Higher water absorption for ceramic aggregate is because of pore structure and clay content. It's reported that density of coarse ceramic aggregate 1188 kg/m^3 and natural crushed coarse aggregate 1425 kg/m^3. It's reported that specific gravity of coarse ceramic aggregate 2.50 and natural crushed coarse aggregate 2.68. Tavakoli et al [13] studied the properties of natural sand and natural coarse aggregate for reference concrete and Ceramic aggregate and ceramic sand as replacement material. It's reported that density of ceramic sand and aggregate 2.35 g/cm^3 and 2.33 g/cm^3 respectively which is lower than natural sand and aggregate 2.6 g/cm^3 and 2.55 g/cm^3 respectively. Water absorption of ceramic sand and aggregate is 7 and 4.8 respectively which is higher than natural sand and aggregate 2 and 0.2 respectively. Anderson et.al [14] studied the properties of floor tiles obtained from demolition site as ceramic waste for the replacement of coarse aggregate. It's reported that some properties of studied material like Density 2278 kg/m^3, Water absorption 1.4 and Crushing value 11.9%. Mandavi et.al [15] studied the properties of crushed vitrified ceramic tiles and find water absorption 0.08% and bulk density 2.35 gm/cc.

IV. Properties of ceramic waste Concrete

The results of the tests performed to determine the properties of concrete made with recycled ceramic waste aggregate and ceramic fume are discussed next.

A. Workability

Workability of concrete is the ability to work with concrete that can be handled without segregation, placed without loss of homogeneity and can be compacted with specified effort. Wioletta et al.[7] find that the highest liquid consistency was achieved for the reference mortar incorporation of an increasing amount of ceramic filler results in a lower mortar consistency and plasticity. The consistency and plasticity test results show that as the ceramic filler content in mortar increased the time of workability retention increased, too. This is because of larger water absorption of sanitary ceramic filler. Even partial replacement of coarse aggregate with 4/12.5 mm crushed ceramic aggregate required extra mixing water to achieve the desired consistency. Katzer [9] find the linear relation for all w/c (0.5, 0.55 and 0.60) ratio and the characterized by very good correlation. Hunchate et.al [11] find that slump value decreased when replacement of coarse natural aggregate by recycled coarse ceramic aggregate increased at constant w/c ratio for all mixes but at 20% , 40% and 60%,80% slump value comes same i.e. 110mm and 100 mm respectively. Tavakoli et al. [13] observed that the slump value decreases as ceramic sand replacement percentage increases up to 50 percentage after that start increasing. Anderson et.al [14] reported that slump value increased up to 35% replacement then start decreasing and finally at 100% replacement it achieve higher slump value. Mandavi et.al [15] reported that slump value decreases as replacement percentage increases. At 10% replacement slump value is 75 and at 50% replacement slum value decreases to 31.

B. Density

Katzer [9] find that density of ceramic is 1.8 g/cm^3 which is so less than density of cement (3.18 g/cm^3) that's way more the cement replacement by ceramic fume smaller the density of the mortar. Hunchate et.al [11] find that density of fresh concrete decreases with increase in replacement of ceramic coarse aggregate i.e. 2436 kg/m^3 to 2328 kg/m^3 with 0 % and 100% respectively replacement of ceramic coarse aggregate. Tavakoli et al. [13] find that the density of fresh concrete decreases as replacement of ceramic sand increases which is 2441 kg/m^3 to 2385 kg/m^3 with 0 % and 100% respectively

C. *Compressive strength*

Wioletta et al. [7] find that after incorporation of ceramic waste aggregate, at 2 day, compressive strength increase up to 42%, the influence become less significant with time after 56 days 11% increase were found. Jiménez et al. [8] find that the use of up to 40% replacement from ceramic waste by volume slightly improved the mechanical properties of the masonry mortar. Mean compressive strength for the five replacement levels at various curing time are approx. same for each age except 180 days. Katzer [9] find that the compressive strength of cement mortar was decreasing with increasing ceramic fume. Medina et al.[10] reported an increase in the compressive strength with increase in the replacement ratio which is because of narrower, more compact and less porosity for mixes with ceramic incorporation than for conventional concrete. Hunchate et.al [11] find that Compressive strength of concrete made of ceramic waste aggregate 32.15 MPa at 100% replacement level and 37.03 Mpa when using natural aggregate. Raval et al. [12] find that compressive strength decreases with increase in replacement of cement with ceramic waste for M 30 grade concrete average 28 days compressive strength for 10%, 20%, 30%, 40% and 50%. Replacement is 37.08, 36.08, 36.08, 3.23, 31.83, and 29.30 respectively. Mandavi et.al.[15] reported that 28days compressive strength increases as replacement up to 30% thereafter start decreasing.

D. *Flexural Strength*

Wioletta et al. [7] find that after incorporation of ceramic waste aggregate, at 2 day, flexural strength increase up to 50%, the influence become less significant with time after 56 days 12% increase were found. Jiménez et al. [8] find that flexural strength for the five replacement levels at various curing times and all the mean values of flexural strength of 7, 28, 90 and 180 day curing time are approx. same. Katzer [9] find that in 10% volume replacement of cement with ceramic fume at w/c 0.55 the highest flexural strength was reached then after flexural strength was decreasing. Anderson et.al [14] find that the flexural strength decreases 25% with 100% replacement of ceramic tile waste. The decreased adhesive property of cement to the ceramic tile aggregate leads to the overall weaker concrete.

E. *Split Tensile Strength*

Medina et al [10] find the increase in split tensile strength with increase in replacement ratio due to narrower, more compact and less porosity for mixes with ceramic content than for conventional concrete. Anderson et.al [14] reported that incorporation of ceramic tile waste increase the tensile strength in concrete except 100% replacement which show maximum 6.5% decay in tensile strength.

F. *Modulus of elasticity*

Anderson et.al [14]reported that incorporation of ceramic floor tile waste aggregate gives the maximum value for modulus of elasticity 27.4 Gpa in 100% replacement which is 26.9% higher the reference mortar which is 21.6 Gpa. Alves et al. [6] reported that as incorporation of ceramic waste increases modulus of elasticity decreases. It's reported that 33.8 % decreases at 100% replacement.

G. *Adhesive strength*

Jiménez et al. [8] tested that up to 40% by volume of natural by replacement of recycled ceramic sand did not affect the mean value of adhesive strength of mortar which is ranged between 0.37 Mpa to 0.45 Mpa.

V. Mathematical equation and correlation

In this section trend line equation and value of coefficient of correlation are presented

A. *Fresh Concrete Density*

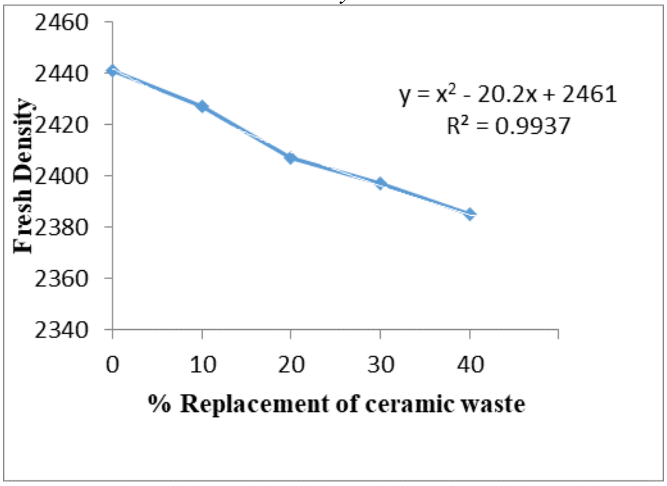

Fig.1 Fig. 2 Representation of fresh concrete density reported by Tavakoli et al. [13]

Value of coefficient of correlation (R^2) of data reported by Tavakoli et al. [13] is 0.9937. R^2 value of Wioletta et al.[7], Jiménez et al [8] , Katzer [9] and Mandavi et.al [15] comes in range of 0.91 to 0.95 which apparent be a good correlation.

B. *Workability*

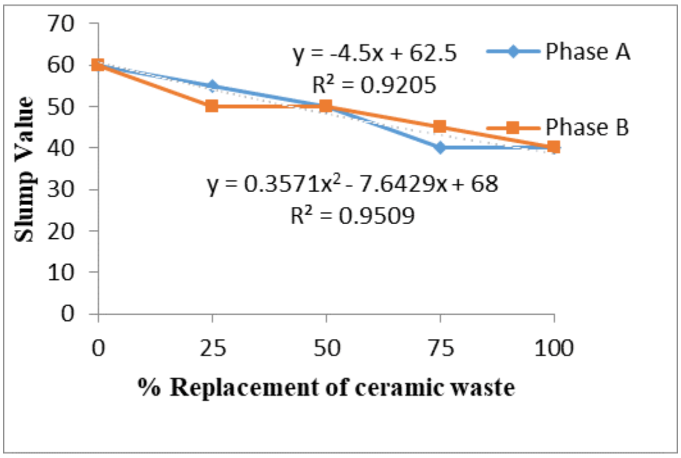

Fig. 2 Representation of slump value reported by Tavakoli et al. [13]

Value of coefficient of correlation (R^2) of data reported by Tavakoli et al. [13] are 0.9205 and 0.9509. R^2 value of data reported by Anderson et.al [14] is 0.4371 which does not apparent be a good correlation. R^2 value of Hunchate et.al [11], Jiménez et al. [8] and Katzer [9] comes in range of 0.87 to 0.98 which apparent be a good correlation.

C. Compressive Strength

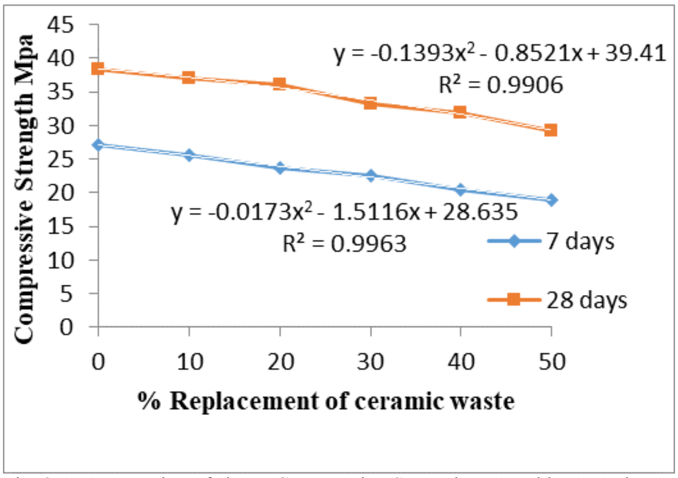

Fig. 3 Representation of slump Compressive Strength reported by Raval et al [12]

R^2 value of data reported by Raval et al [12] is equal to 0.9963 and 0.9906 for 7 days and 28 days. R^2 value of Wioletta et al.[7], Jiménez et al. [8], Medina et al [10], Hunchate et al. [11], Katzer [9] and Mandavi et.al [15] comes in range of 0.97 to 0.99 which apparent be a good correlation.

D. Split tensile strength

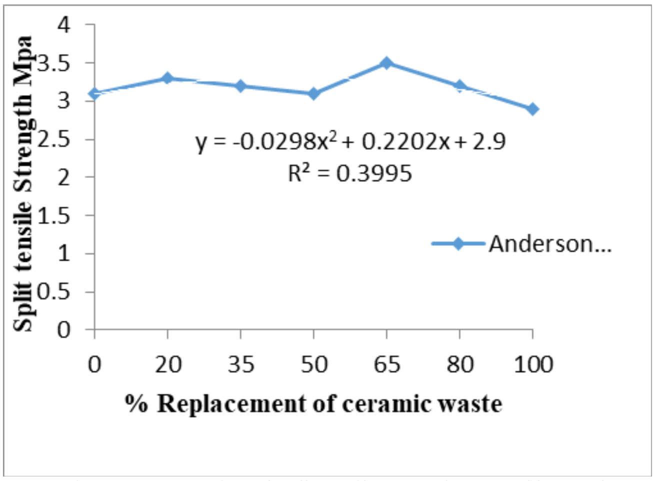

Fig. 4 Representation of Split tensile Strength reported by Anderson et.al [14]

R^2 value of data reported by Anderson et.al [14] is equal to 0.3995. R^2 which does not apparent be a good correlation.

E. Flexural Strength

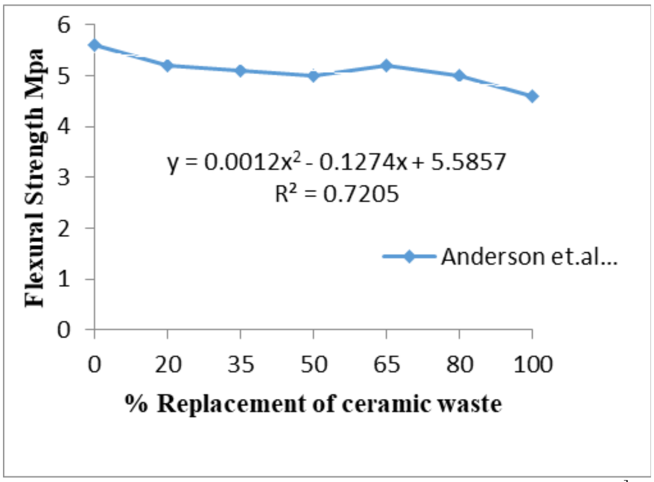

Fig. 5 Representation of Flexural Strength reported by Anderson et.al [14]

R^2 value of data reported by Anderson et.al [14] is equal to 0.7205. R^2 value of Wioletta et al.[7], Jiménez et al. [8] and Katzer [9] comes in range of 0.69 to 0.84 which apparent be an average correlation.

VI. Conclusion

The result of this investigation indicates that the use of recycled ceramic aggregate and ceramic fume as a partial replacement of conventional aggregate and binder material is certainly feasible. The studied properties of recycled ceramic concrete exhibited fairly nominal positive and negative responses with respect to replacement ratio, which is suitable for use in practice. The workability of fresh concrete decreases as replacement ratio increases. The compressive strength, split tensile and flexural strength decreases as replacement ratio increases. In conclusion, it is shown that water absorption is high in ceramic aggregate due to high porosity which also reduces the workability so presoaking is necessary. 40% replacement by volume of natural sand with recycled ceramic fine aggregate does not significantly affect the concrete properties. 25% replacement by volume of natural coarse aggregate with recycled coarse ceramic aggregate does not significantly affect the concrete properties. Replacement of ceramic fume with binder material added with the ceramic fine up to 10% does not significantly affect the concrete. The utilization of ceramic waste in concrete as binder, fine and coarse aggregate can be used easily without affecting the mechanical properties of concrete.

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