Investigation of novel sustainable concrete using optimization technique

V. Subathra Devi[1*], B. K. Gnanavel[2], P. Murthi[3], M. Madhanagopal[2]

[1]*Department of Civil Engineering, Saveetha Engineering College, Saveetha University, Chennai, Tamilnadu, 602105, India*
[2]*Department of Mechanical Engineering, Saveetha Engineering College, Saveetha University, Chennai, Tamilnadu, 602105, India*
[3]*Department of Civil Engineering, Kathir College of Engineering, Coimbatore, Tamilnadu, 641062, India*

[*]Corresponding author, Tel: (+91) 09791076767; E-mail: subidevi@gmail.com

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Abstract

Concrete industry, the largest consumer of natural resources such as water, sand and crushing stone needs to be reoriented by adopting environmental friendly and a highly sustainable technology. Concrete with ceramic industrial waste is termed as Ceracrete. The properties of the ingredients of concrete need comparison before replacing the fine aggregate (FA) and coarse aggregate (CA) by ceramic waste. River sand is used as fine aggregate and broken stone as coarse aggregate. Then the concrete mix is designed as per the IS code provision for M20 grade. Concrete cubes are cast by replacing FA and CA by ceramic waste from 0% to 50% in steps of 10% as type 1(FA replacement), type 2 (CA replacement) and type 3 (FA and CA replacement). The compressive strength and workability of three types of concrete are compared with those of the conventional concrete (0% replacement). Fine aggregate replacement by ceramic waste (type 1) shows better compressive strength than type 2, type 3 and conventional concrete. But the water absorption of type 1 concrete is higher, compared to the other types. The workability of the type 1 concrete is smaller. The optimum percentage of replacement of type 1 concrete is found by design of experiments using the Taguchi method. Concrete with good workability and higher compressive strength is observed for 6.62 % to 13.97 % of replacement of fine aggregate by ceramic waste, whereas, the water absorption for this optimum percentage of replacement is similar to that of the conventional concrete. Hence ceramic waste is used as a replacement material for fine aggregate in the field of construction after analyzing the structural properties, durability, bond strength etc., The analysis shows the higher contribution of the percentage of replacement to the improvement of workability and compressive strength. Copyright © 2017 VBRI Press.

Keywords: Ceramic, replacement, strength, workability, Taguchi.

Introduction

Several industrial by products and waste have the properties suited for production of concrete. Preservation of the natural materials will be of help in ensuring economy in the production of concrete and also in environmental protection. Conservation of primary materials, enhancement of durability in concrete structure and a holistic approach to the technology are all required for the sustainable development of concrete technology. The use of industrial waste in concrete making not only enables utilization of waste material but also helps in alleviating disposal problems. While considering a waste material as a concrete ingredient, economy, compatibility with other constituent materials and their properties are matters of relevance to be considered. The concrete which makes the environment green is considered as Green concrete. When at least 20% of the aggregate consists of industrial residual products, the resulting concrete is referred to as green type concrete. Crushed demolition waste can be used for self-compacting concrete [**1**]. Use of waste materials in concrete manufacture is highly cost effective and reduces the cost of production [**2**]. Ceramic wastes can be separated in two categories in accordance with the source of raw materials. The first one consists of all fired wastes generated by the structural ceramic factories that use only red pastes to manufacture their products, such as brick, blocks and roof tiles. The second one is all fired waste produced in stoneware ceramics such as wall, floor tiles and sanitary ware. These producers use red and white paste; nevertheless, the usage of white paste is more frequent and much higher in volume [**3**]. The wastes from the second category are introduced in concrete production. There is no adverse effect on the compressive strength of mortars in relation to river sand when ceramic waste is used as coarse aggregate [**4**]. No harmful influence with respect to the compressive strength of mortar made of the ceramic waste aggregate has been found [**5**]. Partial substitution of ceramic aggregates from sanitary ceramic waste helps getting eco-efficient concrete which can be used for structural purposes [**6**]. There is scarcity of research and lack of standards regulating the reuse of this type of waste as construction material. Reusing ceramic waste offers technical, economical and environmental advantages which are of great importance [**7**]. The rougher the aggregate surface texture used in concrete, better the bonding will be with the surrounding matrix [**8**]. Selection of the content and the particle size distribution is an important issue in predicting the performance of concrete [**9**]. Sanitary ware fine fire clay waste is used in the production of ceramic waste, which on addition, decreases moisture expansion [**10**]. Loss of slump is observed when mixing is prolonged and absorption of water is substantial by aggregates used in concrete [**11**]. The strength and water absorption characteristics can be influenced by increase in temperature, which also has a positive and strong effect [**12**]. There is an increase in shrinkage with a decrease in water absorption through increase in firing temperature of clay products due to the formation of silicate liquid phase. The liquid surface tension and capillarity helps to reduce porosity by bringing particles close together due to this phase formation. Thus flexural strength increases due to reduced porosity [**13**]. Ceramics are used as reinforcement particles to produce aluminum matrix composites. Different types of ceramic particles provide a homogenous dispersion and good interfacial bonding. Superior hardness and wear resistance are observed in ceramic reinforced aluminum matrix composite [**14**]. The total porosity in the sample determines its mechanical behavior [**15**]. The coefficient of sorptivity is of great importance for characterizing the porosity of ceramic material [**16**]. When steel is coated with ceramic, there is no surface damage, when laser is irradiated. Adhesive strength and surface hardness can be improved through laser quenching of this ceramic coated steel [**17**]. With the increase in temperature, the electrical conductivity increases for ceramics [**18**]. Ceramic material exhibits negative temperature co-efficient of resistance [**19**]. Tungsten bronze ceramics can be used as a replacement material for toxic and hazardous lead based materials [**20**]. Nano structured ceramics can be made from the four types of cellulosic waste materials viz., saw dust, waste paper, corncob and sugarcane bagasse [**21**]. The replacement of aggregates by ceramic waste shows better capillarity, water absorption, oxygen permeability, chloride diffusion [**22**]. Hence ceramic waste can be partially substituted in cement production [**23**]. Several studies have also been published on the subject of finding the viability of ceramic waste usage [**24-26**]. Here it is proposed to use the ceramic industrial waste as fine aggregate and coarse aggregate in concrete making as a partial replacement material in various percentages (10% to 50%).

Ceramics have mixed bonding, a combination of Covalent, ionic and sometimes metallic. This characterization of mixed bonding distinguishes ceramics from other metals and wax. Ceramics are materials which are not metal, plastic or derived from plants and animal. At high temperature, ceramic behaves like a viscous liquid and no longer behaves like a brittle material [**27**]. Ceramic has tubular pores through which it is able to suck liquid. When the diameter of the pore is less than 10 µm, it is called membrane. The ceramic membrane, which comprises multiple layers, requires wetting of solid surface by liquid [**28**].

Ceramics with the many advantages such as flexural strength, compressive strength, density and stiffness, corrosion resistance, biocompatibility, food compatibility, temperature resistance, thermal shock resistance, metallization, thermal expansion, thermal insulation and hardness has a variety of applications in the automobile industry, electronics, medical technology, general equipment, mechanical engineering sectors. This work deals with finding the optimum percentage of replacement of aggregate by ceramic waste, considering properties such as workability and compressive strength. The main objective of this research is to reuse the waste material left to the environment and to reduce the disposal problem. This recycling of waste ceramic material in concrete as aggregate, leads to economic construction by reducing the cost of aggregates in concrete. Moreover, the depletion of natural resources can be reduced to some extent.

Experimental

Materials

Complete knowledge of the properties of the ingredients is required for concrete mix proportioning. Cement is the binding material, which is used to bind fine and coarse aggregates together. It also fills the gap with the presence of water. Ordinary Portland Cement (OPC) of 43 grade, conforming to IS 8112-1989 was used, under the trade name as Chettinad Cement, Karur, Tamilnadu, India. Broken stone was used as coarse aggregate, which contributes more than 80 % volume of concrete. Broken stone was obtained from RPP, Erode, Tamilnadu, India. Good quality crushed stone of maximum 20 mm size was used as aggregate in concrete. Moreover, the depletion of natural resources can be reduced to some extent. Natural river sand was used as fine aggregate with fraction passing through 4.75 mm sieve and retained on 600 µm sieve, for preparing concrete. It is clean, well graded with sharp and angular grains. It is obtained from Cauvery River, Government quarry, Trichy, Tamilnadu, India. Ceramic tiles, which are left unused in construction, are broken into pieces using hammer manually. The size conforming to fine aggregate fraction and coarse aggregate fraction is segregated using IS Sieve 20 mm, 4.75 mm and 600 µm. Ceramic tiles are obtained from Kajaria tiles, Kajaria showroom, Erode, Tamilnadu, India. The purity of the above said materials are tested in the laboratory, in order to analyze the property as per Indian Standards. The accuracy of the readings is verified by the average of three measurements.

Cement

Ordinary Portland cement was used. It was tested as per guidelines of the Bureau of Indian standard (BIS – 1489 part 1). Various properties such as fineness, consistency, setting time, specific gravity are tested and the values are compared with the standards. Satisfaction of the requirements was ascertained.

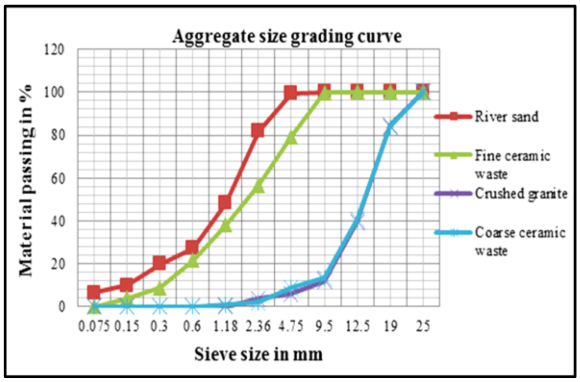

Fig. 1. Particle size distribution.

Aggregates

Various properties such as voids in sand, specific gravity, water absorption and fineness modulus of the river sand and fine ceramic waste are compared with the standard value from IS 2386 (part 3): 1963. All the properties of river sand and fine ceramic waste fall within the limits of standard values as prescribed by IS code, except for the water absorption of fine ceramic waste. The fine ceramic waste was cured as required prior to use in concrete production for overcoming this adverse effect and to ensure satisfaction of the water used for hydration of cement for the purpose. Properties such as impact, crushing, attrition, specific gravity, water absorption and fineness of the broken stone and coarse ceramic wastes were compared with the standard values. Despite the impact value of coarse ceramic waste being greater than the broken stone, it falls within the limit of IS code value. The only thing is that, the crushing strength which is higher than the code provision, for both the broken stone and coarse ceramic waste, has to be taken care of, when used in road pavements with moving loads.

Composition of ceramic waste

The chemical composition of this waste was strongly acidic in nature, with the predominance of silica and aluminum. Traces of iron oxide, calcium oxide, sodium oxide, potassium oxide and zincorium oxides alone are present. The waste does not contain chlorides, soluble sulphates or total sulphur compounds. Ceramics are intermediate in density between polymers and metal. They are anisotropic, having different properties in different directions. They are used as electrical insulators. Most of the ceramics are transparent. They are soluble in certain strong acids and strong bases. They rarely undergo electrochemical corrosion. Their mechanical properties depend on the temperature and the degree of crystallinity. Rigidity and brittleness of the ceramics depends on the temperature and the magnitude of crystallinity. Crystalline phases are brittle at a high temperature, non-crystalline phases are ductile.

Gradation of aggregates

The particle size distribution of aggregates was found as per IS 2386 (part1) 1963. Conforming to code IS: 383, the fraction from 4.75 mm to 150 µ is used as fine aggregate. The fraction from 20 mm to 4.75 mm is used as coarse aggregate. Flakiness and Elongation indices are below 15%. Particle size distribution of the conventional fine aggregate (river sand), conventional coarse aggregate (broken stone), fine ceramic waste and coarse ceramic waste are shown in the **Fig. 1**.

Mix design

As per the procedure recommended for BIS 10262 – 1982, mix ratio was designed with the test results of workability, specific gravity, water absorption and free surface moisture for the materials. Design was stipulated for a good degree of quality control and mild exposure. The mix proportions, by weight were 1: 1.409: 3.284 (cement: fine aggregate: coarse aggregate) with a water cement ratio of 0.50. The concrete mix proportions of various percentage of replacement for fine aggregate (type 1), coarse aggregate (type 2) and both fine and coarse aggregate (type 3) are shown in **Table 1**.

Table 1. Concrete mix proportions in percentage.

	Fine aggregate replacement in % Type 1				Coarse aggregate replacement in % Type 2				Fine and coarse aggregate replacement in % Type 3				
%of replacement	Cement	River sand	Fine ceramic waste	Broken stone	Cement	River sand	Broken stone	Coarse ceramic waste	Cement	River sand	Fine ceramic waste	Broken stone	Coarse ceramic waste
0	100	100	0	100	100	100	100	0	100	100	0	100	0
10	100	90	10	100	100	100	90	10	100	95	5	95	5
20	100	80	20	100	100	100	80	20	100	90	10	90	10
30	100	70	30	100	100	100	70	30	100	85	15	85	15
40	100	60	40	100	100	100	60	40	100	80	20	80	20
50	100	50	50	100	100	100	50	50	100	75	25	75	25

Test details

Using the designed mix, specimens were cast in the mould of size 150mm x 150mm x 150mm cured and then tested after 7 days and 28 days, for determining the compressive strength as per IS 516: 1959 using a universal testing machine. While casting the specimens, workability was determined using slump cone test as per Indian standard code 1199-1959.

Results and discussion

Workability test

Workability is measured using the slump cone test. The Slump value increases with increase in the percentage of replacement, since the water absorption characteristics of coarse ceramic waste are low and the entire water used for concrete mixing is taken away by the cement sand paste in abundance and only very small quantity of water is being absorbed by the coarse ceramic waste. But, as far as the fine ceramic waste is concerned, it absorbs the water used for concrete mixing and decreases the workability of concrete. Therefore, cured fine ceramic waste can be used and also some admixtures for increasing the workability of concrete. This is shown in **Fig. 2**. The workability of the entire replaced concrete is lower than the conventional concrete, whereas the coarse aggregate replacement shows better workability compared to the other two types.

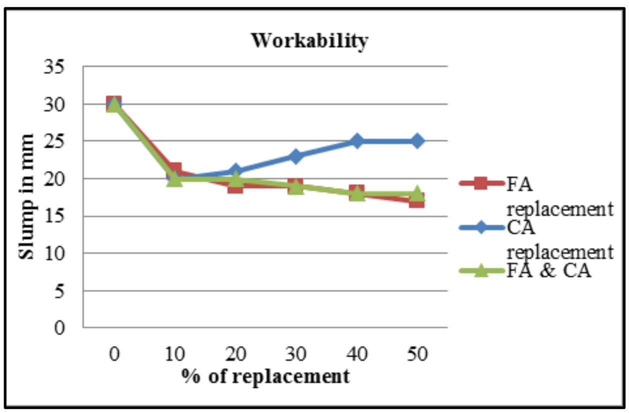

Fig. 2. Slump value for various percentage of replacement by FA and CA.

Compressive strength

The compressive strength results found after tests (7 and 28days) are shown in **Fig. 3(a)** & **(b)** in Mega Pascal (MPa). Each of these is the average of three measurements. The strength for the different percentage of replacement for conventional concrete and ceramic waste concrete for fine aggregate replacement and coarse aggregate replacement are illustrated. As the percentage of replacement increases, the compressive strength for coarse aggregate replacement, decreases for both the 7 and 28 days curing. But, for the fine aggregate replacement, compressive strength decreases up to 20 % replacement and then it increases for 7 days of curing, while for 28 days curing, compressive strength decreases beyond 10% of replacement. Therefore, higher compressive strength obtained is around 10% of fine aggregate replacement by ceramic waste. The exact percentage of replacement of aggregate by ceramic waste is found by Taguchi analysis, for ensuring higher compressive strength along with good workability.

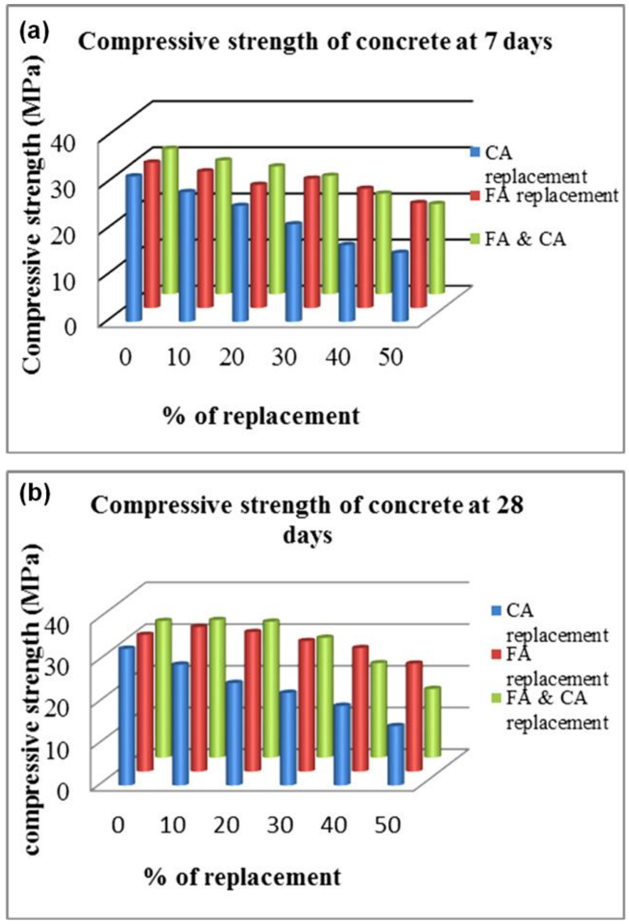

Fig. 3. Compressive strength of concrete (a) 7 days curing (b) 28 days curing.

Taguchi analysis

There are several factors which affect the strength of new concrete in real time applications. Out of the available parameters, factors such as the percentage of replacement and the type of aggregate contribute more to the compressive strength and workability in new concrete. Factors such as percentage of replacement with levels 0 %, 10 %, 20 % and type of aggregate have levels such as fine aggregate, coarse aggregate and mixture of fine and coarse aggregate are selected in these concrete mixtures. L_9 Orthogonal array full factorial experiment table for workability and compressive strength is tabulated. The order of conducting the experiments is based on the orthogonal array matrix and nine experimental runs in all are to be carried out. Based on the results obtained in the compressive strength and workability tests, fine aggregate replacement was found to be better compared to other types of replacement. Gradual increase in workability up to 10% in FA, followed by decrease was found as the fine aggregate replacement was done in steps of 10%. In practice, fine aggregate replaced material was found to be better with required workability and higher compressive strength. The objective of this present study is to get the maximum of workability and compressive strength. Hence, the S/N ratio for larger and better characteristics was selected. Experimental results of workability and compressive strength are converted into signal to noise ratio from which optimum condition was determined, corresponding to the experimental order.

Signal to noise ratio response

The SN ratio and mean values of the L_9 full factorial for workability and compressive strength responses can be calculated by larger the better condition using Taguchi analysis. The effect of each process parameter on the S/N ratio at different levels can be segregated and the mean of the S/N ratios for various levels of the process parameter is calculated by orthogonal experimental design. The optimum level of the factors for type 1 concrete has larger mean SN ratio of 27.48 for10% of replacement, which has the average SN ratio of 27.71 for larger the better condition.

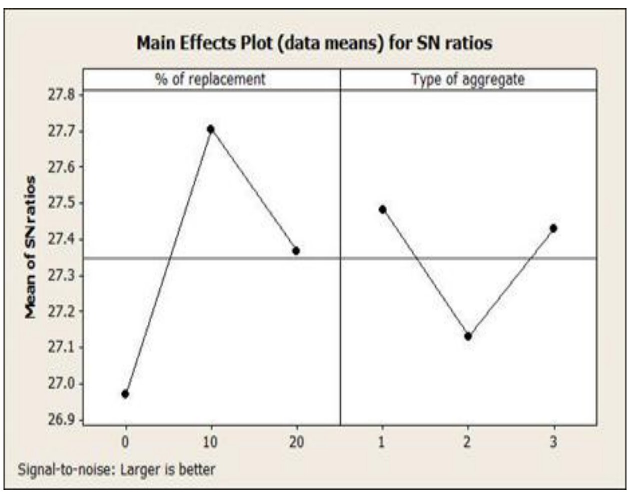

Fig. 4. Main effects plot for S/N ratios.

The optimized process parameters and their levels showed the percentage of replacement as contributing more to the compressive strength and workability which is ranked 1 based on the difference between the maximum and minimum value of SN ratio and the other factors such as the type of aggregate are ranked 2. Factors percentage of replacement at level 2 (10% replacement) and type of aggregate at level 1 (fine aggregate) are the most optimum parameters for obtaining increased compressive strength and improved workability. Main effects for S/N ratios are shown in the **Fig. 4**.

The main effect plots for SN ratio, shows replacement of 10% and fine aggregate as larger SN ratios and these optimal parameters suit best. Contour plot for workability and compressive strength by varying percentage of replacement & type of aggregate are shown in the **Fig. 5(a)**. The contour plot, for type 2 concrete, shows the workability as higher above 19.33% replacement. But, for type 1 concrete, the workability is higher from 10.38% to 11.96 % of replacement. Responses (TTF) obtained for all parameter levels are converted in the surface form and surface plot is shown in the **Fig. 5(b)**. By comparing the type of aggregate and percentage of replacement, the higher compressive strength is obtained in case of type 1 concrete from 4.46 % to 17.31 %. Compressive strength in type 2 concrete is lower. Bulging region in type, shows higher compressive strength than type 2 and it is narrow, as the difference in compressive strength is greater between type 1 and type 2.

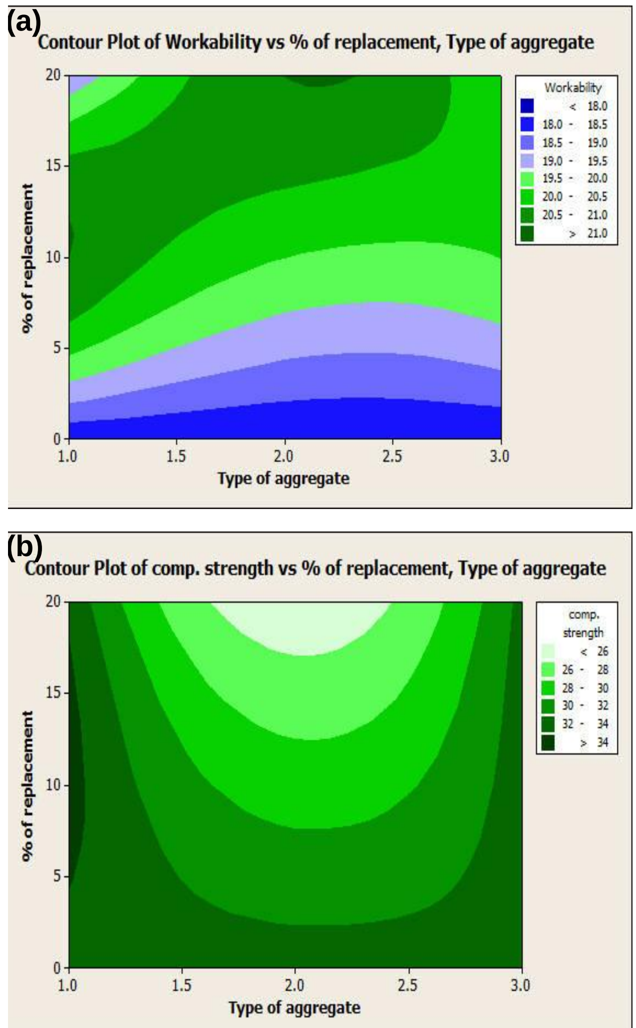

Fig. 5. (a) Contour plot of workability vs percentage of replacement, type of aggregate. (b) Contour plot of compressive strength vs percentage of replacement, type of aggregate.

ANOVA table for S/N ratio

ANOVA table shows the relative importance of the control factor affecting workability and compressive strength. The confidence level was chosen as 95% and the p-value as 0.05, to know the significance of the factors affecting the response. **Table 2** shows the ANOVA table for workability and compressive strength.

Table 2. Analysis of variance for S/N ratio.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
% of replacement	2	0.8065	0.8065	0.40327	6.96	0.050	64.41
Type of aggregate	2	0.2137	0.2137	0.10687	1.84	0.271	17.07
Residual Error	4	0.2319	0.2319	0.05797			18.52
Total	8	1.2522					100

The analysis, the percentage of replacement alone shows the significance of the effect of the workability and compressive strength of this composite material. The main factors such as percentage of replacement contribute about 64.41 % and type of aggregate is about 17.07 % alone. The S – value obtained from the experiment is 0.2408. Hence, amount of replacement has the significant effect on the experiments.

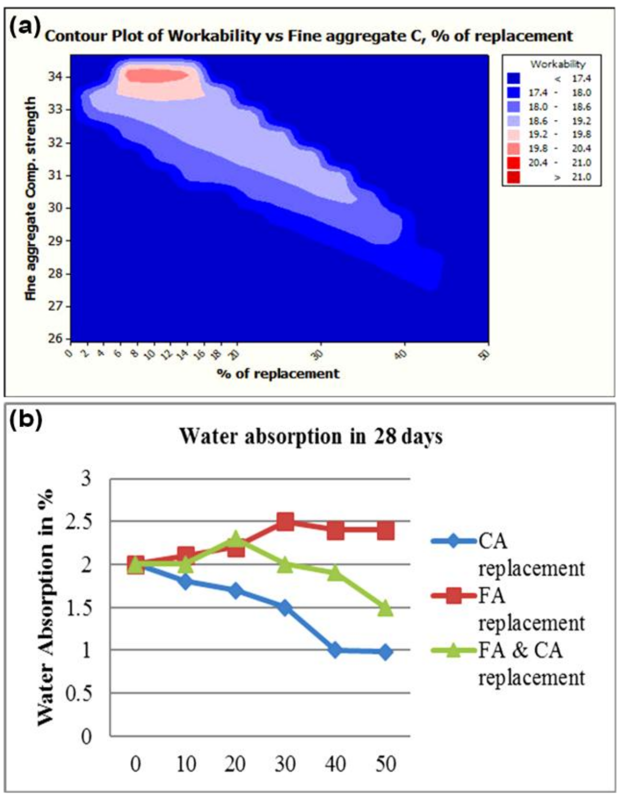

Fig. 6. (a) Linear model analysis: SN ratios versus % of replacement, type of aggregate. (b) Water absorption of concrete at 28 days curing.

The co-efficient of multiple determinations (R^2) is the amount of variation explained by the model and R-Sq value obtained from the analysis was 81.5%. Addition of terms not needed generally decreases the value of R-Sq. (adj) and adjusted R-Sq was about 63.0%. The contour plot shown in the **Fig. 6(a)**, shows the concrete with the ceramic waste having both higher compressive strength and higher workability for the fine aggregate replacement from 6.62 % to 13.97 %. Here the compressive strength is in the range between 33.86 MPa to 34.24 MPa and the workability ranges from 19.8 to 20.4 mm.

Water absorption

Water absorption for various percentages of replacement at 28 days is illustrated in **Fig. 6(b)**. Each of these is the average of three measurements. As the percentage of fine aggregate ceramic waste replacement increases, the water absorption of the concrete also increases when compared with the coarse aggregate ceramic waste replacement. The difference in water absorption is enormous beyond 20% replacement. Admixtures can be added to overcome this drawback, when the replacement goes beyond 20%.

Conclusion

In this research paper, experimental investigation has been done on the possibility of replacing conventional aggregates by ceramic waste based on the compressive strength and workability. The properties of materials were found and analyzed with the help of the design of experiments using the MINITAB software. Conclusions drawn from the preliminary study are as: The workability of the fine aggregate replaced concrete, coarse aggregate replaced concrete and combined replaced concretes are lower than the conventional concrete, whereas coarse aggregate replacement shows better workability compared to the other two types of replacement. Hence coarse aggregate replacement above 19.33% is better for workability. For fine aggregate replacement, workability is higher from 10.38% to 11.96% of replacement. Higher compressive strength is obtained for fine aggregate replacement concrete from 4.46% to 17.31% whereas the compressive strength is lower for coarse aggregate replacement. Ceramic waste for fine aggregate replacement from 6.62 to 13.97% of replacement is observed for both higher compressive strength and good workability. This is, therefore, considered as the optimum percentage of replacement. Water absorption for the optimum percentage of replacement of fine aggregate by ceramic waste is almost similar to the conventional concrete. Water absorption increases with increase in percentage of fine aggregate replacement beyond the optimum percentage of replacement.

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Author's contributions

Conceived the plan: VS, BG; performed the experiments: VS; data analysis: VS, MM; wrote the paper: VS, PM. Authors have no competing financial interests.

Supporting information

Supporting informations are available from VBRI Press.

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