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Mechanical properties of concrete made with waste fine and coarse ceramic aggregates

***A.A. Alkraidi*[1],*M.R. Aldikheeli*[1],*Q.A. Alatiya*[2], *L.A. Alasadi*[1]✉ , *R.A. Aljazaari*[2], *T.M. Almusawi*[1]**

Departmentof Structures and Water Resources Engineering, Faculty of Engineering, University of Kufa, Najaf, Iraq

[2]Department of Civil Engineering, Faculty of Engineering, University of Kufa, Najaf, Iraq

✉*laitha.alasadi@uokufa.edu.iq*

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Abstract. This study aims to produce a new type of waste aggregate concrete by using fine and coarse waste ceramic as aggregate; the waste ceramic used in this study was in 2 types: red ceramic, which has a red color and is produced from waste ceramic tiles, and white ceramic, which produced from the waste of tableware. Replacing ordinary fine and coarse aggregate with a ceramic waste aggregate improved the mechanical properties of concrete, compressive, tensile, flexural strength, and modulus of elasticity of normal concrete by using waste ceramic as aggregates. 20, 40,60, 80, and 100 % replacement by weight of aggregates are studied. Total replacement of normal aggregate with white ceramic aggregates led to an increase in compressive strength from 42.2 to 52.1 MPa; tensile strength also increased from 2.9 to 4.8 MPa, flexural strength increased from 4.3 to 8.7 MPa, and static modulus of elasticityhas risen from 25.6 to 32.8 GPa.The mechanical properties of red ceramic increased until 60 % replacement; a slight decrement in mechanical properties was found after 60 % replacement. Studies show that waste white ceramic has better mechanical properties than red clay ceramic.

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1. *Introduction*

Waste materials have been widely used in recent years, such as plastics, waste iron filing, and chips, waste copper, waste glass, wastebricks, waste tiles, waste old concrete,etc. The benefit of using waste materials in concrete is to have lower costs of concrete production to obtain a more cleanenvironment and less environmental pollution, as well as some increment in mechanical properties, such as compressive, tensile, and flexural strength of concrete. Some waste materials also reduce the density of concrete,whichis very useful for decreasing dead loads on foundations and achieving low cost in building construction, such as using bricks as coarse aggregate [1, 2]. Waste plastics are also used as fibers in concrete and can improve concrete's tensile and flexural strength [3, 4]. Recycled plastics can reduce concrete density to 1800 kg per cubic meter [5], which gives valuable benefits in construction, such as lowering deadloads of buildings and more economic structures. Waste ceramic can improve some mechanical properties of concrete, such as compressive strength;Murali Dharan & Mohan[6]studied ceramic waste as aggregate in concrete with different cement content and improved compressive strength; with 350 kg cement content, the compressivestrength increased from 24 to 31 MPa.Singh& Srivastava[7]use waste ceramics as fine and coarse aggregates in concrete and states that replacing normal aggregates with waste ceramic aggregate leads to decreased compressivestrength, tensilestrength, and flexural strength.Ramadevi[8]study the Effect of using waste ceramic as fine aggregate in concrete and found that using ceramic increasesconcrete compressive and tensile strength until 75 % replacement.Waste rubber is also used in some research to achieve new concretes with specified properties and benefit nature because burning such waste can cause several problems to the heart or harmful gasses.This study aims to use a waste ceramic with two types (red and white ceramic) as fine and coarse aggregate in concrete and study the Effect of replacement on the mechanical properties of concrete.

2. Methods

2.1. Materials Used in The Study

Ordinary Portland cement was used in this study for all mixes;average coarse aggregate was used in the study with grading shown in Table 1 and confirming Indian standards specifications of aggregates IS-383 [9, 10] with maximum size aggregate equal to 16 mm. Ordinary yellow sand is used in reference and partially replacement mixes confirming Zone 4. Table 2 shows a sieve analysis of fine aggregate.Fig. 1 shows the grain size distribution curve for fine aggregates used in the study.The waste ceramic is coarse and fine aggregate and useswhite clay ceramic and red clay ceramic. Some properties of waste white ceramic are shown in Table 3. Also, some properties of red ceramic are given in Table 4. Fig. 2 showsthe waste of red and white ceramics used.

2.2. Mixes Proportion

Table 5 shows the mix proportions and ingredients used in the study, and it contains using materials like cement, fine and coarse aggregate, water in kilograms for each cubic meter of concrete, and using 1.8 liters of Superplasticizer for each 100 kg of cement (10.8 liters for each cubic meter of concrete) for all mixes. In this study, the replacement values by weight of fine and coarse waste ceramic aggregates were 0,20,40,60,80, and 100 %.

2.3. Specimens And Tests:

Cubic steel molds with 10×10×10 cm were used to cast concrete, and three specimens for each mix were cast to find average compressive strength. All specimens were tested after 28 days. The tensile strength test is done by cylinders with 10 cm diameter and 20 mm height and tested after 28 days from the cast for splitting test method according to Eq. (1):

$$Ft = {(2\times p)}\Big/{(\pi\times D\times L)}, \tag{1}$$

where Ft – tensile strength of the concrete specimen; p – maximum load causing failure; D –diameter of the cylinder; L – height of cylinder.

A flexural strength test was done using 10×10×40 cm beams and tested for third point loading according to British standards specification BS-1881 [11]. Also, three beams for each mix were tested after 28 days from casting and then finding the average value. The value of flexural strength can be found inEq. (2):

$$Fb = {\pi(P\times L)}\Big/{(b\times d^2)}, \tag{2}$$

where Fb – flexural strength of the concrete specimen; P – maximum load; b and d – width and depth of the beam; L – length of the beam.

Fig. 3 shows a cubic concrete specimen after the compression test. Figs. 4 and 5 show the concrete beam after failure in testing for flexure strength.Modulus of elasticity was done using 150×300 mm specimens and mechanical strain gauges;Fig. 6 shows tensile strength and modulus of elasticity tests.

Table 1.Sieve analysis of coarse aggregate.

Sieve size	% Passing by weight	% PassingconfirmingIS-383 limits
20 mm	100 %	100 %
16 mm	93.5 %	90–100 %
10 mm	63.9 %	30–70 %
5 mm	5.7 %	0–10 %

Table 2.Sieve analysis of fine aggregate.

Sieve size, mm,micron	% Passing by weight	% PassingconfirmingIS-383 limits
10 mm	100 %	100 %
4.75 mm	100 %	95–100 %
2.36 mm	100 %	95–100 %
1.18 mm	98.2 %	90–100 %
600 micron	92.6 %	80–100 %
300 micron	39.7 %	15-50 %
150 micron	3.4 %	0–15 %

Table 3. Someproperties of white ceramic used in the study.

Properties	Specific gravity	Compressive strength	Tensile strength	Modulusof elasticity	Flexural strength	Absorption
Value	2.3	252 MPa	12.7 MPa	19200 MPa	25.9 MPa	0.2 %

Table 4.Some properties of red ceramic as waste aggregate.

Red ceramic property	Color	Density	Compressive strength	Flexural strength	Absorption
details	Red-brown	1.90 g/cm^3	43.2 MPa	22.4 MPa	1.91 %

Table 5.Ingredients of concrete used in the study forone cubic meter of concrete (reference mix).

Cement	Sand	Gravel	Water	Superplasticizer
600 kg	600 kg	1000 kg	150 kg	10.8 liter

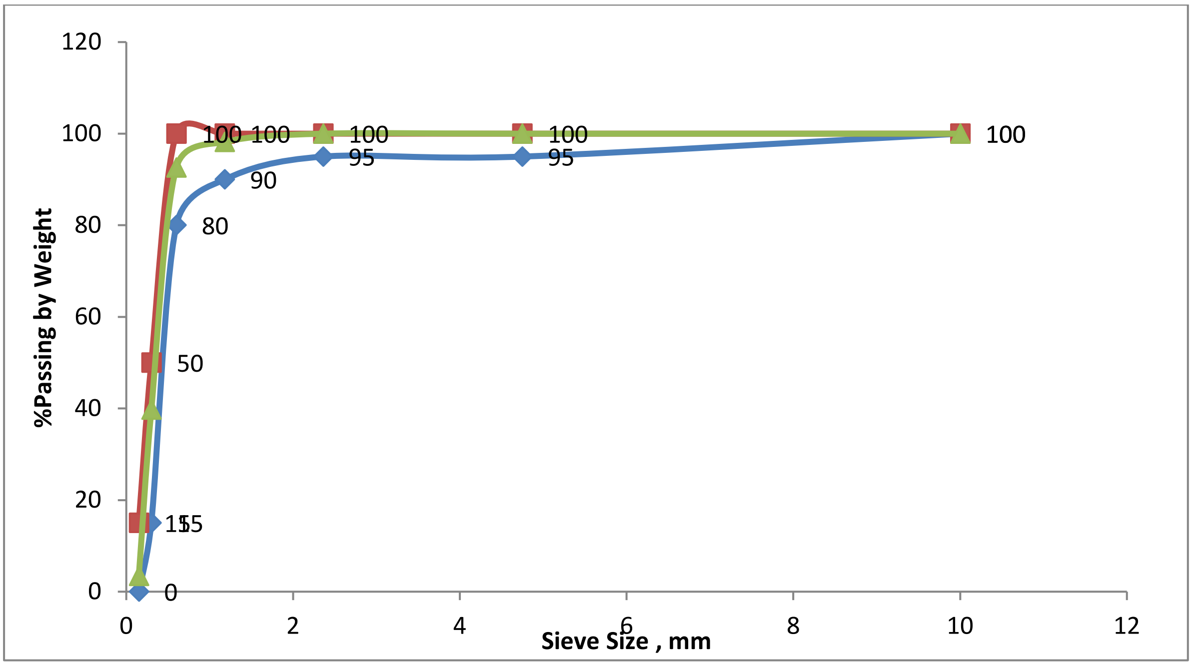

Figure 1.Grain size distribution curve for fine aggregates
(the red and blue curves are the maximum and minimum limits) obtained from sieve analysis.

Figure 2. Red ceramic and white ceramic used in the study.

Figure 3.White waste ceramic concrete after compression test.

Figure 4.Flexural strength test shows ductile failure for white ceramic aggregate concrete.

Figure 5. 100 % white ceramic as waste aggregate (replacement) after flexure test.

Figure 6.Specimens under modulus of elasticity and tensile strength tests.

3. Results and Discussion

Tables6 and 7 show the mechanical properties obtained from experimental work consisting of compressive strength, flexural strength, tensile strength, and static modulus of elasticity of reference mixes for both red ceramic and white ceramic, respectively,and also show reference mixes and mixes with 20, 40, 60, 80 %, and total replacement with waste ceramics as fine and coarse aggregates.As shown in Table 6,the compressive strength increases slightly until 60 % replacement, then decrease slightly after 60 % replacement for both fine and coarse ceramic waste aggregates.Decreasing in higher ratios of replacement can be attributed to the lower strength of red ceramic compared with natural gravel. The increment can be attributed to fine ceramics consistingof silica particles that can react with some products liberated from cement hydration and form an additional gel.

Also, from the same table,tensile, flexural, and modulus of elasticity increased using waste red ceramic until 60 % replacement.Table 7 shows good increment for the mechanical properties,by using white ceramic,compressive strength increased from 42.2 MPa for reference mix to 52.1 MPa for 100 % replacement, there is no decrement in compressive strength by using waste white ceramic until 100 % replacement and that can be attributed to excellent mechanical properties for white ceramic as shown in Table 3 comparing to red ceramic properties, tensilestrength,flexural strength, and modulus of elasticity also increased by using white ceramic until 100 % replacement, the flexural strength increased from 4.3 MPa for reference mix to 8.7 MPa for mixes with 100 % replacement, and modulus of elasticity increased from 25.6 to 32.8 GPa by using 100 % replacement and that can be attributed to the increment of compressive strength[12,13], Figs. 7–10 show the relationship between compressive strength, tensile strength, flexural strength, and modulus of elasticity with % replacement of average coarse and fine aggregate with red ceramic as coarse and fine aggregates. Figs. 11–14 show the relation between % replacement and compressivestrength, tensile strength,flexural strength, and modulus of elasticity using white ceramic. It should be noted that the excellent increment for modulus of elasticity in by using white ceramic can improve the deflection behavior of the structural element under loading if this type of concrete used in structural members , and the values of deflection can be reduced by using white ceramic in concrete , thus , the white ceramic behavior in concrete is better than red ceramic , but both gave a very good results in the mechanical properties , so that give a more durable low cost concrete and also the use of waste aggregate can give less environmental pollution . The main difference of the replacement dosage of the two types of concretes is that the red ceramic dosage equal to 60% while the white ceramic dosage of replacement equal to 100 % in this study .

Table 6. Mechanical properties of concrete with waste red ceramic aggregate concrete.

Mix type	Compressive strength, MPa	Tensile strength, MPa	Flexural strength, MPa	Modulus of elasticity, MPa
Reference mix	42.25	2.92	4.34	25665
20 % replacement	43.16	3.08	4.92	26237
40 % replacement	44.29	3.65	5.33	27154
60 % replacement	45.40	3.73	5.47	27813
80 % replacement	44.57	3.60	5.10	26918
100 % replacement	43.84	3.58	4.86	25937

Table 7. Mechanical properties of concrete withwaste white ceramic aggregate concrete.

Mix type	Compressive strength, MPa	Tensile strength, MPa	Flexural strength, MPa	Modulus of elasticity, MPa
Reference mix	42.25	2.92	4.34	25665
20 % replacement	45.61	3.25	5.19	27987
40 % replacement	47.48	3.78	6.36	28588
60 % replacement	50.81	4.26	7.82	30443
80 % replacement	51.64	4.52	8.41	31098
100 % replacement	52.10	4.83	8.72	32824

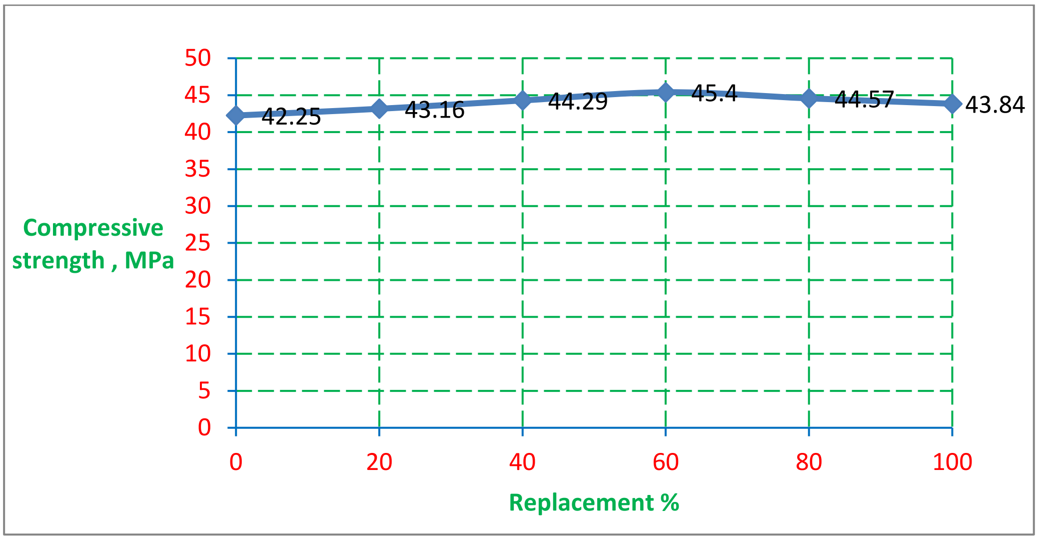

Figure 7. Relationship between replacement and compressive strength by using red ceramic.

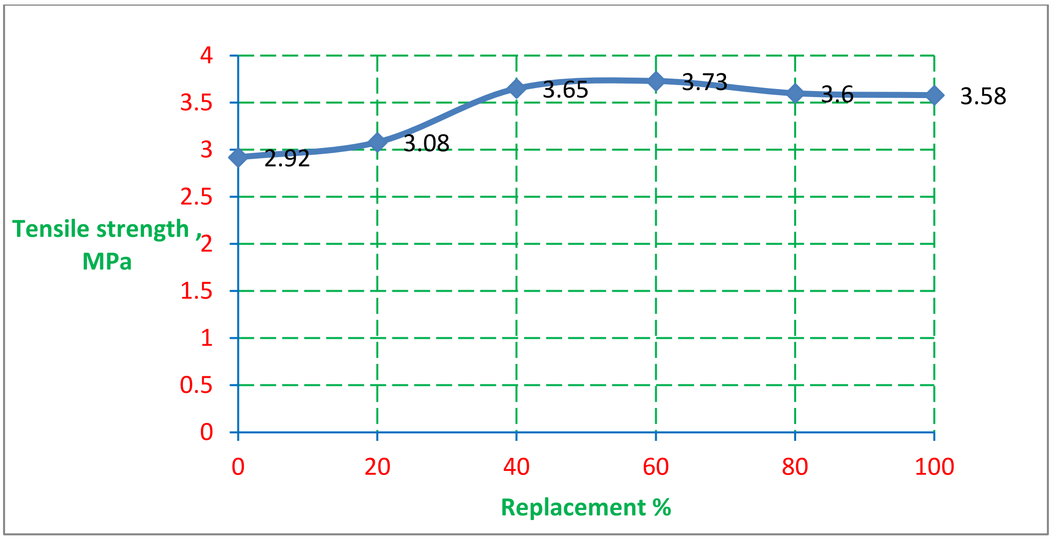

Figure 8. Relationship between replacement and tensile strength by using red ceramic.

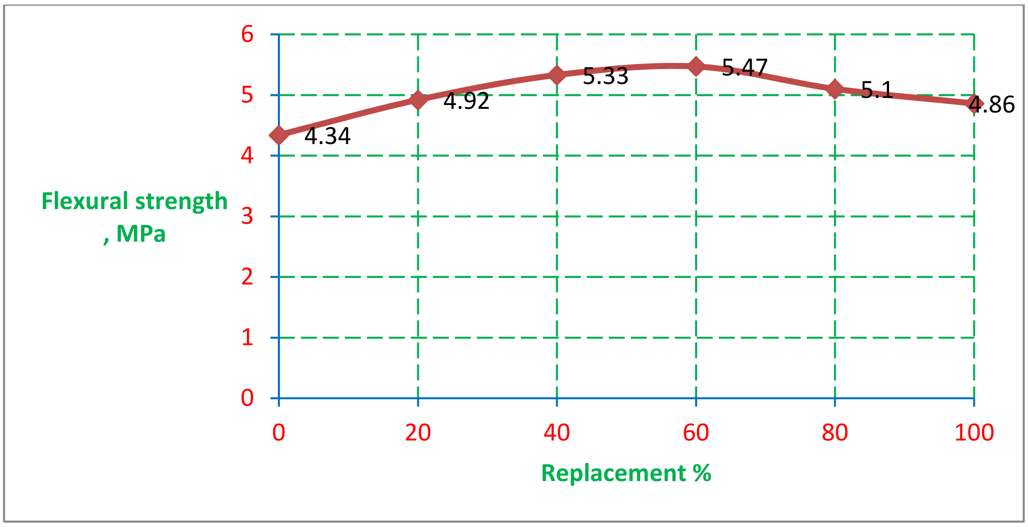

Figure 9.Relationship between replacement and flexural strength by using red ceramic.

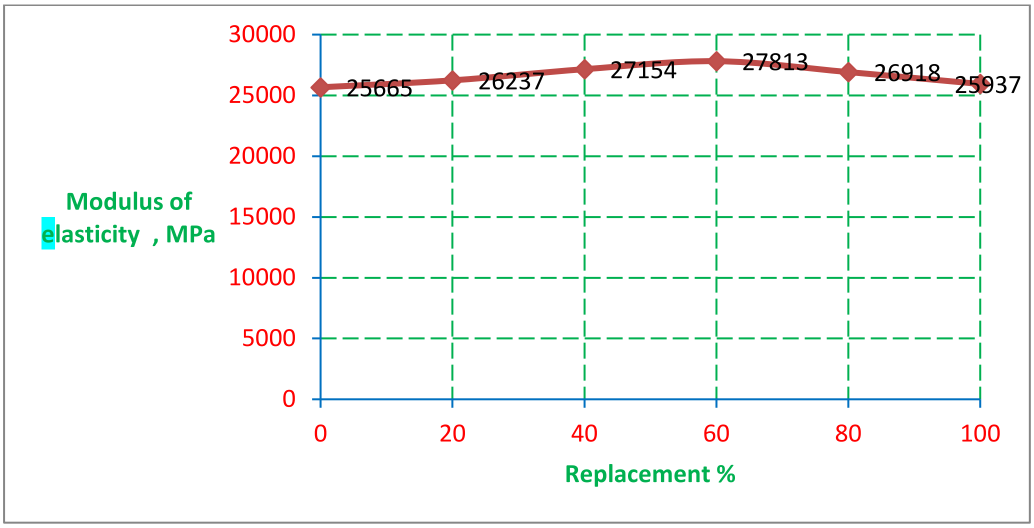

Figure 10. Relationship between replacement and static modulus of elasticityby using red ceramic.

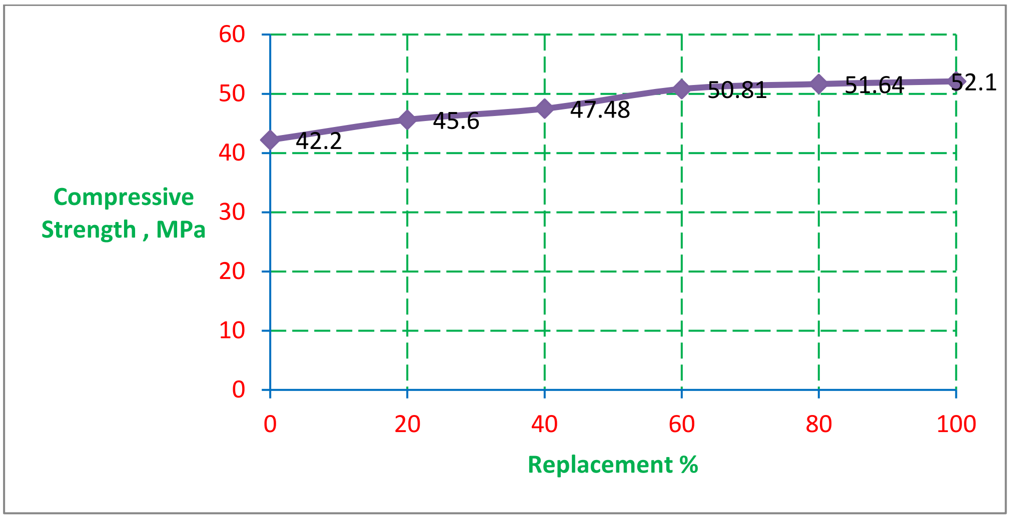

Figure 11. The relationship between % replacement and compressive strength of concrete (white ceramic).

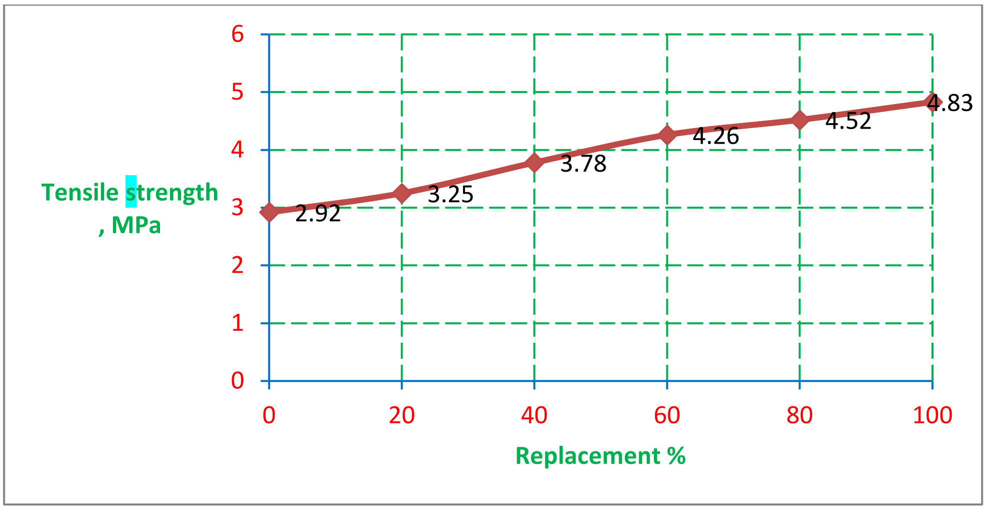

Figure 12. Relationship between % replacement and tensile strength of concrete (white ceramic).

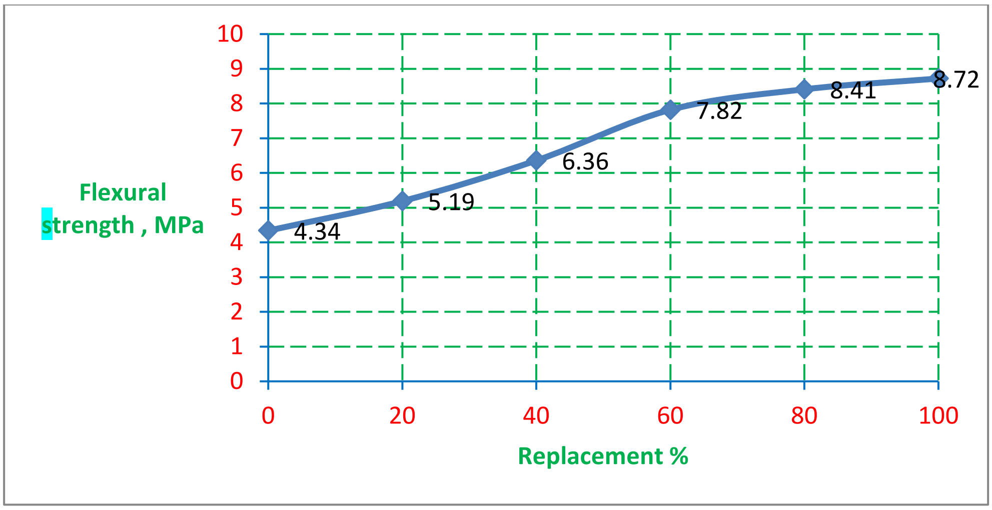

Figure 13. The relationship between % replacement and flexural strength of concrete (white ceramic).

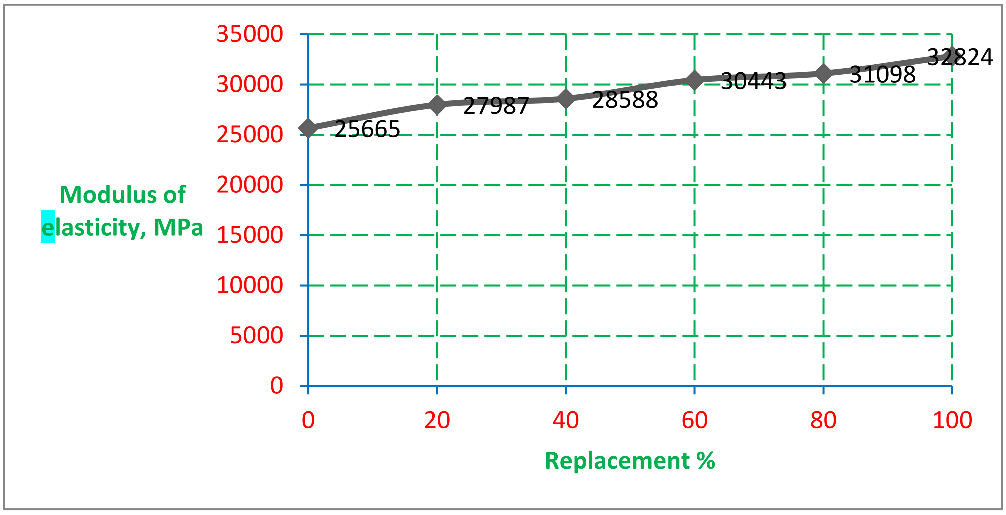

Figure 14. The relationship between % replacement and modulus of elasticity of concrete (white ceramic).

4. Conclusions

The red ceramic, as coarse and fine aggregate, increases mechanical properties, such as compressivestrength, tensilestrength, flexural strength, and modulus of elasticity until 60 % replacement; additional replacement leads to a slight decrement in mechanical properties.

White ceramic, as fine and coarse aggregate,improves concrete's mechanical properties until 100 % replacement.The use of white ceramic enhance the compressive strength from the value of 42 MPa to 52.1 MPa , tensile strength increased from 2.9 MPa to 4.8 MPa and the flexural strength increased also from4.3 MPa to 8.7 MPa and that is very good increment . The modulus of elasticity increased from 2.56 GPa to 3.28 GPa by using 100% replacement with white ceramic aggregate and that increment is very important to decrease the deflection of structural elements if this type of concrete used in structural members .For comparison between these two types of ceramic we can also conclude that optimum replacement for red ceramic is 60 % replacement and further replacement can reduce the strength of concrete , while the optimum replacement of white ceramic is 100% and that can be very useful in construction , because that lowered the total cost of concrete and less environmental pollution .

Conflict of Interest

The authors state no conflict of interest

Data availability statement

Most datasets generated and analyzed in this study are in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

Statements and Declarations

We declare that the manuscript was done depending on the personal effort of the author, and there is no funding effort from any side or organization, as well as no conflict of interest with anyone related to the subject of the manuscript or any competing interest.

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Information about the authors:

Afrah Alkraidi,
E-mail: afrraha.alkridy@uokufa.edu.iq

Rasha Aljazaari,
E-mail: rashaa.aljazaari@uokufa.edu.iq

Mohammed Aldikheeli,
E-mail: mohammedr.aldikheeli@uokufa.edu.iq

Layth Alasadi.
ORCID: https://orcid.org/0000-0001-6244-7965
E-mail: laitha.alasadi@uokufa.edu.iq

Thaaer Almusawi,
E-mail: thaaer.almusawi@uokufa.edu.iq

Qusay Alatiya,
E-mail: qusay.alatiya@uokufa.edu.iq

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