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Research Article

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Effect of Industrial Wastes as Replacement of Fine Aggregate on Properties of Concrete

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Abstract Utilization of waste brick (WB) and bottom ash (BA) has environmental advantages in the present context of sustainability of natural resources and using industrial by-products in concrete can demonstrate both technically and economically beneficial to the construction industry. The aim of this research was to research the possibility of utilization of industrial wastes as partial replacement of fine aggregate in concrete. In this study; using WB and BA instead of river sand (RS) concrete was produced. The resulting concrete samples 7 and 28 days compressive strength and ultrasonic pulse rate value is determined. The test results show that 7 and 28 d compressive strength were not affected on the use of WB and BA concrete but pulse velocity through concrete were affected 28 d. Replacement of fine sand the WB and BA could be effectively used as fine aggregate.

Keywords Fine aggregate, Waste Brick, bottom ash, Compressive strength

Introduction

Concrete is the most commonly used construction material thanks to its properties such as high compressive strength, high durability, low cost and multi-purpose usability. However, it is also assumed that concrete is a non-environmentally friendly material due to a number of disadvantages such as high energy consumption in the manufacturing process, depletion of natural resources for its production, and the recycling problems related to this material [1]. Construction waste created as a result of the demolition of structures, or destruction of buildings due to natural disasters or war and the amount of such waste is increasing every other day [2].

It is estimated that the EU member states produce approximately 450 million tons of construction waste every year; and only 28% of this waste is recycled while the remaining 72% is disposed of. Increasing the recycled percentage of construction waste has become a must in terms of economy and environment [3, 4]. A closer look into the construction sector in terms of natural aggregate resources, environmental protection, and limited waste storage area further reveals the importance of the utilization of recycled aggregates in the production of concrete to be used in many different applications. Moreover, such utilization will also offer benefits in terms of reduced fuel consumption related to the transportation of materials and reduced structural costs, not to mention the reduced recycling needs [5-7]. Many developed countries have put in motion legal regulations with respect to the recovery of structural waste aiming to reduce the amount of waste and to ensure waste recycling [8]. We have the example of Japan in front of us; a country which successfully increased the recycling rate of concrete waste up to 98% using waste material as aggregate [9].

The main requirement for producing quality concrete is to use aggregate with suitable properties and to select the ideal mix ratio and proper concrete production method. Aggregates produced in order to repurpose the construction waste consist either of original concrete wastes or small pieces of waste material such as ceramics, bricks and pumice. This is a parameter which affects the quality of concrete produced using recycled aggregates

[10, 11]. In studies which focus on concrete properties and the use of recycled aggregates, the effects of the replacement of coarse-grained aggregate with recycled aggregates on durability, strength and workability were investigated. In these studies, concrete waste and roof tile and ceramic waste were analyzed most commonly for their use as aggregate.

Turkey provides 28% of its total power need from power stations; and 18 million tons of fly ash and 6 million tons of bottom ash are produced annually as waste during the production process. Only 1% of this huge amount of waste is repurposed in cement and concrete industry [14, 15]. Yüksel and Genç [16], Aggarwal *et al*. [17], Kurama *et al*. [14], Topcu and Bilir [18], Kim and Lee [19] analyzed the effects of using bottom ash at varying ratios as a replacement for aggregate on fresh and hardened concrete properties.

Performed with an interest in the recovery of the waste produced as a result of power generation and industrial production, protection of natural resources and reduction of the environmental impact, river sand (RS) was substituted with waste brick (WB) and bottom ash (BA) by mass in concrete at 0, 10, 20, and 30% replacement levels. In this study, properties such as compressive strength, pulse velocity of concrete obtained using WB and BA were evaluated and compared with reference concrete samples.

2. Materials & Method

2.1. Material

CEM-I 42.5 R Portland cement was used and it was ensured that the material complies with EN 197-1 standard. Three different limestone aggregates, one being RS, were used as aggregate and their sieve analysis values are given in Table 1 in accordance with the sieve analysis performed with respect to TS 3530 EN 933-1. Crushed limestone fine aggregates (LFA) and limestone coarse aggregates (LCA) are used in sizes of 0-5, 5-10 and 10-25 mm. For the specific gravities of 2.65, 2.68 and 2.70 g/cm^3 and absorption levels were 0.80, 0.70 and 0.70%, respectively. RS was used as fine aggregate at a specific gravity of 2.60, and absorption level of 1.20%. WB and BA were replaced by weight with RS at ratios of 10, 20 and 30%. WB was obtained from an industrial-scale brick manufacturing plant, and BA was obtained from Çatalağzı Thermal Plant. WB and BA were passed through a 2.38 mm sieve and the material passing through was used as a replacement for RS. Specific gravities of WB and BA were 2.34 and 1.39 g/cm^3, respectively, and their water absorption levels were 13.05% and 6.60%, respectively. Moreover, fly ash was used in concrete mix as a mineral additive and it was obtained from Çatalağzı Thermal Plant. Physical and chemical properties of the cement are shown in Table 2. A superplasticizer (SP) obtained from Cryso was used also in concrete mix.

Table 1: Sieve analysis results for aggregate

Sieve size (mm)	**RS**	**LFA**	**LCA-I**	**LCA-II**
		(passing %)		
25.4	-	-	-	100
19.1	-	-	-	99.5
12.7	-	-	100	39.4
9.5	-	-	94.6	3.1
4.75	-	100	55.8	0.3
2.38	100	85.5	-	-
1.19	86.2	54.5	-	-
0.597	68.3	27.5	-	-
0.297	45.5	14.2	-	-
0.149	17.1	4.5	-	-
0.075	0.6	-	-	-

Table 2: Characteristics of Portland cement and FA

Content (%)	**Cement**	**FA**
CaO	63.48	1.73
SiO_2	20.35	55.73
Al_20_3	4.47	29.76
Fe_2O_3	3.8	5.41
Na_2O	1.43	1.96

K_20	0.19	3.11
MgO	1.02	3.3
SO_3	2.26	0.3
CaO free	1.3	-
LOI	2.63	-
Physical properties		
Specific gravity (g/cm^3)	3.1	2.2
Blaine (cm^2/gr)	3200	3700

2.2. Method

In the experimental study, a total number of four series, one being the control group, was produced and each one of these series included three concrete samples. WB and BA were replaced by weight with RS at ratios of 10, 20 and 30%. Fine and coarse-grained aggregate were mixed in concrete mixer without the presence of water, then one third of the total water was added, the mixture was left to settle for 5 minutes, and cement and fly ash were added to the concrete mixer and it was mixed until homogeneous; after adding another one third of the total water, it was mixed again for 3 minutes; the remaining one third of the water was added along with SP and it was mixed for another 3 minutes. A total number of 10 different mixtures, one being the control group (R), were stored in casts of 15x15x15 cm in three layers using vibration motion; three samples each for 7-day and 28-day compressive strength tests and one sample for ultrasonic pulse velocity. Samples were than covered with a wrap at 23 ± 2 °C and 55–60% relative humidity and left to set for 24 hours; this was followed by samples being removed from the casts and being cured in water saturated in lime at 20 ± 2 °C until the test day. The samples were subjected to compressive strength tests in accordance with TS 12390-3 [20] and to ultrasonic pulse velocity tests in accordance with ASTM C 597 [21].

Table 3: Mix proportions of concrete

Mix	**Cement (kg/m^3)**	**Water (l)**	**FA (kg/m^3)**	**RS (kg/m^3)**	**LFA (kg/m^3)**	**LCA (kg/m^3)**	**BA (kg/m^3)**	**WB (kg/m^3)**	**SP (kg/m^3)**
Ref.	420	203	42	194	504	971			3.7
BA10	420	203	42	174.6	504	971	19.4		3.7
BA20	420	203	42	135.8	504	971	38.8		3.7
BA30	420	203	42	77.6	504	971	58.2		3.7
WB10	420	203	42	174.6	504	971		19.4	3.7
WB20	420	203	42	135.8	504	971		38.8	3.7
WB30	420	203	42	77.6	504	971		58.2	3.7

3. Results & Discussion

3.1. Effects of WB and BA on Compressive Strength

Compressive strength results of concrete samples produced using WB and BA were recorded for 7-day and 28-day curing and these results are given in Fig. 1.

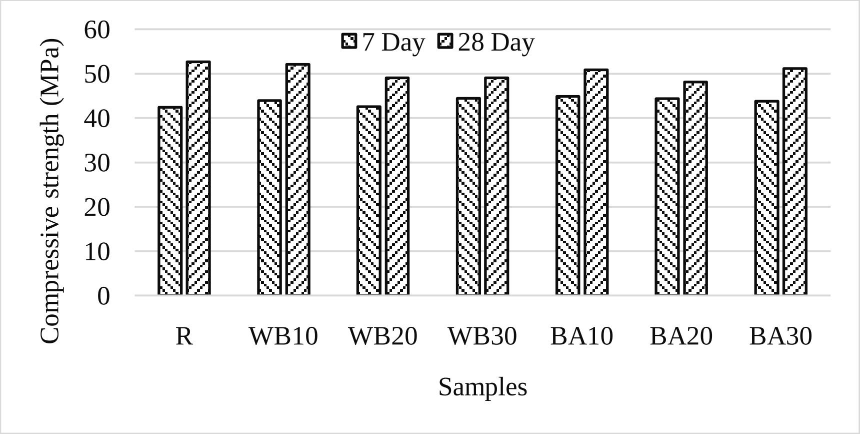


Figure 1: Compressive strength values of concrete samples on 7th day and 28th day of curing.

A closer look into the compressive strength results for 7th day showed that the use of WB and BA as a replacement for crushed sand resulted in no negative impact. Furthermore, the use of BA led to an increase in compressive strength around 3-5% on 7th day. The use of WB also led to an increase in compressive strength around 3-6%, however, it was found that further increase in WB ratio used results in a decrease in compressive strength.

A closer look into the compressive strength results for 28th day showed that the use of WB and BA as a replacement for RS resulted in a significant negative impact. When replaced with BA at 10% and 30% by weight, compressive strength of 28-day samples suffered a loss of 3.5%; and when replaced with BA at 20% by weight, compressive strength of 28-day samples suffered a loss of 9%. When replaced with WB aggregate at 20% by weight, compressive strength of 28-day samples suffered a loss of 9%; and the loss in strength was 3% when the substitution ratio was 30%.

ANOVA analysis was performed in order to define the effects of aggregate type and ratio used as replacement on compressive strength (7-day and 28-day). Results of ANOVA are given in Table 4.

Table 4: Results of ANOVA performed for compressive strength

Time	**Variables**	**Sum of Squares**	**Degree of Freedom**	**Average of Squares**	**F**	**Significance Level**
-day	Waste Aggregate Type	4.79	2	2.40	0.15	0,867
	Waste Aggregate Ratio	12.37	2	6.19	0.41	0,682
	Error	98.62	6	16.44		
	Total	**115.78**	**10**			
28-day	Waste Aggregate Type	126.43	2	63.21	8.64	0,017
	Waste Aggregate Ratio	16.18	2	8.09	0.31	0.74
	Error	154.14	6	25.69		
	Total	**296.75**	**10**			

Table 4 shows that there is no statistically significant effect of the type and ratio of the waste aggregate used on the 7-day compressive strength of the concrete mix ($p>0.05$). Accordingly, the type and ratio of the waste aggregate used did not have neither negative nor positive impact on the compressive strength. However, it was found that the type of waste aggregate has a statistically significant effect on the 28-day compressive strength of the concrete mix ($p<0.05$). This can be accounted for by the fact that the waste aggregate ratio has no negative impact on the compressive strength. Although the type of aggregate was not found to have a negative impact on 28-day samples, any increase in the replaced waste aggregate ratio was found to have a negative impact on the compressive strength. Fig. 2 shows the effects of waste aggregate type and ratio on compressive strength.

The results showed that an approx. 4% increase in the compressive strength was possible in the case of the use of WB, contrary to the use of waste aggregate. However, the samples produced using WB were found to have compressive strength lowered by 6% on the 28th day. A closer look into the effect of waste aggregate ratio on compressive strength (Fig. 2) showed an increase of 5% in 7-day compressive strength when the waste aggregate replacement ratio was 10%. However, this effect was reversed on the 28th day resulting in compressive strength being decreased by 8%. BA was associated with poor compressive strength results for 7th day; however, it was found that BA is more suitable for application when the compressive strength results for 28th day were analyzed. This can be explained by the superior pozzolanic properties of BA over WB. This effect was not observable in the 7-day curing process. It was found that the use of 10% waste aggregate is suitable in terms of early age strength, while the use of 20% waste aggregate is suitable in terms of final strength.

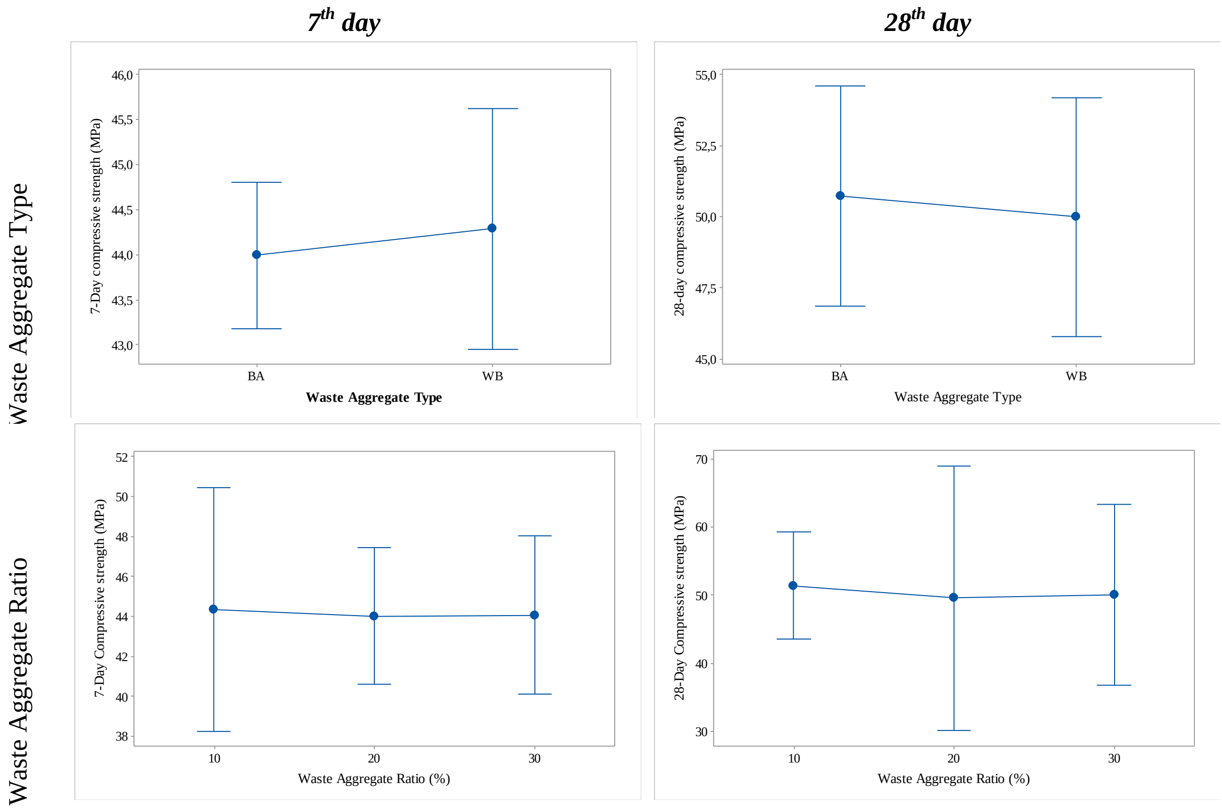


Figure 2: The effect of waste aggregate type and ratio on compressive strength

3.2. Effects of WB and BA on Ultrasonic Pulse Velocity

Concrete samples produced using WB and BA were subjected to ultrasonic pulse velocity test on 7th and 28th days. Fig. 3 shows the ultrasonic pulse velocities of the concrete samples.

As shown in Fig. 3, ultrasonic pulse velocity tends to increase on 7th day when BA and WB are used as a replacement for crushed sand. WB needs to be used as a replacement for crushed sand at ratios of 10% and 30%. WB ratio of 20% as replacement reduces the ultrasonic pulse velocity. When BA is used at a ratio of 30%, ultrasonic pulse velocity increases approximately by 1.5%. It was further found that the use of waste aggregates increases ultrasonic pulse velocity on 28th day (Fig. 3), and especially the replacement with BA at 30% results in approx. 2.5% increase in ultrasonic pulse velocity; however, these increases in ultrasonic pulse velocity were negligible.

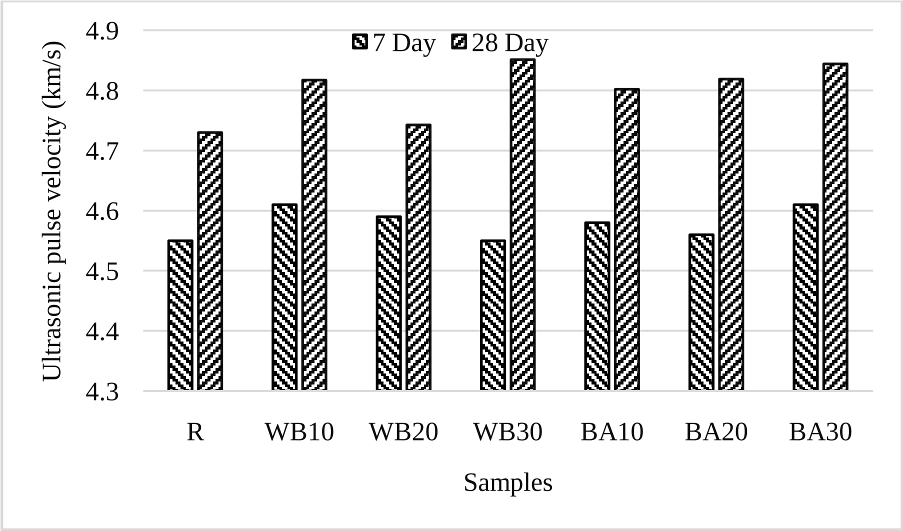


Figure 3: Ultrasonic pulse velocities of concrete samples on 7th day and 28th day of curing

ANOVA was performed in order to define the effect of waste aggregate type and ratio on ultrasonic pulse velocity. Results of ANOVA are given in Table 5.

Table 5: Results of ANOVA performed for ultrasonic pulse velocity

Period	**Variables**	**Sum of Squares**	**Degree of Freedom**	**Average of Squares**	**F**	**Significance Level (p)**
7-day	Waste Aggregate Type	0.26	2	0.13	0.49	0,636
	Waste Aggregate Ratio	0.38	2	0.19	0.77	0,506
	Error	1.49	6	0.25		
	Total	2.13	10			
28-day	Waste Aggregate Type	0.68	2	0.34	0.59	0,585
	Waste Aggregate Ratio	0.83	2	0.42	0.76	0,509
	Error	3.46	6	0.58		
	Total	4.97	10			

As shown in Table 5, waste aggregate type and ratio have no statistically significant impact on the ultrasonic pulse velocity on 7th and 28th days. Accordingly, it was suggested that the waste aggregate type and ratio has no impact on the ultrasonic pulse velocity. Fig. 4 shows the effects of waste aggregate type and ratio on ultrasonic pulse velocity.

A closer look into the effect of waste aggregate type and ratio on ultrasonic pulse velocity on 7th and 28th days of test (Fig. 4) showed that the use of BA increases the ultrasonic pulse velocity. In the case of combined use of WB and BA, the result was an ultrasonic pulse velocity of 4.50 km/s or more.

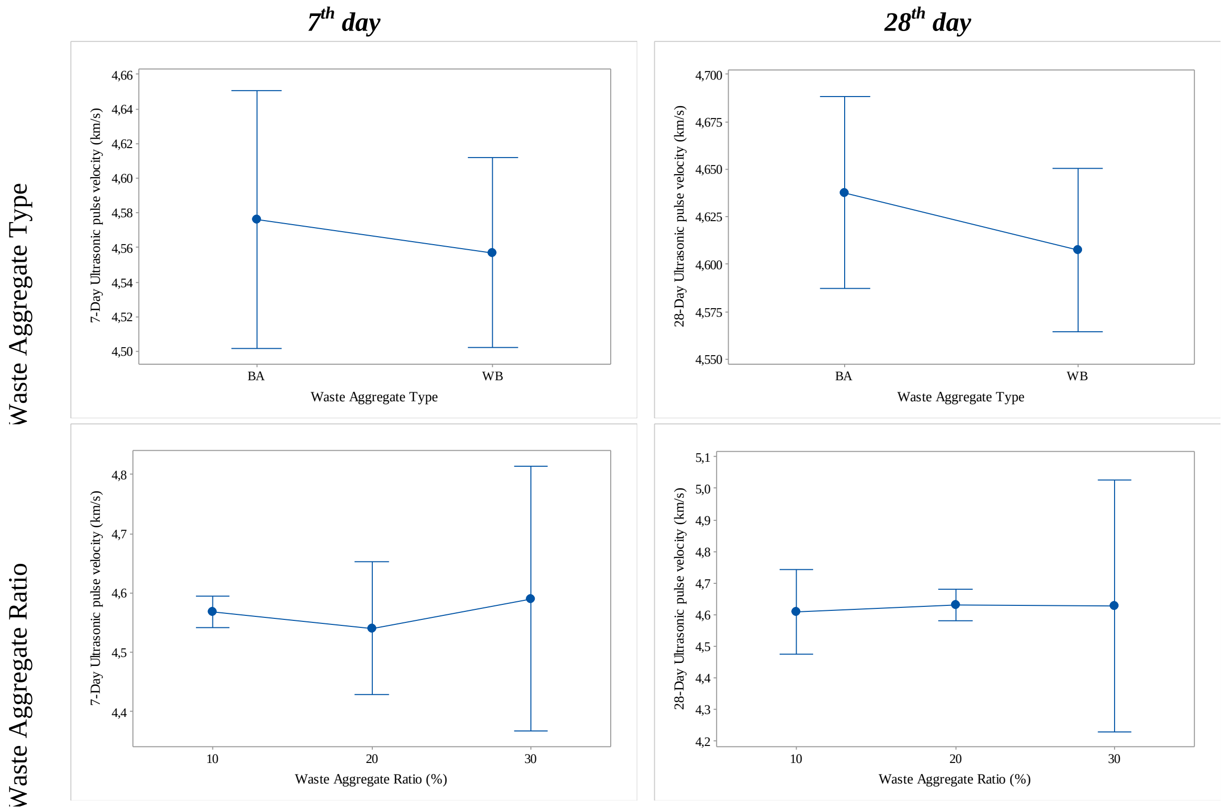


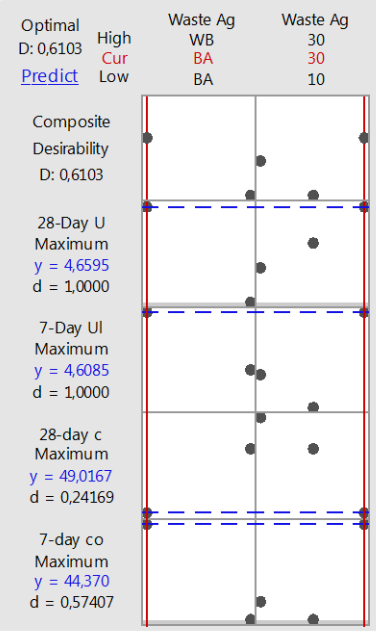
Figure 4: The effect of waste aggregate type and ratio on ultrasonic pulse velocity

Fig. 4 further shows that the waste aggregate must be used at a ratio of around 30%. Negligible reductions in the ultrasonic pulse velocity were recorded when waste aggregate ratio was set to be 10% and 20%.

The waste aggregate type and ratio were optimized with respect to factorial design. Dependent variable and objective functions used in this optimization are listed in Table 6. Objective function for compressive strength and ultrasonic pulse velocity values obtained in this study was defined at a maximum. Optimization results showed that the optimal waste aggregate type to be used is BA and the optimal waste aggregate ratio is 30%.

When BA is used as a replacement of RS at a ratio of 30%, compressive strength on the 7th day increases by 5% and the same decreases by 3% on the 28th day. Ultrasonic pulse velocities on 7th and 28th days increased by 1.4% and 2.5%, respectively.

Table 6: Optimization of waste aggregate type and ratio

Dependent Variable	***Objective Function***	
Compressive strength at 7 days	Maximum	
Compressive strength at 28 days	Maximum	
Ultrasonic pulse velocity at 7 days	Maximum	
Ultrasonic pulse velocity at 28 days	Maximum	
OPTIMIZATION		
Waste Aggregate Type	***BA***	
Waste Aggregate Ratio	***30%***	

4. Conclusion

Based on this study performed with the aim to ensure economic use of wastes, the following conclusions can be drawn.

- The most suitable aggregate type is WB in terms of 7-day compressive strength values. Moreover, concrete produced using BA aggregate offers higher compressive strength when compared to BA on the 28th day.
- With respect to 7-day compressive strength, the use of 10% waste aggregate as replacement increases the compressive strength. Nevertheless, the use of aggregate at ratios of 20% and 30% is more appropriate for 28th day. The use of waste aggregate at ratios of 20% and 30% gave similar results for all experiment days.
- The use of waste aggregate at a replacement ratio of 30% leads to increased ultrasonic pulse velocity.
- The best waste aggregate type was found to be BA and the optimal waste aggregate ratio was found to be 30% according to the optimization performed based on full factorial design.
- This study was designed to use BA and WB as a replacement for RS. Mainly produced as a by-product in thermal plants and known for its environmental consequences, BA is now being repurposed in many fields.
- Negative properties of RS such as high methylene blue values or crystalline calcite structure will be reduced with the use of aggregate. Moreover, it will be possible to reduce the use of RS consumption while improving the areas of use of BA and other waste material which in return will allow for the production of sustainable construction material.

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