



Article Effect of Recycled Coarse Aggregate and Bagasse Ash on Two-Stage Concrete

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Abstract: Numerous research studies have been conducted to improve the weak properties of recycled aggregate as a construction material over the last few decades. In two-stage concrete (TSC), coarse aggregates are placed in formwork, and then grout is injected with high pressure to fill up the voids between the coarse aggregates. In this experimental research, TSC was made with 100% recycled coarse aggregate (RCA). Ten percent and twenty percent bagasse ash was used as a fractional substitution of cement along with the RCA. Conventional concrete with 100% natural coarse aggregate (NCA) and 100% RCA was made to determine compressive strength only. Compressive strength reduction in the TSC was 14.36% when 100% RCA was used. Tensile strength in the TSC decreased when 100% RCA was used. The increase in compressive strength was 8.47% when 20% bagasse ash was used compared to the TSC mix that had 100% RCA. The compressive strength of the TSC at 250 °C was also determined to find the reduction in strength at high temperature. Moreover, the compressive and tensile strength of the TSC that had RCA was improved by the addition of bagasse ash.

Keywords: bagasse ash; sustainable concrete; sustainable development; mechanical properties; natural coarse aggregate; recycled coarse aggregate; two-stage concrete; materials design; green concrete; recycled concrete

1. Introduction

The most extensively used building material around the globe is concrete [1]. Normal concrete is made by mixing coarse aggregate, fine aggregate, cement, water, and admixture in a mixer according to ASTM C192-02. In TSC, coarse aggregates are set in formwork, and then grout or mortar is infused through a pipe with high pressure from the bottom to the top. The grout fills the pores between the coarse aggregates [2]. Maximum density is achieved without mechanical compaction or using a vibrator [3]. In contrast to conventional concrete, compressive stresses in TSC are first passed through the body of coarse aggregates due to point-to-point contact and, after deformation, they then pass through the hardened mortar [2]. TSC is environmentally friendly concrete as the coarse aggregates are not mixed in a mixer, which reduces the consumption of energy. The grout is made on-site, which eliminates the usage of transit trucks, which in turn results in decreasing pollution and reduces cost [4]. The cost of TSC is 40% less than that of traditional concrete because it consists of about 70% coarse aggregate, consuming about 30% less cement [5]. Due to



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). point-to-point contact of the coarse aggregates, the modulus of elasticity of TSC is very high [6]. Drying shrinkage in TSC is lower than in normal concrete, which results in less volume change [7]. TSC is mainly used where a low heat of hydration is required, such as mass concreting in tunnels, and underwater construction and repair [6].

Around 25 billion tons of concrete is produced annually, making it the largest consumer of Earth's natural resources, which are water, natural aggregates (gravel and crushed rock), and sand [8]. Around 12.6 billion tons of natural aggregate is used annually [9]. Due to urbanization, a lot of construction and demolition waste (CDW) is produced. CDW has a serious impact on our environment as it creates pollution when it is disposed of in landfills. Over 1 billion tons of CDW is produced annually [9]. To protect our environment from depleting virgin aggregate resources, recycled coarse aggregates (RCA) have been used to produce concrete [10]. RCA consists of natural aggregates and adhered mortar. Concrete obtained from demolished buildings is crushed to obtain RCA. Due to increased absorption capacity, 5% more water is required for concrete made with RCA to acquire a similar workability as that of normal concrete [11]. Due to traverse cracks in RCA, increased porosity, less information regarding the interfacial transition zone (ITZ) between RCA and cement paste, impurities, adhered mortar, and inferior quality, this makes the use of RCA as structural concrete difficult [12]. RCA has two ITZs, one with new cement paste and the other with old mortar. Therefore, the structure of concrete made with RCA demonstrates a more complex structure than that of concrete made with natural aggregates. Old ITZ has micro-cracks that decrease the strength of the concrete and also increase its water consumption [13]. RCA may contain impurities such as organic matter, sulphates, carbonates, and chlorides [14]. When Sheen et al. [15] made concrete using RCA, it was observed that the compressive strength of the concrete with RCA decreased because of fine particles. The compressive strength of the concrete with RCA can be increased by adding natural admixtures [16]. The permeability of the concrete can be increased by increasing the amount of the RCA [17]. The shape and texture of RCA depends on the crusher plant, which directly affects the workability of the concrete [18]. Pakistan is an agricultural country. Sugar cane is the second largest cash crop of Pakistan, which accounts for 3.6% of gross domestic product [19]. Bagasse is a by-product of the sugar industry and is used as an energy source for sugar production in this industry [20]. Sugarcane contains about 25% bagasse. Fourteen million tons of bagasse is produced in Pakistan annually. Bagasse is also used in the paper industry. When bagasse is burnt for energy purposes, it produces 3% ash, which is dumped in landfills [21]. Waste obtained from agriculture and some other industries can be used as a partial replacement of cement in concrete [22]. One of the ways to decrease the negative environmental impact of concrete is to use mineral admixtures as a partial replacement of cement, which will not only reduce pollution but will also decrease the cost and improve the strength of the concrete [23].

The objective of this research is to evaluate the mechanical properties of TSC made with NCA and RCA. In order to achieve the objective, four mixes of TSC were prepared. One mix was prepared with 100% NCA, while in the other three mixes, NCA was replaced with 100% RCA. Bagasse ash was used as a partial replacement of the cement at 10% and 20% in two mixes of the TSC that had RCA. Compressive strength, compressive strength at 250 °C, tensile strength, and mass loss at 250 °C were then determined. In addition, two mixes of conventional concrete were also prepared. One mix was prepared with 100% NCA, while the other mix was prepared with 100% RCA. The results of the compressive strength of the conventional concrete were then compared to that of the TSC.

2. Materials and Methods

2.1. Materials

2.1.1. Cement and Bagasse Ash

Ordinary Portland cement (ASTM Type-I) from the Cherat cement factory was used for the preparation of the TSC. Twenty-eight-day strength of cement was up to 69 MPa. The fineness of the cement was 93.15%. The surface area of the cement was 2137 cm^2/gm . Bagasse ash was brought from Premier sugar mill, Mardan, Pakistan. It was then ground/ crushed in PCSIR, Peshawar, Pakistan. It was passed through sieve#200. The specific gravity of bagasse ash was 1.35. The surface area of the bagasse ash was 2840.7 cm²/gm. The chemical composition of the bagasse is shown in Table 1 and was used according to ASTM C618 criteria.

Chemical Composition	Bagasse Ash	ASTM C618 Requirement
Silicon dioxide (SiO ₂)	64.81%	J
Aluminum oxide (Al ₂ O ₃)	11.36%	−
Ferric oxide (Fe ₂ O ₃)	1.53%	- J
$SiO_2 + Al_2O_3 + Fe_2O_3$	77.70%	77.70% > 70%
Magnesium oxide (MgO)	3.49%	
Calcium oxide (CaO)	11.13%	
Sodium oxide (Na ₂ O)	1.14%	
Manganese oxide (MnO)	0.09%	
Potassium oxide (K ₂ O)	3.99%	
Phosphorous pentoxide (P_2O_5)	1.99%	
Titanium dioxide (TiO ₂)	0.47%	

Table 1. Chemical composition of bagasse ash.

2.1.2. Aggregates

Coarse and fine aggregates were obtained from a quarry near COMSATS University Islamabad, Abbottabad Campus, Pakistan. The concrete waste from a demolished building was obtained from an empty plot near Daewoo terminal, Abbottabad, Pakistan. The demolished concrete waste was crushed with the help of a crusher to obtain the RCA. Twenty-five millimeters was the maximum size of both the natural and recycled aggregates. Table 2 shows the physical properties of both the natural and recycled aggregates.

Table 2. Physical properties of the natural, recycled coarse, and fine aggregates.

Physical Properties	Natural Coarse Aggregates	Recycled Coarse Aggregates	Fine Aggregate
Water absorption	1.85%	7.59%	1.1%
Specific gravity	2.75	2.62	2.35
Impact value	14.72%	22.23%	-
Fineness modulus	2.04	2.19	2.96
Density	1532.3 kg/m^3	1399.2 kg/m^3	1610 kg/m^3

2.1.3. Superplasticizer

Ultra-Super Plast 470 was used throughout the casting of the TSC. The Ultra-Super Plast 470 was procured from Ultra Chemicals, Peshawar, Pakistan. The product was light brown, and the specific gravity was 1.15.

2.2. Mixture Proportions

Six groups of concrete mixtures were prepared in total as shown in Table 3. Two mixtures were prepared with the conventional method. Four different mixtures of TSC were made. All six groups were prepared with a ratio of 1:1:2.7 (cement: fine aggregate: coarse aggregate). Control mix-N was prepared using the conventional method and contained 100% natural coarse aggregate (NCA). Control mix-R was prepared using the conventional method and contained 100% NCA. Control mix-TSCI was a TSC and was made with 100% NCA. Control mix-TSCII was a TSC and was made with 100% RCA. The fifth mix was a TSC and was prepared with 10% bagasse ash as a fractional substitution

of the cement and 100% RCA. The sixth mix was a TSC and was made with 20% bagasse ash as a fractional substitution of the cement and 100% RCA. The water-to-cement ratio (W/C) used in this experimental research was 0.5. This ratio was used for all six of the mixes. Superplasticizer was added at a rate of 1% by the weight of the cement in TSC10BA and TSC20BA.

Table 3. Mix types with identification based on replacement ratio.

Mix Types	Concrete Mix Proportion
CM-N	Control mix made with the conventional method (100% NCA)
CM-R	Control mix made with the conventional method (100% RCA)
CM-TSCI	Control mix made with TSC (100% NCA and 100% cement)
CM-TSCII	Control mix made with TSC (100% RCA and 100% cement)
TSC10BA	TSC with 100% RCA and 10% cement replaced by bagasse ash
TSC20 BA	TSC with 100% RCA and 20% cement replaced by bagasse ash

2.3. Specimen Casting and Curing

CM-N and CM-R were normal concrete mixes. The RCA used during casting of the normal concrete and the TSC were prewet. Fine aggregate and coarse aggregates were first dry mixed for one minute in a mixer. Cement was then added and dry mixed for a further minute. Finally, water was added, and the total mixing time was five minutes. Cylindrical molds of 6 inches (152.4 mm) in diameter and 12 inches (254.8) in height were used for casting as per ASTM C 31/C 31M-03. For the TSC, a pipe with a diameter of 1 inch (25.4 mm) and a height of 2 m (2000 mm) was placed in the middle of a mold. Then, a mold was filled with coarse aggregates. Following this, grout was injected from the top via a pipe. The grout was injected with the help of pressure created by gravity. As the voids in the coarse aggregate were filled, the pipe was raised. After the appearance of grout at the top of a mold, the pipe was removed from the mold. This procedure was used for all the specimens and was also used by Abdelgader [24]. After 24 h, the specimens were taken out of the molds and were kept in a water tank. Ninety specimens were prepared in total; CM-N and CM-R had three specimens each, while each mix of the TSC had twenty-one specimens.

3. Results and Discussions

3.1. Compressive Strength

The compressive strength of all the concrete mixes is shown in Figure 1. Each compressive strength is an average of three measurements. The compressive strength of CM-N and CM-R was determined at day 28 of the curing process, whilst the compressive strength of all the TSC mixes was determined at days 7, 28, and 56 of the curing process. The figures show that the compressive strength of CM-TSCI is at its highest among all mixes at days 7, 28, and 56 of the curing process. The compressive strength of CM-TSCI is 3.32% more than that of CM-N at 28 days Thus, the compressive strength of the TSC is greater than that of the conventional concrete. The increase in strength is due to the point-to-point contact of coarse aggregates in the TSC; stresses in the TSC are first passed through the skeleton of the coarse aggregates and then through the grout, while in normal concrete, stresses are passed through a non-homogenous matrix. Due to this phenomenon, the crack mechanism and the ultimate strength of the TSC were different [25].

The compressive strength of CM-TSCI was at its highest at 56 days of curing. When 100% RCA is used, compressive strength is decreased. The compressive strength of CM-TSCII is reduced by 14.14% when compared with CM-TSCI at 28 days, while the compressive strength of CM-R is reduced by 22.13% when compared with CM-N at 28 days [26–28]. Noritaka Morohashi [29] evaluated the compressive strength of TSC by replacing 30% of the NCA with RCA in TSC, which resulted in a reduction in compressive strength of 12.6% at 28 days. RCA has a porous structure due to the adhered mortar and absorbs more water, which makes it weaker than NCA and causes a reduction in compressive strength [30]. This

5 of 10



adhered mortar also decreases the density of RCA. Tavakoli and Soroushian [31] reported that the compressive strength of concrete made with RCA is less than that of concrete made with NCA when the same w/c ratio is used. Li [32] observed in his study that the percentage of RCA in concrete has an inverse relation with compressive strength.

Figure 1. Compressive strength of the concrete mixes at 7, 28, and 56 days.

The compressive strength of the TSC mixes that had 100% RCA was improved by the addition of bagasse ash as a partial substitution of cement. The compressive strength of TSC10BA and TSC20BA was increased by 4.57% and 8.47%, respectively, when compared with CM-TSCII at 56 days of curing. The increase in strength is due to the pozzolanic reaction between calcium hydroxide and bagasse ash, which forms a calcium silicate hydrate gel [33]. Figure 2 shows the development of compressive strength of all four mixes of the TSC. Figure 2 clearly shows that the increase in compressive strength was rapid until day 7. CM-TSCII, TSC10BA, and TSC20BA show a very similar compressive strength at day 7. From day 7 to day 28, CM-TSCI shows more of an increase in compressive strength than that of the other mixes. From day 28 to day 56, the increase in compressive strength was low for all four of the mixes of the TSC. Kou, Poon, and Agrela [12] reported that there was an increase in compressive strength in RCA concrete mixes when mineral admixture was used. This is mainly due to the porous nature of the RCA; mineral admixture penetrates into the pores of the RCA, which improves the ITZ bond strength between the cement paste and the RCA. Another reason for the increase in compressive strength is the filling of cracks present in the RCA with hydration products.

3.2. Compressive Strength at 250 °C

The compressive strength of the TSC mixes at 20 °C and 250 °C is demonstrated in Table 4. The compressive strength at 250 °C is compared with the compressive strength of the mixes at 20 °C to determine the decrease in compressive strength due to high temperature. All mixes of the TSC demonstrated a loss of strength at 250 °C. The compressive strength loss in all of the mixes was less than 5.2%. The highest strength loss was 5.13% in TSC10BA and the lowest strength loss was 3.53% in CM-TSCI. The decrease in compressive strength at high temperature was mainly due to a loss of water and dehydration of the calcium silicate hydrate. Maanser et al. reported a 4% decrease in compressive strength at 200 °C [34]. The decrease in compressive strength in the mixes that had RCA was slightly



more than that of CM-TSCI. This is mainly due to the weak interfacial bond between the RCA and the hardened paste in the concrete matrix. Otherwise, there is no significant difference in the strength loss between the TSC that has NCA and RCA.

Figure 2. Development of compressive strength of TSC mixes.

Mix Type	Days	Mean Compressive Strength (MPa)	SD
	7	-	-
CM-N	28	24.38	0.093
	56	-	-
	7	-	-
CM-R	28	18.99	0.098
	56	-	-
	7	16.06	0.089
CM-TSCI	28	25.19	0.095
	56	27.02	0.081
	7	13.85	0.087
CM-TSCII	28	21.63	0.098
	56	23.14	0.099
	7	14.41	0.076
TSC10BA	28	22.62	0.083
	56	24.2	0.095
	7	14.96	0.079
TSC20BA	28	23.44	0.082
	56	25.11	0.093

Table 4. Mean compressive strength with standard deviation.

3.3. Tensile Strength

The results of the split tensile strength of the TSC at any given curing age are demonstrated in Figure 3. A split tensile test was only conducted on the TSC samples. Each value is an average of three measurements. It is evident from Figure 3 that the tensile strength of the TSC mixes that have RCA is less than that of the TSC mix that has NCA. The tensile strength of CM-TSCI is highest among all the mixes of the TSC throughout all curing days. There was a rapid decrease in tensile strength when 100% RCA was used. CM-TSCII tensile strength was reduced by 26.84% when compared with CM-TSCI at 56 days of curing. Tensile strength increased with the addition of bagasse ash as a partial substitution of the cement in TSC mixes that have 100% RCA. Tensile strength showed similar behavior as that of compressive strength. Lee and Choi [35] and Padmini, Ramamurthy, and Mathews [26] reported that the tensile strength of the concrete that had RCA was less than that of the concrete that had NCA. The tensile strength of TSC10BA and TSC20BA was increased by 22.1% and 26.86%, respectively, when compared with that of CM-TSCII at 56 days of curing.

The TSC mixes prepared with bagasse ash and 100% RCA showed better results in tensile strength as compared to the TSC mix that had only 100% RCA.



Figure 3. Tensile strength of concrete mixes at 7, 28, and 56 days.

3.4. Mass Loss at 250 $^{\circ}C$

All the TSC mixes exhibited a mass loss due to the evacuation of free water due to an increase in temperature from 20 to 250 °C, which is demonstrated in Table 5. The decrease in mass loss is expressed in percentage form. The maximum mass loss was found in CM-TSCII, which was roughly 4.35%. The lowest mass loss was found in TSC10BA, which was 2.6%. The water present in concrete comes in three forms, which are the free, adsorbed, and bonded forms. This water escapes at high temperature and causes a mass loss. From 20 to 150 °C, a small mass loss occurs, while from 150 to 300 °C, there is an increase in mass loss. This mass loss is mainly due to dehydration of C-S-H [36]. A lesser mass loss is mainly due to the superplasticizer in TSC10BA and TSC20BA, which is due to the effect of resistances. Mean tensile strength is shown in Table 6 while percentage mass loss is shown in Table 7.

Mix Types	Compressive Strength at 20 °C (MPa)	Compressive Strength at 250 °C (MPa)	% Decrease
CM-TSCI	25.18	24.29	3.53
CM-TSCII	21.63	20.67	4.43
TSC10BA	22.63	21.47	5.13
TSC20BA	23.45	22.33	4.77

Table 5. Compressive strength at 20 °C and 250 °C.

Table 6. Mean tensile strength with standard deviation.

Mix Type	Days	Mean Compressive Strength (MPa)	SD
	7	1.92	0.065
CM-TSCI	28	2.51	0.078
	56	2.69	0.073
	7	1.45	0.086
CM-TSCII	28	1.92	0.087
	56	1.97	0.084
	7	1.57	0.092
TSC10BA	28	2.33	0.077
	56	2.41	0.088
	7	1.79	0.073
TSC20BA	28	2.42	0.067
	56	2.5	0.081

Table 7. Mass loss of the TSC.

Mix Types	Mass at 20 $^\circ C$ (kg)	Mass at 250 $^\circ C$ (kg)	% Decrease
CM-TSCI	13.24	12.69	4.15%
CM-TSCII	12.39	11.85	4.35%
TSC10BA	12.27	11.95	2.6%
TSC20BA	12.35	12.01	2.75%

4. Conclusions

The use of recycled coarse aggregate and bagasse ash in two-stage concrete would be beneficial for sustainable and environmentally friendly construction. The following conclusions are deduced from the experimental investigation:

- 1. Compressive strength of the samples made with the two-stage concrete method showed 3% more strength than that of the conventional concrete that had the same ratios, demonstrating the superior nature of the two-stage concrete method.
- 2. Compressive strength was decreased both in the TSC and the conventional concrete when RCA was used. However, compressive strength was reduced in the conventional concrete by 22%, compared to the TSC, which demonstrated a 20% increase in compressive strength.
- 3. A maximum increase in compressive strength was achieved when 20% bagasse ash was used. This increase in strength was found to be 8.47% at 56 days.
- 4. Minimum reduction in compressive strength (3.57%) at 250 °C was achieved when natural aggregates were used. However, the reduction in compressive strength in mixes that had RCA was also very minimal (maximum 5%).
- 5. Every mix that was used experienced mass loss at 250 °C. The maximum mass loss was 4.35% in the two-stage concrete that contained all natural aggregates.

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