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Use of Waste Materials for Sustainable Development of Rigid Pavement

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ABSTRACT

Earth's natural resources belong to everyone and must be maintained for future generations. Thus, waste management and consumption are researchers' main concerns. Using waste resources to build sustainably. It's growing increasingly popular due to its environmental and economic advantages. This paper uses waste materials to increase the sustainability in construction work with cement-based such as waste concrete as a normal aggregate replacement and ground-granulated blast-furnace slag (GGBFS) as supplementary cementitious materials (SCMs) to improve the sustainability in rigid pavements production, to decrease the use of raw materials, and to reduce the CO_2 production in Portland cement (PC) factories. Cubic, cylindrical, and prismatic specimens were prepared in the laboratory with (0%, 10%, 20%, 30%, and 40%) by weight of aggregates waste concrete (WC) as replacements from the natural aggregates. The strength activity index (SAI) of the concrete specimens was in the acceptance strength zone with a slight reduction when compared with the conventional concrete strength. On the other hand, the hybridized effect of using the GGBFS as SCMs with various proportions of GGBFS/PC (0.8, 1.2, 1.6, 2), and WC at (40%, 30%, 20%, and 10%) respectively appeared that SAI was enhanced. Three manufactured specimens in each type of mixture were tested after 7 and 28 days of age curing. The findings from compressive strength, splitting, and flexural tests conducted on mixtures containing recycled aggregate indicate their suitability for use in rigid pavements for secondary roads. It was observed that as the proportion of recycled aggregate in the mixture increased, the strength of the concrete decreased. when ground granulated blast furnace slag (GGBFS) was added to the concrete mixtures, the results varied depending on the ratio of GGBFS present in the mixture. Among the different mixes tested, the mix designated as R30S1.2 was the highest strength load and it can be used for main roads. The results indicate that the use of recycled aggregates at a ratio of 30% and 55% GGBFS gave the best strength results and at the same time reduces the amount of cement and natural aggregates used, and this has an impact on the environment by reducing the presence of waste.

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1. INTRODUCTION

The positive side of sustainable concrete includes preserving the environment by reducing harmful effects such as the accumulation of concrete waste resulting fromthe demolition of buildings, as well as reducing the use of natural aggregates. This is driven not just by environmentalconcerns, but also by the preservation of natural aggregateresources, a scarcity of trash disposal sites, and the rising expense of waste treatment before disposal. Several research investigations have been carried out on the utilization of RA in concrete to comprehend the propertiesof RA cement; however, the majority of these studies are focused on the mechanical characteristics of the results concrete. An effort is made to comprehend durability. Aspects of construction materials derived from them and a comparison to concrete produced with natural aggregates [1, 2]. It is estimated that annually around 15.5 million tons of building debris are created in China [3], the bulk of which is concrete and bricks. Waste concrete aggregate is achieved by using the demolished concrete into small pieces with a specific process called grinding or crushing process to produce the waste aggregate in different sizes. This process is done by fixed crusher or mobility, as this process results in recycled aggregate and its use in variousconcrete mixtures. Several works used recycled materials to achieve the sustainability concept by using

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recycled concrete aggregate (RCA) and studied the behavior of concrete including the physical and chemical properties offresh and hardened concrete [4-7].

The consumption of raw aggregates (fine and coarse), accounting for up to 70-80% of the overall volume of the concrete mixture design, is accelerating in tandem with theexpansion of concrete production and use. The use of reused stones derived from demolition and building waste is introducing new construction trends, substituting for basic (natural) aggregates. It conserves natural resourcesand reduces the amount of landfill space required [8-10]. RCA concrete typically has a lower compressive strength than concrete with pristine aggregate. Depending on thegrade of RCA, Manimaran et al. [11] suggested that the compressivestrength of RCA concrete might reduce by up to 25%.According to Tam et al. [12], an increase in the proportionof coarse RCA used as a replacement for virgin aggregate decreased compressive strength. The reduction in strength was attributed to the weak residual mortar in RCA. Dawood et al. [13] confirmed this trend, attributing it to RCA's lowspecific gravity and high absorption or porosity. In addition, they stated that the strength of RCA concrete was determined by the weakened interface between the residualmortar and the original stone and between the residualmortar and the new mortar. Olivier et al. [14] stated that thecompressive strength is affected by several variables, such as the water-to-cement ratio, the percentage of coarse aggregate substituted with RCA, and the quantity of residual mortar in the RCA.

To modify bitumen and porous asphalt mixtures, it was used the ground granulated blast-furnace slag (GGBS) as asubstitution material for styrene-butadiene-styrene (SBS) [10]. An effort was made in investigating the viability of utilizing industrial waste Ground Granulated Blast FurnaceSlag (GGBS) and agricultural waste Groundnut Shell Ash (GSA) as stabilizing agents in the soil stabilization technique [11].

The use of ground granulated blast furnace slag (GGBFS) as an alternate material to cement leads to reduce the production of carbon dioxide (CO_2) resulting from the cement industry. Nowadays, global cement production contributed to increased CO_2 pollution of around 8% with subtracted 1 ton of CO_2 pollution per ton of cement production and decreased raw materials (limestone, clay, etc.) that are used in the production process of Portland cement. The GGPFS is one of the products of the molten iron industry [12-14]. The American Concrete Institute, ACI 318 code, section 5.1.1, indicates that concrete should have a compressive strength of more than 17.3 MPa after 28 days of casting to refer to it as structural concrete [9]. So, this indicates that this type of concrete has good strength properties and can be used in building facilities at various members. On the other hand, the usage of waste materials to achieve sustainability at this time become necessary and urgent to reduce the negative impacts on theenvironment, keep the raw materials for future generationsand reduce landfilled materials.

The (GGBS) should be activated by combining it with Portland cement before it can be utilized in concrete. A typical mixture consists of 50% GGBS and 50% Portland cement, but amounts of GGBS [4] ranging from 20% to 80% are frequently employed. The greater the amount of GGBS, the greater impact on the properties of concrete.

The importance of this research came from the need for test results and their practical effects on the construction industry. The research includes an evaluation of the properties and behaviour of high-strength concrete mixtures. This evaluation includes factors such as compressive strength, toughness, workability, and other mechanical properties. By understanding how these admixtures perform, the study provides valuable insights to improve concrete design and construction practices and is important to identify accessible data on the properties and behavior of high-strength formwork with recycled aggregates and/or with GGBFS. To do this, recycled concrete aggregate (RCA) is produced and partially replaced by virgin aggregate to manufacture concrete mixes. Furthermore, the hybrid use of RCA as a pre- preparation of virgin aggregates and GGBFS as a partial substitute for Portland cement is also being investigated. In summary, this research is important because it explores the use of recycled concrete aggregates and GGBFS in high-strengthconcrete, contributing to sustainable construction practices, resource efficiency, performance assessment, potential industry impact, and filling the knowledge gap in this field.

2. EXPERIMENTAL TEST DETAILS

2. 1. Materials The following raw materials were employed in the work:

2. 1. 1. Portland Cement The Portland cement used is sulfate resistant, Type VCEM I 42.5SR according to Iraqi Standard No. 5/1984, which is a production of the Karbala cement factory [15]. The chemical and physical properties confirm to ASTM C150 (Table 1) [16]. The sulfate-resistant 3 cement (SRC) is the result of crushing a dry mix of SRC clinker and gypsum and it is a hydraulic bonding grey fine powder.The applications of this type of cement are in concrete foundations and structures like rigid pavement, which is in contact with the soil that contains sulfates. The Chemical and physical requirements of sulfate- resistant Portland cement summarized in Table 1.

TABLE 1. Chemical and physical requirements of sulfate- resistant Portland cement [15]. (Data processing was done by a material processor)

Test Type	Test Method	Limitation	Test result
Chemical requirements			
“Loss on ignition (as LOI), %	IQS 472/1993	< 4.0	3.56
Non-Soluble Substances, %		≤ 1.5	0.50
SO3 Content, %		2.5 if C3A ≤3.5 2.5 if C3A ≥3.5	2.37
C3A, %		≤ 3.5	2.49
MgO, %		≤ 5.0	1.75
Chloride content, %	BS EN 196-2/2013	≤ 0.1	0.03
Physical and mechanical requirements			
Finesse (Blaine), m^2/kg	IQS 198/1990	≥ 300	344
Initial setting time, minute	BS EN 196-3/2016	≥ 45	150
Final setting time, hour		≤ 10	3.18
Soundness (expansion)-LeChatle, mm		≤ 10	0.29
Compressive strength, notless than (mN/m^2): 2 days 28 days	BS EN 196-3/2016	≥ 20.0 ≥ 42.5	23.9 48.2

2. 1. 2. Sand The sand used in this work was washed and screenedred sand, and it was quarried from the Al-Ukhaidir area inKarbala. Water-washed sand is used to get rid of salts andimpurities, as well as clay particles because their presence affects concrete and reduces the cohesion of the mixture. The other benefit of this process is to obtain clean, saturated and saturated surface dry (S.S.D) sand. It was sieved to meet the graduation requirements of Iraqi SCRB Standards/R10-2003 [15]. The gradation test was carried out using 1 kg of fine aggregates by using a sieve shaker and the results are shown in Table 2 and figuratively presented in Figure 1.

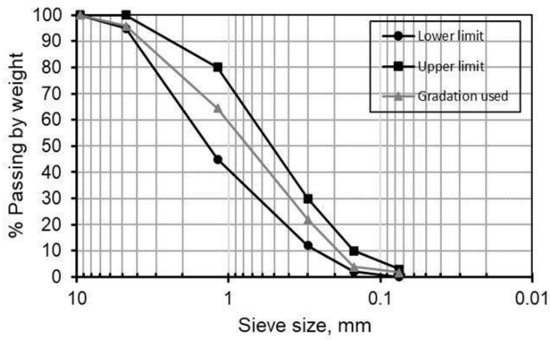

Figure 1. Gradation limits and the selected gradation of the fineaggregates used [15]

2. 1. 3. Coarse Aggregate The crushed coarse aggregate used in the research is from the Al-Nibai quarry, which is located north of Baghdad. It is washed with water to clean the impurities that affect concrete and reduce cohesion. Crushed aggregates with multiple angles were used to increase bonding and reduce voids in concrete. Specific particle sizes were used that meet the grading requirements according to Iraqi SCRB Standards/R10-2003 [16]. The gradation test was carried out using 5 Kg of coarse aggregates by using a sieve shaker as given in Table 3 and presented in Figure 2.

TABLE 2. Gradation of the sand used according to Iraqi specifications R10 [15]

Sieve size (mm)	% Passing by weight	
	Gradation limit	Gradation used
9.5	100	100
4.75	95-100	95.87
1.18	45-80	64.37
0.30	12-30	21.96
0.15	2-10	3.95
0.075	0-3	1.71

TABLE 3. Gradation of the crushed gravel used according to Iraqi specifications R10 [15]

Sieve size (mm)	% Passing by weight	
	Gradation limit	Gradation used
50.0	100	100
37.5	90-100	99
19.0	35-70	70
9.5	10-30	30
4.75	0-5	1

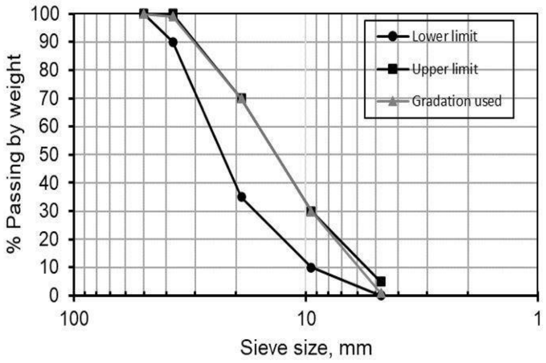

Figure 2. Gradation limits and the selected gradation of the coarse aggregates used [15]

2. 1. 4. Ground-granulated Blast-furnace Slag (GGBFS) It is considered as a supplementary cementitious material with hydraulic bonding properties used inconstruction materials that contain cement based. Thismaterial is produced from the process of making iron molten by placing iron ore, limestone, and coke in a blast furnace. Various chemical reactions occur at a high temperature of up to 1500°C, resulting in molten iron and molten slag, which is considered a waste material. The molten slag is quickly cooled with water or steam, and it produces calcium silicate hydrate (granular slag), which is a fine, glassy powder then milling well, produces GGBFS,which is then mixed with cement to obtain a concrete mixwith perfect cementitious properties. It is greenish and symbolized particles.

2. 1. 5. Water and Superplasticizers For the mixing and curing stage of the samples, clean water that was free of contaminants was employed. A water-reducing admixture was also used as a chemical additive to reduce the amount of water, as well as increase the workability. The physical properties and test results of GGBFS are summarized in Tables 4 and 5. Its characteristics are shown in Table 6.

2. 2. Testing Setup The ELE for compressive strength test setup is shown in Figure 3.

➢ ELE International compressive test machine _ 3000 kN:

1. Cube:- To check the compressive strength of concrete, cubic models of 100 were used, which are sufficient to obtain results of concrete resistance to failure, and at the same time have a benefit in sustainability by reducing the use of concrete materials, as well as in terms of disposal ofthese models after testing, and determining this measurement depending on the type of examination as wellas the highest size of coarse aggregate The user, where three concrete models were used and the average testresults were relied upon, which are sufficient to meet the routine test for compressive strength and achieve approved results for the projects. The test is carried out by placing the concrete cube inside a compressive strength device between two steel surfaces, where pressure is applied to thesurface area of the cube. the models were tested at the rateof loading 6 KN/s until failure.

Calculate the compressive strength of the specimen as follows: C= A/P Where: A= area of square mm^2 and P= maximum applied load, N

According to ASTM C39 [17]

2. Cylinder: Possibility to perform a spliting test for cylindrical samples with a length of 200 mm and a diameter of 100 mm, since the test results are based on 28days of water curing. When the sample is placed in the device, uniaxial loading causes a relatively high stress along the length of the sample, and 25 mm thick wood strips are placed between the surface of the sample and theupper and lower bearing steel blocks to distribute the stresson the axis, Calculate the splitting tensile strength

TABLE 4. Physical properties of GGBFS (Data processing wasdone by a material processor)

Model Number	Slag	Color	Type	Fineness	Standard
S95	Hot	Near White Color	Powder	490-510 M2/Kg	GB/T 18046 BS6699

TABLE 5. Test results of GGBFS (Data processing was done bya material processor)

No.	Items of testing	Limits	Results	Decision
1	Specific surface area, m^2/kg	≥400	418	Passed
2	Relative water, %	≥95	106	Passed
3	Density, g/cm^3	≥2.8	2.9	Passed
4	Moisture Content, %	≤1.0	0.1	Passed
5	Sulfur trioxide, %	≤4.0	0.3	Passed
6	Chlorine ion, %	≤0.06	0.02	Passed
7	Loss on ignition, %	≤3.0	0.2	Passed
8	Vitreous content, %	≥85	93	Passed

TABLE 6. Technical information on the superplasticizer used isprovided by the manufacturer (Data processing was done by a material processor)

Base	Appearance/ colour	Specificgravity	Chloride content	Air environment	Compatibility
Polycarboxylate polymer technology	Brownishliquid	1.085 ± (0.01) g/cm^3	Nil	Nil	All types ofPortland cement

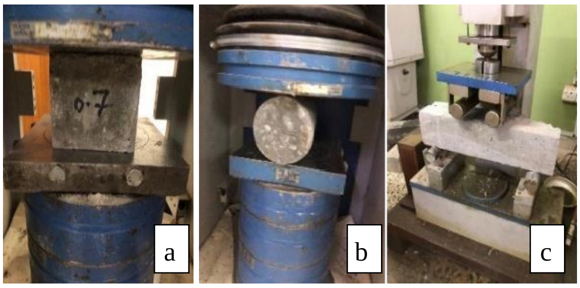

Figure 3. (a) ELE for compressive strength test (b) ELE splitting tensile strength test, (c) Prism of flexural test concrete

of the specimen as follows:

$$T = 2P/\pi ld \quad (1)$$

where: T = splitting tensile strength, MPa ,
P = maximum applied load indicated by the testing machine, N
l = length, mm , andd = diameter, mm.
tested at the rate of loading 0.95 kN/sec until failed, and according to ASTM C496/C496M [18].

- ELE International Flexural strength_ 1000 KN: used four points for prism sample 100×100×400 mm, four- point load, and span length 300 mm between supportblocks, All sample surfaces must be smooth to obtain accurate results and keep the samples moist in the period between removal from water curing to the time of examination because drying of the sample surface results in a measure of bending strength. The examination is carried out by shedding the pregnancy continuously and without shock. the rate of loading 0.2 KN/s until failure. Calculate the splitting tensile strength of the specimen as follows:

R= PL/bd^2 according to ASTM C78/C78M [19] where:
R = modulus of rupture, MPa,
P = maximum applied load indicated by the testing machine, N,
L = span length, mm,
b = average width of specimen, mm, at the fracture, and
d = average depth of specimen, mm

2. 3. Methods of Working and SamplesProcessing

The trial program is first stage was to study the effect of using recycled aggregates to produce concrete materials from the recycled aggregate. Slump according to ASTM, C143 [20], was used to analyze the properties of fresh concrete from recycled aggregates. The compressive, tensile, and flexural strengths of hardened concrete are determined after 7, and 28 days of age. These tests are performed to obtain the properties of the hardened concrete.

The proportions of Portland cement, sand, and gravel used in this work by weight are (1:2.32:3.26) respectively. The properties of mixes of part 1 are explained in Table 7.It demonstrates the use of recycled aggregates obtained from crushing concrete, with replacement ratios of (0%, 10%, 20%, 30%, and 40%) by natural aggregates.

The second part of the research is shown in Table 8. which explains the same proportions of RCA, with the addition of GGBFS as a replacement ratio for cement withfour different proportions of GGBFS/PC (0.8, 1.2, 1.6 and 2.0)

The specimens produced in this work within the first and second stages are cubes with dimensions of 10×10×10 cm, cylinders with a diameter × height of 10×20 cm, and prisms with 10×10×40 cm (height × width× length). The cubic specimens were monotonically tested under compression loads. Indirect tension test was carried out specimens were tested under four-point flexural loads.

The primary reason for utilizing three geometric shapes, namely the cube, cylinder, and prism, is to represent the strength characteristics of concrete under different loading conditions. Each shape represents the specific testing method used in concrete strength testing. The cube shape is commonly employed to determine the compressive strength of concrete. Cubes are cast and subjected to a compressive load until failure occurs. The dimensions of the cube faces are equal, providing a uniform distribution of stress during the test. The cylindershape is typically used to evaluate the tensile strength of concrete. Cylinders are subjected to a point load until they fracture. This test helps determine the resistance of concrete to cracking or splitting. The prism shape, specifically a rectangular prism, is utilized to represent the flexural strength of concrete. The prism specimens have longer dimensions in one direction, Simulate a beam or a structural element. The load applied to the prism determines the amount of bending that occurs before fracture. This test is significant for evaluating the capacity of concrete to bear vehicle loads or other types of loads without failure. these three geometric shapes provide different insights into the strength properties of concrete under varying loading conditions, allowing engineers and researchers to represent its performance in real-world applications. Figure 4 presents the manufactured specimens.

The process of preparing the models was done by preparing the weights of the materials and lubricating the molds, and the materials were mixed in two stages, the drymixing, where the materials were mixed well until they were evenly distributed inside the mixer, and the second stage was the wet mixing, by adding water and plasticizer gradually to the mixture until the appropriate consistency was obtained. When the concrete was put into the molds itwas then placed on the vibration table. The goal of concrete consolidation, referred to as compaction, is to produce thedensest concrete. In low-slump concrete, air voids may make up to 20% of the

TABLE 7. Concrete mix proportions – part 1

Mix	Code of mixes	Waste concrete (R)%	Cement, %	Fine aggregate	Coarse aggregate	Water/ cement ratio	SP, %	Slump(mm)
Mix1	R0 Plain mix	0%	100	100	100	0.35	0.3	50
Mix2	R10	10%	100	100	90	0.35	0.3	48
Mix3	R20	20%	100	100	80	0.35	0.3	45
Mix4	R30	30%	100	100	70	0.35	0.3	42
Mix5	R40	40%	100	100	60	0.35	0.3	39

TABLE 8. Concrete mix proportions – part 2

Mix	Code of mixes	GGBFS/ Cement	GGBFS, %	Cement, %	Waste concrete%	Natural coarse	Fine aggregate	W/C	SP, %	Slump (mm)
Mix6	R10S2	2	67	33	10	90	100	0.40	0.3	41
Mix7	R20S1.6	1.6	62	38	20	80	100	0.40	0.3	38
Mix8	R30S1.2	1.2	55	44	30	70	100	0.40	0.3	36
Mix9	R40S0.8	0.8	45	55	40	60	100	0.40	0.3	33

Figure 4. Samples of the produced specimens

total volume of freshly cured concrete. The movement of the particles has the effect of dispersing the liquid in the mixture, thus reducing the internal friction and filling the coarse aggregate. in respectof obtaining a composition similar to coarse aggregate particles. The vibration continues to expel the majority of the trapped air to increase the strength of the concrete [15].Tables 7 and 8 summarized concrete mix proportions.

3. RESULTS

3. 1. Effects of the Composition of Mixtures

3. 1. 1. Using of Recycled Aggregate

The study's goal is to determine the impact of employing recycled materials such as waste coarse aggregates produced from crushing concrete and mixing in proportion with natural aggregates and creating new concrete suitable for rigid pavement, high traffic loads, and the lowest possible cost.

The effect of replacing coarse aggregate for waste was explored by 10%, 20%, 30%, and 40% on fresh concrete, where the stagnation values of sustainable concrete is shown in Table 8. Data were recorded, as the results showed a decrease in slump values with an increased in thereplacement percentage.

The compressive strength of mixes that included recycled aggregates was found to be lower compared to thebase mix containing natural aggregates, as given in Table

9. Similar findings were reported in other studies as well [21-23]. The reduction in compressive strength exhibited arange of approximately 0.73-12.25%. The underlying cause of the strength reduction can be ascribed to the heterogeneous composition of the recycled aggregate, which is due to the existence of bound of the old mix on the outside surface of the recycled aggregates. Concrete production was adversely affected due to the high porosity of the material, as reported by Tam et al. [24].

As can be seen in Table 9, all the mixtures showed a decrease in tensile strength compared to the plane mix, andit seems that the strength was affected by the amount of recycled aggregate replacement and this is due to the quality of the crushed concrete [6].

Cylindrical specimens of crushed sustainableconcrete were tested to evaluate the failure condition. Figure 7, shows the values obtained from examining mixtures that contain returned aggregate. It was found that increasing the percentage of recycled aggregates in concrete leads to a decrease in the amount of tensile resistance by a rate ranging between 0.33%-40% compared with the natural mix.

According to the results of flexural strength, all concrete mixtures made of recycled aggregates achieved less strength than the results of the base mixture (Table 9)after comparing the results of concrete mixtures with recycled aggregates with the reference mix. The results exhibit that the higher the amount of reconstituted aggregate, the lower the load resistance to fracture [25].

Age curing has several effects on sustainableconcrete content, Ground Granulated Blast Furnace Slag (GGBFS), and recycled concrete aggregate (RCA) in concrete.

Age curing positively influences the performance of GGBFS in concrete. As the concrete cures and ages, the GGBFS particles continue to react with the calcium hydroxide produced during cement hydration. This reaction leads to the formation of additional hydration products, such as calcium silicate hydrate (C-S-H) gel, which contributes to increased strength and improved durability of the concrete. As for the recycled aggregate Age curing can have a positive impact on the properties of concrete incorporating RCA. With time, the RCA particles continue to bond and interact with the cementitious matrix, resulting in improved interfacial transition zones and enhanced mechanical properties. Age curing allows for thefurther development of strength and durability, making the concrete with RCA more sustainable.

3. 1. 2. The Effect of Using Recycled Concrete Aggregate and GGBFS Table 9 shows that the use of recycled aggregates contributed to reducing the compressive, splitting and flexural strengths of concrete compared to the concrete made with natural aggregates. This deficiency was tried to compensate by adding GGBFS, and thus sufficient strength was reached. As stated in [26-28], the strength of concrete is affected by the exact properties of the surface area between the RCA and the cement paste. Thus slag is believed to strengthen concrete by strengthening the bond between the cement paste and the recycled aggregate. It has been shown that the microstructure and microhardness in this transition zone of sustainable concrete can be improved with increasing slag content in the concrete mixture [29]. This can help explain the advances made concretely.

The inclusion of more than 50% GGBFS in the concrete gave activity at 7 and 28 days after curing the specimens in clean water. Among the four mixtures studied, mixture 8 gave the highest compressive strength by 16.7%, thus obtaining a stronger and better mixture thanthe base mixture, and reducing the use of cement and natural aggregate by 55% and 30%, respectively. The use of GGBFS with high percentages of more than 60% in mixR20S1.6 led to an 11.59% reduction in compressive strength compared to the concrete containing recycled aggregates.

Table 9 gives the results obtained from examining the cylindrical specimens that manufactured by adding GGBFS to concrete with recycled aggregate under indirect tensile load. The strength gained by mixtures containing GGBFS with RCA compared to mixtures containing RCAonly can be seen clearly. Moreover, a slight improvement of mix 8 compared with the plane mixture has been achieved.

The concrete increased the rate of strength gain progressively with an increase in the percentage of GGBFSin the mixture, where the mix R30S1.2 which contains 55% slag achieved the highest results, The substitution of cement reaches 45%.

The flexural strength performance of the recycled aggregates with GGBS is shown in Table 9. The results showed an increase in the flexural strength in all mixtures containing GGBFS and RCA compared with mixtures thatwere manufactured with RCA only or those made with virgin aggregates and a full amount of Portland cement. Asa reminder, these mixtures contain GGBFS with different dosages of 45%, 55%, 62, and 67% that represent the ratios of GGBFS/PC of 0.8, 1.2, 1.6 and 2.0 respectively. The superiority of mixtures containing

TABLE 9. The test results of mechanical properties of concrete samples

Mix ID	Mix code R (recycle coarse aggregate) S (slag), Sh (steel shaving)	Compressive Strength (MPa)		Splitting Strength (MPa)		Flexural Strength (MPa)	
		7 days	28 days	7 days	28 days	7 days	28 days
Mix1	R0	22.18	31.13	2.12	2.99	2.28	2.97
Mix2	R10	22.07	31.09	1.85	2.71	2.24	2.92
Mix3	R20	21.93	30.74	1.80	2.54	1.96	2.55
Mix4	R30	20.87	30.04	1.44	1.97	1.53	2.01
Mix5	R40	19.76	27.92	0.88	1.20	1.38	1.78
Mix6	R10S2	20.33	27.86	1.77	2.36	2.57	3.23
Mix7	R20S1.6	21.19	28.73	1.75	2.43	3.15	4.20
Mix8	R30S1.2	28.01	35.07	2.24	3.03	4.72	6.13
Mix9	R40S0.8	25.41	31.65	2.08	2.93	2.43	3.20

GGBFS and RCA over those made with RCA only are with percentages of 10.62,64.71, 67.21 and 79.77 at 28 days age for the mixtures that have RCA of 10, 20, 30 and 40% respectively.

3. 2. Interpretation of Results andDiscussion

3. 2. 1. Workability The workability of all compounds was evaluated usingthe slump test for the base mixture and mixtures containing reconstituted materials. Figure 5 exhibits the values of the slump in each mixture. It was noted that the slump values differ from one mixture to another based on the proportions of additives such as recycled aggregates and GGBFS. The workability is lower in the sustainable mixtures (R10, R20, R30 and R40) compared to the reference mixture, as presented in Figure 4. The decrease in the slump values when the RCA is increased in the mix is because of the negative effect of incorporating crushed concrete into the new concrete, as this decrease can be attributed to the coarse surface of the recycled aggregate containing the old concrete, which is mainly due to the higher absorption capacity of the restored aggregate, and the lower water level in the fresh mix that leads to a decrease in the workability and a decrease in the amount of slump of the concrete relative to the concrete containing only virgin aggregates [30-32].

In the presence of recycled concrete aggregates, the addition of GGBFS had a detrimental effect on the workability and slump. The value of slump decreased with the increase in the proportion of GGBFS in the mixes (R10S2 and R20S1.6). This negative effect has been attributed to the fact that the surface area of GGBFS particles is larger than that of cement particles [19, 33].

Mostly, the compressive strength of the mixtures that contain natural aggregates is higher than the compressive strength of the concrete containing RCA because it is a weaker material. The amount of decrease in the compressive strength depends on the percentage of recycled aggregates in the mixture and on the quality of the concrete waste.

3. 2. 2. Strength Activity Index In Figure 6, it can be observed that the compressive strength in the mixtures from R10 through R40 decrease gradually for both curing ages (7 and 28 days) if it is compared with

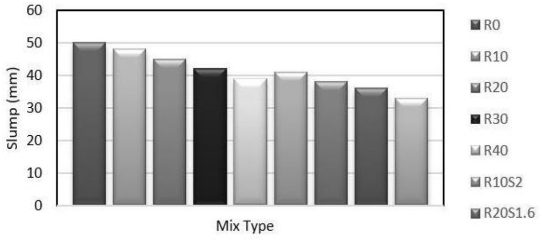

Figure 5. Slump test results

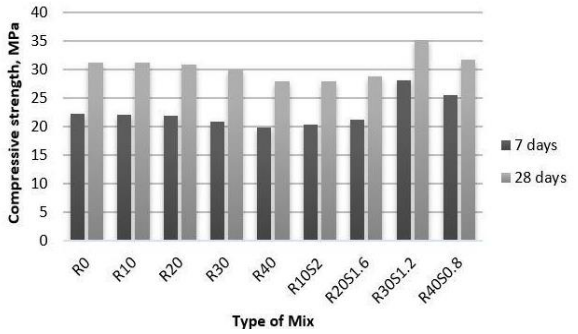

Figure 6. Compressive strength test results

the reference mixture (R0) and in close proportions. According to ASTM C39 [17] and previous studies, many factors may affect the mechanical properties of concrete such as:

-The water absorption of recycled coarse aggregate is more than that of natural aggregate, and the higher the water absorption percentage, the lower the concrete compressive strength [30, 34, 35].

-The source of crushed concrete also may affect the compressive strength of the sustainable concrete. If the demolished concrete has high load-bearing strength, this leads to the production of concrete with high strength compared with the concrete produced from normal recycled concrete. Moreover, the workability of fresh concrete can also be attributed to a decrease by a small amount compared to the base concrete [36-38].

-The phenomenon under observation pertained to the compression of concrete cubes on a vibration table. Poon et al. [39] stated that recycled aggregate particles have the potential to migrate toward the cement during vibration. Design a region characterized by a progressive increase in the water-to-cement ratio, resulting in an elevated level of porosity. The aforementioned process has the potential to diminish the cohesion between the repurposed aggregates and the matrix of cement [40].

Previous works suggested that the utilization of recycled aggregates in concrete, when exposed to saturated water, may lead to an ineffective interfacial transition zone (ITZ), thereby significantly impacting the concrete's properties. The effects have been observed to be the potential weak link in the chain, in comparison to cement paste and the accumulation of particles. It should be noted that the use of recycled aggregates in concrete production has both advantages and disadvantages in different regions. A new bond can be formed between recycled aggregates, including gravel and old mortar, as well as between these recycled aggregates and newly created cement putty. A specific condition can create a non-uniform region that has the potential to diminish the strength of concrete [6, 37].

The compressive strength changes by adding GGBFS as a relative alternative material to cement. It was noted that the suitable replacement ratio in the compressive strength examination was in the mixture R30S1.2 with 30% recycled aggregate and GGBFS 55%. The strength increased by 26.3 and 12.6% compared to the base mixture for the curing periods 7 and 28 days respectively, which may be due to the increased effectiveness of the pozzolanic reaction [41]. When the percentage of GGBFS decreases for the R40S0.8 mixture to be 45% of cementitious materials, the compressive strength begins to decrease compared with the previous mixture but is still a little higher than the reference mixture.

With the addition of higher amounts of GGBFS in the cases of mixtures R10S2 and R20S1.6 (more than 55% of total cementitious materials), the compressive strength registered lower values than that of the original mixture, which is due to the acute shortage of Portland cement

Figure 7 presents the results of the tensile strength, By comparing the splitting tensile results of concrete containing both ground granulated blast furnace slag (GGBFS) and recycled aggregates with those of concrete containing only recycled aggregates, an increased splitting tensile strength was observed.

The use of GGBFS as a partial replacement for cement in concrete improved the mechanical properties of the material. GGBFS is a by-product of the iron and steel industry with pozzolanic properties, which means that it can react with calcium hydroxide to produce additional cementitious compounds. This reaction improves the strength and tensile properties of concrete.

Recycled aggregate is crushed concrete or construction waste that is replaced with natural aggregate in concrete production. Although the use of recycled aggregates alone may reduce the overall strength of the concrete due to the presence of weak interfacial transition zones between the old and new cementitious materials, it can still provide satisfactory performance depending on the application.

However, when combined with recycled aggregates, GGBFS can help mitigate a potential decrease in strength that would result from using recycled aggregates alone. GGBFS contributes to the formation of additional hydration products and a denser microstructure in concrete, thus improving tensile strength. By combining GGBFS and recycled aggregates in concrete, the tensile strength to fracture was increased compared to concrete containing only recycled aggregates. The exact extent of improvement depends on variables such as the proportions and properties of the materials used, the curing conditions, and the mix design of the concrete. According to ASTM C496 [18].

Figure 8 demonstrates the results of the flexural test. Itis also called the modulus of rupture test. This test was conducted by applying a gradual four points flexural load on concrete prisms according to ASTM C78 [19], which simulates traffic loads on rigid pavement. The addition of GGBFS and recycled aggregate to concrete can improve flexural performance in comparison to using recycled aggregate alone. GGBFS is a cementitious material that can be used to supplant a portion of the cement in concrete. It increases the workability and durability of concretewhile decreasing hydration heat. GGBFS can enhanceflexural strength by enhancing the chemical and physical properties of the concrete matrix as a whole. Recycled aggregate: When using recycled aggregate in concrete, the pulverized concrete residue is substituted for a portion of the natural coarse aggregate. Typically, recycled aggregate has weaker tensile properties than natural aggregate. Therefore, recycled aggregate alone results in lower flexural strength than concrete with natural aggregate. However, when GGBFS and recycled aggregate are combined in concrete, the GGBFS can help improve the recycled aggregate's properties, mitigating the recycled aggregate's potentially negative impacts on strength. The pozzolanic activity of GGBFS can enhance the adhesion between the cementitious matrix and recycled aggregate particles, resulting in enhanced flexural strength.

By combining GGBFS and recycled aggregate, it is possible to create a concrete mixture that takes advantage of the strength-enhancing properties of GGBFS while stillmaking use of recyclable materials. This combination can result in greater flexural strength than using recycled aggregate concrete alone table, the precise increase in flexural strength will depend on many variables, includingthe exact proportions of GGBFS and

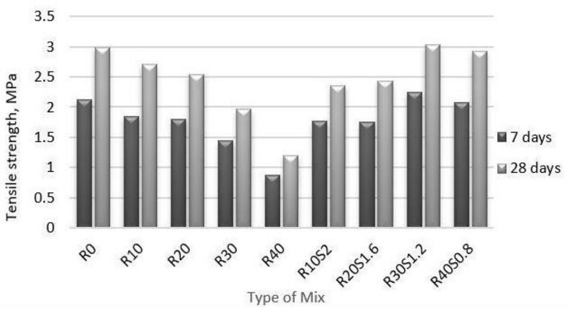

Figure 7. Indirect tensile strength of different mixtures

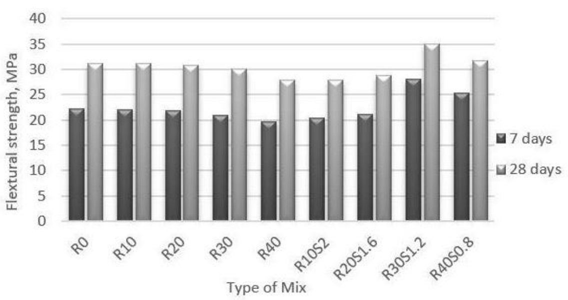

Figure 8. Results of flexural strength test

recycled aggregate, the grade of the materials, curing conditions, and the overall mix design. According to ASTM C78 [19].

It is common knowledge that GGBFS endures a pozzolanic reaction when combined with water and cement. In addition to improving the durability, the addition of GGBFS may have a positive influence on its mechanical properties [20, 39, 42]. The pozzolanic response, which results in an increase in calcium silicate hydrate (C-S-H) and contributes to the improvement of cement paste strength and, by extension, the general strength of concrete [43, 44], is the primary cause of the strength and durability enhancements.

The reason is due to the increase in concrete strength after adding GGBFS to the fresh mortar, as the cement reacted with water to produce C-S-H gel (concrete bond strength), which represents the strength of concrete but it is fixed at 60-70% by volume of concrete with 20-25% calcium hydroxide. The use of supplementary cementitious materials is to make a chemical reaction between these materials and calcium hydroxide to produce a new concrete bond (C-S-H) that has the same strength when compared to conventional concrete.

Instead of natural to reach sustainability and at the same time the strength required to bear the loads placed on the pavement, on the other hand, the mechanical behaviour of these materials acts as filling for the voids that exist due to the mechanical interaction and this is another reason for increasing the strength (the optimal water content of the concrete to complete the reaction is 0.23 but the excess amount helps to make the concrete easier to operate and weakens the concrete). So, the surplus water undergoes evaporation until the void ratio of the reactant attains approximately 5-6%. The reactant materials assume a role in the void ratio by functioning as fillers. The fillers like GGBFS present in the material are composed of particles that are smaller in size than cement, which consequently enhance the mechanical characteristics and the overall structure of the material [13].

Adding GGBFS into concrete reduces the heat of hydration by substantially lowering the amount of heat produced during the hydration process. This is particularly important in large concrete structures, such as dams or foundations, where excessive heat accumulation can lead to thermal fracture. Using GGBFS assists in preventing hyperthermia and heat-related complications [40].

In contrast, adding GGBFS to concrete reduces its carbon footprint because the production of GGBFS involves fewer carbon emissions than conventional cement. Since GGBFS is a byproduct, its incorporation into concrete reduces the quantity of cement required, thereby reducing the greenhouse gas emissions associated with cement production. This makes GGBFS an environmentally preferable option for the production of concrete [41].

It can be noted from the above results that the presence of the reconstituted aggregate in the mixture gave good results, but less than the results of the main mixture, indicating that the reconstituted aggregate is less strong than the natural aggregate and that the old concrete surrounded by the aggregate constitutes a weak point, and at the same time this concrete absorbed a quantity of water from the mixture, and this in turn led to Reduction in workability and slump, and this conclusion has an inverse relationship with the proportion of recycled aggregate added to concrete.

Moreover, the presence of the reconstituted aggregate in the mixture gave good results, but less than the results of the main mixture, indicating that the reconstituted aggregate is less strong than the natural aggregate and that the old concrete surrounded by the aggregate constitutes a weak point, and at the same time this concrete absorbed a quantity of water from the mixture, and this in turn led to Reduction in workability and precipitation, and this conclusion has an inverse relationship with the proportion of recycled aggregate added to concrete. However, adding GGBFS at a ratio of (62, 67%) leads to a decrease in resistance. The reason for this is due to a lack of chemical bonding because granular furnace slag contains a high percentage of silicates and alumina, which are materials that act as pollutants with the cement components. When using a high percentage of GGBFS, competition may occur between cement components and slag for water and calcium available for chemical bonding, which reduces the speed of formation of calcium hydroxide compounds, silicates and alumina required for concrete strength, and the other reason is the increase in empty parts because granular slag has high porosity properties and when using a high percentage of it, it increases the empty parts in the concrete. The presence of empty parts leads to weak concrete strength and a lack of strength to external influences such as freezing, thawing and corrosion.

However, when using GGBFS at a ratio of (44, 55%) the led to an increase in strength, especially in the mixture (R30S1.2) which contains the ideal ratio of GGBFS and recycled aggregates, where the highest results of stress resistance were obtained compared to other mixtures in this research.

4. CONCLUSION

The above study shows the following conclusions:

1. The research findings demonstrate the potential of wastematerials, specifically waste concrete and ground-granulated blast-furnace slag (GGBFS), in enhancing sustainability in construction practices.
2. The workability of the sustainable mixtures was observed to decrease compared to the reference mixture due to the rough surface of recycled aggregate and the

adverse impact of GGBFS on workability and slump.

3. The compressive strength of mixtures containing recycled concrete aggregates (RCA) gradually decreased compared to the reference mixture, primarily influenced by factors such as higher water absorption of recycled coarse aggregate and variations in the load-bearing strength of the original concrete.

4. Incorporating GGBFS as a substitute for cement positively influenced the compressive strength, with the optimal replacement ratio identified as 30% recycled aggregate and 55% GGBFS.

5. The combination of GGBFS and recycled aggregates resulted in improved splitting tensile strength compared to concrete containing only recycled aggregates, attributed to the pozzolanic activity of GGBFS. GGBFS and other pozzolanic materials react with calcium hydroxide (CH) generated during cement hydration to form additional cementitious compounds. These compounds occupy the voids and strengthen the bond between the cement matrix and aggregates, thereby increasing the tensile strength. attributed to the pozzolanic activity of GGBFS.

6. The flexural strength of concrete improved when GGBFS and recycled aggregates were combined. GGBFS contributes to this improvement by strengthening the bond between the cement matrix and the recycled aggregate particles. The finer particles of GGBFS occupy the cavities between the larger recycled aggregates, resulting in more efficient load transmission across the matrix-aggregate interface. This enhanced bonding increases flexural rigidity.

7. Integrating refuse materials into construction can contribute to sustainable practices by decreasing the demand for virgin materials and waste disposal. However, it is essential to optimize the proportions and properties of the materials to assure their suitability for particular applications and conditions. During the material selection and design process, factors such as the type and quality of the waste materials, the intended performance requirements, and environmental considerations must be taken into account.

8. Further research is warranted to determine optimal combinations of waste materials and explore additional factors influencing mechanical properties and the overall performance of the concrete.

9. The study highlights the potential of refuse materials, such as waste concrete and GGBFS, to increase sustainability and improve the mechanical properties of building materials. The construction industry can reduce its environmental impact and contribute to a circular economy by reusing refuse materials. This strategy is consistent with the principles of sustainable development and offers opportunities to create more enduring and resilient structures while simultaneously reducing resource consumption and refuse production.

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Persian Abstract

چکیده

منابع طبیعی زمین متعلق به همه است و باید برای نسل های آینده حفظ شود. بنابراین مدیریت و مصرف زباله دغدغه اصلی محققین است. استفاده از منابع ضایعاتی برای ساخت و ساز پایدار این به دلیل مزایای زیست محیطی و اقتصادی آن به طور فزاینده ای محبوب شده است. این مقاله از مواد زاید برای افزایش پایداری در کارهای ساختمانی با پایه سیمانی مانند بتن ضایعاتی به عنوان جایگزین سنگدانه معمولی و سرباره کوره بلند دانه‌بندی شده زمینی (GGBFS) به عنوان مواد سیمانی مکمل (SCMs) برای بهبود پایداری در تولید روسازی‌های صلب، کاهش استفاده از مواد خام CO2 و کاهش تولید سیمان بندری استفاده می‌کند. نمونه‌های مکعبی، استوانه‌ای و منشوری در آزمایشگاه با (۰، ۱۰، ۲۰، ۳۰، و ٤۰ درصد) وزن دانه‌های بتن زباله (WC) به عنوان جایگزین از سنگدانه‌های طبیعی تهیه شدند. شاخص فعالیت مقاومتی (SAI) نمونه‌های بتن در ناحیه مقاومت پذیرش با کاهش جزئی در مقایسه با مقاومت بتن معمولی بود. از سوی دیگر، اثر ترکیبی استفاده از GGBFS به عنوان SCM با نسبت های مختلف GGBFS/PC (0.8، ۱.۲، ۱.٦، ۲)، و WC به ترتیب (٤۰٪، ۳۰٪، ۲۰٪ و ۱۰٪) به نظر می رسد که SAI افزایش یافته است. سه نمونه تولید شده در هر نوع مخلوط پس از ۷ و ۲۸ روز از سن پخت مورد آزمایش قرار گرفتند. یافته‌های حاصل از آزمون‌های مقاومت فشاری، شکافتن و خمشی انجام‌شده بر روی مخلوط‌های حاوی سنگدانه بازیافتی، مناسب بودن آن‌ها برای استفاده در روسازی‌های صلب برای جاده‌های فرعی را نشان می‌دهد. مشاهده شد که با افزایش نسبت سنگدانه های بازیافتی در مخلوط، مقاومت بتن کاهش می یابد. هنگامی که سرباره کوره بلند دانه بندی شده آسیاب شده (GGBFS) به مخلوط های بتن اضافه شد، نتایج بسته به نسبت GGBFS موجود در مخلوط متفاوت بود. در میان مخلوط های مختلف آزمایش شده، مخلوطی که به عنوان R30S1.2 تعیین شده است، بالاترین بار مقاومتی را داشت و می توان از آن برای جاده های اصلی استفاده کرد. نتایج حاکی از آن است که استفاده از سنگدانه های بازیافتی به نسبت ۳۰٪ و ٥٥٪ GGBFS بهترین نتایج استحکام را به همراه داشته و در عین حال میزان مصرف سیمان و سنگدانه های طبیعی را کاهش می دهد و این امر با کاهش حضور ضایعات بر محیط زیست تاثیر می گذارد.