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Studying the Effect of Adding Marble and Porcelain Waste on Mechanical Properties of Concrete Containing Recycled Aggregate

Abstract*- In this research an experimental study was carried out to investigate the effect of adding marble and porcelain waste as replacement of sand by certain percentages on mechanical properties of concrete containing (100%) recycled coarse aggregate and compare its properties with concrete mixture containing natural coarse and fine aggregate. Four mixes were prepared the first one is the control mix having natural coarse and fine aggregate, second mix containing (100%) recycled aggregate and natural fine aggregate, third mix containing (100%) recycled aggregate and (5%) marble waste as replacement of sand and last mix containing recycled aggregate(100%) and (10%) porcelain waste as replacement of sand.The ratios of Added Materials (marble, porcelain waste) depended on the results obtained from tested cement mortar cubes having different proportions of the two materials, the selected ratios were the ones giving the highest compression strength. The results of tests showed that using of recycled coarse aggregate as alternative to natural coarse aggregate gives good quality concrete and a compressive strength higher than the compressive strength of original concrete by (5.1%) and it helps increasing modulus of rupture by (19.5%) compared to the original concrete. The results show that using recycle aggregate lead to reducing tensile strength by (35%) compared to the original concrete. Using of marble waste as replacement of sand lead to significant increase in compressive strength by (5.1%), while using porcelain waste gives same compressive strength of reference mix. Using marble and porcelain waste lead to significant increase in tensile strength reach to (35%) and (17.6%) respectively. The results show there is an increase in modulus of rupture when using marble and porcelain waste reach to(24%) and (19.5%) respectively, but it reduced workability of concrete mixtures.*

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Keywords*- Concrete, Compressive strength, Marble waste, Porcelain waste, Recycled aggregate.*

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1. Introduction

Concrete is one of the most important materials used in construction and building. It is widely used in all types of civil engineering activities, including infrastructure, low and high-rise buildings, defense installations, and environmental protection facilities [1]. Concrete needs large quantities of aggregate, and this consumption of environmental resources in addition to many places not having aggregates requiring transportation process meaning more costs. Use again of waste concrete as recycled aggregates in new concretes is useful in terms of protection and preservation of the environment, natural resources [2]. Recycled concrete reduces the impact on landfills and saving costs by eliminating transportation process. Many studies were made to investigate the behavior of concrete containing recycled aggregate. Akbari et al. studied the effect of recycled aggregate on behavior of normal strength concrete. Where the researchers study the change in water cement ratio and replacement of natural aggregates by recycled aggregates. The results of the research indicated that there was a reduction in compression strength by 25%, reduction in flexural strength by 23% and reduction in split tensile strength by 26%. It has also been found that there is a noticeable decrease in the amount of the workability with an increase in the proportion of recycled aggregate [3]. UCHE studied the effect adding recycled aggregate concrete (RCA) as an alternative to the original coarse aggregate in the compressive strength of plain concrete. Different percentages of recycle coarse aggregate (0, 25, 50, 75, and 100) were used in replacing the original aggregate percentage in the mix. The results of the research indicated that there was a reduction in compressive strength and this reduction is increasing with increase in percentage of the RCA [4]. Yaprak et al. made an experimental investigation to study the effects of the recycled fine concrete aggregate (FRA) that was obtained from concrete wastes on the concrete properties. In concrete mixtures, 0, 10, 20, 30, 40, 50 and 100% by weight FRA were used as a replacement for river sand. The test results showed, FRA could be used up to 10 % ratio for producing C30 concrete, between 20-50% ratios for producing C25 concrete [5]. Yong and Teo

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made investigation about the possibility of using recycled aggregate obtained from site-tested concrete specimen. The result of the test it makes good class concrete. The compressive strength of recycled aggregate concrete (RAC) is found to be higher than the compressive strength of normal concrete. Recycled aggregate concrete is in closeness to normal concrete in terms of split tensile strength, flexural strength and wet density [6]. Malešev et al. made a comparative analysis of the an experimental results of the properties of fresh and hardened concrete with different replacement ratios of natural with recycled coarse aggregate. Three types of concrete mixtures were tested: concrete made entirely with natural aggregate (NAC) as a control concrete and two types of concrete made with natural fine and recycled coarse aggregate (50% and 100% replacement of coarse recycled aggregate). Results showed recycled aggregate concrete (RAC) had a satisfactory performance, which did not differ significantly from the performance of control concrete [7]. Murali et al. found that the use of recycled aggregate weakens the quality of recycled aggregate concrete, which limits its application. For improving the quality of recycled coarse aggregate, they are using various surface treatment methods are being used such as washing the recycled aggregates with water and diluted acid. Strength properties of the treated and untreated coarse aggregate were compared. The results indicated that the compressive, flexural and splitting tensile strength of recycle aggregate is found to be less than the natural aggregate [8].

2. Research Significance

This paper aims at studying the effect of addition marble and porcelain waste(as alternative to fine aggregate) on mechanical properties of concrete containing recycled coarse aggregate as (100%) replacement with nature aggregate and compared its behavior with concrete containing natural coarse aggregate and natural fine aggregate.

3.Experimental Details

The experimental program of this investigation consists of three stages as follows:

First Stage: In this stage, the specifications and materials properties .were specified.

Second Stage: in this stage two types of mortar concrete are prepared according to (ASTMC109/C 109M)[9], first one was prepared with various percentages of marble waste(5,10,15,20,and 30%)as replacement to sand. second one was prepared with various porcelain waste (5, 10, 15, 20, and 30%) as a partial replacement to sand.

Third stage: In this stage, four mixes are prepared M1, M2, M3 and M4, having same mix ratios.

M1: control mix with natural sand and natural coarse aggregate.

M2: in the mix the natural coarse aggregate were replaced by 100% recycled aggregate.

M3: In this mix, the natural coarse aggregate was replaced by 100% recycled aggregate and also having marble waste as replacement to sand but with a percentage yielding highest strength that was obtained from second stage

M4: in the mix the natural coarse aggregate was replaced by 100% recycled aggregate containing porcelain waste as replacement of sand but with a percentage yielding highest strength that was obtained from second stage.

I. Materials

1) Cement

Cement used in this study is locally manufactured in ALMASS manufactory. The chemical compositions and physical properties, of the used cement, are in accordance with Iraqi Standard (IQS5–1984) [10] as listed in Tables 1 and 2.

Table 1: Chemical Analysis of Cement

Property	Test result (Percentage)	Standard IQS, No.5 1984[10]
1.Oxides composition		
Alumina, Al_2O_3	5.51	
Silica, SiO_2	20.6	
Ferric Oxide, Fe_2O_3	3.96	
Lime, CaO	57.23	
Sulphuric Anhydride, SO_3	2.33	Max. 2.3
Magnesia, MgO	2.44	Max. 5
2.Compounds composition		
C_3S	27.0356	
C_2S	32.595	
C_3A	7.9091	
C_4AF	12.0384	

Table 2: Physical Properties of Cement

Property	Test result	Standard IQS, No.5 1984
Specific surface "Blaine"	335.9 (m^2/kg)	Min. 230 (m^2/kg)
Initial setting time	110	≥45 (min.)
Final setting time	155	≤600 (min.)
Specific gravity	3.15	
Compressive strength 70.7mm cubes		
at 3 days	19.5	≥15.0 (MPa)
at 7 days	25.5	≥23.0 (MPa)

2) Coarse Aggregate

River rounded gravel complying with the (ASTMC33-99a) [11] was used as coarse aggregate with max aggregate size 12.5mm. Recycled coarse aggregate was obtained by crushing cubes cast and tested in the laboratory, the crushing process was carried out manually, and by using this method the material was pure, without impurities. Recycled Aggregate size 12.5mm it had same grading of normal aggregate. The recycled coarse aggregate was washed after grading. Tables 3 and 4 show the grading and properties of normal coarse and recycled coarse aggregate. Figure1 shows the normal and recycled coarse aggregate.

3) Fine Aggregate

River sand was used as fine aggregate, the results of the sieve analysis and properties was carried out in accordance with the (ASTMC33-99a) [11] and is shown in Tables 5 and 6 respectively.

4) Marble

This paper studies the influence and possibility of using waste materials produced from different manufacturing activities as fine aggregate by partial replacement of sand. Using manufacturing waste as replacement material confer upon many benefits as reducing cost, and reducing solid wastes material which is disposed in landfills. Marble is one of the building materials; used for many purposes in floors, roofs, etc. For using marble as fine aggregate it was prepared by crushing soiled waste of marble so that it is used as a fine powder passing sieve NO.4 (4.75mm)with a high surface area.

Table 3: Grading of normal and recycle coarse aggregate

Grading of Coarse Aggregate M.A.S 12.5 mm		
Sieve Size (mm)	**%Specification Limits According to ASTMC33-99a**	**%Passing of used sample**
12.5	90-100	100
9.5	40-70	55
4.75	0-15	0
2.36	0-5	0

Table 4: Properties of coarse aggregate

Type of coarse aggregate	Rounded gravel	Recycled aggregate
Specific Gravity S.S.D	2.713	2.68
Absorption%	0.15	0.55
Compact unit weight(kg/m^3)	1795	1607
Loose unit weight(kg/m^3)	1713	1521
Angularity index	1.14	2.1

Natural Aggregate

Recycled Aggregate

Figure 1: Natural Aggregate and Recycled Aggregate

Table 5: Grading of fine aggregate

Sieve Size(mm)	%Specification Limits According to ASTMC33-99a	%Passing of used sample
4.75	89-100	100
2.36	60-100	93
1.18	30-100	84
600μm	15-100	41
300μm	5-70	13
150μm	0-15	6

Table 6: Properties of fine aggregate

Type of fine aggregate	Medium sand
Color	Brown
Specific Gravity	S.S.D basis 2.48
Absorption%	2
Compact unit weight(kg/m^3)	1795
Loose unit weight(kg/m^3)	1713
Fineness modulus	2.63

5) Porcelain

Porcelain is one of the building materials. Porcelain tiles are currently used as wall and floor finishes, and used in facades [12]. For using porcelain as fine material, it is prepared by crushing soiled waste of porcelain so that it is used as a fine powder-passing sieve NO.4 (4.75mm) with a high surface area.The chemical compositions of the used marble and porcelain waste are listed in Table 7.

Table 7: Chemical analysis of marble and porcelain

Property	Marble waste	Porcelain waste
Oxides composition	Test result (Percentage)	Test result (Percentage)
Alumina, Al_2O_3	0.0	0.0
Silica, SiO_2	0.0	0.0
Ferric Oxide, Fe_2O_3	68.16	55.38
Lime, CaO	35.99	10.03
Sulphuric Anhydride, SO_3	0.17	0.14
Magnesia, MgO	0.0	0.0
Free Lime	0.56	0.0

II. Mixes

1) Mortar Mixes

Five mixes of mortar was prepared according to (ASTMC109/C 109M) [9]; natural sand was partially replaced by (5%, 10%, 15%, 20%, 30%) of marble. The compressive strength of mortar (for 3, 7 and 28 days) is tested according to (ASTMC109/C 109M).Three samples were prepared for every single test. Therefore 9 specimens were made for one mix ratio. Similarly, the same procedure and percentages was carried out with the addition of porcelain.

2) Concrete Mixes

Four concrete mixtures are prepared in this investigation, the proportions by weight kg/m^{3}of those mixes are shown in Table 8. For each mix workability, Compressive Strength, Splitting Tensile Strength and Flexural Strength were measured and recorded. To determine Compressive Strength cubical specimens of (100×100×100mm) were prepared, to determine Splitting and Flexural Strength cylindrical specimens of (100×200mm) and beams specimens (100×100×500mm) were used respectively. The compressive strength was determined according to (BS 1881: Part 116) [13] for all concrete mixtures at 3,7,28 days. The splitting and flexural strength were carried out in accordance with the ASTM C496-96 and ASTM C78-94 [14,15] for all mixtures at 28 days.

Table 8: Details of concrete mixes (kg/m^3)

Mixture	M1	M2	M3	M4
Cement	350	350	350	350
Sand	805	805	765	724.5
Natural gravel	1103	0	0	0
Recycle coarse aggregate	0	1110	1110	1103
Marble waste	0	0	40	0
Porcelain waste	0	0	0	80.5
water	202	202	202	202

4. Results and Discussions

I. Mortar Mixes

Figure 2 shows the relation between compressive strength of cement mortar having five different percentages of marble waste and age of mortar cubes with respect to control mix having (0%) marble waste. It can be seen that the mix containing (5%) marble as partial replacement of sand gives the highest strength by (43%) compared with control mix. Figure 3 shows the relation between compressive strength of cement mortar having five different percentages of porcelain waste and age of mortar cubes with respect to control mix having (0%) Porcelain waste. It can be seen that the mix containing (10%) Porcelain as partial replacement of sand gives highest strength by (27.4%) compared with control mix.

Based on this it can be said that addition (5%) of marble waste and (10%) of porcelain waste as partial replacement of sand is the optimum ratios because it gives highest strength, the first reasons of this that these ratios helped in reducing the void ratio,the second reason is that since these material are fine material and have large surface area which means they demanded more water than mixes having sand only [16]. According to the results obtained the marble waste added by (5%) as a sand replacement. With regard to the Porcelain waste, a ratio of (10%) will be added. Tables 9 and 10 shows the grading of sand with (5%) marble and (10%) porcelain respectively. There are within the limitation of (ASTMC33-99a) [11].

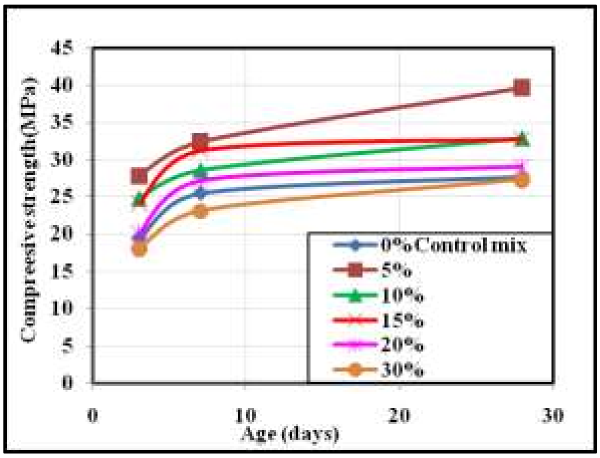

Figure 2: Compressive Strength of Cement Mortar 1:2.75 Containing Different percentages of Marble Waste

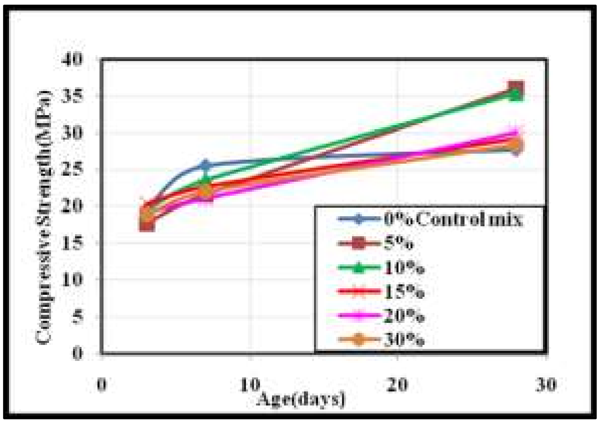

Figure 3: Compressive Strength of Cement Mortar 1:2.75 Containing Different percentages of Porcelain Waste

Table 9: Grading of sand with (5%) marble

Sieve Size(mm)	%Specification Limits According to ASTMC33-99a	%Passing of marble waste
4.75	89-100	100
2.36	60-100	94
1.18	30-100	85
600µm	15-100	26
300µm	5-70	7
150µm	0-15	3

Table 10: Grading of sand with (10%) porcelain

Sieve Size(mm)	%Specification Limits According to ASTMC33-99a	%Passing of marble waste
4.75	89-100	100
2.36	60-100	94
1.18	30-100	84
600µm	15-100	25
300µm	5-70	8
150µm	0-15	4

II. Concrete mixes

1) Fresh properties

Workability

Figure 4 shows the effect of using recycled aggregate on the workability of fresh concrete. Slump test was carried out according to (ASTM C143) [17]. As it may be noticed the workability is reduced when the coarse aggregate was replaced by (100%) recycled aggregate and this is due to the adhered mortar of old concrete which increase the absorption capacity of aggregate of the mixing water therefore it is recommended to use saturated surface dry (SSD) condition to improve the workability [6]. M3 and M4 have low workability and this due to the addition of marble and porcelain waste having large surface area as compared to sand, which reduces the workability [18-20].

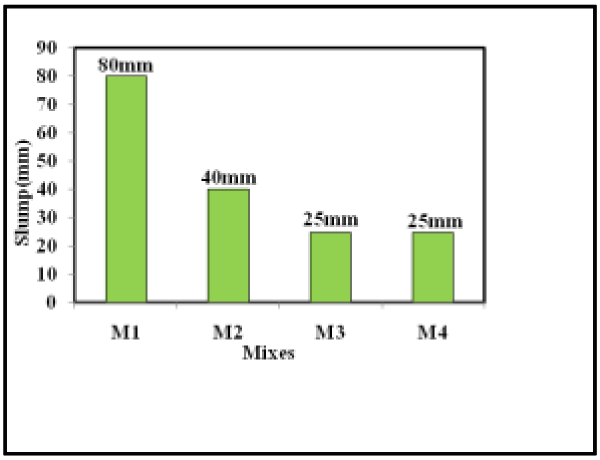

Figure 4: Slump of Concrete Mixture

2) Hardened properties

I. Compressive Strength

Figure 5 shows the relationship between compressive strength and age of control mix (M1) that contained natural coarse aggregate and natural fine aggregate without any additions and (M2) that contained (100%) recycled coarse aggregate with natural fine aggregate without any additions. The figure shows that there is an increase in compressive strength with age for the two mixes. As can be observed from the figure, at an early age there is no significant difference in compressive strength for the two mixes, also it can be seen that M2 gives higher compressive strength of (5.1%) compared with M1 at 28 day which indicate that using recycle aggregate gives good quality concrete especially when the recycled aggregate is originated from good quality concrete [6].

Based on this it can be said that the recycled coarse aggregate extracted from good quality concrete, clean surface, washed and free from impurities can be used as coarse aggregate in new concrete because it gives good strength.

Table 11 and Figure 6 illustrate the relationship between Compressive strength and age for four concrete mixtures, results show that the addition of marble and porcelain waste contributed clearly in increasing the compressive strength of concrete compared with reference mix. It can be noted that the effect of two materials in increasing compressive strength is clear (especially at early ages), the reason for this is that these filler materials are active, and not inert, the increased compressive strength of M3 and M4 mixtures having constant despite amount of cement but the marble and porcelain waste have clear contribution in the interactions of cement and rehydration process [21].

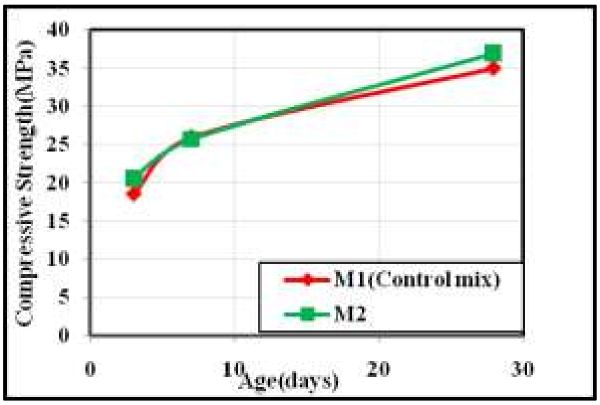

Figure 5: Compressive Strength of M1 (Control Mix) and M2

Table 11: Compressive Strength of Concrete Mixture

Mixes	Compressive Strength (MPa)		
	3 days	7 days	28 days
M1	18.5	26	35.2
M2	20.6	25.7	37
M3	22.6	27.6	35
M4	24.4	28.5	37

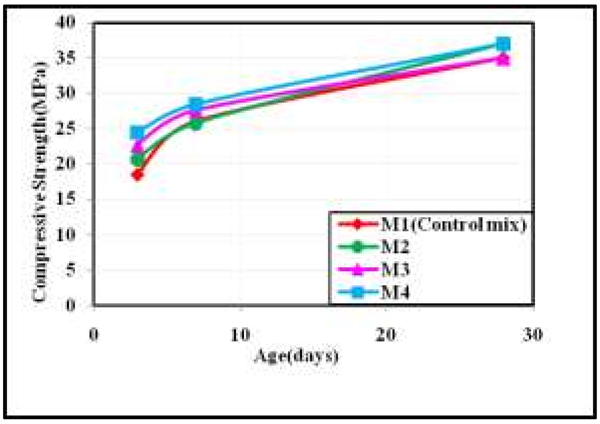

Figure 6: Compressive Strength of Concrete Mixture

II. Indirect Tensile Strength

Figure 7 shows the values of tensile strength of the concrete mixtures, It is noted that the use of the recycled aggregate in the concrete help to reduce tensile strength by (35%) compared with original mix, due to the weakness of the surface bonding to new paste, as well as due to the form of recycle aggregate and the nature of its porous surface which reduces the concrete tensile strength. By the addition of marble and porcelain waste it is can noted that there is a clear increase in the tensile strength up to (35%) when adding marble waste and (17.6%) when adding porcelain waste with respect to the original mix, the main reason for this is that these materials having high surface area which help to give good coherence with mortar and concrete [18,19].

III. Modulus of Rupture

Figure 8 shows the results of Modulus of Rupture of concrete mixtures, it is noted that the use of recycle aggregate helps increasing Modulus of Rupture by(19.5%) compared to reference mix the addition of marble and porcelain waste also contributed clearly to the increase of the Modulus of Rupture by (24%) and(19.5%) respectively compared with the reference mix.

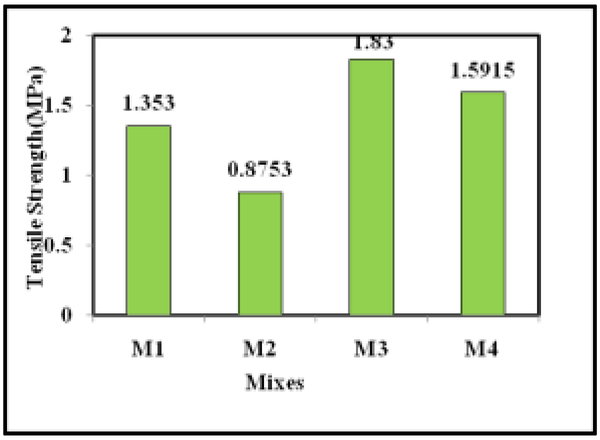

Figure 7: Tensile Strength of Concrete Mixture

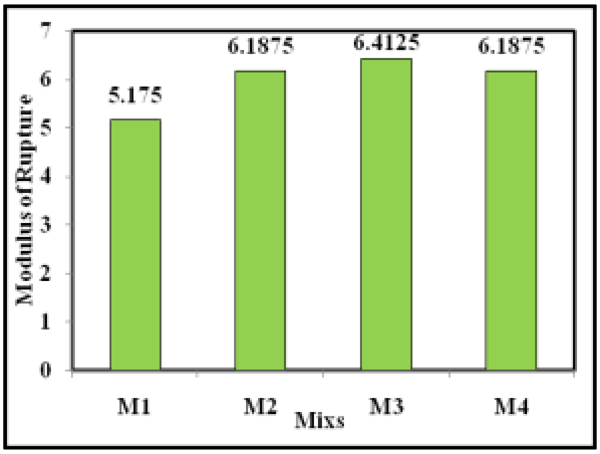

Figure 8: Modulus of Rupture of Concrete Mixture

5. Conclusions

1) Marble and Porcelain waste cab be beneficial when using it as fine material in concrete mixture.

2) Using of recycled coarse aggregate extracted from good quality concrete, i.e (clean surface, washed and without impurities) gives new concrete higher compressive strength than the compressive strength of original concrete by (5.1%).

3) Using marble waste(as alternative of sand)helps in increasing compressive strength by (5.1%) compared with reference mix, while using porcelain waste give the same compressive strength of reference mix at 28 day.

4) Using marble and porcelain waste help in increasing tensile strength by (35%) and (17.6%) respectively compared with reference mix.

5) An increase in modulus of rupture when using marble and porcelain waste reached (24%) and (19.5%) respectively.
6) Using recycled aggregate with marble or porcelain waste lead to reducing workability of concrete.

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