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Study of the Mechanical Properties and the Durability of Concrete Based on Recycled Wastes Aggregates

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Abstract: This work focuses on the valorization and recycling of waste materials of brick aggregates (BA) and demolition concrete aggregates (DCA) for the formulation and mechanical characterization as well as the study of the durability of concrete.Five (05) concrete formulations; a control concrete based on natural aggregates and four concrete formulations based on recycled aggregates by volume substitution of natural aggregates with rates of 25% and 50% brick waste and 50%, 75% demolition concrete waste, were studies in the fresh state to estimate the workability and the density and in the hardened state to estimate the mechanical properties and the durability of concretes: Compressive and flexural strengths, impermeability to water and the diffusion of chloride ions.The results of this experimental study show that the increase in the rate of demolition or brick aggregates wastes in substitution of natural aggregates causes a decrease in the mechanical characteristics and the durability of the concrete. Nevertheless, concrete mixes containing 50% of recycled aggregates have good mechanical resistance and good durability which are close to that of concrete based on natural aggregates. Therefore, the results obtained suggest a possible use of brick and demolition concrete wastes, as aggregates in the formulation of structural concretes.

Keywords: Waste, Brick, Demolition concrete, Recycled aggregates, Durability

Introduction

Aggregate is one of the main ingredients in producing concrete. It covers 75% of the total for any concrete mix. The strength of the concrete produced is dependent on the properties of aggregates used. However, the construction industry is increasingly making higher demands of this material and is feared to accommodate the many requests at one time. Hence need for an alternative coarse aggregate arises (Sivakumar et al., 2014).

The use of recycled aggregates from construction and demolition wastes is showing prospective application in construction as alternative to primary (natural) aggregates. Research on the usage of waste construction materials is very important since the materials waste is gradually increasing with the increase of population and increasing of urban development. The reasons that many investigations and analysis had been made on recycled aggregate are because recycled aggregate is easy to obtain and the cost is cheaper than virgin aggregate (Saadani, 2006).

Faced with the ever-increasing needs for material resources and the requirements and conditions for preserving the environment in a vision of sustainable development, it has become necessary and relevant to prospect and

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study all the possibilities and opportunities for reusing and recovering waste and industrial by-products, particularly in the field of civil engineering and public works (Hobnob & Belachia, 2011).

In Algeria, an abusive use of a non-renewable resource of natural aggregates is observed even for the production of simple elements such as sidewalks. For this use, demolition materials can be an ‘economic and ecological’ alternative. The production of recycled aggregates developed in the early 80s, it meets the need for another source of aggregates and the reduction of waste volumes (Saadani, 2006). In this context, the use of recycled products takes on its full meaning. The right approach is to use the 'right product', for the 'right use', under the 'right conditions'.

This waste has been the subject of work using, for example, marble as aggregates in concrete (Saadani, 2006), ceramics (Shruthi et al., 2016; Anderson et al., 2016; Abadou et al., 2016; Al Bakri et al., 2013; Rabehi et al., 2017), tires (Fedroff et al, 1996; Segre & Joekes, 2000), glass (Tung et al, 2012; Kou & Poon, 2009, Topcu et al, 2008), but also waste from brick demolitions (Debieb & Kenai, 2008; Poon & Chan, 2006; Bhanbhro et al., 2014; Khalaf, 2006; Ghernouti et al., 2016) and crushed concrete (Berredjem et al, 2015; Silva et al ,2015; Gomez, 2002; Tu et al., 2006). Some studies have shown the benefit of combining bricks and demolition waste in the manufacture of hydraulic concrete (Meftah & Arabi, 2011; Bourmatte, 2017; Kenai & Debieb, 2011). Other work focuses on the recovery and recycling of plastic waste for the formulation and characterization of concrete based on this waste (Guendouz et al., 2015; Rebeiz, 2007; Siddique et al., 2008; Ghernouti et al., 2012; Ghernouti et al., 2014; Boucedra et al., 2020).

In this study, natural aggregates were replaced by waste materials of brick aggregates and demolition concrete aggregates to produce concrete. Then, the fresh and hardened states properties of the concrete: workability, compressive and flexural strengths, impermeability to water and the diffusion of chloride ions of the recycled waste concretes were examined by conducting physic- mechanical and durability tests.

Experimental program

Materials Used

Cement

All concrete mixtures investigated in this work were prepared with Ordinary Portland cement (OPC) CEMII/A42.5.

Water

The water used for mixing concrete is drinking water.

Super Plasticizer

As super plasticizer, a new generation super-plasticizer high range water reducer, named Master Glenium 26, based on polycarboxylate with solid contend of 30% and specific gravity of 1.08 was used to achieve the required workability of all mixtures.

Aggregates

In this work, we used three types of aggregates for making concrete: natural aggregates recycled concrete demolition waste aggregates and recycled brick waste aggregates.

- The natural aggregates used are natural sand (NS), with a maximum particle size of 3 mm and two natural crushed limestone gravel with particle size between 3/8 and 8/15 (Fig 1)
- The recycled concrete demolition waste aggregates used in this work come from local sources resulting from the crushing of demolition concrete waste to different grain sizes: sand 0/3 and gravels (3/8 and 8/15) (Fig 2)
- The recycled brick waste aggregates used come from local sources resulting from the crushing of brick waste to different grain sizes: sand 0/3 and gravels (3/8 and 8/15) (Fig 2)

The physical properties of the aggregates used are given in tables 1 and 2.

Table 1. Physical properties of fines aggregates

	Natural sand	Recycled brick waste sand	Recycled demolition concrete sand
Apparent density, (g/cm^3)	1.56	1.26	1.24
Specific gravity, (g/cm^3)	2.64	2.22	2.3
Visual sand equivalent, VES (%)	81	26.52	73.45
Fineness modulus	3	2.3	3.4
Water absorption (%)	3	19	8

Table 2. Physical properties of coarse aggregates

	Natural coarse aggregates (3/8 and 8/15)	Recycled brick coarse aggregates (3/8 and 8/15)	Recycled demolition concrete coarse aggregates (3/8 and 8/15)
Apparent density, (g/cm^3)	1.20	1.02	1.19
Specific gravity, (g/cm^3)	2.38	2.27	2.4
Los Angeles (%)	28.5	24.7	28.5
Micro-Deval (%)	27.5	26.4	27.2

Figure 1. Natural aggregates

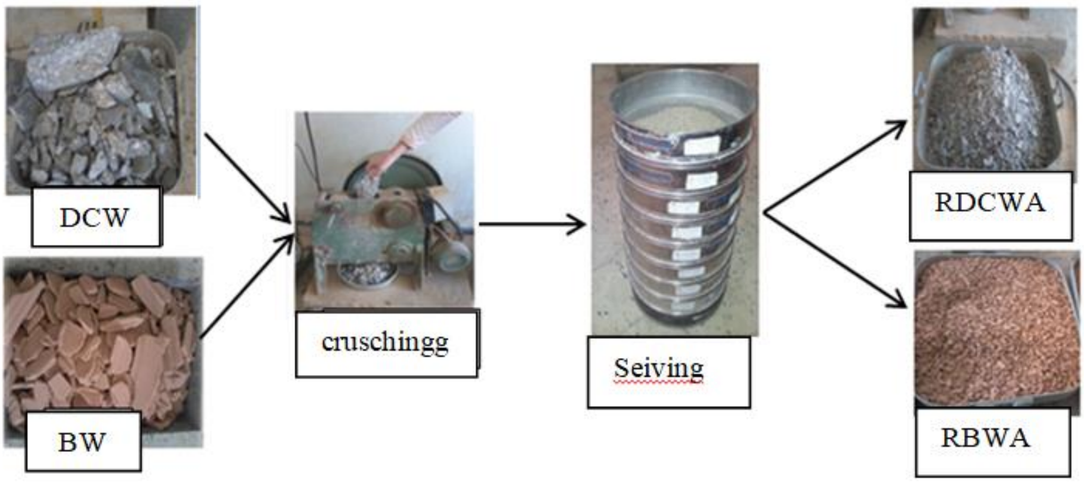

Figure 2. Preparation of recycled aggregates

Mixtures Proportion

The concrete formulation method used, is the "Dreux Gorisse" method (Dreux & Festa, 1998). Five (05) concrete formulations were studied; a control concrete based on natural aggregates (C-NA) and four (4) mixtures based on recycled aggregates by volume substitution of natural aggregates with rates of 25% and 50% recycled brick waste (C-25BW, C-50BW) and 50%, 75% Recycled demolition concrete waste (C-50DCW,C-75DCW). All mixtures concretes were made with a constant W/C ratio (0.46) and cement amount of 400 kg/m^3, respectively.

Fresh State Tests

Two tests were carried out in the fresh state of all concretes mixtures, the first is the Abrams cone slump test according to the specification of EN 12350-2 to measure workability. The other is the fresh bulk density determination test according to the recommendations of EN 12350- 6.

Figure 3. Fresh state tests: Slump test and bulk density.

Hardened State Tests

Bulk Density and Mechanical Strengths Tests

The bulk density of hardened SCC concretes cured 28days was measured according to the standard NF EN 12390-7; it was calculated by dividing the dry weight of each sample by its overall volume. The tests performed to determine the mechanicals strengths were compressive and flexural strengths at the age of 28 days. The compressive strength carried out on cubic specimens (10x10x10) cm according to standard NF EN 12390-3 and the flexural strength on prismatic specimens (7x7x28) cm, according to standard NF EN 12390-5. The test results were reported as the average of three tested specimens

Durability Tests

This study evaluated the three following durability indicators: Water absorption and porosity, water permeability test and Diffusion of chloride ions test.

Water Absorption and Porosity:

Water absorption and porosity tests of all concretes were carried out on specimen discs of (11x5) cm at the age of 28 days. The porosity was determined by the knowledge of the saturated and oven-dried mass of samples. The dried mass was obtained after drying saturated in an oven at 60°C until constant weight. The method used is a variant of water porosity by hydrostatic weighing. It gives the value of the total porosity but does not allow the pore distribution to be determined.

The water absorption test was carried out on the same samples which were served for the determination of porosity according to ASTM C642-13. The dry mass of each sample was recorded and then they were totally immersed in water at 20°C until they achieved a constant mass. The constant mass was taken as the saturated mass of sample after 24h. The absorption percentage was then obtained by the ratio of the amount of water absorbed to oven-dried mass.

Water Permeability Test

The water permeability test is a method of determining the depth of penetration of water under pressure into hardened concrete. Water permeability measurements were carried out according to standard NF EN 12390-8. (28). Cube specimens with dimensions of 150x150x150 mm were casted, demoulded 24 hours after casting and conditioned for 28 days in a moisture chamber. The specimens were then placed into a water permeability measurement apparatus, and a sealing ring with an inner diameter of 100 mm was placed on top. A constant water pressure of 500 kPa was exerted on the specimens for 72 hours. At the end of this period the specimens were split, and the maximum depth of penetration was measured to assess the extent of water permeation.

Diffusion of Chloride Ions Test

The resistance to penetration of chloride ions in concretes is one of the most important questions about the durability of concrete structures. When the chloride concentration exceeds a certain threshold, a depassivation steel occurs and there is a beginning of corrosion of reinforcing steel (Thomas, 1996; Alonso et al., 2000). Consequently, the development of protection materials with resistance to penetration of chlorides is required for concrete structures. For this test we used cylindrical specimens (11x22) cm which are sawn to obtain 5 cm discs, whose hardening was in drinking water for up to 28 days. The samples are introduced into a concentrated solution of 10% NaCl, to evaluate the durability of all concretes to the penetration of chloride ions; we followed the evolution of the depth of penetration of chloride ions at 28. The solutions were changed every 7 days until the age of 28 days. Each test specimen is divided into two parts and then solution of silver nitrate $AgNO_3$ was poured on each section according to UNI 79287 (1978). A whitish color appeared on the specimen surface, using a caliper measuring the depth of penetration of chloride ions.

Figure 4. Compressive and flexural strength tests

Figure 5. Water absorption and porosity tests

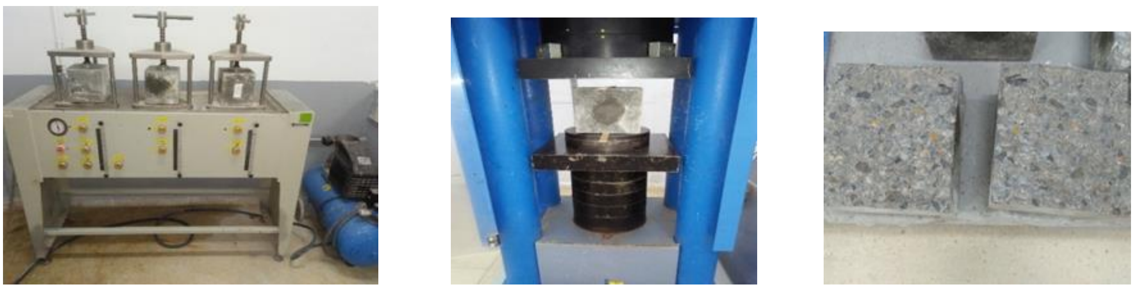

Figure 6. Water permeability test

Figure 7. Diffusion of chlorine ions test

Results and Discussion

Workability

The results of slump tests of all mixtures concrete studied are shown in figure 8. The obtained results show that the increase in the rate of demolition concrete or brick waste aggregates reduces the slump value but these decrease is more remarkably by the use of brick waste, in fact the recycled brick waste aggregates is more porous than natural aggregates, leads the mixture to a high water absorption resulting in a decrease in workability. The concretes based on 25% and 50% of recycled brick waste aggregates have very low slump 4 and 0 cm, which corresponds to a firm concrete. However, it was necessary to vary the water content, due to their absorption, to obtain the required consistency that guarantees the S2 class of flowability.

For recycled demolition concrete waste aggregates, the phenomenon is less remarkable because they have similar characteristics of natural aggregates. The mixtures containing 50% and 75% of recycled demolition concrete waste aggregates exhibited satisfactory slump flows in the range of 15 and17cm respectively, which is an indication of a good fluidity of these concretes. The same findings were reported by (Khalaf & DeVenny, 2005) that in case of using crushed brick aggregate in concrete, it will be less workable than concrete containing natural aggregates.

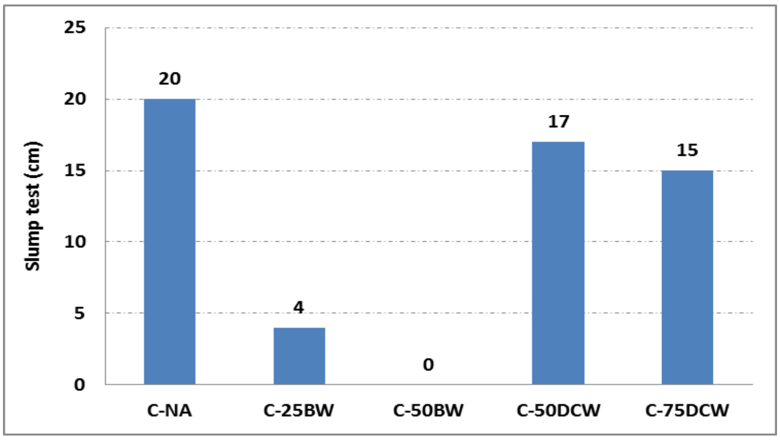

Figure 8. Slump test of all mixtures

Fresh Bulk Density

Figure 9, show the fresh bulk density test results of all mixtures concretes. It was clearly observed according these results, that increasing the rate of brick or demolition concrete waste aggregates by substitution of naturel aggregates, decreases the bulk density of all mixtures. The low density of the recycled aggregates used compared to the natural aggregates is the probable cause of this difference.

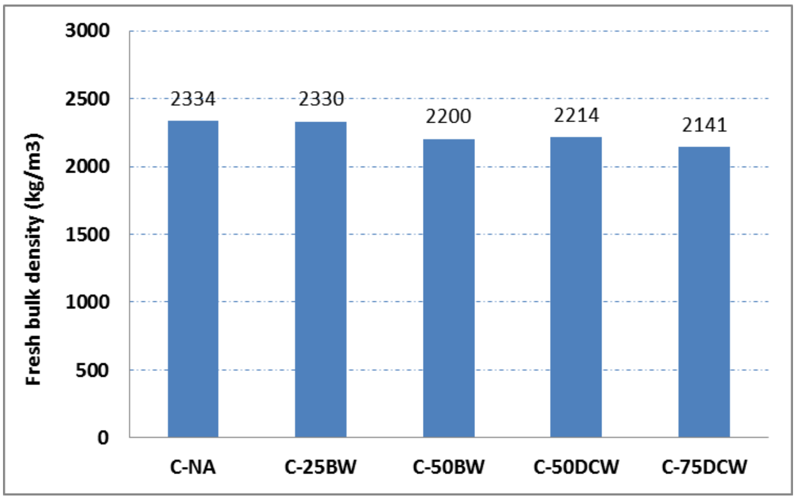

Figure 9. Fresh bulk density of all mixtures

Dry Bulk Density

The Dry bulk density values in kg/m3 for the all concretes mixes at 28 days curing time as a function of the substitution percentage of natural aggregates are shown Figure 10. Density values ranges from 2141 to 2214 kg/m^3 for concrete containing DCW aggregates and 2200 to 2330 kg/m^3 for concrete containing BW aggregates, while the control mixture exhibit the largest dry bulk density in the order to 2325 kg/m^3. A decrease in bulk density of concretes can be observed as the percentage of recycled aggregate content increases.

The hardened bulk density for 50% replacement of BW aggregates had dropped around 8.94%. Even up to 50% replacement by DCW aggregates, the Hardened bulk density gets reduced only to a maximum of 5.3% with respect to that of control concrete. There is a drop of 9 % bulk density for the 75% DCW aggregates.

The reduced dry bulk density of the concretes based on recycled aggregates is due to the reduced unit weight of recycled aggregates compared to natural aggregates. These results are similar to those obtained by Sadek (2012). The decreasing of hardned bulk density of concrete by increasing the recycled aggregate ratio was found by several authors (Hansen, 1992; Sanchez de Juan, 2004)

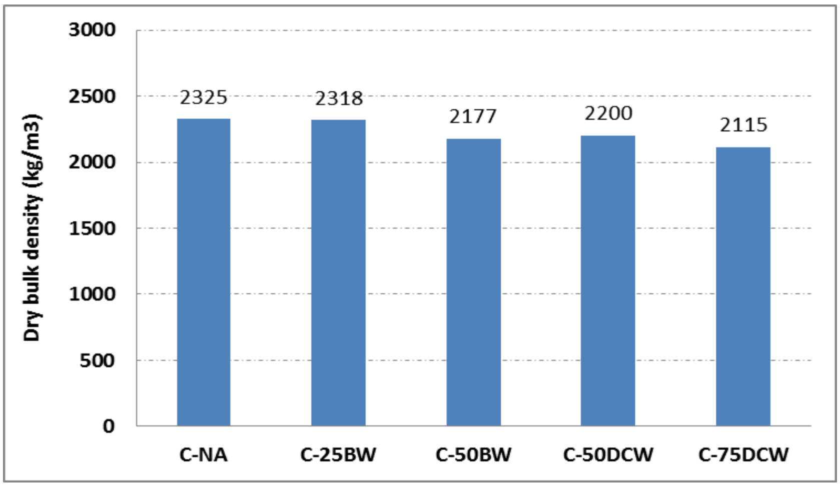

Figure 10. Dry bulk density of all concretes

Compressive and Flexural Strength

Figures 11 and 12 illustrate the mechanical strengths evolution of all mixtures concretes. It can be observed that all concrete samples based on natural aggregates or recycled wastes aggregates, have a compressive strength higher then 29MPa at the age of 28 days, so we can classify them as structural concretes. A decrease in the compressive and flexural strength for all concrete compositions based on recycled brick and demolition concrete wastes aggregates, compared to the control concrete based on natural aggregates is recorded. This decrease in mechanical strengths can be explained by the decrease in the compactness of the granular mixture which causes an increase in porosity and a decrease in resistance, as well as the low hardness of the recycled aggregates wastes used compared to natural aggregates.

We note that for a rate of 25% and 50% of recycled brick waste aggregates (C25-BW and C50-BW), the loss of compressive strength reaches 12.94% and 16.42% respectively compared to the control concrete. For the flexural strength, we noticed the same trend. Indeed, by increasing the rate of recycled waste aggregates substitution, the flexural strength decreases.

The concretes based on recycled demolition waste aggregates (C50-DCW and C75-DCW) also presents a decrease in mechanical strengths according to the rate of substitutions, or we recorded a loss of compressive strength in the order of 16.17% with 50% of the recycled demolition concrete aggregates waste compared to the control concrete, this loss increases in the case of 75% of these aggregates and reaches 27.87%. Differences between compressive and flexural strengths of concrete based on BW and DCW are negligible for the same rate of substitution.

On the basis of the results presented figure 11 and 12, it was concluded that compressive and flexural strength of concrete decreases when the recycled aggregate ratio increases, This conclusion is similar to results of other authors (Yang et al., 2008; Xiao et al., 2005; Poon et al., 2004), who found that compressive strength decreases with increasing quantity of recycled aggregates in concrete with the same effective water-cement ratio. However, in these experiments, recycled aggregate was obtained from demolished concrete structures of unknown compressive strength. Hansen (1992) find out that substitution of natural aggregate with recycled concrete aggregate up to 30% has no significant influence on concrete compressive strength. On the other hand Mirjana et al. 2(010) concluded that differences between measured compressive strengths of concrete made entirely with natural aggregate (R0) 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) are insignificant (all results belong to the same set of results). This conclusion led to the fact that coarse aggregate type didn't influence the concrete compressive strength value in this experimental research. These results confirm the statement that compressive strength of RAC depends more on the quality of recycled aggregate than on the quantity.

Results of previous work on recycled aggregate concrete vary in wide limits, sometimes are even opposite, but general conclusions about the properties of concrete with recycled coarse aggregate compared to concrete with natural aggregate are decreased compressive strength up to 25% (Hansen, 1992; Rahal, 2007; Yang et al., 2008, Ajdukiewicz & Kliszczewicz, 2002) and decreased flexural strength up to 10% (Hansen, 1992; Yang et al., 2008; Ajdukiewicz & Kliszczewicz, 2002).

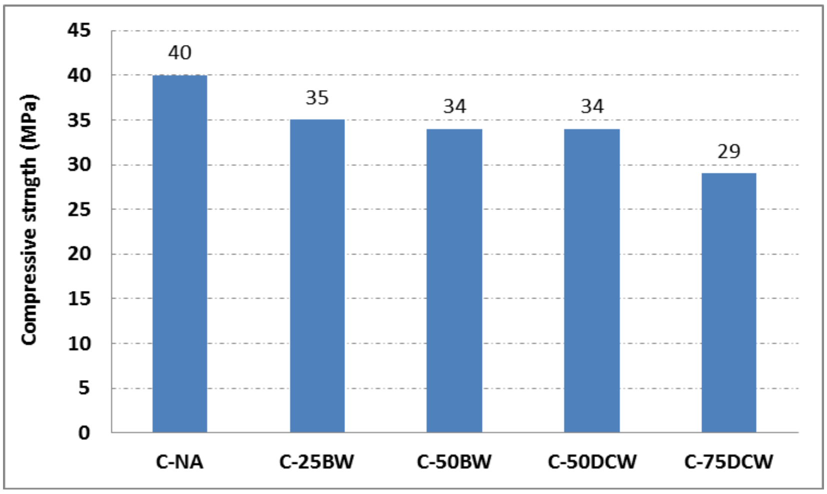

Figure 11. Compressive strength evolution of all concretes

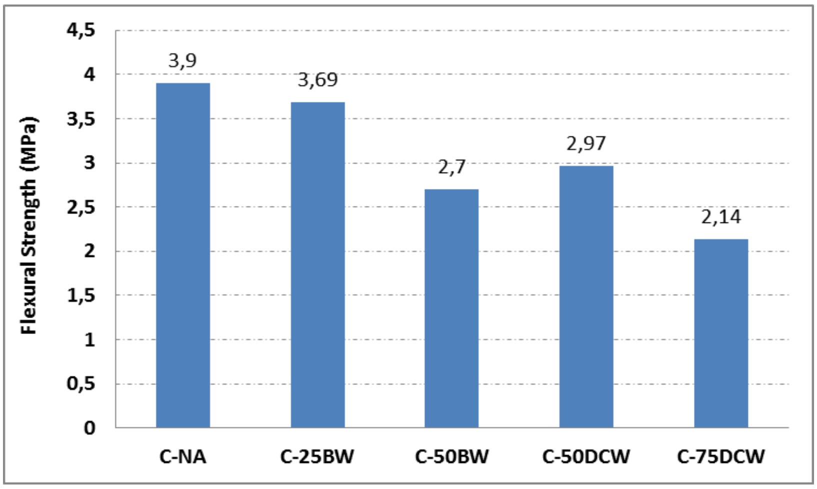

Figure12. Flexural strength evolution of all concretes

Water Absorption and Porosity

The main agents of deterioration require the presence and movement of water within the material itself. The presence of water can cause freeze-thaw damage to the product. Furthermore, water can carry chlorides and sulfates as well as other harmful ions. Hence, the absorption of the product has a great effect on its durability

(Dina M. Sadek, 2012). The Water absorption and porosity of all concretes studied are given in figure 13, according to the results obtained, it can be seen that the incorporation of the waste used (brick and demolition waste aggregates) in the concrete causes an increase in the porosity, probably due to the geometric shape of the recycled aggregates which are flattened compared to the natural aggregates, this leads the mixture to a high absorption of water.

Water absorption of recycled brick aggregate was from 19% and 8% for recycled demolition concrete aggregates. Water absorption of aggregate reflects to water absorption of concrete. That is reason why water absorption of concrete with recycled aggregate was significantly increases compared to concrete with natural aggregates. The water absorption for 50% replacement of brick waste aggregates (BW) had increased around 215.38%. Even up to 50% replacement by Demolition concrete waste aggregates (DCW), water absorption gets increased only to a maximum of 88.46% with respect to that of control concrete. There is an increase of 276.92 % water absorption for the 75% DCW aggregates.

The main problem of using the recycled brick as an aggregate for concrete is its high water absorption. The water absorption of recycled crushed brick aggregate concrete is significantly greater than the one of the natural aggregate concrete (Debieb & Kenai, 2008). The evolution porosity of all concretes varies with the same trend as the water absorption.

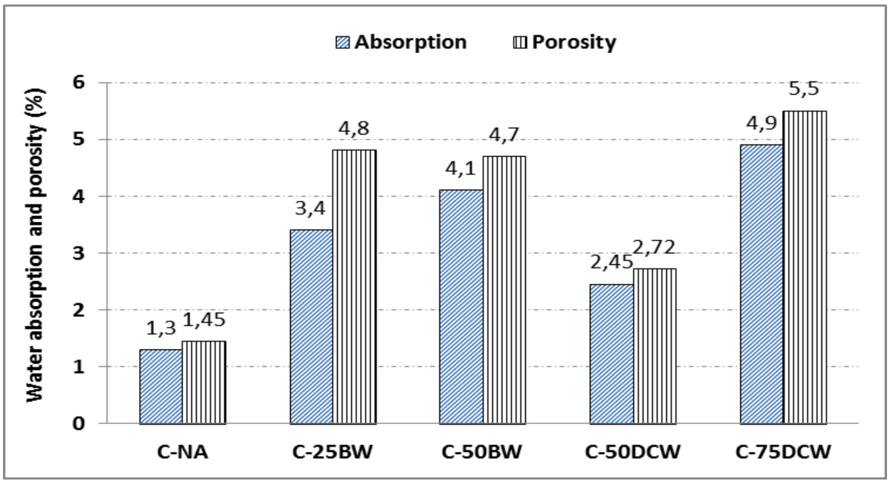

Figure 13. Evolution of water absorption and porosity of all concretes

Water Permeability

Figure 14 shows the water penetration depth values for the different concrete compositions.

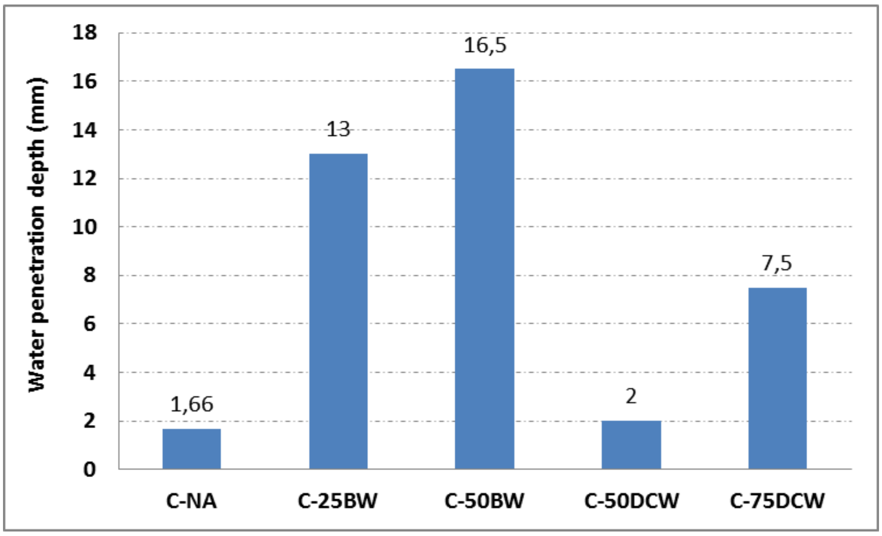

Figure 14. Water penetration depth of all concrete

The obtained results indicate that the substitution of natural aggregates by the brick or demolition concrete aggregates causes an increases of the depth of water penetration and when the rates of substitution increase, the water penetration depth values increased, and it is more remarkably by the substitution of brick waste. For demolition waste, the phenomenon is less remarkable. This increase in water penetration depth is probably due to the height porosity of the concretes based on recycled aggregates compared to the control concrete based on natural aggregates.

The maximum value of water penetration depth recorded is that of the concrete based on 50% brick waste aggregates (C-50BW) it is in the order of 16.5 mm, while in the control concrete based on natural aggregates (C-NA) the value is 1.66mm. In all tested concretes, the average water penetration depth is smaller than 50 mm and so the tested concretes according to DIN 1045 are considered watertight.

Diffusion of Chloride Ions

Figure 15 chows the depth chloride ion penetration in the all concrete compositions, an increase in the depth of chloride ion penetration of all concrete compositions based on recycled brick and demolition concrete wastes aggregates is recorded compared to the control concrete based on natural aggregates (figure 17). This increase can be explained by the decrease in the compactness of the granular recycled wastes mixtures, which causes an increase in the porosity and a decrease in the penetration resistance of the concrete. Two variants concrete, the control concrete based on natural aggregates (C-NA) and the concrete based on 50% demolition concrete aggregates (C-50DCW), showed better resistance to the penetration of chloride ions. The penetration depth of the chloride ions of the two variants (C-NA) and (C-50DCW) is of the order of 9 mm and 1.05 mm respectively. The test method followed in the present investigation to determine the depth of chloride ions penetration is reliable and accurate, and has also been recommended by other researchers (Erhan & Kasım, 2007; Wee et al, 2000; Otsuki et al, 1992; Wee et al, 1999; Meck & Sirivivatnanon, 2003).

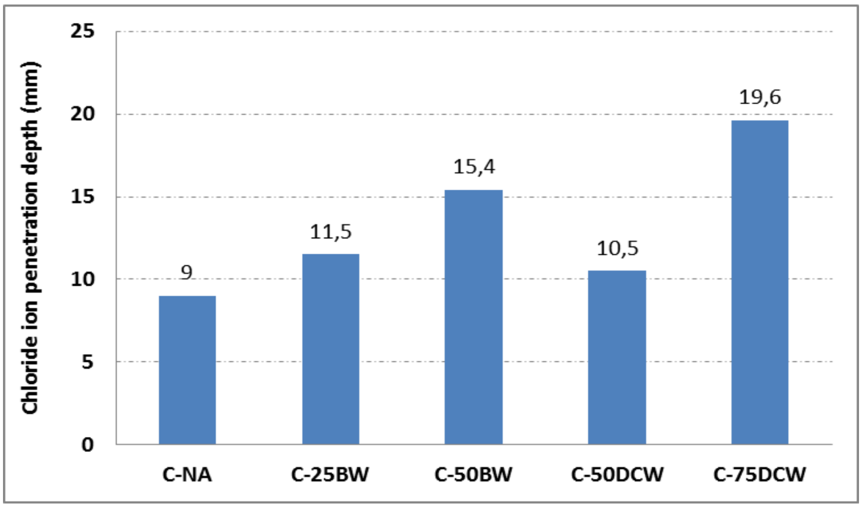

Figure 15. Chloride ion penetration depth in the all concretes

Conclusion

In this study, the effects of brick and demolition concrete wastes aggregates on the physic-mechanical properties and the durability study of concrete are presented. Based on the above results, the following conclusions can be drawn:

- The increase in the rate of demolition concrete or brick waste aggregates reduces the slump value of concrete but this decrease is more remarkably by the use of brick waste. The concretes based on 25% and 50% of recycled brick waste aggregates have very low slump 4 and 0 cm, which corresponds to a firm concretes. The mixtures containing 50% and 75% of recycled demolition concrete waste aggregates exhibited satisfactory slump flows in the range of 15 and17cm respectively, which is an indication of a good fluidity of these concretes.

- A decrease in bulk density of concretes is recorded when the percentage of recycled aggregates content increases. The hardened bulk density for 50% replacement of BW aggregates had dropped around 8.94%. Even up to 50% replacement by DCW aggregates, the Hardened bulk density gets reduced only to a maximum of 5.3% with respect to that of control concrete. There is a drop of 9 % bulk density for the 75% DCW aggregates.
- A decrease in the compressive and flexural strength for all concrete based on recycled brick and demolition concrete wastes aggregates, compared to the control concrete based on natural aggregates is recorded, and when the recycled aggregate ratio increases, the compressive and flexural strengths decreased.
  All concrete samples based on natural aggregates or recycled wastes aggregates, have a compressive strengths higher then 29MPa at the age of 28 days, so we can classify them as structural concretes.
- The substitution of natural aggregates by brick and demolition concrete waste aggregates in the concrete causes an increase in the porosity; this leads the mixture to a high absorption of water.
- The substitution of natural aggregates by the brick or demolition concrete aggregates causes increases of the water penetration depth, and when the rates of substitution increase, the water penetration depth values increased, and it is more remarkably by the substitution of brick waste.
  In all tested concretes, the average water penetration depth is smaller than 50 mm and so the tested concretes according to DIN 1045 are considered watertight.
- An increase in the depth of chloride ion penetration of all concrete based on recycled brick and demolition concrete wastes aggregates is recorded compared to the control concrete based on natural aggregates. The depth of chloride ion penetration of the control concrete based on natural aggregates (C-NA) and the concrete based on 50% demolition concrete aggregates (C-50DCW) is in the order of 0.9 mm and 1.05 mm respectively, consequently these variants showed better resistance to the penetration of chloride ions.

Finally we we concluded that the increase in the rate of recycled demolition concrete or brick wastes aggregates in substitution of natural aggregates causes a decrease in the physic-mechanical characteristics and the durability of the concrete. Nevertheless, concrete mixes containing 50% of recycled wastes aggregates have good mechanical properties and good durability which are close to that of concrete based on natural aggregates. Therefore, the results obtained suggest a possible use of brick and demolition concrete waste as aggregates in the formulation of structural concretes.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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