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# Manufacture of Lightweight Thermal Insulation Concrete Using Recycled Aggregates and Syrian Pozzolan

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**ABSTRACT**

This research is part of the national project for the recycling and reuse of demolished building and infrastructure in Syria. It is an attempt to find a lightweight concrete mix with local components suitable for use in the concrete mixes with acceptable resistance to pressure and low thermal conductivity and good workability. Syrian Pozzolan aggregate (PA) was used with recycled concrete (RCA) aggregates to manufacture concrete mixtures for use in a concrete mixes or in the outer cover of the buildings, as slabs of inclination on the last roofs, and in the non-load-bearing exterior walls to benefit from it as a thermal insulator and get rid of important quantities of rubble that constitute an environmental and economic damage on the government in the reconstruction phase.

A practical program was designed to include 12 groups for mixing concrete samples, where groups were distributed as follows: 6 groups, natural aggregate (NA) were mixed with PA, and also 6 groups, PA were mixed with RCA. The replacement percentage of PA was 90%, 85%, 80%, 75%, 70%, and 65% of NA and RCA. Replaced PA was from the total volume of NA due to the different densities. The results showed that the compressive concrete have good values related to the Syrian standard, and the thermal conductivity decreased very significantly. The use of 90 %PA with 10% RCA is an optimum ratio, as CSC value was 58 MPa, considered relatively high, density was 1529 Kg/cm3 and it is light compared to ordinary mixtures of more than 1800 Kg/cm3, for thermal conductivity it is also low. The use of PA and RCA improved the thermal performance of concrete mixtures with a relatively lightweight.

**Key words***:* Thermal Insulation, Natural Aggregate, Lightweight concrete, Syrian Pozzolan.

## 1. INTRODUCTION

One of the important factors in preserving the natural resources of the countries is the reuse of the RCA resulting from the destroyed structures [1][2]. Using RCA cab be kept approximately 60% of natural aggregates (NA) and decrease CO2 emissions around 15-20% [3]. The production of concrete is a major factor for the depletion of natural aggregates. It has become the use of RCA in construction projects very common and is a priority all over the world. For example, in the UK, the RCA enters 10% of all construction [4]. Initial estimates indicate that the depletion of NA will reach 2.5 x $10^9$ tons annually in the United States at the end of 2020 [5]. Numerous studies and research have demonstrated that the use of RCA has a satisfactory performance in terms of mechanical resistance to concrete mixtures, where the compressive strength of RCA mixes is lower 10 to 25% than conventional mixes at 100% percentage of RCA replacement. But in terms of the percentage of replacement and durability studies are still under investigation. RCA can be used in secondary constructions, such as highways pavement, building floors, and in the block industry, as walls [6].

Generally, aggregates (main component), Portland cement, water, and admixture is sometimes added to enhance the performance of the concrete [7][8][9][10]. Water also plays an important role in hydration process for cement [11]. A number of research carried out on RCA show that the concrete strength declines as the ratio of RCA increases in concrete mix [12]. As is known, the concrete suffers from weak tensile strength. To overcome this problem, it is necessary to search for new additives and techniques to obtain greater strength to the concrete [13][14][15].

Regarding studies on RCA, Etxeberria et al [16] studied compressive strength of RCA, and elasticity modulus with replacement ratio 0, 25, 50 and 100% of only coarse aggregates, the research showed that the compressive strength of RCA at 25% of replacement ratio is very close to reference mixes with NA. Experiments also showed that, not useful in practice in using the RCA at a 50% or 100% replacement ratio. The same result is obtained by Valeria Corinaldesi, he stated that the compressive strength of RCA at the 30%-replacement of NA by RAC decline the compressive strength value about 20%, and decline elastic modulus around 16% when 28 curing days [17].

Before the first century AD, the Romans managed to use volcanic pozlan in the manufacture of cement mortar with specific characteristics [2].

In general, the importance of Pozzolan is a thermal and sound insulator and it has constructional uses in buildings such as lightweight aggregate (LWA) and insulating blocks in addition to its many practical uses in the cement industry. Pozzolan is an environmentally friendly, as it is a natural substance that does not need any chemical process during its preparation or application, therefore its use contributes to the reduction of $CO_2$ emissions [18]. LWA have voids on their surface, which helps form a strong bond with cement and with the chemical reaction between them, a boslanic reaction is formed. With the voids on the surface LWA, the bleeding water of the inner zone is small and thus part of the cement bond can enter it [19]

Thermal insulation of major facilities and residential buildings has attracted the attention of civil engineers in recent years, as it is one of the important factors in reducing energy consumption when choosing a suitable thermal insulation for construction [2]. Pozzolan materials can replace cement by 30 to 20% while maintaining concrete resistance in addition to improving the durability of cement mixtures [20].

Bessenouci, M.Z et al [21] studied the thermo mechanical properties of concrete mixes which made of LWA with Pozzolan aggregate (PA). The results revealed that LWA and PA can be provide good performance compared to regular mixtures without additives.

The study also showed that thermal connectivity of these mixtures is interesting and of good specifications when compared with theoretical relationships, which helps to be used in construction works [21]. Another research examining the sustainability of boslan in concrete. Prannoy et al examined the properties of RCA with several Pozzolan slurries. The investigational results shown that the permeable structure of RCA with the old mortar cause the drop in the engineering properties of RCA compared with NA, the compressive strength concrete was lower about 12–25%, flexural strength decreased 9–22%, and elasticity modulus elasticity 16–30% at 28 curing days. But the surface of RCA and the interfacial transition area of RCA between the RCA and cement were developed for the concrete mix modified with pozzolan slurries [22].

## 2. METHODOLOGY

The sample preparation program adopted 12 groups for mixing concrete samples, where groups were distributed as follows: 6 groups, NA were mixed with PA, and also 6 groups, PA were mixed with RCA, Replaced PA was from the total volume of natural aggregate due to the different densities.

The replacement percentage was 10% NA- 90% PA, 15% NA- 85% PA, 20% NA- 80% PA, 25% NA- 75% PA, 30% NA- 70% PA, 35% NA- 65% PA. As for the RCA, the percentage of replacement was as follows: 10% RCA- 90% PA, 15% RCA - 85% PA, 20% RCA - 80% PA, 25% RCA - 75% PA, 30% RCA - 70% PA, 35% RCA - 65% PA. A 36 concrete cubes of 100 x 100 x100 mm were made to determine the compressive strength of concrete (CSC).

In order to study the thermal conductivity of mixtures, 24 concrete plates were manufactured, 12 samples of NA- PA, mixtures and 12 RCA - PA, while maintaining the same previous ratios (PA, RCA). W/C ratio was 0.70 for all of samples. Portland cement got from local Cement Industry. Coarse aggregate passing of sieves 1½ inch, 1 inch, ¾ inch, ½ inch, ⅜ inch, for fine aggregate passing of sieves ⅜ inch, #.4, #10, #16, #30, #40, #100 and pan. Previous mixtures were carried out using PA from the floor of a clean site from the city of As-Suwayda, Syria. Syria has a reserve of PA, estimated at 3 billion tons, while annual production amounts to about one million tons [18]. NA and PA were selected consistent with the typical specifications, such as free of any impurities, granular gradation, durability that deteriorate the aggregate properties. RCA in this study was brought from a demolished construction (residential building). It was crushed by hand with hummer till it converted into small pieces enough to be added to the concrete mixtures.

L. A. Abrasion for NA and RCA was 27%, 44% respectively (ASTM C131 – 81). Specific Gravity of NA and RCA was 2.58, 2.42 respectively (ASTM C127), Water Absorption of NA and RCA was 1.6% 6.7% respectively (ASTM C127).Table 1 shows the chemical composition of PA used in concrete mixtures. Compressive strength of concrete was determined in accordance to ASTM C39-05. The volumes of the concrete constituents was 1.0 Cement; 1.5 Sand 3.0, Coarse aggregate. Table 2 and table 3 illustrated the individual and average CSC for NA with PN and RCA with PA. Figure 1 shows some of the stages of sample making in the laboratory.

**Table 1:** the chemical composition of PA

| Oxides and the main constituents of PA | Percentage based on international studies and references | percentage The according to the chemical analysis of research |
|---|---|---|
| **$SiO_2$** | 35 - 80 | 46.43 |
| **$Al_2O_3$** | 22-Aug | 13.74 |
| **$Fe_2O_3$** | 30-Apr | 10.31 |
| **MgO** | 30-Apr | 8.95 |
| **CaO** | 30-Apr | 6.08 |
| **$Na_2O$** | 1.5 - 8 | 3.18 |
| **$K_2O$** | 0.5 - 8 | 1.33 |
| **$H_2O$ waste is burned L.O.I** | by Variable location of PA | 10.07 |
| **$P_2O_5$ +** | < 0.15 | |
| **$CO_2$** | Variable by location of PA | |
| **Specific gravity** | | 2.42 |

**Figure 1:** some of the stages of sample making in the laboratory

**Table 2:** Individual CSC Average CSC for NA with PA mixes

| # groups | Mix components | # | Individual CSC (MPa) | Average CSC (MPa) |
|---|---|---|---|---|
| B1 | 90%PA+ 10% NA | 1 | 8,5 | 10 |
| | | 2 | 9 | |
| | | 3 | 13.50 | |
| B2 | 85%PA+ 15% NA | 1 | 95 | 109 |
| | | 2 | 118 | |
| | | 3 | 115 | |
| B3 | 80%PA+ 20% NA | 1 | 18 | 24 |
| | | 2 | 24 | |
| | | 3 | 30 | |
| B4 | 75%PA+ 25% NA | 1 | 85 | 83 |
| | | 2 | 86 | |
| | | 3 | 78 | |
| B5 | 70%PA+ 30% NA | 1 | 54 | 63 |
| | | 2 | 74 | |
| | | 3 | 61 | |
| B6 | 65%PA+ 35% NA | 1 | 95 | 94 |
| | | 2 | 98 | |
| | | 3 | 90 | |

**Table 3:** Individual CSC Average CSC for RCA with PA mixes

| # groups | Mix components | # | Individual CSC (MPa) | Average CSC (MPa) |
|---|---|---|---|---|
| B7 | 90%PA+ 10% RCAA | 1 | 57 | 58 |
| | | 2 | 64 | |
| | | 3 | 62 | |
| B8 | 85%PA+ 15% RCA | 1 | 75 | 75 |
| | | 2 | 68 | |
| | | 3 | 82 | |
| B9 | 80%PA+ 20% NA | 1 | 80 | 73 |
| | | 2 | 70 | |
| | | 3 | 68 | |
| B10 | 75%PA+ 25% RCA | 1 | 80 | 68 |
| | | 2 | 58 | |
| | | 3 | 65 | |
| B11 | 70%PA+ 30% RCA | 1 | 97 | 104 |
| | | 2 | 130 | |
| | | 3 | 85 | |
| B12 | 65PA+ 35% RCA | 1 | 85 | 71 |
| | | 2 | 61 | |
| | | 3 | 67 | |

## 3. DISCUSS INVESTIGATIVE RESULTS

### Determination of the Concrete Density

PA has a low density compared to NA as a result of containing voids within their structure, which can fill with water or air. It is distributed in dissimilar sizes and shapes in the material where it forms a large proportion of the total volume of the material. The importance of voids is to design of the thermal insulation systems [23][18].

Figure.2 displays the relationship between concrete densities for PA-NA and PA-RCA concrete mixes versus PA replacement%. It is noticeable that the concrete density increase with increasing of PA percentage for two mixes. This behavior can be interpreted as a consequence of a decrease in the amount of PA, which has a lower density as described above. It is observed that the density values for PA and RCA are close together because the RCA has a significant voids ratio in its structure. The difference in density between the percentages of 90%PA-10% RCA is and 65%PA-35% RCA was about 19%. In general, the density of PA mixtures is less than that of RCA mixtures, and this is what this study obtained and these results are consistent with what Bessenouci [21] reached. At a rate of 90% PA of the total weight of the aggregates, the density is only 1397 Kg/cm$^3$. It corresponds to LWA concrete [24][25][26].

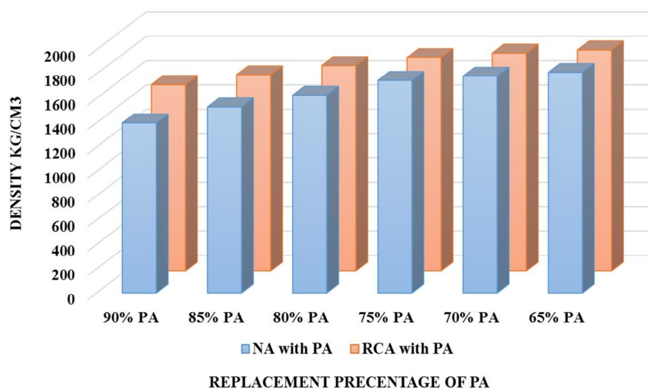


**Figure 2:** Density versus PA replacement%

### CSC of concrete after 28 Curing Days

CSC is the material's ability to withstand mechanical pressures that the material is exposed to during transportation and installation operations, or during its life without a breakdown in its structures, failure, deformation, or loss of any of its other functional characteristics [18][27].

As revealed in the figure 3, the CSC at 85% PA-15% NA have a higher value (109 MPa), at 75% PA-75%NA was 83 MPa, and then at 65%PA-35%NA the CSC was 94 MPa. As the RCA-PA mixes, the higher value of CSC was 70% PA-30% RCA (104 MPa). The high hardness of PA has given high CSC values. From the above, it is clear that the use of RCA with PA gives satisfactory results and is close to NA. Acceptable CSC values for PA of concrete mixtures can be obtained by entering a low-density RCA with good gradation of aggregates and these CSCs are good compared to the resistance of NA concrete, these results are very close with the investigation results for Prannoy et al [28] and Bessenouci [21].

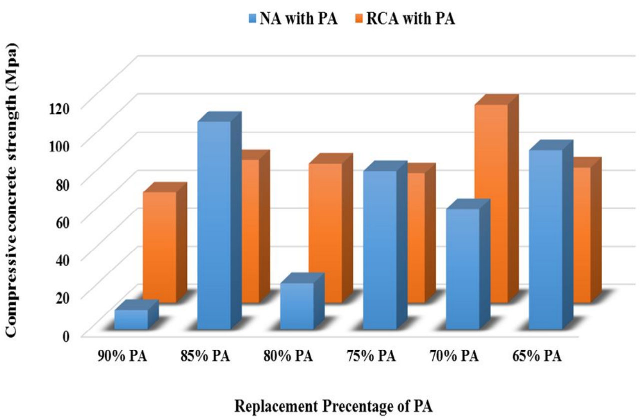


**Figure 3:** Compressive concrete strength versus PA replacement%

### Determination of Thermal conductivity of Concrete

Thermal conductivity is the amount of heat transferred vertically through the surface of one square meter and one-meter-thick, and that due to thermal change resulting from one temperature (1 Celsius degree) between the upper and lower surface. Their importance is in the knowledge of any of the materials of construction is better than the other, according to the amount of heat transmitted. PA is characterized by low values of thermal conductivity versus high conductivity values for heavy materials such as metals [777][18].

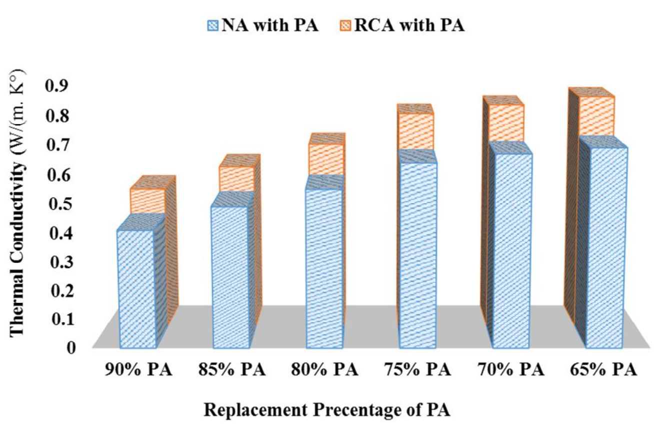


**Figure 4:** Thermal Conductivity versus PA replacement%

Figure 4 shows that the use of PA in NA or RCA concrete mixtures leads to the production of new mixtures that help reduce the thermal conductivity. Figure 4 also shows a decrease in the measured thermal conductivity whenever the PA ratio increases with both NA and RCA. This is mostly due to the nature of the PA that has a high ratio of air voids in the mixture. The thermal conductivity of PA-NA mixtures is less than PA-RCA mixtures, and the percentage of decrease in this thermal conductivity is 21% at 90% PA- 10% NA.

Analysis also indicate that there are an enhancement in the thermal performance of concrete mix with NA and RCA, these results fall in within all researches results that display in introduction. As a summary of the previous stages, it turns out that the use of 90 PA with 10 RCA is an optimum ratio, as CSC 58 MPa was considered relatively high, density was 1529 Kg/cm$^3$ and it is light compared to ordinary mixtures of more than 1800 Kg/cm$^3$, for thermal conductivity it is also low.

**The relationship between concrete density and thermal conductivity:**

Replacing the NA with PA led to a decrease in the values of concrete density and thermal conductivity as shown in Figure 5, the relationship between them is inverse because the density of PA is less than the density of the mixture concrete materials.

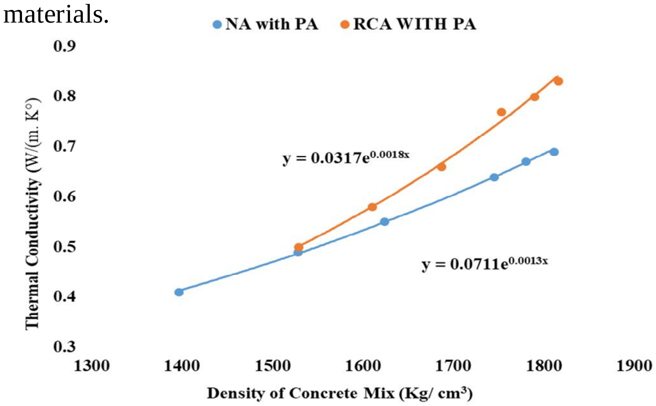


**Figure 5:** Relationship between concrete density and thermal conductivity versus PA replacement%

The relationship derived from the laboratory results shown above is an exponential relationship, this is very close to the relationship of the American Concrete Institute (ACI): $\lambda = 0.072 \text{ x } e^{0.00125\rho}$ [18]. Where $\lambda$ is thermal conductivity coefficient, W/(m.K °). $\rho$ is concrete density, Kg/m$^3$

## 4. CONCLUSIONS

Based on the investigational outcomes of previous tests, the next conclusions were found as shown:

[1]The concrete density decrease with increasing of PA percentage for PA-NA and PA-RCA mixes. The difference in density between the percentages of 90% PA-10% RCA and 65% PA-35% RCA was 19%. This means the production of light concrete mixtures

[2]The use of RCA with PA gives satisfactory results is close to NA. Acceptable CSC values for PA of concrete mixtures can be obtained by adding a low-density RCA, these CSCs are good compared to the resistance of NA. CSC at 85% PA-15%NA have a higher value (109 MPa), and the higher value of CSC was 70% PA-30% RCA (104 MPa).

[3] The measured thermal conductivity increases

when NA and RCA increase. The thermal conductivity of PA-NA mixtures is less than PA-RCA mixtures, and the percentage of decrease in this thermal conductivity is 21% at 90% PA-10% NA.

[4] Analysis also indicate that there are an enhancement in the thermal performance of concrete mix with NA and RCA.

[5] The use of 90 %PA with 10% RCA is an optimum ratio, as CSC value was 58 MPa, considered relatively high, density was 1529 $Kg/cm^3$ and it is light compared to ordinary mixtures of more than 1800 $Kg/cm^3$, for thermal conductivity it is also low.

[6] There is an inverse relationship between the ratio of PA and both the density and the thermal conductivity

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