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Producing Light Weight Concrete Using Pumice and Mineral Aggregates and Comparing the Curing Process of Autoclave with Saturated Condition

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Abstract: In this study, several specimens of concrete are constructed of light pumice and mineral aggregates with different aggregate grading, water cement ratio and different weight combinations. Optimum mixing design using micro silica is given and then curing process of constructed concrete with finally mixing design is compared in the saturated condition with the combination of saturated and autoclave conditions. The results show that using above-mentioned light weight materials reduce the specific weight for 14% and gain 28-day cylindrical strength up to 287 kg cm^{-2}, the best way to get fast compressive strength of specimens is to keep them in saturated conditions for three days after making and then placing them in the autoclave environment under pressure for 15 min under the 1.5 atmosphere pressure. To achieve 28-day compressive strength without placing specimens in saturated environment, they can be placed, 24 h after being made, for 2 h in the autoclave environment under 1.5 atmosphere pressure.

Key words: Mix design, compressive strength, grading analysis, bulk weight

INTRODUCTION

Twentieth century witnessed rapid growth in use of concrete as construction materials and especially after World War II in European countries a large amount of this material is used in construction. The main reason is the rapid construction of precast concrete buildings, especially. Some advantages of precast concrete are rapid construction, quality control methods applied in the factory, quick curing process, possibility of embedded in layers of thermal insulation. Despite the listed advantages for the use of precast concrete there are also following restrictions that can be mentioned:

- The need for heavy transport equipment
- Transportation and installation of concrete components and its high cost
- High weight of precast concrete parts

The main disadvantage of precast concrete is the overweight parts. So there are always efforts to reduce the specific weight of structural and precast concrete and to use lightweight concrete.

Some types of light weight concrete according to the production method are:

- The use of light and porous aggregates that lead to produce light aggregate concrete
- Creating large holes in the concrete that can be different types with names spongy concrete, porous concrete and gaseous concrete
- Elimination of fine aggregates to create so many holes in concrete that is known the concrete without fine aggregates

Light concrete according to its application can be also classified to three categories:

Light weight structural concrete, light weight concrete used in construction works and lightweight concrete used in the precast separator and partition components

In precast concrete components curing time of concrete is important and shortening the access time to reach the expected strength causes to increase in the production of precast parts. Therefore, various methods for achieving this goal is run. One of these methods that can be mentioned is steam bath or autoclave. Applying environmental conditions increase cement hydration reaction rate (Neville, 1981).

HISTORY OF LIGHTWEIGHT CONCRETE APPLICATION

In general, concrete containing light aggregates is not considered a new material. Some types of light

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concrete in the early Roman Empire was recognized. Examples like the Colosseum Amphitheater and some parts of the Pantheon temple was made from materials that can be categorized as light concrete.

Development of light aggregates depends on the existence of raw materials in each region. That is why in the Germany and Norway variety of types of aggregates made of light expanded clay has been developed (with different brand names including: Liapor and Leca). In the Netherlands and England ash based products has been developed (Lytag and Aardelit). In America, there is diversity of expanded shale.

During World War II, about 104 ships in America was built of lightweight aggregate concrete; their capacity was 3 to 140,000 tons. Successful performances of them cause development of application of light structural concrete in the buildings and bridges (Zhang and Gjorv, 1991).

ACI 213B (1994) expresses the most important factors for selecting Light Weight Aggregate Concrete (LWAC) as follow:

To reduce dead load, flexibility in design, save construction costs and significant long-term durability.

Also in Europe, this reasoning in selecting (LWAC) is very important. In Germany, Norway, the Netherlands there are numerous successful applications of light concrete in bridges with long spans.

Offshore activities in oil industry are suitable opportunity to introduce (LWAC) to build a platform. In 1950 many small and simple platforms that parts of them were built from LWAC installed in shallow coastal waters of the Gulf of Mexico. In 1980 two oil exploration platforms that parts of them were made of LWAC was used in frozen Beaufort waters. The most important advance in this field is selection of LWAC to build four platforms in the North Sea (Owens and Newman, 1999). The platforms have recently been completed. Light weight aggregate concrete is used in construction of shell of Hibernia oil platform's float part (Owens and Newman, 1999). Structures of this kind of concrete platforms are made of strong special LWAC with modified normal density (MND). MND concrete developed to reduce weight and for special applications. This type of concrete has 75 MPa strength and density of 2250 kg m^{-3}. Structures built in the North Sea contain special high resistant light aggregates of Leca type.

Nowadays using light aggregates in the England reduced to only two types made from the ashes (Lytag) and (Pellite). LWAC has been widely used in the past. Especially in floor of office buildings, as well as offshore structures and sports stadiums are also used. Recently, using LWAC concrete in the main structural members is rarely considered, first because it costs more second inadequate information of light concrete properties and finally possible future cost reduction due to weight reduction and thermal properties.

Application of concrete with pumice for use in residential buildings, have been developed which have a good thermal insulation capacity and good workability. Application of lightweight structural concrete is developing. This requires improving the quality and legal context (Weigler and Karl, 1972).

During the years 1960 and 1973, about 15 bridges with long spans using LWAC were built in the Netherlands. Economic calculation shows about five to ten percent saving due to dead load and foundation size reduction. Use of LWAC in the precast parts is increasing. From economical perspective, all applications of LWAC are attractive, even though the cost of this material is somewhat more but ultimately the total building cost is less (Mijnsbergen *et al*., 2000).

LIGHT WEIGHT AGGREGATES

One of lightweight aggregates characteristics is their high porosity which is the cause of less specific weight. Some of the lightweight aggregate is available naturally while others are produced artificially (Neville and Brooks, 1987). As the natural aggregates Pumice, mineral aggregate and volcanic ash can be mentioned. Pumice is of igneous rocks and forms when molten material enters the sea and a fast cooling occurs. This black rock contains wide open pores and with smaller grains its density increases and approaches the density of igneous rock. Pumice's bulk weight is between 1100 to 1200 kg m^{-3}. Mineral aggregate with white yellow and light gray color is found in nature. This stone has closed and open irregular pores and uneven surface. Mineral aggregate is being created when volcanic ashes accumulate and gradually lose their temperature with expansion of the bubbles created by the gases in it. Its bulk weight is between 500 to 900 kg m^{-3}. Artificial aggregates are known according to their brand name. In general, this type of aggregates can be divided into two groups. The first group is being made from heating and expansion of materials such as clay and perlite. Heating clay with a small percentage of coal or mazut and cooking it in a furnace in temperature of 1150 to 1200°C produces light weight pellets called Leca. If volcanic rock perlite is heated in 900 to 1000°C temperature porous and light material is produced which can be used in producing non-structural lightweight concrete. Lightweight aggregates in the next group are produced of rapid cooling the iron furnace slag. To better understand the internal structure of natural and

Table 1: Chemical analysis of natural and artificial lightweight aggregate

	Type of light aggregate			
Chemical compounds (%)	Expanded clay	Tehran's mineral pumice aggregate	Tabriz's mineral pumice aggregate	Pumice
SiO_2	65.28	63.50	67.96	48.30
Al_2O_3	15.9	15.23	16.20	9.62
Fe_2O_3	8.4	9.14	2.00	17.88
CaO	3.92	4.11	3.36	10.15
MgO	1.8	0.60	0.80	5.18
Cl	-	1.32	-	-
SO_3	1.06	0.03	0.75	0.72

artificial aggregates, chemical compounds of the aggregates are given in Table 1.

REDUCING THE WEIGHT OF STRUCTURAL CONCRETE USING PUMICE AND MINERAL AGGREGATES AND OPTIMUM SELECTION OF MIX PROPORTIONS

The purpose of this study is to produce light weight concrete for structural applications. So, specimens are tried to gain 28-day compressive strength of 270 to 300 kg cm^{-2} and also with less bulk weight. Therefore, to lower the bulk weight of concrete instead of using the river materials pumice aggregates were used and different specimens were prepared with various aggregate grading and different water cement ratios and also different weights of cement and micro silica. Results proved that if coarse pumice aggregate is selected, compressive strength of concrete specimens are low due to weakness of compressive strength of aggregates and if fine pumice is used, Although compressive strength of specimens increases but bulk weight of concrete is very close to normal concrete; so no longer that concrete can be defined as lightweight concrete. To overcome this problem, lighter mineral aggregate materials were used. This concrete has a low bulk weight, but the concrete during construction and also during autoclave processing environment faces many problems. Due to the high percentage of water absorption of mineral aggregate, water cement ratio is increased and selection of water cement ratio less than 0.4 because of low workability of concrete is not possible. If the water/cement ratio less than the above mentioned amount is considered while specimens are put in autoclave environment to reduce curing time, due to incomplete hydration from little water they are faced relaxation and are destroyed. So the water/cement ratio should be increased and accordingly the mentioned problem is removed. On the other hand increasing water to cement ratio decreases obtained strength of specimens thus their use as a structural concrete will not be possible. Consequently in the next step a combination of different weight percentages of pumice aggregate and mineral aggregate with different water/cement ratio and various quantities of cement and micro silica with the high lubricant used to build cubic concrete specimens with 5 cm dimensions. In these specimens, use of mineral aggregate reduced bulk weight while pumice aggregates increased their compressive strength. Since pumice water absorption is less than mineral aggregate the use of pumice in concrete mix also reduced water/cement ratio. Therefore, this will increase the compressive strength. It should be mentioned that the main factor in increasing the compressive strength of specimens is more strength of pumice aggregates compared to mineral aggregates and reduction of water/cement ratio is of importance as next factor. The use of pumice in concrete mix also removes before mentioned relaxation problem of specimens. Among different types of concrete mix proportions, a mixture with both 28-day compressive strength of about 270 to 300 kg cm^{-2} and the lowest bulk weight was selected for more tests. After testing dozens of mix designs with different materials and different grading analysis ultimately the final mix design was found that is given in Table 2 and 3.

CURING PROCESS OF SPECIMENS

After selecting optimum mix design according to Table 2 and 3, concrete cubic specimens in 5 cm dimensions were prepared then after 24 h of construction time the specimens are pull out of molds and then were applied four different methods of curing process as following:

- Placement of specimens in saturated environment and applying compressive strength test for ages 3, 7, 28 and 42 days
- Placement of specimens in autoclave environment for 15, 30 min, 1, 2 and 3 h under 1.5 atm pressure
- Placement of specimens in saturated environment for a day and then putting in the autoclave environment for 15, 30 min, 1, 2 and 3 h under 1.5 atm pressure
- Placement of specimens in saturated environment for three days and then putting in the autoclave environment for 15, 30 min, 1, 2 and 3 h under 1.5 atm pressure

Table 2: Materials used in producing light weight concrete

Cement (g)	Microsilica (g)	Water (g)	Pumice aggregate	Mineral pumice aggregate	High lubricant (cc)	W/C	W/(C+F)
9223	2762	4210	19967	5847	300	0.45	0.35

Table 3: Aggregate grading analysis

Type of aggregate	Sieve No.	Sieve size	Weight retained (g)	Weight passing (g)	Percentage passing
Pumice	4	4.75	9150	16664	64.55
Pumice	8	3.35	6400	10264	39.76
Pumice	16	1.18	4417	5847	22.65
Mineral pumice	16	1.18	115	5732	22.21
Mineral pumice	30	0.60	2665	3067	11.88
Mineral pumice	50	0.30	2288	779	3.02
Mineral pumice	100	0.15	779	0	0.00

Table 4: Compressive strength (kg cm^{-2}) and the average bulk weight of concrete specimens (kg m^{-3})

	Protecting time in autoclave					
Curing process	15 min	30 min	1 h	2 h	3 h	Bulk weight
Without saturated environment in autoclave	181	240	266	328	335	2056
14 days in saturated environment and in autoclave	296	320	331	335	420	2064
3 days in saturated environment and in autoclave	330	340	376	445	452	2080
5 days in saturated environment and in autoclave	333	359	422	456	476	2080
	Time					
Curring process	3 days	7 days	28 days	42 days		Bulk weight
In saturated environment without placement in autoclave	193	219	287	326		2080

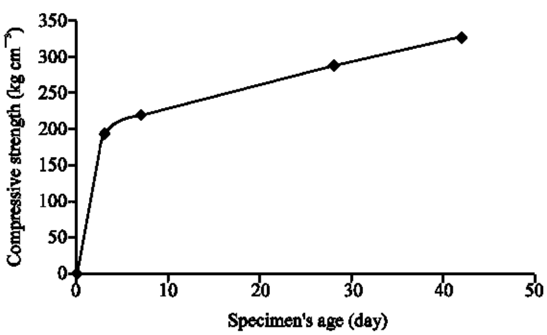

Fig. 1: Compressive strength growth at different ages

- Placement of specimens in saturated environment for five days and then putting in the autoclave environment for 15, 30 min, 1, 2 and 3 h under 1.5 atm pressure

Considering the compressive strength results for the specimens according to Table 4, it is clear that in the similar conditions longer curing time increases the compressive strength of specimens. According to the results of compressive strength tests increase of specimens' strength for ages 3, 7, 28 and 42 day while specimens are put in saturated environment is shown in Fig. 1.

CONCLUSIONS

Specific weight of light concrete made of light mineral aggregate and pumice materials with 28 days compressive strength between 270 to 300 kg cm^{-2} is about 2.07 ton m^{-3}. That is reduced about 14% compared to normal weight concrete.

If the specimens after they are made are placed immediately in the autoclave environment (for 24 h) without putting in the saturation environment, the gained compressive strength will be low so it is better to put specimens first in saturated environment then in the autoclave.

Twenty eight day compressive strength for specimens that their curing processes were completely in saturated environment is 287 kg cm^{-2}.

Increasing the curing time of specimens in saturated environment before placement in the autoclave environment increases strength of specimens, but adding placement time of specimens in the saturated environment over three days has negligible effect on the increase of compressive strength.

In order to gain fast 28 day compressive strength of light concrete made from pumice and mineral aggregates, specimens can be placed inside the autoclave for 2 h without putting in the saturated environment. If the specimens after they are made are placed in the saturated environment for a day or more, placement time in the autoclave for 15 min will be enough.

The placement of specimens in saturated environment for three days and then putting the specimens in the autoclave environment for 2 h leads to compressive strength of 445 kg cm^{-2}. This strength compared with strength of 42 day saturated specimen (326 kg cm^{-2}) shows 37% increase.

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