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The effect of pumice powder on the self-compactability of pumice aggregate lightweight concrete

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HIGHLIGHTS

- The self-compacting pumice aggregate concrete satisfies the strength requirement of semi-structural lightweight concrete.
- The flowing ability and thermal conductivity of self-compacting pumice aggregate concrete is expressive.
- Increasing pumice ratio increased the tendency to segregation of fresh concrete.
- The grading and moisture content of pumice aggregate are the main parameters of self-compacting concrete mix.

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ABSTRACT

This paper presents the results of an experimental study about the effects of pumice powder, different water/(cement + mineral additive) ratios and pumice aggregates on some physical and mechanical properties of self-compacting lightweight aggregate concrete. In this study, pumice was used as lightweight aggregates. Several properties of self-compacting pumice aggregate lightweight concretes such as unit weight, flow diameter, T50 time, flow diameter after an hour, V-funnel time and L-box tests, 7, 28, 90 and 180-day compressive strength, 28-day splitting tensile strength, dry unit weight, water absorption, thermal conductivity and ultrasonic pulse velocity tests were investigated. For this purpose, 24 series of concrete samples were prepared in two groups. In the first group, pumice aggregate at the rate of 100% was used for the production of self-compacting lightweight aggregate concrete with constant w/(c + m) ratios as 0.35, 0.40 and 0.45 by weight. Furthermore as the second group, pumice aggregate was used as a replacement of natural aggregate, at the levels of 0%, 20%, 40%, 60%, 80%, and 100% by volume with fly ash and blast furnace slag mineral additives at the constant rate of 40%. The flow diameters, T50 times, paste volumes, 28-day compressive strengths, dry unit weights, thermal conductivities and ultrasonic pulse velocity of self-compacting lightweight aggregate concrete were obtained in the range of 560–800 mm, 2–11 s, 435–558 l/m^3, 10.5–65.0 MPa, 840–2278 kg/m^3, 0.347–1.694 W/mK and 2611–4770 m/s respectively, which satisfies not only the strength requirement of semi-structural lightweight concrete but also the flowing ability requirements and thermal conductivity requirements of self-compacting lightweight aggregate concrete.

1. Introduction

Concrete is a multiphase exceedingly complex heterogeneous material and one of the principal materials for structures. However, the heterogeneous structure of concrete results in some undesirable effects. Heterogeneity and other properties of concrete are mostly concerned with the hydration. Hydration, the chemical reaction between water and ingredients of cement, is one of the most important properties of its strength gain process. This property of hydration caused volume change of hydrated cement, varying hydration rate through the concrete and time dependency of strength gain. One of the main effects of strength gain is the improved mechanical properties of concrete. The mechanical properties of cement based material is needed by designers for stiffness and deflections evaluation, and is a fundamental property required for the proper modelling of its constitutive behaviour and for its proper use in various structural applications. For this reason,

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Nomenclature

SCC	self-compacting concrete
SCLC	self-compacting lightweight aggregate concrete
LWAC	lightweight aggregate concrete
UPV	ultrasonic pulse velocity
SGF	specific gravity factor
SG	specific gravity
w	water
c	cement
m	mineral admixture
CS	control sample
FA	fly ash
BFS	blast furnace slag
NP80	%80 pumice as aggregate (the number varies according to percentage of pumice aggregate)
PP1	%100 pumice aggregate and pumice powder as mineral admixture, w/(c + m) = 0.35
PP2	%100 pumice aggregate and pumice powder as mineral admixture, w/(c + m) = 0.40
PP3	%100 pumice aggregate and pumice powder as mineral admixture, w/(c + m) = 0.45
EFNARC	The European Federation of Specialist Construction Chemicals and Concrete Systems
T_{50}	time to flow a diameter of 50 cm
T_{400}	the time for SCLC to reach 400 mm from three steel bars
T_v	V-funnel flow time
D_{max}	maximum grain size
STS	splitting tensile strength

determination of mechanical properties of concrete has become very important in terms of design. However, due to economic considerations, there is strong demand on natural resource usage. Moreover, when structure weights are considered, not only natural light weight aggregates but also artificial light materials such as gas concrete are used. Incorporation of natural/artificial resources in concrete brings environmental, economic and/or technological benefits [1–13].

Self-compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self-weight with little or no vibration effort and which is at the same time cohesive enough to be handled without segregation or bleeding [14]. SCC was originally developed at the University of Tokyo, Japan in 1986 by Prof. Okamura and his team to improve the quality of construction and to overcome the problems of defective workmanship [15]. It is used to facilitate and ensure the proper filling and good structural performance of the restricted areas and heavily reinforced structural members. SCC can also provide a better working environment by eliminating the vibration noise [16].

Self-compacting lightweight aggregate concrete (SCLC) is a kind of high-performance concrete developed from self-compacting concrete (SCC). SCLC combines the favourable properties of lightweight aggregate concrete (LWAC) and SCC, needs no external vibration, and can spread into place, fill the formwork and encapsulate reinforcement without any bleeding or segregation [17,18]. On the other hand, the use of chemical admixtures is always necessary when producing SCC in order to increase the workability and reduce the segregation. The content of coarse aggregate and water to binder ratio in SCC are lower than those of normal concrete. Therefore, SCC contains large amounts of fine particles such as, blast-furnace slag, fly ash and lime powder in order to avoid gravity segregation of larger particles in the fresh mix. The wide variety of the lightweight aggregate source result in distinguishing behaviour among the SCLCs. Thus, properties of SCLCs have to be examined individually [19–21].

Pumice is a natural material of volcanic origin produced by the release of gases during the solidification of lava, and it has been used as the aggregate in the production of lightweight concrete in many countries around the world. So far, the use of pumice was dependent on the availability and limited to the countries where it is locally available or easily imported. Approximately, 7.4 billion m^3 (40%) of the total 18 billion m^3 of pumice reserve is located in Turkey [22]. Therefore, the use of pumice as aggregate or mineral additive in the production of self-compacting concrete may be a good approach for the production of lightweight, easy workable, economic and environmentalist concrete.

There has been an increase in the usage self-compacting concrete (SCC) in recent years and a number of papers have been published on this topic [19]. However, there is very little documentation on self-compacting lightweight aggregate concrete, which has superior advantages as using natural materials, lightness and easy workability. Thus, a study was performed under the light of the literature information given above. For this purpose, experimental studies were carried out in two base groups. In the first group, concrete specimens with three different water/(cement + mineral additive) portions, were prepared by using volcanic originated pumice aggregate at 100%. In the second group, concrete specimens with constant water/(cement + mineral additive) portions and complemented by blast furnace slag instead of cement were produced by replacing pumice five different ratios instead of the normal aggregate. Then, some physical and mechanical properties such as workability, unit weight, compressive and splitting tensile strength, thermal conductivity and ultrasonic pulse velocity (UPV) of self-compacting concrete were investigated.

2. Materials and experimental study

2.1. Materials

In this study, CEM I 42.5 N type cement, fly ash and blast furnace slag were used. The fly ash that was supplied from Nallıhan Factory of Park Thermal Electric & Trading Co. is accepted as class F fly ash, because CaO content is less than 10%.

Table 1
Chemical properties of Portland cement, fly ash, blast-furnace slag and pumice aggregate.

Components	Portland cement (%)	Fly ash (%)	Blast furnace slag (%)	Pumice aggregate (%)
SiO_2	20.79	47.50	38.54	69.78
Al_2O_3	5.17	15.95	14.90	11.16
Fe_2O_3	3.43	16.60	1.50	2.11
CaO	60.29	6.60	33.50	2.47
MgO	3.03	4.65	8.20	0.60
SO_3	3.12	3.94	0.62	0.06
Na_2O	0.41	1.74	0.22	4.33
K_2O	0.66	1.96	1.50	2.87
Cl^-	0.0251	–	–	0.0496
Free CaO	0.34	0.56	–	–
$Na_2O + K_2O$	–	3.70	–	–
Insoluble matter	2.47	–	–	–
Ignition loss	2.79	–	1.00	4.66
Undetermined*	0.32	–	–	–

* Undetermined: acid insoluble residue, a non-cementing material which is present in Portland cement.