materials proceedings

Proceeding Paper

GUNITECH®: An Innovative Pumice Based Dry Shotcrete Application †

Maria Nomikou [1], Vasileios Kaloidas [2], Christos Triantafyllos Galmpenis [1,*], Nicolaos Anagnostopoulos [3] and Georgios Tzouvalas [1]

1 HERACLES Group, 32 D. Solomou Str., Lykovrisi, 14123 Attica, Greece; maria.nomikou@lafargeholcim.com (M.N.); george.tzouvalas@lafargeholcim.com (G.T.)
2 Research Consultant, Labrou Katsoni 48 B, 14561 Kifisia, Greece; vkaloid@gmail.com
3 Sika Hellas, Protomagias 15, 14568 Krioneri, Greece; anagnostopoulos.nikos@gr.sika.com
* Correspondence: christos.galmpenis@lafargeholcim.com

† Presented at International Conference on Raw Materials and Circular Economy, Athens, Greece, 5–9 September 2021.

Abstract: Pumice quarried by LAVA MINING AND QUARRYING SA from Yali Island, Dodecanese, is used in domestic and foreign markets mainly as concrete lightweight aggregate, masonry unit constituents, road substrate, and loose soil stabilization. It is a porous natural volcanic rock with low density, low thermal and noise transmission, and the highest strength among all the natural or artificial lightweight materials of mineral origin. Nowadays, pumice is of additional interest as it has a reduced CO_2 footprint because thermal energy is not needed for its expansion compared with the artificial lightweight aggregates. In this context, HERACLES GROUP in collaboration with Sika Hellas has launched a new product containing pumice stone under the brand name GUNITECH®. GUNITECH® is an innovative bagged material for spraying concrete applications. It is a ready lightweight concrete, for building repairs certified as EN 1504-3.

Keywords: pumice stone; lightweight shotcrete; lightweight gunite; spraying concrete

Citation: Nomikou, M.; Kaloidas, V.; Galmpenis, C.T.; Anagnostopoulos, N.; Tzouvalas, G. GUNITECH®: An Innovative Pumice Based Dry Shotcrete Application. *Mater. Proc.* **2021**, *5*, 46. https://doi.org/10.3390/materproc2021005046

Academic Editor: Anthimos Xenidis

Published: 1 December 2021

1. Introduction

Dry spraying is a concreting technique (gunite) that consists in blowing dry concrete material with high momentum out of a hose with compressed air, injecting water at the nozzle as the material was released. This technique aims to form a compact, dense, and firmly adhering layer with the lowest possible rebound loss [1]. As in ACI 506R [2], the density of high-quality gunite is usually between 2230 and 2390 kg/m^3.

In situ preliminary trials, laboratory investigations, and discussions with contractors and structure design engineers indicated that there is a market need for a lightweight gunite with a wet density of around 1800 kg/m^3 (around 1600 kg/m^3 dry oven) and modulus of elasticity not less than 15 GPa. HERACLES Group and Sika Hellas cooperated to develop in their R&D facilities, GUNITECH®, a two-component sprayed cementitious mortar containing a special pumice mixture, cement, and concrete chemicals used for high-performance structural repairs and reinforcements and meeting the requirements of class R3 according to EN 1504-3 [3]. It is designed for spray application using the dry-spray method.

2. Components and Applications

GUNITECH® consists of two components, which are packed in two separate bags marked A and B and mixed at the job site in 1:1 bag proportions.

The constituents of Component A, packed in bags of 20 kg, are:

- Cement CEM I 52,5 N EN 197-1 (HERACLES Group)
- Silica sand of special granulometric gradation (Sika Hellas)

- Concrete additive with pozzolanic components (Sika Hellas)
- Alkali free accelerator (Sika Hellas)
- Concrete admixtures (Sika Hellas) and
- Macro synthetic fibers (Sika Hellas)

The constituent of Component B, packed in bags of 15 kg, is:

- Pumice of special granulometric gradation and a controlled range of moisture from 18 to 22% on a wet basis (HERACLES Group).

Pumice quarried by LAVA MINING & QUARRYING SA (HERACLES Group) from Yali Island, Dodecanese, is a porous pozzolanic natural volcanic rock with low density, low thermal and noise transmission, and the highest strength among all the natural or artificial lightweight materials of mineral origin. Pumice is of additional interest as it has a reduced CO_2 footprint because no thermal energy is needed for its expansion compared with artificial lightweight aggregates.

Particle size distribution of component B is shown in Table 1. The content of fine particles passing the 0.063 mm sieve is less than 15% *w*/*w*. Although pumice is classified in fractions with particles more than 40 mm, the fraction 0/3 mm was chosen, providing higher strength than the other fractions with larger particles and better particles, resulting in a dense adhering layer. Pumice exhibits the highest crushing resistance (EN 1055-1 A) (4.9 MPa) among all natural lightweight aggregates, improving lightweight concrete strength.

Table 1. Particle size distribution of component B (EN 933-1).

Sieve, mm	Passing, % *w*/*w*
3.15	99
2	86
1	60
0.5	40
0.25	23
0.125	17

Pumice an amorphous silicate rock with typical chemical composition, as shown in Table 2. The content of reactive SiO_2 is in the range of 45–65%, with pozzolanic activity resulting in chemical bonding with cement paste and long-term increase of strength. It is noticed that sulfate content of pumice is enough low due to its natural expansion (no use of combustion gases).

Porosity-related properties of pumice 0/3 mm are presented in Table 3. Pumice particles contain closed and open pores. Closed pores decrease the apparent density of particles to 2.10 g/cm^3 (determined according to EN 1097-6) against the apparent particle density of conventional limestone particles, which is about 2.65 g/cm^3. The specific volume of closed pores is around 9.1% *v*/*v*. Open pores present a specific volume of around 7.7% *v*/*v* and contain water providing a continuous internal curing of the hardened material [4,5]. The pre-wetted particles with a close range of moisture provide good regulation of the mixing water and particle momentum during spraying and repeatability of the properties of the wet and hardened GUNITECH®.

Table 2. Typical chemical analysis of pumice.

Component	Content, % *w/w*
SiO_2	71.91
Al_2O_3	12.66
Fe_2O_3	1.13
CaO	1.46
MgO	0.32
SO_3	0.03
K_2O	4.30
Na_2O	3.45
Loss on ignition	4.53
Chlorides	<0.05
Total S	<0.10

Table 3. Porosity related properties.

Property	Magnitude	
Skeleton density, ρ_s	g/cm^3	2.33
Apparent particle density, ρ_a	g/cm^3	2.10
Oven dry particle density, ρ_{rd}	g/cm^3	1.94
Specific volume of open pores $1/\rho_{rd} - 1/\rho_a$	cm^3/g	0.040
Specific volume of closed pores $V'_{cl,m} = 1/\rho_a - 1/\rho_s$	cm^3/g	0.047
Specific volume of open pores $V'_{op,v}$	%	7.7
Specific volume of closed pores $V'_{cl,v}$	%	9.1

The components A and B are mixed at the jobsite and ejected from the hose of the gunite machine. GUNITECH® covers a wide range of applications:

- Repairs for large volumes/surfaces
- Reinforcement of reinforced concrete elements
- Reinforcement of masonry due to a compatible modulus of elasticity
- Transforming of filling walls to load bearing ones
- Wall panels construction
- Structural mantles
- Manual repairs; an alternative to repair mortars R2 & R3 according to EN 1504-3

3. Usage Quality

Usage quality of GUNITECH® includes properties desirable for the builders and contractors during and after the application of the product:

- Rapid strength development due to accelerator and concrete additives
- Workability and cohesion improvement due to concrete additives
- Minimizing early cracking with macro synthetic fibers
- Increased earthquake energy absorption with macro synthetic fibers; extended elastic deformation
- Pumpability due to special granulometry
- Enhanced mechanical and durability properties with pozzolanic components

The use of pumice in GUNITECH® contributes to the following characteristics

- Load 25% less in weight on the structure vs. normal density gunite
- Enhances thermal insulation

- Contributes to internal curing due to the contained moisture
- Reduces dust emission due to the contained moisture
- Up to 45 m high pneumatic transport in the hose
- Inverse layer (ceiling) thickness up to 120 mm
- Minimum rebound up to 50% less than conventional gunite

4. Technical Properties

GUNITECH® is certified conforming EN 1504 R3 classification. Its technical properties are summarized in Table 4.

Table 4. Technical properties of GUNITECH®.

Property	Result	Standard
Early strength	≥0.2 MPa @ 30 min ≥0.3 MPa @ 60 min ≥0.5 MPa @ 120 min	Needle penetration
Compressive strength in cores from panels (L/D = 1)	≥15 MPa @ 1 day ≥20 MPa @ 7 days ≥30 MPa @ 28 days	EN 12504-1/EN 14888-1
Compressive strength in prismatic specimens (lab testing)	≥3 MPa @ 6 h ≥20 MPa @ 1 day ≥35 MPa @ 7 days ≥40 MPa @ 28 days	EN 12190
Strength classification	Class R3 C20/25 LC20/22 Cs25 Class M25	EN 1504-3 EN 206-1 (EN 14487-1) EN 206-1 (EN 14487-1) ISO 4012 EN 998-2
Flexural strength in prismatic specimens (lab testing)	≥4 MPa @ 1 day ≥5 MPa @ 7 day ≥6 MPa @ 28 day	EN 12190
Adhesive bond	≥1.5 MPa @ 28 days	EN 1542
Modulus of elasticity (compression)	≥15 GPa @ 28 days ≥15 GPa @ 28 days ≥20 GPa @ 180 days	EN 13412 ASTM C 469 ASTM C 469
Restrained shrinkage/expansion	≥1.5 MPa	EN 12617-4
Water capillary absorption	$\leq$0.5 kg/m^2 x$\sqrt{h}$	EN 13057
Resistance to carbonation	d_k (carbonation depth) ≤ reference concrete MC (0.45)	EN 13295
Resistance to chloride permeability	Low ≤ 2000 coulombs	ASTM C 1202
Fire classification	EUROCLASS A1 non combustible	
Chloride ion content	<0.05%	EN 1015-17

Compressive strength of GUNITECH® is determined more than 40 MPa at age of 28 days using lab techniques with prismatic specimens 40 × 40 × 160 mm conforming EN 1504 R3 as a repair material. In addition, for technical evaluation and structural design, compressive strength is determined with hardened cores conforming LC20/22 lightweight concrete class. Modulus of elasticity indicates a material compatible for masonry repair.

The use of pumice does not make the hardened material lag behind in performance. Water capillary absorption is less than 0.5 kg/m^2 x$\sqrt{h}$, and resistance to carbonation is equivalent of the reference mortar with water to cement ratio 0.45.

Resistance to Chloride Permeabity

Although a porous material, pumice increases the resistance of GUNITECH® to chloride permeability. Figure 1 shows the decreasing permeability with the age using the test ASTM C1202-19 [6]. This test method consists of monitoring the amount of electrical current passed through 50-mm thick slices of 100-mm nominal diameter cores or cylinders during a 6-h period. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration.

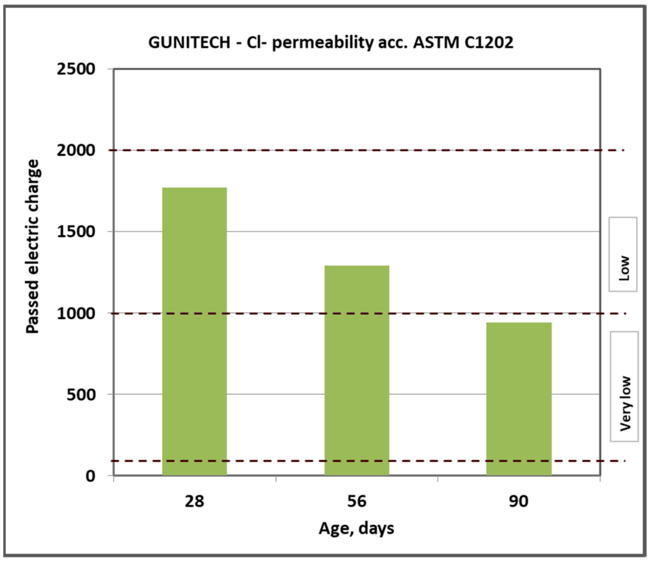

Figure 1. Chloride permeability according to ASTM C1202.

At the age of 90 days after concreting, GUNITECH® cores cured in controlled conditions (21 °C, ≥95% relative humidity) show "Very low" permeability to chlorides according to ASTM C1202-19 [6] (Table 1).

Institutional Review Board Statement: Not Applicable.

Informed Consent Statement: Not Applicable.

Data Availability Statement: Experimental data are results of tests according standard methods without intermediate calculation as exactly contained in the experimental files of Hellenic Concrete Technology Center (Heracles Group) and Sika HELLAS R&D Lab.

References

1. EFNARC. *European Specification for Sprayed Concrete, Guidelines for Specifiers and Contractors*; EFNARC: Flums, Switzerland, 1999; p. 13.
2. ACI 506R. *Guide to Shotcrete*; American Concrete Institute: Farmington Hills, MI, USA, 2016; p. 6.
3. EN 1504-3. *Products and Systems for the Protection and Repair of Concrete Structures. Definitions, Requirements, Quality Control and Evaluation of Conformity. Structural and Non-Structural Repair*; European Committee for Standardization: Brussels, Belgium, 2005.
4. Bentz, D.P.; Weiss, W.J. Internal Curing: A 2010 State-of-the-Art Review. Available online: https://nvlpubs.nist.gov/nistpubs/Legacy/IR/nistir7765.pdf (accessed on 15 February 2011).
5. Cavalline, T.L.P.E.; Tempest, B.Q.; Leach, J.W.; Newsome, R.A.; Loflin, G.D.; Fitzner, M.J. *Internal Curing of Concrete Using Lightweight Aggregate*; NCDOT Project 2016-06; University of North Carolina at Charlotte: Charlotte, NC, USA, 2019.
6. *ASTM C1202-19 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*; ASTM International: West Conshohocken, PA, USA, 2019.