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EXPERIMENTAL INVESTIGATION ON MASONRY PANELS MANUFACTURED WITH PUMICE LIGHTWEIGHT CONCRETE

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Parole chiave: pomice, calcestruzzo alleggerito, inerti leggeri, muratura armata.

Abstract. *The possibility of using pumice aggregates for concrete in structural applications is discussed. In particular, the mix design of lightweight concrete for the manufacturing masonry units having proper strength, is discussed. Moreover, the design of the unit shape according to the technical code requirements and making it possible to arrange reinforcing steel bars is described.*

Reinforced bearing masonry walls, made with the concrete units in question, were manufactured and tests on the panels and on the designed units were carried out.

For comparison, tests on concrete units and structural elements were carried out after the substitution of pumice aggregates with ordinary lightweight aggregates, proving that pumice can be considered an alternative to them.

Sommario. *L'uso della pomice come inerte per il confezionamento di calcestruzzo è poco diffuso sebbene essa sia stata usata già in antiche costruzioni come il Pantheon in Roma.*

In questo studio si affronta la possibilità di realizzare blocchi in calcestruzzo alleggerito con granuli di pomice. I blocchi, progettati e realizzati secondo le indicazioni normative correnti, sono stati usati per realizzare pannelli murari armati da sottoporre a carichi ciclici orizzontali.

I risultati ottenuti, messi a confronto con quelli di pannelli realizzati con blocchi in cls alleggerito con argilla espansa, hanno mostrato la possibilità di utilizzare la pomice come validissima alternativa all'argilla espansa.

1 INTRODUCTION

Pumice is an effusive igneous and porous rock which originates during explosive eruptions from the sudden cooling of magma in a closed cell-like and consequently very light product.

Volcanic pumice has been used as an aggregate in the production of lightweight concrete in many countries in the world. In particular, it can be found in the Mediterranean area (Italy, Turkey, Greece, and Spain). In the United States it is mined mainly in the Rocky Mountains and Pacific Coast States. From the commercial point of view, pumice can be found in the form of granulates characterized by different distribution curves. Production is only devoted to non-structural concrete elements although historically it was used from ancient Roman times for structural applications (the dome of the Pantheon in Rome is a famous example). With respect to the components of reinforced concrete, pumice is an inert material, i.e. it has no chemical reaction with cement paste or steel reinforcement.

Pumice granules show a sharp-cornered polyhedral form with a coarse surface which is an important feature for getting a good bond with cement mortar.

The porous structure and the total absence of crystalline substance grant good thermal and acoustic insulation, which is definitely higher than that of other inorganic materials. Moreover, granulate fire resistance is much higher than the lower limit provided by technical codes.

On the other hand, pumice does not have excellent mechanical characteristics and this drawback for a long time barred its use for manufacturing lightweight structural concrete, as European and American codes (EC2 [1], ACI 530 [2], ACI committee 213 [3]) prove.

The structural use of pumice as a natural light inert for lightweight concrete has already been studied by Failla et al. 1982 [4], Mancuso et al. 1983 [5], Arici and Miraglia 1989 [6], Campione et al. 1999 [7] and Cavaleri et al. 2003 [8]: here, for the first time, it is considered for manufacturing units to be used in reinforced masonry. Many studies can be found in the literature regarding reinforced masonry (for example Scrivener and Williams 1971 [9], Priestley 1980 [10], Shing et al. 1990 [11], Modena 1992 [12], Haider and Dhanasekar 2004 [13], Voon and Ingham 2006 [14]) but not focused on use of pumice as an aggregate for concrete nor devoted to lightweight concrete masonry.

Nevertheless, in seismic engineering reinforced masonry can be even more advantageous if light materials, capable of cutting inertial forces, are used for manufacturing masonry units.

In the context of lightweight inerts a comparison between pumice and expanded clay (which is the most diffused lightweight inert and is characterized by good mechanical properties) is necessary. The paper shows that pumice is an equally gifted inert and that structural elements made with this material can achieve the same performances or better ones than those made with expanded clay, whose use is well-established in the market.

In this paper the mix design study carried out for obtaining the qualified concrete strength and the geometric research made to guarantee units compliant with the prescriptions of the codes in force will be described. Hence the mechanical behaviour of masonry prisms in lightweight concrete made of pumice and expanded clay, loaded with in-plane forces, will be given and finally the experimental results will be discussed.

2 MIX DESIGN FOR THE CONCRETE

The lightweight structural concrete considered here is obtained by substituting ordinary aggregate with pumice. In order to obtain a concrete with proper strength, the suggestions of the American and European codes (EC2, EC6 [15], ACI 530, ACI 211 [16], ACI 213) regarding structural lightweight concrete were considered.

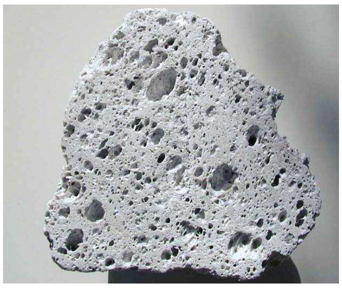


Figure 1: Cross-section of a pumice granule

After different size distributions for pumice grains were tested, grains having a size in the range 3.1-11.2 mm, whose granulometric curve can be seen in Figure 2, were used. No grains with higher dimensions were considered due to the reduced web thickness of the units.

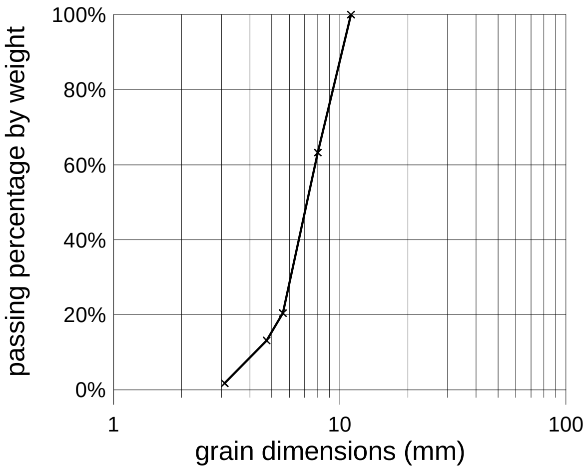


Figure 2: Granulometric curve of pumice grains (3.1-11.2 mm)

The components for the concrete casting were the following: cement type Portland 425, water, pumice grains having size between 3.1 and 11.2 mm, and crushed siliceous sand.

The percentages of the inerts in the mix were 58.5 % of sand, 27.5 % of 3-8 pumice aggregates (size between 3.1 and 8 mm), and 14 % of 8-12 pumice aggregates (size higher than 8 mm up to 11.2 mm).

In order to obtain a straightforward compressive strength value, six cubic specimens having edge size 150 mm were cast for each mixture. Compressive tests were made at the 3rd, 7th and 28th days to verify the achievable strengths of mixtures in a short period, in relation with the possibility of form removal. The results, reported in Table 1, show that there is little difference with the ordinary mixture based on the use of expanded clay and suggest the actual possibility of using pumice for structural concrete.

Days	Pumice concrete (MPa)	Expanded clay concrete (MPa)
3	14.55	15.35
7	16.22	17.89
28	22.05	23.0

Table. 1 Average values of compressive strength

3 EXPERIMENTAL INVESTIGATION ON REINFORCED MASONRY PRISMS

To compare the performance of pumice and expanded clay as lightweight inerts for reinforced lightweight concrete masonry, cyclic tests were carried out on masonry prisms. In this connection it was necessary to design, in the first place, pumice concrete units able to meet the requirements quoted in the recent technical codes.

The designed units are shown in Figure 3. The following external sizes were set: width 250 mm, length 488 mm, height 188 mm. The unit area was equal to 1220 cm^2 while the hole area was 39% of the gross area. In this connection, the central holes to be used for the reinforcement had sizes equal to 100 x 100 mm. The other holes were uniformly distributed and their sizes were designed on the basis of practical matters.

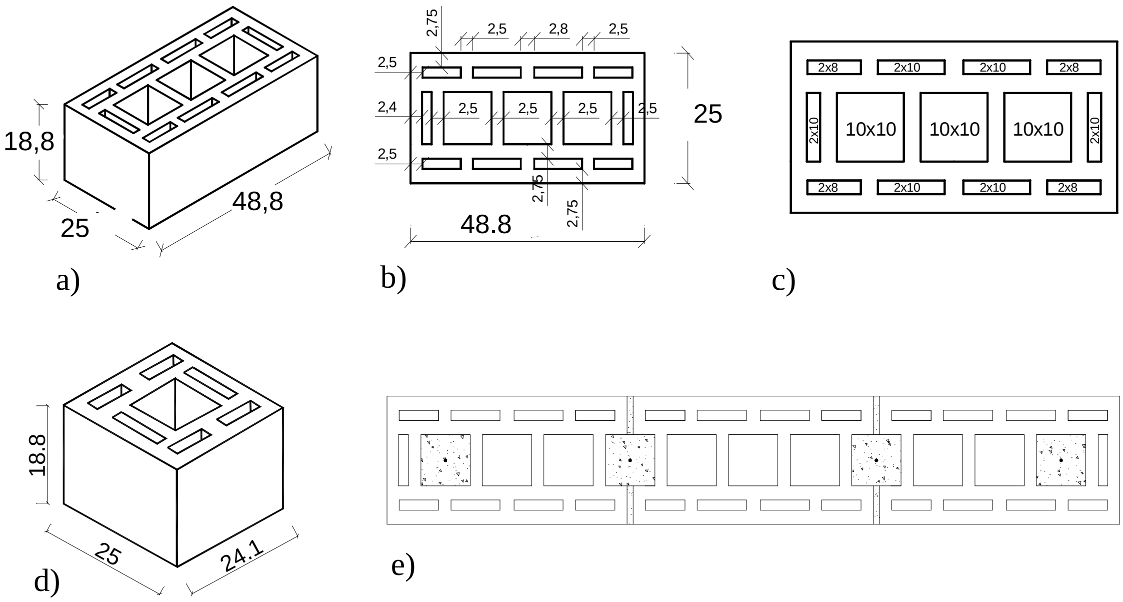


Figure 3: Unit geometry (cm): a) external dimensions; b) tiles dimensions; (c) internal cells; (d) half a block; (e) units arrangement in a course.

Compressive tests on pumice units gave an average strength value equal to 8.4 MPa along the hole direction and equal to 1.9 MPa in the orthogonal direction. These compressive strengths are consistent with code requirements.

The strength values of units manufactured using expanded clay in place of pumice were equal to 9.0 MPa (along the direction of the holes) and 2.1 MPa (orthogonally to the direction of the holes).

The geometrical characteristics of the prisms are shown in Figure 4. To constrain the test specimens the prisms were assembled on a concrete base and a stringcourse was set up on the specimen top to uniformly distribute the horizontal and vertical loads.

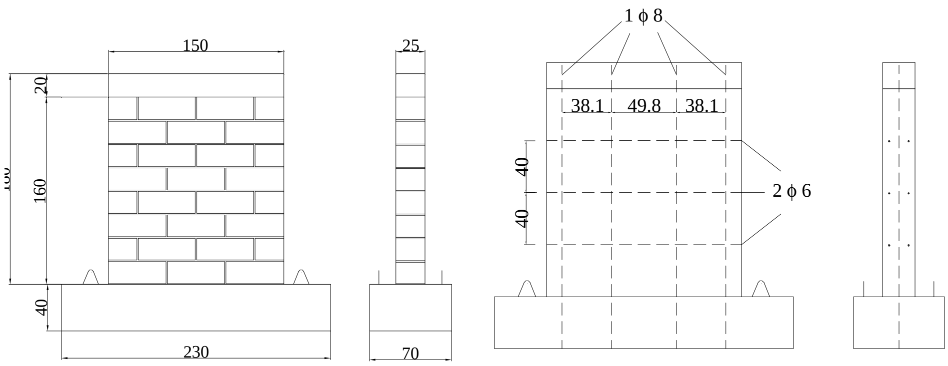


Figure 4: Specimen geometry and reinforcement layout: front and side views

Vertical and horizontal joints had nominal thickness equal to 12 mm. The mortar used had a 1:3 binder/sand volume proportion and a water/cement ratio equal to 0.5. Compressive tests on mortar specimens revealed an average strength higher than 12 MPa.

Improved bond steel rebars with characteristic yielding strength of 450 MPa were used for specimen reinforcement.

Six specimens were set up, three manufactured with lightweight concrete units having expanded clay inert (EC) and three with lightweight concrete units having pumice inert (P).

Figure 5: Specimens manufacturing

The number and distribution of steel reinforcement (reported in Table 2) were chosen to conform to the following scheme: horizontal reinforcement area greater than 0.4 ‰ of the product of height and thickness of panel, rebar diameter greater than 5 mm and spacing lower than twice the panel thickness.

Reinforcement	Rebars number and diameter	Geometrical reinforcement ratio
Horizontal	6Φ6	0.05 %
Vertical	4Φ8	0.05 %

Table 2 Reinforcement details

The loading conditions were designed to simulate those of a first-storey panel in a building of about six or seven floors. A constant vertical load of 700 kN, corresponding to an average stress equal to 1.6 MPa, and a cyclic horizontal load having amplitude increasing from 60 kN up to the specimen capacity, were applied on each specimen by means of the test setup shown in Figure 6.

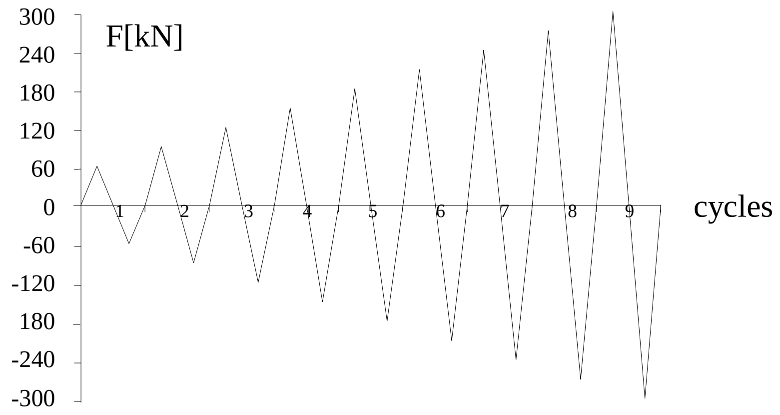


Figure 6: Horizontal loading pattern

Two mutually sliding steel crossbeams, one tied down to the panel (beam B) and the other one countering the vertical load (beam A) were used to guarantee the horizontal direction of the cyclic loading. A loading cell with a nominal capacity of 500 kN was connected by an articulated joint to beam B and to the contrast frame.

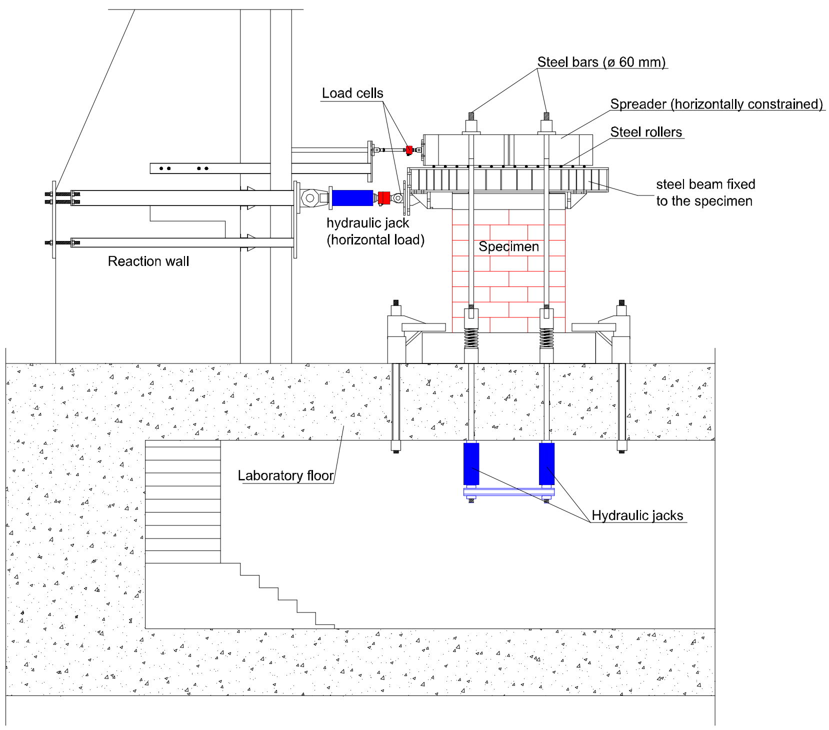


Figure 7: Scheme of the experimental setup and testing frame

Millesimal comparators with ±13.5 mm range, six per face, measured the strains on the two sides of the specimens as shown in Figures 8 and 9, while two more were placed on the base of the panel to monitor the tie-down effectiveness. The displacement of the top of the panel was measured by an electronic rule having a measurement range of ±75 mm.

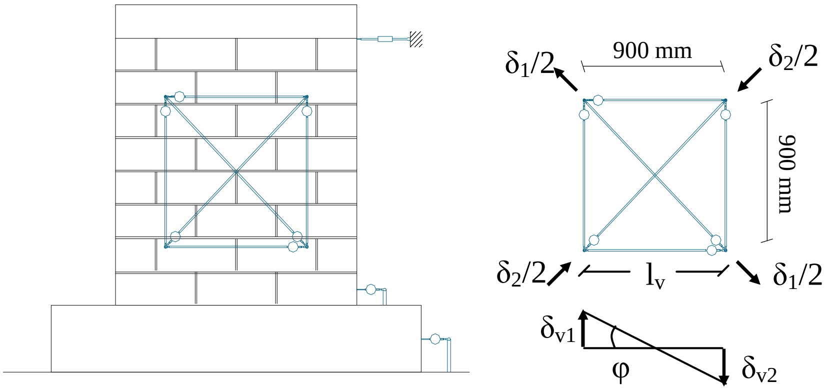


Figure 8: Positioning and gauge lengths of the measuring devices

Figure 9: Loading and measuring instrumentation

4 EXPERIMENTAL RESULTS

In Figure 10 the horizontal load vs. displacement curves, measured at the panel top, of the pumice specimens, are reported.

The curve shapes are almost linear for the first cycles and then show a tapered feature typical of fragile materials. The slope of the unloading branch, lighter than that of the loading one, is connected with cracks which close during load inversion. The cycles show very low dissipation also due to the low reinforcement geometric ratio and to the absence of localized reinforcement. The cracking patterns of these specimens are displayed in Figure 12.

In Figure 11 and Figure 13 the force vs. displacement curves and the cracking patterns of the panels manufactured using expanded clay lightweight concrete are reported. It can be noticed that the branch shapes and strength and displacements values are similar to those of the specimens manufactured by using pumice, as are the collapse mechanisms.

All the experimental tests were stopped when a noticeable decrease in strength was measured, an event due to the crushing of the external unit tiles caused by excessively high vertical stress. On the other hand, the diagonal cracking process did not imply a sudden strength decrease because of the reinforcement capacity of redistributing stress.

In both the expanded clay and the pumice specimens, due to the flexural behaviour, the most external reinforcing bars yielded. Hence this could imply that an addition of vertical reinforcement at the sides of the panel could modify the failure mechanism allowing shear failure to happen first.

Regarding dowel action all the tests showed that the vertical reinforcement was sufficient to avoid bed joint sliding.

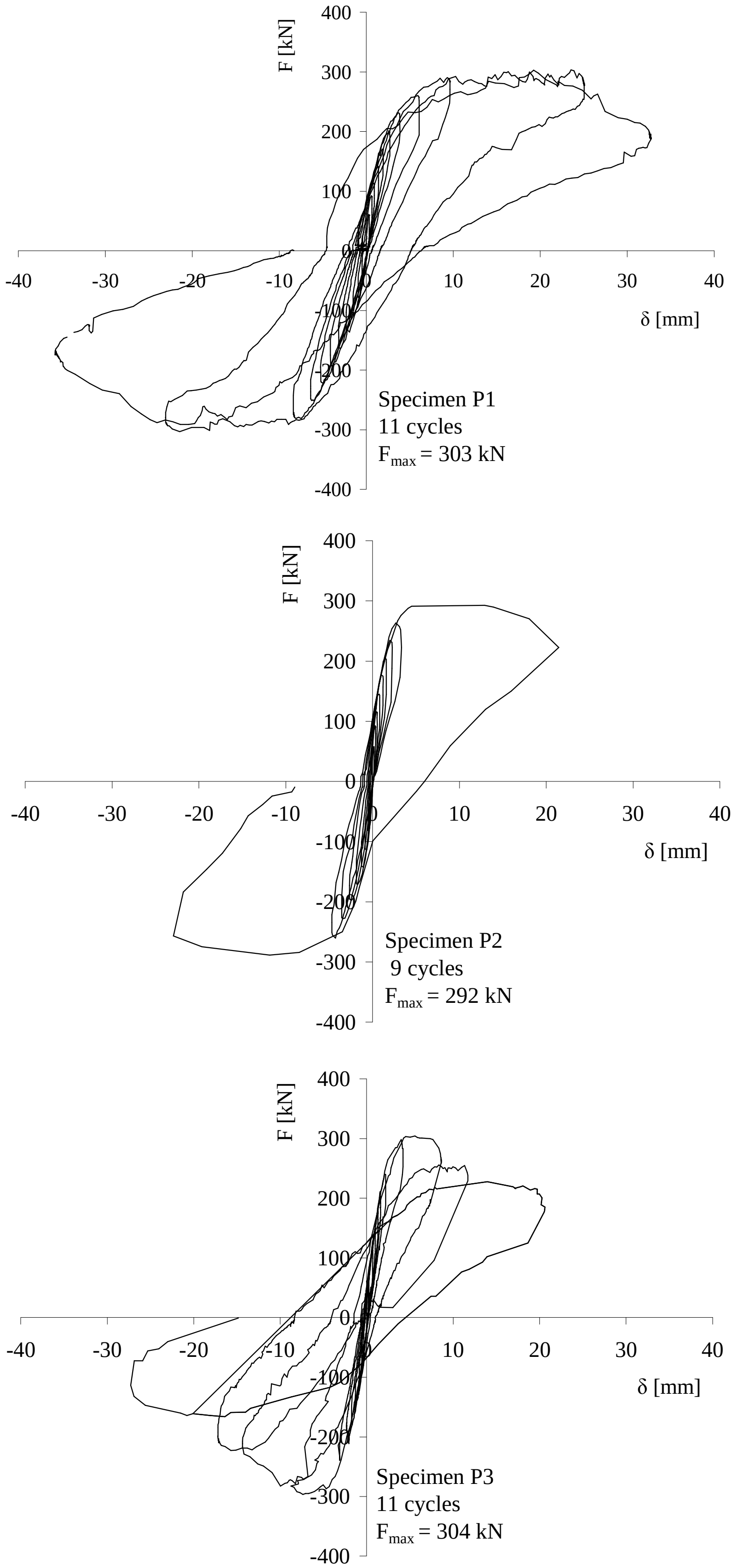
For both type of specimens the horizontal reinforcement, embedded in the bed joints every two running bonds, was sufficient to guarantee confinement and to redistribute tangential stresses. This is shown by the presence of several diagonal cracks (ductile shear failure mechanism), unlike unreinforced masonry in which a single crack usually runs along the diagonal dimension (fragile shear failure mechanism).

Horizontal force-panel top displacement of P and EC specimens, reported in Figures 10 and 11, show evidences of good resistance to damage until the 7th cycle (maximum load equal to 240 kN), which is when a noticeable stiffness decay occurs.

All the experimental strengths of prisms and component, mortar and units, are reported in the following Table 3.

Data	**Pumice**			**Expanded clay**		
Mean unit strength		8.4	MPa		9.0	MPa
Mean mortar strength		12	MPa		12	MPa
Axial load		700	kN		700	kN
Experimental wall lateral strength	Specimen			Specimen		
	P1	303	kN	EC1	274	kN
	P2	292	kN	EC2	303	kN
	P3	304	kN	EC3	294	kN
	Average	**300**	kN	Average	**290**	kN

Table 3: Experimental maximum horizontal forces



a)

b)

c)

Figure 10: Force vs displacement curves, pumice specimens: a) P1; b) P2; c) P3

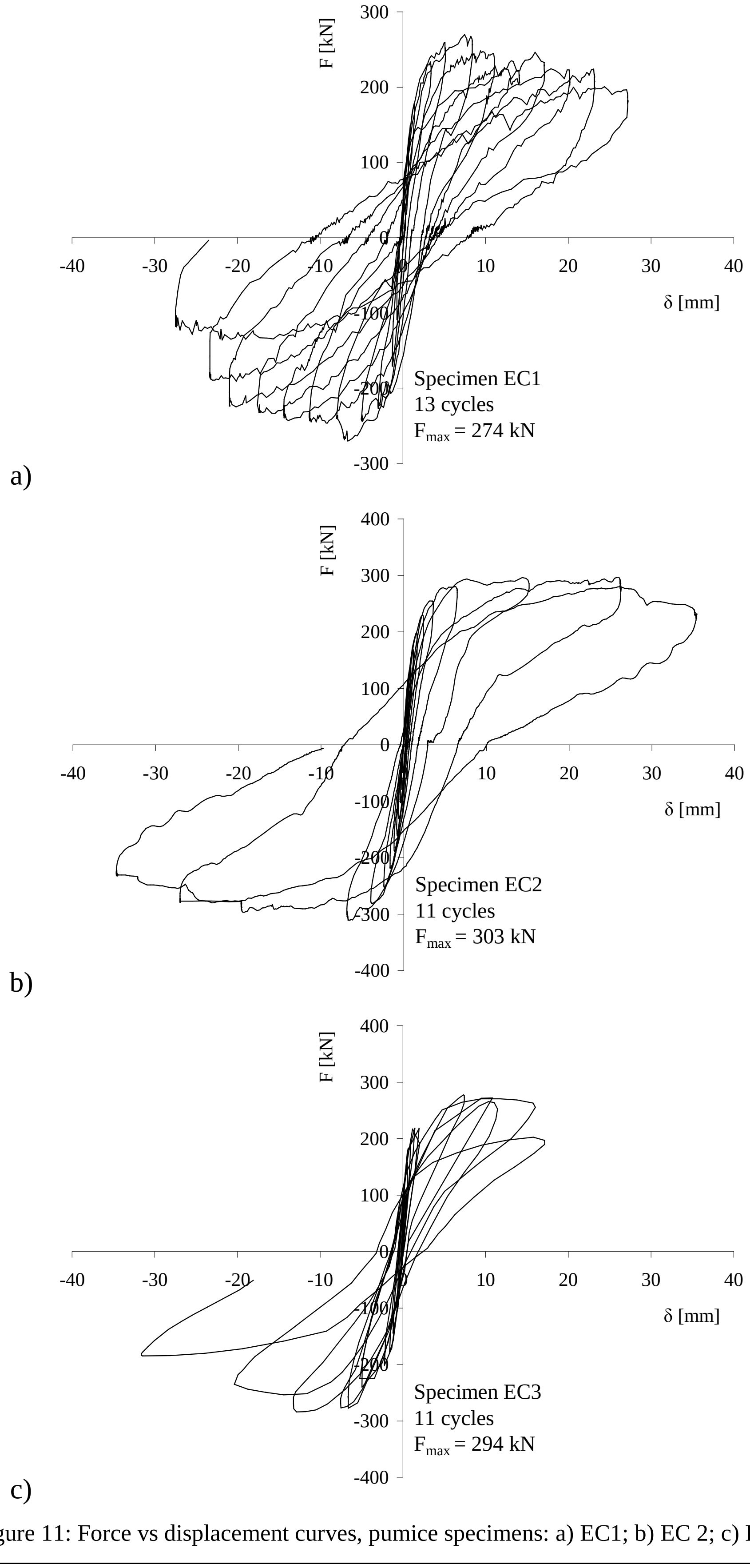


Figure 11: Force vs displacement curves, pumice specimens: a) EC1; b) EC 2; c) EC 3

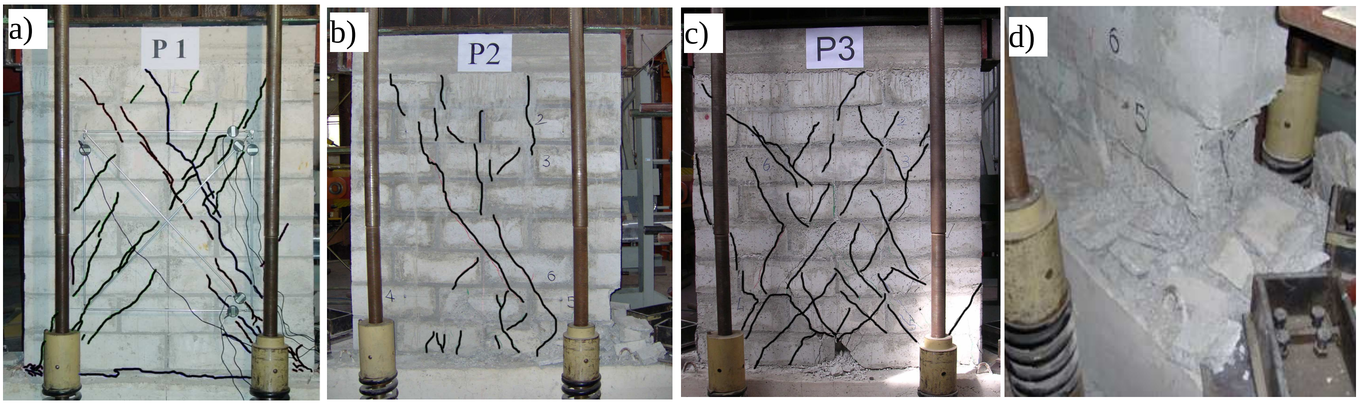


Fig. 12Cracking patterns of specimens P1 (a), P2 (b), P3 (c) and crushing failure of panel P2(d).

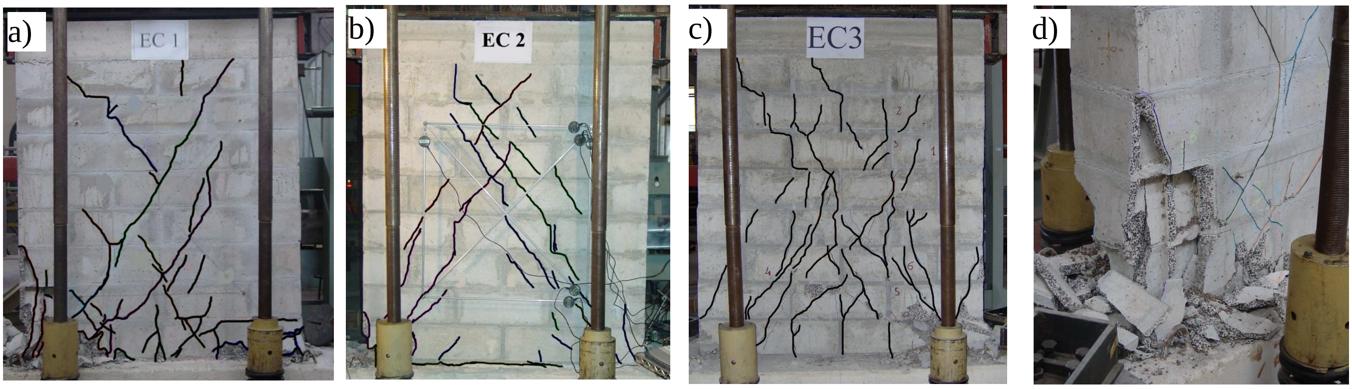


Figure 13: Cracking patterns of specimens EC1 (a), EC2 (b), EC3 (c) and crushing failure of panel EC1(d).

5 CONCLUSIONS

The experimental activity described in this paper has showed that pumice, as expanded clay, is a good material for structural applications.

In fact, it is possible manufacturing lightweight concrete having proper mechanical strength and structural elements, such as units and masonry panels having strength, collapse mechanisms and energy dissipation not differing from nominally identical structural elements made using expanded clay.

Specifically, reinforced masonry panels were tested under lateral and vertical loads and all the tested structural elements revealed that the use of pumice for manufacturing concrete units is not disadvantageous with respect of the use of expanded clay.

On this basis pumice, which is an advantageous material for the low production cost, can really be an alternative to expanded clay, at least for the type of structural elements studied.

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