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Compression tests of cement-composite bearing pads for precast concrete connections

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Abstract

A cement-based material is developed to produce bearing pads for precast concrete connections. The material consists of sand mortar that includes additions of soft aggregate, latex, and short fibres to obtain greater deformability and high toughness. The additions used in this study were vermiculite, styrene–butadiene latex and either PVA or glass fibres. The proposed material is tested in the form of cylindrical samples, bearing pads under uniform load and bearing pad strips under concentrated loads. Based on the experimental results, the main conclusions are: (a) the largest amount of fibres should be used, within the limits of mixture workability, mainly for enhancing the bearing pad capacity to accommodate surface irregularities, (b) glass fibres perform better than PVA fibres when the material is subjected to concentrated loads, and (c) bearing pad thickness beyond 10 mm is of limited value.

Keywords: Bearing pad; Precast concrete; Connections; Cement-based material

1. Introduction

This paper presents a study of bearing pads, made with cement-based material, for precast concrete connections subjected predominantly to compressive loads. This type of connection may be: (a) by direct contact, or (b) by insertion of material between the elements. Due to the low tensile strength and quasi-brittle behaviour of the concrete, direct contact is not often used.

The material inserted between the precast elements can be flexible or effectively rigid. The rigid material may consist of metallic elements embedded in the components, so that the contact would be through these metallic elements, whereas the flexible material may be in the form of elastomer bearing pads. The most common elastomer is polycloroprene. As this material is flexible, it compensates for irregularities of the concrete surface, which promotes a more uniform distribution of stresses, and allows for relative movements between the precast elements. The ability to accommodate relative movements is essential since length changes in the elements, such as those due to thermal effects, would otherwise introduce large forces into the structure. The disadvantages of this type of material include its higher cost, lower durability compared to the concrete components, low fire resistance and relatively low compressive strength.

It is also possible to place other materials between the precast elements, such as the placement of seat mortar and the pouring or injection of infill mortar (grout). Controlling the dimensions is difficult in the case of seat mortar and the strength would also be relatively low. In the grouting process, the components are assembled leaving a space to be filled by either dry-packed mortar or non-retractile grout. For either case, additional fieldwork is required compared to the placement of ready-made products.

The primary objective is to develop a cement-based material with characteristics of greater deformability and higher toughness, compared to ordinary cement-based

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materials, to be used between precast concrete components. The material can be obtained from Portland cement and sand mortar incorporating the following ingredients: (a) soft aggregate or an additive to entrain air in the mixture, (b) latex, and (c) short fibres.

The soft aggregate (e.g., vermiculite) and/or air entraining agent significantly increase the deformation capacity of the material in the hardened state. The addition of latex to mortars improves the following properties of the material in the hardened state: durability, bending and impact strength, permeability and resistance to both freezing and abrasion [8]. Due to the presence of surfactants used in the production of the latex, a significant amount of air can be incorporated into the mixture, also increasing the deformation capacity of the material. The addition of short fibres to the concrete generally improves the impact and fatigue strength of the hardened material and increases its toughness [1]. In large quantities, the fibres reduce the workability of the mixture and can incorporate air into the hardened material, reducing its elastic modulus.

In order to analyze the applications of bearing pads made with this cement-based material, the bearing connections between precast concrete elements can be divided into two groups. Group 1 is comprised of beams bearing on columns (beam-to-column connections), and slabs bearing on beams or walls (slab-to-beam and slab-to-wall connections). Group 2 is comprised of the connections between elements of walls or columns (wall-to-wall and column-to-column connections) and connections between these elements and the foundation (wall-to-foundation and column-to-foundation connections).

For group 1 connections, the compressive stresses over the area of contact are not very high, and it is necessary to allow for relative rotation between the contact surfaces. As the proposed material is practically a variation of the concrete, it has the advantage of good durability and fire resistance. Compared to elastomeric bearing pads, bearing pads of this material would not allow the same degree of horizontal displacements between the contact surfaces and, thus, would not relieve stresses due to length variations of the supported element. To overcome this problem, the proposed material can be used on only one end of the supported element, which would still be a significant improvement. Alternatively, the proposed material can be used on both ends of the supported element. The associated restraint forces introduced into the structure can often be accommodated without significant differences in the design of the structural elements.

For group 2 connections, the compression stresses are high, and it is not necessary to allow for rotations between the connecting elements. Filled grout is normally used for this type of connection. In this case, the advantages of using the proposed material include facilitating the fabrication process in the field and the possibility of increasing the load capacity of the connection.

Thus, the use of the proposed bearing pad is advantageous for a variety of bearing connections, including group 1 and group 2 type connections described here. El Debs et al. [4] present applications of this material to beam-to-column connections and wall-to-wall connections in precast concrete systems.

This paper reports on the characteristics of the proposed material, as determined from tests of cylindrical specimens and bearing pads. For the bearing pads, two types of compression tests were performed: (a) bearing pads under uniform load, and (b) bearing pad strips under concentrated load.

2. Characteristics of the proposed material

2.1. Materials used

Early strength Portland cement and river sand, with maximum diameter of 2.4 mm, were used in this research. The soft aggregate was small-sized (maximum diameter of 2.4 mm) thermo-expanded vermiculite with a specific mass of 0.173 kg/dm^3. The latex was styrene–butadiene polymer, SB 112, with a solid amount of 50% and specific mass of 1.02 kg/dm^3 at 25 °C. Rhodia of Brazil, Ltd., supplied the latex and its specifications.

Two types of fibres were used: (a) polyvinyl alcohol (PVA) fibre and (b) Cem-FIL glass fibre. The PVA fibres (12 mm in length, equivalent diameter of 0.2 mm and specific mass of 1.3 kg/dm^3) were employed in previous research of El Debs and Naaman [7] and El Debs and Ekane [6]. The glass fibres were also 12 mm long with a diameter of 0.014 mm, as indicated by the manufacturer, and specific mass of 2.55 kg/dm^3. A superplasticizer was used for the mixtures with a great amount of vermiculite. This additive was SP 1, SPA type supplied by MBT of Brazil.

2.2. Tested mixtures

The compressive strength, tensile strength by split-cylinder test and modulus of elasticity were determined for several mixtures. The basic mixtures were chosen based on the previous studies of Barboza et al. [2] and El Debs et al. [5], in which a cement/aggregate ratio of 0.3 and a water/cement ratio of 0.4 were fixed to obtain a minimum compression strength of about 20 MPa. The water amount in the mixtures takes into account the water in the latex.

Table 1 shows the mixtures used for the cylindrical specimens. They were chosen based on the following aspects:

(a) A mixture with 5% of vermiculite, 3% of PVA fibre and 30% of latex was fixed as the basic mixture, whereas the other mixtures were variations of this basic one.
(b) The proportion of vermiculite and sand was limited to 50%. In Barboza et al. [2] this proportion reached 80%, but compression strength was significantly reduced.

Table 1
Tested mixtures

Mixture	Vermiculite (1) (%)	Fibres (2) (%)	Latex (3) (%)
REF	0	0	0
V0P2L30	0	2	30
V0P2L40	0	2	40
V0P3L30	0	3	30
V0P4L30	0	4	30
V5L30	5	0	30
V5P1L30	5	1	30
V5P2L20	5	2	20
V5P2L30	5	2	30
V5G2L30	5	2	30
V5P3L40	5	3	40
V5P3L30	5	3	30
V5G3L30	5	3	30
V5P4L30	5	4	30
V10P3L30	10	3	30
V25P2L30 (4)	25	2	30
V25G2L30 (4)	25	2	30
V25P3L30 (4)	25	3	30
V50G2L30 (4)	50	2	30

(1) Vermiculite amount as a percentage of the total aggregate mass. (2) Fibre amount as a percentage of the composite volume (fibre volumetric rate in %). (3) Latex styrene-butadiene amount as a percentage of cement mass. (4) Mixtures with 1% of superplasticizer with respect to cement mass.

(c) In principle, the greater the amount of fibres included in the mixture, within appropriate limits, the better the material performed. Previous studies indicate that volume fractions of 3–4% of PVA fibres can be reached. The effects of these and other volume fractions are analyzed in this study.
(d) Glass fibres were included mainly because they are more commercially available in Brazil. As these fibres provide almost the same workability as PVA fibres, they were used in the same amount.
(e) The amount of 30% of latex was employed in early studies based on the information that larger amounts decrease the compression strength. Other amounts, 20% and 40%, were also used to analyze the influence of this variable.
(f) The superplasticizer, in a ratio of cement amount, was used in the mixtures with 25% and 50% of vermiculite.
(g) A mixture without vermiculite, latex and fibre was included to serve as a reference.

2.3. Strength and modulus of elasticity

For each chosen mixture, tests of 50 × 100 mm cylindrical specimens were carried out to determine the compressive strength (four specimens), the tensile strength by split-cylinder test (four specimens) and the modulus of elasticity (three specimens). The average compressive and tensile strengths for each mix are shown in Figs. 1 and 2, respectively.

The modulus of elasticity was determined by two clip-gauges fastened on diametrically opposite positions on

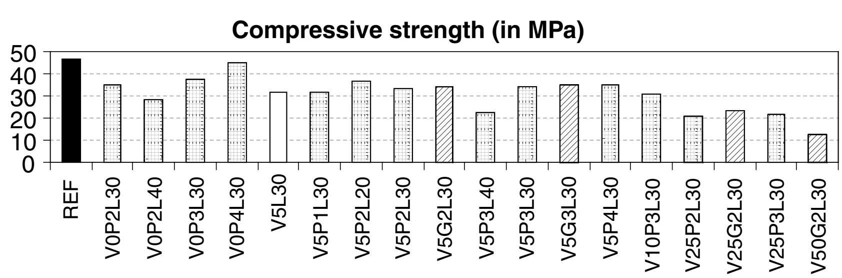


Fig. 1. Compressive strength (average of four samples).

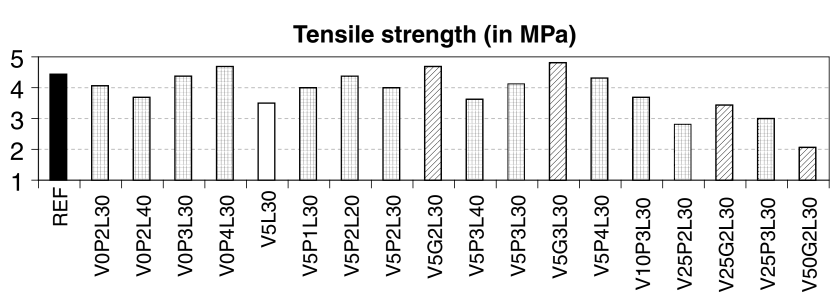


Fig. 2. Tensile strength by split test (average of four samples).

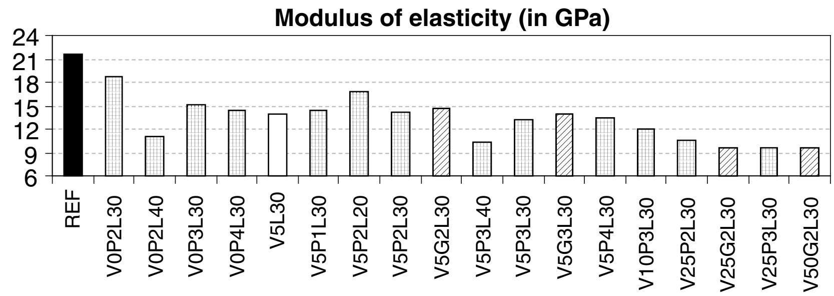


Fig. 3. Modulus of elasticity (average of three samples).

the sample. An adjustment with polynomial of second degree of the stress vs. strain curve was made, using the average of the specific deformations measured. From the adjusted equation of the curve, the modulus of elasticity was obtained by the tangent at the origin. Fig. 3 presents the modulus of elasticity from the average of three samples.

The values of compressive strength, tensile strength and modulus of elasticity indicate that: (a) a larger amount of vermiculite decreases the modulus of elasticity, but also decreases the compressive and tensile strengths; (b) if a lower limit of 20 MPa compressive strength is established, the amount of vermiculite cannot exceed 25% of the sand mass; (c) latex reduces the modulus of elasticity, but also reduces the compressive strength and tensile strength; (d) the reduction of strength due to latex addition is dramatic when the amount of latex reaches 40%, suggesting a limit of 30% for the latex amount; (e) the amount of fibres had little consequence on the modulus of elasticity and tensile strength, while for the compressive strength it was insignificant as well; and (f) only for tensile strength, a perceptible difference can be observed due to the type of fibre, where glass fibre presents better results. Discarding the outlying results (i.e., for the mixtures without vermiculite, with 50% of vermiculite, with 40% of latex, and with 20% of latex), the following values are representative of the proposed material: 20–45 MPa for compressive strength, 3.0–4.5 MPa for tensile strength and 10–15 GPa for modulus of elasticity.

3. Bearing pads under uniform load

3.1. Test description

The bearing pads are subjected to a nominally uniform load applied by the plates of a universal test machine. The objective of this test is to determine the deformation capacity of the bearing pads when subjected to this type of loading.

In addition to the bearing pads of the proposed material, elastomer bearing pads were included in this study because they are usually employed in beam-to-column bearing connections. Two types of wood bearing pads were also included as they are generally used in the storage of precast elements. The first type (Pinus Taeda) is a soft wood, whereas the second type (Eucalyptus Citriodora) has an intermediate rigidity. The elastomer and wood bearing pads provide a reference for the analysis of the bearing pads with the proposed material.

The main variables for these tests were the mixture, the bearing pad thickness and the bearing pad area. The thicknesses were 5 mm, 10 mm and 20 mm. The areas were 150 mm × 150 mm and 100 mm × 100 mm. Tables 2 and 3 present the mixtures of 150 mm × 150 mm and 100 mm × 100 mm bearing pads, respectively. From these tables, it can be noticed that: (a) the vermiculite amount ranges from 5% to 25%, (b) the latex amount was fixed at 30%, and (c) the amount of fibres varied from 2% (for 25% vermiculite amount) to 4% (for 5% vermiculite amount), but it was set at 3% in most cases.

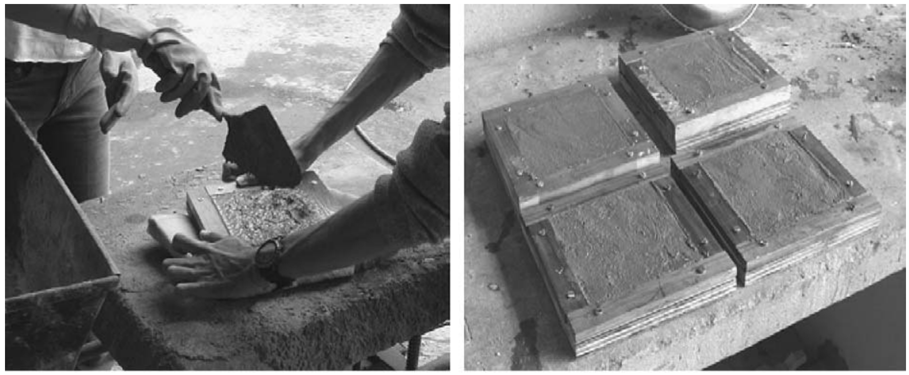
Bearing pad production is quite easy. The material is mixed by hand and wood moulds are filled up on one side. The photographs in Fig. 4 show some details of bearing pads manufacture. In the day after casting, the bearing pads were placed in a wet chamber and removed five days later. Seven days after the casting, the bearing pads were tested.

Table 2
Mixtures used in the 150 mm × 150 mm bearing pads for uniform load testing

Mixture	Vermiculite (%)	Fibres (%)	Latex (%)
V5P2L30	5	2	30
V5G2L30	5	2	30
V5P3L30	5	3	30
V5G3L30	5	3	30
V5P4L30	5	4	30
V10P3L30	10	3	30
V25P2L30	25	2	30
V25G2L30	25	2	30

Table 3
Mixtures used in the 100 mm × 100 mm bearing pads for uniform load testing

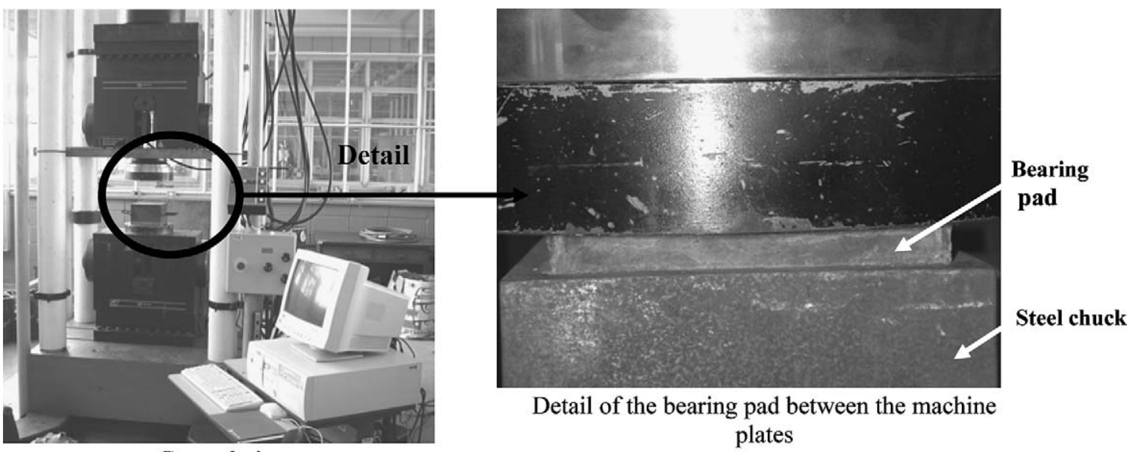
Mixture	Vermiculite (%)	Fibres (%)	Latex (%)
V5P3L30	5	3	30
V25P2L30	25	2	30
V25G2L30	25	2	30



Pouring the mixture into the mould over shaking table

Bearing pads after finishing the upper side

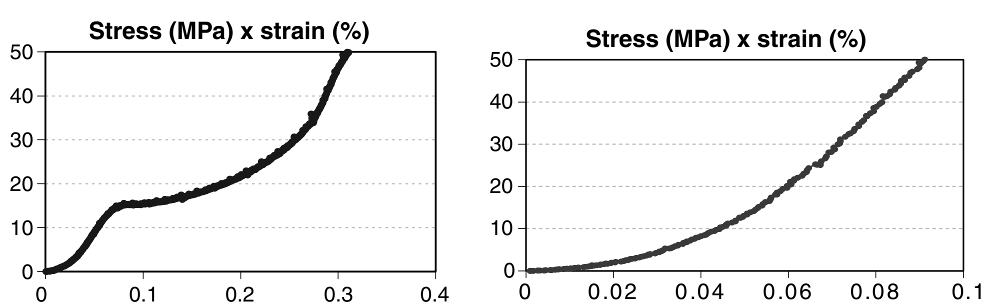
Fig. 4. Some details of bearing pad manufacture.



General view

Detail of the bearing pad between the machine plates

Fig. 5. Set-up for uniform load test.



(a) (b)

Fig. 6. Typical stress vs. strain curves. (a) Bearing pad of 100 mm × 100 mm × 20 mm mixture of V25P2L30. (b) Bearing pad of 100 mm × 100 mm × 20 mm mixture of V5P3L30.

The tests were performed in an Instron universal machine with 2500 kN compression capacity. Fig. 5 shows a general view of the test and the detail of the cushion between a machine plate and a steel chuck. The load was applied at 5 kN/s rate. Two basic types of stress vs. strain curves were observed, as shown in Fig. 6. The curve shown in Fig. 6a represents 25% vermiculite mixtures and the curve in Fig. 6b is representative of the other mixtures. From the stress vs. strain curves, the bearing pad rigidity could be determined by the expression:

$$R = \frac{\sigma}{\Delta h/h} \tag{1}$$

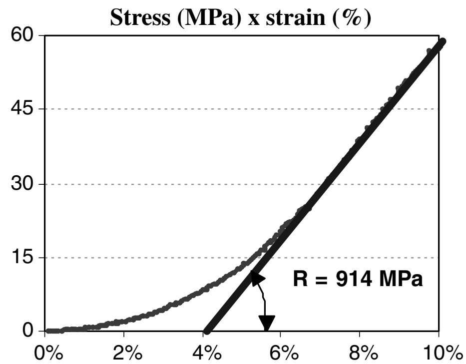


Fig. 7. Bearing pad rigidity evaluation (100 mm × 100 mm × 20 mm – mixture V5P3L30).

where σ is the applied stress; h is the initial bearing pad thickness; and Δh is the bearing pad deformation (change in thickness). As the initial portion of the curves is affected by the seating of the bearing pad, the bearing pad rigidity was determined by the approximately linear portion of the curve, as shown in Fig. 7.

3.2. Results

Taking the average values for two samples, Tables 4 and 5 present the bearing pad rigidity and the bearing pad deformation for a stress level of 25 MPa. It should be pointed out that: (a) the load was applied until 1800 kN for the 150 mm × 150 mm size bearing pads, corresponding to a stress of 80 MPa since the bearing pads are confined between the machine plates; (b) the stress of 25 MPa was fixed to compare the bearing pad deformation; and (c) the bearing pad deformation included the initial branch of the curves as shown in Fig. 7. Figs. 8 and 9 show the bearing pad rigidity for 10 mm of thickness and area of 150 mm × 150 mm and 100 mm × 100 mm, respectively.

Table 4
Rigidity and deformation of the 150 mm × 150 mm bearing pads

Mixture	Rigidity (MPa)			Deformation (mm) at stress of 25 MPa		
	$h = 5$ mm	$h = 10$ mm	$h = 20$ mm	$h = 5$ mm	$h = 10$ mm	$h = 20$ mm
V5P2L30	224	442	724	1.360	1.490	1.760
V5G2L30	228	440	731	1.350	1.470	1.780
V5P3L30	240	447	728	1.390	1.540	1.800
V5G3L30	244	453	734	1.410	1.550	1.790
V5P4L30	256	461	750	1.440	1.650	1.840
V10P3L30	202	337	531	1.690	1.840	2.000
V25P2L30	165	226	402	1.850	2.390	3.970
V25G2L30	169	224	410	1.940	2.410	4.150
Elastomer	–	73	38			
Wood 1	–	68	126			
Wood 2	–	144	283			

Table 5
Rigidity and deformation of the 100 mm × 100 mm bearing pads

Mixture	Rigidity (MPa)			Deformation (mm) at stress of 25 MPa		
	$h = 5$ mm	$h = 10$ mm	$h = 20$ mm	$h = 5$ mm	$h = 10$ mm	$h = 20$ mm
5P3L30	–	558	914	–	1.620	1.850
V25P2L30	–	315	352	–	2.590	5.210
V25G2L30	–	326	377	–	2.680	5.190
Elastomer	–	102	47			
Wood 1	–	89	159			
Wood 2	–	189	328			

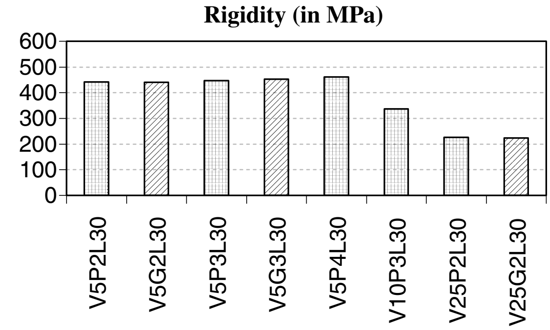


Fig. 8. Rigidity of 150 mm × 150 mm × 10 mm bearing pad.

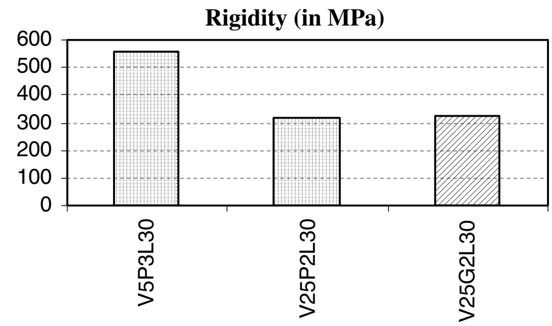


Fig. 9. Rigidity of 100 mm × 100 mm × 10 mm bearing pad.

3.3. Analysis

From the results in Tables 4 and 5 and in Figs. 8 and 9, it can be observed that: (a) as expected, the bearing pad rigidity decreases with the increase of vermiculite amount; (b) comparing mixtures V5P2L30, V5P3L30, and V5P4L30 for the bearing pad with 150 mm × 150 mm area, it can be noted that the fibre amount does not have a significant influence on rigidity, (c) the type of fibre practically does not affect the bearing pad rigidity, when a comparison of mixtures V25P2L30 and V25G2L30 is done; and (d) when the thickness increases the bearing pad rigidity increases for the proposed material and wood, but for the elastomer bearing pad the opposite occurs.

In fact, there is a significant difference when one compares the deformed shape of the bearing pad for the different materials. The exposed faces of the bearing pads of the proposed material remain planar. This behaviour is quite different from that of the elastomer bearing pad in which the exposed faces bulge convex outward. In fact, the elastomer bearing pad has a peculiar behaviour. It is associated with the shape factor that corresponds to the relationship between the support area and the lateral area, given by

$$\beta = \frac{(a \cdot b)}{2h(a+b)} \tag{2}$$

where a and b are the dimensions of the support area, and h is the bearing pad thickness.

The shape factors for the bearing pad of 150 mm × 150 mm are 3.75 for the thickness of 10 mm and 1.87 for the thickness of 20 mm. For 100 mm × 100 mm bearing pad, the shape factor is 2.5 for the thickness of 10 mm and 1.25 for the thickness of 20 mm. The rigidity of the elastomeric bearing pad is practically proportional to its shape factor. This verification is in accordance with Vinje [9], who concluded that the deformation increases with a decrease in the shape factor.

For the proposed bearing pad, the rigidity was expected to be independent of the bearing pad thickness, since the exposed faces remain planar. However, the bearing pad rigidity increases with the increasing of the thickness. This fact can be justified by strain concentrations near the pad surface, due to irregularities in the surface associated with the production process.

The relationship between bearing pad rigidity and modulus of elasticity for a bearing pad area of 150 mm × 150 mm and thickness of 10 mm is shown in Fig. 10. For the various material designs considered, the R/E ratio ranges from 0.033 to 0.020 and the inverse relationship ranges from 30 to 50. These values indicate that strain concentrations near the surface can strongly affect the specific deformation of the material. For this reason, the deformability of precast concrete joints on wall-to-wall connections can be given independent of joint thickness, as presented in Bljuger [3].

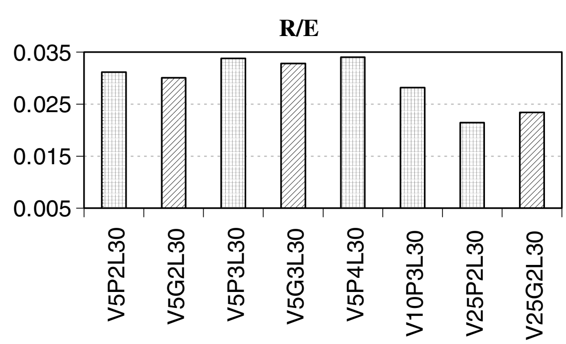


Fig. 10. Relationship of the bearing pad rigidity and the modulus of elasticity for 150 mm × 150 mm × 10 mm bearing pads.

4. Bearing pad strips under concentrated load

4.1. Test description

This test was conceived to evaluate the bearing pad capacity to accommodate the concentrated stresses that would occur when there are irregularities on the surface. The test consists in applying a concentrated load on a bearing pad strip and measuring the deformation and the ultimate load. A steel device with two semi-cylinders was manufactured to apply the concentrated load (Fig. 11). Two semi-cylinders were used instead of only one to facilitate the set-up of the bearing pad strips and the device between the two plates of the Versatester 30 M test machine.

The mixtures were basically the same as those used for the previous test of 150 mm × 150 mm bearing pads, but one mixture without vermiculite, fibres, and latex was included as a reference. Table 6 shows the mixtures used in this test. The experimental program included six bearing pads of 150 mm × 150 mm for each mixture, with thickness of 5 mm, 10 mm and 20 mm, which means two bearing pads for each thickness. The bearing pads were produced as presented in the previous section and also tested seven days after casting.

Table 6
Mixtures of the bearing pads for concentrated load testing

Mixture	Vermiculite (%)	Fibres (%)	Latex (%)
REF	0	0	0
V5P2L30	5	2	30
V5G2L30	5	2	30
V5P3L30	5	3	30
V5P4L30	5	4	30
V10P3L30	10	3	30
V25P2L30	25	2	30
V25G2L30	25	2	30

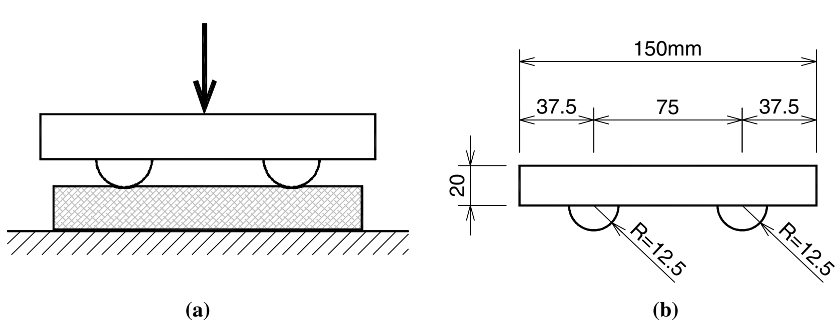


Fig. 11. Test scheme and metallic device configuration. (a) Test scheme and (b) metallic device.

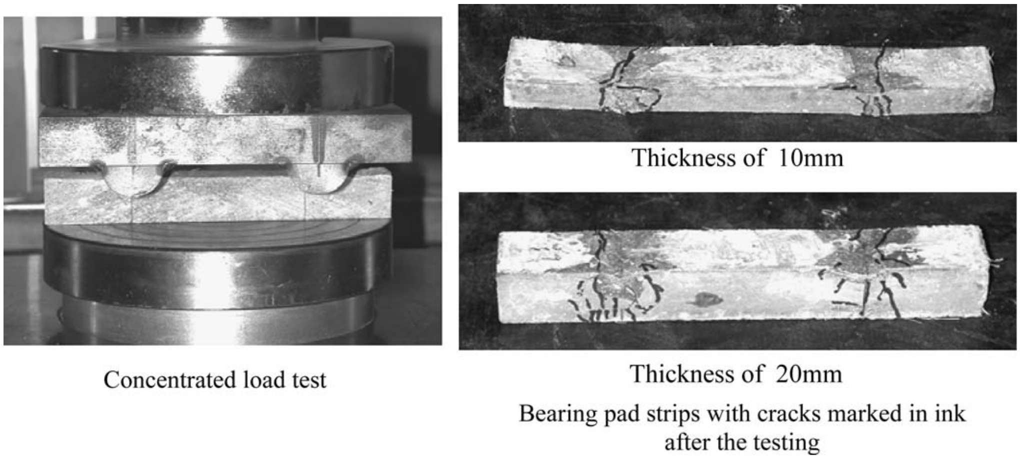


Fig. 12. Bearing pad strip test with concentrated load.

The bearing pads were sawed to produce six strips, each with a width of 25 mm. The strips were sanded in the regions of load application, to avoid the effects of surface irregularities. Then, the thickness at the load application points was measured by digital callipers. The load was applied until the material yielded. After that, the strip was removed and the thickness was measured at the same locations. The deformations were determined by the differences with the previous thickness measurements.

4.2. Results

Fig. 12 shows one strip placed within the testing device and two bearing pad strips after the tests with the visible cracks marked by ink. The bearing pad strips show several cracks, but they do not split because the fibres act to bridge the cracks. Table 7 shows the ultimate loads and the respective deformations. These values are the average of four measurements of four strips, which means the average of sixteen measurements. Fig. 13 shows the diagram of the ultimate loads, whereas Fig. 14 shows the respective deformations for the bearing pad of 10 mm thickness. The horizontal line in Figs. 13 and 14 represents the reference mixture without vermiculite, fibres or latex.

Table 7
Ultimate load and deformation for concentrated load test

Mixture	Ultimate load (kN)			Deformation (mm)		
	$h = 5$ mm	$h = 10$ mm	$h = 20$ mm	$h = 5$ mm	$h = 10$ mm	$h = 20$ mm
REF	11.00	10.50	9.50	0.0315	0.0370	0.0480
V5P2L30	21.00	20.50	20.00	0.2865	0.3690	0.4940
V5G2L30	21.25	20.50	19.50	0.3160	0.5730	0.6620
V5P3L30	22.50	21.50	21.00	0.3195	0.6110	0.7100
V5P4L30	25.50	25.00	24.00	0.4270	0.8500	1.2480
V10P3L30	19.00	18.25	17.50	0.3107	0.7165	0.8953
V25P2L30	13.00	11.00	10.00	0.7530	1.4310	1.4160
V25G2L30	16.00	15.00	13.50	0.7405	1.2660	1.5680

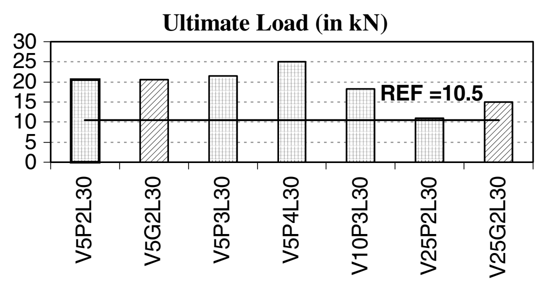


Fig. 13. Ultimate load for bearing pad of 10 mm thickness.

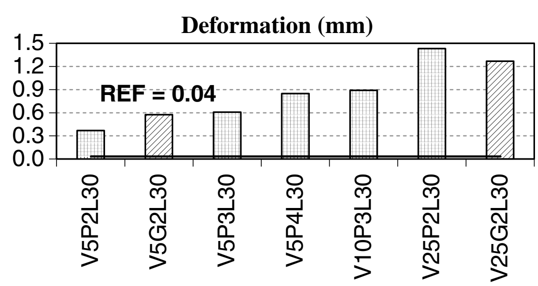


Fig. 14. Deformation at the ultimate load for bearing pad strip of 10 mm thickness.

4.3. Analysis

The results presented in Table 7 and in Figs. 13 and 14 indicate that: (a) although minor, the ultimate load decreases when the thickness increases; (b) the ultimate load decreases when the vermiculite amount increases; (c) the deformation increases when the vermiculite amount increases; (d) the ultimate load increases with the amount of fibres; and (e) the deformation increases with the amount of fibres. Comparing only the amounts of fibres (mixtures V5P2L30, V5P3L30 and V5P4L30), one can clearly notice that a larger amount of fibres results in a better performance of the bearing pads subjected to concentrated stresses.

5. Conclusions

From the results of this experimental study, the following conclusions can be drawn:

(a) The results of the cylindrical specimen tests indicate the latex amount should be limited to a maximum of 30% of the cement mass.
(b) The largest amount of fibres, within the limits of mixture workability, should be used mainly to enhance bearing pad capacity to accommodate the effects of surface irregularities.
(c) The PVA fibres and glass fibres have a similar behaviour regarding uniform load, but glass fibres perform better with regards to concentrated loads.
(d) The mixtures with vermiculite amounts of 5% and 10% present strength and deformability compatible with the intended use and allow the placement of fibre amounts of 3–4%.
(e) Additional vermiculite could be used if the fibre amounts of 3–4% could be placed with suitable workability.
(f) The proposed bearing pads are more rigid than their elastomeric counterparts by a factor of about 3–6 for the 10 mm thickness and about 8–20 for the 20 mm thickness used in this study.
(g) As the deformation is concentrated near the surface, a bearing pad thicker than 10 mm is of limited value.

These conclusions are based on a cement/aggregate ratio of 0.3 and water/cement ratio of 0.4. In addition, this research has been limited to quasi-static, monotonic loading of the test specimens. For the case of cyclic loads and/or fatigue loading, further studies are necessary.

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