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Cement-base bearing pads mortar for connections in the precast concrete: study of surface roughness

Almofadas de apoio feitas de argamassa para ligações de concreto pré-moldado: estudo da rugosidade superficial

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Abstract

Bearing pads are used in precast concrete connections to avoid concentrated stresses in the contact area between the precast elements. In the present research, the bearing pads are Portland cement mortar with styrene-butadiene latex (SB), lightweight aggregate (expanded vermiculite-term) and short fibers (polypropylene, glass and PVA), in order to obtain a material with low modulus of elasticity and high tenacity, compared with normal Portland cement mortar. The objective of this paper is to analyze the influence of surface roughness on the pads and test other types of polypropylene fibers. Tests were carried out to characterize the composite and test on bearing pads. Characterization tests show compressive strength of 41MPa and modulus of elasticity of 12.8GPa. The bearing pads tests present 30% reduction of stiffness in relation to a reference mortar. The bearing pads with roughness on both sides present a reduction up to 30% in stiffness and an increase in accumulated deformation of more than 120%, regarding bearing pads with both sides smooth.

Keywords: bearing pads; connections; precast concrete structures.

Resumo

Almofadas de apoio são usadas nas ligações de concreto pré-moldado para evitar concentração de tensões na área de contato entre os elementos. No presente trabalho, são confeccionadas almofadas em argamassa de cimento Portland e areia, que recebem ainda látex estireno-butadieno (SB), agregado leve (vermiculita termo-expandida) e fibras curtas (polipropileno, vidro e PVA), buscando tornar o material com baixo módulo de elasticidade e elevada tenacidade, comparado com a argamassa de referência, contendo apenas cimento Portland e areia. O objetivo deste trabalho é analisar a influência da rugosidade superficial nas almofadas e testar um novo tipo de fibras de polipropileno. Foram realizados ensaios de caracterização do compósito e ensaios em almofadas. Os resultados de caracterização indicam resistência à compressão de 41 MPa e módulo de elasticidade de 12,8 GPa. Os ensaios de almofadas revelam uma redução de 30% da rigidez em relação à argamassa de referência. Nas almofadas com rugosidade em ambos os lados houve uma redução de até 30% na rigidez e um aumento do afundamento acumulado de mais de 120%, em relação às almofadas com ambos os lados lisos.

Palavras-chave: almofadas de apoio. ligações. estruturas de concreto pré-moldado.

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1. Introduction

Precast elements are characterized by offering ease of manufacture. On the other hand, the need to make connections between these elements to form structures is one of the main problems to be faced in the use of precast concrete. Thus, the connections are the most important parts in the design of precast concrete structures and are of fundamental importance both in relation to their production (manufacture of part of the adjacent elements to the connections, mounting structure and complementary services in the buildings) and to the performance of the finishing structure.

The transfer of compressive stresses on the connections between components of precast concrete is usually made by direct contact or by placing boards between the parties. Due to the low tensile strength and brittle performance of concrete, the first method (direct contact) is rarely used and is limited to cases where there are very low compressive stresses.

The second method consists of placing a board between the elements, which is made of a material with good deformation capacity to minimize the concentration of compressive stresses.

Usually, these boards are denominated bearing pads and are made of elastomer, the most common polychloroprene pads. Being made of a very soft material, these pads accommodate the irregularities of the surface, promoting a more uniform stress distribution and allow certain movements of the structure. The movements allowed are the rotation and horizontal displacement. The rotation causes the performance of the connection to be similar to a pinned connection. The horizontal displacement enables the relief of stress caused by the variation in length of the supported elements, which would be a great advantage of this type of material when remarkable loads are introduced in the structure. The disadvantages of this type of material are cost, less durability compared to concrete, low resistance to fire and relatively low compressive strength.

This paper presents the development of bearing pads made of Portland cement mortar, modified to be more deformable and have a higher toughness than the usual mortars. The pads made of this material are intended to transfer compressive stress - uniform or not - to avoid stress concentration and, if appropriate, allow small rotations between the elements without introducing high stresses along the edge of the contact area. These pads are made of Portland cement mortar adding the following components: a) lightweight aggregate or air-entraining agents, b) latex, and c) short fibers.

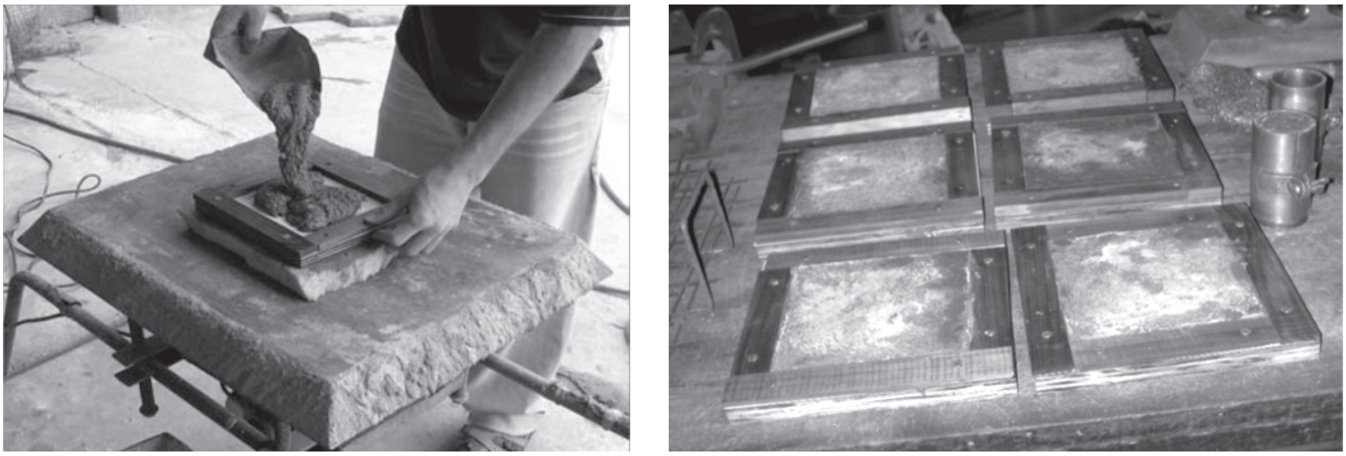
The lightweight aggregate (expanded vermiculite-term) or air-entraining agent significantly increases the deformation capacity of the material in the hardened state. Due to the presence of surfactants used in the production of latex, a significant amount of air can be incorporated into the mix, while increasing the deformation capacity of the material. The addition of fibers reduces the workability of the mix and can incorporate air into the hardened material, reducing its modulus of elasticity.

Several studies were performed to obtain mixtures with low modulus of elasticity but with acceptable compressive strengths: Barboza et al [1], El Debs et al [2], El Debs et al [3], El Debs et al [4], Montedor [5] and Siqueira [6].

As the mortar pads are less deformable than the corresponding polychloroprene pads, they initially promote a more rigid structure. In the case of beam-column connection with grouted dowel, the replacement of elastomeric pads with this type of pad makes possible the partial transmission of the bending moment and therefore increases the rigidity of the structure. A comparison between the pads of mortar and the pads of polychloroprene can be seen in Montedor [5].

Thus, the performance of the pinned connections becomes semi-rigid. Compared to the pinned connections, semi-rigid connections present a significant improvement in the structural behavior of lateral loads, even for connections with a low degree of rigidity (El Debs et al [7]). On the other hand, the effects of length variation on structural elements must be carefully considered to minimize the loads that may be introduced in the structure, since the mortar pad is stiffer than the polychloroprene pad.

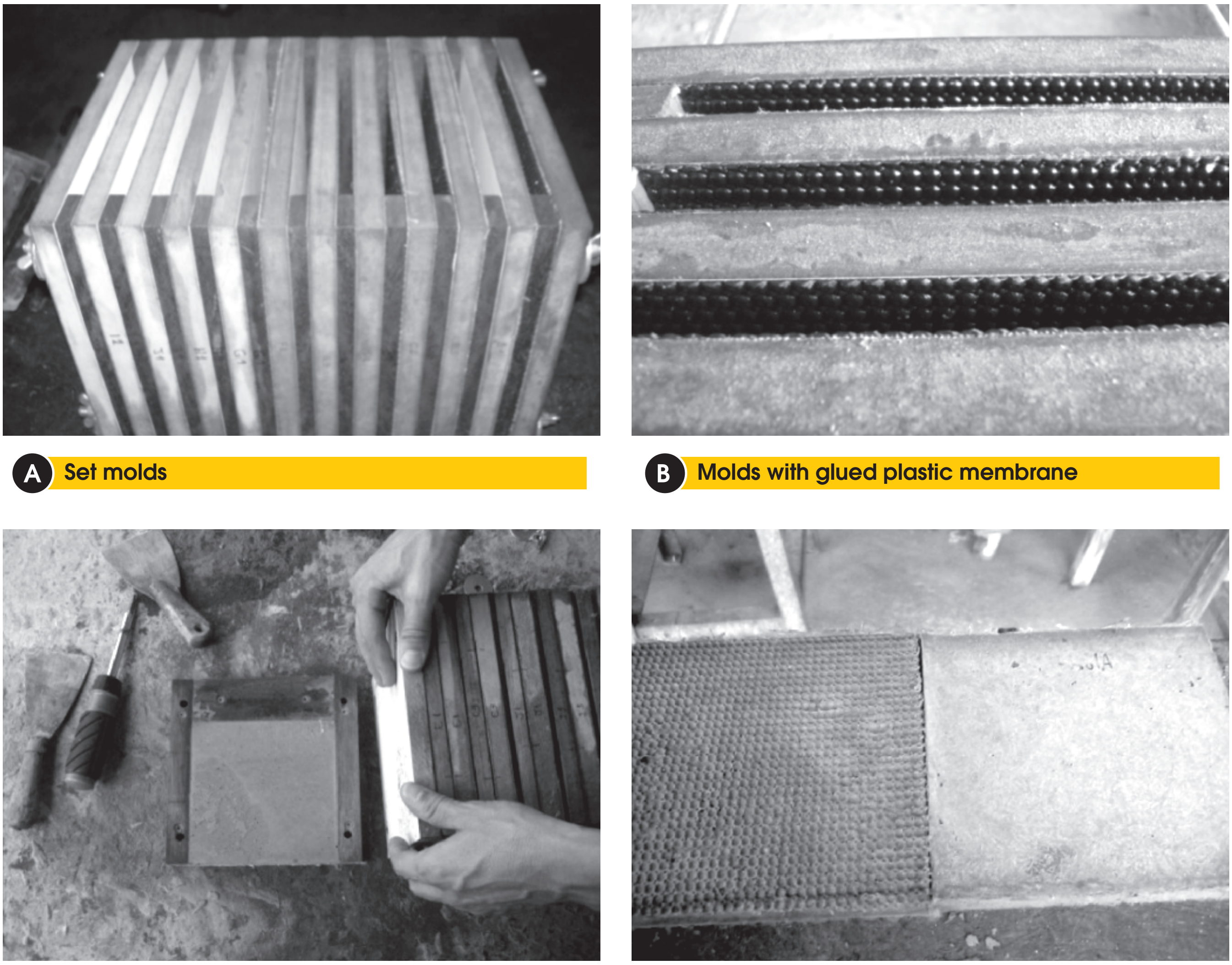
Figure 1 – Bearing pads manufacture



A Bearing pads casting

B Bearing pads in curing process

Figure 2 – Details of the molds and the texture of pads



A Set molds

B Molds with glued plastic membrane

C Demolding of pads

D Pads with rough and smooth surface

Continuing previous studies to develop this type of bearing pad, this paper aims to present an experimental study of the use of surface roughness on mortar pads with the use of a new form of molding in order to increase the deformation capacity of the pads.

2. New bearing pads manufacture technique

The molds used in previous researches, as in studies of Montedor [5] and Siqueira [6], did not provide control of the surface of the pad, which was exposed and just went through a finishing process during the curing of the mortar (Figure 1).

A battery mold was developed in Bellucio [8]. In addition to enabling the introduction and control of roughness on both sides of the pads, the new manufacturing technique also provides large-scale production. A plastic membrane with roughness of 1.2 mm of thickness, measured by a digital pachymeter, was glued in the molds to analyze the effect of surface roughness of the pads. Thus, a comparison between the pads with smooth and rough surfaces can be made (Figure 2).

3. Experimental program

In this paper, the following tests were performed to characterize the material: compressive strength, tensile strength by diametral compression and modulus of elasticity. In addition to these standardized tests, tests on the performance of the material were conducted. Concentrated and bending loads were applied under four points load on strips of pads. The pads were tested by applying a distributed load (monotonic and cyclic). In order to study the influence of surface roughness, pads were molded with two smooth surfaces (LL); a smooth and a rough surface (LR); and two rough surfaces (RR).

3.1 Utilized Materials

The utilized materials are as follows: a) Portland cement of high initial resistance (CP V-ARI), b) sand sifted by an ABNT30 sift with hole diameter of 0.59 mm, c) expanded vermiculite-term with a maximum dimension of 4.8 mm d) styrene-butadiene latex; superplasticizer agent based on a modified carboxylic ether chain, polypropylene fibers with nominal length of 10 mm, nominal diameter of 12µm and specific weight of 0.90kg/dm³.

The mixtures utilized in previous studies which have had better results use as reference 1:0.3:0.1 (Portland cement, sand and water) and Montedor [5] added to this mixture V5L30F3 (5% of sand replaced by expanded vermiculite-term, added 30% of latex and 3% of PVA fiber). Siqueira [6] utilized V10PP4L30 (10% of sand replaced by expanded vermiculite-term, added 4% of polypropylene fiber and 30% of latex). Because of the battery molding process it was necessary to modify the mixture in order to mold the mortar and continue to meet the criteria of strength and toughness.

The amount of fiber incorporated to the mixture was due to the workability of the mortar because it was necessary to have a fluid mass to mold it into the battery (Fig. 3). Since the goal is to find a mixture with good strength, but with a low modulus of elasticity, fibers are added as much as possible.

Based on preliminary studies, the following composition was estab-

Figure 3 – Casting of pads utilizing the funnel and the 'comb'

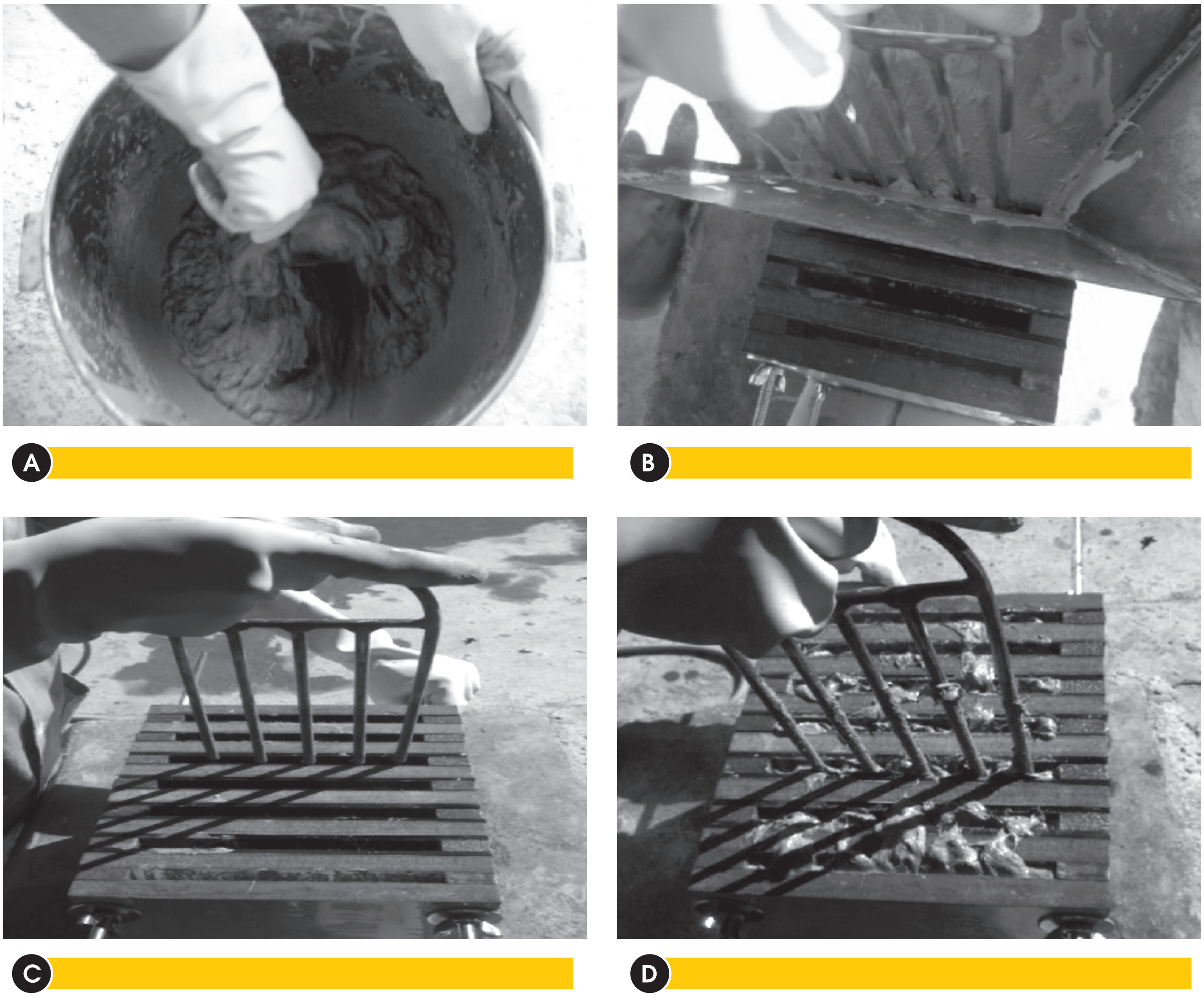


Figure 4 – Stress *versus* strain diagram to obtain the modulus of elasticity

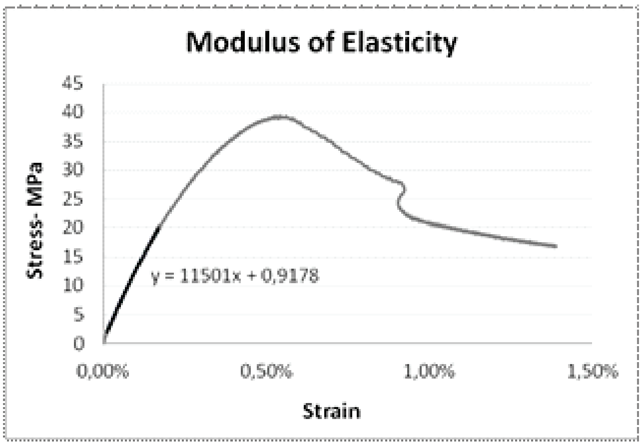
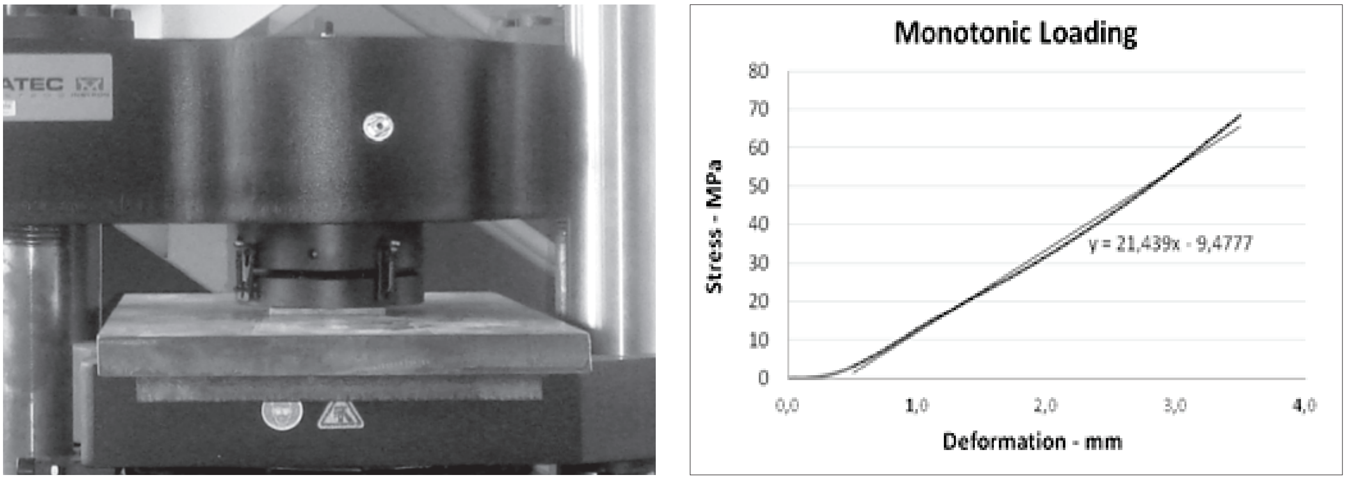


Figure 5 – Monotonic loading test



A Test scheme

B Stress versus deformation diagram to obtain pads stiffness

lished, in volume, for the mortar (PP12): 1:0.285:0.35:0.02 (Portland cement: sand: water, superplasticizer), V15L20F2 added (1.5% of expanded vermiculite-term, 20% of latex and 2% of polypropylene fiber). The studies also included a reference mixture, no fibers and expanded vermiculite-term, adding the amount of water contained in the latex emulsion, and analyzing the influence of these components. The proportion for this mixture is 1:0.3:0.35:0.01 (Portland cement: sand: water: superplasticizer).

3.2 Standard Tests for Mortar Characterization

a) Simple Compression
The simple compression tests were performed in cylindrical specimens of 100mm x 50mm, according to the recommendations of ABNT NBR5739/2007 [9] with loading rate at 0.005 mm/s.

b) Tensile strength by diametral compression
These tests were performed on cylindrical specimens of 100mmx50mm, according to the recommendations of ABNT NBR7222/1994 [10], with patterned loading rate at 0.005 mm/s.

c) Modulus of Elasticity
This test is performed by applying an axial load to the cylindrical specimens. The application is performed in a circular area of 50 mm diameter and two transducers with rods of 50mm are used, placed on opposite sides of the specimens to be tested, approximately 25mm from the base of the 100mm specimens. Thus, the stress *versus* strain diagrams are made from the load obtained in the acquisition system of the machine and the average of the two displacement transducers. From the curve representing stress *versus* strain and the equation curve (regression) the modulus of elasticity can be obtained. The regression is made between 5% and 50% of the maximum load of the specimen. Figure 4 shows a typical diagram.

Figure 6 – Diagram of the cyclic test showing stiffness calculation and accumulated deformation to stress of 20 MPa

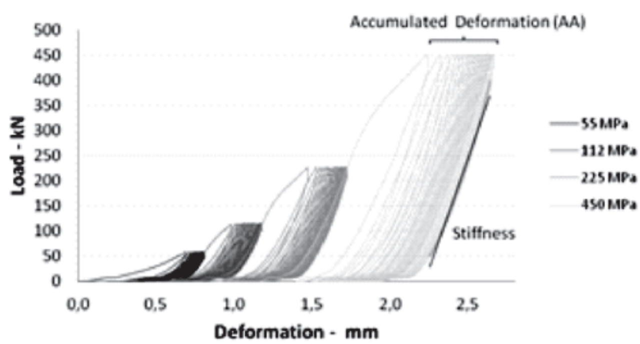
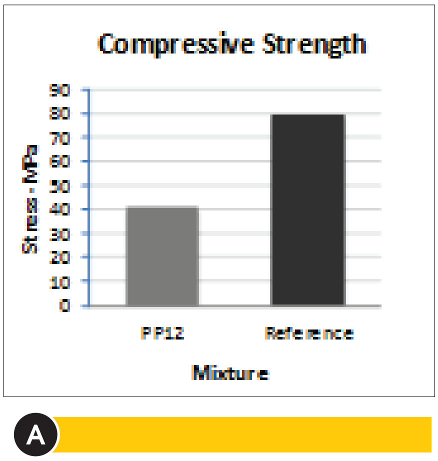
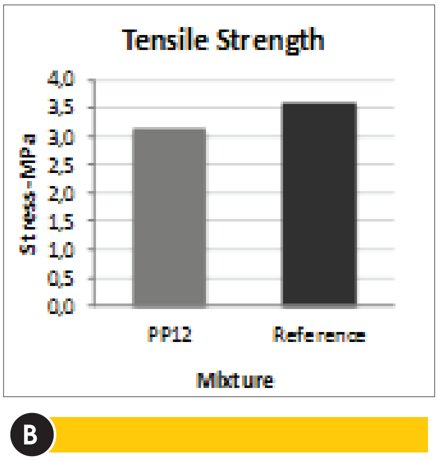
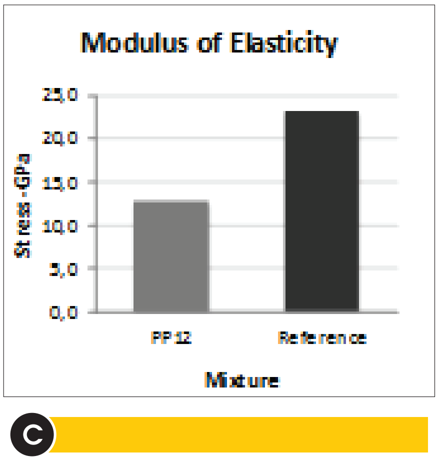


Figure 7 – Results of characterization tests in cylindrical specimens







3.3 Mortar characterization tests in strips of pads

As described, the mortar placement in the molding of the pads was performed manually (Figure 3) and also by vibration table. The demolding process was performed after two days of the molding, being placed for 24 hours in a humid chamber. Then, the samples were removed from the humid chamber and placed at room temperature until the day of the testing. The tests were performed after 14 days of the molding.

a) **Concentrated load**
This concentrated load test was derived from tests performed by Montedor [5] and Siqueira [6] in order to measure the capacity of accommodation under concentrated loads on strips of composite pad, or accumulated deformation. This test was performed to compare the influence of fiber in the accommodation capacity.
These tests consist in cutting pads of 150mm x 150mm into strips of 25mm x 150mm, in which loads are applied at two points located at 37.5 mm from the edge of the strip. The load is applied by the deformation control machine at a rate of 0.01mm/s. For each mixture, 10 strip samples of pads are tested, obtaining the load *versus* displacement curve for each sample.

b) **Bending tests**
These tests were performed to verify the performance of the mortar to bending. The bearing capacity after cracking due to the influence of the fibers was also verified. Six tests were conducted for each mixture and each sample was 150mm x 12mm with 30mm wide.

Although performing specific tests on pads, the requirements of ABNT NBR 12142:1991 [11] were established as a standard for the test. Thus, the same measures of support distance and load application according to ABNT NBR 12142:1991 [11]. The support were placed at 1cm from the edge of the sample and the points of load application were 1/3 support of the brand. The load was applied to a deformation where the pad began to lose load. To compare the results, stress versus displacement curves were designed and the performance of the specimens was verified.

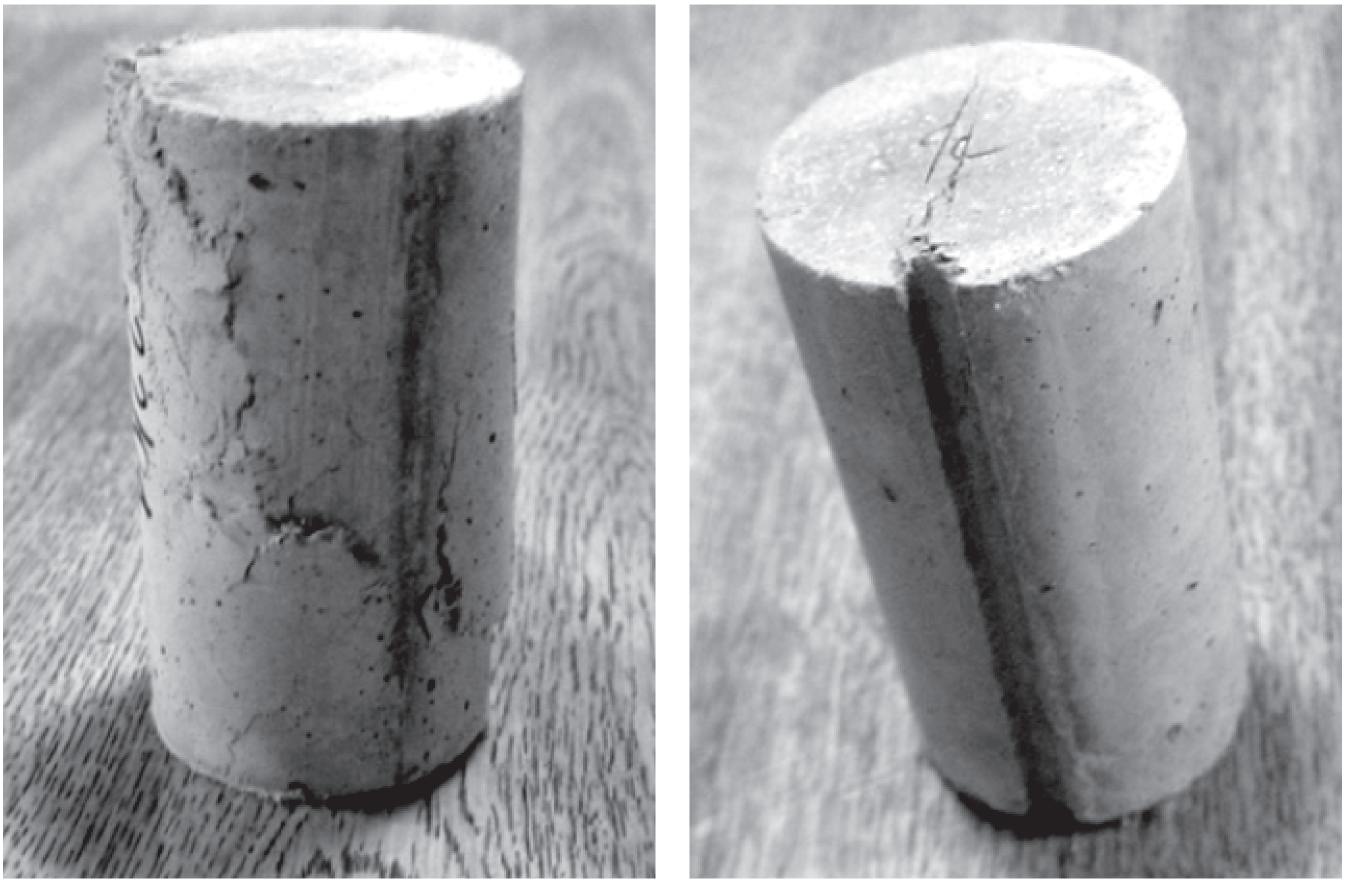
3.4 Bearing pads tests

a) **Monotonic loading**
In this case, six pads of 150mm x 150mm were molded for each mixture and for each roughness. The load was applied to the limit of the machine (1500 kN).
The purpose of these tests is to analyze the performance of the pad, which is conventionally named stiffness. The relation can be made from the diagram stress *versus* deformation. However, as the displacement is concentrated on the surface of the pads, a stress *versus* displacement analysis was performed.
With the diagram stress *versus* displacement a curve is obtained. Along the curve, a line is drawn past many points, starting where the variation of the curve tends to a straight line. The straight line is drawn once the pad is accommodated due

Table 1 – Results of characterization tests

Mixture	Compression - MPa	Tensile - MPa	Modulus of Elasticity - GPa
PP12	40,9	3,1	12,8
Reference	79,5	3,6	23,2

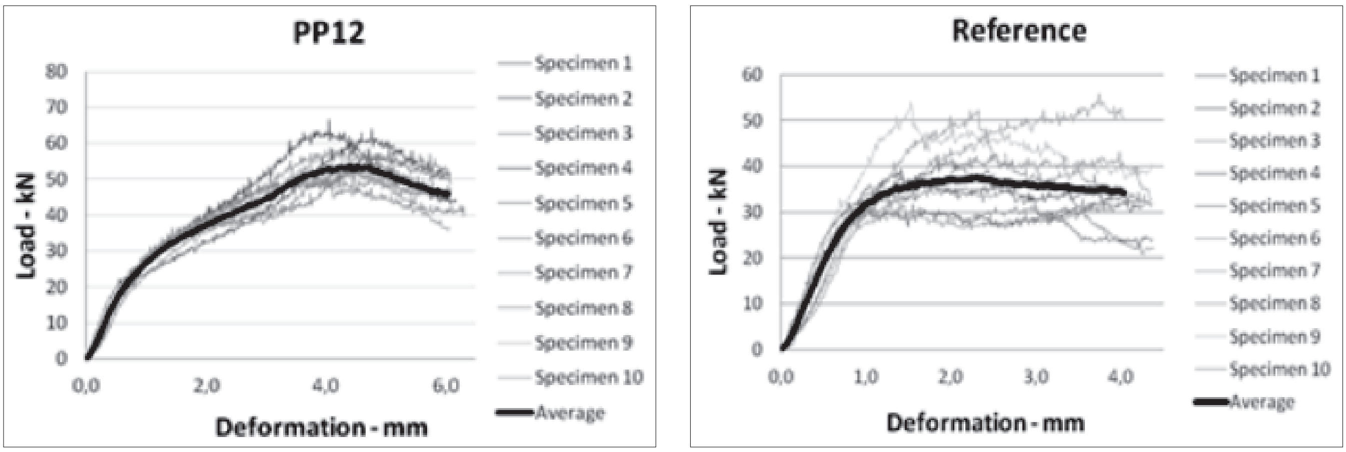
Figure 8 – PP12 samples after tests



A Modulus of Elasticity

B Tensile for diametral compression

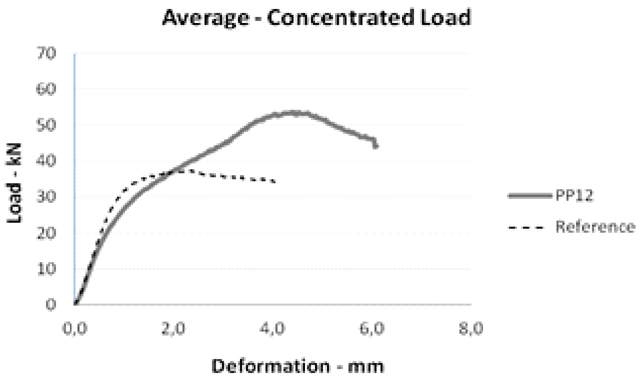
Figure 9 – Load *versus* deformation diagram



A PP12 Mixture

B Reference Mixture

Figure 10 – Average results of concentrated load



Stiffness was analyzed utilizing the load evolution and the accumulated deformation of cycles. Stiffness is calculated in the typical manner of the monotonic loading tests. The accumulated deformation is the consolidation of the material, therefore, the displacement suffered by the pad during each cycle. The accumulated deformation is calculated via the difference between the initial and final value of the displacement cycle (Figure 6).

4. Results and Discussion

4.1 Mortar characterization tests

Six specimens were tested in three different moldings (two samples per molding). The average of the results is presented in Figure 7 and Table 1. Through the analysis of the results it is indicated that adding materials decreases the resistance of the mortar, but it would still be compatible with use. The samples of modified mixtures did not present brittle fracture due to the presence of fibers (Figure 8).

Figure11 – (a) Samples test; (b) details of reference sample; (c) details of PP12 sample

to its imperfections. The slope of the straight line represents the stiffness of the pad (Figure 5).

b) Cyclic Loading

The cyclic loading test is used to determine the evolution of stiffness when exposed to repeated loading. The basic scheme of the cyclic test was also used for the monotonic test, and the pads used in this test have the same dimensions of the ones used in previous tests (150mm x 150mm base and thickness of 12mm). The difference is that the loading was repeated cyclically and the load values used were similar to the ones which promote contact pressure of the same magnitude found in practical situations of use of the bearing pads.

The stress used for this test were the same adopted by Siqueira [6] of 2.5MPa, 5.0MPa, 10.0MPa and 20.0 MPa. By adopting these values stress, loads in the respective phases of the tests were approximately 55kN, 112kN, 225kN and 450kN. For each value of stress, cycles of 50 repetitions for each loading were performed, corresponding to 0.02mm/s. The loads were applied to the limits and led to a value close to zero.

Figure 12 – Results of bending tests of the PP12 mixture

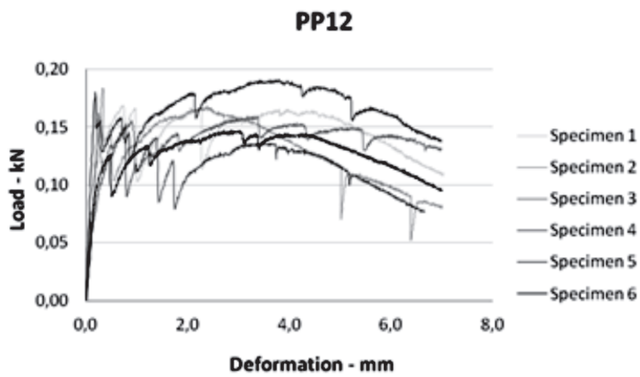
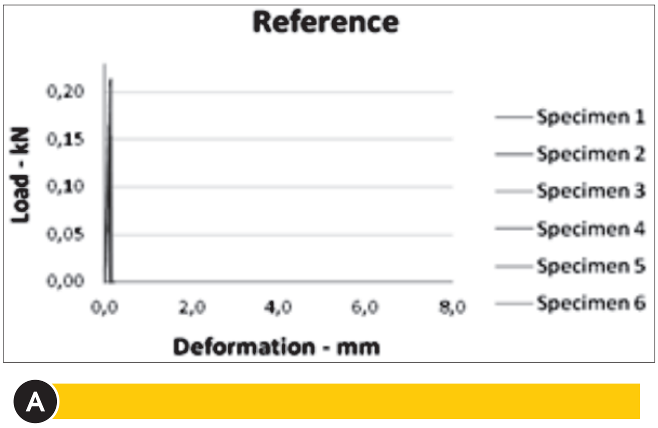
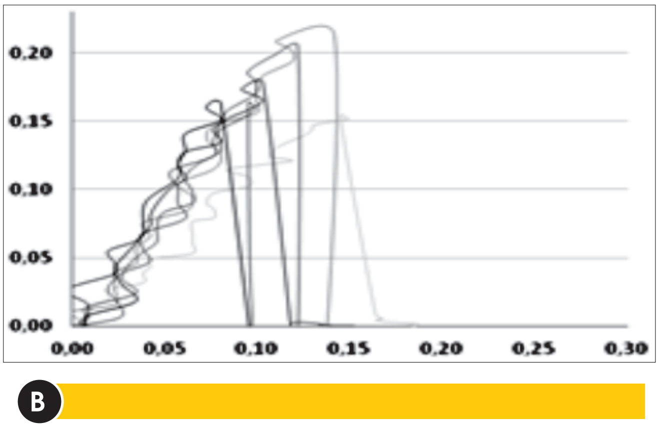


Figure 13 – (a) Results of bending test of the reference mixture; (b) Details of diagram of initial deformations





There are no significant differences between the tensile strengths. There is a tendency of the strength values of the reference mortar being slightly larger than the others. For the modulus of elasticity test, comparing the results of modified mortars with the reference mixture, there is a significant decrease in this parameter. This is the main focus of the research: the material should be as deformable as possible to be used as bearing pad. The results of this test are consistent with those obtained by Siqueira [6] (35MPa of compression, 2.7 MPa of tensile strenght and 13.2 GPa of modulus of elasticity), and even with lower values of compression, they are sufficient to be used in bearing pads.

4.2 Mortar characterization tests in strips of pads

a) Test of concentrated load

Ten strips of each mixture were tested and an analysis of the

Figure 14 – Picture of the bending test of the PP12 mixture

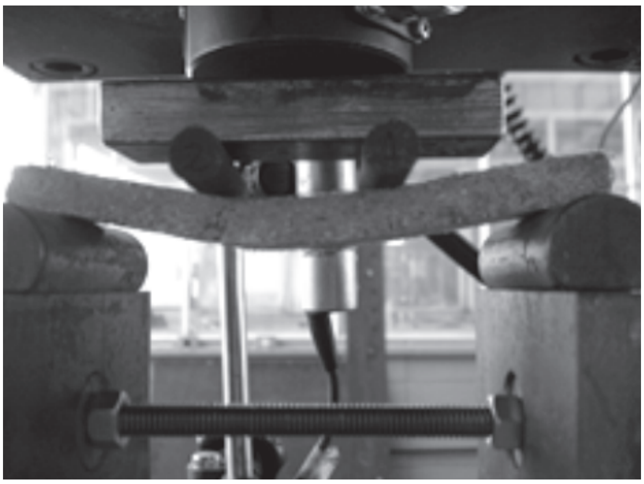


Figure 15 – PP12 mixture stiffness results

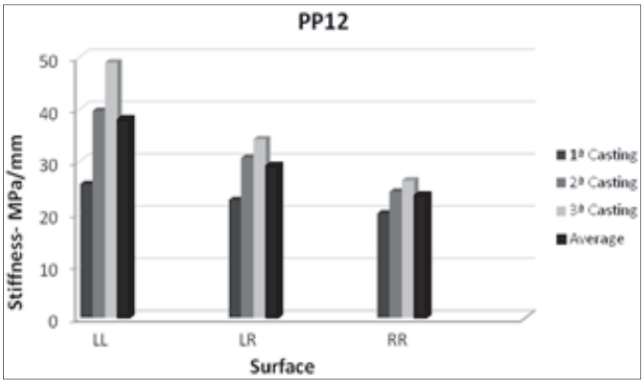


Figure 16 – Reference mixture stiffness results

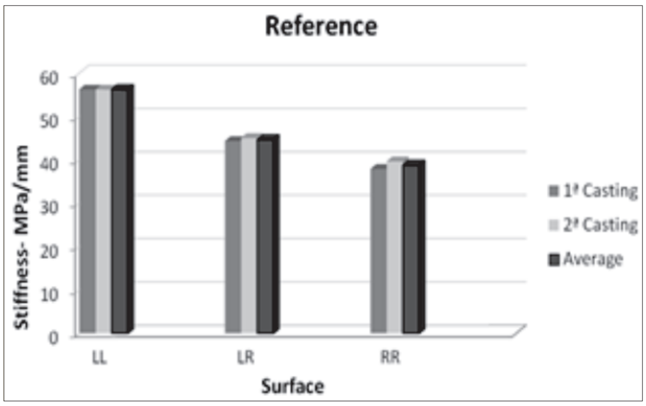


Table 2 – Results of stiffness average of monotonic tests (MPa/mm)

	PP12 Mixture			
	1ª Casting	2ª Casting	3ª Casting	Average
LL	307	461	580	449
LR	286	386	444	372
RR	268	313	340	307
	Reference Mixture			
	1ª Casting	2ª Casting	3ª Casting	Average
LL	636	649	-	642
LR	536	544	-	540
RR	473	506	-	490

load versus displacement diagram (Figure 9) was performed. Figure 10 shows the comparison between the average curves of the PP12 and the reference mixture.

As expected, the strip of mortar made of the mixture with fibers presented a better performance, as it resisted a greater load in the evolution of the loading process. This strip had a performance similar to the beginning of the loading of the reference mixture to the point of the first crack and the mixture PP12 absorbed more load. The maximum load achieved by the mixture PP12 was 53.65 kN to 4.53 mm of displacement. The maximum load achieved by the reference mixture was 37.60 kN to 2.31 mm of displacement, which corresponds to 43% increase in load and 96% increase in displacement.

The difference between the performances of the mortars is clear, as presented in Figure 11. The reference mortar hardly deformed due to the compression and the sample was completely in pieces. The sample with mortar PP12 deformed well before cracking, and even with the cracks, the fibers allowed the sample to remain complete.

b) **Bending Test**

In the strip bending test, six samples taken from each mixture were used and an analysis of the load versus displacement graphs was performed. The results are shown in Figure 12 and Figure 13.

It was verified that each peak point in the curve corresponded to a crack in the sample in samples with fibers. Thus, it can be noted that the volumetric rate of the utilized fibers (2%) ensured the appearance of multiple cracks, which gives an acceptable degree of tenacity for the material. Comparing the values of ultimate load of the graphics of the samples with and without fibers, it is clear that the values are very close.

It can be seen in the photo in Figure 14 that the strip has a pronounced curvature due to the good tenacity that fibers promote to the material.

4.3 Bearing pads tests

a) **Monotonic loading**

The difference between the studied mixtures and the influence of surface roughness applied on the pads were analyzed through stiffness. The stiffness is the ratio of stress *versus* displacement of the pads, excluding the initial part of the diagram which quantifies the ability of elastic deformation of the material.

To facilitate comprehension, the identification 'LL' was adopted for pads with both sides smooth, 'LR' for pads with one side smooth and one rough and 'RR' for pads with both sides rough.

For this test 18 pads were casted in two stages: nine pads were made in a first casting (being 3LL, and 3LR 3RR) and other nine pads were made in a second casting. However, through the results of the mixture PP12 it was possible to observe a significant difference between the two casts. Thus, we chose to cast nine more pads of this mixture to confirm these results. Even with a new casting the stiffness values were quite different, especially for the LL and LR pads. Fig-

Figure 17 – Stiffness comparison according to the applied roughness

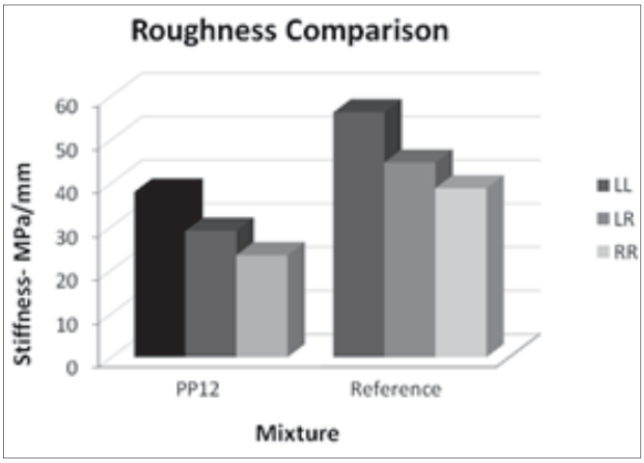
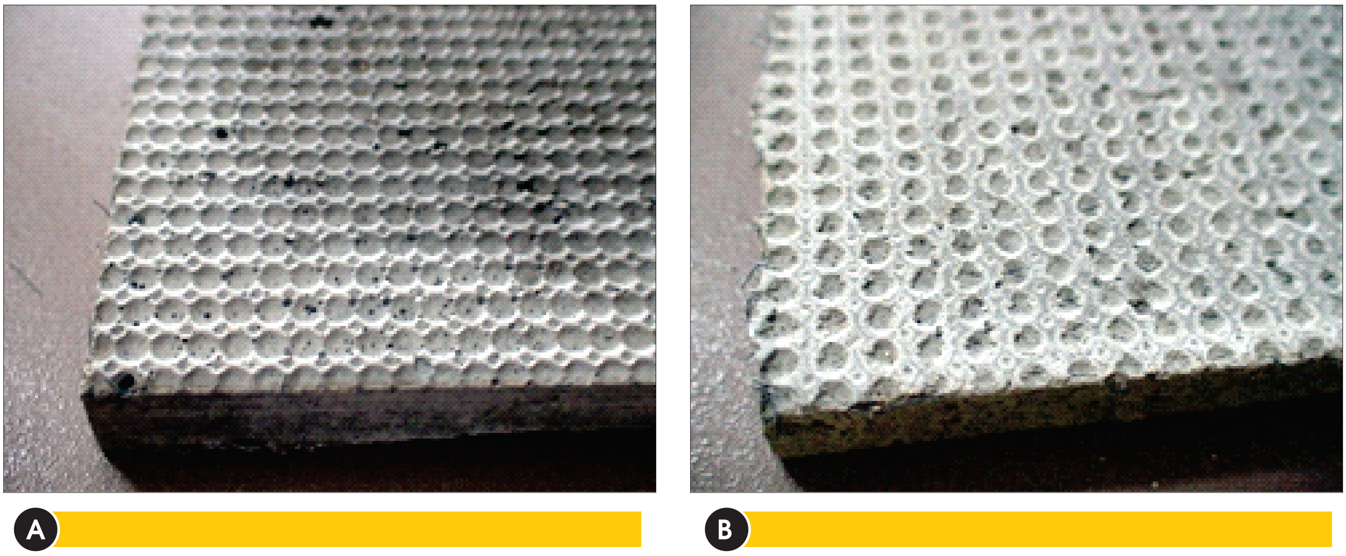


Figure 18 – PP12 bearing pad details PP12 (a) before and (b) after the test



ure 15 and Table 2 show the average values found.
Based on the results, it was detect that the differences between the results of RR pads were much smaller than the others. Furthermore, these results have much lower stiffness values compared with the LL and LR pads. Therefore, as the aim of this work is to reduce the stiffness of the pads, the results were satisfactory compared to those found by previous studies. It is possible to conclude that, even with different results between the castings, the RR pads have good characteristics for their application. The results for the reference mixture are presented in Figure 16 and Table 2.
In this case, there was no significant difference between the two casts. Thus, we conclude that the differences found in the mixtures with fibers are related to the addition of new materials.
Figure 17 shows a comparison of the stiffnesses. In this diagram, the significant reduction in stiffness of the pads with the

Figure 19 – Stiffness results comparing 10MPa and 20MPa stresses

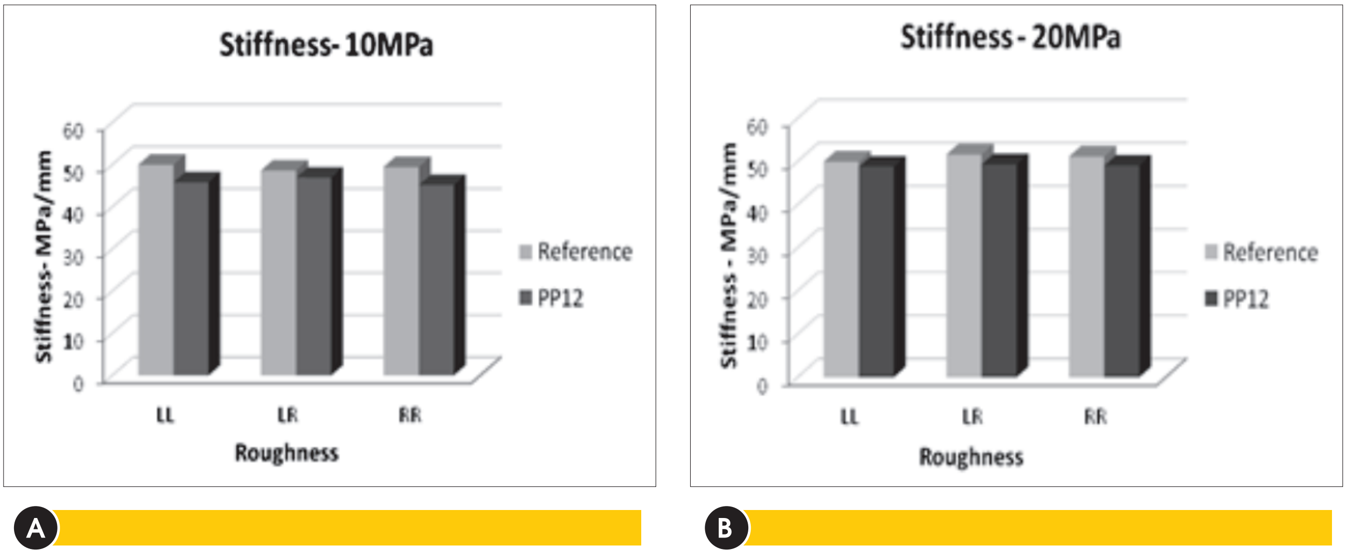
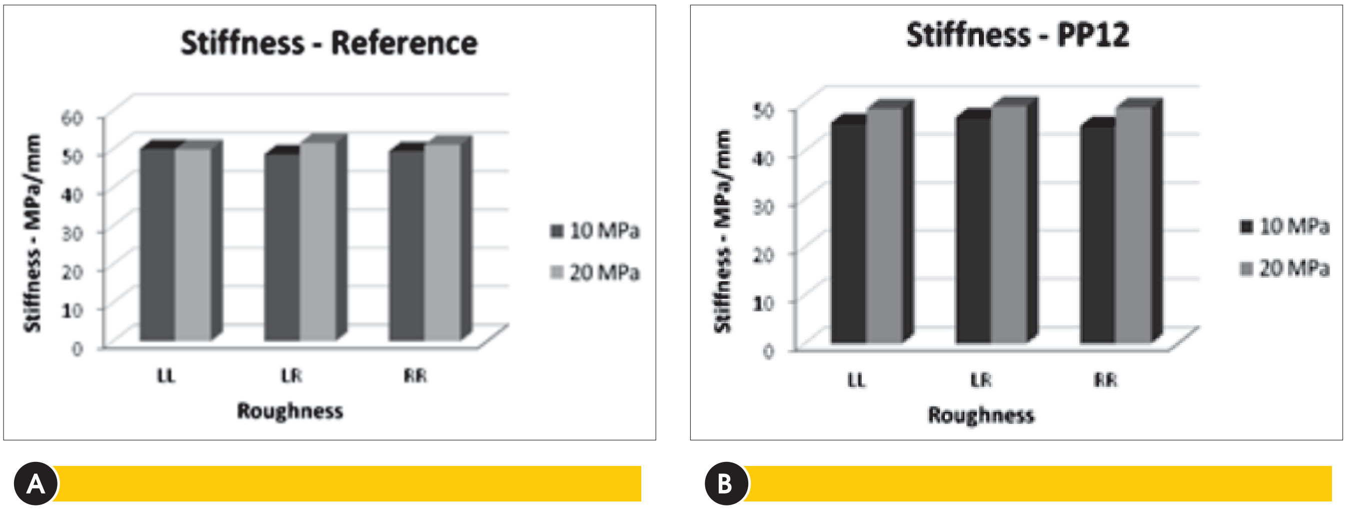


Figure 20 – Stiffness results comparing PP12 mixture and reference mixture



addition of fibers, latex and expanded vermiculite-term can be noted. There was a reduction of more than 30% in stiffness.
In all mixtures, the application of roughness to the surface reduced the stiffness of the pad; therefore, the RR pads present a better result. The difference between the LL and RR pads reaches 30% of reduction in stiffness. Analyzing once more the stiffness values of the mixture PP12 in Figure 16, it is clear that, even though it has been a difference between the values in the casting, there is not a considerable difference between the stiffnesses for RR pads. The after testing pads remained intact. (Figure 18).

b) Cyclic Loading

For this test, 18 pads of each mixture were tested: six pads for each type of roughness, as in the monotonic test. When analyzing the stiffnesses, there is a difference between the stress of the mixture with fibers and the reference mixture in Figure 19, for the cycle subjected to stress of 10MPa and 20MPa.
Considering the average of the values found, it is possible to state that the mixture PP12 obtained less stiffness than the reference mixture. Figure 20 presents the difference between the stiffness of 10MPa and 20MPa.

Figure 21 – Stiffness results comparing applied roughness

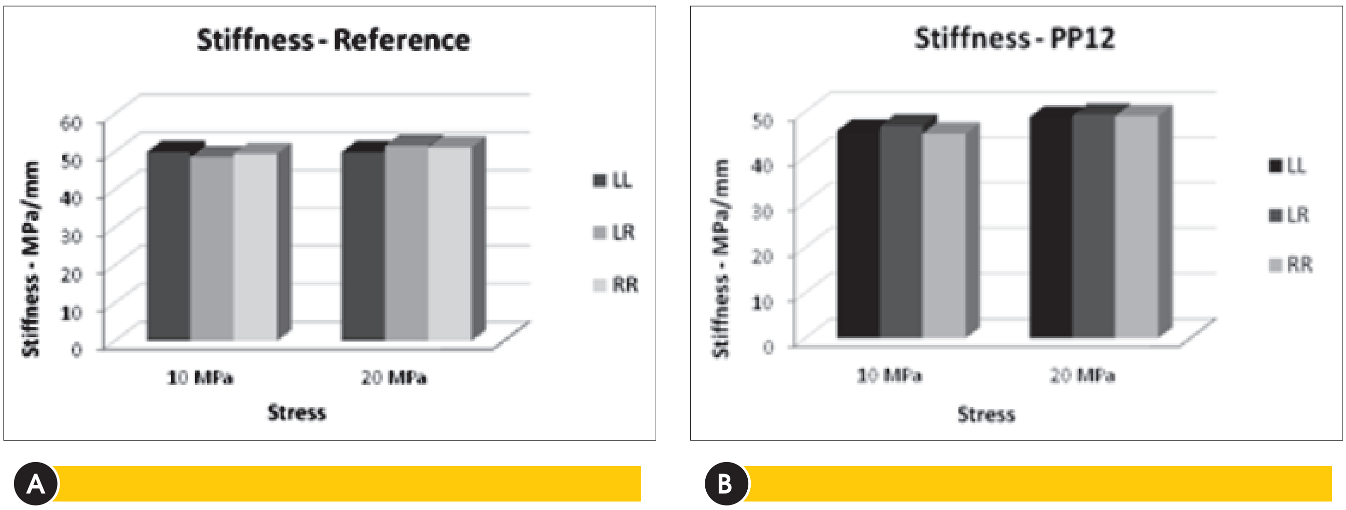
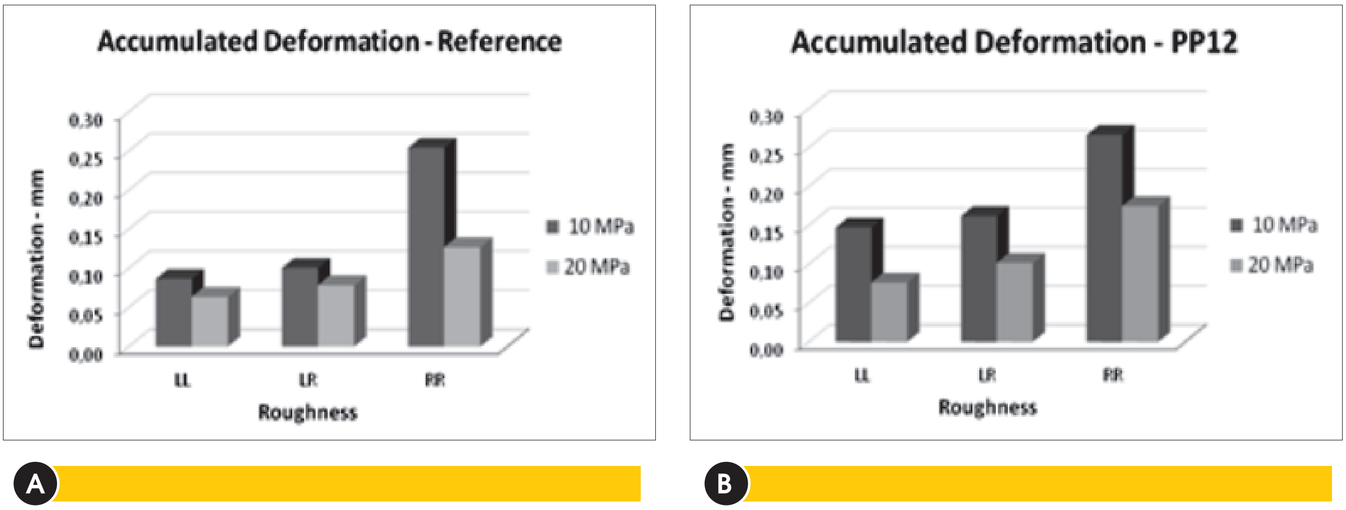


Figure 22 – Accumulated deformation results comparing stiffness



The stiffness for the loading of 20MPa are higher than those of 10MPa. This is due to the fact that this sample was submitted to the cyclic loads of 2.5MPa and 5MPa, as the 10MPa sample. It also received all the cyclic loading of 10MPa, therefore, the sample is more compressed.

Analyzing the values of the results and comparing the roughness, it is observed in Figure 21 that there were not significant differences between the results. It is believed that the pads have suffered adaptations due to the previous loadings. Therefore, the roughness did not affect the results.

Besides stiffness, the accumulated deformations were also analyzed. The results for the studied mixtures are shown in Figure 22. Through the results it is clear that the pad suffers a higher plasticization for the loading of 10MPa. This is due to the fact that this loading was applied before the loading of 20MPa; hence the sample is already deformed. The performance of the mixtures can be observed in Figure 23.

It is possible to see a larger deformation in the pads of mixture PP12 when analyzing the diagram. This deformation occurs as expected, since the purpose of this pad is to be more deform-

Figure 23 – Accumulated deformation results comparing mortars

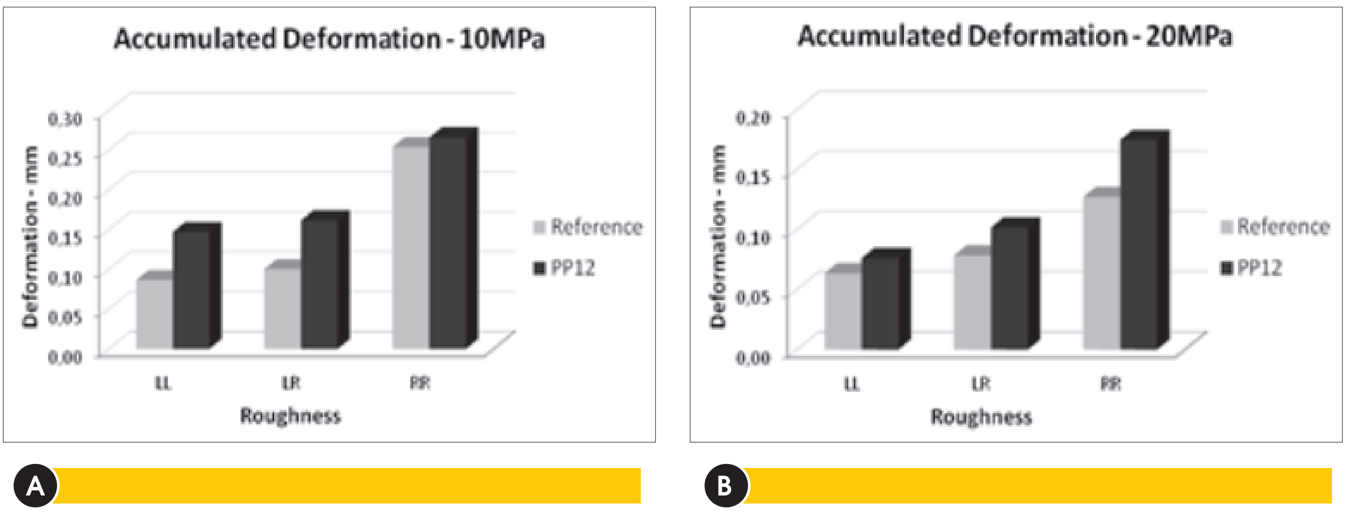
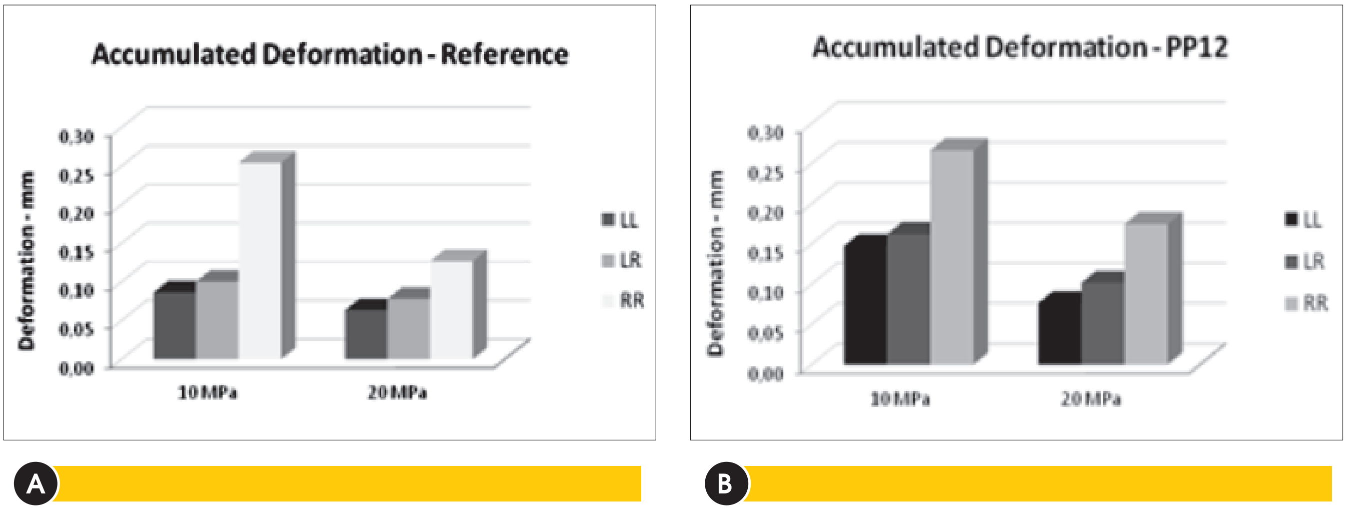


Figure 24 – Accumulated deformation results comparing applied roughness



able. A comparison between the roughness in Figure 24 was made utilizing the deformation results found.

Considering the two loadings, there was a considerably higher displacement on the pads with applied roughness. This result is considered positive, confirming the importance of the use of these pads.

5. Conclusions

From the analysis of the characterization tests, it is observed that:

a) the values of compressive strength of the material samples are around 41MPa and of the reference mixture are 79.5 MPa. Thus, there was a reduction of approximately 48% of the value of the modified mixture compared to the reference mixture. The value around 41MPa can be considered sufficient to be utilized in bearing pads.

b) for the tensile tests, the values found for the mixture with fibers and the reference mixture are very close, on the order of 3.0 MPa, and this difference is not significant;

c) the modulus of elasticity of the material reached a 45% reduction in relation to the reference mixture, reaching 12.8 GPa;

d) in the concentrated load tests there was a better performance of the mortar with the use of fibers. It was able to absorb 43% more load than the reference mortar, and it allowed a displacement of 96% more than the reference mortar.

e) the volumetric rate of the utilized fibers (2%) ensured the appearance of multiple cracks, which provides an acceptable level of tenacity for the material.

From the bearing pads tests, it can be concluded that:

a) There was a significant difference between the mortar with the use of fibers and roughness and the reference mortar;

b) In the monotonic loading tests it was observed a clear reduction of the stiffness of the pad with the application of roughness on both sides (RR). Comparing the LL and RR pads, the difference was more than 30%, which indicates that the application of roughness on both sides enables a significant reduction of this parameter;

c) Although the mixture with fibers presented a variation in the results between the casts, these differences were not significant for the RR roughness, that is, for the results of the mixture PP12 and RR roughness, the values found were satisfactory. For this mixture it was obtained 307MPa/mm, which is 37% less stiffness than that found for the reference mixture, RR (490MPa/mm). Through the accumulated deformation it was observed that the mixture PP12 has good deformation capacity compared to the reference mixture, reaching 37% more displacement than the reference mixture. It was also observed that, with the increase of the loading cycles, the material tends to have little elastic deformation. It was also concluded that there was a better performance of the RR roughness pads, and the displacement was 120% higher compared to LL pads.

Based on all the results achieved, it can be conclude that the PP12 mixture has a good performance with a reduction in stiffness compared to previous results, and that the best performance occurred with the application of roughness on both sides of the pad as shown in the results of monotonic loading.

6. Acknowledgements

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