

Alumina addition influence on the polymer composites properties

1. Introduction

Environmental, health and sanitation issues are part of our routine and can no longer be ignored. This underscores the importance of adopting civil construction practices that are in line with an improved quality of life. The development of new, more resistant, durable materials with a longer service life is quickly becoming a key requirement in this booming market. Polymer concrete (PC) is an example of a highly durable material with outstanding mechanical strength, weathering properties and resistance to aggressive environments (1) and requires little maintenance. The chemical composition of PC is different from conventional concrete in that it uses a resin that polymerizes with the aid of additives as a substitute for Portland cement (2). PC consists of aggregates bound together by a polymer. Its properties are closely connected with the characteristics of its components, namely the type and amount of polymer and additions used. However, composites manufactured with polymer resins may have flammability restrictions, which in turn could limit their applicability in civil construction (3-5). This is explained by the fact that the outbreak and duration of a fire is linked to factors such as the amount and type of flammable materials used in the building. PC is widely used in many countries but not yet in Brazil, probably because of the cost of the final composite (a result of the use of polymer as binder). In addition, knowledge of the use of polymers as binders and the properties and applications of PC is still limited (1). Some studies are currently in progress to offer less costly alternatives to conventional PC and one of such is the substitution of waste material such as recycled PET for fresh polymer (6-8). Fowler (2001) mentions that unsaturated polyesters produced from recycled PET present a potentially low-cost alternative that can also help conserve power. The use of recycled PET offers several advantages because these materials do not require thorough cleaning and colour sorting given that the final product will absorb all components (9). River sand is usually used as the inorganic phase of PC (10-13). Sand is the material of choice in cement and polymer matrixes because it is made up of round particles that can improve the interactions between binder and aggregate (14). Sand is also readily available in most places. The addition of fillers is a common feature of polymer composites since this improves their mechanical and chemical properties by helping to reduce the porosity in the finished product (15). Calcium carbonate and fly ash are some of the materials that are used for this purpose. Polymer composites can also contain other types of ad-

ditives depending on their intended applications and properties. In the case of flammability, it is known that most polymer composites are susceptible to flame propagation. The addition of substances such as alumina and calcium sulphate to polymer matrixes can improve the mechanical and chemical resistance properties of the material and at the same time reduce the flammability of the composite, resulting in a product with improved fire performance (16). Alumina trihydrate (ATH) is a commercially available flame retardant used in polymers and other materials. When added to the polymer and in contact with fire, it breaks down to absorb heat and reduce the temperature of the material. The water that is released in the process will also dilute the flammable gases in the flame. Aluminum oxide (Al_2O_3) results and forms a protective surface layer on the material, thus reducing oxygen diffusion in the reactive medium and acting as a barrier to heat exchange and flame propagation (17). In light of the above and also because of the widespread availability of patented products in the market that are added to polymers to improve their fire resistance, this study investigated the effect of incorporating polishing alumina residue (Al_2O_3), a waste material in the steel industry, on the flammability characteristics of PC. The benefits of using this product would be twofold: first, it would provide a destination for a waste material that is otherwise dumped in landfills, and second, it would also allow manufacturers to sell it as a by-product, thus providing an additional source of revenue for companies that generate this waste. The results achieved with the addition of polishing alumina residue were compared with samples produced with a commercially available flame retardant (ATH) to provide reliable standards of effectiveness. The composites in this study were prepared with waste materials and recyclables, such as PET (resin), which is produced from polyethylene terephthalate scrap, fly ash (filler), generated in power plants, and polishing alumina (flame retardant). It is hoped that this composition can contribute to the study of new materials that can support sustainable, innovative practices in the civil construction sector.

2. Experimental program

The present study investigated the polymer concrete properties produced with polyester resin, partially derived from recycled PET and addition of polishing alumina, aiming to broaden the knowledge of this material in the civil construction industry. The tests were

made with samples having 0, 15, 30, 45 and 60% of flame retardant addition, both commercial and alternative waste. Flexural strength, porosity and heating strength were determined.

2.1. Materials

1) Resin

This study used unsaturated polyester resin made with recycled and fresh polyethylene terephthalate (PET). The use of recycled PET in the production of PC has yielded similar results to those observed when virgin polyester was used in PC, but the former has the advantage of lower production costs and reduced need of energy for processing. Finally, the amount of waste that needs to be dumped in landfills is also decreased (8, 18). The curing system in this study was methyl ethyl ketone peroxide as the initiator and cobalt naphthenate as the catalyst.

2) Agregate

River sand was used as the aggregate because it is widely used in the production of PC in research studies throughout the world (10-11, 7, 12-13). These studies have clearly shown that the round granular shape of the sand enhances the interaction between the polymer binder and aggregate. This interaction may account for the improved mechanical performance of PC while also affecting porosity, a property which directly impacts durability and flame resistance, the main focus of this study. The sand was quarried locally, and its particle size distribution was determined using Brazilian Standard NBR NM 248:2001. The fraction in the optimal range was selected, as defined in Brazilian Standard NBR 7211:2005. This use of the „optimal range“ allows for a more reliable assessment of the behaviour of the properties investigated in this study, such as the effect of additions of recycled PET resin and flame retardant. The specific mass of the sand was determined using NM 52:2002, and was found to be 2.72 g/cm³.

3) Filler

The fly ash used in this study is a by-product from the burning of coal in power plants. The particle size distribution of this material shows a higher concentration of particles in 10 – 100 µm range, which characterizes it as a powdery material. Its specific mass is 2.1 g/cm³ according to standard NM 23:2000.

4) Additives

– Alumina Trihydrate Flame Retardant (commercial grade)

The addition of aluminum hydroxide flame retardants to polymer matrices inhibits ignition and the formation of combustible gases that feed the propagation of flames. It also reduces the formation of smoke and carbon monoxide because of the endothermic degradation of aluminum hydroxide. The manufacturer's data sheet shows that trihydrated alumina is a modified form of aluminum hydroxide (2Al₂(OH)₃) that has been specifically developed for use in polymer systems as a flame retardant and smoke suppressant and is also used as a filler instead of conventional mineral fillers.

Table 1

PROPERTIES OF THE REFERENCE FLAME RETARDANT (ALBEMARLE - REICHHOLD)

CHEMICAL ANALYSIS	%
CHARACTERISTICS	Typical
Al(OH) ₃	99.6
Na ₂ O – soluble	0.04
Moisture content (105°C)	0.25
Loss on ignition (1200°C)	34.5

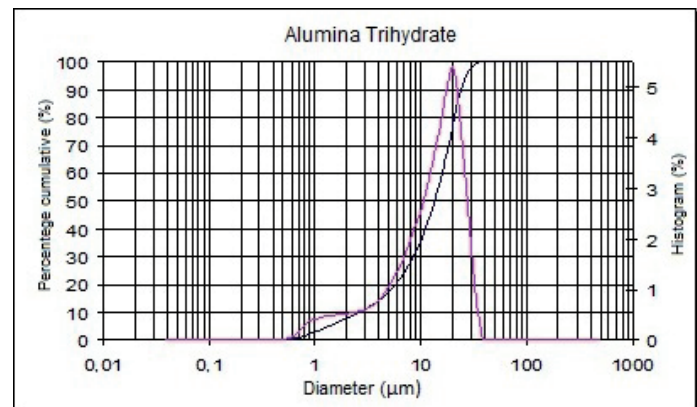


Fig. 1. Particle size distribution of trihydrated alumina

This product also has a significant effect as a degradation inhibitor in polymeric systems used in electric insulation (19). Table 1 shows the composition and properties of the product, as listed by the manufacturer.

Figure 1 shows that ATH has a narrower particle size distribution when compared with fly ash (values between 1 and 50 µm), which justifies its use as a filler, according to a study by Fu at al. (2008) (20) and as suggested by the manufacturer. The specific mass of aluminum hydroxide is 2.40 g/cm³ and its particle size distribution is shown in Figure 1.

– Polishing alumina residue flame retardant

Alumina (Al₂O₃), is obtained through the controlled calcination of aluminum hydroxide, and it is a highly inert chemical, classified as a refractory oxide because it can withstand extremely high temperatures without undergoing changes in chemical structure. Alumina has several industrial applications such as the manufacture of china and ceramics and as an abrasive polishing agent (21). Polishing alumina is made up of small spheres and is chiefly used in polishing operations in the steel industry. This operation generates vast amounts of alumina residue as the spheres gradually wear down and become too small. The spheres also lose their roundness and edges are formed, rendering them unsuitable for polishing. This alumina residue has to be discarded and dumped in industrial landfills. Based on what has just been reported, the polishing alumina waste was added to the polymeric composites in this study to test its efficiency as flame retardant. For doing so, this waste was subjected to physical characterization of granulometric analysis and also chemical characterization. Its granulometric distribution

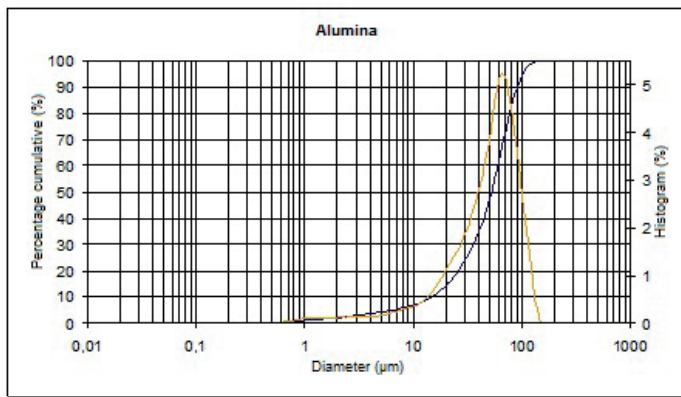


Fig. 2. Particle size distribution of polishing alumina residue after sieving

was made by laser diffraction. When the particle size distribution of alumina residue is compared with that of trihydrated alumina (commercial grade) as shown in Figure 1, it can be seen that the residue shows a broader distribution, with the largest share falling in the 50 to 500 µm range. To eliminate the difference in particle size between the residue and the commercial grade alumina, the residue was passed through a 75 µm sieve and only the passing fraction was used. In this way, it was possible to compare both flame retardants using similar particle sizes while reducing the discarded fraction of alumina residue (the fraction greater than 75 µm). Following this procedure, the particle size distribution of alumina residue was again determined using the Cilas 1064 Particle Size Analyzer and the resulting graph is shown in Figure 2.

The particle size distribution curve of alumina residue then showed a greater concentration of particles in the 10 to 100 µm range, still larger than trihydrated alumina but similar to the particle size distribution of fly ash. The specific mass of the alumina residue was determined using standard NM 23:2000 and was found to be 4.54 g/cm³. This is considerably higher than the value of trihydrated alumina (2.40 g/cm³). This difference may be related to the presence of metallic particles in the residue composition. The chemical composition of the polishing alumina waste was obtained from the X-ray fluorescence test. The results are displayed in Table 2, where the waste component elements as well as the quantities found in this are noted.

XRF results are shown in Table 2, which lists the chemical composition of the alumina residue before and after polishing operations. Although the composition before and after the polishing procedure is the same, the concentrations of some elements such as aluminum, sulphur, iron, silicon and potassium were higher after polishing operations, which can probably be explained by the incorporation of trace elements from the metallic alloys and impurities found in the polishing equipment. It should be noted that the percentages shown in the table refer to the metallic forms of the elements, but these are actually present in the form of oxides (e.g. Al₂O₃, Na₂O, Fe₂O₃, etc). The polishing aluminum data sheet shows that this material has a moisture content of 0.2% at 300°C and loss on ignition of 0.5% (300 to 1000°C) (19).

Table 2

Chemical analysis of polishing alumina before and after polishing operations (X-Ray fluorescence assay)

Chemical element	% BEFORE the polishing	% AFTER the polishing
Aluminum	54.5	63.2
Zircon	18.9	10.9
Sodium	13.8	8.9
Sulphur	0.8	3.9
Silicon	1.7	3.6
Iron	0.8	3.3
Potassium	1.9	2.2
Chlorine	4.2	1.9
Titanium	1.4	1.1
Calcium	0.6	0.6
Strontium	1.4	0.4

2.2. Methods

The flexural strength test was made according to ASTM C 78-2009. For each percentage of addition 3 test specimens were made. For the PC compositions to be assessed in different progressive temperature, as if they were in real fire, the samples were submitted to heat, where the variable was the mechanical strength loss, according to the proposed Hammel et. al. methodology (20-21). In this study, the author submitted polymeric composites to high temperature (800°C) for 1h, because he was testing geopolymers. After this period he measured the remaining mechanical strength. For this study the composite exposition temperatures were chosen by preliminary tests conducted in the oven. First of all, representative samples were tested at temperature intervals, 100°C each, until established maximum temperatures resisted by the samples before these samples display drastic degradation signs. Although the samples with additions resisted higher temperatures (about 470°C), for the samples not to show combustibility signs, the chosen temperatures for this work were: 125°C, 225°C and 325°C; for each temperature 2 samples were tested for each composition. The tests were conducted in a chamber oven, with heating speed ranging from 10 to 15°C per minute, and a potency of 7.7 Kw. According to Amiante and Botaro (22), the porosity tests are usually applied to determine the composite's durability, since the porosity reduction is an important sign of reduced permeability and, therefore, less material degradation. In addition, the material porosity is one of the factors which influences in the temperature evolution as well as in the fire spread (23). Even considering cement composites, the distribution pore analysis contributes to the understanding of this material property. For this test, the samples were cut with a diamond saw in the specimen holder dimensions (about 7 mm x 7 mm x 35 mm), for the porosity testing by mercury addition. The pore size filled by mercury during the test may be associated to the applied pressure by the Washburn equation (24), where:

$$d = \frac{-4 \cdot Y \cdot (\cos \theta)}{p} \quad [1]$$

d = pore diameter; Y = superficial mercury tension = 0.485 N/m; θ = contact angle between

Mercury and pore surface 140°; p = applied pressure: 250 MPa. The results of the tests underwent statistical analysis using the SPSS software package. In the analysis of variance (ANOVA), the total variance of a given response (dependent variable) is divided in two parts, the first related to the regression model and second to errors. Fisher test (F-test) is used to compare the components of the total deviation in the variables and test their statistical significance. The dependent variables in this test are the results of the flame propagation test and the flame propagation times. A significance level (α) of 0.05 was adopted. The tables use the following acronyms: **SQ** = sum of squares; **GDL** = degree of freedom; **MQ** = mean squared (= SQ/GDL); **F** = MQ/MQError (effect of interaction between factors); **S** = significance; **SI** = significant; **NS** = non-significant. The **S** factor reveals the significance of the factors or of their interaction. If S is less than 0.05, the interaction is significant and has an effect on the response.

2.3. Compositions of PC composites

After the initial analysis, an experimental program was proposed to assess the polymer concrete compositions listed in Table 3.

3. Results and discussion

This section presents and discusses the results of mechanical and microstructure tests in the samples of this study and their statistical analysis. The following codes are used to identify the compositions tested:

REF. – reference samples prepared only with aggregate and fillers but no addition of flame retardants.

R – samples prepared with aggregate, filler and the addition of polishing alumina residue.

A – samples produced with aggregate, filler and the addition of trihydrated alumina.

The numbers **15**, **30**, **45** and **60** in the tables with the results are the respective percentages of addition by weight of resin in the compositions. The binder content was always kept at 17% of the total mass of aggregate plus filler. **S** and **CV** are the standard deviation and variation

coefficient, respectively. All results underwent statistical analysis as described above.

3.1. Heating strength test

After the preliminary tests to determine the composites exposition temperature limits in this study presented in item 3.2.2.1, the samples were subjected to temperatures of 125°C, 225°C and 325°C being tested two samples from each composition for each temperature. Each two samples from each composition (R15, R30, R45, R60, A15, A30, A45, A60 e REF.) were kept in each temperature for one hour. After being taken out, the samples were put in a climatized room for 72 hours and so assessed in the flexural strength test. Table 4 displays the averages obtained in this mechanical strength test for each composition after being keeping oven in the above mentioned temperatures.

According to Table 4, it is observed that the composites R30, R45, R60, A15, A30 and A60 presented an increase in the flexural strength after being exposed to temperatures of 125°C for one hour. It is suggested this temperature has subjected the samples to a post-curing process, which usually favours the polymer strength increase. This conclusion was also presented in the research of Pinto et al. (26) who observed that the heat exposition of the polymeric composites, in an oven with forced air circulation working at 110°C in short periods (until 4 days), caused mechanical strength increase, which were attributed to the post-curing

Table 3
POLYMER CONCRETE MIXES

Components of PC	Composition	Mass, %
Resin	Unsaturated polyester from recycled PET	17 ^b
Initiator	Methyl ethyl Ketone peroxide (MEKP)	1.0 ^a
promoter	Cobalt naphtenate	1.0 ^a
Aggregate	River sand	100%
Filler	Fly ash	6 ^c
Additions	Polishing alumina residue	0, 15, 30, 45 and 60 ^a
	Trihydrated alumina	0, 15, 30, 45 and 60 ^a

a – b/w of binder; b – b/w of binder + filler; c – b/w of aggregate

Table 4
AVERAGE FLEXURAL STRENGTH FOR EACH COMPOSITION AFTER SAMPLES WERE SUBJECTED TO TEMPERATURES OF 125, 225° AND 325°C

Type-percentage	Average in room temperature	Average at 125°C	Average at 225°C	Average at 325°C	Ft loss at 325°C, %
R-15	31.6	31.1	20.8	18.7	40.8
R-30	25.9	29.2	22.5	22.9	11.5
R-45	31.6	32.6	24.7	21.4	32.2
R-60	31.2	34.5	29.1	23.0	26.3
A-15	30.9	31.5	25.7	20.4	33.9
A-30	24.5	31.5	26.8	17.2	29.8
A-45	31.9	28.9	27.3	25.9	18.8
A-60	30.5	35.2	27.0	22.8	25.2
REF.	30.5	29.2	22.3	16.3	46.5

reactions. The polymer unsaturated resins manufacturers suggest that the post-curing process in the composites must be done in temperatures ranging from 60 to 80°C (27, 28). This specification of the manufactures applies to the pure resin used, without aggregates, different from the PC case. In this study the inorganic elements, including aggregates, filler and additions, increase the composites post-curing temperature. Anyway, it is observed that in a the temperature of 125°C, this process of mechanical strength gain happened only in the composites with retardant addition, for it kept the composites temperature low, making it the ideal condition for the occurrence of the post-curing in these cases. This fact did not occur in the reference composite, which presented strength loss soon after the exposition at 125°C. From the temperature of 225°C it is observed that the mechanical strength loss begins, showing an even higher strength loss in the temperature of 325°C. Observing Table 4, except by the composites R30 and A45, it is noticed that the mechanical strength loss increases in the samples which present less quantity of flame retardant, both in the case of waste retardant as in the commercial one. It is suggested that this considerable mechanical strength loss reduction at a temperature of 325°C is due to the polymeric binder volatilization -the main reason for the composite's mechanical performance; however, it is the most susceptible material to the action of heat. In addition, it is suggested that the flame retardant additions aggregated a higher strength to the composites when subjected to the action of heat, especially when compared to the reference composite. Anyway, it must be emphasized that, although showing flexural strength loss after the samples were subjected to temperatures of 325°C, remaining values, after being in the oven, are close to the values presented in the researched studies (1-2, 6), pointing out that the same ones were not subjected to heat in these researches.

3.2. Test of heat resistance – Statistical analysis

The statistical analysis data, whose results were shown in item 3.2, are displayed in table. The results were not only analysed in relation to the percentage influence and addition type of the composites used in the study, but also concerning the temperatures to which the samples were submitted to. In addition, the above mentioned variances interaction was evaluated so that the significant factors for the composites behaviour in this test could be known.

Table 5

VARIANCE ANALYSIS OF RESISTANCE TO THE ACTION OF HEAT, ACCORDING TO DATA IN TABLE 5

VARIANCE	GLD	SQ	MQ	F	S	SIGNIFIC.
% os addition (A)	3	118.240	39.413	10.924	0.000	SI
Addition type (B)	1	11.455	11.455	3.175	0.081	NS
Temperature (C)	3	1021.571	340.524	94.380	0.000	SI
Interaction(AB)	3	6.127	2.042	0.566	0.640	NS
Interaction (AC)	9	153.228	17.025	4.719	0.000	SI
Interaction (BC)	3	30.289	10.096	2.798	0.050	NS
Error	49	176.793	3.608	-	-	-

According to Table 5, the results show that the factors temperature variance, percentage of addition and the interaction between these factors influenced the studied compositions ($\alpha= 0,000000$) to what the heat strength test is concerned. The types of flame retardant addition added in the composites did not show any influence in this test. Moreover, the interactions between the factors, type of addition and temperature and type of addition and addition percentage were not significant in the samples behaviour. In Table 5, regarding the waste retardant PC, it is observed that there was a mechanical strength increase related to the post -curing process, mainly in the composites with higher percentage addition: 30, 45 and 60%. In this way, and when compared to the reference composite behaviour, it is noticed that the waste retardant had an important influence on the composites protection against heat, since, without retardant addition it lost strength ,as expected. This fact occurred in Browne et al. (29) as well, where the authors subjected polymeric concrete samples to long high temperature exposition periods and concluded that the safe limit, without strength loss, would be around 60°C in case of continued exposition. Temperatures between 100 and 120°C would be acceptable for short periods, or could display mechanical strength loss. Davies ET AL. (30) tested the temperature influence on reinforced fibre-glass panels, made of phenolic resin, and subjected them to temperatures of 60, 90, 120, 150, 200 and 250°C. From the room temperature to the one of 250°C, the mechanical strength loss was 91%. According to this study that included a comparison with a numeric model of behaviour of this composites type, the authors agreed there was an agreement between the tests obtained results and the calculated ones. In this research, the mechanical strength loss was not expressive, for the composites displayed a higher inorganic elements quantity as well as aggregates and filler, giving them a greater efficiency to the action of heat. In this study, based on the data presented in Table 4.5, it is observed that the composite reference displayed a mechanical loss of 46.5% at a temperature of 325°C, when compared to the obtained results in room temperature. In relation to the waste retardant compositions, the least mechanical strength loss was observed for the composite R30, which had only a 11.5% loss strength. It is suggested that this may have occurred due to its absence of pores larger than 10 µm, which would then be the responsible for conducting the heat into the structure, thus weakening it. Nevertheless, it is observed that the highest mechanical

strength loss seen in the composites with waste retardant addition was displayed by the 15% addition composite. Anyway, the R15 composite had a strength loss even more inferior than the one displayed by the composite reference, which proves the waste retardant addition efficiency for the proposed use. According to what was proved by the statistical analysis, the type of flame retardant addition, waste or commercial, was not significant. In this way, it is observed that both additions displayed a similar behaviour when submitted to the action of heat, mainly when compared to the reference composite. When

it comes to the commercial retardant, except by the 45% addition, the other composites also displayed a mechanical strength increase after subjected to a temperature of 125°C, as observed in the waste retardant addition composites. As occurred with the waste retardant addition PC, the 15% commercial retardant addition PC also showed a higher mechanical loss, that confirms the significance shown by the statistical analysis in relation to the influence of flame retardant addition to the composites. However, regarding what also happened with the waste retardant addition, the A15 strength loss (33.92%) was also inferior than the composite reference loss, which displayed 46.5% of loss in relation to its behaviour without being subjected to heat.

3.3. Porosity by Mercury intrusion

Figures 3 and 4 show the relationship between the pore size and the pore volume for the four studied composites with the polishing alumina waste retardant addition in relation to the composite.

The pore analysis is important information for the mechanical behaviour understanding which is a fundamental property for a higher or lower flame propagation control in the composites in fire situation. The porosity may be a way for the access of the heat into the structures interior putting them mechanically at risk. It was not found in the researched literature data regarding the porosity analysis in polymeric concretes, probably due to the low pore percentage usually observed in this concrete type. It is known, however, that the composites conformation and its higher or lower permeability may put at risk not only its mechanical strength, durability as well as making it more susceptible to the fire attack in case of fire. In the figures, it is observed that, regardless the composite applied addition, the compositions with 60% addition displayed a higher quantity of intruded volume, and, therefore, bigger pore quantity. It is believed that this behaviour is due to the fact that these compositions have, in their total, a lower resin quantity for the embedded inorganic elements. This happened because of the resin quantity used as fixed in 17% in relation to the total aggregated mass + filler, regardless of the quantity of addition. Anyway, it is worth pointing out that the pore quantity shown by the A60 and R60 composites were no enough to put at risk its mechanical strength. This is proved through the mechanical behaviour test results, which showed 60% as being the highest one, regardless of the type of addition. This confirmation can also be observed in the flame spread test, where the composites with 69% addition displayed the shortest spread fire period. Among the studied composites, the 30% composition with retardant waste addition is pointed out; this composition behaved differently from the other composites, according to what is observed in Figure 3. This composite displayed a lower cumulative intrusion volume of mercury concentrated, mainly, in pores with diameter between 1 and 10 µm, not displaying pores with diameter larger

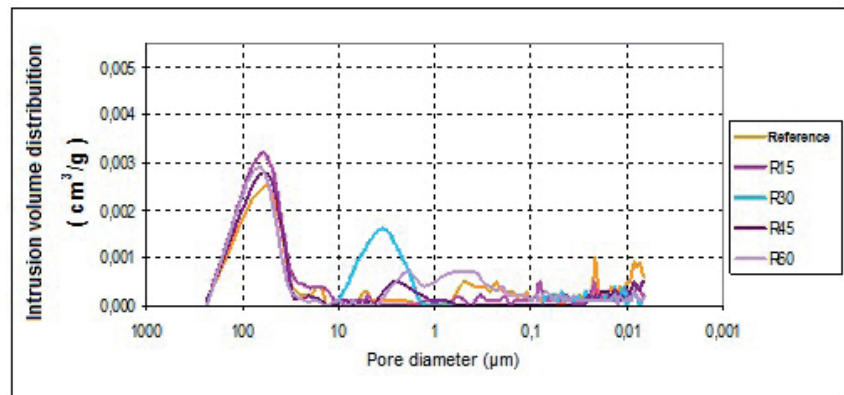


Fig. 3. Relation between pore diameter and the volume distribution obtained by PIM for the polishing alumina waste addition composites and reference composites

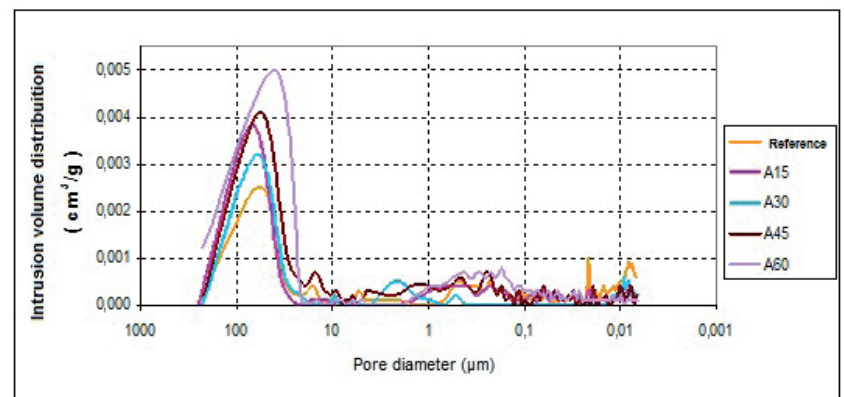


Fig. 4. Relation between the pore diameter and the accumulated volume obtained by PIM for the trihydrated alumina addition composites

than that one (differently from the other composites). According to the results, the R30 composite displayed the lowest strength loss after exposition at 325°C; it is suggested that this is not only due to the lower pore concentration displayed by this composite but also the absence of pores larger than 10 µm, fact that would hamper the entry of heat into the sample.

4. Conclusions

- The addition of flame retardant, commercial and waste, aggregated to composites increased strength against heat, especially when compared to the reference composite.
- After being subjected to the oven to 125°C for one hour, the compositions R30, R45, R60, A15, A30 and A60 showed a flexural strength increase, attributed to post-curing process, when compared to composites remained at room temperature.
- Increasing the temperature to 225 and 325°C had significant effect on the composites resistance loss, but the figures remaining after being subjected to the oven at 325°C are close to those reported in the literature. The composites with more additions of retarder (60%), for example, regardless of type, showed remaining flexural strength with values of 23.0 MPa (R60) and 22.8 MPa (A60). The biggest resistance decrease

was displayed by reference composite which showed a loss of 46.5% in its flexural strength.

- The statistical analysis indicated that the factors of temperature variation, the addition percentage and the interaction between these factors had influenced the compositions under study ($\alpha = 0.000000$) with regard to the heat strength test. The flame retardant addition type included in the composites did not show influence on this test. Moreover, interactions between factors, type of addition and temperature and type of addition and addition percentage were not significant in the samples behaviour .
- Regardless of the flame retardant addition or without using it, in the physical aspect, samples were subjected to temperatures of 125°C and 225°C apparently showed no signs of degradation or burning.
- The samples exposed to a temperature of 325°C showed signs of burning, with its darkened surface and part of its edges eaten, worn-looking, where the samples most affected were those that contained no addition of flame retardants of any kind.
- In general, the polymeric composites porosity of this research can be considered minimal when compared to conventional Portland cement concrete. For a conventional hardened cement paste with, for example, 28 days, and a water / cement ratio of 0.6, the amount of mercury would reach nearly 0.4 cm³/g (MEHTA and MONTEIRO, 1994). This value can be considered high compared to the value obtained by the composition of PC with a higher intruded mercury volume, which was 0.022 cm³/g (A60).
- Regardless of the addition used in the composites, composites with 60% addition of flame retardants had a higher mercury intruded amount volume and thus higher porosity. However, the number of pores made by the composite A60 and R60 were not enough to compromise its mechanical strength, even its resistance to the a fire or heat action, where these composites showed the best results
- The composite with 30% of waste retardant addition showed a lower cumulative mercury intrusion volume, concentrated mainly on the pore diameter between 1 and 10 µm, not showing ,unlike other composites, pores with diameters larger than this. Because of this, this composite showed the smallest flexural strength loss after its exposure to the heat strength test at 325°C.

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