A review about the use of industrial by-products in the lightweight aggregates production of expanded clay

A review about the use of industrial by-products in the lightweight aggregates production of expanded clay

J R Cáceres[1], **J P Rojas**[2], **and J Sánchez**[2]
[1] Grupo de Investigación Polímatas, Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia
[2] Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia

E-mail: joserafaelcr@ufps.edu.co

Abstract. The fabrication lightweight aggregates in recent years has included the addition of industrial by-products in the expanded clay manufacture as modifier agents of the expansion capacity, and also as a destination for the disposal of waste and residues in countries where lightweight concrete is used for the construction of high-rise structures. This article provides a review of the use of by-products as additives in the production of lightweight aggregates from expanded clay available in the literature. As a methodology, the bibliographic search was used through the consultation of specialized databases such as Sciencedirect and other documentary sources of open access scientific journals in several countries. The selection criteria for documents were specified according to the frequency the by-product use. 58 references on investigations by-products addition to the lightweight aggregates production were revised. In conclusion, the study of the use of Colombian byproducts as additives in the expanded clay aggregates production is suggested as a research subject due to the absence of articles related to this topic.

1. Introduction

This article reviews the addition of secondary materials such as by-products, waste and residues to the process of manufacturing lightweight aggregates from clay. The raw materials used for the lightweight aggregates production are natural minerals such as clays, slate and shales, to which are added known by-products such as flying ash, blast furnace slag and others [1]. The expanded clay aggregate is a product used in a constructions large number due to its lightweight properties, high strength and durability [2]. Being one of the main problems the waste generated minimization by the industries processes in the lightweight aggregates production; it's possible to include industrial by-products, waste and residues to be used in the construction industry and other applications [3-10]. Some of the main wastes used for the lightweight aggregates manufacture have been sewage sludge [11,12], industrial sludge [13], flying ash [14-16] and bottom ash from the incinerator [17-19], Mining residues [20-24]. The use of the aforementioned byproducts has a positive environmental impact and contributes to a more circular economy.

2. Process of lightweight aggregates production by clay expansion

Clay is the raw material for the lightweight aggregates production and is processed by forming appropriate size granules, with low density but with high resistance when they're sintered at high temperatures. The expanded clay aggregate production consists of the raw materials mixture, agglomeration or union of particles, hardening and sintering.

Figure 1. Clay expanded in the production process of light aggregates.

The lightweight aggregate produced from clay can be seen in Figure 1. The product must meet a series of specifications to be considered a lightweight aggregate. Worldwide there are numerous companies dedicated to the production of lightweight aggregates, for example, Leca (United Kingdom) and Fibo (Scandinavia) [25].

3. Mechanisms of clay expansion

The expanded clays study to be used as lightweight aggregates has a beginning with the work of Riley, 1951 [26], who studied the relationship between the chemical composition of clays and the ease of expansion based on the relationship SiO_2, Al_2O_3 and fluxes (CaO, MgO, FeO, Fe_2O_3, K_2O and Na_2O), in a ternary diagram. Later studies developed by Cougny, 1990 [27], included other factors that allow predicting the clay's expansibility, in particular temperature and presence of materials that generate gases during the sintering process.

Recently in 2016, Dondi [28,29] studied the effect of the by products addition on the clay's expansibility. The clay must contain enough gas-producing components and must reach the pyroplasticity at the point where the gas begins to form. The gas can be developed by a series of reactions, as shown in Table 1:

Table 1. Reactions involved in the expansion of the lightweight clay aggregate.

Process	Temperature
Volatilization of sulfides	400 °C
Decomposition of crystallization water from clay minerals	600 °C
Combustion of carbon-based compounds	700 °C
Carbonate decarbonation	850 °C
Reaction of Fe2O3, causing the release of oxygen	1100

4. By-products addition to the lightweight aggregates production process of expanded clay

The methodology used was the consultation of specialized databases such as Sciencedirect and other sources of open access scientific journals. A search strategy for the by-products use, as an additive in the lightweight aggregates manufacture was established.

Table 2 shows the related revised references. In addition, the most commonly used materials were established based on the frequency of use. In Table 2, it can be seen that flying ash is the most recently studied by-product, then there are ashes from the agro-industry, such as oil palm ash, kiln bottom ash, and by-products from large industries like aluminum, glass and dust captured in air pollution control systems.

Table 2. Research on the addition of industrial by-products to the production of aggregates.

By-product	References
Slag	[30]
Mining and steel slag byproducts	[4]
Palm ash	[4,31]
Flying ash	[4,20,32]
Kiln bottom ash (FBA)	[4,18]
Bayer process byproduct (red mud)	[33,13]
Dust product of the control of air pollution (APC)	[34,35]
Sand	[36]
Stone dust	[37]
Glass	[38,39]
Byproduct of granite sawing	[40]
Ashes of automotive plastics	[41]
Flying ash with high carbon content (HCFA]	[46]
Rejection of sepiolite (SEP)	[42]
Tailings of low iron in silicon	[43]
Ferrochrome slag	[44]

Table 3 has the revised references on the waste and residues addition to the aggregate production process. The definition of waste or residue is taken according to the original articles reviewed.

The most mentioned material is the sewage sludge which appears nine times in the search, probably associated with the large number of treatment plants existing around the world. Secondly, there is slag incineration of urban solid waste and fine clays sedimented in ports and canals, in all three cases they are wastes that accumulate in large volume and must be reused in some process to avoid being destined to a landfill.

Table 3. Revised researches on the addition of waste and residues to the aggregate production process.

Waste or Residue	References
Heavy metal sludge and paper, marine clay	[4]
Sludge treatment plant	[4,5,12,20], [45-49]
Mullite wool waste	[50]
Washing of aggregate sludge, sediment rich in clay	[5]
Grinding and polishing granite sludges, Porcelain tile mud	[6]
Incineration slag from MSW	[51-53]
Amber glass waste	[54]
Sludge made of steel	[10]
Masonry rubble	[55]
Aluminum recycling waste (NMP)	[56]
Fine clay sediments	[57,58]
Washing of aggregate sludge from a gravel pit	[20,45]
Waste containing boron (MBW)	[21]
Sludge from granite and marble (COR)	[42]

Table 4 shows that Asia, with Taiwan and China lead the study of the addition of by-products, waste and residues to lightweight aggregates, on the other hand, Europe is represented by the United Kingdom, Spain, Portugal and Germany. The main focus of research is the use of waste sludge from treatment plants for the two regions. The rest of the world is dedicated to researching the by-products, waste or residues that have the highest volume per country or possibly the worst environmental liability, such as the United Kingdom and Iran with red mud.

Table 4. Number of revised articles per country and topic.

Number of articles	Country	Byproduct, waste or residue	References
8	Taiwan	Residual sludge, fly ash, fine clay sediments, municipal incineration ash	[10,12,14,46,52,53,57,58]
6	China	Fly ash, iron tailings, ferrochrome slag, sewage sludge	[16,43,44,47,49]
5	UK	Residual sludge, red mud, bottom ash, fly ash	[11,13,17,19,38]
4	Spain	Mining waste, coal ash, sewage sludge	[5,20,42,45]
3	Portugal	Ashes for incineration, Pollution control wastes	[7,34,35]
3	Germany	Sludge from steel, rubble from masonry, sand sludge	[55,]
3	Australia	Automotive plastic waste, glass waste	[15,41,54]
2	South Korea	Kiln bottom ash, sewage sludge	[37,48]
2	India	Flying ash	[4,9]
2	Malaysia	Oil palm ash	[3,31]
1	Italy	Various	[6]
1	France	Polyurethane	[8]
1	Hong Kong	Ash bottom kiln	[18]
1	Turkey	Boron waste	[21]
1	Slovenia	Various	[22]
1	Holland	Various	[32]
1	Iran	Red mud	[33]
1	Tunisia	Sand	[36]
1	Lithuania	Various	[50]
1	Latvia	Aluminum waste	[56]
1	Vietnam	Glass	[39]
1	Egypt	Granite sawdust waste	[40]

5. Conclusions

From the consulted articles it was found that the most investigated by-product corresponds to fly ash, being the result of the combustion in thermoelectric plants. Among the waste and residues, the residual mud is the most studied to be used as an additive in the production of lightweight aggregate of expanded clay, followed by the incineration slag and clay sediments.

58 references on investigations of the addition of by-products, waste and residues to the production of lightweight aggregates were revised.

Research around the world is structured as follows: Asia is a leader, with Taiwan and China in the study of the addition of by-products, waste and residues of lightweight aggregates, on the other hand, Europe is represented by the United Kingdom, Spain, Portugal and Germany. The main focus of research is the use of waste sludge from treatment plants for the two regions. The rest of the world is dedicated to researching the by-products, waste or residues that have the highest volume per country.

In the search, articles developed with materials from Latin America were not observed. In particular, Colombia is not represented despite having a very important agroindustry that generates a large quantity of tons of byproducts, such as oil palm, coffee cisco or rice chaff. In conclusion, the study of the use of Colombian byproducts as additives in the production of expanded clay aggregates due to the lack of articles related to the subject is suggested as a research topic.

References

[1] Chandra S and Haber L 2002 *Lightweight aggregate concrete* (Norwich: Noyes Publications)
[2] Holm T A and Ries J 2007 *Reference manual for the properties and applications expanded shale clay and salte lightweight aggregate* (Chicago: ESCSI)
[3] Shafigh P, Mahmud H B, Jumaat M Z B, Ahmmad R and Bahri S 2014 *Materials and Design* **60** 320–327

[4] Priyadharshini P, Mohan G, Santhi A S, 2012 *International Journal of Earth Sciences and Engineering* **5(3)** 540-546
[5] González-Corrochano B, Alonso-Azcárate J, Rodas M, Barrenechea J F and Luque F J 2011 *Construction and Building Materials* **25** 3591
[6] De Gennaro R, Graziano S, Cappellett P, Colella A, Dondi Michele, Langella A and De Gennaro M 2009 *Environmental Science & Technology* **43(18)** 7123-7129
[7] Vilarinho C, Castro F, Mendonça B and Coelho C 2009 Incorporation of wastes in lightweight aggregate of expanded clay for Construction Applications *ISWA World Congress 2009* (Lisbon) (Wien: International Solid Waste Association) p 1-12
[8] Ben Fraj A, Kismi M, Mounanga, P 2010 *Construction and Building Materials* **24** 1069–1077
[9] Nadesan M and Dinakar P, 2017 *Case Studies in Construction Materials* **7** 336-347
[10] Wei Y L 2017 *Journal of Cleaner Production* **165** 905-916
[11] Cheeseman C R, Virdi G S 2005 *Conservation and Recycling* **45** 18-30
[12] Chiou I J Wang K S and Lin Y T 2006 *Waste Management* **26(12)** 1453–1461
[13] Molineux C J, Newport D J, Ayati B, Wang C, Connop S P, and Green J E 2015 *Journal of Cleaner Production* **112** 401-408
[14] Chen H-J, Shun Y-W and Chao W-T 2010 *Construction and Building Materials* **24** 46-55
[15] Liu P, Farzana R, Rajarao R and Sahajwalla V 2017 *Construction and Building Materials* **145** 283–291
[16] Lo T-Y, Cui H, Memon S A, Noguchi T 2015 *Journal of Cleaner Production* **112** 753-762
[17] Cheeseman C R, Makinde A and Bethanis S 2005 *Conservation and Recycling* **43** 147–162
[18] Zhang B, Sun Poon C, 2015 *Journal of Cleaner Production* **99** 94-100
[19] Ciaran J Lynn, Ravindra K Dhir and Gurmel S Ghataora 2016 *Construction and Building Materials* **127** 504–517
[20] González-Corrochano B, Alonso-Azcárate J and Rodas M 2009 *Journal of Environmental Management* **90** 2801–2812
[21] Kavas T, Christogerou A and Pontikes Y 2011 *Journal of Hazardous Materials* **185** 1381–1389
[22] Ducman V and Mirtic B 2009 *Waste Management* **29** 2361–2368
[23] Ayati B, Ferrándiz-Mas V, Newport D, Cheeseman C 2018 *Construction and Building Materials* **162** 124-131
[24] Tarek I A, Ahmed Abd E-W 2017 *Applied Clay Science* **150** 10-15
[25] Clarke J L 2005 *Structural lightweight aggregate concrete* (London: Blackie Academic & professional)
[26] Riley C 1951 *Journal of the American Ceramic Society* **34(4)** 121-128
[27] Cougny G 1990 *Bulletin of the International Association of Engineering Geology* **41** 47- 55
[28] Dondi M, Cappelletti P, D'Amore M, de Gennaro R, Graziano S F, Raimondo M and Zanelli C 2016 *Construction and Building Materials* **127** 394–409
[29] Loutou M, Hajjaji M M 2017 *Applied Clay Science* **150** pp 56–62
[30] Moayeri M ,Ashrafi H, Beiranvand P 2017 *Buildings* **7(1)** 2
[31] Lau P C, Teo D C L and Mannan M 2017 *Construction and Building Materials* **152** 558–567
[32] Sarabèr A, Overhof R, Green T and Pels J 2012 *Waste Management* **32** 144–152
[33] Nikbin I M, Aliaghazadeh M, Charkhtab S H and Fathollahpour A 2017 *Journal of Cleaner Production* **162** 2683-2694
[34] Quina M, Almeida M, Santos R, Bordado J, Quinta-Ferreira R 2014 *Applied Clay Science* **102** 71–80
[35] Quina M, Bordado J, Quinta-Ferreira R 2014 *Waste Management* **3** 430–438
[36] Fakhfakh E, Hajjaji W, Medhioub M, Rocha F, Lopez Galindo A, Setti M, Kooli F, Zargouni F and Jamoussi F 2007 *Applied Clay Science* **35(3-4)** 228–237
[37] Han M C, Han D and Shin J K 2015 *Construction and Building Materials* **99** 192–199
[38] Kourti L, Cheeseman C 2010 *Resources, Conservation and Recycling* **54** 769–775
[39] Bui L A T, Chao-Lung H, Kae-Long L, Yuan-Yuan C and Mung-Pei Y 2013 *Construction and Building Materials* **47** 334–339
[40] Abdel M M S, Wolf-Achim K, Fawzia A E-R, Baher A-H E-K, Mohamed A-K S and Noha A A K 2016 *Journal of Cleaner Production* **117** 139-149
[41] Vijayalakshmi R and Ramanagopal S 2018 *Indian Journal of Science & Technology* **11(16)** 1-12
[42] Moreno-Maroto J M, Gonzalez Corrochano B, Alonso Azcarate J, Rodriguez L and Acosta A 2017 *Cement and Concrete Composites* **83** 335-348
[43] Yang C, Cuin C, Qin J 2015 *Ceramics International* **41** 1213–1221
[44] Zhang L, Zhang Y, Liu C, Liu L and Tang K 2017 *Construction and Building Materials* **142** 31–41

[45] González-Corrochano B 2016 *Construction and Building Materials* **116** 252–262
[46] Huang C-H and Wang S-Y 2013 *Construction and Building Materials* **43** 174–183
[47] Li Bo, Tung C-L Quc L and Wangc Y 2016 *Construction and Building Materials* **114** 119–126
[48] Mun J K 2007 *Construction and Building Materials* **21** 1583–1588
[49] Wanga X, Jin Y, Wang Z, Nie Y, Huang Q and Wang Q 2009 *Waste Management* **29** 1330–1335
[50] Malaiškiene J, Vaiciene M Zurauskiene R 2011 *Construction and Building Materials* **25** 3869–3877
[51] Castells X, 2012 *Reciclaje de residuos industriales: Residuos sólidos urbanos y fangos de depuradora* (Madrid: Ediciones Díaz de Santos S.A.)
[52] Lu C-H, Chen J-C, Chuang K-H and Weya M-Y 2015 *Construction and Building Materials* **101** 380–388
[53] Chen H-J, Wang S-Y and Tang C-W 2010 *Construction and Building Materials* **24** 46-55
[54] Mohajerani A, Vajna J, Homan Cheung T H, Kurmus H, Arulrajah A and Horpibulsuk S 2017 *Construction and Building Materials* **156** 443–467
[55] Mueller A, Sokolova S N and Vereshagin V I 2008 *Construction and Building Materials* **22** 703-712
[56] Bajare D, Korjakins A, Kazjonovs J and Rozenstrauha I 2012 *Journal of the European Ceramic Society* **32**141–148
[57] Chen H-J, Tang M-D, Tang C-W and Wang S-Y 2012 *Construction and Building Materials* **28** 387–394
[58] Hwang C-L, Bui L A-T, Lin K-L and Lo C-T 2012 *Cement & Concrete Composites* **34** 1159–1166