Fly Ash and Silica in Expanded Polystyrene Concrete: Finding the Research Gap (preliminary study)

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ABSTRACT
There are various types of lightweight concrete that already exist today. In producing lightweight concrete, the use of added materials in lightweight concrete has been widely studied. Among of those materials, fly-ash and silica based material are commonly being used as additive material in concrete. The purpose of this literature research is to determine the extent of the use of fly-ash and silica in Expanded Polystyrene (EPS) lightweight concrete. From several studies that have been done previously, lightweight concrete from EPS was quite significant to give good results in order to reduce the unit weight of concrete, but has not shown the expected compressive strength results. The literature review method to gather information about the use of fly ash and silica in EPS lightweight concrete will be conducted in a systematic way. Data search was performed on qualified journal databases such as Science Direct and Scopus. The timeframe of journals taken was that published between 2000-2020 to ensure getting the latest research. From the results of observing and searching the article, there were at least two methods of using fly-ash and silica as added material, which were in pure/as-is form (as part of concrete mixture material) and modified form (both modifying the form of fly-ash and silica or as part of modifying the aggregate). The use of fly-ash and silica have shown positive results in improving the quality of lightweight concrete. But from the literature search results, there were still many gaps or things that can be developed and processed to look for other mixed methods and materials. This can increase the ability of fly-ash and silica as an additive material in order to create better EPS lightweight concrete.

Keywords: Lightweight Concrete, Expanded Polystyrene, Fly Ash, Silica, Literature Review

INTRODUCTION
There are various types of lightweight concrete that already exist today. Lightweight concrete is concrete that has a weight less than 2000 kg/m3 [1]. There are 3 methods for creating lightweight concrete. Those method are by removing fine aggregate components, by creating air bubbles in the concrete or often called aerated concrete [2], and by using/replacing coarse aggregate with light weight materials. This kind of material could come from natural resources, fabricated material, or made on purpose/artificial [3], [4]. An example of the use of fabricated materials that have been widely used as lightweight aggregates in concrete is Expanded Polystyrene [5]. The use of Expanded Polystyrene (EPS) is proven to be able to reduce the dead weight of concrete [6], and has good heat insulation capabilities [7]. However, EPS concrete still has weaknesses, including low compressive strength and a lack of resistance to fire [8]. Therefore, although a lot of research has begun to be done to overcome this weakness, further research still needs attention and becomes an interesting topic to discuss.

The use of additives in the concrete mixture is expected to be able to improve performance and cover the shortcomings of lightweight concrete. Fly ash (FA) and silica based material are kind of material that commonly used as an additive in concrete. Fly ash is the residual burning material from coal from power plants [9]–[12]. The chemical composition of FA consists mostly of silicate dioxide (SiO2), alumina (Al2O3), iron dioxide (Fe2O3),

calcium oxide (CaO) [6]. Based on the composition of these constituents, there are two categories of fly ash, namely class C and class F. Class C is fly ash with a CaO content of more than 20%, and a combination of other compositions (SiO2 + Al2O3 + Fe2O3) of at least 50%, while class F fly ash has a CaO levels less than 10% with other compositions (SiO2 + Al2O3 + Fe2O3) of at least 70% [12]. As for the physical appearance, FA can be in the form of powder [13] but also in the form of hollow grains or cenosphere [14]. The use of cenospheres fly ash tends to have the ability to create better density [15] which can lead to better compressive strength and low water absorption. However, the use of metakaolin seemed to have a better result in permeability than the fly ash [16]. Moreover, class C cenosphere influenced the reduction of the compressive strength at temperatures above 400 °C due to the dehydration and dehydroxylation processes [17].

The use of fly ash in the concrete mixture usually functions as a binder and replaces a portion of the cement volume based on a certain proportion starting from 10% [6], [18], 30% [19], [20], 50% [9], [21], even up to 70% [22]. Furthermore, another application of fly ash has been successfully used as a coating material using the encapsulation technique in order to make artificial aggregates [23] and is also used as a brick making material [24] even though it has not shown satisfactory results yet. On the other hand, because of FA has cementitious material properties, it is potential to be used as a full subtitution material of the portland cement in the concrete mixture [25] especially for class C fly ash [12]. This kind of concrete, which produced from fly ash as a cement substitute, is called geopolymeric concrete [10], [26]–[28]. Geopolymeric concrete is believed to be concrete that is more environmentally friendly. Apart from as a waste/residual material from burning coal, the use of fly ash is also expected to reduce or even eliminate dependence on cement. Until now, cement still has been the main component in making concrete. However, the cement production process, which leaves a large carbon footprint, is feared to have environmental damaging effects in the long term. Therefore, researchs on component reduction or even substitution of cement materials that are more environmentally friendly are interesting topics to study.

Materials containing silica (SiO2) become interesting to study since these components are also present in cement with a composition of about 20% [4], [23], [29]. Silica-based materials are believed to have an impact on the properties and characteristics of concrete. Therefore, many studies have used silica-based aerogels [8], [30]–[32], silica fume [20], [26], [33] or natural silica sand [34] with the aim of adding value to the concrete. Airgel based on silica material with a composition of 94–99% of the volume being air voids [8] effective to produce a lightweight concrete (410 kg.m3) with thermal conductivity value (0.085 W.m~1.K~1) [30]. On the other hand, silica in powder form or often known by other names such as micro silica, condensed silica fume, volatilzed silica or silica dust [35] is proven to have a positive impact in increasing the compressive strength of concrete [36]. However, the excessive use of silica fume actually has an impact on the increasing need for superplasticizers [37] and it is advisable to limit it to the percentage of replacement for cement to an amount of 10% micro-silica and 2% for nano-silica.

There have been many studies and articles discussing the use of fly ash and silica in concrete. However, specific research that discusses the use of fly ash and silica fume especially in lightweight EPS concrete still needs to be explored more because of its good potential as an environmentally friendly building material [38]. This literature review will aim to identify and analyse the development of research on EPS lightweight concrete, especially in the use of fly ash and silica as an additive/supporting material.

RESEARCH METHODOLOGY

A systematic literature review (SLR) adapted from Wahono 2015 [39] was used as a method in this study. This SLR consists of 3 major stages, namely: the planning stage, the conducting stage and the reporting stage (Fig. 1).

In the first stage the requisite for systematic review was identified. Then, a guidance or protocol was made to driven the searching of the suitable literature. This stage include the preparing of the search string or keywords by

using boolean operator system. The next stage, the selected articles/papers were analysed and then finally that findings being reported. The significances conducting the literature review were discussed in the introduction previously and transformed into research questions.

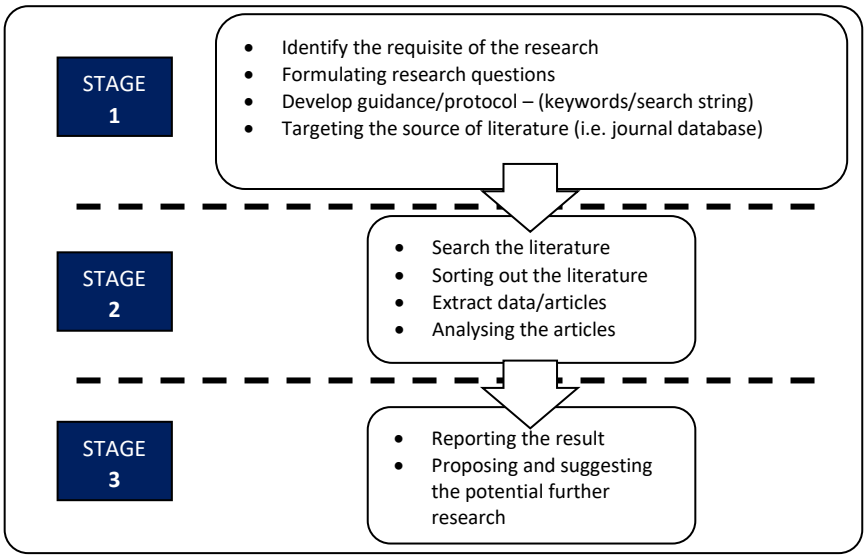

Fig. 1. Literature Review Stages

The research questions designed with the help of CIMO-logic [40] instead of using SPIDER [41] or PICOC [39]. Table 1 describe the CIMO structure as the basic for formulating research questions.

Table 1. Summary of CIMO

C (Context)	Previous study/research related to EPS lightweight concrete
I (Intervention)	Additive material that can enhance and give beneficially impact to concrete properties
M (Mechanisms)	A systematic literature review to gain information and supporting data
O (Outcomes)	Better properties of EPS lightweight concrete

Table 2. Research Questions

Research Questions	Aim and Objectives
What types of additive are currently widely used as additives	Identify characteristics of additive material (fly ash and silica)
How the added material affects the properties of the concrete	Identify the method, and impacts of additive material (fly ash and silica) on EPS lightweight concrete
What are the opportunities for further research	Identify the gap from previous research

After determining the direction and purpose of the research, the search process begins by preparing keywords to be used as search strings on search engines in electronic journal databases. The process of making search strings is carried out with the help of boolean operators ANDs and ORs, by combining keywords that can reflect the purpose of the research, and ensuring article searches can be more directed and as expected. Keywords / search string used in the search process: ("lightweight concrete") AND ("expanded polystyrene") AND ((silica) OR (fly ash)).

The designated electronic journal databases were Scopus and Scicence Direct. The selection of this database is

based on the consideration that these two sources are trusted journal indexing institutions and are connected with many prestigious journals that publish articles resulting from good selection or review processes. Journal databases cannot be accessed by just anyone, especially when doing data extraction / downloading articles. Therefore, with the access that the researcher has, who is currently a post graduate student at Coventry University-United Kingdom, it is possible to do this. The search for articles is limited to the year published in the last 20 years (2000-2020) to ensure that the articles obtained were the result of the most recent studies. From the search process that has been previously carried out, it is also necessary to limit the choice to only review and research articles to reduce data which is sometimes only a table of contents from a conference.

There are 179 articles from the search results of the journal ScienceDirect journal, and 15 articles from the Scopus database. The total number of articles detected was 194 articles. From these 194 articles, a sorting process was carried out with the help of a reference manager software by first extracting / downloading metadata containing the article identity and abstract. The software used is Mendeley. Mendeley itself is free software and is quite easy to use. From the results of this collection, it was detected that there were 8 similar articles (duplicate articles). For this reason, at this stage the first selection process was carried out, leaving only 186 articles left. Of these 186 articles, the titles and abstracts of the articles were screened. This screening process used criteria that have been previously prepared (table 3).

Table 3. Inclusion and Exclusion Criteria

Inclusion	Article which contain and discussing: Fly Ash, Silica, Expanded Polystyrene, and Concrete
Exclusion	Articles not written in English ; Repository Access

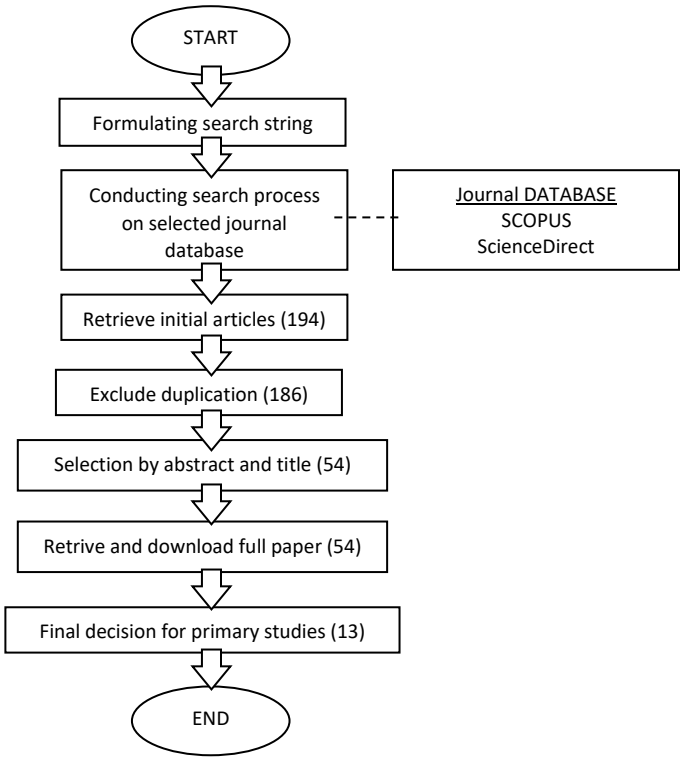

Fig. 2. Searching and selecting process

After going through the sorting stages based on the title and abstract, there were 54 suitable articles and then the data extraction process was carried out by downloading the complete articles. The articles are then stored and managed using Mendeley software, then the analysis process is carried out with the help of NVivo data analysis

software. Unlike Mendeley, which can be accessed for free, NVivo is a software produced by QSR International and Coventry University has a licence for it so that it can be used by students.

Of the 54 articles obtained, not all of them discuss the use of fly ash or silica in EPS concrete. Many articles were found to contain only one keyword to be discussed. Therefore, another selection was carried out to select articles as the main articles that were in accordance with the research objectives. From this process, 13 articles were obtained which were deemed very suitable for the research objectives. However, from those 54 articles several data and information were observed related to the research about fly ash and silica in lightweight concrete. The process of searching and selecting articles is briefly shown in Figure 2.

RESULT, ANALYSIS AND DISCUSSION

This section will present several things that specifically discuss the effect of fy ash and silica on EPS lightweight concrete. While the search results of literature on fly ash and silica in general have been explained and used as an introduction.

In previous research, Cadere (2018) observed that fly ash in EPS concrete was not enough to uniform the distribution of polystyrene granules [6]. This result was different from what Wu (2007) had previously done, which stated that there was no bad distribution or segregation in EPS concrete [42]. There is a possibility because Wu (2007) first activated fly ash by using an alkaline solution. Activated fly ash was able to produce better concrete mixing.

Fly ash is also able to provide an effect on the level of workability and flowability which is very good when used as an additive to EPS self compacting concrete [43], although not as good as the effect produced when using silica fume [44]. Nekooi's research can answer the problem that have occurred in previous studies [25] which showed a decrease in the value of workability along with the addition of fly ash content. From the explanation in Herki's article (2013) which includes information about the high carbon content, it can be predicted that the fly ash used by Herki was classified as fly ash class C different from that used by Nekooi (2015). This showed that although class C fly ash classified more cementitious material than class F fly ash, the influence on the level of workability and flowability is not good. There are opportunities to do more research on the types of class C fly ash.

The problem of segregation in EPS concrete can be overcome by adding silica to the concrete mixture, but this becomes less effective with the addition of EPS beads content in the concrete [36]. by adding silica to EPS concrete can produce concrete that has a good density, because silica is able to fill the gaps between the agegrat with cement paste. Moreover, the smaller the silica grain size, the better the concrete density [45]. Silica makes the bond between EPS beads and cement better, but too much silica can increase the need for superplasticizer to maintain good workability [37].

Both fly ash and silica fume are able to cover the weaknesses of EPS concrete regarding the compressive strength of concrete. Fly ash [21] dan silica [45] as a substitute for some of the cement elements it can increase the compressive strength value of concrete, even though the value decreases with the increase in the amount of EPS in the concrete. The increase in compressive strength of concrete using fly ash tends to be slow in the early ages of concrete [21], but it still showed a trend of increasing concrete strength as the concrete ages. On the other hand, EPS concrete containing silica shows a very rapid increase in the early age of the concrete [33]. The more silica content the faster the development of the increase in compressive strength [46]. Therefore, the use of silica-based additives can be an option if you need concrete that has better early-age performance [43].

Table 4. Selected Article as the Primary Studies

	Chemical Composition	Silica (SiO_2)	Alumina (Al_2O_3)	Ferric oxide (Fe_2O_3)	Calcium oxide (CaO)
Babu2003 [33]	Cement	21.78	6.56	4.13	60.12
	Fly Ash				
	Silica	74.07	2.22	1.57	2.95
Chen2004 [45]	Cement				
	Fly Ash	not recorded			
	Silica				
Babu2005 [21]	Cement	21.78	6.56	4.13	60.12
	Fly Ash	58.29	31.74	5.86	1.97
	Silica				
Babu2006 [20]	Cement	21.78	6.56	4.13	60.12
	Fly Ash	58.29	31.74	5.86	1.97
	Silica	74.07	2.22	1.57	2.95
Wu2007 [42]	Cement				
	Fly Ash	57.8	29.5	2.9	0.7
	Silica				
Chen2010 [36]	Cement	21.6	4.13	4.57	64.44
	Fly Ash				
	Silica	92.4	0.8	0.5	0.91
Chen2011 [46]	Cement	21.6	4.13	4.57	64.44
	Fly Ash				
	Silica	92.4	0.8	0.5	0.91
Madandoust2011 [44]	Cement	21.46	5.55	3.46	63.95
	Fly Ash				
	Silica	91.7/99.9	1	0.9	1.68
Sadrmomtazi2012 [47]	Cement	21	4.6	3.2	64.5
	Fly Ash				
	Silica	91.1	1.55	2	2.42
Herki2013 [25]	Cement	22.8	3.8	1.4	66.5
	Fly Ash	13.2	6.7	6.2	1.4
	Silica				
Nekooie2015 [43]	Cement	23.5	5	3.4	62
	Fly Ash	51.2	24	6.5	5.6
	Silica	93.7	0.29	0.36	0.4
Fathi2017 [37]	Cement	27	5.2	4.6	65
	Fly Ash				
	Silica	85-92/99	1	2	10.5
Cadere2018 [6]	Cement				
	Fly Ash	*18.37*	*13.09*	*4.01*	*3.17*
	Silica				

Data analysis software can be used to find words that are often used in articles. This is useful for knowing what sections get the most attention or are discussed in selected articles. The analysis result showed that the word "strengths" was quite dominant comes after the words "concrete" and "EPS". This showed that the selected articles mostly discussed the strength or mechanical properties of concrete.

Fig. 3. 15 most frequent words from selected paper

Apart from compressive strength, the addition of fly ash [20] and silica [37] on EPS concrete is able to have an impact on reducing the water absorption value. This can be possible because the element of EPS beads is hydrophobic and there are also added materials such as fly ash and silica which can increase the density of the concrete. With a good density level, EPS concrete with fly ash or silica has the potential to be more resistant to high temperatures, corrosion and other chemicals attack. From the results of this literature search, there is still lack of information about the influences of fly ash and silica in EPS concrete related to its performance on thermal conductivity.

CONCLUSIONS

From the results of the literature review activities that have been carried out, several conclusions can be drawn as follows: From the results of the literature review activities that have been carried out, several conclusions can be drawn as follows:

1. Planning and conducting searches and systematically analyzing literature from journals can help to find articles that can answer our research questions. Searching and analyzing articles in a systematic manner allows for a more comprehensive source of information and reduces the researcher's subjectivity and bias. By applying these stages, the literature review process can be justified and may give better confidence in reading the results of the review.
2. Fly ash and silica fume have a positive impact on lightweight EPS concrete. However, the use of these materials will be maximized when combined with other materials.
3. Class F fly ash tends to be more widely used as an additive to lightweight concrete, especially lightweight EPS. Although the chemical composition of class C fly ash contains more CaO, which can make this type of fly ash more like cement, class C fly ash is not widely used. Maybe this is due to the difficulty to get it. However, we can observe that Fly Ash class C has the potential as a better cement substitute and is interesting for further study. Activated fly ash has a better effect than unactivated fly ash. There are still opportunities for further research on modification of the use of fly ash in order to provide added value and maximize the potential of the fly ash material itself on the properties and characteristics of the resulting concrete.
4. The use of silica-based materials in lightweight EPS is still a lot of powder, both micro and nano-sized. The smaller the size of the silica particles will have an impact on the density level of the concrete which is denser, but with the consequence of the increasing need for water as a solvent or the need for added materials such as

superplasticizer which can increase the cost of making concrete. Based on previous research on other types of lightweight concrete, the use of silica-based aerogel is very effective at reducing the weight of the concrete and is also able to provide other added values such as insulation ability. There have not been many studies regarding the combination of this material with EPS as concrete aggregates which can be used as a discussion that has the potential to be further explored.

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