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Compressive Strength of Foamed Cement Composites with the Addition of Fly Ash and Polystyrene Beads

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Abstract: Foamed cement composites with lightweight properties and strength improvement have drawn the attention amongst the researchers towards sustainability concern in the construction industry. This paper presents a study of the compressive strength in foamed cement composites, which has utilized fly ash as waste material and polystyrene beads in the various mixture proportions. In the research, two sets of A and B samples with the same mixture proportions have been produced but consumed the different content of polystyrene beads of 0.1 wt. % and 0.3 wt. % respectively. Two other sets of A and B also have the same proportions, but the samples are sent into the furnace to decompose the polystyrene beads before being compress. According to the results, the decomposed samples with the addition of 0.1 wt. % of polystyrene beads were found to have the highest compressive strength as compared to 0.3 wt. %. Besides that, the highest content of fly ash added in the mixture has also contributed to the best results of compressive strength in the foamed cement composites as well. Therefore, the decomposed of 0.1 wt. % polystyrene beads are more suitable to be used in order to produce stronger foamed cement composite and at the same time will minimize the usage of sand, reuse the waste material, and preserve the environmental ecology.

Key words: *Fly ash, polystyrene beads, foamed cement composites, compressive strength*

INTRODUCTION

Nowadays, cement composite had been chosen to be one of the most important components to produce foamed cement composites. Basically, cement composite is a mixture which use cement as a basic material to mix up with water at certain proportion to form a composite [1] such as mortar which widely used for plastering and other building works. Owing to waste concern, the sustainability construction industry becomes the priority all over the world due to the detrimental effects happened. For this reason, there are many waste materials utilized in the concrete industry. Industrial processes such as power plant generate vast amounts of fly ash. The majorities of these have no specific use and are dumped in landfill sites. Therefore, it is necessary to establish recycling procedures or ways of reusing fly ash in order to minimize its environmental impact. Several types of research are in progress to find out the various ways to utilize fly ash to restrain the environmental problems as well as effectively use them to produce new reusable materials [2]. Fly ash had been added to cement composite in order to increase its performance to suit with several conditions such as to increase its ultimate strength [3]. In the same way, polystyrene is one of the favorably popular industrial material especially in the packaging industry, which tends to cause pollution and harmful to the ecosystem. In fact, polystyrene is a non-biodegradable material and taking thousands of years to decompose in case of land filing and creating hazardous effects on the environment [4]. Despite its shortcomings, this material also has several advantages to be chosen as alternative materials in the construction industry. In particular, the automotive industry generates a large amount of waste resulting from the manufacture of rigid polyurethane foam panels [5]. When these are destroyed and crushed, they are converted into low-density particles which can be useful in the manufacture of lightweight materials. The addition of these polymer foam wastes to lightweight mortar and concrete is potentially a viable alternative for their disposal.

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THE USAGE OF FLY ASH IN CEMENT COMPOSITES

Generally, fly ash is a waste product which was extracted from the burning of coal, mostly is a power plant in Malaysia for electricity-generating purpose. Fly ash consisting mostly of silica, alumina, and iron, forms a compound similar to Portland cement when mixed with lime and water. Fly ash is a non-combusted by-product of coal-fired power plants and generally ends up in a landfill. There are two types of fly ash according to ASTM C-618 [6], which are Class C and Class F. However, Class F fly ash is more widely used in the manufacturing of fly ash concrete in industry, owing to its properties that able to produce concrete with higher ultimate strength compare to Class C fly ash. Moreover, the concrete made with Class F fly ash also exhibits improved resistance to sulphate attack and chloride ion ingress. Naturally, fly ash is composed of tiny spherically shaped particles that act like ball bearings, make it able to fill small voids and produce denser cement composites that require less water for installation which resulting in water savings [7]. In addition, it also lowers the heat of hydration, in turn reducing shrinkage and thermal cracking [8, 9]. Out of the research made by the expert, it is shown that fly ash cement composite has a lot of benefits that are less energy-intensive manufacture, higher ultimate strength, more durable, requires less water, uses a waste by-product, and creates fewer global warming gases [7]. Fly ash also can be substituted for a large portion of cement, to create cement composite which has higher ultimate strength compare to other conventional cement composite product. Consequently, there are lots of new cement composite’s product in the market are using fly ash as partial cement replacement in cement composite mixture. However, this method is considered a bit unsuitable as the more fly ash use as partial cement replacement in the cement composite mixture. On the other hand, this situation will indirectly cause the cement composite to require a longer time before it is fully set, or it means that cement composite which using fly ash as partial cement replacement will have slower hydration rate [10]. A research done by Ravina (1997) [11] by substituting fine aggregate with fly ash had found that there are several advantages compared to the conventional one. Due to the fineness and to the predominantly spherical shape of fly ash particles, fly ash has a plasticizing effect on the fresh concrete mix. Besides that, the previous researches towards fly ash as a material to partially replace cement or fine aggregate found that fly ash has an ability to increase the workability and ultimate strength for cement composite [12, 13, 14].

FOAMED CEMENT COMPOSITES

From another angle, polystyrene foam widely use in packaging and some building material which require good heat insulation, such as wall panel and partition. Basically, polystyrene is an aromatic polymer made from themo-nomer styrene, which is known as thermocole, where a liquid hydrocarbon that is manufactured from petroleum by the chemical industry. Polystyrene is a thermoplastic substance, which is in solid state at room temperature, but flows if heated above its glass transition temperature of about 100 °C and becomes solid again when cooled. Pure solid polystyrene is a colorless, hard plastic with limited flexibility. It can be cast into molds with fine detail. Polystyrene can be transparent or can be made to take on various colors. Solid polystyrene is used for disposable cutlery, plastic models, disc cases, and smoke detector housings. Products made from foamed polystyrene are nearly ubiquitous, for example packing materials, insulation, and foam drink cups [15]. In the aim of civil engineering, foamed cement composites are the value-added products for lightweight construction applications. Foamed cement composites have a number of properties which make them attractive for the cores of constructing the non-load-bearing structure for the building, such as partition panel, architecture components, and roof covering [16]. Foamed cement composites are stiff, cheap, lightweight and incombustible. Indeed, their thermal conductivity is higher than other conventional construction material, which makes them one of the newest and compatible materials which can be widely applied onto building in the future. Because of their low cost, foamed cement composite can be compensated for by the use of thicker sections. Besides that, foam cement composite offers many unique benefits over other forms of cement composite [17] including good energy-absorbing properties, highly fluid material which is suitable for pumping over long distances, will not break down when attacked by hydrocarbons, bacteria or fungi. However, their main limitation is their brittleness and low tensile strength [18]. According to Mohd Roji Samidi (1997) [19], foamed cement composites are very sensitive to water content in the mixtures, and mixing time is longer than conventional concrete to assure the proper and homogenous results. When a polystyrene granule is ripped out of foamed cement concrete, the emerged ‘hole’ closely repeats the structure of the granule and there is some polystyrene residue left in it. This proves that the foam cement concrete contact zone is stronger than the polystyrene granule material [14]. When fine polystyrene granules are used, it disintegrates along the contact zone. Such composite has the lowest adhesion strength; however, it is stronger in comparison with a composite, made with different foam polystyrene granules, provided by the better macrostructure [7]. Strength and thermal conductivity of the composite depend on its density, the filler, and its sort and amount used [20]. Research by Ravindrayah (1999) [13] showed that by replacing 10, 20 and 30 percent from the total volume of the coarse aggregate with polystyrene beads, the density of concrete reduces from 2455 kg/m³ to 2330, 2210 and 2080 kg/m³, respectively. Besides that, polystyrene aggregate concrete is more durable when it is subjected to sulphate attack or freeze-thaw cycles. When conventional cement is used, problems such as zonal isolation, formation fracture and lost circulation may be encountered and the use of foamed cement may be one of the most effective methods to eradicate related problems.

COMPRESSIVE STRENGTH OF FOAMED CEMENT COMPOSITES

A compression test is a test that practices defining the maximum compressive strength of a sample with a size of 40 mm x 40mm x 100 mm. Foamed cement composite had been mix according to the design mixture as tabulated in Table 1. After 24 hours, the hardened samples will be removed from its mold, and undergoing the curing process by placing them in water. Then the sample will be bringing out and undergoing a crushing test in the compressive machine on the 14th and 28th days respectively. All the methods, techniques, and apparatus followed the guide given in BS 1881-116, 1983 [21] while the testing is conducted with the Gotech Testing Machine model of NT-7001-BS300.

Table 1: Sample's mixture proportion

Sample Name	Proportion C:S:FA:PS	PS Beads (wt. %)
A1	1:1:1:0.6	0.1
A2	1:0.97:1.03:0.6	
A3	1:0.94:1.06:0.6	
B1	1:1:1:1.7	0.3
B2	1:0.97:1.03:1.7	
B3	1:0.94:1.06:1.7	
A1 (DC)	1:1:1:0.6	0.1
A2 (DC)	1:0.97:1.03:0.6	
A3 (DC)	1:0.94:1.06:0.6	
B1 (DC)	1:1:1:1.7	0.3
B2 (DC)	1:0.97:1.03:1.7	
B3 (DC)	1:0.94:1.06:1.7	

In this part, sample A is added with 0.1 wt. % of polystyrene beads (PS beads), while sample B is using 0.3 wt. % of PS beads of the entire composition. According to Figure 1, it had shown that a sample A containing 0.1 wt. % of PS beads within its composition to have higher compressive strength compared to sample B, which uses 0.3 wt. % of PS beads on 14th curing days. Sample A3 has the highest compressive strength of 17.28 MPa on 14th curing days, which is made according to a designed proportion of 1: 0.94: 1.06: 0.6 (cement: sand: fly ash: PS beads). Whereas, the sample with the lowest compressive strength of just 3.87 MPa on 14th curing days is B1, which using a designed proportion of 1: 1: 1: 1.7. Both samples A and B were consumed to undergo a compression test once again on 28th days and found that the compressive strength of each sample had experienced minor increment. As shown in Figure 2, the result of sample A3 is recorded to have the highest compressive strength of 20.25 MPa, while the sample with the lowest compressive strength is B1 with a reading of just 4.40 MPa. When observation is made towards both samples A and B independently, it is found that the presence of PS beads had decreased their compressive strength.

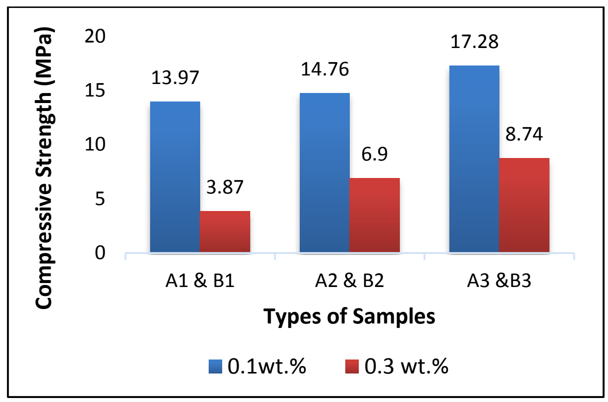

Fig 1 Compressive strength of cement composites with 0.1 wt.% and 0.3 wt.% of PS beads at 14th days of curing

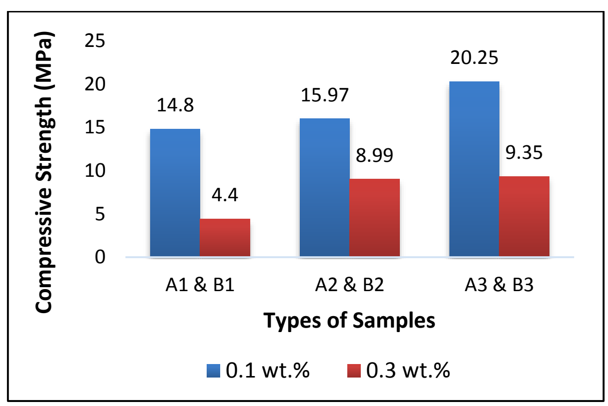

Fig 2 Compressive strength of cement composites with 0.1 wt.% and 0.3 wt.% of PS beads at 28th days of curing

The justification of this situation because polystyrene itself is a soft particle and unable to resist enormous force when the compression load applied. However, the unique-soft PS beads able to absorb shock and force during compression process, make the foamed cement composite to have longer resisting time before it is fully ruptured [1]. Besides that, it is found that the sample contained more fly ash but less sand has higher compressive strength. This is mainly because when partial sand is removed within a cement composite, it will able to reduce the presence of voids since sand itself has the largest particle size compare to cement and fly ash [22]. Hence, when more sand is reduced and replaced by fly ash, it can easily fill up the voids more effectively, thus making the cement composite more compact and having higher compressive strength [10]. Based on the result, it can be seen clearly that the utilization of 0.3 wt. % of PS beads contribute to lower compressive strength compared to 0.1 wt. % of PS beads. According to the observation, when more PS beads are used, it will cause the weight of cement composite to become lighter besides softening the structure of it. As a result, the cement composite unable to resist much force when it is compressing [20]. Next, two sets of sample A with the utilization of 0.1 wt. % of PS beads are produced as presented in Table 2 for been test of compression on days 14th and 28th. The selection of sample A in this test because the results obtained previously show higher compressive strength when using 0.1 wt. % of PS beads, compared to 0.3 wt. %. Afterward, the samples are sent into the furnace in order to decompose all the PS beads within it. As a result, the cement composite will present honeycomb structure after the decomposing process, and then the compression test will be run onto the samples so that further comparison can be made.

Table 2: Sample's mixture proportion

Sample Name	Proportion C:S:FA:PS	PS Beads (wt. %)
A1	1:1:1:0.6	0.1
A2	1:0.97:1.03:0.6	
A3	1:0.94:1.06:0.6	
A1 (DC)	1:1:1:0.6	0.1
A2 (DC)	1:0.97:1.03:0.6	
A3 (DC)	1:0.94:1.06:0.6	

On the 14th day, all the decomposed samples of A which contain 0.1 wt. % PS beads displayed the highest results compared to normal cement composites as charted in Figure 3. The normal cement composites showed the result of A1 is 13.97 MPa, then slightly increased to 14.76 MPa for A2 and last is 17.28 MPa. This increment occurred consequences to the percentages of fly ash in the cement composites as well. On the other hand, when the sample of cement composites has been sent into the furnace, the result indicates the rising trend. The result notably indicated that the decomposed cement composites with the most fly ash have the highest compressive strength of 19.60 MPa. Whereas, the sample with the lowest strength is A1 with 14.31 MPa. It seems that after PS beads had been decomposed, it left quite a lot of hollow cells all around the structure that looks similar to the honeycomb structure, which can help optimize the amount of used material to reach minimal weight and material cost of cement composites. The geometry of these hollow cell structures can vary widely but the common feature of all such structures is an array of voids formed between the cement composite. These hollow cells shaped structure provides the cement composite with minimal density and relative high out-of-plane compression properties and out-of-plane shear properties [23, 20]. Further to this, Figure 4 also shows that all samples A had experienced strength increment on the 28th of curing days.

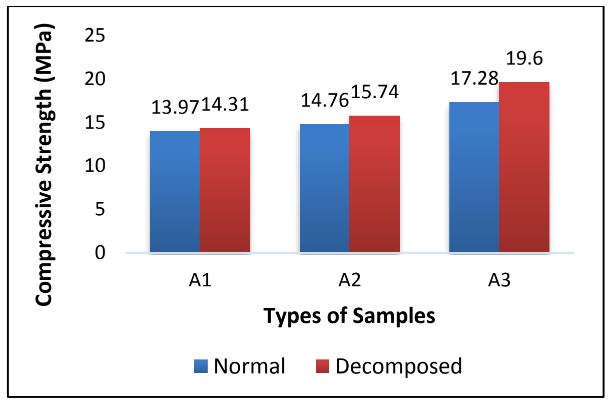

Fig 3 Compressive strength of cement composites with 0.1 wt.% of PS beads at 14th days of curing

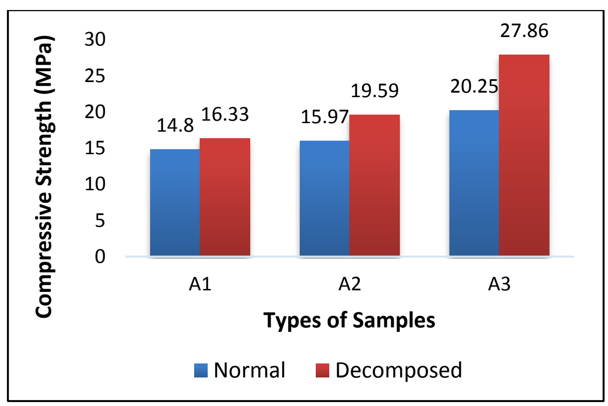

Fig 4 Compressive strength of cement composites with 0.1 wt.% of PS beads at 28th days of curing

Besides, it is found that the sample that uses more fly ash able to gain extra compressive strength on 28th days of curing ages. The result showed the increment trend for decomposed cement composites compared to the normal one. In this case, sample A3 has revealed the highest compressive strength of 27.86 MPa after all PS beads within it had been decomposed. On the whole, the comparison of compressive strength between the normal sample and the decomposed sample can be made. Since the discussion earlier had stated that the decomposed cement composite had higher compressive strength compared to the normal sample, thus the relationship amongst them will find out. Firstly, the decomposed sample of A3 that contains 0.1 wt. % of PS bead and 1.06 part of fly ash had the highest compressive strength on both 14^{th} and 28^{th} days of curing, with a reading of 19.60 MPa and 27.86 MPa, respectively. This is because sample A3 used the most amount of fly ash compared to other samples, thus making more voids within the cement composite can be effectively fill up by fly ash, hence strengthen up its structure and making it strong. Secondly, it is found that all decomposed samples of A had gained the strength at 14^{th} and 28^{th} days of curing ages in this study. This is owing to the dense combination of materials within the cement composite, such as cement, sand and fly ash. Undoubtedly, the percentages of PS beads must be ideal so that it won't produce excessive voids once it had been decomposed and consequently weaken up the whole foamed cement composite's structure [14, 5]. Therefore, the decomposed of 0.1 wt. % of PS beads is more appropriate to be used in order to produce stronger foamed cement composite. The longer the cement composite's age, the higher its compressive strength will be, since all materials had fully saturated and hardens. Up to a point, the compressive strength of cement composites indicated that the best result was on 28^{th} days. Commonly, since the percentage strength of cement composites at 28^{th} days is 99 percent, it can be consumed as full strength. To some extent, the strength beyond the 28^{th} days is referred for the design purpose and safety factor of the structures [24].

CONCLUSION

Based on the presented results, it is found that foamed cement composite has better properties in few aspects compare to the conventional cement composite, which also made it more appropriate to be used in the actual work field. The designed proportion had shown more fly ash will help increase the strength of foamed cement composite, but not more than 35 percent of the overall composition. Besides, the usage of polystyrene beads must not exceed 0.3 wt. %, since the results had shown the decreasing trend in the strength of foamed cement composite. Once polystyrene beads within foamed cement composite had been decomposed, it is found that the strength of the particular cement composite had become higher. The use of polystyrene beads had reduce the usage of other conventional material for foamed cement composite, such as cement and sand, thus this can reduce the actual cost of construction as well. For this reason, it can be used as one of the most simple and economic ways to produce lightweight cement composite that strong enough to withstand great strength. As a conclusion, both of the waste materials used in this study has a value-added as potential alternative materials in sustainable construction, and at the same time overcomes the environmental issues.

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