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EXPERIMENTAL INVESTIGATION OF AXIAL COMPRESSIVE STRENGTH OF LIGHTWEIGHT FOAMED CONCRETE WITH DIFFERENT ADDITIVES

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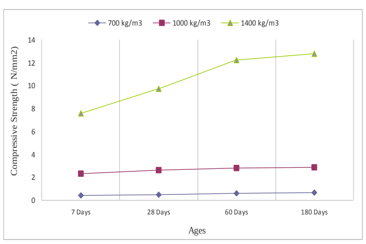
Graphical abstract



Abstract

This paper focuses on experimental study to investigate the effects of different additives on axial compressive strength of lightweight foamed concrete (LFC). The additives used are pulverized fuel ash, wood ash, silica fume, palm oil fuel ash, polypropylene fibre, coconut fibre and steel fibre. These additives have different abilities that contribute positive outcomes to the properties of LFC. Pozzolanic materials and fibres were used as additives to be associated with plain LFC mixtures to improve its mechanical properties. Coir fibre recorded the highest compressive strength in 7 days compared to other additives and the control sample. Coir fibre of 0.4% (CF 0.4) reached highest strength in 180 days without allowing other additives to overcome its strength. The more the inclusion of fibres, the higher the strength obtained due to its low cellulose content, and high percentage and large diameter of lignin. The short length fibres hold the particles stronger.

Keywords: Foamed concrete, compressive strength, additives, pozzolanic material

Abstrak

Kertas kerja ini menumpukan kepada kajian eksperimen untuk mengkaji kesan bahan tambah yang berbeza ke atas kekuatan mampatan konkrit ringan berbusa (LFC). Bahan-bahan tambah yang digunakana dalah abu lumat bahan api, abu kayu, wasap silika, abu bahan api minyak sawit, serat polypropylene, serat kelapa dan gentian keluli. Bahan-bahan tambah ini mempunyai kebolehan yang berbeza yang menyumbang hasil positif kepada sifat-sifat LFC. Bahan pozzolanik dan serat digunakan sebagai bahan tambah untuk dikaitkan dengan campuran LFC biasa untuk memperbaiki sifat mekanikal. Serat sabut mencatatkan kekuatan mampatan yang paling tinggi dalam 7 hari berbanding bahan tambahan lain dan sampel kawalan. Serat sabut sebanyak 0.4% (CF 0.4) mencapai kekuatan paling tinggi dalam 180 hari tanpa membenarkan tambahan lain untuk mengatasi kekuatannya. Semakin kemasukan serat, semakin tinggi kekuatan yang diperolehi kerana kandungan selulosa yang rendah, dan peratusan yang tinggi dan diameter besar lignin. Gentian panjang pendek memegang zarah kuat..

Kata kunci: Konkrit berbusa, kekuatan mampatan, bahan tambah, bahan pozolanik

1.0 INTRODUCTION

Many researchers have studied several ways to improve the properties of LFC by adding different materials as additives. There are some additives with noticeable behaviors were found and investigated in previous studies, to produce improvement on the properties of LFC [1]. The additives can be added by cement replacement or total volume of fraction because each additive used will affect the characteristics of LFC in different ways. This part fully concerns on the characteristics of additives which can give positive changes on the properties of LFC.

Fly ash can be used as a total or partial replacement for sand to produce LFC with noticeable strength below dry density of 1400kg/m^3 in accordance to BS 3892: Part 1: 1997. Fly ash is major by-product of industrial waste which can be obtained from exhaust gases of coal-fired power stations and utilized as filler and it has a great significance on economy and environment ([2]. Utilization of fly ash in LFC has numerous benefits such as minimizing greenhouse emission, better long term strength and durability, lowering water content, reducing energy consumption and pressure on natural resources [3]. High specific area of fly ash particles can able to react with calcium hydroxide during hydration process. The particles of fly ash normally have diameter between 1µm and 100µm and the surface area will be between 250 and 600m^2/kg. In addition, during cement hydration, the silicon oxide and aluminium oxide of fly ash will react with calcium hydroxide to form additional calcium silicate hydrate and calcium aluminate hydrate to form denser matrix which lead to higher strength and better durability [4]. High percentages of ash in LFC will reduce early compressive strength due to pozzolanic reaction during early stage of hydration process. Hydration process transforms the complex particle from different size and shape to another form with different phase [5]. The reaction of fly ash in hydration will be completed after 150 days. The sphere particle is then transformed to some prismatic members with semi-crystalline gel.

Palm oil fuel ash (POFA) is considered as a cement replacement in LFC mixing because of the pozzolanic properties [6]. According to MPOB, (2010), approximately 61.1 million tonnes of solid waste by-products in the form of fibers are produced which is about 70% of fresh fruit bunches processed. POFA contains high amount of silicon dioxide in amorphous form which can produce calcium silicate hydrates gel (CSH) when reacts together with calcium hydroxide generated from hydration process [7]. The products of pozzolanic reaction cannot be produced from primary cement reaction. Silica fume known as micro silica which is a by-product of producing of silicon and ferrosilicon alloys. Silicon oxide SiO was released from the process and this can be oxidized to form into very fine spherical particles of SiO_2 [8]. It will accelerate the reaction between calcium hydroxide produced during hydration of cement due to the presence of small highly reactive silica particles. Small silica particles are capable of filling the empty spaces between the cement particles due to free water, thus the strength will be improved. Silica fume contains very fine vitreous particles with surface area range from 13,000 to 30,000m^2/kg. The reduction in the size and amount of capillaries is able to reduce the permeability of the concrete [9].

2.0 ADDITIVES USED

Additives were selected based on behaviour and properties. These locally available ingredients can be categorized as pozzolanic materials and fibres (natural and synthetic). As mentioned above, the additives were integrated into the mortar mix by cement replacement and total fraction volume. The fibres were associated with the cement paste after the flow test and before the density of the mortar mixture is taken; meanwhile, the pozzolanic materials were added together with cement and sand before a flow test was carried out. The listed additives are pulverized fuel ash, wood ash, silica fume, palm oil fuel ash, polypropylene fibre, coconut fibre and steel fibre. These additives have different abilities that contribute positive outcomes to the properties of LFC. The properties of the additives used in this study are shown below in Table 1.

Table 1 The properties of selected additives

Additives	Properties
Pulverished Fuel Ash (PFA)	• Size (5µm to 100µm) • Specific gravity: 2.3g/cm^3 • Chemical composition (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, Na_2O)
Wood Ash	• Average size particle of 230µm • Alkaline material • 50-70% Calcium • 6-8% Potassium • Magnesium & Phosphorus
Palm Oil Fuel Ash (POFA)	• Specific gravity: 2.42-2.56g/cm^3 • Passing through 45µm sieve% : N.A • Chemical composition (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, Na_2O, K_2O, P_2O_2)
Silica fume	• Hygroscopic • Diameter 0.15micron • Specific gravity: 2.3g/cm^3 • Surface area between 15 and 30m^2/g
Steel Fiber	• Hooked-end steel fiber • None coating • Diameter: 0.55mm • Length: 35mm • Tensile strength: 1250MPa
Polypropylene Fiber	• Length: 12mm • Specific gravity: 0.90g/cm^3 • E-Modulus: 3900N/mm^2 • Carbon 33% • Hydrogen 67%
Coir Fiber	• Fibrous material • Length: 10 to 30cm • Diameter 10 to 20µm • Brown fiber • Water proof • Specific gravity: 0.90g/cm^3

3.0 EXPERIMENTAL SETUP

Compressive strength is one of the important properties of LFC and it is normally used for designing purposes in the concrete industry. The compressive test has been done as specified in the test method

MS EN 12390-3: 2012 on LFC cubes with the aid of a compressive test machine (GOTECH GT-7001-BS300 Universal Testing Machine) at the HBP Testing Unit in the School of Housing Building & Planning USM as shown in Figure 1. The compressive strength was measured by the maximum resistance from the axial loading. The size of the cubes was used is 100x100x100mm. In order to gain strength, the samples were wrapped with black plastic bags for the curing process. At the time of testing, they had been kept in the oven for 24± hours to attain a dry density. The samples were left to cool to reach a stable temperature after having completed the drying process. The weight of each cube was noted for the data analysis. These LFC cubes were tested for 7, 28, 60 and 180 days of curing [10].

Figure 1 Sample being tested by the compressive machine

4.0 RESULTS AND DISCUSSION

Density usually plays a leading role in determining the compressive strength of LFC when compared with other factors. In order to investigate and justify the effects of density on the compressive strength of LFC, LFC of three different densities (700kg/m^3, 1000kg/m^3 and 1400kg/m^3) were cast. Table 2 shows that the LFC with a density of 700kg/m^3 gives the lowest compressive strength of 0.7 N/mm^2 in 180 days. Meanwhile, the LFC with a density of 1400kg/m^3 shows the highest result in compressive strength with 9.9 N/mm^2, followed by the LFC with a density of 1000kg/m^3 which gives medium strength of 2.2 N/mm^2 in 180 days. From this table, it can be clearly seen that density is directly proportional to the compressive strength of LFC. Besides that, the strength of LFC is parallel with its age. Figure 2 shows the changes in the compressive strength of LFC at different densities.

Table 2 Compressive strength of the control LFC with different densities at different testing ages

Sample	Density (Kg/m³)	Compressive Strength (N/mm²) 7 Days	28 Days	60 Days	180 Days
Normal LFC (NFC-1)	700	0.4	0.5	0.6	0.7
Normal LFC (NFC-2)	1000	1.9	2.1	2.2	2.2
Normal LFC (NFC-3)	1400	5.3	7.1	9.4	9.9

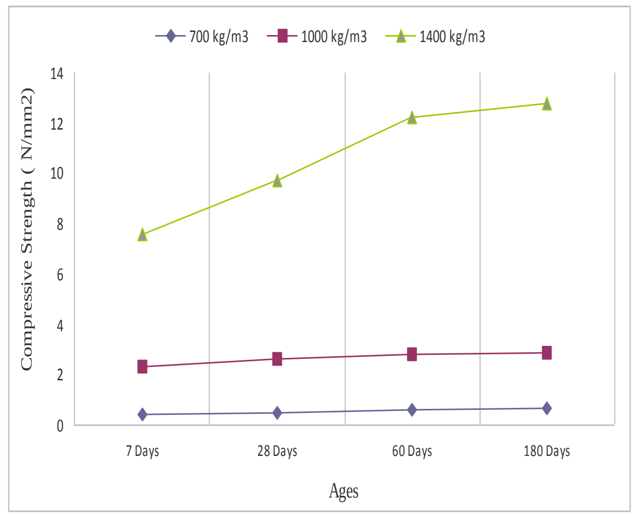


Figure 2 Relationship between density and compressive strength of LFC at different testing ages

The compressive strength of LFC is not only affected by its density and porosity. Some other factors also cause the variations in the compressive strength of LFC. Important elements such as pore formations, size of voids and matrix were attributed to the microstructure. As discussed previously, the percentage of porosity in the LFC influences its density and it leads to a different range of compressive strength. Inevitably, high porosity reduces the density of LFC and at the same time decreases its compressive strength. Based on the results, the addition of different kind materials as additives into the LFC mix has been proven to enhance the strength of the LFC. The effects of the additives on the compressive strength of the LFC are shown in Table 3.

Table 3 describes on the changes of the compressive strength of LFC with each additive at different testing ages. The strength of the LFC with the additives increases over the testing ages due to the hydration process. In this study, pozzolanic materials and fibres were used as additives to be associated with plain LFC mixtures to improve its mechanical properties. Previously, Nambiar and Ramamurthy (2006) mentioned that LFC mixes with Fly ash requires a lesser dosage of foam because of its lower specific gravity (2.09) than fine sand (2.52), hence it unable to perform at a low density. Apart from that, fibre such as polypropylene fibre could not contribute to the strength of LFC at a higher density [5]. Therefore, the density of the LFC was fixed as 1000kg/m^3 for all tests with additives in order to do a comparison as it has a useful amount of mechanical properties of LFC.

Table 3 The compressive strength of LFC with various additives

Sample	Ref.	Compressive Strength (N/mm^2)			
		7 Days	28 Days	60 Days	180 Days
Normal LFC	NFC-2	1.9	2.1	2.2	2.2
POFA 25%	POFA-25	1.3	1.7	3.0	3.4
POFA 40%	POFA-40	1.2	1.5	1.9	2.4
Polypropylene 0.2%	PF-0.2	1.8	2.1	2.5	3.1
Polypropylene 0.4%	PF-0.4	2.0	2.9	3.0	3.3
Steel Fiber 0.25%	SF-0.25	2.0	2.5	2.5	2.7
Steel Fiber 0.40%	SF-0.4	2.1	2.7	2.7	3.0
Silica Fume 10%	SLF-10	2.0	3.1	3.3	3.6
PFA 15%	PFA-15	1.7	2.5	3.0	3.3
PFA 30%	PFA-30	1.6	2.2	4.1	4.8
Wood ash 5% PFA 15%	W5-P15	1.8	2.6	3.2	3.4
Wood ash 10% PFA 15%	W10-P15	1.5	2.4	2.9	3.2
Coir Fiber (0.2%)	CF-0.2	2.2	2.7	3.2	3.3
Coir Fiber (0.4%)	CF-0.4	2.9	3.5	4.2	5.1

According to the tests conducted, the highest compressive strength obtained in 7 days was by the specimen with coir fibre (coconut fibre) among the other materials. The inclusion of 0.2% (CF-0.2) and 0.4% (CF-0.4) of coir fibre have shown higher strength which are 16% and 53% increment in strength respectively in 7 days compared to the control mix (NFC-2). Eventually, coir fibre of 0.4% (CF-0.4) reached highest strength in 180days without allowing other additives to overcome its strength. It provided tremendous increase in strength by about 67%, 90% and 131% in 28 days, 60 days and 180 days, respectively compared to the control mix. The more the inclusion of fibres into the LFC mix, the higher the strength obtained due to its low cellulose content, large diameter and high percentage of lignin. Natural fibres are reinforcing agents because of their biodegradable characteristics. Naturally, coir fibre has a higher failure strain which can provide a better compatibility between the fibres and the matrix. As the fibre content increases, the degree of obstruction increases and this will cause the hardness to increase. The short length fibres will hold the particles stronger. The coir fibres were capable of absorbing energy because of the strong particle bonding between the fibre and the matrix. The strength increased linearly with the addition of coir fibre in the mixtures and it is expected to be further increased if the testing ages were extended.

On the other hand, the lowest strength was achieved by the specimen with 40% palm oil fuel ash (POFA-40) at the early stage (day 7). The crushed and grinded POFA-40 (median particle size is 10.0μm) did not give major contribution to the strength at the early age compared with the control LFC specimen. Due to the pozzolanic reaction, the reaction during the hydration process took longer time to achieve its optimum strength. However, it showed an increment in the strength after 60 days. In 180 days, POFA-40 showed a 9% increase in strength than the control mix which is very low compared to the other additives. It has been proven that pozzolanic materials require a longer period of time to react with the cement in the hydration process. The duration for the process depends on the percentage of pozzolanic materials that were added into the mix. 25% of palm oil fuel ash (POFA-25) showed better strength than POFA-40 at the early stages as expected. The strength of POFA-25 becomes higher after 28 days and showed a 36% increment in strength when compared to the control mix. This is because lesser amounts of pozzolanic materials were added into the mix and it took a shorter time in the hydration process to reach optimum strength. Coarser POFA containing large particles is a weak pozzolanic material. The POFA which undergoes a crushing and grinding process will attain smaller size particles and also increase its fineness and specific gravity [11].

Fine POFA has emerged as good and high reactive pozzolanic material. The pozzolanity of POFA increased linearly with the fineness of the particles. The reaction between the silica and the calcium hydroxide increases due to the high silica content (SiO_2) and its high fineness, producing additional compound calcium silicate hydrates (C-S-H) during hydration which cause the compressive strength to be enhanced [13]. The ratio of silica/alumina will increase due to the increment in percentage of POFA added and this will reduce the early strength development of the LFC. Based on the results, the compressive strength decreased with the increase of the replacement levels. The surface area of POFA as well as the chemical compositions will give significant effects on the density and compressive strength of the LFC.

Furthermore, explanations and justifications were given in detail for the reactions of other additives in the LFC. Pozzolanic materials usually lacked in early strength because of the pozzolanic reaction during the hydration process. Meanwhile, steel fibre and polypropylene fibre obtained higher strength at early stages followed by coir fibre. 0.4% of steel fibre (SF-0.4) increased the strength by 11%, 29%, 22% and 36%

in 7, 28, 60, and 180 days respectively compared to the control mix. The 0.25% of steel fibre also never failed to increase the strength of the LFC compared to the control sample but recorded a rather low reading than the 0.4% steel fibre along the testing ages due to less addition of fibre. The steel fibre did not give massive changes in the strength of the LFC from age to age. Steel fibres act as crack development avoider due to the sufficiently strong bond formed between the fibres and the cement paste. Therefore, it will increase the ultimate strength of the LFC by controlling the micro-crack development in the pre-peak region.

Polypropylene fibre shows the same trend in the improvement of the compressive strength as steel fibre. In 180 days, both percentages of polypropylene fibre had obtained better strength than steel fibre. The amount of fibre plays an important role in determining the strength value of the sample. It increases linearly with the addition of fibres in the mix along the testing ages. The strong bonding connection between the pores enhances the strength of the LFC. Normally, fibres will increase the flexural strength better than compression. Fibres that are used as reinforcements in cement matrix in order to increase the toughness and energy absorption ability to reduce the crack development on the concrete [14]. From this study, it can be concluded that a large percentage (0.4%) of polypropylene fibres is highly capable of reducing the swelling of mixtures and enhancing the plastic strength compared to the mix with a low percentage (0.2%). Therefore, PF-0.4 further develops the compressive strength due to the strong bonding connection with the matrix [15].

The LFC with 10% silica fume (SLF-10) showed high early strength compared to the other pozzolanic materials. Since the cement replacement is very low, the SLF-10 had gone through a hydration process in a short period of time and increased 5% in strength compared to the control mix at day 7. The strength continuously increases by 48%, 50% and 64% correspondingly in 28, 60, and 180 days. Silica fume is in the nano-range which is capable of influencing the strength of the LFC. A high content of amorphous silicon dioxide from the silica fume is the cause for the pozzolanic reaction. It will improve the strength over the testing ages due to the longer period of hydration process. The strength will be higher because total volume of pores has reduced and the pore formation becomes discrete.

Followed by coir fibre (CP-0.4), 30% of pulverized fuel ash (PFA-30) in the LFC has produced the highest strength by 180 days. CF-0.4 obtained a 6% increase in strength compared to the mix of PFA-30 in 180 days. At the early stage (day 7), the strength of PFA-30 is found to be below the control mix and there is no improvement in the strength because of the pozzolanic reaction. PFA-30 increased the strength after 60 days as a longer curing period is required for it to gain strength during the hydration process. There were drastic changes recorded in the compressive strength of PFA-30 at 60 days and 180 days. The strength was expected to be improved further when the age is increased. For both PFA-15 and PFA-30, there is no improvement in the strength at 7days but tremendous increases were recorded in the strength from the testing age of 28 to 180 days. Within this period, the quick change in the hydration product by the PFA during the hydration process could be due to better interlocking between each particle. The transformation of these complex particles continued until more consolidated particle shapes were formed. The study showed that a high amount of pozzolanic materials will downgrade the early strength of the LFC due to the longer hydration process [16]. Since wood ash is a weak and unstable reactant, strong pozzolanic materials must be associated with it because wood ash might collapse if it reacts only by itself in the LFC. Therefore, a fixed quantity (15%) of PFA is added with 5% and 10% of wood ash [17]. There are no previous studies or researches on wood ash with LFC.

Figure 3 shows comparison between various additives and compressive strength at 1000kg/m^3. From Figure 3, 5% of wood ash with 15% PFA (W5-P15) has been proven to give a good strength when compared to the control mix. As usual, the early strength is lower than the control mix but higher than PFA-15 and PFA-30 due to the pozzolanic reaction. On the other hand, the mix with 10% of wood ash and 15% of PFA showed lower strength than W5-P15 from day 7 until day 180. It can be concluded that the addition of wood ash must be lower in a mix to reach the desired strength; otherwise the compressive strength of a mix will collapse because wood ash is a low pozzolanic material. The effects of setting time delays become more crucial with the increasing levels of the cement replacement with wood ash. Wood ash does not satisfy the requirement of being a Class N pozzolan according to the ASTM Standard C618. It has large median particle size and higher surface area than ordinary Portland cement. From the results shown, it was observed that the increasing of wood ash as a replacement for cement resulted in increasing the surface area of the constituent material, thus decreasing the amount of cement, which can cause a decline in strength. It also had higher water requirements to achieve the standard level of consistency. When compared to the normal weight concrete, wood ash contributed to the development of strength even though the cement content was reduced by about 15% [17].

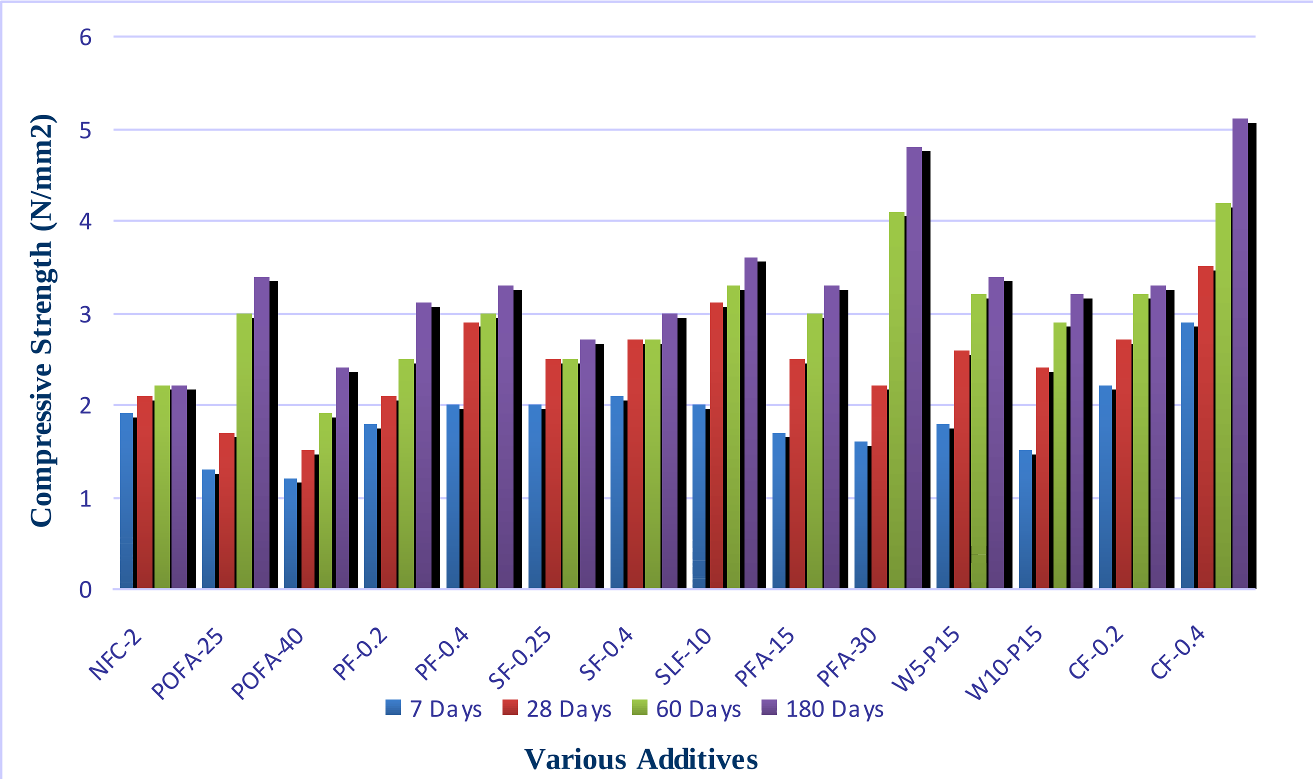


Figure 3 Comparison between various additives and compressive strength at 1000kg/m^3

5.0 CONCLUSION

This paper has deliberately discussed the experimental studies on the mechanical performance of LFC samples with the integration of various densities and admixtures. Pozzolanic materials and fibres were used as additives to be associated with plain LFC mixtures to improve its mechanical properties. Coir fibre recorded the highest compressive strength in 7 days compared to other additives and the control sample. Coir fibre of 0.4% (CF 0.4) reached highest strength in 180 days without allowing other additives to overcome its strength. The more the inclusion of fibres, the higher the strength obtained due to its low cellulose content, and high percentage and large diameter of lignin. The short length fibres hold the particles stronger.

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