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A synopsis about the effect of basalt and natural fibers on geopolymer properties

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ABSTRACT

Currently, the introducing of basalt and natural fibers into different geopolymer swift growth of geopolymers. Despite of geopolymers have good properties such as fire resistance, flame resistance, higher compressive strength and higher durability, they suffer from low tensile strength and flexural strength. Different types of fibers were used to increase flexural strength, tensile strength, fracture toughness and ductility of geopolymers. The current article goals to brief the available earlier studies focused on the effect of basalt fibers and different natural fibers on the properties of geopolymers.

Keywords:*Geopolymers; basalt fibers; Natural fibers; mechanical strength*

1.Introduction

As known, emission of greenhouse gases, resulted in different industries, is the main impact on global warming. Cement industry is one of the most industries which releases a lot of CO_2. It was estimated that around 5-8% CO_2 of worldwide emissions release to the atmosphere is due to cement industry. This industry not only release a lot of CO_2, but also consumes a large amount of energy. The new automation system of cement production procedure consumes an extraordinary energy of ~3.42 Gj/t. In addition, cement industry consumes a huge amount of virgin raw materials, of which production of one tonne cement need about 1.5 tonnes of raw materials. One choice to limit these problems is to replace cement with large amount of waste materials such as slag[1-3] and fly ash (FA)[4] in blended cement systems. Another choice is to replace cement by an inorganic polymer materials which known as "geopolymers". Geopolymers are manufactured by alkali activation of aluminosilicate minerals such as slag, FA, metakaolin (MK) and others. In addition to their low carbon footprint and energy consumption, geopolymers exhibited good properties in comparison with those of traditional cement system such as higher strength, higher fire resistance, higher corrosion resistance and higher durability[5-7]. Although these superior properties, unfortunately, geopolymers undergo from their poor tensile and flexural strengths due to their ceramic nature. Furthermore, geopolymers are more susceptible to micro cracking. These can cause brittle failure which may limit their use in many applications. To overcome these problems, fibers can be used. The introduction of fibers into geopolymers can increase flexural strength, tensile strength, toughness and ductility.

Basalt is a natural material found in volcanic rocks initiated from frozen lava, with 1500-1700 ^oC melting temperature. Natural volcanic basalt rock was used to manufacture basalt fibers. The manufacturing process of basalt fibers is similar to those of glass fibers, but with low consumption of energy. The raw material was heated into special furnace up to its melting point at 1450-1500 ^oC. The molten product was forced through a rhodium/platinum crucible bushings to form fibers[8]. Basalt fibers(Fig. 1) were used by American scientists as earlier to 1923. This type of fibers were used in aeronautical and defense applications thought World War II by the Europe, United States and the Soviet Union[9]. Basalt fibers have high chemical stability, good resistance to alkaline, acids Basalt fibers can be used in several fields such as automotive, marine, civil, sporting equipment etc.[8].

The stiffness and strength properties of basalt fibers are higher than those of E-glass fibers. The Young's modulus of basalt fibers fluctuated from 100 to 110 GPa depending on the chemical composition of the basalt rock source. The tensile failure stress of these fibers fluctuated from 4.15 to 4.8 GPa, whilst the thermal conductivity fluctuated from 0.031 to 0.038 W/m.K, the softening temperature around 1050 oC [10].

Figure 1. Basalt fibers.

Currently, natural fibers (Fig. 2) have widely used in cementitious materials due to their wide availability, low cost, lightweight, high specific modulus, lower energy consumption, low tear and wear in processing[11], comparable specific tensile properties, non-irriation to the skin, renewability, less health risk biodegradability and recyclability [12]. .Natural fibers such as abaca, sweet sorghum, coir, cotton, sisal, raffia wool and coconut can be added into the matrix to complement some properties of the composites. Sisal fibers is one of the natural fibers. About 4.5 million tonnes of sisal are produced each year all over the world[13]. The leaves of the sisal can be used in the production of bags, brooms, hats, rope, twine, carpets, mats, fine paper, furniture, automotive industries, geotextile industries etc[14]. The sisal fibers can restrain plastic shrinkage and have good resistance against moist when added to traditional cementitious materials. Coir or coconut is extracted from the outer shell of the coconut fruit. Matured coconut fibers containing lesser cellulose and more lignin than other types of natural fibers such as cotton and flax fibers. These make them less flexible and stronger. Coconut fibers are relatively water-proofing and can resist the damage caused by salt water[13]. A mesh made with coconut fibers is used in European countries to contain slopes. Coconut fibers can be used to make parts of banks, automobiles and can replace fiberglass[14]. Abaca or banana fibers were obtained from the pseudo-stem of banana plants. Abaca fibers can be used in furniture, decorative accessories, making currency and bank notes, coffee filters, tea bags, surgical caps and masks, orthopedic materials. In construction field, abaca fibers can be used as a part of ceramics, fiberboards, tiles, replacing glass fibers etc.[15]. Raffia fibers are obtained from the raffia palm. Raffia fibers can be used as ligature for grafting and for making dresses. They also are used for sticks, ropes, supporting beams and various roof coverings [16].

Abaca Coir/ Coconut Raffia

Sisal Flux Cotton

Figure 2. Natural fibers.

The development in the geopolymer/fiber composite is illustrative of their promising applications in the nearest future as a new generation of improvement materials. This growth heartens researchers to spend more attention on these compound. The current paper aims to collect the prior studies focused on the effect of basalt and different types of natural fibers on the properties of geopolymers. The effect of basalt, abaca, sweet sorghum, coir, raffia, cotton, sisal, flax and wool fibers on the properties of geopolymers has been reviewed.

2. Basalt fibers

Li and Xu,[17,18] incorporated 0.1-0.3% basalt fibers (length 18 mm and diameter 15 µm) into 75% slag/25% FA-based geopolymer concretes activated with NaOH and sodium silicate solution. The results disclosed an improvement in the deformation and energy absorption with including basalt fibers, whilst there was no notable enhancement in the dynamic compressive strength. Masi *et al*.[19] incorporated 0.5% and 1% basalt fibers (length 5 mm and diameter 16 µm) into FA-based geopolymer pastes activated with NaOH and sodium aluminate solution. Hydrogen peroxide solution was used as chemical foaming agent. The results disclosed 3.7% and 14.81% reduction in the flow with including 0.5% and 1% fibers. The cured density was reduced by 1.74% and 1.16% with including 0.5% and 1% basalt fibers, respectively. The compressive strength, flexural strength and energy absorbed during loading were not affected with including fibers, whilst the fracture toughness was enhanced with including fibers. The flexural strength of specimens containing fibers did not change significantly after exposure to temperatures of 600 and 700 ºC. Beyond 700 ºC and up to 1000 ºC, the flexural strength was increased by approximately twice times than the control. This improvement could be attributed to the sintering of the pastes leading to fibers-matrix adhesion. Dias and Thaumaturgo[20] incorporated 0.5% and 1% basalt fibers (length 45 mm and diameter 9 µm) into MK-based geopolymer concretes. The results disclosed an increase in the VeBe time with including fibers. The incorporation of 0.5% and 1% basalt fibers increased VeBe time by 87.5% and 594.64%, respectively. The 28 days compressive strength was reduced by 27.59% and 6.58% with including 0.5% and 1% fibers, respectively. However, the 28 days splitting tensile strength was enhanced by 34.4%, and 25% with including 0.5% and 1% fibers, respectively, whilst the 28 days flexural strength was enhanced[21] by 7.5% and 31.25%, respectively. Zhang *et al*. incorporated 0.5% and 2% short basalt fibers (length 6 mm and diameter 13 µm) into 95% MK/5% FA-based geopolymer mortars activated with potassium hydroxide and potassium silicate solution. The results disclosed that the addition of 0.5% and 2% short fibers reduced the bond strength by ~55.5% and ~73%, respectively. Kumutha *et al*.[22] incorporated 0.5-2% basalt fibers into FA/slag-based geopolymer concretes activated with NaOH and sodium silicate solution solution. The results disclosed 8.55%, 14.34%, 26.82% and 43.19% enhancement in the 28 days compressive strength with including 0.5%, 1%, 1.5% and 2% basalt fibers, respectively, whilst the splitting tensile strength was enhanced by 11.82%, 21.82%, 36.36% and 50%, respectively. The flexural strength was enhanced by 34.78%, 86.95%, 117.39 and 139.13% with including 0.5%, 1%, 1.5% and 2% basalt fibers, respectively.

Arunagiri *et al*.[23] incorporated 0.5-2.5% basalt fibers into 80% Class F FA/20% slag-based geopolymer concretes activated with NaOH and sodium silicate solution. The results disclosed higher 7 and 28 days mechanical strength with including fibers. The 7 days compressive strength was enhanced by 18.27%, 35.55%, 46.53%, 60.33% and 54.43% with including 0.5%, 1%, 1.5%, 2% and 2.5% fibers, respectively, whilst the 28 days compressive strength was enhanced by 10.57%, 33.11%, 41.8%, 61.28% and 48.45%, respectively. The incorporation of 0.5%, 1%, 1.5%, 2% and 2.5% fibers enhanced the 7 days splitting tensile strength by 17.45%, 39.48%, 51.38%, 82.76% and 62.61%, respectively, whilst the enhancement in the 28 days splitting tensile strength was 13.13%, 34.47%, 52.39%, 81.59%, 81.59% and 55.1%, respectively. The 28 days flexural strength was enhanced by 8.78%, 21.41%, 42.83%, 46.25% and 32.33% with including 0.5%, 1%, 1.5%, 2% and 2.5% fibers, respectively. Ronad *et al*.[24] incorporated basalt fibers into 60% Class F FA/40% slag-based geopolymer concretes activated with NaOH and sodium silicate solution. The results disclosed higher 7 and 28 days compressive strength and splitting tensile strength with including fibers. The enhancement in the 7 days compressive strength was 9.96%, 14.78%, 18.35% and 16.11% with including 0.5%, 1%, 1.5%, 2% and 2.5% fibers, respectively, whilst the enhancement in the 28 days compressive strength was 10.43%, 17.28%, 25.28%, 34.74% and 27.91%, respectively. The incorporation of 0.5%, 1%, 1.5%, 2% and 2.5% fibers enhanced the 7 days splitting tensile strength by 10.1%, 23.85%, 33.48%, 48.8% and 35.78%, respectively, whilst the enhancement in the 28 days splitting tensile strength was 10.74%, 21.9%, 3.47%, 47.52% and 35.95%, respectively. Timakul *et al.*[25] incorporated 10-30% basalt fibers (length 12-60 µm and diameter 4 µm) into Class C FA-based geopolymer pastes activated with NaOH and sodium silicate solution. The results disclosed 37% enhancement in the 28 days compressive strength with including 10% fibers, whilst the compressive strength started to reduce with including 15-30% fibers, but still higher than the control. In such a way, the same trend was observed for the density results. Table 1 presents the effect of basalt fibers on some properties of geopolymers.

Reference	Fiber content (%)	Fiber length (mm)	Fiber diameter (µm)	Geopolymer matrix	Optimum (%)	Effect
Li and Xu [17,18]	0.1-0.3	18	15	FA-concrete	0.2	-Improvement in deformation and energy absorption -No notable enhancement in dynamic compressive strength
Masi *et al.* [19]	0.5 and 1	5	16	FA-paste	1	-Reduced workability and density -Increased fracture toughness
Dias and Thaumaturgo [20]	0.5 and 1	45	9	MK-concrete	0.5	-Reduced workability -Reduced 28 days compressive strength -Increased 28 days splitting and flexural strengths
Zhang *et al.* [21]	0.5 and 2	6	13	MK/FA-mortar	-	-Reduced bond strength
Kumutha *et al.* [22]	0.5-2	NA	NA	FA/slag-concrete	2	-Increased mechanical strength
Arunagiri *et al.* [23]	0.5-2.5	NA	NA	FA/slag-concrete	2	-Increased mechanical strength
Ronad *et al.* [24]	0.5-2.5	NA	NA	FA/slag-concrete	2	-Increased compressive and splitting strengths
Timakul *et al.* [25]	10-30	0.012-0.06	4	FA-paste	10	-Increased density and compressive strength

Table 1. Effect of basalt fibers on geopolymer mechanical strength

From the previous studies it can be noted that the incorporation of basalt fibers into geopolymers still needs additional studies, of which some studies contradictor the others. Zhang *et al.*[21] reported lower bond strength of MK/FA mortars with including 0.5-2% basalt fibers and Dias and Thaumaturgo[20] found lower 28 days compressive strength of MK concrete with including 0.5-1% fibers. On the contrary, other studies such as Kumutha *et al.*[22], Arunagiri *et al.*[23], Ronad *et al.*[24] found higher compressive strength of geopolymers with including 0.5-2% fibers. Whatever, all studies agreed that the incorporation of basalt fibers increased higher flexural strength, splitting strength and fracture toughness, but reduced workability.

3. Natural fibers

3.1 Abaca and sweet sorghum fibers

Malenab *et al.*[26] treated abaca fibers (length 250 mm and diameter 162 µm) with NaOH solution or aluminum salt solution. They incorporated 1% of the treated fibers into Class C FA-based geopolymer pastes activated with NaOH and waterglass solution. The results disclosed higher flexural strength with including fibers compared to the control.

Chen *et al.*[27] treated sweet sorghum fibers (size < 840 μm) with alkaline solution. The treated fibers were incorporated into Class F FA-based geopolymer pastes activated with NaOH at levels of 1%, 2% and 3%. The results disclosed lower unit weight with including treated sweet sorghum fibers. The unit weight decreased with increasing treated sweet sorghum fibers content. The incorporation of 3% treated sweet sorghum fibers exhibited 6.5% reduction in the unit weight. In such a way, the incorporation of 1%, 2% and 3% treated sweet sorghum fibers reduced the 7 days compressive strength by 9.4%, 17.3% and 26.3%, respectively. However, higher 7 days splitting tensile strength and flexural strength were obtained with including 1% and 2% treated sweet sorghum fibers, whilst including 3% slightly decreased them. This reduction could be attributed to the poor workability of the mixture and fibers agglomeration with incorporating 3% fibers resulting in increasing air bubbles entrapped and non-uniform distribution of fibers. The incorporation of 1% and 2% treated sweet sorghum fibers enhanced the splitting tensile strength by ~10% and ~36%, respectively, whilst flexural strength was enhanced by ~36% and ~50%, respectively. The incorporation of fibers enhanced the ductility of the matrix. The enhanced ductility came from the debonding and pull-out of fibers that bridging the cracks, which can carry larger loads. The pulling out of the fibers during loading can absorb energy resulted in an improvement in the tensile behavior. The 7 days toughness increased with including fibers. The incorporation of 1%, 2% and 3% treated sweet sorghum fibers enhanced the toughness by ~12.6, ~17.9 and ~6.7 times greater than the control, respectively.

3.2 Cotton, coir, sisal and raffia fibers

Komiejenko *et al.*[28] incorporated 1% coir or cotton or raffia or sisal fibers into FA-based geopolymer pastes activated with NaOH and sodium silicate solution. The 28 days compressive strength was enhanced by 26.55%, 14.7% and 1.53% with including coir, cotton and sisal fibers, respectively, whilst including raffia fibers reduced it by 44.87%. The 28 days flexural strength was enhanced by 5.4% and 6.31% with including cotton and sisal fibers, respectively, whilst including coir and raffia fibers reduced it by 5.4% and 45%, respectively. Alomayri *et al.*[29] incorporated 0.3-1% cotton fibers (length 10 mm and diameter 0.2 mm) into Class F FA-based geopolymer pastes activated with NaOH and sodium silicate solution. The results disclosed lower 28 days density with including cotton fibers. As the content of cotton fibers increased as the density decreased. The incorporation of 1% cotton fibers reduced the density by 11.11%. The porosity at age of 28 days increased with increasing cotton fibers content. The porosity increased from 20% (for the control) to 30% with including 1% cotton fibers. This increment in the porosity with including fibers could be explained by the fact of water absorbed by fibers. The fibers tend to clump together though mixing, entrapping water-filled spaces that consequently convert into voids. The 28 days flexural strength was enhanced with including 0.3%, 0.5% and 0.7%, whilst including 1% fibers reduced it. The flexural strength reached its highest value (the enhancement was 12.5%) with including 0.5% fibers, whilst including 0.3% and 0.7% enhanced it by ~6.73% and ~3.85%, respectively. The same tendency of the results was observed for flexural modulus. The incorporation of 0.3% and 0.5% cotton fibers significantly increased flexural toughness, of which it was enhanced by ~30% and ~60%, respectively. On the other hand, the incorporation of 0.7% and 1% cotton fibers reduced it by 27.54% and 49.27%, respectively. Alomayri and Low [30] incorporated 0.3%-1% cotton fibers (length 10 mm and diameter 0.2 mm) into Class F FA-geopolymer pastes activated with NaOH and sodium silicate solution. The results disclosed higher hardness with including 0.3% and 0.5% cotton fibers, whilst including 0.7% and 1% cotton fibers reduced it. The incorporation of 0.5% cotton fibers increased the hardness by 32.86%. The 28 days compressive strength was enhanced with including cotton fibers. The compressive strength reached its highest value (the enhancement was 140.84%) with including 0.5% fibers, whilst including 0.3%, 0.7% and 1% fibers enhanced it by ~41%, ~83.25% and ~44%, respectively. The 28 days impact strength was enhanced with including 0.3% and 0.5% cotton fibers, whilst including 0.7% and 1% cotton fibers reduced it. The impact strength reached its highest value (the enhancement was 136.84%) with including 0.5% fibers, whilst including 0.3% cotton fibers enhanced it by ~67%. The incorporation of 0.7% and 1% cotton fibers reduced the impact strength by ~5.3% and ~21%, respectively. The incorporation of 0.5% cotton fibers exhibited the highest stress-strain curve. Thus, 0.5% cotton fibers can mitigate the brittle failure.

Patel and Josh[31] incorporated 0.5%-2.5% sisal fibers (after suitable treatment) into FA-based geopolymer concretes activated with alkaline activator. The results disclosed higher 3, 7 and 28 days compressive strength with including sisal fibers. The enhancement in the 3 days compressive strength was 30.46%, 42.38%, 56.86%, 84.16% and 45.1% with including 0.5%, 1%, 1.5%, 2% and 2.5% sisal fibers, respectively, whilst the enhancement in the 28 days compressive strength was 18.11%, 31.26%, 48.68%, 50.48% and 14.33%, respectively. Kumar[32] incorporated 0.75-3% coir fibers (length 25 mm) (after suitable treatment) into Class F FA-based geopolymer concretes activated with NaOH and sodium silicate solution. The results disclosed an enhancement in the 7, 14 and 28 days compressive strength with including 0.75%, 1.5% and 2.25% coir fibers, whilst including 3% coir fibers reduced it. The 7, 14 and 28 days splitting tensile strength and flexural strength was enhanced with including coir fibers. The incorporation of 2.25% coir fibers exhibited the optimum content. Bhavsar *et al.*[33] manufactured Class F FA geopolymer concretes activated with NaOH and sodium silicate solution. FA was partially replaced with burnt coconut fibers ash (size < 150 µm) at levels of 0.5%, 1%, 1.5% and 2%. The results disclosed 3.26% and 4.87% enhancement in the 28 days compressive strength with including 1% and 1.5% fibers, respectively, whilst including 2% fibers reduced it by 5.71%. Table ^ presents the effect of natural fibers on the properties of geopolymer

3.3 Flax and wool fibers

Alzeer and MacKenzie[34] incorporated 4-10% natural flax fibers (diameter 10-80 µm), without treatment, into MK-based geopolymer pastes activated with NaOH and sodium silicate solution. The results disclosed 372.4%, 801.72% and 1110.34% enhancement in the flexural strength with including 4%, 7% and 10% flax fibers, respectively, whilst enhancement in the elastic modulus was 11.39%, 13.92% and 22.78%, respectively. The specimens containing flax fibers exhibited graceful failure, unlike the brittle failure of the matrix. The chopped flax fibers exhibited little improvement to the flexural strength of unreinforced matrix. Alzeer and MacKenzie[35] incorporated 5% natural protein-based (wool) fibers into MK-based geopolymer pastes activated with NaOH and sodium silicate solution. Two different types of the fibers were used either merino wool (diameter 18-25 µm) or carpet wool (diameter 30-35 µm). The results disclosed higher flexural strength and peak load capacity with including fibers. The incorporation of merino wool, cleaned merino wool and treated merino wool enhanced the flexural strength by 41.38%, 56.9% and 41.38%, respectively, whilst the peak load capacity was increased by 48.53%, 62.57% and 46.2%, respectively. The incorporation of carpet wool, cleaned carpet wool and treated carpet wool enhanced the flexural strength by 39.65%, 39.65% and 50%, respectively, whilst the peak load capacity was increased by 15.79%, 50.88% and 55.55%, respectively. Table 2 presents the effect of natural fibers on the some properties of geopolymer.

Reference	Fibers type	Fibers content (%)	Fibers length (mm)	Fibers diameter (µm)	Geopolymer matrix	Effect
Malenab *et al.* [26]	Abaca	1	250	162	FA-paste	Increased flexural strength
Chen *et al.* [27]	Sweet sorghum	1-3	NA	< 840	FA-paste	-Reduced unit weight -Reduced 7 days compressive strength -1% and 2% fibers increased 7 days splitting and flexural strengths, whilst 3% fibers reduced them -Increased toughness - Optimum fibers content was 2%
Komiejenko *et al.* [28]	Coir	1	NA	NA	FA-paste	-Increased 28 days compressive strength -Reduced 28 days flexural strength
	Cotton or sisal	1	NA	NA	FA-paste	-Increased 28 days compressive and flexural strengths

	Raffia	1	NA	NA	FA-paste	-Reduced 28 days compressive and flexural strengths
Alomayri *et al.* [29]	Cotton	0.3-1	10	200	FA-paste	-Reduced density -Increased porosity -0.3-0.7% fibers increased 28 days flexural strength and flexural modulus, whilst 1% fibers reduced them -0.3% and 0.5% fibers increased flexural toughness, whilst 0.7% and 1% fibers reduced it - Optimum fibers content was 0.5%
Alomayri and Low [30]	Cotton	0.3-1	10	200	FA-paste	-Increased 28 days compressive strength -0.3% and 0.5% fibers increased hardness and 28 days impact strength, whilst 0.7% and 1% fibers reduced them -Optimum fibers content was 0.5%
Patel and Joshi [31	Sisal	0.5-2.5	NA	NA	FA-concrete	-Increased 3-28 days compressive strength - Optimum fibers content was 2% fibers
Kumar [32]	Coir	0.75-3	25	NA	FA-concrete	-Increased 7-28 days mechanical strength - Optimum fibers content was 2.25% fibers
Bhavsar *et al.* [33]	Coconut	0.5-2	NA	< 150	FA-concrete	-0.5% and 1.5% fibers increased 28 days compressive strength, whilst 2% fibers reduced it - Optimum fibers content was 1.5% fibers
Alzeer and MacKenzie [34]	Flax	4-10	NA	10-80	MK-paste	-Increased flexural strength and elastic modulus
Alzeer and MacKenzie [35]	Wool	5	NA	18-25 30-35	MK-paste	-Increased flexural strength and peak load capacity

Table 2. Effect of natural fibers on some properties of geopolymer

From the prior studies, it can be decided that natural fibers can be used to improve some properties of geopolymer matrix. Including suitable content of coir, cotton, sisal or coconut can enhance the compressive strength. Including suitable content of abaca, sweet sorghum, cotton, sisal, coir, flax or wool fibers can enhance the flexural strength. Including suitable content of sweet sorghum or coir fibers can increase the splitting tensile strength. Including suitable content of sweet sorghum or cotton fibers can increase the toughness. The incorporation of suitable content of flax fibers can increase the elastic modulus, whilst the flexural modulus can be enhanced with including cotton fibers. The influence of natural fibers on the properties of geopolymer still lackey and needs to be studied further.

4. Remarks

In the current paper, the effects of basalt and different types of natural fibers on geopolymers properties have been summarized. The major remarks extracted from this review can be summarized as following:

There are contradictor results about the effect of basalt fibers on the compressive strength of the geopolymers

The incorporation of basalt fibers increase flexural strength, splitting strength and fracture toughness, but reduce workability.

Including suitable content of coir, cotton, sisal or coconut into geopolymers enhance the compressive strength, whilst including abaca, sweet sorghum, cotton, sisal, coir, flax or wool fibers enhance the flexural strength.

Including suitable content of sweet sorghum or coir fibers into geopolymers increase the splitting tensile strength, whist including sweet sorghum or cotton fibers increase the fracture toughness

The incorporation of suitable content of flax fibers into geopolymers increase the elastic modulus, whilst the flexural modulus can be enhanced with including cotton fibers.

From this summarize, it can be confirmed that the effects of basalt and natural fibers on the properties of geopolymers still need further studies. Whatever, the previous studies focused on the effect of fibers on mechanical strength and fracture toughness. Less attention was observed on the effect of fibers on the workability. On the other hand, there are missed information about the effect of fibers on some properties of geopolymers such as setting time, abrasion resistance, fire resistance, thermal conductivity, freeze/thaw resistance, electrical conductivity, electrical resistance, chloride ion penetration, permeability, water absorption, carbonation resistance, acid resistance, sulfate resistance and shrinkage. Consequently, these missed information can be used as topics for upcoming studies. It is worth noticing that most of the studies related to both of basalt and natural fibers are performed on pastes and concretes, whilst mortars have less attention (Fig. 3).

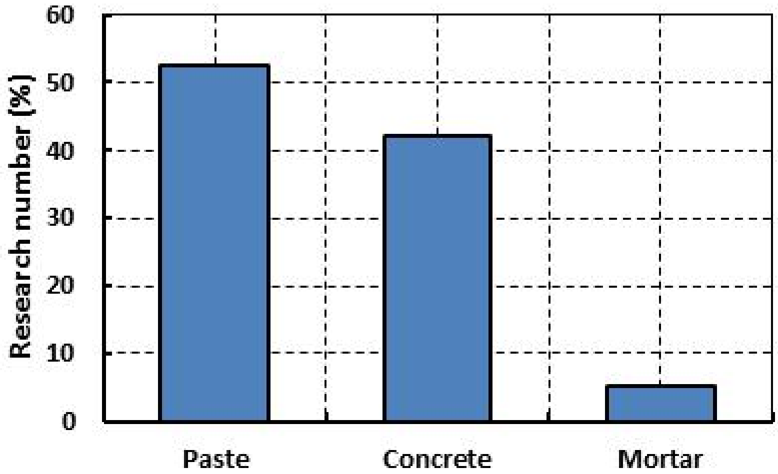

Figure 3. Percentage of research number of carbon fibers incorporated into paste, concrete and mortar

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