ISSN 2303-4521
Periodicals of Engineering and Natural Sciences *Original Research*
Vol. 10, No. 2, April 2022, pp.304-313

Evaluation the effectiveness of a non-chopped basalt fiber and water-based of isocyanate-polyester polyol prepolymer on the properties of cement fiberboard

Mohammed Ali Jaber[1], Haleem K. Hussain[2], Nadhim A. Abdullah[3]
[1]University of Basrah, Polymer Research Center, Department of Materials Science, Iraq
[2*] University of Basrah, Engineering College, Civil Engineering Department, Iraq
[3] University of Basrah, Polymer Research Center, Department of Materials Science, Iraq

ABSTRACT

Cement board reinforced with basalt fibers were prepared by using polymer compounds, 5% of water-based of isocyanate-polyester polyol prepolymer blend was used as a fixed percentage, and the rates of basalt fiber used were 5%, 7.5%, 10%, 12.5%, and for each of them used water/cement ratios (W/C) as 1.4, 1, 0.75, 0.4, and 0.5 respectively. The sample cured for 28 days, and the mechanical and physical properties of cement fiberboard were greatly improved due to additional fibers in cement compounds, the tests procedures of properties were carried out according to ASTM standard c-1185. It results reveals that 12.5% is the best percentage, in bending resistance, water absorption percentage, and the moisture content have improved, but it showed less thermal conductivity compared to other ratios, furthermore the compressive strength was improved. It is essential to indicate when increasing the polymer ratio, leads to a certain decrease in mechanical properties but improves the wetting surface of the basalt fibers and adhesion to cement. Therefore, a 5% polymers ratio chooses and the basalt fıber mix proportions changed to enhance the mechanical and physical properties of fiber board

Keywords: Basalt Fiber, Isocyanate-polyester polyol prepolymer, Mechanical properties, Thermal conductivity

Corresponding Author:
Haleem K. Hussain
Civil Engineering Department
University of Basrah/ Engineering College
Basrah City, Iraq
Email: haleem.hussain@uobasrah.edu.iq; haleem.albremani@gmail.com

1. Introduction

Basalt fibers have emerged as a viable option in the composites industry, as they are regarded as new fibers that are environmentally friendly and have industrial potential. Considering the physical and mechanical properties of basalt fibers, these fibers can compete with carbon and glass industrial fibers. This type of fibers offers a lot of potential for development in various industries because of their abilities including being greener, lighter, and reducing reinforcing bar corrosion [1, 2]. As a nontoxic and biodegradable material, basalt fiber has no environmental risks [3]. Given the high silica concentration of basalt stone, basalt fibers have emerged as a viable option that is well matched with a cemented matrix. Polymers reinforced with basalt fibers (BFRPs) is becoming more common, and several studies on BFRPs have been conducted [1, 4].
A smaller fiber diameter leads to a higher aspect ratio, which, in turn, is more difficult to disperse. Conversely, shorter fibers have a lower aspect ratio and a simpler fiber spreading. Fibers with a tiny diameter or a long length tend to stick to one another. The degree of fiber dispersion influences the efficiency of a fiber additive in enhance the structural or useful potentials of cemented materials. Fiber volume fractions in the low range, achieving a high degree of fiber dispersion is especially important. Increasing the fiber content reduces the workability, increases the air void content, and reduce the compressive strength due to the material cost is high [5], a low fiber volume fraction is usually selected. Water is a key ingredient in the cement mix, boosting the hydrophilicity of the fibers improves fiber dispersion. Surface treatment of the fibers before integration of the fibers in the

cement mix can influence their hydrophilicity [6, 7]. Furthermore, the admixtures that may be utilized in conjunction with the fibers have an impact on fiber dispersion. These admixtures could be fine particles like silica fume, which helps the fibers separate from one another during mixing [8, 9]. Other admixtures could include polymers like polyurethane, which aid fiber-cement bonding and fiber dispersion [10, 11].

In the year 2020, P. Manibalan and R. Baskar attempted to create a concrete cast for M40 grade that included basalt fiber in various proportions such as 0%, 0.3%, 0.6%, 0.9%, and 1%. A large increase in compressive strength was observed from the use of basalt fibers, as well as a high increase in flexural and split tensile strengths, even at low contents [12]. Mohamad Hanafi et al. employ bottom ash and basalt fiber blends in pure cement paste as an alternative novel-based composite in 2020. The results demonstrated that adding basalt fiber to paste enhance the mix's physical, mechanical, and chemical stability capabilities up to a specific content of basalt fiber addition (0.3 percent volume fraction), over which a detrimental effect was observed. It is obvious that the findings can lead to the creation of concrete industry sustainability strategies utilizes of bottom ash and basalt fiber as a different binder [13].

N. Sathish et al. experimented in 2017 to minimize the cost of construction while increasing strength and durability. Fine aggregate is largely substituted with foundry sand (20%,30%, 40%) in this project, and basalt fiber is used to improve concrete compression and tensile strength (2,2.5,3 percent). All preliminary tests for concrete ingredients, including foundry sand, were completed [14]. F. N. Rabinovich et al. studied the stability of basalt and alumni silicate fibers of various diameters in the presence of an alkaline hydrating cement media in 2001. (concrete). The information gained can be used to analyze and deduce estimated long-term strength dependences of basalt-fiber composites based on cement matrixes [15].

2. Experimental work

2.1. Materials

An Iraqi cement utilizes in this work, produce (Um Qaser-Basrah), which has a hardness test of 5 mm and fineness using sieve analysis method So, cement must be replaced within a short period after opening and use not exceeding three days as exposure to moisture and hardening during use, tap water used in this study. A large amount of non-chopped basalt fiber was provided in this study from waste material supplied from local market produced by General Company for Mining Industries (Baghdad– Iraq). Composition of the chemical compounds and physical properties of Portland cement illustrated in Table 1 and Table 2. Basalt fibers were prepared from basalt rocks by melting rocks at 1500 ° C and pulling them into fibers. The used polymer in this study consists of two parts: First. 3.75% di-isocyanate and 1.25% acrylic resin were used in the mixture. The used fiber with diameter (2 to 25 cm) and length varying between 2cm to 20 cm. The shape of basalt fiber is shown in figure 1.

Figure 1. Basalt fiber shape

Table 1. Cement Composition

The chemical components of cement										The main components of cement			
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Insoluble residue	LOI	C_3S	C_2S	C_3A	C_4AF
20.7	5.3	3.9	62.8	1.94	0.35	0.66	1.96	0.47	1.4	50.2	24.3	6.81	10.5

Table 2. Physical properties of cement

Property	Standard	Test Method	Unit	Result
Setting time	ASTM C191 [16]	Initial	Minute	130
		Final	minute	250
Compressive Strength	ASTM C349 [17]	3 days	MPa	18.1 MPa
		7 days	MPa	25.4 MPa

3. Mixing and sample preparation

The process of producing the cement fiberboard use a constant of water-based of isocyanate-polyester polyol prepolymer blend ratio (5%), with different basalt fıber ratio, as 5%, 7.5%, 10%, 12.5%. The process start with mix polymer with water, these steps provide a well mixing gradually until obtain a homogenous mix, finally the cement added and keep mixing with ingredient then the mixture poured into the mold.

Basalt fıber is immersed in a mixture, while immersion was done in batches to make sure that the mixture permeates basalt fıber completely. Furthermore, the fiber must be immersed in one direction and not randomly to avoid the clumping of fiber and formation any balls inside the basalt fıber, which definitely causes inconsistency resulting much difficulty in manufacturing boards. The mixture placed in a wooden mold with dimensions of 30 mm x 30 mm x 12 mm. The samples left for 24 hours until the material hardened, after removing the samples from the mold the fiberboard left for 48 hours to dry in air. The samples were ready to cut in size suitable for testing specimens by electrical cutting machine after seven days.

4. Tests procedure

4.1. Compression test

A compression machine type (HUMBOLDT) was used to perform the compressive strength. The tested cube samples with dimensions (50mm x 50mm x 50mm) loaded gradually up to failure according to international standards ASTM-D1037-06a. Data were collected and recorded for all tested samples and the values represents the average of three samples. Figure 2 shows the cube test for compressive strength

Figure 2. Sample and flexural test device

4.2. Flexural tests of fiber board

flexural tests were conducted before and after immersion and its performed accordance to standard specification ASTM-C1185-99. The specimen's dimensions of flexural test (300 mmx75 mmx12 mm), where a sample loaded in three-point test with clear span loading 270 mm. The flexural test was performed after the samples were immersed in water for 24 hours and the maximum load causing failure was recorded. Figure 3 shows the samples and loading set up device of test.

Figure 3. Sample and Flexural test device

4.3. Water Absorption

According to ASTM – C1185-99, the sample size for water absorption testing was (100mm x 100mm x 12mm). All specimens dried at a temperature (90 °C ± 2) to constant weight then left to cool and recorded the weight of each specimen in room temperature. The specimens submerged in water for (48± 8 hours) then remove from the water and weighted after remove the water from the samples surfaces by a piece of cloth. The formula was used to measure the difference in weight before and after the samples were immersed in water for 28 hours.

$$\text{Water absorption} = \frac{W2-W1}{W1} \times 100$$

Where:

W_1: weight of dry specimen (g).
W_2: weight of specimen before immersion (g.).

4.4. Moisture content

The moisture content of sample used in flexural bending test dimensions (150mmx75mmx12mm) according to standard of ASTM – C1185-99. The test was performed after samples were getting the equilibrium condition in room temperature, then the samples were accurately weighed. The samples were dried in oven at a temperature (90 °C ± 2) for 24 h after that, the all the samples were weighed again after 24 hours. The weight difference of the sample before and after immersion is equals to the weight of moisture absorbed by the sample.

$$\text{Moisture content } M\% = \frac{W-F}{F} \times 100$$

Where:

M: moisture content (%).
W: weight of dry specimen (g).
F: weight of specimen after immersion (g).

4.5. Thermal Conductivity Test

Tested specimens were prepared in accordance with to the specification requirements of American standard ASTM-C1113-90 with dimensions (100mm x 50mm x 50mm) at the National Center for Laboratories and Structural Research (Baghdad Central Laboratory) in Iraq. Thermal conductivity coefficient was conducted for each sample by using QTM-500 technology, which is a Japanese technique based on platinum wire method sensor consists of two wires, heated, and a sensitive wire. Temperature change through the sample, As energy

transfers between high- and low-temperature regions. A temperature gradient is proportional to the heat transfer rate per unit area.
Figure 4 shows the thermal conductivity test device, when the device is running, a current proportional with the density of sample to heat the surface of sample and then at the equilibrium condition will be occurred between the temperature of wire generated as a result of flowing the current through the surface of sample, the two sensor to detect the speed of heat transfer through the surfaces of the sample and the heat transfer proportional to temperature gradient.

Figure 4. Thermal conductivity test device

5. Outcome and discussion

The outcomes of experimental work are listed in Table 3 including, density, water absorption, compressive strength, flexural strength and thermal conductivity Table 3

Table 3. Test result with Polymer ratio 5% and different Basalt fiber ratio

Fiber Ratio	Model	W/C	Volume (cm^3)	Weight (g)	Density (g/cm^3)	Water Absorption (%)	Moisture Content (%)	Comp. Strength fcu (MPa)	Flexural strength (Before Immersing) (MPa)	Flexural strength (After Immersing) (MPa)	Thermal Conductivity Coefficient (k) (W/m. K)
Basalt Fiber Ratio 5%	L1	1.25	778.4	891	1.144	55.05	1.286	1.30	0.61	0.35	0.28
	L2	1.0	940.8	1101	1.17	42.64	1.042	1.60	0.76	0.46	0.33
	L3	0.75	1019.2	1432	1.41	28.72	0.604	6.04	0.87	0.59	0.35
	L4	0.5	1097.6	2111	1.92	15.53	0.285	9.76	1.62	1.52	0.407
	L5	0.40	1254.3	2615	2.08	9.05	0.153	10.12	2.38	2.36	0.432
Basalt Fiber Ratio 7.5%	M1	1.25	862.4	911	1.06	55.66	1.02	3.80	0.66	0.44	0.233
	M2	1.0	1011.9	1111	1.098	48.15	0.82	4.82	0.94	0.56	0.304
	M3	0.75	1098.8	1446	1.32	33.0	0.418	8.12	1.10	0.61	0.314
	M4	0.5	1176.0	2135	1.82	15.64	0.230	10.10	1.68	1.63	0.388
	M5	0.40	1242.3	2587	2.08	10.42	0.112	12.20	2.40	2.40	0.423
Basalt Fiber Ratio 10%	N1	1.25	863.6	942	1.04	56.06	0.82	3.64	0.76	0.56	0.193
	N2	1.0	940.8	1099	1.08	49.10	0.64	4.64	1.10	0.65	0.283
	N3	0.75	1018.5	1451	1.32	35.41	0.32	8.80	1.20	0.697	0.301
	N4	0.5	1177.1	2109	1.79	16.88	0.18	11.0	1.75	1.77	0.334
	N5	0.40	1254.4	2611	2.08	10.67	0.06	13.3	2.50	2.50	0.391
	O1	1.25	934.1	1032	1.01	58.3	0.698	3.64	1.13	0.70	0.173

Fiber Ratio	Model	W/C	Volume (cm^3)	Weight (g)	Density (g/cm^3)	Water Absorption (%)	Moisture Content (%)	Comp. Strength fcu (MPa)	Flexural strength (Before Immersing) (MPa)	Flexural strength (After Immersing) (MPa)	Thermal Conductivity Coefficient (k) (W/m. K)
Basalt Fiber Ratio 12.5%	O2	1.0	1017.1	1160	1.03	50.20	0.478	4.64	1.32	0.89	0.194
	O3	0.75	1094.6	1479	1.32	37.33	0.199	9.04	1.33	1.20	0.219
	O4	0.5	1244.2	2178	1.79	18.33	0.137	14.12	1.86	1.83	0.312
	O5	0.40	1323.3	2668	2.08	11.01	0.03	16.84	2.60	2.62	0.364

Figure 5 demonstrate the influence of adding fıber on compressive strength results. it can be observed the essential effect of the Water/Cement ratio on compressive strength. The normal reason is increases the porosity in cement paste, which reduces compressive strength. Likewise, more basalt fıber, compressive strength increases because when the basalt fıber increases, the percentage of silica increased cause its contains a large percentage of silica, so a chemical reaction will take place between cement and silica fibers produce the ceramic compositions filling the voids existing inside the cement board composition.

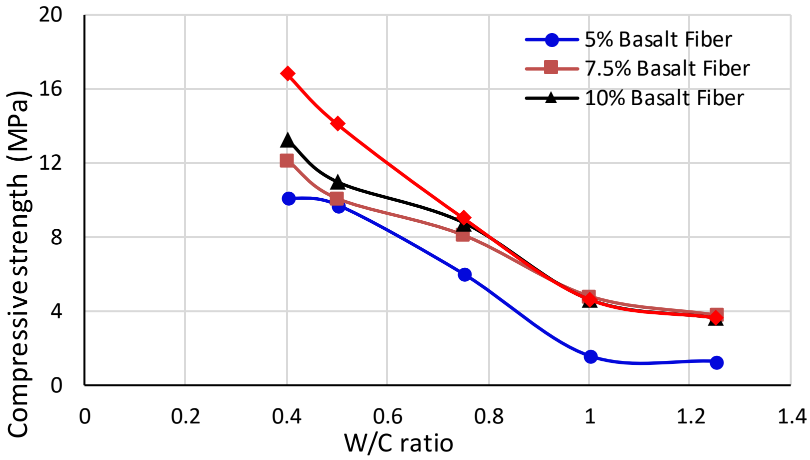

Figure 5. Effect of W/C ratio on compression strength of fiber board with different basalt fıber ratio

The results of flexural strength before immersion with existing basalt fıber in different ratios varies between 5% to 12.5% are shown in Figure 6. From results its can be seen that the effect of W/C ratio on flexural strength, where the flexural strength highly decreases when the W/C ratio increases from 0.4 to 1.25 and this because the porous spread through the sample structures. The extra voids of cement can directly affect on sample density of mixture, and this is one of main reason reducing the flexural strength capacity of sample. Also, with increasing the basalt fıber ratio, where the chemical composition of fiber contains the percentage of silica, producing a ceramic bond of existing cement and provide good quality of sample with enhancement of mechanical properties.

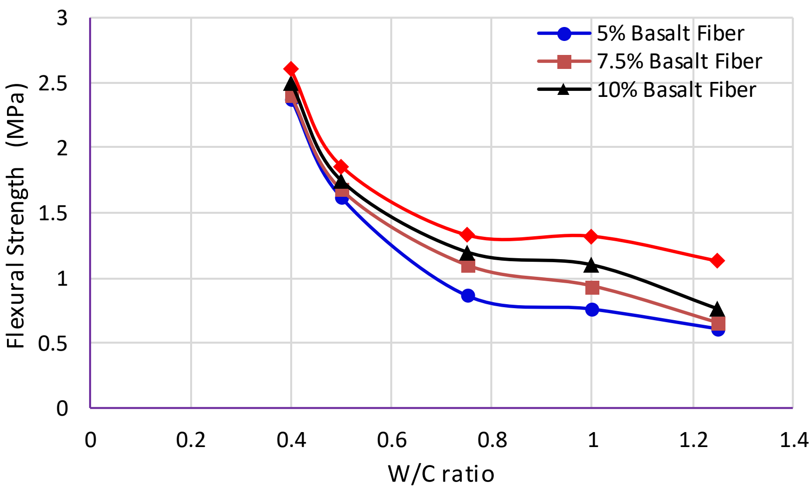

Figure 6. Effect of W/C ratio on flexural strength of fiber board with different basalt fıber ratio

Figure 7 shows flexural strength of specimens after immersion in water. There is actual effect of adding basalt fıber in different concentrations from 5% to 12.5% through submerging specimens in water for 48 hours with W/C ratio varies between 0.4 and 1.25 for each percentage of basalt fiber in mixture comparing with specimens in normal environmental conditions. The curves reveal that percentage of 5% basalt fiber has a weak flexural resistance due to less amount of basalt fıber that leads to the presence of large pores in cement board sample and because of the cement ratios are small at values of W/C 0.75,1, and 1.25, produce weak bond material. The samples reinforcement by a small basalt fıber ratio produced a weak flexural strength for all rates of basalt fıber. From the curve can be concluded that with increasing in bonding cement ratio, a good improvement was conducted at W/C ratios 0.5 and 0.4 and for all basalt fıber ratios, this is due to fill the pores and voids between basalt fıber with cement paste, which gives the internal structure of board extra strength and durability leads to improve its mechanical and physical properties. In addition, with higher percentage of basalt fıber, the flexural strength was improved, and the ratio of 12.5% basalt fıber was the best. All the ratios of basalt fiber were almost identical in behavior and results.

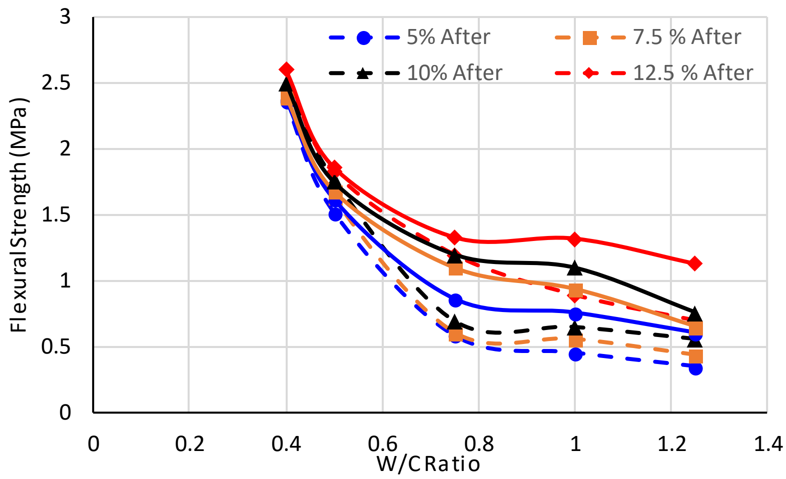

Figure 7. Effect of W/C ratio flexural strength of fiber board with different basalt fiber ratio before and after immersing in water

The thermal conductivity test results are shown in Figure 8. As basalt fıber increases, the thermal conductivity decreases, this result is because the basalt fıber contains many compounds, and the most important of these compounds is silicon oxide, which gives the main character being a heat insulator. It is also noted that the higher the W/C ratio gave a lower thermal conductivity, due to an increase in porous structures inside panels, which reduces thermal conductivity, where it is well known that the heat transferred by air or gas, which filled the voids, is very small.

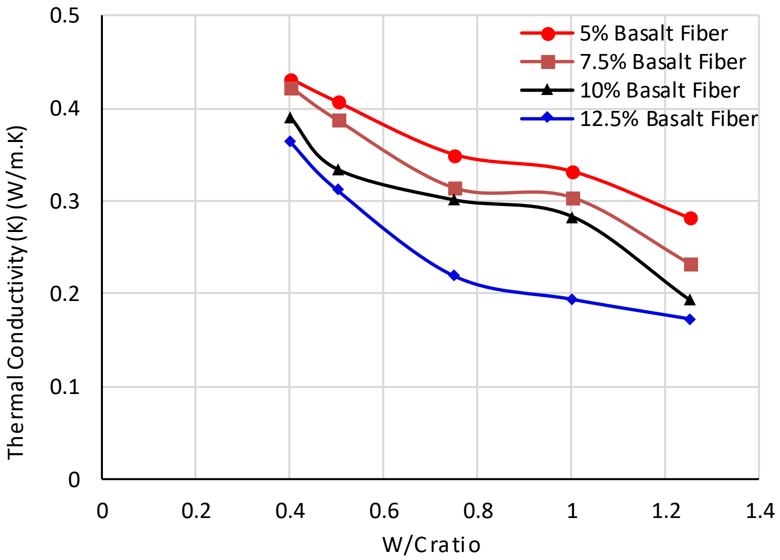

Figure 8. Effect of W/C ratio on Thermal conductivity of fiber board with different basalt fıber ratio

Figure 9 show the effect of basalt fıber on density, it is shown that greater percentage of basalt fıber gives the lower density, the reason for this, the amount of basalt fıber increases and the ratio of wetter/cement decreases, that means reinforcement with basalt fiber become higher of bond materials. For higher ratio of Basalt fiber and higher W/C ratio, the change in density became close with very slightly different.

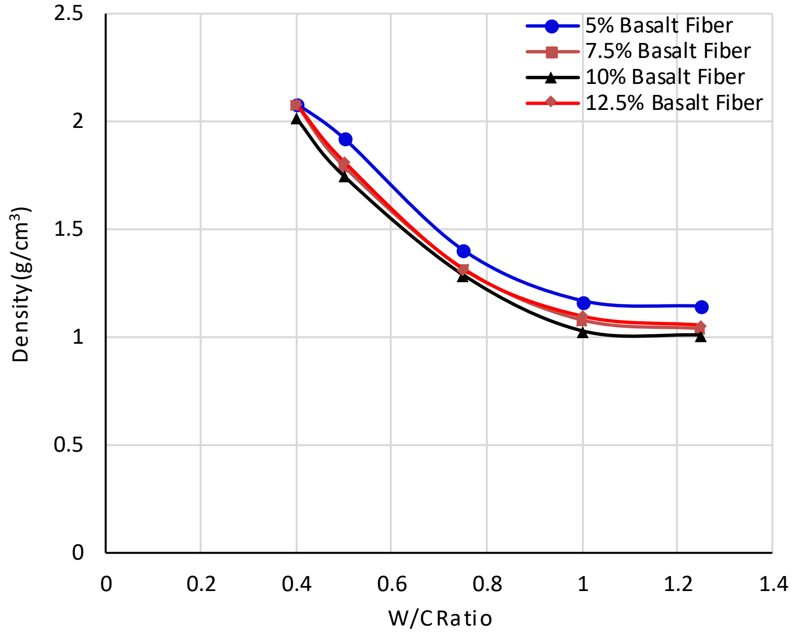

Figure 9. Effect of W/C ratio on density of fiber board with different basalt fıber ratio

The moisture content of the samples highly affected when adding basalt fıber at rates from 5% to 12.5%, moisture content decreases due to increase the basalt fıber ratio, this because of less pores in composition of board. In addition, adding basalt fıber will provide a ceramic concentration, due to the presence of silica material in basalt fıber, which leads to a chemical reaction, and then it forms ceramic concentrations. Also, it is noticed that whenever the ratio of W/C increases, the percentage of moisture increases, due to an increase in the porosity of boards, which leads to an increase voids in the board structure and increases their influence humidity. Figure 10 shows the results of adding basalt fıber on moisture content of boards.

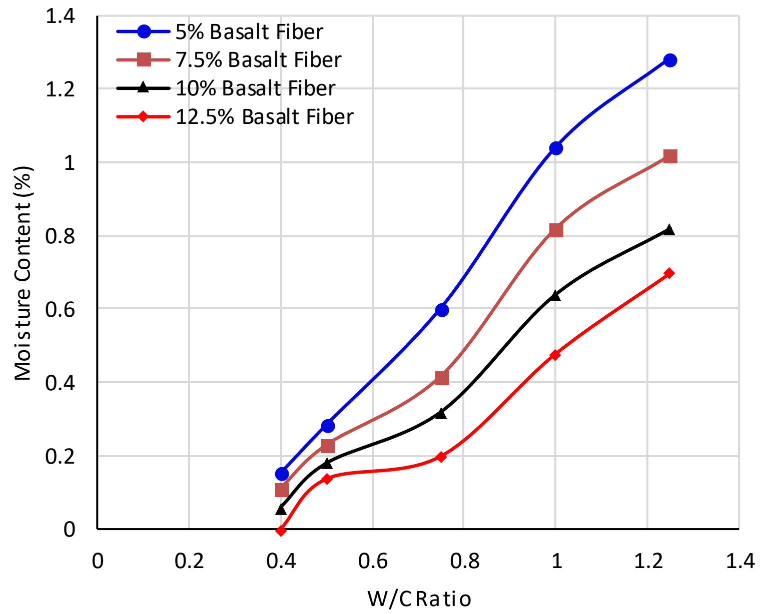

Figure 10. Effect of W/C ratio on moisture of fiber board with different fıber percentage

The Effect of adding basalt fıber percentage on water absorption from 5% to 12.5% is predicted in graph shown in Figure 10. It is clearly that more basalt fıber amount giving more absorbance, because large quantities of basalt fıber reduce of porosity in mixture, but this depends on the W/C ratio, which is necessary. There is an inverse relationship W/C ratio and Basalt fiber ratio, with increasing in the amount of basalt fıber, there must be a decrease in ratios of W/C, which considered the basalt fıber is a bonding material produce a high quality of board in strength and durability. If taking ratio W/C equal to 1, absorbance rises from 28.72% to 42.64%, i.e. approximately 12% water absorption ratio increases with decreasing the W/C ratios, water absorption rate decreases.

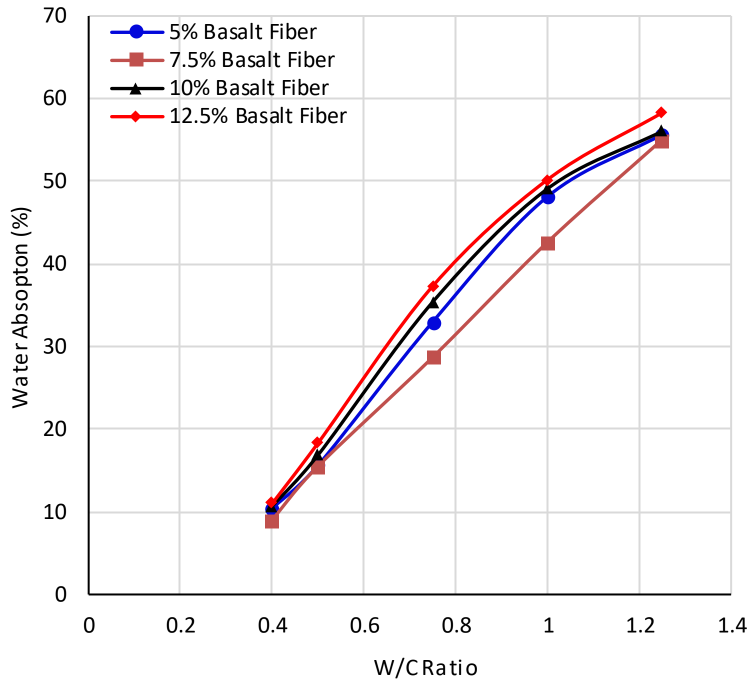

Figure 11. Effect of W/C ratio on moisture of fiber board with different basalt fıber ratio

6. Conclusion

In this study, using a new composite material were used to produce a cement board which have a wide range use in structural and building construction projects. The summarized results can be briefly listed below:

1. Produced Cement Fiber boards showing highly improvement in compressive strength for constant W/C ratio and variable basalt fiber ratio. The improvement in compressive strength for W/C ratio 0.4 and basalt fiber ratio change from 5% to 12.5% is 64.4 %.
2. The flexural strength of manufactured cement fiber board (in normal condition –before submerged in water) was the maximum with fiber basalt ratio 12.5% and W/C ratio is 0.4. the Enhancement was a slight 9.2%. while for those samples tested after submerged in water was 11%
3. Thermal conductivity of cement fiber board test results show a slightly improvement in insulation. The samples with fiber basalt ratio 12.5% enhanced the thermal conductivity 15.7 % compared with cement board of 5% basalt fiber ratio at W/C 0.4. When W/C varying from 0.4 to the 1.25 highly reduction in thermal conductivity occur at basal fiber ratio 12.5% and 10% is 87.6 and 102% respectively.
4. The W/C ratios between 0.4 to 0.75 shows highly reduction in densities of cement fiber board with increasing the basalt fiber ratio. While for high W/C ratio the change in densities become ineffective.
5. The moisture content and the absorption property of cement fiber board increases with increase the W/C ratio for all ratios of basalt fiber.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

Refreneces

[1]. Morova, N., (2013),(Investigation of usability of basalt fibers in hot mix asphalt concrete) (Construction Building Materials), Vo. 47, 2013, pp 175-180, https://doi.org/10.1016/j.conbuildmat.2013.04.048.

[2]. Fiore, V.; Di Bella, G.; Valenza, A. (Glass–basalt/epoxy hybrid composites for marine applications). Mater. Des. 2011, vol. 32, pp. 2091–2099. https://doi.org/10.1016/j.matdes.2010.11.043

[3]. Zhang, Y., Yu, C., Chu P.K., Lv, F., Zhang, C., Ji, J. and Wang, H., (Mechanical and thermal properties of basalt fiber reinforced poly (butylene succinate) composites) (2012), (Material Chemistry Physical), Vol. 133, pp. 845, https://doi.org/10.1016/j.matchemphys.2012.01.105

[4]. Yeboah, D., Taylor, S., Mc Polin, D. and Gilfillan, R., (Pull-out behaviour of axially loaded Basalt Fibre Reinforced Polymer (BFRP) rods bonded perpendicular to the grain of glulam elements). (Construction Building Material, (2013), Vol.38, pp.962-969, https://doi.org/10.1016/j.conbuildmat.2012.09.014.

[5]. Chen, Pu-Woei and D. D. L. Chung. "Low-drying-shrinkage concrete containing carbon fibers." *Composites Part B-engineering* 27 (1996): 269-274.

[6]. Fu, X., Lu, W., and Chung, D. D. L., "Ozone treatment of carbon fiber for reinforcing cement", *Carbon, (1998)*, Vol.36, No. 9, pp. 1337–1345 https://doi.org/10.1016/S0008-6223(98)00115-8.

[7]. Xu, Y., and Chung, D. D. L., "Cement based materials improved by surface treated admixtures" *ACI Material. Journal*, (2000), No. 97-M39, pp. 333–342.

[8]. Chen, P.-W., Fu, X., and Chung, D. D. L., "Microstructural and mechanical effects of latex, methylcellulose, and silica fume on carbon fiber reinforced cement" *ACI Mater. J.*, (1997), 94, 2, 147–1.

[9]. Chen, P.-W., and Chung, D. D. L., "Improving the electrical conductivity of composites comprised of short conducting fibers in a non-conducting matrix: The addition of a non-conducting particulate filler ", *Journal of Electronic. Materials*), (1995), Vol. 24, No. 1, pp. 47–51.

[10]. Fu, X., and Chung, D. D. L., "Improving the bond strength between steel rebar and concrete by ozone treatment of rebar and polymer addition to concrete", *Cement Concrete. Research*, (1997a), vol.27, No. 5, pp. 643–648.

[11]. Fu, X., and Chung, D. D. L., "Single fiber electromechanical pull-out testing and its application to studying the interface between steel fiber and cement", (1996 b), *Composite Interfaces journal*, Vol 4, issue 4, 197–211. https://doi.org/10.1163/156855497X00163

[12]. P. Manibalan and R. Baskar," Experimental Research On Mechanical Properties of Basalt Fiber Reinforced Concrete", *Journal of Critical Reviews* Vol 7, Issue 13, 2020.

[13]. Mohamad Hanafi, Ertug Aydin and Abdullah Ekinci, "Engineering Properties of Basalt Fiber-Reinforced Bottom Ash Cement Paste Composites", *Materials* 2020, 13, 1952.

[14]. N. Sathish, R. Vivekachandiran, S. Surendiran, K. Sathyanarayanan and M. Pandiyanrajan, "Evaluation of Basalt Fibre with Partial Replacement of Fine Aggregate by Foundry Sand in Concrete", *International Journal of ChemTech Research*, 2017,10(11): 120-126.

[15]. F. N. Rabinovich, V. N. Zueva and L. V. Makeeva, "Stability of Basalt Fibers in a Medium of Hydrating Cement", *Glass and Ceramics*, 58, Pp 431-434, 2001.

[16]. ASTMC191-13. Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle; *ASTM International: West Conshohocken*, PA, USA, 2013.

[17]. ASTM C349-02. Standard Test Method for Compressive Strength of Hydraulic-Cement Mortars (Using Portions of Prisms Broken in Flexure). 2002. 4P. *ASTM International, United States.*