Assessment of basalt micro-fiber for use in cementitious mortar

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Abstract

Stiff and durable cement mortar is considered the most widely wanted building materials. The durable cement mortar will decrease the costs of concrete maintain and future repair in the construction work. Basalt fiber (BF) is modified to different specific micro sizes to basalt micro-fiber (BMF) in order to achieve good mechanical with better microstructural properties of the casted cementitious mortar. This paper verifies the improvements that are made to the cement by the prepared basalt micro fibers BMF1 and BMF2 with different replacement contents (0.2, 0.5 and 1%) of the cement. All BMF additions influence on the physico-mechanical properties of the casted cementitious mortar. Low BMF replacement ratios led to an significant increase in the mechanical properties whereas, the higher replacement 1% shows slightly decreasing than the control sample. The modified BMF1 with replacement 0.2% show the highest value in both compressive and split tensile strength, it also show compacted microstructure by increase cohesion forces between particles in the mix. The more finely modified BMF2 show tiny micro equant particles beside the retained small fiber shape due to the relatively longer time of specific grind leading to dense mortar and helping in inhibit connected pores in the mortar internal microstructure. Finally, It has become important to discuss the modify BF and recommended to use the BMF in case of enhancement cementitious mechanical strength.

Keywords: Basalt Micro-fiber; Cementitious Mortar; Mechanical Properties; Internal Micro-structure.
Kulcsszavak: bazalt mikroszál, cementhabarcs, mechanikai tulajdonságok, belső mikrostruktúra

1. Introduction

Basalt is a widely distributed type of volcanics formed by the rapid cooling of lava at the surface of the earth. So, it is the most common rock in the Earth's crust. Fibers can be formed from molten basalt stone at high-temperature by extrusion. The basalt can be melt (1300-1700 °C) and spin into hairy fine fibres, where high quality fibers are made from basalt deposits with uniform chemical makeup [1]. The resulting basalt fibers chemically are containing 45%–52% SiO_2, and are considered environmentally friendly and non-hazardous materials. Basalt fibers have excellent properties such as high-modulus, high-heat resistance, sound insulation and thermal stability [2]. Also their processing and physical property leads to decreases in production costs which make it less expensive than alternative glassy fibers [3-4]. Basalt fibers are also show good abrasion resistance and less prone to damage from aggressive salts, alkali or acid solutions [5–9]. These excellent properties facilitate many potential applications especially in building material industry. Researchers have used basalt fibers as a reinforcing material in concrete manufacturing due to its good mechanical characterization. It used for reinforcing concrete alone or modified with other additives [10–17]. As well as, it can be chopped and grinded as cement additive to gain high mechanical properties [18-20].

Fibers have been added to concrete and mortar for many years in order to reduce the amount and size of cracks. It show better binding properties of cementitious composite due to the similarity of chemical properties [21]. In addition to the physical parameters as fiber length, fiber concentration and temperature condition can effect on mechanical properties and enhance the concrete strength [22]. There is an advice to study the effect of basalt fiber with different modification [23]. It can be modified by many methods leading to improve the internal structure of cementitious matrix. So, the effect of the modified basalt fiber size may make significant change in mechanical properties of the cement mortar when it modified to different micro lengths. The main aim of this research is to clarify the effect of the modification of the basalt fiber to the size of micro-fiber (BMF) and significant changes in mechanical and micro-structural properties of the cement mortar modified with different percentages and micro sizes, showing the optimal micro length and its cement replacement level with BMF.

2. Materials and methods

2.1 Materials

The materials used in the research (cement, sand, basalt fiber) are analyzed by XRF and XRD, and are found identical to the Egyptian standard specifications [24]. Their major oxides are listed in *Table 1*. The used cement is Egyptian Ordinary Portland Cement (CEM II with Rank 42.5) produced by Beni-Suef Cement Company. The sand is composed mainly of quartz mineral and it is sourced from a common quarry around Cairo district, Egypt, serves as fine aggregate in the mix design. Basalt fibers were supplied by a company called Rockal specialized in the manufacturing of Rock fibers. Basalt fibers are shown to be amorphous when examined by XRD and having silica content 41% estimated by XRF as shown in *Table 1*.

Material	Major oxides by XRF													
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Na_2O	K_2O	P_2O_5	SO_3	MnO	LOI	Total	Mineral content (XRD)
Basalt fiber	41.01	12.10	11.0	23.90	5.20	2.69	2.04	1.19	0.27	0.20	0.19	0.03	99.91	amorphous
Sand	97.30	0.08	0.24	1.50	0.11	0.01	0.19	0.41	0.00	0.04	0.00	1.33	99.81	Quartz
Cement (OPC)	20.05	4.69	3.52	62.00	1.61	0.40	0.40	0.19	0.16	2.39	0.09	4.40	99.90	
	Cement specific gravity = 3.11 , Ins.Res = 1.27													

Table 1 Chemical composition of the used materials by XRF
1. táblázat Használt anyagok kémiai összetétele XRF alapján

2.2 Preparation of BMF

The basalt fiber as received average length is about 10 cm with individual fiber diameter approximately 10 µm. The sequence of preparation of the BMF is as follow; firstly, basalt fibers are separated with hand into individual fibers to use as it is and in order to be uniformly distributed in the mix. Secondly, a small fraction from the basalt fibers bundle is fed to the grinding machine by feed capacity (50 g/L) and grinded on two intervals, 30 sec and 300 sec. and termed BMF1 and BMF2 corresponding to 30 sec and 300 sec respectively.

2.3 Mixing procedure

Mortar Mix	Mix proportions (kg/m³)				
	Cement	Sand	BMF	water	Super Plastizer
Control	568	1670	0	212.8	2.8
BMF0-0.25%	558.6	1670	1.4	212.8	2.8
BMF0-0.5%	557.2	1670	2.8	212.8	2.8
BMF0-1%	554.4	1670	5.6	212.8	2.8
BMF1-0.25%	558.6	1670	1.4	212.8	2.8
BMF1-0.5%	557.2	1670	2.8	212.8	2.8
BMF1-1%	554.4	1670	5.6	212.8	2.8
BMF2-0.25%	558.6	1670	1.4	212.8	2.8
BMF2-0.5%	557.2	1670	2.8	212.8	2.8
BMF2-1%	554.4	1670	5.6	212.8	2.8

Table 2 Mix proportion of the studied cementitious mortars
2. táblázat A vizsgált cementkötésű habarcsok keverési aránya

In order to evaluate the effect of BMF blended with cement on the physical and mechanical properties of BMF cement based mortar, OPC is mixed with sieved sand passing 1.18 mm sieve in ratio equals 1/3 to form a control sample with 0% BMF and utilizing water-to-cement ratio (w/c) 0.38. Secondly, mixing BMF with cement by weight replacement (0.25, 0.5, and 1%) standing for BMF0, BMF1 and BMF2 as shown in *Table 2*. Then dry density and water absorption are measured for each mix according to [25], also, compressive and split tension strength evaluated for each mortar mix following the Egyptian standard code [24]

3. Results and discussions

3.1 Size characteristics

3.1.1 Particles distribution of modified BMF

The effect of size modification of BMF on the cementitious mortar, particle size estimation for BMF samples (BMF1 and BMF2) is performed by laser particle size. The results showed the particle size distribution of the BMF1 sample ranged from 451µm to 0.6 µm length with a mean size (112 µm), as shown in *Fig 1*. However, the BMF2 sample that was subjected to relatively longer time of grinding (300 sec), it is obvious that it became more finer showing fibers dimension ranged between 251 µm:0.5 µm with a mean size equal 6 µm (*Fig 2*).

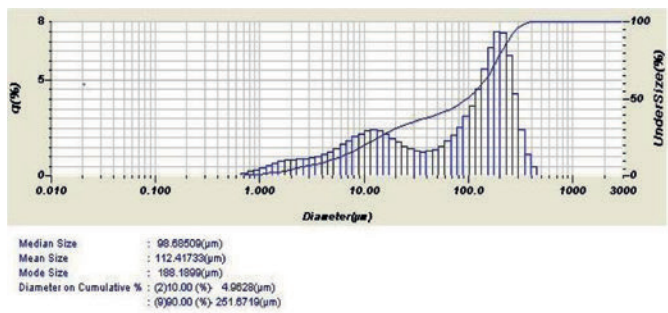

Fig. 1 Laser scattering Particles size distribution chart of BMF1 (30 sec)
1. ábra BMF1 (30 mp) szemcseméret-eloszlási diagramja lézerszórással

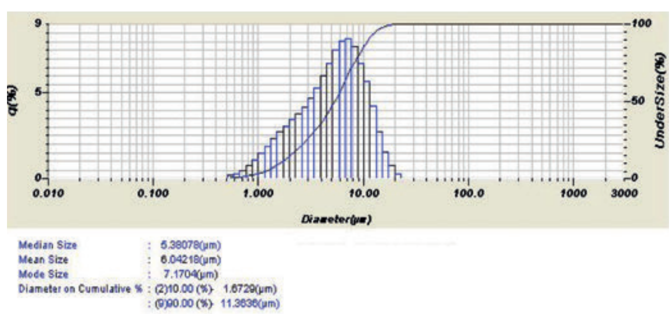

Fig. 2 Laser scattering Particles size distribution chart of BMF2 (300 sec)
2. ábra BMF2 (300 mp) szemcseméret-eloszlási diagramja lézerszórással

3.1.2 Microscope examination

Examination of size modified BMF0 sample using optical microscope (*Fig. 3.a*), which is chopped by hand show long fiber structure. Also, the examination of BMF1 sample revealed that most of its particles show large to medium micro fibers length and retained its fiber shape after suffered to 30 sec of grinding. However, the BMF2 sample with longer time of grinding show lesser and smaller micro fibers beside to scattered small angular micro particles (*Fig. 3.c*) indicating the beginning of losing fibrous structure.

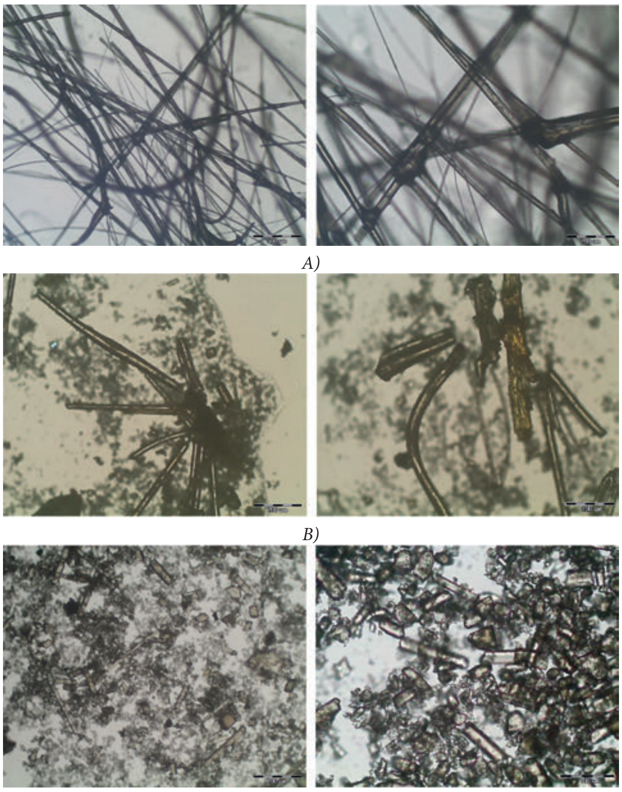

Fig. 3 Photomicrographs of BMF A) fibers network of BMF0 sample with magnification (left -4X) and (right-10X), B) micro fibers of the sample BMF1 (10X magnification) at left and (20X magnification) at right, C) Distribution of equant micro particles beside to microfibers of BMF2 sample with magnification (10X) to the left and (20X) to the right

3. ábre BMF mikrofotók A) BMF0 minta szálhálózata nagyítással (balra -4X) és (jobbra -10X), B) BMF1 minta mikroszálai (balra 10X nagyítás) és (jobbra 20X nagyítás), C) BMF2 minta egyenletes mikrorészecskéinek eloszlása a mikroszálak mellett, nagyítással (balra 10X) és (jobbra 20X)

3.2 Dry density

There is hardly noticeable difference in dry density between all the studied mortars prepared by the modified BMF at low cement replacement levels (0.25, 0.50, and 1.00%). However the density values decreased from 2.392 kg/cm^3 of the control sample (0% replacement of BMF) to 2.376 kg/cm^3 at the highest replacement level of the sample (BMF0-1%). And the modified BMF1 sample show slight decrease in the density from 2.388 of (BMF1-0.25%) to 2.382 kg/cm^3 with the highest replacement (BMF1-1%). While the modified BMF2 samples show slightly relative increase in density values compared to BMF0 and BMF1 samples as shown in *Fig. 4*. That may relate to the differences in fiber size and shape of the three modified types. From the concept of cementitous mortar density may affect its strength as discussed by authors [26]. These relatively increasing density values of BMF2 are considered reasonable to a good mortar if compared with other mixes, as it can lead to more compaction by finer fibers interaction with other particles in the mix.

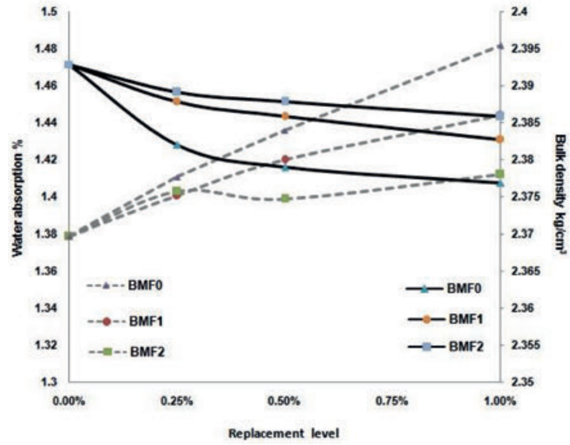

Fig. 4 A relation showing mortar dry density versus water absorption using prepared BMF of different sizes

4. ábra A habarcs száraz sűrűsége és vízfelvétele közötti összefüggés különböző méretű előkészített BMF-ek használatával

3.3 Water absorption

The water absorption property is very important for special mortar types, since it is used for determined the quality of the mortar and its application [23]. There is direct relation between the water absorption values and bulk density of mortars mixed by BMF as shown in (*Fig. 4*). The fact that low density due to increase in voids content between particles leads to higher water absorption, may be explained that replacement by 1% of BMF0 and BMF1 show the highest water contents between all samples equals 1.48 and 1.44% respectively, than mortar with finest fibers (BMF2) which equals 1.41%. That is explained further by increasing of voids since grain size distribution of studied BMF may stifle filling cavities especially in the case of hand chopped basalt fiber (BMF0) also the relatively higher in modified fibers length as in case of (BMF1).

3.4 Compressive strength

Compressive strength was evaluated by testing moulded mortar cubes according to the Egyptian code for each BMF mix. There is a variation in strength values by using different modified BMF with different cement replacement levels (0.2, 0.5, and 1%). The control sample reached compressive strength value 30.5 MPa and evaluated as class (C30). The compressive strength after 28 days increased about 5.0, 20.6 and 6.9% when using in the mix 0.25% of BMF0, BMF1 and BMF2 respectively. However, the replacement value 0.5% show slightly decreasing in value reached to 29.6, 32.6, 32.1 MPa when cement replaced by (BMF0, BMF1 and BMF2) respectively. In addition to the cement replacement with 1% of (BMF0, and BMF1) decrease the strength with 9.5 and 0.2% of the control sample respectively. Unlike 1% of (BMF2) show very slightly increase in the compressive strength. That means the optimum replacement value of the BMF mortar may be (0.5%) or (1%) depending on the method and time of mechanical modification. However cement replacement level (0.25%) shows the highest values especially in the mortar mix with BMF1 may relate to the good physical properties of this cementitious mortar [25]. On the other hand, the finer BMF2 obtained by 300 second of grinding seems to be more effective for keep strength than others. This may explained as the smaller fiber length may easily distribute in the mixture resulting in higher bond strength between the micro fiber filaments and the other mix particles. That helps more specific surface of fibers to interact with the cement making good compaction. Their terminals give a connecting growing pattern providing the materials a higher strength [19]. Therefore using modified BMF in cementitious mortar mix may help in strengthening objects.

3.5 The split tensile strength

The split tensile strength of BMF mortars show to some extent similarity to compressive strength curves (*Fig. 5*). Tensile strength values increased with all the replacement percents (0.25, 0.5 and 1%) by the prepared basalt microfiber (BMF0, BMF1 and BMF2). that is attributed to the fibers bridging interaction [23], where the mortar ductility is improved preventing further crack growth [27-28]. All tensile strength values varies between 2.25 and 3.87 MPa which is considered higher than the control value (2.04 MPa) up to 1% replacement, unlike the compressive strength values with 1% replacement by (BMF0, BMF1). It mentioned that BMF had no effect on the compressive strength but might significantly improve the tensile strengths [9].

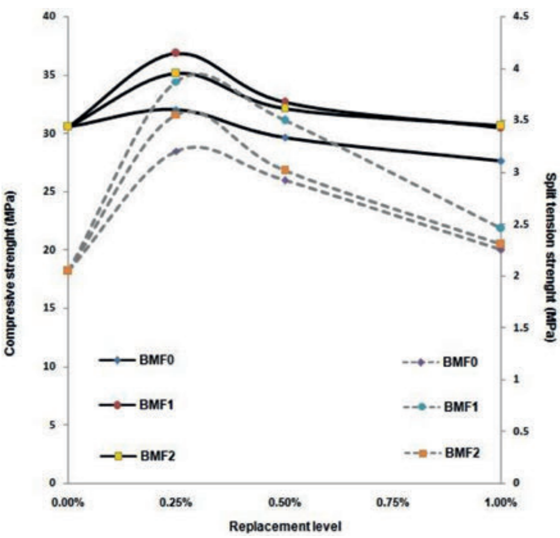

Fig. 5 A graphic relation between compressive strength and split tension strength of BMF mortars
5. ábra A BMF habarcsok nyomószilárdsága és hasító húzószilárdsága közötti grafikus összefüggés

However there is a decreasing with increasing replacement percent up to 1%. Also there are a noticeable difference between the three prepared BMF used. The mortar samples mixed with BMF0 without grinding show the lowest split tensile strength values (3.20, 2.92 and 2.25 MPa) with the alternatives (BMF1 and BMF2). This may attributed as discussed by [9] to the increasing fiber content which give negative effect on workability which reflect segregation and poor fiber distribution may occur. Thus the perfect mechanical adherence with high BMF content may be prevented from occurring especially with continuous longer fiber filaments in case of BMF0 using as it is. The samples with finer micro fibers (BMF2) which showed good compaction unexpectedly showed relatively decrease in split tension strength values (3.55, 3.01 and 2.30 MPa) than values of (BMF1) samples (3.87, 3.50 and 2.46 MPa) with (0.25, 0.5 and 1%) replacement respectively. That may attributed to more grinding time (5 m) begin to destroyed the fiber structure but in case of BMF1 the fiber shape is still retained with more sharp terminals which may make a good kind of internal tension with hydrated cement particles.

3.6 Scanning electron microscope of BMF mortar

The morphological structure of different BMF mortar mixes were visualized using SEM (*Fig. 6*). Control mortar sample described by dense homogeneous cement paste however there are few micro cracks and micro voids accompanied the periphery of sand aggregates. Most of mortar samples with BMF illustrate that fibers act as a bridge between cement paste grains, that simply explain the better strength gained by using basalt microfibers. However, increasing content of BMF by relatively higher replacement 1% may accompany by fiber agglomeration lead to poor distribution of the fiber in the mix.

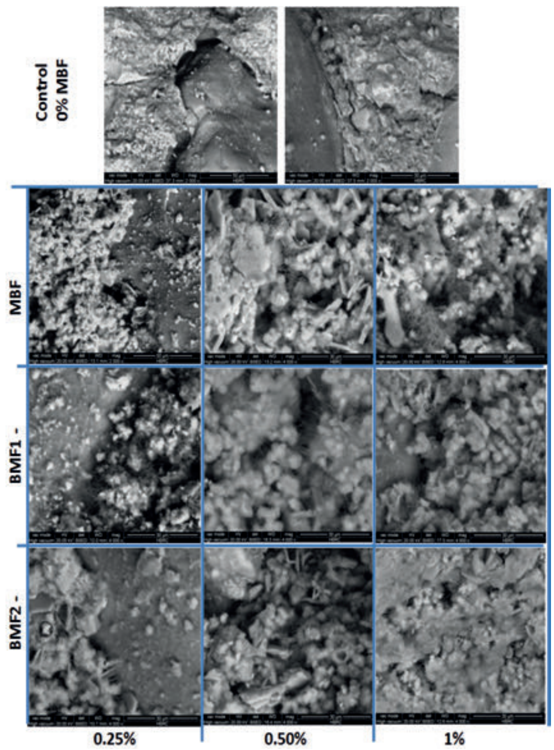

Fig. 6 SEM micrographs of the different studied BMF mortar mixes
6. ábra SEM felvételek különböző vizsgált BMF habarcsokról

Mortar samples with BMF1 show better fiber distribution, more compaction and void filling improvement than the unmodified BMF due to the increase of its role as abridge linkage filling voids. Finer particles and specific short fibers length of such samples may help for well distribution within the cement matrix. Micrographs of BMF2 mortar samples illustrate to some extent similarity to BMF1 samples, however there is an appearance of more compaction if compared with other mixes. The dense appearance of that samples may explained by finer microfibers and tiny equant shape micro particles formed by longer grind help in good distribution and well fishering with other particles in the mortar mix. It is noticed that BMF2 may lead to decrease the possibility of formed micro pores within the cement matrix or around the aggregates periphery.

4. Conclusion

Micro basalt fibers can be used as admixtures for cementitious mortar. Basalt micro fiber can be prepared by grinding for different specific time (30 or 300 sec) to yield micro fibers with a mean size about (112 μm) and (6 μm). Grinding effect can change the fiber shape where basalt fiber grinded for longer time can lose its fiber structure.

It is preferable to use BMF with prepared micro fiber sizes than unmodified fiber. Preparation and modification of BMF will help in well distribution in the mortar during mixing. Basalt fiber characteristics in micro length have a slightly influence on the physical mortar properties especially its density and w absorption ability. Increasing of BMF content prepared with different micro fiber lengths can increase the water ability of the cementitious mortar and lower its density. Types of fibers and their characteristics sizes can control the differences of the studied mortar water absorption.

Modified BMF can enhance the mechanical properties of cementitious mortar since it increases both its compressive and tension strength. Especially split tension strength results showed more positive effect with BMF than the compressive strength of the same mortar samples. And that in very fine micro sizes basalt fibers that retained the hairy fiber shape can perform well than others fibers which loses its fiber shape. Because of the fiber filaments still have sharp terminals which make a good kind of internal tension with hydrated cement particles. Therefore, using prepared BMF in cementitious mortar mix can help in concrete strengthening purposes.

Finally, the prepared BMF with the specific micro sizes effectively will be positive the internal microstructure of the cementitious mortar giving more dense and compacted appearance due to the modified basalt fiber particles concluded that using BMF will be a good step for improving mortar characteristics.

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