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Research Paper

Use of Microgrid Fiber type new Additives to Improve Load Bearing and Energy Absorption Capacities of Shotcrete Mixes

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ABSTRACT

In this study, different polypropylene type polymer fiber additives were comparatively examined carrying out a series of EFNARC plate (slab) loading test, which is a popular test for evaluation of the shotcrete liner performances. A new fiber type called microgrid fiber (MGF) was compared with the conventional polypropylene fiber (PPF) additives. Shotcrete mixes were tested to determine their load bearing, deformability and energy absorption capacity properties. Additionally, indirect (splitting) tensile strength (ITS) values of specimens were determined to compare influences of different fiber types. According to the slump test findings, the workability of the fresh mixes decreased with an increase in fiber content. It was determined that the workability properties of conventional PPF and MGF added specimens were similar. However, it was found that the MGF type additive reduced the fresh mix workability more than the PPF additive due to the increase in the fiber content. It was found that MGF additive was found to supply better improvements in ITS values, load bearing and energy absorption capacity properties of slabs in comparison with the conventional PPF additive. The new MGF type additive was assessed to be usable to effectively improve the shotcrete performances.

1 Introduction

Shotcrete is a widely used liner material in mining and geo-engineering works. It supplies important advantages in engineering because of needing no molds and allowing relatively fast applications. Shotcrete liners are primary support elements for rock masses, which are sprayed on the excavation surfaces using the compressed air. To improve the load bearing performances of the shotcrete liners, various reinforcement methods like use of meshes or fiber additives can be preferred. Instead of using meshes, fiber contents can supply more practical applications because of eliminating the mesh setting time and extra labor costs. Fiber additives are popular products used to improve the tensile strength of shotcrete materials, improve crack propagation resistance, ductility and energy absorption capacity values [1-3]. The most commonly used fiber materials in concrete mixes are steel and polymer (synthetic) ones. Against the corrosion problem of the steel fiber products, non-corrosive polymer fibers provide significant advantages in terms of the service life times of the concrete

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materials. In terms of the shotcrete mixes, the corrosion problem is also disadvantageous especially for excavations in moist or watery rock masses. The corroded steel fiber has a negative effect on the mechanical properties of shotcrete materials by reducing the strength values. For this reason, polymer fiber types with high chemical resistivities are used in shotcrete mixtures. Polypropylene type engineering polymer is one of the most common synthetic plastic fiber material [4-6]. Typical polypropylene fiber strand lengths vary from 1 cm to 5 cm, and strand diameters of different products generally vary within a range from 30 to 250 micrometers. Ideal length and diameter properties of the geofiber strands can change depending on the concrete material content, aggregate particle sizes and application details. For instance, long fiber lengths are not preferred in shotcrete mixes because of supplying proper sprayability properties. For typical fiber additives, nozzle diameter should be at least 1.5 times higher than the fiber length [7-9].

In this experimental study, use of a new polypropylene fiber type called microgrid fiber (MGF) has been investigated to assess its effect on the strength and deformability properties of a shotcrete mix. This study is a novel and pioneering one to investigate the use of MGF added shotcrete mixes. MGF is the combination of thin plastic fibers in groups of two or more different directions which form mini grids (Fig. 1). The “microgrid” term is suggested to use for grid sizes below 2.5 mm. In studies conducted by authors other than the author of this study, the MGF-type fiber was tested only for soil improvement purposes. It was noted that MGF-type fiber additives provide higher performance in terms of sand reinforcement and stiffness increase compared to conventional fibers [10]. In previous investigations carried out by the author of this study, MGF was also used in some different binder added sand and cementitious minefill mixes and found to supply better reinforcement performances than those of the conventional fiber (PPF) additives. It was found that MGF additives supply better compressive and tensile strength improvement performance in comparison with the conventional PPF additives. Instead of the conventional fiber use, modulus of elasticity values were also higher in the case of using novel MGF additive. In addition, the ductility property was found to be better improved using the MGF additive [11-13]. As same with this study, MGF and PPF products were made of the same polypropylene type fiber in the studies aforementioned above. Also, MGF and conventional fibers with same lengths were used within previous studies. As a novelty of this study, microgrid fibers were used as a new fiber additive for shotcrete mixes.

As a motivation of this study, a bettered adherence performance in concrete mixes was estimated from MGF additives because combined fibers can work together in their use. Also, the MGF reinforcement was predicted to provide a bettered adherence in the shotcrete mixes due to its structural properties. In addition, grid type physical property was thought to make an additional friction coefficient for the aggregate contacts by attaching grain edges to the grids. Grid type reinforcement inclusions can provide an interlocking mechanism with the grains [14-16]. A good adherence property of the reinforcement provides a significant advantage not only in the strength values, but also in the crack propagation resistance, as well as the energy absorption capacity of the fiber reinforced concrete materials [17-19].

Use of conventional fiber additives and new MGF additives in typical shotcrete mixes was comparatively examined in this study to evaluate whether the new MGF type additive provides an advantageous reinforcement for shotcrete mixes, or not. In addition to the strength properties of the shotcrete mixes, their workability properties were also tested to better investigate the usability of the new MGF type additive in shotcrete mixes. Differences in strength values and deformability properties of specimens were investigated. The novel MGF type additive’s convenience was aimed to assess in terms of its reinforcement effect in the shotcrete mixes. Details about the experimental study carried out within this research are given under the next section.

2 Materials and Methodology

A typical shotcrete mix was examined in this study. The shotcrete mix tested in this study is used with meshes in an underground copper mine located in the Black Sea Region of Turkey. The specimen with no fiber additive (NF) is the shotcrete mix itself used in the mine. The content details of specimens can be seen in Table 1. In this study, MGF and conventional PPF type different fiber additives were used in the shotcrete mix to compare their reinforcement performances and investigate the usability of MGF type novel fiber additive type. Typical shotcrete mixes generally do not contain coarse aggregates over 12 mm size and have a higher amount of fine aggregate compared to the molded concrete materials. The maximum particle size of the aggregate used in the study is also 12 mm. 66% of the aggregate has the particle sizes below 4 mm and 34% has particle sizes between 4 mm and 12 mm. Since shotcrete applications are carried out without using molds and it is aimed to start bearing loads in a short time, the accelerator type chemical additives are preferred to use. In order to provide suitable fluidity for spraying, fine aggregate usage requires a higher amount of water than those in the concretes with

the coarse aggregate content. In the tested shotcrete mixes, a plasticizer chemical additive was used with an amount of 1% of the cement by mass. CEM 1 42.5 R type ordinary Portland cement which is a product of a Turkish cement company located in the Unye district of Ordu city was used in the mixes.

Densities of polypropylene fiber materials are quite low in comparison with steel fiber materials. This situation allows polypropylene fibers to be used in much less masses in concrete mixes. To compare with newly investigated MGF additive, a conventional polypropylene type fiber (PPF) product was also tested in this study. It should be noted herein that both MGF and PPF products were purchased from the same supplier and made of the same polypropylene type fiber material with tensile strength, modulus of elasticity and density values of 350 MPa, 4.5 GPa, 0.93 g/cm³, respectively. For a proper comparison, all the fiber additives used in this study have same strand diameter and fiber length values. Strand diameter of MGF and PPF additives is 0.25 mm. As another size parameter, length of both MGF and PPF type fibers is 20 mm. MGF additives with width to length ratio (B/L) values of 0.5 were used in the mixes. The MGF type fiber additive used in this study has the grid size of 1.2 mm. Content details of tested shotcrete mixes are given in Table 1.

Table 1 - Mass proportions of the specimen mixes (Ms: Sum of cement+water+aggregate masses, Mc: mass of cement, NF: no fiber use)

Specimen type	Cement	Water	Aggregate (0-4 mm)	Aggregate (4-12 mm)	Plasticizer	PPF	MGF
NF	0.19 M _s	0.10 M _s	0.47 M _s	0.24 M _s	0.01 M _c	0 M _s	0 M _s
PPF (0.2%)	0.19 M _s	0.10 M _s	0.47 M _s	0.24 M _s	0.01 M _c	0.002 M _s	0 M _s
PPF (0.4%)	0.19 M _s	0.10 M _s	0.47 M _s	0.24 M _s	0.01 M _c	0.004 M _s	0 M _s
PPF (0.6%)	0.19 M _s	0.10 M _s	0.47 M _s	0.24 M _s	0.01 M _c	0.006 M _s	0 M _s
MGF (0.2%)	0.19 M _s	0.10 M _s	0.47 M _s	0.24 M _s	0.01 M _c	0 M _s	0.002 M _s
MGF (0.4%)	0.19 M _s	0.10 M _s	0.47 M _s	0.24 M _s	0.01 M _c	0 M _s	0.004 M _s
MGF (0.6%)	0.19 M _s	0.10 M _s	0.47 M _s	0.24 M _s	0.01 M _c	0 M _s	0.006 M _s

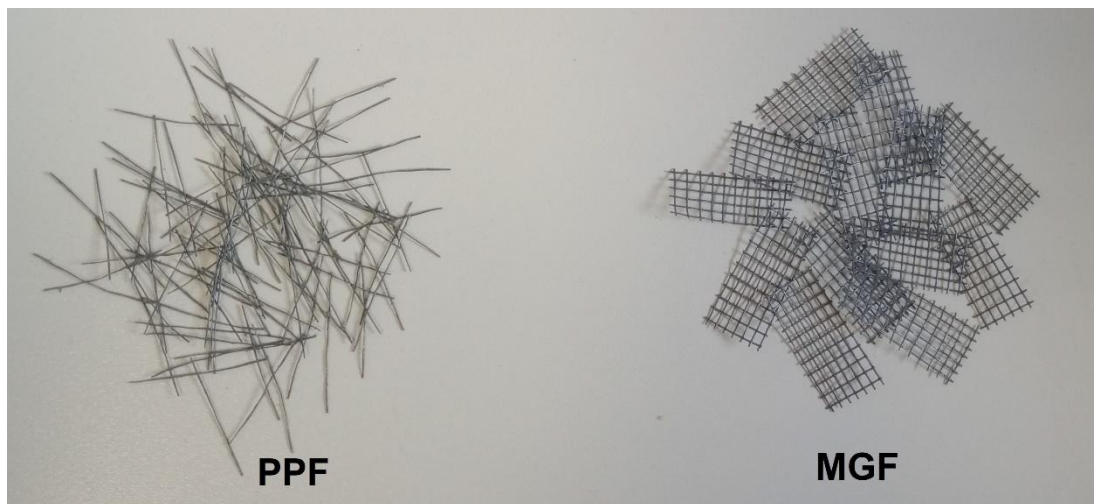


Fig. 1 – MGF and PPF type fibers

In the slump test, workability properties of specimens with four different fiber content amounts of 0%, 0.2%, 0.4%, 0.6% were investigated for the use of each fiber types. The slump test is a popular method to investigate the workability properties of fresh concrete mixes. The slump value is an important indicator for the ease of transferring and flowability properties of the fresh concrete mixes. The test is popular due to the simplicity of the testing equipment and its simple procedure. The slump test was carried out in accordance with the ASTM C143/C143M-12 coded standard [20]. The cone mould with the upside diameter of 10 cm, downside diameter of 20 cm and the height of 30 cm was filled in three layers. Volume of each layers were approximately one third of the mold volume. Fresh mixes were tamped with 25 strokes of the standard tamping rod to remove air after filling each layers. As the cone is full, topside of specimens were leveled by removing excess fresh

concrete. Then, the mold was removed from the concrete by raising it carefully in the vertical direction. As the cone vertically lifted, the slump value which is the height difference between the top of the cone and the demolded fresh mix was measured (Fig. 2). The slump values of fiberless, MGF added, PPF added mixes were separately determined to compare their workability properties for different fiber contents in the mixes.

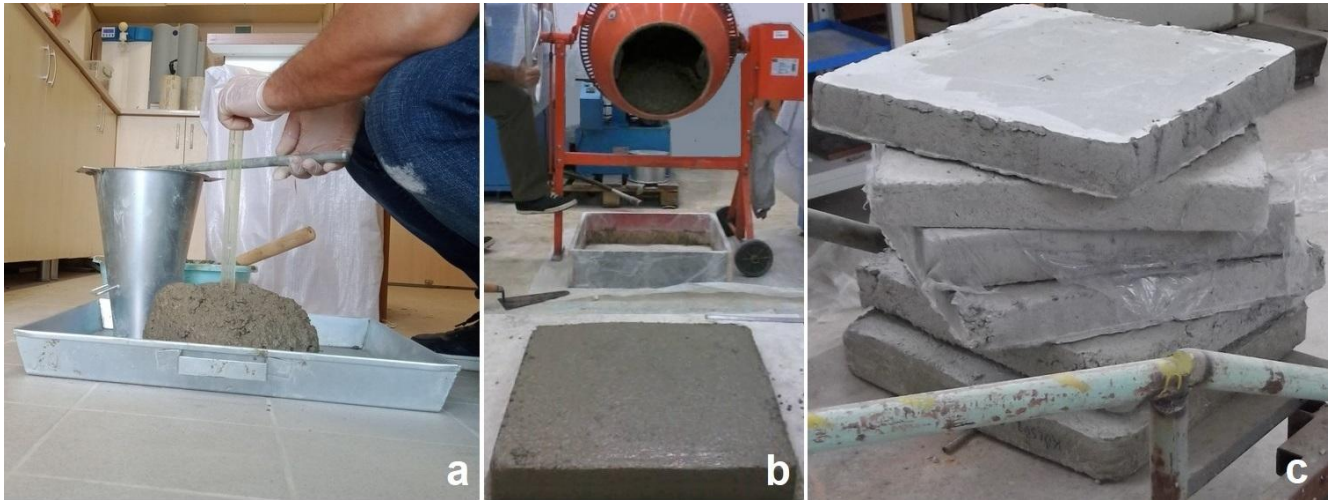


Fig. 2 – a) The slump test, b) slab casting, c) slab specimens casted in the laboratory

In addition to the slump test, the EFNARC plate (slab) loading test which is a popular test for determination of the shotcrete material performances were carried out. The slab loading test is a type of three dimensional flexural strength test applied on the slab specimens with dimensions of 60 cm x 60 cm x 10 cm. The test was carried out in accordance with the EFNARC shotcrete testing guide [21]. According to the relevant testing details, the loading rate was chosen to be 0.3 kN/s. In the slab loading test, load (kN) and deflection (mm) data is used to calculate the energy absorption capacity (EAC) values of concrete materials in the unit of Joule (J:N·m). The area under the load deflection graph gives the EAC values. Areas under the graphs have been calculated considering the changes in load values for the 0.1 mm deflection increase sensitivity. The slab loading test supplies information about load bearing, stiffness, ductility and EAC properties of the shotcrete mix specimens. To measure the deflection of slab specimens, an LVDT device was used in the test. According to the relevant standard, loading was continued until reaching the 25 mm deflection of the fiber added specimens. On the other hand, fiberless specimens could not be loaded until the 25 mm deflection because of their early failure due to the high brittleness property. With an increase in the ductility property, the deformability limits of the cracked specimens increase. Therefore, the fiber added specimens can be deformed more by supplying bettered EAC values. The maximum load level and EAC values of specimens with different fiber types were investigated within the EFNARC slab loading test. The 60 cm x 60 cm specimens are placed on the steel frame with 50 cm x 50 cm opening size, and loaded by 5 cm diameter steel platen placed on the center of the slabs (Fig. 3). The LVDT was contacted under the slabs at the middle span of the frame to measure the deflection values during the loading period. Shotcrete mix specimens were homogenized for eight minutes in a drum mixer. Then specimens were casted in the molds with 60 cm x 60 cm x 10 cm dimensions.

Shotcrete mixes of the slab loading test were casted in two layers and compacted with 80 strokes of the tamping rod after each of the layers. Tamping rod strokes were moved on all of the surface area of the layers. After casting layers, up-side surfaces of the fresh slabs were flattened by using a trowel. Mixes with different fiber types were preferred to have the same workability properties. For this reason, MGF and PPF added concrete specimens with 0.2% fiber content were tested in the slab loading test. By this way, fiber added shotcrete mixes with the same slump value were compared to assess whether the new MGF type additive is advantageous, or not. In the study, all shotcrete specimens were casted and molded with the same procedure. Slab loading test specimens with a total curing time of 28 days were used in the experiments. The slab specimens were cured in air and room temperature conditions.

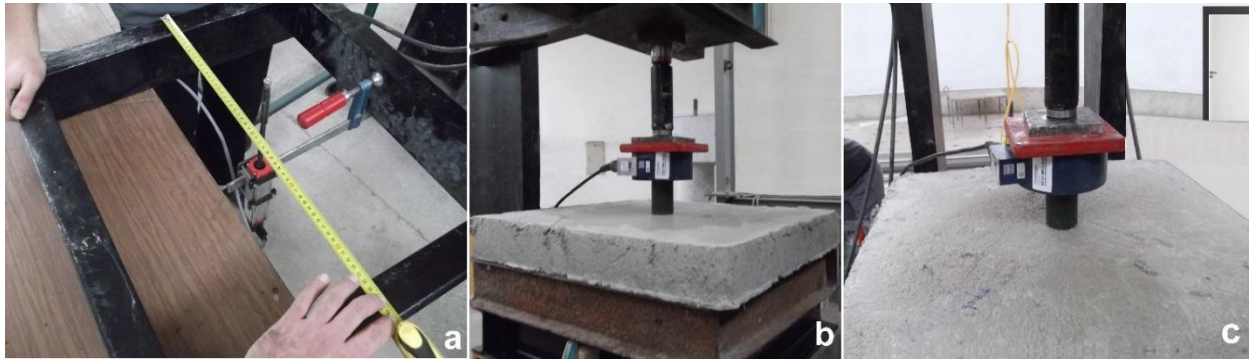


Fig. 3 – a) LVDT device montage, b and c) some photos from the slab loading test

The EFNARC plate (slab) test which is a popular method used to examine shotcrete performances is a three dimensional flexural strength test. Tensile stresses occur in materials subjected to the flexural effect. For this reason, flexural strength tests are a type of indirect tensile tests. Shotcrete liners are usually subjected to tensile stresses due to the loads coming from the rock masses. For this reason, determination of the tensile strength values of shotcrete mixes is important in the selection of the appropriate material design. The quality of the shotcrete liner is a determinative factor in terms of support design processes. The impracticality of the method for direct tensile strength tests of concrete specimens has led to the more widespread use of indirect tensile strength tests. The most popular one in the indirect tensile strength test methods is the splitting (Brazilian) tensile strength (BTS) test. Because, the BTS test can be practically performed using a compressive strength test press.

The BTS test specimens were filled into the moulds in three layers and compacted using tamping rods after each layers. The up-side surfaces were flattened and roughness of the surfaces of the specimens was gently removed by using a steel ruler. In the BTS test, 10 cm × 20 cm cylindrical specimens were tested in accordance with the statements of the TS EN 12390–6 coded Turkish standard [22]. The loading rate of the BTS test specimens was selected as 0.02 MPa/sec. According to the relevant standard, two metal loading strips with the width of 20 mm, thickness of 3 mm and length of 200 mm were placed on and under the cylindrical specimens (Fig. 4). In the BTS test, horizontal tensile stresses are indirectly induced as cylindrical specimens are diametrically compressed in the vertical direction. BTS strength values were calculated as seen in Equation 1 [22].

$$BTS = \frac{2P}{\pi dt} \quad (1)$$

where, t is the length, d is the diameter of specimens and P is the maximum load in the BTS test. As in the EFNARC test, PPF and MGF added specimens with 0.2% fiber content were compared in the BTS test. Preferring 0.2% fiber content in the test is for the purpose of comparing concrete mixes with the same slump value, as stated above. Additionally, 0.4% fiber content case was also tested in the BTS test to obtain a further idea on a different fiber amount usage.



Fig. 4 – a) Brazilian (splitting) tensile strength (BTS) test specimens, b) a photo from the BTS test

3 Results

The slump test results are given in Table 2. As seen from the results, slump values decreased with an increase in the fiber content. The PPF and MGF gave same slump values for the fiber content of 0.2%. MGF added specimens were determined to have a bit lower workability for the 0.4% fiber content case. On the other hand, slump values of the PPF and MGF added specimens with the 0.6% fiber content were found to be significantly different. For this reason, specimens with 0.2% fiber content were tested in slab loading experiments in order to compare mixes with the same slump value and the workability property. The load bearing capacity and EAC values of the slab specimens are given in Table 3. Load deflection graphs obtained from the slab loading test are given in Fig. 5. According to the findings, fiber additive significantly increased the bearing capacity and EAC values. Specimens containing MGF type fiber additive provided higher bearing capacity and EAC values compared to those of the specimens with the conventional PPF additive. To express it quantitatively, it can be noted that MGF provided 14% higher mean load bearing capacity and 22% higher mean EAC values in comparison with the conventional PPF additive. Load bearing values for different deflection levels of the slab specimens are given in Table 4. It was found that the fiberless specimens have notably lower load values than those of the specimens with fiber additives. As another outcome, the MGF additive was evaluated to supply significantly higher load bearing values for a same deflection case, in comparison with the conventional PPF type fiber. The BTS test results are given in Table 5. As seen from the table, both fiber additives were found to supply remarkable increases in the BTS values in comparison with the strength values of fiberless specimens. Rather than the conventional PPF fiber, the MGF additive was assessed to be a better choice in terms of improvements in the indirect tensile strength values of shotcrete mixes. To compare different fiber additives used in this study, the MGF added specimens can be noted to supply up to 27% higher BTS values compared to the PPF added ones.

Table 2. Slump test results

Specimen type	Slump value
NF	19 cm
0.2% PPF	18 cm
0.4% PPF	16 cm
0.6% PPF	13 cm
0.2% MGF	18 cm
0.4% MGF	15 cm
0.6% MGF	11 cm

Table 3. Maximum load ($F_{\max}$) levels and Energy absorption capacity (EAC) values

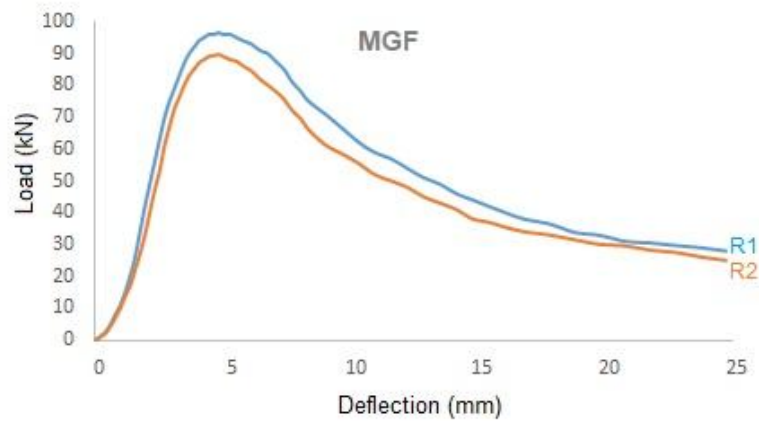
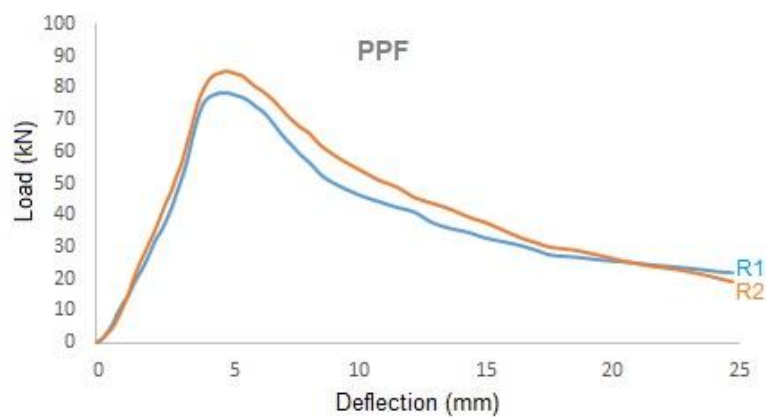
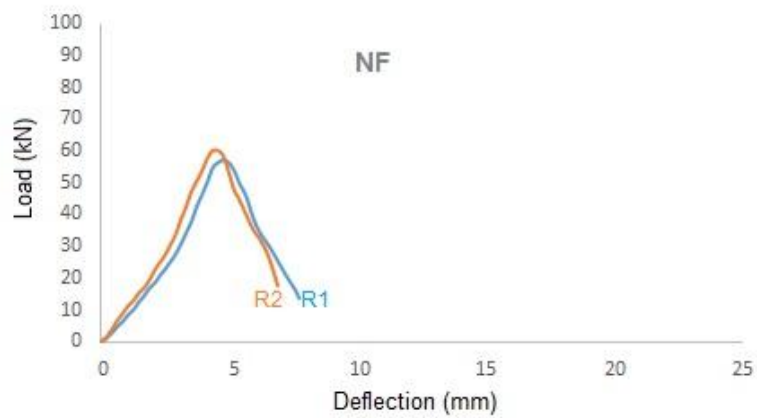
Specimen type	$F_{\max}$ in mean (kN)	EAC in mean (J)
NF mix	58.6	219
PPF added mix (0.2% PPF)	81.9	957
MGF added mix (0.2% MGF)	93.1	1168

Table 4. Mean load values at various deflection levels (F_5 : Load at 5 mm deflection, F_{10} : Load at 10 mm deflection, F_{15} : Load at 15 mm deflection, F_{20} : Load at 20 mm deflection, F_{25} : Load at 25 mm deflection)

Specimen type	F_5 (kN)	F_{10} (kN)	F_{15} (kN)	F_{20} (kN)	F_{25} (kN)
NF mix	53.0	-	-	-	-
PPF added mix (0.2% PPF)	80.7	51.4	35.9	26.5	19.8
MGF added mix (0.2% MGF)	91.5	59.0	40.2	31.3	26.4

Table 5. Mean BTS values of specimens

Specimen type	BTS (MPa)
NF mix	3.27
0.2% PPF added mix	4.05
0.4% PPF added mix	3.91
0.2% MGF added mix	4.63
0.4% MGF added mix	4.98

**Fig. 5- Load and deflection graphs obtained from slab specimens (R: Replicate)**

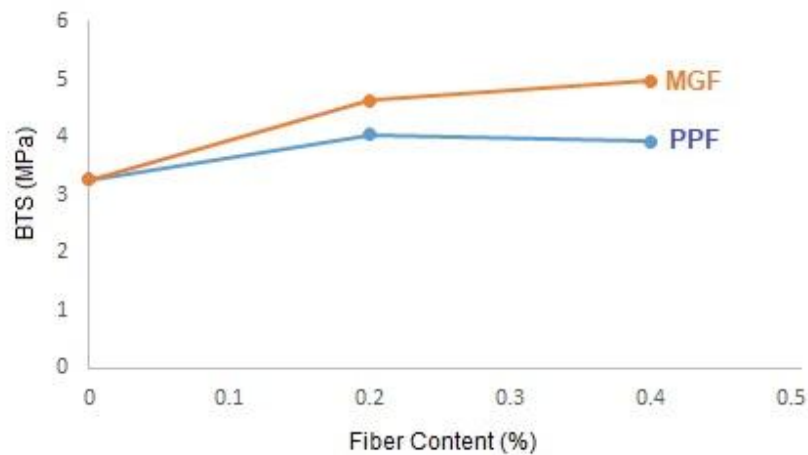


Fig. 6- BTS test results

4 Discussions

The main reasons for using fiber additives in concrete mixes are to increase load bearing capacity values, improve ductility and EAC properties [23-25]. It is an ideal situation for shotcrete liners to provide high bearing capacity, high crack propagation resistivities, proper ductility and EAC properties. For this reason, using the right amount of fiber provides a great advantage. Fiber additive must be used in a correct amount in mixes. Excessive fiber contents which are higher than a threshold level can cause decreases in the strength values [26-28]. Excessive amount of fiber use is also disadvantageous because of causing improper workability properties. According to the findings of relevant studies, the slump value decreases with an increase in the fiber content. Excessive fiber content causes the notable increases in the void ratio and hence remarkable decreases in the strength values. As parallel, BTS test results of the PPF added specimens with 0.2% fiber content were found to be higher than those of the 0.4% PPF added specimens. This situation shows that using 0.4% conventional PPF content is not economically applicable. Therefore, it shows for the 0.4% fiber content that the limited decreasing in the slump value of the MGF added specimens can be assessed as no quite important. Although the MGF additive negatively affects workability in the case of high fiber contents, it has been determined that it provides an improved strength increase in strength values compared to specimens with PPF additives.

According to the results, MGF type new fiber additive supplied better load bearing and EAC values than those of the specimens with the conventional PPF additive. The findings of this study confirmed that the MGF type new fiber additive has a bettered adhesion performance in the shotcrete mixes. An improvement in the adhesion property makes the shotcrete mixes to have bettered crack propagation resistivities and ductility properties [29-31]. The improved ductility property directly increases the EAC values as a result of increases in the deformation limits of the cracked liner material. Liner materials that have the ability to bear a significant amount of load after the crack initiation and have a high deformability limit without a complete failure are advantageous in terms of shotcrete applications [32-34]. For this reason, the properties provided by the new MGF type fiber additive as a novel shotcrete fiber were found more advantageous and preferable compared to conventional fibers.

Within the scope of this study, EFNARC slab loading tests which are widely used to determine the load bearing and EAC properties of shotcrete materials were carried out. This study is a pioneering study on the usability of the new MGF type fiber additive in shotcrete mixes. It is hoped that it will benefit new researches on the subject. New research will be beneficial for a better understanding of the advantages of MGF usage. There are many different topics that can be examined within further researches on the use of MGF type fiber in shotcrete mixes. For instance, MGF geometry, grid dimensions, material selection, grain size and concrete content details can be listed as some further research topics to investigate their effect.

It was found that MGF additive provides better increases in the mechanical properties of shotcrete mixes when the same amount of fiber is used. This outcome confirms that the MGF can be used more economically compared to conventional fibers. The MGF additive increased the maximum load bearing capacity values of EFNARC test slabs by 14% and EAC

values by 22% compared to PPF additive. By carrying out different investigations on the effect of MGF in shotcrete mixes, it is possible to develop new commercial products.

In addition to the slab loading test, MGF added shotcrete mixes were also determined to supply higher strength values according to the BTS test results. It was evaluated that MGF added specimens provided 80% and 30% higher BTS values compared to fiberless and conventional PPF fiber added mixes, respectively. According to the results, it was assessed that the MGF additive provides a remarkable advantage by significantly increasing the tensile strength of the shotcrete mixes.

Since shotcrete materials are sprayed with compressed air, the void ratio is higher than those in the molded concrete materials. In addition, the void ratio values of molded concretes are reduced due to the compaction processes by the vibration machines, tamping rods and etc. This situation positively influences the strength values of mold concretes. Therefore, mold concretes generally have higher strength values compared to shotcrete materials [35-38]. For this reason, to evaluate shotcrete performances, it will be beneficial to take into account the strength values of sprayed specimens. The results obtained from the shotcrete mix specimens of this laboratory study encourage to test MGF additive within site studies by using professional shotcrete robots to prepare the sprayed specimens.

5 Conclusion

It can be concluded that the MGF was found to better improve both load bearing and EAC properties of shotcrete mixes, against the conventional PPF type fiber. The new MGF additive was found to be more advantageous to increase the tensile strength and ductility properties of shotcrete mixes. In the near future, numerous new topics can be studied regarding novel MGF products with different designs and their uses in various shotcrete mixes. Considering the findings from this study, MGF type new fiber additives can be estimated to become more popular in the shotcrete liner works of the construction industry.

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