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Determining Optimal Polypropylene Fiber Dosages In Sprayed Concrete For Mining And Civil Engineering Applications

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ABSTRACT

In this study, experimental investigations were carried out on polypropylene fiber (PF), steel mesh (SM) and PF+SM reinforced shotcrete (RS) panels to evaluate performance characteristics of energy absorption and load capacity. In addition to this, material cost evaluation of shotcrete mixtures for unit energy absorption and load capacity has been given. The panel tests, along with the European specification for sprayed concrete (EFNARC), were done on 18 prismatic specimens having the same mix designs and were cured for 28 days but reinforced at varying fiber dosages. Test results indicate that in terms of unit cost performance for PF, the best dosages were 2 kg/m³ and 5 kg/m³ respectively. When compared with SM, it was determined that PF is more expensive within the range of 37 - 53%.

Key words: Shotcrete, Polypropylene Fiber, Energy Absorption, Panel test.

RESUMEN

En este estudio se realizaron investigaciones experimentales en fibras de polipropileno, en mallas de acero y en paneles de hormigón proyectado reforzados con fibra de polipropileno y con mallas de acero para evaluar las características de desempeño en absorción de energía y en capacidad de carga. Adicionalmente, se provee una evaluación del costo de materiales en mezlas de hormigón proyectado por unidad de absorción de energía y por capacidad de carga. Los exámenes en paneles, con las especificaciones europeas para hormigón proyectado (EFNARC, inglés), se realizaron en 18 muestras prismáticas con los mismos diseños de mezcla y se curaron por 28 días con refuerzos de diferentes dosis de fibras. Los resultados de la evaluación indican que, en términos de desempeño por unidad de costo para fibras de polipropileno, las mejores dosis fueron 2 kg/m3 y 5 kg/m3, respectivamente. Cuando se comparó con las mallas de acero, se determinó que las fibras de polipropileno son entre el 37 % y el 53 % más caras.

Palabras clave: hormigón proyectado; fibras de polipropileno; absorción de energía; evaluación de paneles.

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Introduction

Sprayed concrete is a mixture of cement, aggregate, and water projected pneumatically from a nozzle into place to produce a dense homogeneous mass. Sprayed concrete normally incorporates admixtures and may also include additions or fibers or a combination of these (EFNARC, 1996). Shotcrete (sprayed concrete) is widely used as rock support in mines and civil engineering projects. It is applied through a process by which concrete or mortar is sprayed onto a surface to produce a compacted self-supporting and load-bearing layer. The main design principle for shotcrete as well as for other rock support elements is to help the rock to carry its inherent loads (Malmgren, 2005).

The use of shotcrete for the support of underground excavations was pioneered by the civil engineering industry. Reviews of the development of shotcrete technology have been presented by Morgan (Morgan et al., 1989). Rabcewicz was largely responsible for the introduction of the use of shotcrete for tunnel support in the 1930s, and for the development of the New Austrian Tunneling Method for excavating in weak ground. In recent years, the mining industry has become a major user of shotcrete for underground support (Hoek, 2007).

In mining, flexible linings are preferred because large displacements of underground openings are allowed. It often results in extensive cracking of the shotcrete. Therefore, the toughness of shotcrete is very important which is enabled by the use of reinforcement (Morgan et al., 1989).

Toughness is the amount of energy that is absorbed before and after fracture. Ductility and high-fracture strains are also important characteristics of fiber-reinforced shotcretes (FRS) because the main reason for incorporating fibers in concrete and shotcrete is to impart ductility to an otherwise brittle material. In addition, fiber reinforcement improves the energy absorption and crack resistance of shotcrete (Morgan et al., 1995). With an increasing load on the composite, fibers will tend to transfer the additional stress to the matrix through bond stresses until they fail or pull out (Mehta and Monteiro, 1993). In this way, they enable shotcrete to continue to carry the load after cracking, the so-called post cracking behavior (Vandewalle, 1997).

In this study, RS panels were made with PF, SM and PF+SM. These RS panels, moreover, examined for load capacity and energy absorption tests. This study shows that the use of PF in RS, with sufficient fiber content can greatly improve energy absorption and ultimate load capacity. PF, SM and PF+SM concrete mixture estimation costs, furthermore, were compared in terms of unit load and energy absorption cost.

2.Materials and Experimental Work

In previous studies, Malmgren discussed the comparison of steel fibers and PF and its effects on shotcrete. Results of Malmgren's study show us the shotcrete reinforced with steel fibers and the PF had almost the same energy absorption.

In this study, to investigate the load capacity and the energy absorption of reinforced shotcrete, EFNARC panel test was used. Firstly energy absorption and peak load of PF at different dosages and SM is examined. Then the PF content was evaluated in terms of unit cost. For this aim, 27 shotcrete mixtures are prepared and then the energy absorption of mixtures is tested.

2.1.Materials

In the design of test panels, Turkish Portland Cement was used for the production of concrete mixtures (PC 42.5 R, ASTM Type I). Crushed rock having a particle size between 0-3 mm and 3-7 mm were equally used as aggregates. The sieve analysis of aggregate is given in Table 1. As a high range water reducing admixture, RHEOBUILD® T90, was used in shotcrete mixtures. The specifications of PFs are given in Table 2. The steel mesh (diameter: 5.5 mm; intervals: 100 mm) was used as a reinforcement.

Table 1. Sieve analysis of aggregates in shotcrete

	Cumulative percent passing		
Sieves (mm)	**0-3 mm Aggregate**	**3-7 mm Aggregate**	**Mixture (% 50 0-3) (% 50 3-7)**
+8	99.78	100.00	**99.89**
+4	28.73	98.95	**63.84**
+2	2.88	70.66	**36.77**
+1	1.79	42.19	**21.99**
+0.5	1.52	27.64	**14.58**
+0.25	1.34	17.16	**9.25**
-0.25	0.00	0.00	**0.00**

Table 2. Specification of PF (RHEOBUILD® T90)

Properties	**Value**
Nominal x section area (mm^2)	0.75
Melting Point (°C)	150-170
Density (g/cm^3)	0.88-0.92
Color	Translucent white
Fiber lengths (mm	40
Elongation at yield, (%)	24.4
Water absorption	0
Acid/alkali resistance	High

2.2. Shotcrete Mixtures

The shotcrete mix proportions used in this experimental study are given in Table 3. Shotcrete mixes having 0.47 water/cement ratio were prepared and put into molds.

Table 3.Base concrete mix proportions

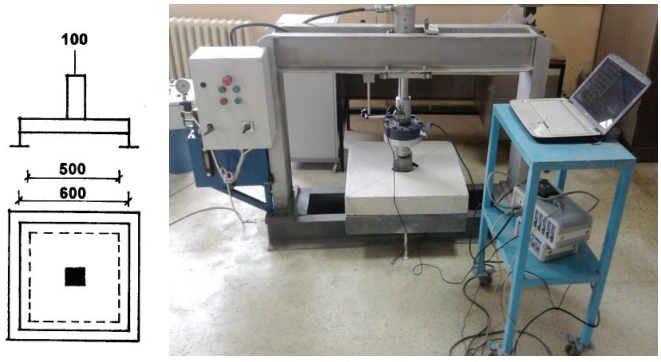
Materials (kg/m³)	PF-0*	PF-2	PF-3	PF-4	PF-5	PF-6	PF-8	PF-4+ SM**	SM
Cement	450	450	450	450	450	450	450	450	450
Coarse Aggregate	825	825	825	825	825	825	825	825	825
Fine Aggregate	825	825	825	825	825	825	825	825	825
Water	210	210	210	210	210	210	210	210	210
Admixture (WRA)	4	4	4	4	4	4	4	4	4
PF	0	2	3	4	5	6	8	4 +SM	SM

*:PF dosages **:Steel Mesh

2.3. Experimental Work

The EFNARC panel test was used to compare the toughness of shotcrete panels with different reinforcement and amount of reinforcement. The toughness was calculated as the absorbed energy corresponding to the area under the load-displacement curve between 0 and 25 mm (EFNARC, 1996).

The test panel 600 mm x 600 mm x 100 mm was supported on its four edges rigidly (Figure 1-B). The free face of the panel is 500 mm x 500 mm because of the thickness of the support (Figure 1-A). The load was applied through a contact surface of 100x100 mm at the center of the panel by 100 kN testing machine at 1.5 mm/min deformation rate. During the test load and displacement at the center are recorded up to of 25 mm deflection has occurred at the center of the panel.



(a) (b)

Fig. 1. a. EFNARC Panel Test (EFNARC, 1996), **b.** Testing Machine (100 kN) used for Panel Test

2.4. Shotcrete Cost

The required amount of shotcrete, to cover 10 cm thick, and 1 m long shotcrete of a decline of 5x5 m cross-section was taken as basis for calculating the shotcrete cost. In these calculations, rebound was assumed to be % 20. Accordingly the amount of shotcrete was found to be 1.93 m³ for 1 m advancement. The cost of 1.93 m³ shotcrete was found for every mixture using the current prices given in Table 4, These values were divided by load capacity and energy absorption of each mixture, and thus the unit load and energy cost performance of the mixture were calculated (Table 4).

Table 4. Shotcrete Costs

Concrete mix materials	Unit	Unit Cost
Aggregate (0-7 mm)	$/t	9,90
Cement, CEM 1 42,5	$/t	56,81
RHEOBUILD® T90	$/kg	0,57
Fiber - MEYCO® FIB SP 540	$/kg	6,01
Steel Mesh (5x2 m)	$/unit	31,03

3. Results and Discussion

The load–deformation curves (Figure 2) were obtained as an average of the results of the tests performed on nine groups having three panels each. PF-0, PF-2, PF-3, PF-4, PF-5, PF-6, PF-8, PF-4+SM, SM panels.

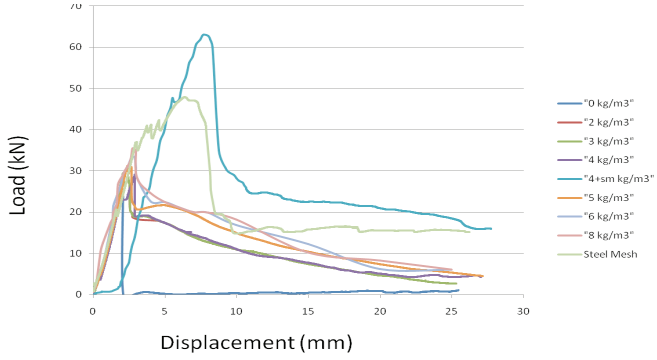


Fig. 2. Load Deformation Curves

Then the energy absorption of shotcrete lining is calculated by integrating the area under the load-displacement curve. The load–deformation curves of tests are given in Figure 2.

The area under the load - displacement curve between 0 and 25 mm calculated by the aim of CAD based program and the results are given in Table 5. Also unit costs per peak load and unit costs per absorbed energy are calculated and given in Table 5.

Table 5. Results of Panel Tests

Test	Peak Load (kN)	Energy Absorption (Joule)	Total Cost ($)	Cost/Peak Load $/kN	Cost/Energy Absorption $/Joule
PF-0	24.10	36.65	83,00	3,44	2,26
PF-2	27.96	248.26	106,20	3,80	0,43
PF-3	29.52	252.71	117,80	3,99	0,47
PF-4	29.15	275.42	129,40	4,44	0,47
PF-5	31.20	316.23	141,01	4,52	0,45
PF-6	33.46	330.85	152,62	4,56	0,46
PF-8	34.46	349.86	175,83	5,10	0,50
PF-4 + SM	63.05	683.50	160,4	2,54	0,23
SM	47.89	541.17	114,0	2,38	0,21

The test results show us the dosage of PF has a moderate effect on the peak load of panel samples. On the other hand, energy absorptions of samples have considerable differences by the changes of fiber dosages. The results from panel tests are summarized in Figure 3. As inferred from the Table 4 and Figure 3, use of both PF and SM has the maximum energy absorption but it should also be evaluated in terms of costs. However, in any case both PF and SM will be used for high-stress areas like as intersections of underground spaces.

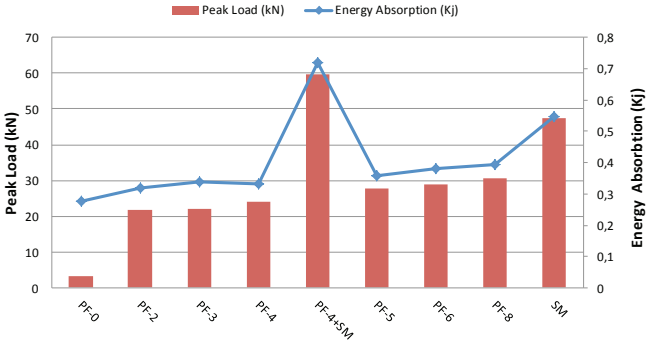


Fig. 3. Peak load and energy absorption of test samples

When the effect of PF in a mixture is discussed, the tests show us increasing of PF dosage have a positive effect on energy absorption of shotcrete lining. Another issue that must not be forgotten is the effect of mixture ratios on shotcrete.

The results are discussed in terms of cost per load and cost per energy absorption. As seen from the table when the fiber dosage increased from 2 kg/m3 to 8 kg/m3 the peak load increases 19% whereas the unit cost per peak load increases 26%. On the other hand, the energy absorption increases 29% but the cost per energy absorption increases only 15%.

Similarly when the SM and SM + PF are discussed the cost per peak load and the cost per energy absorption decrease up to 50%.

4. Conclusion

The experimental investigation was performed on polypropylene fiber, steel mesh, and polypropylene fiber + steel mesh panels to evaluate performance characteristics of energy absorption and load capacity. In addition, material cost evaluation of shotcrete mixture for unit energy absorption and load capacity were discussed.

The obtained results are summarized as follows;

1. The dosage of PF has not considerable effect on peak load of shotcrete linings, but the use of SM or SM+PF together has a positive effect on peak load.

2. According to the achieved results, by the increasing of PF dosage a linear rise of energy absorption of shotcrete linings is observed. Especially compared with zero dosage of fiber, the existence of PF has a favorable effect on shotcrete lining.

3. If the cost of PF discussed in terms of energy absorption the study shows when the energy absorption increases 29% the cost per energy absorption increases 15%. However, if the peak load discussed the cost per peak load increases with the increase of fiber dosages, because the fiber dosages have no remarkable positive effect on peak load

4. The uses of PF and SM together have the maximum energy absorption and minimum cost per energy absorption. Although the SM and SM + PF has a few disadvantages such as time-consuming installation, difficult installation, etc., especially in the unstable formations the SM and SM + PF linings should be preferred

5. It should be kept in mind that the change of energy absorption is not related to only the fiber dosages. It is also the function of mixture component ratios.

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