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AN INVESTIGATION OF FOAM CONCRETE USABILITY AS A CAVITY FILLER MATERIAL IN MINING

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ABSTRACT

Strength and deformability properties of different cavity filler materials of a phenolic foam, a polyurethane based foam and a foam concrete (FC) mix were investigated and compared in this study. Instead of using polymeric foam fillers, FC usage was found to supply better load bearing capacity and modulus of elasticity values. The fresh FC mixes consisting of cement, water and foaming agents are able to be filled into the mine cavities. In the cavity filling applications, typical polymer foams cause support reactions with low stiffnesses and let the rock mass at the roof to be loosened. A relatively stiff cavity filling material can help rock masses to bear itself by prevention of the loosening. To avoid excessive deformations of the rock masses, the deformation modulus is an important parameter as well as the strength property. The FC filler materials were found advantageous because of economical supply of improved load bearing capacities and stiffness values for controlling the rock mass convergences.

Keywords: Cavity filling; Concrete foams; Foam filler materials; Underground mining.

1 INTRODUCTION

In mining and tunnelling applications, the cavities can occur due to the overbreaking in excavations and/or rock block falls due to the lack of the needed support pressure. To prevent progressive block loosening and major collapses, filler materials are pumped into the cavities. Nowadays, the polymeric foam fillers are widely preferred because of their ability to conform to the shape of the cavities and supplying good contact to rock surfaces. In addition, the polymeric foams have low densities and make low pressures on the support elements like concrete liners, steel sets, etc. The polymeric foams have good chemical resistivity which is an advantage for their usability in rock engineering. Furthermore, the ability to solidify soon after pumping into the cavities supplies load bearing capacity in early times [1–3].

Both load bearing capacity and deformability properties of the filling materials must be paid attention for a proper selection. Stiffness of the filler materials increases with an increase in the modulus of elasticity property. In other words, the filler materials with relatively high modulus of elasticity values can supply a needed support pressure under lower deformations. The load bearing capacity is not the only parameter for a safe rock support design. The deformability property is also a key parameter for a proper support reaction which prevents excessive rock mass deformations [4–6]. As seen from the scheme in Figure 1, highly deformable cavity fillers can cause high displacements at discontinuities of rock masses, let the rock mass at the roof to be loosened and occurrence of high dead loads. Therefore, the soft foams are disadvantageous in blocky and highly jointed rock masses. A relatively rigid (stiff) foam material can help rock masses to bear its own load by limitations of displacements at the joints [7–9].

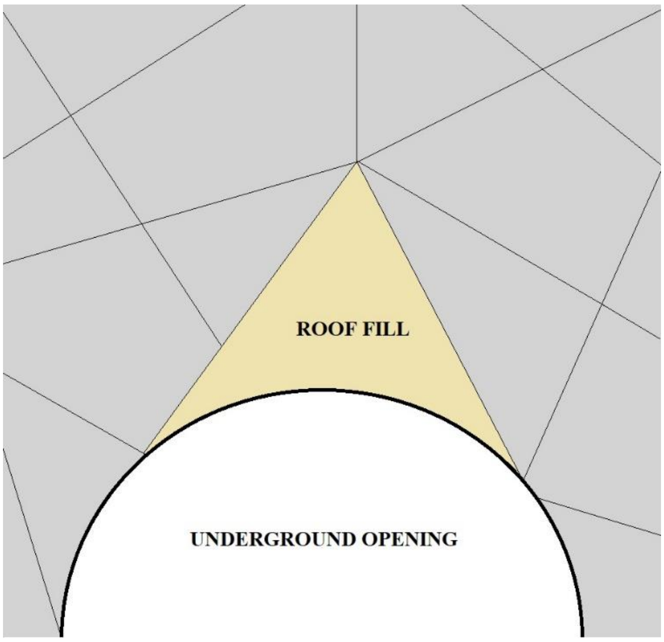

Figure 1. *A schematic shown of using cavity fillers in rock masses*

Since the 1990s, polymer-based cavity filler materials have started to be used in the mining industry [10–13]. The polyurethane based thermoset foams are the first polymeric cavity filler material and still being used in the mining industry. Especially, the polymeric foams have become much more popular and diversified as the cavity fillers in the 2010s. Phenolic foams are also a widely used cavity filler material in mining operations [14, 15]. The polymeric foams are generally thermoset products which are in liquid form before their polymerization reactions. The thermoset products polymerize owing to contact of their liquid components. The polymer foams can have one, two or more components. Frothing ratio (swelling factor) and solidification times of the thermoset products can vary within a wide range, depending on the self-properties and production details. Liquid components of thermoset polymer foams should be mixed well before their polymerization reactions for a good filling performance. Instead of manual applications, special equipment use is preferred for both polymerization and filling efficiencies in underground mines.

From the various point of views, low deformation modulus values of ordinary polymer foam fillers can be assessed as an important disadvantage. Their low stiffnesses cause high rock mass convergences and loss of the bearing capacity of the rock mass itself. With an increase in the deformation modulus and stiffness values of the filler materials, rock convergence limitation capacities can increase. Instead of foams with low densities, high density foams are preferable to obtain relatively stiff fills. However, high costs and raw material consumptions are needed for applications of high-density foams. The foam densities typically vary between 30 kg/m^3 to 80 kg/m^3 in the cavity filling operations.

Two-component polyurethane foam (PF) and two-component phenolic foam (FF) materials were investigated in this study. Additionally, a new foam concrete (FC) material was also investigated as an alternative material for economical supply of improved strength and deformation modulus properties.

FC is a new outcome in the last years of the concrete technology developments. In comparison with ordinary concrete mixes, foam concretes (FC) have quite low densities which can typically be as low as 400 kg/m^3, and generally consist of a synthetic foaming agent and the cement slurry (the mix of cement and water). The foaming agent is used for making an aerated mix and obtaining a light weight concrete. It is possible to obtain many different foaming agent products for using in FC materials. A synthetic foaming agent product with some contents like palmitic acid, triethanolamine, stearic acid and lauryl glucoside was selected to use because of its practical and effective frothing property while mixing with water. In the free frothing case, the foam density can decrease to quite low values between 55 kg/m^3 and 60 kg/m^3. In the FC mixes, the foam is made before mixing with the cement slurry. The foam and cement slurry should be properly homogenized but not mixed for a long time to prevent

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notable decreases in the void ratio of the FC mixes. Therefore, the cement slurry should be well homogenized before mixing with the foam. It was aimed to produce a new cavity filler material with higher strength, higher deformation modulus and lower costs in comparison with those of widely used polymeric foams. Details of the new FC material used in this study are given below.

2 MATERIALS AND METHODS

PF and FF products used in this study have foam form density of 40 kg/m^3 and 33 kg/m^3, respectively. The polymeric foam materials which are commercial cavity filler products sold to various mines in Turkey were used in this study. PP and FF samples were cut from well polymerized foam blocks applied by professional equipment (Figures 2 and 3). The liquid foaming agent product was mixed with water for the frothing process to obtain the foam of the FC mix. The density of the foam was evaluated to be 58 kg/m^3 before mixing with the cement slurry (Figure 4).

Figure 2. *Spraying a foam (PF) block*

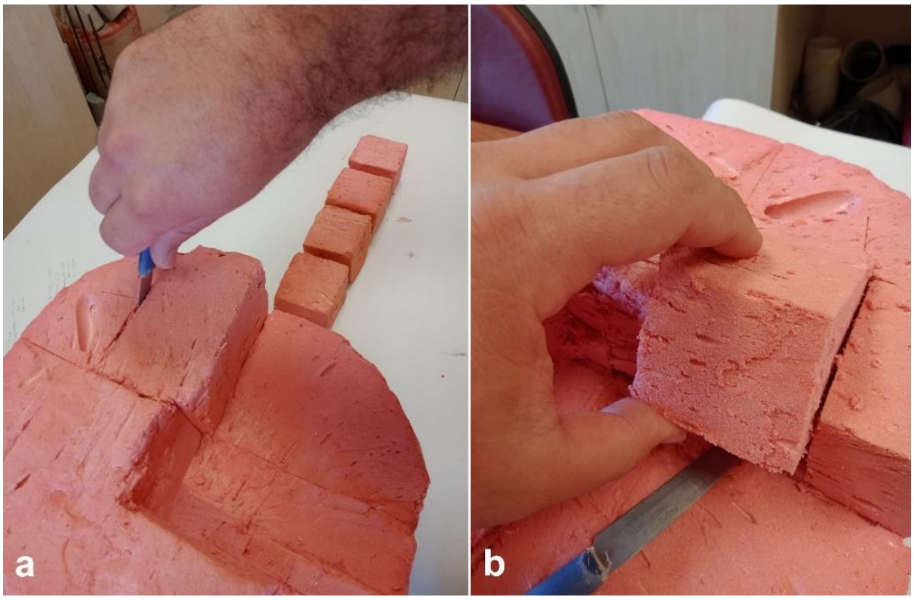

Figure 3*. a) Foam cutting for specimen preparation, b) taking a cut specimen (FF)*

In the foam of FC, the foaming agent to water ratio is 0.05 by weight. A detail of the foam made using the agent is given in Figure 4. The CEM 1 type ordinary Portland cement was used in this study. After the cement slurry with the water to cement ratio of 0.5 by weight was homogenized for 5 minutes, it was mixed with the foam. The cement slurry (cement and water mix) and the foam were mixed for only 30 seconds using a cement mixer. In the FC mix, foam to cement ratio is 0.25 by weight. FC specimens were poured into the moulds with same geometry and sizes of PF and FF specimens. 14-day-cured cubic FC specimens were weighed before mechanical tests and evaluated to have the mean density value of 640 kg/m^3.

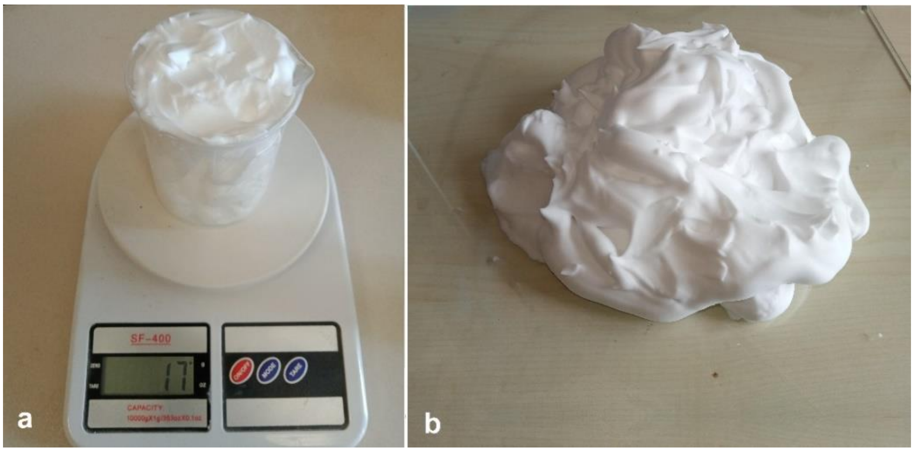

Figure 4. *a) Foam density measurements, b) A foam sample made using the agent*

As parallel to the suggestions stated in the ASTM-D1621 coded standard for the determination of compressive strength values of foam materials, the cubic specimens with the sizes of 7 cm x 7 cm x 7 cm were used in the experimental study (Figures 5 and 6). Using an LVDT (Linear Variable Differential Transformer) device, load-displacement graphs were obtained during the compression test. Strength and deformability properties of PF, FF and FC specimens were determined to comparatively investigate different foam materials according to the laboratory test results.

Figure 5. *a) FC samples, b) UCS test of FC samples*

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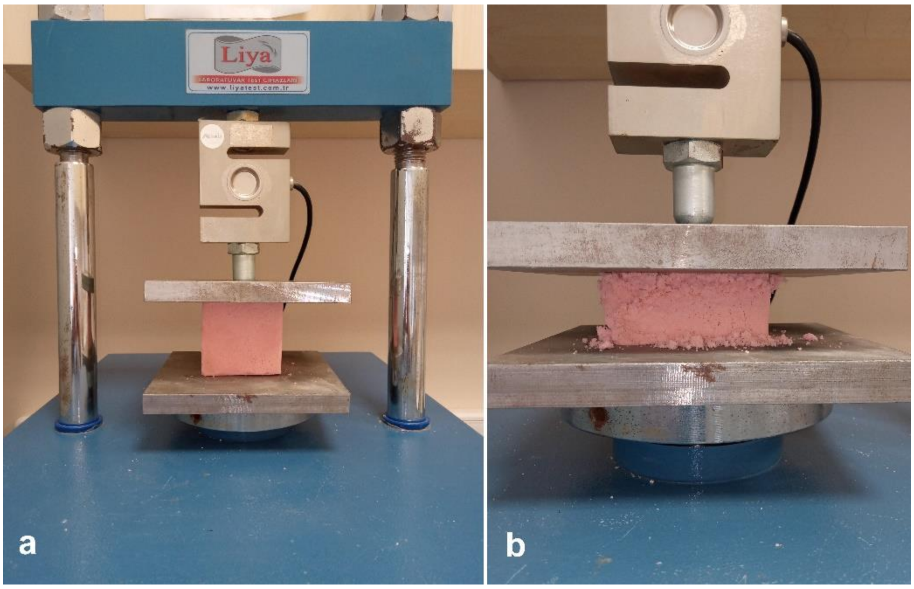

Figure 6. *a) UCS test of foam samples, b) A FF specimen loaded under %50 strain*

3 RESULTS

The loading was continued to the 50% strain level for PF and FF specimens. The failure did not happen in PF or FF specimen test. The stress-strain curves of polymeric foams under quasi-static compression tests have three definite regions which are linear elastic, plateau and densification regions (Figure 7). At a strain level of 11 % as mean, the plateau regions started for PF specimens. The stress level was about 58 kPa during deformations of the plateau region which can be accepted as the yielding stages of the foam products. The densification of PF specimens started at strain values between 29–32 % and the load values notably increased up to 99 kPa at the 50% strain. Deformation modulus values of the foam products were calculated for the linear elastic deformation intervals (Table 1). At a strain level of 14 % as mean, the plateau region started for FF specimens. The stress level was about 46 kPa during deformations of the plateau region, and the densification started at strain values between 32–34 %. The load values increased up to 71 kPa at the 50% strain.

In contrast to PF and FF (full polymeric foams) specimens, the FC specimens were determined to not have a typical foam material stress-strain behaviour. The FC type foams exhibit a relatively low ductility compared to the full polymeric foams (Figure 7). The FC specimens were found to have no significant plateau parts of the stress-strain graph. As another difference of the FC specimens, the failure happened following the plastic region displacements instead of the densification stage. As seen in Tables 1 and 2, strength values and modulus of elasticity values of FC specimens were determined to be notably higher than those of the FF and PF specimens. It should be reminded herein that the modulus of elasticity values given in the tables were calculated for the elastic deformation stages. To indicate further details for the comparison of the stiffnesses of the tested filler materials, strain data for various stress levels are given in Table 2.

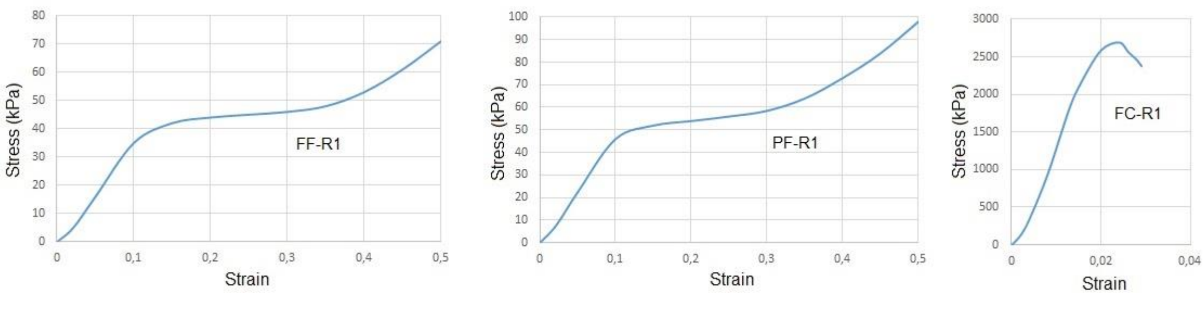

Figure 7. *Stress strain graphs obtained from different specimen types (R: replicate)*

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Table 1. *Uniaxial compressive strength (UCS) and modulus of elasticity (E) values (SD: Standard deviation, SN: Specimen number, note: UCS values are considered as yielding stresses for FF and PF specimens)*

Specimen type	UCS (kPa)	SD for UCS (kPa)	E (MPa)	SD for E (MPa)	SN
FF	46	3	0.45	0.02	5
PF	58	3	0.70	0.04	5
FC	2741	79	184.23	5.17	6

Table 2. *Mean strain (ε) values under various loads levels (NA: not available)*

ε (Specimen)	30 kPa	60 kPa	90 kPa	120 kPa	150 kPa
ε (FF)	0.085	0.44	NA	NA	NA
ε (PF)	0.070	0.31	0.48	NA	NA
ε (FC)	0.001	0.001	0.002	0.002	0.003

4 DISCUSSIONS

According to the results of this study, foam concrete (FC) mixes can be used to obtain higher strength and stiffer cavity filling materials rather than typical polymeric foams. The FC mix tested in this study has an approximate material cost of 30 USD/m^3 (Price of the frothing agent is 2 USD/kg). To determine material costs, it can be noted that the amounts of cement and the foaming agent in the FC mix are 366 kg/m^3 and 4.4 kg/m^3, respectively. On the other hand, material costs of PF and FF type foams tested in this study are 73 USD/m^3 and 58 USD/m^3, respectively. It can be stated that relatively high strength and modulus of elasticity values can be supplied with lower costs by using FC fillers. With an increase in the polymeric foam density, the strength values and material costs also increase. To have as high strengths as those of the FC mixes, highly dense and quite expensive polymer foam products are needed to use [7].

The FC mixes topic is a new one and able to be detailed by further parametric studies on the foaming agent type, frothing ratio, the liquid phase time, density, cement content, cement type, mixing details, use of some other chemical additives and etc. This laboratory study is expected to contribute to new FC design studies. The composite material designs can supply different solutions in mining support applications. Further investigations within new site studies will be helpful for better understanding the advantages and disadvantages of FC fillers. This study is believed to be beneficial for further site investigations on improving application details of FC filling operations.

In comparison with the polymeric foam products, both strength and stiffness values were found to be significantly higher for the FC mix. The strength property is not the only parameter by itself for the support performances of the cavity filling materials. The displacement limitation property depending on the modulus of elasticity values of the filler materials is also a major parameter for underground openings. Excessively low modulus of elasticity values can cause unwanted convergences in case of using low density polymeric foams. High stiffness values can make proper limitations in the rock mass deformations, prevention of progressive loosening and dead load occurrences in underground openings [17–19]. Because the FC filler material has significantly higher modulus of elasticity values, they are more advantageous than light polymeric foams in terms of having a proper stiffness for controlling convergences in the rock masses.

Because of their brittle material characteristics, FC mixes have some disadvantages against the polymeric foam use. The high ductility properties of the polymeric foams make them advantageous in terms of the energy absorption capacity [20–22]. In some specific rock masses like those with swelling, squeezing or burst problems, the energy absorption capacity property is a quite important parameter for selection of support materials [23–25].

On the other hand, it should be noted that excessively deformable material characteristics increase the need for high load bearing capacities as a result of dead load occurrences due to the notable loosening in the ground reactions. Densities of FC mixes are higher than typical polymer foams used in the underground cavity filling

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operations. The low-density property is another advantage of the polymer foams because of low material usage amounts in mass and easier transportation facilities.

The rapid polymerization reactions which are typically completed within a day supply early strengthening advantage of the polymer foams [26–28]. The late curing reactions in comparison with the polymerization processes can be assessed to be another considerable point for future FC applications. In this regard, the accelerator chemicals can be used to increase the short-term strength values of FC mixes. In despite of various advantages like those listed above, low strength and modulus of elasticity values of polymeric foams are considerable for using alternative filler materials such as FC mixes.

In the polymeric foam applications, the toxicity properties should be well examined to select an appropriate product. The gases released during polymerization reactions should be considered in terms of the occupational safety and worker health. For underground working conditions, concrete materials can be seen as healthier compared to the polymeric foams like PF and FF products. In any case, an adequate ventilation must be carried out in underground mines.

5 CONCLUSION

According to the results, following research findings can be noted as conclusion matters:

1. The FC filler material is more economical in comparison with the widely used polymeric foam materials to supply relatively high strength values.
2. The FC filler material has much higher modulus of elasticity values than those of the polymeric foams.
3. In comparison with the polymeric foams, the FC materials are more effective as cavity fillers for limitation of the rock mass convergences supplying stiffer support reactions.
4. The FC materials have relatively low ductility property compared to the polymeric foams.
5. Outcomes from this laboratory study indicate that FC materials have a great potential to become popular as economical cavity fillers in rock masses.

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