Potential use of crushed pyroclastic rocks from mount Kelud as alternative backfill materials

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Abstract. Pumice and scoria are pyroclastic rocks that can be found where volcanic mountains appear. In Indonesia, pumice and scoria are found in large deposits in the area of Mount Kelud at Kali Putih River in Blitar Regency, Province of East Java. Thus, it is important to evaluate their potential uses as alternative backfill materials. Standard Proctor compaction tests were conducted to determine the maximum dry density (MDD) and optimum moisture content (OMC) to evaluate their compaction properties. Constant head permeability tests were also conducted to determine the coefficients of permeability. Direct shear tests were also applied to investigate the shear strength characteristics of these materials. The results showed that the MDD values of scoria are slightly higher than pumice. The OMC values of pumice and scoria are 23\% and 15.5\%, respectively. The internal friction angle of pumice and scoria are higher than natural sand, which are approximately 55-64\º and 46-59\º respectively. Pumice and scoria with different relative densities had coefficients of permeability that ranged from 0.0003 to 0.002 cm/s and 0.001 to 0.002 cm/s respectively. Due to their mechanical properties, it can be concluded that these materials have potential as alternative backfill materials.

Keywords: backfill, compaction, pyroclastic rocks

1. Introduction

Mount Kelud is one of the most active volcanoes in Indonesia, which is located in the Province of East Java aligned with Mount Kawi-Butak, Mount Anjasmor, and the Arjuno-Welirang Volcano [1]. After its eruption, a large amount of pyroclastic material was deposited on the upper slope of Mount Kelud which can then be mobilized by rainfalls and generate lahar along the river under Mount Kelud. Pumice and scoria are pyroclastic rocks that can be found along the Kali Putih River in Blitar Regency, Province of East Java as the result of the Mount Kelud eruption. These two materials have almost similar appearances; however, scoria is usually denser and darker in colour than pumice [2].

Presently, pumice and scoria are widely used in many industrial applications, for example as adsorbents, lightweight aggregates, fillers, and filtering media. However, their applications as backfill materials are still limited. Backfill materials can be used behind bridge abutments, earth retaining walls, and as part of subsurface drainage systems or buried pipes. Based on the geotechnical aspects, it is important to determine their engineering characteristics as potential backfill materials. This must take into account the engineering characteristics required for the backfill, such as density, compaction, shear strength, and permeability. The proper properties of the backfill material will ensure that desirable performance will be achieved as the material is placed [3].
Figure 1. Large deposits of pumice and scoria mixed with river sand at Kali Putih River, Blitar Regency.

Figure 2. The appearance of surface voids of pumice and scoria stone.

From SEM analysis, it was observed that both materials have inter-connected vesicular forms with varied pore sizes; however, it is clearly seen that scoria has smaller cavities than pumice. For pumice, it was observed that the volume of surface voids is much greater than that of internal voids [2]. It is known that pumice and scoria have different physical characteristics when compared with natural silica sand. They have low grain strength, but high angle of friction, void ratio, and compressibility [4]. These characteristics are influenced by the vesicular voids of their particles. Their particles contain large amounts of fine holes; they may be interconnected and open to the surface, or may be entirely isolated inside the particles [5]. The appearance of surface voids of pumice and scoria stone is presented in Figure 2. The volume of surface voids was observed to be much greater than that of internal voids. It was also observed that pumice particles have fragile structures because they have
many voids (are porous) and are very angular in nature [6]. Thus, from the geotechnical engineering aspects, it is important to study their shear strength and permeability characteristics as alternative backfill materials.

2. Materials and Methods
The natural condition of pumice and scoria along river is as rock materials. To simulate their size as backfill materials that can be tested in the laboratory, they were crushed by using a stone crusher machine. These materials originate from the eruption of Mount Kelud in 2014. Then, a sieve test was carried out to obtain the grain size distribution of these samples. The pycnometer method was used to measure the specific gravity (Gs) of the particles. The density and void ratio index were also examined on these materials to investigate their physical characteristics. All of these previous tests were conducted following ASTM standards. Then, a series of tests were carried out to determine the mechanical characteristics of such materials. Standard Proctor compaction tests were conducted to determine their maximum dry density (MDD) and optimum moisture content (OMC) in order to evaluate their compaction properties as backfill materials. Constant head permeability tests were also performed to determine the coefficients of permeability. Finally, the parameters of shear strength of these materials were examined by the direct shear test and unconfined compression test.

3. Results and Discussion

3.1. Physical Properties of Crushed Pumice and Scoria
From the results of sieve analysis (Figure 3), crushed pumice and scoria from Mount Kelud were dominated by medium to coarse sand fraction and it appeared that they have similar gradation with natural river sand from the same location. Table 1 shows the physical property indices of crushed pumice and scoria from Mount Kelud. It was found that the value of void ratio of pumice is higher than scoria. Void ratio is an important soil property in geotechnical engineering. This parameter can be related to packing density, which is also associated with volume change tendency and particle movement.

![Figure 3](image-url)  
**Figure 3.** Grain size distribution of crushed pyroclastic rocks (pumice and scoria) from Mount Kelud eruption at Kali Putih River in Blitar Regency.
Table 1. Physical property indices of crushed pumice and scoria from Mt. Kelud.

| Parameter                          | Pumice  | Scoria  | River sand |
|------------------------------------|---------|---------|------------|
| Specific gravity (Gs)              | 2.878   | 2.781   | 2.65 - 2.697 |
| Maximum void ratio ($e_{max}$)     | 1.537   | 1.377   | 0.667 - 0.882 |
| Minimum void ratio ($e_{min}$)     | 1.137   | 1.150   | 0.383 - 0.585 |
| Maximum dry density, $\gamma_d^{\max}$ (gr/cm$^3$) | 1.347   | 1.293   | 1.893 (avg) |
| Minimum dry density, $\gamma_d^{\min}$ (gr/cm$^3$) | 1.134   | 1.170   | 1.559 (avg) |

The above indicates that pumice has a higher volume of pores than scoria. It is predicted that the chemical and mineralogical elements and the volcanic process play an important role in characterizing the unique vesicular voids of pumice and scoria particles. Pumice particles are highly crushable, compressible, and lightweight as a result of the vesicular nature and the presence of internal voids [7]. Due to these characteristics, the compaction process is important to ensure their performance as backfill materials.

For soil classification, crushed pumice can be classified as SP by the standard of USCS (poorly graded clean sand), whereas by the AASHTO standard, it can be classified as A-3, or sand with fine grain. Crushed scoria is classified as SW (well-graded clean sand) by USCS, while according to AASHTO, it can be classified as A-3, as fractions of sand with fine grain. Well-graded backfill materials provide the best performance to drain water. Well-gradation can be defined as having a wide range of grain sizes. Crushed rock has several advantages as a backfill material. High internal shear strength, good compaction characteristics, and excellent drainage capabilities provide the advantages needed for stable retaining wall structures. It is important to note that well-gradation can be achieved easily by arranging the appropriate screen sizes from stone crushing machines.

3.2. Permeability Characteristics

From the constant head permeability test, pumice and scoria having different relative densities have coefficients of permeability ranging from 0.0003 to 0.002 cm/s and 0.001 to 0.002 cm/s respectively (Table 2). Increasing their relative densities decreased their coefficients of permeability. In relation to their application for backfill or drainage for pavement materials, they can be classified as rapidly-draining materials (Figure 4). It is widely known that moisture is the major cause of retaining wall and bridge abutment damages. Pumice and scoria are suitable as backfill materials because they have many voids or pores that can drain water rapidly. Moreover, the presence of large amounts of voids in backfill material reduces hydrostatic pressure that can be built in saturated soil.

Table 2. Variation of coefficients of permeability (k) of crushed pumice and scoria with different relative densities.

| Sample | Dr (%) | k (cm/s) |
|--------|--------|----------|
| Pumice | 50     | 0.002    |
|        | 70     | 0.001    |
|        | 90     | 0.0003   |
| Scoria | 50     | 0.002    |
|        | 70     | 0.001    |
|        | 90     | 0.001    |
Figure 4. Ranges of permeability for different soils used for pavement materials [8].

3.3. Shear Strength Properties

From the direct shear test, the angle of internal friction ($\phi$) of pumice and scoria are higher than natural sand, which are approximately 55-64° and 46-59°, respectively. A high angle of internal friction of backfill materials is related to more stable soil structures. It can then be concluded that these materials have good shear resistances as backfill materials. Figure 5 shows the effect of relative density on the values of $k$ and $\phi$. At a low relative density (Dr = 50%), crushed pumice had a higher value of $k$ and a slightly higher angle of internal friction compared to crushed scoria. For pumice, the compaction process can increase its packing density and will decrease its permeability significantly.

Figure 5. Effect of relative density (Dr) on the values of $k$ and $\phi$. 
3.4. Compaction Characteristics
As a result of Standard Proctor test, it can be found that the maximum dry density (MDD) values of scoria are slightly higher than pumice (Fig. 6). MDD and OMC values of pumice and scoria are 1.49 g/cm³ with OMC of 23% and 1.55 g/cm³ with OMC of 15.5%, respectively. These parameters are almost similar to river sand, considering the fact that they have similar gradations to natural river sand. For backfill materials, a good compaction process should be applied properly in order to stabilize their particle structures. However, over-compaction of these materials can cause damage to their brittle particles, which can lead to a decrease in their engineering performance.

![Compaction curve from the Standard Proctor Test.](image)

4. Conclusion
As the final results of this research, it has been found that crushed pumice and scoria having different relative densities have coefficients of permeability ranging from 0.0003 to 0.002 cm/s and 0.001 to
0.002 cm/s respectively. They can be classified as rapid-draining materials. The internal friction angles of pumice and scoria are higher than natural sand, which are approximately 55-64° and 46-59°, respectively. From the Standard Proctor tests, the maximum dry density values of scoria are slightly higher than pumice. The optimum moisture content values of pumice and scoria are 23% and 15.5% respectively. High internal shear strength, good compaction characteristics, and excellent drainage capabilities make them advantageous as suitable backfill materials. Due to their mechanical properties, it can be concluded that these materials have potential for alternative backfill materials. However, it should be noted that over-compaction can cause damage to their brittle particles, which can lead to a decrease in their engineering performance. Thus, the addition of required water should be applied during compaction to minimize their brittleness. Extreme caution should also be taken when applying a compactor machine on these materials.

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References
[1] Dibyosaputro S, Dipayana G A, Nugraha H, Pratiwi K, Valeda H P 2015 Lahar at Kali Konto after the 2014 Eruption of Kelud Volcano, East Java: Impacts and Risk, Forum Geografi, Vol. 29 (1) 59 - 72
[2] Hendrawan A P, Suprijanto H, Yuliani E and Hidayat M N 2017 Proc. of the 7th Annual Basic Science International Conference, p 73
[3] Evans E J, Inglethorpe S J D, Wetton P D 1999 Evaluation of Pumice and Scoria Samples from East Africa as Lightweight Aggregates, British Geological Survey, UK.
[4] Yildiz M, Soganci A S 2015 Scientia Iranica A, 22 (1), 81.
[5] Wesley L. 2001 Geotechnical Testing Journal, 24 (4), 418.
[6] Kikkawa N, Orense R P, Pender M J 2013 Canadian Geotechnical Journal, 50(11), 1109.
[7] Orense R P, Pender M J, O’Sullivan A S 2012 Liquefaction Characteristics of Pumice Sands, University of Auckland, New Zealand.
[8] Road Construction Authority, Victoria, Australia 1982 Drainage of subsurface water from roads, Technical Bulletin No. 32.