Effects of weathering grade of metavolcanic aggregates on mortars

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Abstract. The aim of this work is to study the effect of weathering grade on physical, mechanical and microstructure properties of metavolcanic aggregates and on mortars containing aggregates. Samples were collected from several locations in the Central and Southern Eastern desert in Egypt and they were characterised by XRF, polarized light, and SEM microscopy. Beside compressive strength, bulk density, apparent porosity and water absorption, modified weathering potential index (MWPI) was also determined based on the chemical composition of the rock aggregates. Seven mortars with metavolcanic aggregates were mixed and specimens were formed. Physical and mechanical properties of specimens were measured according to standards. Results showed that MWPI had the good relation with geotechnical properties of metavolcanic aggregates. Physical and mechanical properties of metavolcanic aggregates and concretes depended on weathering grade of rocks and on ratio of weathering minerals in aggregates.

1. Introduction
Weathering of both soils and rocks is one of the most important problems, which the engineering geologist has to concern [1]. Weathering takes place in all environments, but it is most intense in hot, wet climates, where weathering may be expected to extend to great depths. Physical weathering led to open up of discontinuities by rock fractures. On the other hand, the chemical changes of minerals were the most crucial key for chemical weathering. Physical and chemical weathering greatly affected engineering structures found at or near the earth’s surface [2,3,4]. Weathering degree of rock can be measured by many qualitative and quantitative prediction models. Qualitative models are based on observation and descriptions. Results of these models are the colour of rock, weathering degree of minerals and observational description of physical weathering, like exfoliation [5,6,7]. Quantitative approaches result consistent and objective rock weathering degree [6]. Rock weathering has several states which affects the aggregate characteristics. Therefore, this research is aimed to study the effect of weathering grade on physical and mechanical properties of metavolcanic aggregates and also on mortars based on aggregates.
2. Materials and methods
Metavolcanic samples were collected from different locations in the Southern and Central Eastern Desert, Egypt. Uniaxial compressive strength; bulk density; apparent porosity and water absorption were measured according to ASTM C-170 (2006), ASTM C-20 (2005), ASTM C-33 (1986) and ASTM C-127 (2006) [9,10,11,12], respectively. Chemical composition of the metavolcanic samples was analyzed by XRF (Axios, Sequential WD_XRF Spectrometer, PANalytical 2005) The microstructure of the samples was investigated by the use of scanning electron microscopy (JSM 6300) and transmitted light microscopy (TLM - B-150POL-MALC LM). In order to describe the effect of weathering on the mechanical and physical properties of metavolcanic aggregates, based on data originated from result of XRF, weathering indices were calculated according to the following equations:

MWPI (weathering potential index) = \[ \frac{\text{K}_2\text{O} + \text{Na}_2\text{O} + \text{CaO} + \text{MgO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 + \text{CaO} + \text{MgO} + \text{K}_2\text{O} + \text{Na}_2\text{O}} \times 100 \]

CIA (chemical index of alteration) = \[ \frac{\text{Al}_2\text{O}_3 \times 100}{\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}} \]

CIW (chemical index of weathering) = \[ \left( \frac{\text{Al}_2\text{O}_3 + \text{K}_2\text{O}}{\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O}} \right) \times 100 \]

The chemical weathering indices are definite equations used to quantify the degree of depletion of mobile components relative to immobile components [13,14].

Seven different mortars were prepared for tests. Three components, cement (CEM I 42.5N); fine and coarse aggregates were added to mixes in the ratio of 1:2:4. Mixes were devoid of sand fraction. Water-cement ratio was set to 0.5. Each mix was thoroughly blended to ensure homogeneous admixture. Physical and mechanical tests of samples from metavolcanic mortars were determined on cubic samples (50x50x50mm) according to the ASTM C109/C109M-16a [15]. Three cubes samples were produced for each mix. Curing time of samples was 28 days under water.

3. Results and discussion
3.1. Characteristics of metavolcanic aggregates
Geotechnical characteristics of the metavolcanic aggregates were summarized in Table 1. Results show that the values of MWPI increase as the weathering grade decrease and density increase. This is similar to findings from Jayawardena and Izawa [16] and Gupta and Rao [17]. Alternatively, CIA and CIW values show a continuous increase with increasing degree of weathering. Weathering index MWPI had good relation with geotechnical properties of metavolcanic aggregates (Figure. 1). Compressive strength, bulk density and specific gravity were a direct relation with the MWPI (Figures 1a, 1b, respectively). On the contrary, apparent porosity had negative relation with the MWPI (Figure 1b).

Table 1. Weathering indices, physical and mechanical properties of the aggregates and mortars.

| Rock type      | Rock unit | UCS, (MPa) | BD, (g/cm³) | AP, (%) | SG, | UCS, (MPa) | BD, (g/cm³) | (MWPI) | (CIA) | (CIW) |
|----------------|-----------|------------|-------------|---------|-----|------------|-------------|--------|-------|-------|
| Metabasalt     | AMB1      | 140        | 3.05        | 0.46    | 3.4 | 32.51      | 2.48        | 24.22  | 50.76 | 52.25 |
|                | ESMB2     | 104        | 2.80        | 0.26    | 2.89| 21.01      | 2.27        | 19.83  | 57.25 | 60.41 |
|                | SMB3      | 87.76      | 2.7         | 0.48    | 2.78| 32.01      | 2.34        | 19.11  | 60.93 | 62.36 |
|                | SMB4      | 40.21      | 2.9         | 1.14    | 3   | 32         | 2.39        | 20.25  | 55.85 | 64.49 |
| Metadacite     | UKMD5     | 40         | 2.5         | 1.80    | 2.6 | 10.71      | 2.07        | 19.63  | 54.94 | 60.35 |
| Meta-andesite  | SMA6      | 31.26      | 2.49        | 2.04    | 2.67| 7          | 1.9         | 12.76  | 63.01 | 76.91 |
| Basaltic meta- andesite | ESMB7 | 102.55 | 2.87 | 0.76 | 2.9 | 24.06 | 2.29 | 21.34 | 57.0 | 57.58 |

UCS: uniaxial compressive strength; BD: bulk density; AP: apparent porosity; SG: specific gravity; modified weathering potential index: MWPI; chemical index of alteration: CIA; chemical index of weathering: CIW.
Mineralogical, weathering indices, physical and mechanical characteristics of the AMB1 were confirmed by its blocky and massive nature and its compact microstructure. Studying the microstructure of AMB1 by TLM, beside Ca-plagioclase, augite, olivine, actinolite, it contained only a small amount of weathering contents like chlorite and epidote (Figure 2 a). Interpretation of results focused only on the highest and the lowest values of all properties. Density and compressive strength of AMB1 (metabasalt) were the highest values, whilst the apparent porosity value of it was the lowest one (3.05 g/cm³, 140 MPa and 0.46 %, respectively) compared to the other tested aggregates. The MWPI value for AMB1 was the highest 24.22, whilst the CIA and CIW values are the lowest, 50.76 and 52.25 respectively, compared with the other metavolcanic samples (Table 1). Therefore, the AMB1 sample seemed to the most suitable metavolcanic aggregate in concrete. On the other hand, SMA6 consisted of highly fractured and weathered minerals (Figure 2 b). It mainly composed of plagioclase, hornblende chlorite, quartz and fractured calcite (Figure 2b). The plagioclase in meta-andesite sample (SMA6) was highly-altered into sericite. Density and compressive strength of SMA6 were the lowest values, whilst apparent porosity was the highest value (2.49 g/cm³, 31.26 MPa and 2.04 %, respectively). SMA6 has the lowest MWPI value of 12.76, but values of CIA and CIW were the highest 63.01 and 76.91, respectively. Therefore, the SMA6 sample is the unsuitable metavolcanic aggregates for concrete.
Figure 2: a) Augite minerals with compacted structure of AMB1 (cross nicole (XN)).
b) Photomicrograph showing highly fractures veinlets of calcite SMA6 (cross nicole (XN)).
Au: augite, Pl: plagioclase, Ca: calcite

3.2. Characteristics of metavolcanic mortars
According to ASTM C109/C109M-16a (2016) standard, seven mortars containing metavolcanic aggregates were mixed, samples were formed, cured and measured. Table 1 includes the average results for each tested mortars (three samples per mortar). Physical and mechanical characteristics of aggregates affected the physical and mechanical properties of its mortar. Therefore, density and compressive strength of aggregates were in direct relation with the compressive strength of mortars (Fig. 3). Compressive strength and bulk density of AMB1 mortar were the highest values (32.51 MPa, 2.48 g/cm³). On the other hand, the compressive strength and bulk density of SMA6 mortar sample were the lowest values (7 MPa, 1.9 g/cm³) (Fig. 3).

Figure 3: Relations between compressive strength of mortars and compressive strength-bulk density of aggregates.
3.3. SEM micrographs
Figure 4a illustrates the SEM micrograph of AMB1 mortar. Structure was highly compacted, no pore observed on analysed surface. It can be seen interlocking phases of aggregates and cement. AMB1 contained cementitious compounds such as calcium hydroxide (CaOH$_2$) and calcium silicate hydrate (CSH). On the contrary, the SMA6 aggregate was extensively weathered, where plagioclase and hornblende crystals are highly altered into sericite. In addition, SMA6 sample was characterized by fractured calcite veinlets indicating existence of micro-pores (Figure 2b). Therefore, SMA6 mortar was showed uncompact microstructure with large pores with cotton shape CSH phases. Latter indicated on Figure 4b with white arrows.

![SEM micrographs of AMB1 mortar](image1)

![SEM micrographs of SMA6 mortar](image2)

**Figure 4:** (a) SEM micrograph of AMB1 mortar; (b) SEM micrograph of SMA6 mortar.

4. Conclusions
The weathering grade is the vital key for effecting on metavolcanic aggregates, which can be used in concrete. The modified weathering potential index was calculated based on the chemical composition of the rock aggregates. This index has good relation with geotechnical properties of metavolcanic aggregates. Compressive strength, bulk density and specific gravity were in direct relation with the MWPI. On the contrary, apparent porosity indicated a negative relation with the MWPI. MWPI proves that the SMA6 sample is the most weathered among all samples. Therefore, physical and mechanical properties of its mortar were very low.

On the other hand, AMB1 metabasalt had the highest compressive strength and bulk density and the lowest porosity among of tested aggregates hence mortars based on AMB1 had also good properties. Highest values of compressive strength and density of AMB1 metabasalt aggregate and mortar were explained by its compact microstructure. In addition, the development of the cementitious phases contributes to the acceptable values of apparent porosity of AMB1 mortar. Application of AMB1 metabasalt is recommended as aggregates in concrete.

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