The impact of secondary phyllosilicate minerals on concrete strength produced from mafic and ultramafic aggregate rocks

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Abstract

The aim of this study is to highlight the impact of the secondary phyllosilicate minerals in mafic and ultramafic rocks used as aggregates on concrete strength and more specifically the influence of microroughness of the aggregates in the adherence of the cement paste. The studied aggregate samples used for the production of concrete, were collected from ophiolite complexes in Central Macedonia. Quantitative petrographic analysis indicates that the tested samples display various percentages of secondary phyllosilicate minerals. Mineral quantification of the studied rock samples was performed by using the Rietveld method on bulk samples. The ocean-floor metamorphism variably affected the collected ultramafic and mafic samples. During this process primary minerals from ultramafic and mafic rocks are often altered to secondary ones as a result of the ocean-floor metamorphism process. Chlorite is the dominant secondary phase in mafic rocks, such as diabase, gabbro and basalt which attributes to their low microroughness and to unfavorable interfaces between cement paste and aggregate particles. On the other hand, in ultramafic rocks, such as serpentinized peridotites, serpentine, chlorite and talc seem to be the dominant secondary phases. Additionally, ultramafic aggregates are characterized by low microroughness contributing on de-bonding between the aggregate particles and the cement paste. Phyllosilicates constitute an important group of minerals which includes serpentine, chlorite, micas, and clay minerals. The basic structure of the phyllosilicate minerals is based on interconnected six-member rings of $SiO4^{-4}$ tetrahedral that extend outward in infinite sheets. Several researchers have highlighted the impact of secondary phyllosilicate minerals on the engineering properties of various igneous aggregates (Petrounias *et al*., 2018b). More specifically, Petrounias et al. (2018b) proposed two petrographic indexes M_{ph} and U_{ph}. The petrographic index M_{ph} which is the sum of the phyllosilicate minerals in mafic samples is describing by the following equation M_{ph}= Chlorite (%). On the other hand, the petrographic index U_{ph} (%) which is the sum of the secondary phyllosilicate minerals present in ultramafic rocks is describing by the following equation: U_{ph} = Serpentine (%) + Chlorite (%) + Talc (%).

Concrete is the most used man-made material and comprises a mixture of mortar, aggregates and water (Jackson, 1981). Usually, aggregate is considered as inert filler, which accounts for 60 to 80% of the volume and 70 to 85% of the weight of concrete. Aggregates are divided into natural stone aggregates (sand and gravel) and crushed aggregates (crushed stones). The quality of aggregate, including its long-term durability and resistance to cracking, influence the properties of both fresh and hardened concrete. The inhomogeneous structure of concrete can be described as a three-phase system consisting of hardened cement paste, aggregate and the interface between aggregate particles and cement paste. Many researchers investigate the relationship between the percentages of different mineralogical compositions of aggregates and the final compressive strength of concrete. Several researchers (Petrounias *et al.,* 2018a, Petrounias *et al.,* 2018c) investigating various igneous rocks from Greece concluded that the secondary products of serpentinites and andesites largely influence their mechanical properties, which definitely have an adverse effect on their performance as concrete aggregates. However, a research gap is identified concerning the effect of these minerals on the produced concretes by different type of mafic aggregates.

Representative mafic and ultramafic rocks were collected from the Veria-Naousa and Edessa ophiolite complexes and were prepared normal concrete cube specimens. The Veria-Naousa ophiolite complex in northern Greece belongs to the Almopias subzone of the Axios geotectonic zone. It consists, from base to top, of serpentinised lherzolite and harzburgite, which are cut by scarce pyroxenite dykes, gabbro, diabase and pillow basalt (Rogkala *et al.,* 2017). The Edessa ophiolite represents remnants of oceanic lithosphere, which was thrust out of one basin during the Upper Jurassic to the Lower Cretaceous time (Rogkala *et al,* 2019). It is intensively tectonized and consists of several tectonic units.

Mafic and ultramafic aggregates used in order to prepare concrete specimens using normal Portland cement (CEM II 32.5N), which is conformed to EN 197-1. Potable tap water, free of impurities such as salt, silt, clay and organic matter, with pH = 7.0, was used for mixing and curing the concrete. In order to keep a consistent composition for all the concrete specimens, we adopted the principle of maintaining the same volume of aggregate per m^3 of the mixture. The proportions of the concrete mixtures, by mass, were 1/6/0.63 cement, aggregate and water ratio. The mineralogical characteristics of aggregates were examined in thin sections with a polarizing microscope and their mineralogical composition was also determined by XRD analysis and was calculated using the Rietveld refinement method. Normal concrete cubes specimens (150 mm × 150 mm) were prepared according to ACI-211.1-91. The compression test of concrete was elaborated according to BS EN 12390-3:2009. After the compressive strength test, the textural characteristics of concretes were examined. Thin sections were studied in a polarizing microscope according to ASTM C856–17. In a next stage, 3D depiction of thin sections of the concrete specimens was carried out (Fig. 1) showing the adherence between the aggregates and the cement paste as well as the microroughness of the aggregate particles.

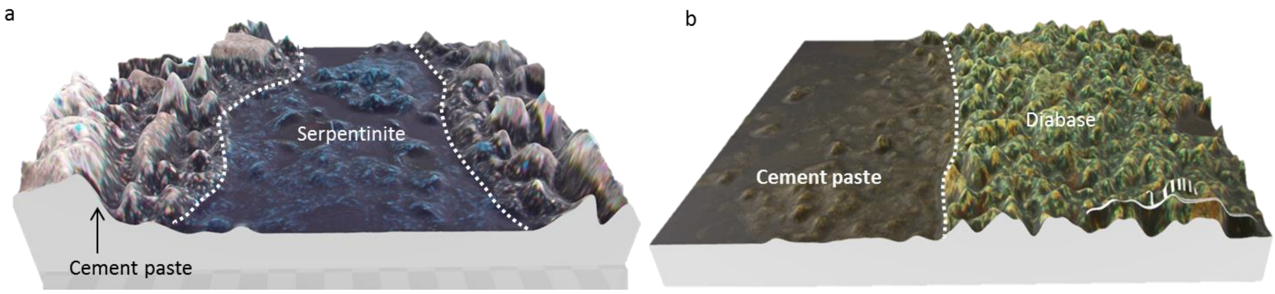

Figure 1. 3D depiction of thin sections of concrete specimens: a. ultramafic rock (serpentinite) used as aggregate, b. mafic rock (diabase) used as aggregate

The influence of secondary phyllosilicate minerals on concrete strength is confirmed by the correlation between the (UCS_{con}) strength of concrete and the percentage of secondary phyllosilicate minerals contained in the tested mafic and ultramafic rocks. Regression analysis is the commonest statistical method for the investigation of the interdependence of the physical and mechanical parameters. Figure 2 shows that as the percentage of serpentine, talc and chlorite in ultramafic rocks as well as the percentage of chlorite in mafic rocks increases, the yield strength of the produced concrete decreases. This is partly due to the ability of the phyllosilicate minerals to absorb water in their structure. In order to perform the regression analysis under a single correlation, U_{Ph} values were used as representative phyllosilicate values in ultramafic rocks and M_{Ph} values as representative phyllosilicate values in mafic rock formations. The function that links the above sizes is possible to describe by the following relation:

$$UCS_{con}= -0,0667^* (U_{Ph} /M_{Ph})+31,246,\ R^2=0,82.$$

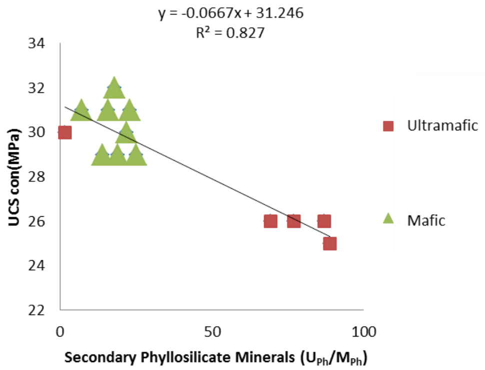

Figure 2. Secondary phyllosilicate minerals of mafic (M_{Ph}) and ultramafic rocks (U_{Ph}) respectively plotted against the strength of the produced concretes (UCS_{con}).

To conclude, as the percentage of secondary phyllosilicate minerals like serpentine, chlorite and talc increases the compressive strength of the produced concretes decreases respectively as more cracks, detachments and de-bonding between the aggregates containing the secondary phyllosilicate minerals and the cement paste.

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