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## Mechanical properties and interfacial transition zone microstructure of concrete with waste basalt powder addition

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### HIGHLIGHTS

- The basalt powder as a replacement of sand, improves the strength of concrete.
- The ITZ in concrete with basalt powder addition is denser and stronger.
- The addition of basalt powder leads to physical densification of cement matrix.
- Some chemical reactions between basalt powder and pore solution are possible.

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### ABSTRACT

This study evaluates the use of waste basalt powder as a replacement of the fine aggregate to enhance concrete properties. Experiments were carried out to determine the compressive and flexural strengths of concrete with basalt powder and the influence of the basalt powder on the microstructure of the ITZ. Results indicate that addition of basalt powder as a replacement of sand, improves the compressive and flexural strength of concrete. It is mainly due to the filler effect of the basalt powder. The ITZ in concrete with basalt powder addition is denser and stronger than in concrete without basalt.

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## 1. Introduction

The work presented herein evaluate the use of waste basalt powder as a replacement of the fine aggregate (sand) to enhance concrete properties. The waste basalt originates from the preparation of aggregate used in asphalt mixture production in Europe. Previous studies that analysed wastes have concluded that fine powder can have a beneficial effect on mechanical properties of concrete as well as durability [1–6].

The microstructure of hydrated cement paste directly adjacent to aggregate particle differs much from that of the bulk hydrated cement paste in terms of morphology, composition, and density [7–10]. During hydration cement reacts with water to form the two major hydrate phases: calcium silicate hydrate (C-S-H) and calcium hydroxide. The microstructure of the interfacial transition

zone (ITZ) largely depends on the way these hydrates are deposited in this zone [11]. At early stages of hydration, the concentration of silicate ions in solution is very low, thus the C-S-H phase precipitates mostly around the cement particles. Due to the higher mobility of calcium ions, calcium hydroxide can form in the open pores at greater distance from cement grains. Furthermore, silica inhibits the nucleation of calcium hydroxide, which favors the precipitation of this phase as far from the cement grains as possible [11].

Due to the so called “wall effect”, cements grains are unable to become closely packed against the relatively flat aggregate surface. Therefore, in the ITZ there are less products of cement hydration. Aggregate particles are surrounded with a thin water film. Therefore, the region of paste around the aggregate particle surface is a water-rich zone, which results in a higher local water/cement ratio in the vicinity of the aggregate surface that in the bulk cement paste. Since less cement grains are present to hydrate and fill the original voids, and because of higher local water/cement ratio in the vicinity of the aggregate surface a more porous zone around the aggregate is formed when compared to the bulk hydrated

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cement paste further away from the coarse aggregate [12]. This water-rich zone favors the heterogeneous nucleation of more relatively large hexagonal calcium hydroxide crystals in this region and is directly responsible for the features of the ITZ, particularly its higher porosity when compared to the bulk cement paste [9,11,12,13].

The mechanical and durability properties of concrete are significantly influenced by the bond between the aggregate and cement matrix and thus the microstructure of the ITZ. Microcracks initiate in the ITZ and then propagate to the bulk cement paste. For this reason, the ITZ is regarded as a weak link in concrete [14]. The bond between aggregate and cement paste is primarily due to the interlocking of the cement paste with the rough surface of aggregate. A rougher surface, such as that of crushed particles, results in a better bond due to mechanical interlock. In addition, bond is affected by other physical and chemical properties of aggregate, related to its mineralogical and chemical composition, and to the electrostatic condition of the particle surface [14].

Many decades ago the aggregate was considered to be chemically inert. However, depending on its composition, the aggregate may not be completely inert, and its chemical properties affect the properties of concrete [14]. Although relatively little attention is paid to the chemical and mineral composition of the aggregates and the influence of aggregate chemistry on the properties of the ITZ during mixture proportioning, some researchers have pointed out that the interaction of the aggregate with the cementitious matrix is not only physical but also chemical in nature. The reaction between aggregate and pore solution leads to modification of the ITZ microstructure and as a consequence may increase the cement paste-aggregate bond strength. Kurdowski [15] claims that it is a simplification when considering the transition zone to treat the aggregate surface as a “single mineral” material. Rocks from which aggregates are obtained are composed of minerals. The size of these mineral particles are often in the range of 200–500  $\mu\text{m}$ , so it's about ten times larger than cement grains. Because of this, the cement paste remains in contact with minerals of different chemical compositions and different properties and, in fact, there are many transition zones.

Between some minerals and the pore solution in a cement paste, ion exchange can take place, which leads to modification of ITZ [16–19]. For example, the chemical reaction between calcite—the main mineral constituent of limestone and marble—and tricalcium aluminate leads to formation of calcium carboaluminate phases that improves bond strength [20–22]. Due to reaction of minerals from feldspar with calcium hydroxide in the pore solution, the surface transformation of albite layer into C-S-H phase takes place, which has positive influence on the structure of the transition zone [16,17]. Other studies have shown that chemically reactive aggregates significantly affect the amount and the orientation of  $\text{Ca}(\text{OH})_2$  crystals in the ITZ, which leads to the modification of their microstructure [18,23,24]. It has also been found that different mineralogical aggregate types affect the concentration of silicate, alumina, calcium, and alkalis ions in the pore solution [17–19,25,26].

## 2. Paper objectives

The main objective of the work covered in this study is to evaluate the effect of the addition of basalt powder on the ITZ and concrete properties. The effect of basalt powder addition on both particle packing and ions exchange between minerals of the basalt particle and pore solution will also be evaluated.

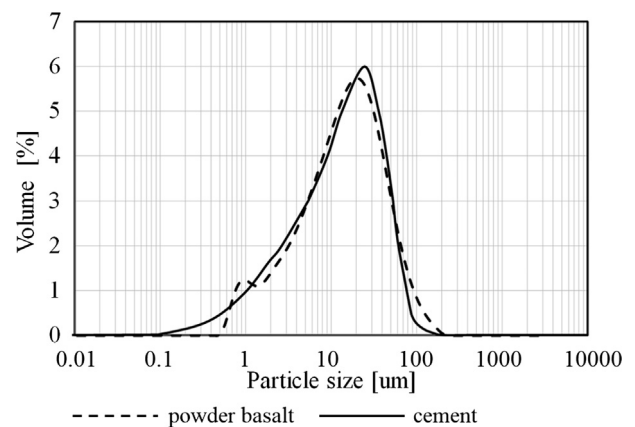
## 3. Materials and test methods

The physical properties and chemical compositions of waste basalt powder were first determined. Next, the compressive and flexural strengths of five concretes made by replacing (by mass) 5%, 10%, 20% and 30% of fine aggregate (sand) with basalt powder were analyzed. Because of the high importance of the ITZ and the possibility of influencing its microstructure through the addition of minerals, studies on the influence of the waste basalt powder on the microstructure of the ITZ was conducted. An attempt was also made to analyze the role of waste basalt powder addition in influencing the ionic chemical interactions between minerals on the basalt particles surface and the pore solution.

Concrete mixtures were produced with Ordinary Portland Cement CEM I 42.5. In accordance with European Standard EN

**Table 1**  
Chemical and mineral composition of portland cement.

Chemical Composition,%		Mineral Composition,%	
$\text{SiO}_2$	19.39	$\text{C}_3\text{S}$	59.7
$\text{Al}_2\text{O}_3$	4.67		
$\text{Fe}_2\text{O}_3$	3.34		
$\text{CaO}$	63.17	$\text{C}_2\text{S}$	12.4
$\text{MgO}$	1.24		
$\text{SO}_3$	2.95		
$\text{K}_2\text{O}$	0.62	$\text{C}_3\text{A}$	2.8
$\text{Na}_2\text{O}$	0.17		
$\text{Cl}^-$	0.07	$\text{C}_4\text{AF}$	11.8
$\text{P}_2\text{O}_5$	0.12		



**Fig. 1.** Particle size distribution of basalt powder and portland cement.

**Table 2**  
Chemical composition of basalt powder.

Chemical Composition,%	
$\text{SiO}_2$	42.61
$\text{Al}_2\text{O}_3$	12.90
$\text{Fe}_2\text{O}_3$	14.05
$\text{CaO}$	13.00
$\text{MgO}$	7.82
$\text{SO}_3$	0.07
$\text{K}_2\text{O}$	1.15
$\text{Na}_2\text{O}$	1.76
$\text{Cl}^-$	0.10
$\text{P}_2\text{O}_5$	1.80
$\text{MnO}$	0.25

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