

Effect of basalt powder addition on properties of mortar

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Abstract. The study evaluates the use of waste basalt powder as a replacement of cement to enhance hydration of cement and mortar properties. The basalt powder is a waste resulting from preparation of aggregate used in asphalt mixture production. Previous studies have shown that analysed waste used as a fine aggregate replacement has a beneficial effect on some properties of mortar and concrete, i.e. compressive strength, flexural strength and freeze resistance. The present study shows the results of the research concerning the modification of cement paste and mortar with basalt powder. The modification consists in adding the powder waste as a partial replacement of cement. The percentages of basalt powder in this research are 0-40% and 0-20% by mass of cement in the pastes and mortars respectively. The experiments were carried out to determine the influence of basalt powder on cement hydration, as well as compressive and flexural strength. Results indicate that addition of basalt powder as a replacement of cement leads to deterioration of compressive strength. The flexural strength of mortar is improved in some cases. Waste basalt powder only slightly influences the cement hydration.

1 Introduction

On one hand, excessive exploitation and limited availability of raw materials and, on the other hand, the problem with the increasing number of industrial waste and the lack of landfills, have led to the development of studies related to potential use of waste materials in building material production. Such a method of managing waste is consistent with the principle of sustainable development that assumes efficient management of non-renewable (consumable) natural resources and their replacement with recycled waste substitutes. Utilisation of waste materials in the construction sector contributes to the environmental protection by reducing energy consumption, enhancing natural resource efficiency, and reducing greenhouse gas emissions, especially carbon dioxide, to the atmosphere. Cements with mineral additives are commonly used nowadays in the cement industry. Searching for ways to reduce energy consumption and CO₂ emission will only reinforce this tendency [1]. Fly ash, granulated blast furnace slag or silica fume are used as a partial substitute for Portland cement clinker in cement, or a partial substitute of cement in concrete.

Possibilities of using other waste materials as a partial cement replacement, such as natural mineral dust (rock dust), are also explored, i.e. limestone dust [2-4], marble dust [5-8], granite dust [9,10] or basalt dust [11,12]. Rock dusts, often referred to as stone powders, are used in concrete and cement mortar primarily as inert additives i.e. fillers. Their positive effect on some

properties of cement mortar and concrete is mainly related to the filler effect. The influence of stone dust on mechanical parameters of cement composites depends mainly on the stone dust replacement and the specific surface area of the additive. A partial replacement of cement for stone dust generally results in deterioration of mortar and concrete strength parameters, which are obviously related to lower cement content [13].

However, some authors have observed that a slight dust share in cement mass, i.e. up to about 5–10%, causes the increase of material strength, when comparing it with the strength without dust additives. Lawrence et al. [14] have noted that the strength of cement mortar increases when the specific surface area of stone dust increases. Knop et al. [4] have come to the conclusion that cement mortar with limestone dust additives, which has smaller particle size than cement particles, achieves better early strength than control mortar without dust additives. After a certain amount of time, i.e. after 28 days, the situation is reversed and the strength of the control mortar becomes higher than the strength of the mortar with dust additives.

2 Research significance

It can be concluded from the literature review that basalt powder is more often use as a fine aggregate (sand) replacement than a partial cement substitution. Introduction of basalt powder as a replacement for the part of sand contributes to the improvement of physical

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and mechanical properties of mortars and concretes [15-19]. There is a lack of information on the possibility of using basalt powder as a cement substitution, therefore this problem needs to be investigated. The study shows the results of modification of mortar with basalt powder added as a partial replacement of cement. Firstly, the properties of basalt powder were studied. Next, the influence of basalt powder on cement hydration, as well as the compressive and flexural strength were analysed.

3 Experimental procedure

3.1 Materials

Paste and mortar mixtures were produced with ordinary Portland Cement CEM I 42.5 R, which complies with the requirements of European Standard EN 197-1 44. The specific gravity of cement is 3.13 g/cm³ and Blaine fineness is about 3500 cm²/g. Table 1 presents chemical and mineral composition. Standard quartz sand and de-ionized water were used in all mortar mixtures.

Table 1. Chemical and mineral composition of OPC.

Chemical composition, %		Mineral composition, %	
SiO ₂	19.39	C ₃ S	59.7
Al ₂ O ₃	4.67		
Fe ₂ O ₃	3.34		
CaO	63.17	C ₂ S	12.4
MgO	1.24		
SO ₃	2.95		
K ₂ O	0.62	C ₃ A	2.8
Na ₂ O	0.17		
Cl ⁻	0,07	C ₄ AF	11.8
P ₂ O ₅	0.12		

Waste basalt powder was obtained from Asphalt Batch Mix Plant. Significant amounts of by-product in the form of mineral powder are the result of Asphalt mixture production. A mineral aggregate used in asphalt mixture production is dried at the temperature of about 200°C. Exhaust gases exit the dryer with powder particles. Coarser fractions of powder are collected in a special separator, but very fine fractions are placed in a filter of the dryer. This very fine material is treated as a waste, by-product. The quantity of this waste powder is about 5% of aggregate mass used to the production of asphalt mixture. Mineral powder used in this study is the by-product of basalt, therefore, it is defined as basalt powder. The chemical composition of basalt powder is presented in Table 2. The mass fractions of silica and alumina oxide dominate, which is typical for basalt rock, and are about 55%. The particle diameters of powder directly obtained from Asphalt Batch Mix Plant are in the range of 1 to 100 µm. The largest volume, i.e. ca. 57%, is occupied by particles of about 20 µm in diameter. The specific gravity of powder is 2.99 and Blaine fineness of about 3500 cm²/g.

Table 2. Chemical composition of basalt powder.

Chemical composition, %	
SiO ₂	42.61
Al ₂ O ₃	12.90
Fe ₂ O ₃	14.05
CaO	13.00
MgO	7.82
SO ₃	0.07
K ₂ O	1.15
Na ₂ O	1.76
Cl ⁻	0.10
P ₂ O ₅	1.80
MnO	0.25

Basalt powder was subjected to mechanical activation by grinding in a laboratory mill. The largest volume of ground basalt powder, i.e. ca. 59%, is occupied by particles of about 12 µm in diameter. The Blaine fineness of ground powder is of about 5600 cm²/g. The grading curves of basalt powder before and after grinding are shown in Figure 1.

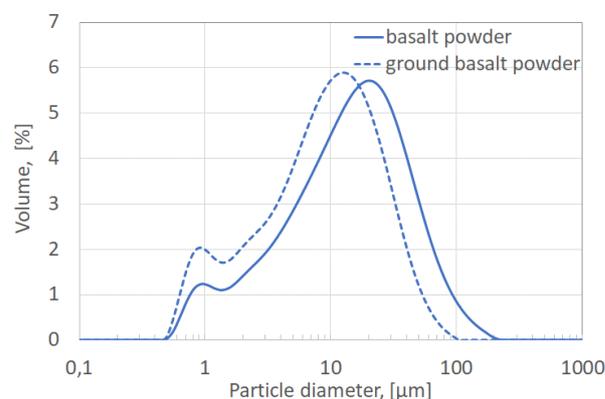


Fig. 1. Particle size distribution of basalt powder before and after mechanical activation.

The XRD pattern presented in fig. 2 indicates that in mineralogical composition, plagioclase rich in anorthite particles (Ca-Plagioclase) dominates, as well as pyroxene and amphibole. There is a small amount of Illite, which is probably the effect of plagioclases weathering.

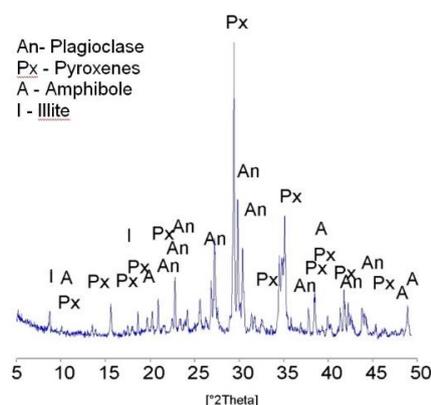


Fig. 2. XRD pattern of the basalt powder.

3.2 Mixture proportion and method

The influence of basalt powder content and its fineness on cement hydration was investigated by preparing pastes of cement and basalt powder in amount of 10%, 20%, 30% and 40% mass of cement. Cementitious paste mixtures were prepared at a fixed water-to-solids ratio ($w/s=0.50$). The proportion of the mixture shown in Table 3 is the same, regardless of the degree of fineness of basalt powder. The paste without basalt powder was marked as P0 and these with basalt addition as P0-P40, where the number stands for the amount of basalt powder in the mixture.

Table 3. Paste mixture proportions.

Paste	Material [g]		w/c ratio	w/s ratio
	Cement	Basalt powder		
P0	5	-	0.50	0.5
P10	4.5	0.5	0.56	
P20	4.0	1.0	0.63	
P30	3.5	1.5	0.71	
P40	3.0	2.0	0.83	

The influence of cement replacement on the hydration was monitored by isothermal heat conduction calorimetry. Thermal power and energy were measured and then used to investigate the rate of heat evolution and the cumulative heat release of cement paste.

In order to investigate the influence of mechanical activation of basalt powder on the strength properties of mortars, nine different mixtures were prepared, i.e. without basalt powder and with basalt powder, before and after mechanical activation. Basalt powder was used as a partial replacement of cement. The percentages of basalt powder were 5%, 10%, 15% and 20% mass of cement. Mortar without basalt powder was marked as M0, while these with basalt powder were labelled as the abbreviations of M5-M20, where the numbers indicated the percentage of cement replacement. Each mixture proportion of mortars is presented in Table 4. They were the same in both cases, activated and non-activated basalt powder.

Table 4. Mortar mixture proportions [g].

Mortar	Cem.	Water	Sand	Basalt powd.	w/c ratio	w/s ratio
M0	450	225	1350	0	0.5	0.5
M5	427.5			22.5	0.53	
M10	405			45	0.56	
M15	382.5			67.5	0.59	
M20	360			90	0.63	

All mortar mixtures were prepared in accordance with European Standard EN 196-1. The water-solid ratio of 0.50 was kept constant for all mortars. The cement mortars were cast into 40×40×160 mm prism steel molds and consolidated through external vibration. Before demoulding, the prepared specimens were kept in a controlled chamber at temperature of 20±2°C for 24 h. Then the specimens were cured at 20°C and

at 100% relative humidity (in water) until the experiment was launched.

The European specification EN 196-1 was employed to determine the compressive and flexural strength after 2, 7, 28, 90 and 180 days of curing. Compressive and flexural strength are the average value from six and three samples respectively.

4 Experimental results and discussion

4.1 Isothermal calorimetric measurement

The effect of non-activated basalt powder on rate of heat development and cumulative heat release of the paste were shown in the fig. 3 and fig. 4. The addition of basalt powder slightly extended the dormant period compared to the pure cement paste. It can be particularly observed for the paste with 40% basalt powder addition, where the dormant period increased by 50 minutes compared to the paste without basalt powder. The main peak of heat evolution curve decreased with the increase in the amount of basalt powder, and slightly shifted to the left for the mixed cement paste with 20% of basalt.

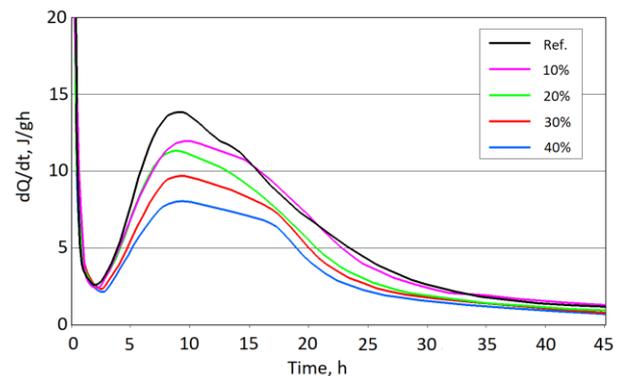


Fig. 3. Measured heat flow as a function of time and basalt powder content.

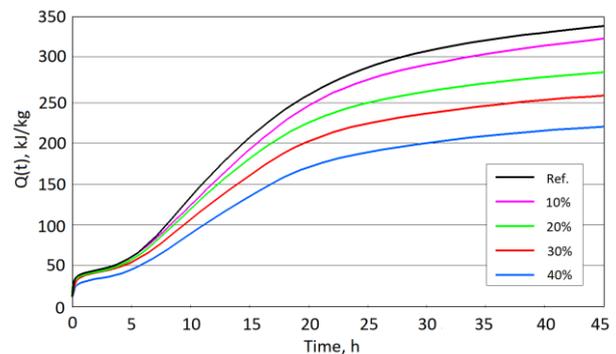


Fig. 4. Cumulative heat release as a function of time and basalt powder content.

A small additional peak is visible in the calorimetry curve in the case of cement with basalt powder addition. This peak has been identified as the second dissolution of the aluminate C_3A and it is often attributed to AFm formation [20,21]. This phenomena cannot be clearly noticed in the case of pure cement paste, i.e. cement

paste without basalt powder addition. As the amount of basalt powder content increases, cumulative heat release decreases which indicates a lower hydration degree of cement with basalt powder.

Fig. 5 and Fig. 6 show the effect of ground basalt powder on the hydration kinetics of cement.

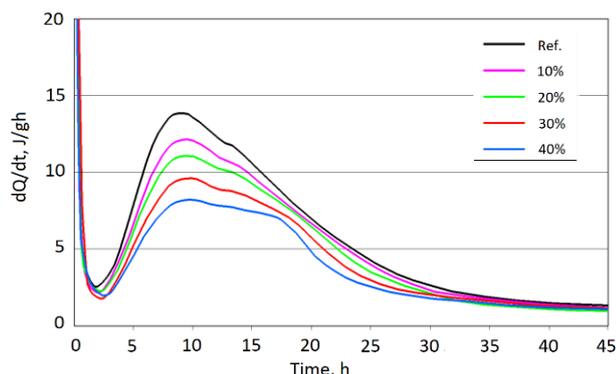


Fig. 5. The measured heat flow as a function of time and ground basalt powder content.

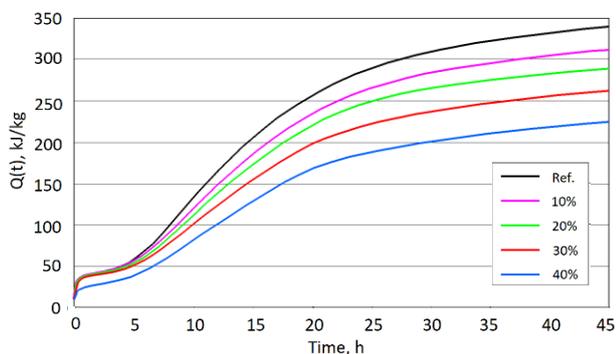


Fig. 6. Cumulative heat release as a function of time and ground basalt powder content.

Presented results show that the fineness of basalt powder only slightly influences the hydration kinetics of cement. The main peak of hydration in the calorimetry curve, mainly attributed to the silicate reaction, appears more or less at the same time for both basalt powders. The length of the dormant period and cumulative heat release do not change a lot compared to the addition of basalt powder to a smaller specific surface area.

Table 5. Percentage decrease of heat effect with reduction of cement content.

Reduction in cement content	Basalt powder	
	after 24h	after 44h
0.9	0.95	0.96
0.8	0.86	0.84
0.7	0.77	0.75
0.6	0.65	0.64
Reduction in cement content	Ground basalt powder	
	after 24h	after 44h
0.9	0.92	0.92
0.8	0.86	0.85
0.7	0.77	0.77
0.6	0.65	0.66

The relative decrease of cumulative heat release as a consequence of cement reduction is shown in Table 5. It can be seen that the percentage decrease of heat effect after 24 and 44 hours is smaller than reduction of cement content. It indicates a slight pozzolanic reaction of basalt powder [11, 15, 16, 22, 23] and heteronucleation of C-S-H phase on basalt powder particles.

Results presented in the literature indicate that inert particles accelerate the rate of the acceleration period of cement hydration mainly due to their physical interaction. This effect is usually referred as the ‘filler effect’ and has been attributed to the increase of the number of nucleation sites provided by the extra surface from the inert particles [24-31]. It enables heteronucleation of the larger number of growing C-S-H phase and, consequently, accelerates the hydration rate [24-28, 32-35]. The major factors affecting the hydration kinetics are the inert particle content and its fineness. The rate of cement hydration in the acceleration period increases with the increase of mineral powder and its fineness. This phenomena was observed by many authors in the case of limestone and quartz powder [28, 32, 35], as well as slag and fly ash [32].

Results referred to the influence of basalt powder on cement hydration rate presented in this study do not confirm the above observations. The addition of basalt powder results in a delay of the cement hydration. The increase in the fineness of basalt powder only slightly influenced the hydration kinetics. Laiboa et. al. [11] came to the same conclusions and pointed out the retardation effect of basalt powder on cement hydration. The partial replacement of cement by inert particles leads to dilution of cement and the increase of water-cement ratio as a consequence. In the dormant period, the increase of water reduces the calcium concentration in the pore solution. Therefore, it prolongs the dormant period by increasing the time when the supersaturated state can be reached [11].

A small additional peak is visible on the calorimetric curve of cement with basalt powder during the deceleration period. It corresponds to the second dissolution of aluminat C_3A . The reaction of C_3A is controlled by the sulfate content. The partial replacement of cement by basalt powder leads to the dilution of cement, and to the lower concentration of sulfate in the solution compared to plain cement. Therefore, the second reaction of aluminat appears earlier and it is much more marked in the blended system than in plain cement.

4.2 Strength properties

Fig. 7 shows the variation of 7, 28, 90 and 180-days compressive strength of cement mortars with respect to replacement of basalt powder. It is shown that the addition of basalt powder as a cement substitution causes the constant decrease of the compressive strength of mortar in all curing time. The most visible decrease is observed in the case of mortar with 20% replacement of cement by basalt powder, i.e. 33% at the age 28 days.

Basalt powder only acts like inert mineral admixtures reducing the strength. The main reason of decreasing strength is cement dilution. Cement content decreases with the increasing amount of basalt powder. It leads to gradual increase of water-cement ratio from value 0.5 in a case of the control mortar to 0.63 for mortar with 20% addition of basalt powder.

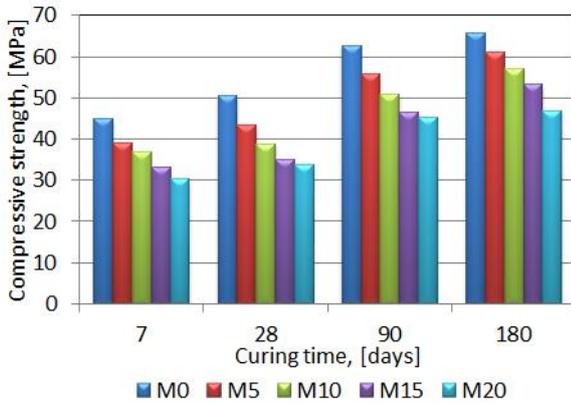


Fig. 7. Compressive strength of mortars with basalt powder addition.

Different effect is observed in the case of flexural strength (Fig. 8). In contrast to the compressive strength where the monotonic decrease in strength is observed in proportion to the reduction in the amount of cement, the changes in bending strength are small. The flexural strength after 28 days drops by 9%, 3%, 17% and 11% in the case of 5%, 10%, 15% and 20% basalt powder addition respectively. In later time, i.e. after 90 and 180 days, the flexural strength of the reference mortar and mortar with 5-15% basalt powder addition does not differ much. Only slight decrement is observed, while the flexural strength of mortar with 20% addition of basalt powder increases by 7% and 6% after 90 days and 180 days respectively.

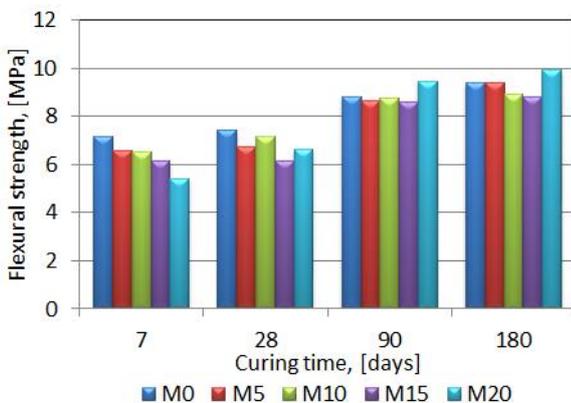


Fig. 8. Flexural strength of mortars with basalt powder addition.

Generally, the decrease in bending strength is much smaller than the reduction of cement content in mortars and in some cases even greater than the reference. The effect is probably related to the large irregularity and roughness of the surface of basalt grains which have the ability to mechanical wedging in the cement matrix.

During the progress of hydration, the amount of C-S-H phase increases tightly filling the space between irregular grains. This allows to transfer the stress effectively through the basalt-cement paste interface and the exploit of relatively high strength of basalt. After a longer period of hydration, the pores in the ITZ are filled up by C-S-H phase and, as a consequence, the probability of finding a critical defect decreases. The macroscopic manifestation of this effect is a much smaller decrease of bending strength than caused by the reduction of cement.

The influence of stone dust on mechanical parameters of cement composites depends mainly on the stone dust replacement and the specific surface area of this additive. The increase of specific surface area causes the improvement of the mechanical properties of cementitious composites [4, 14].

Fig. 9 presents the compressive strength of mortar with ground basalt powder determined by different time periods. When compared to the previous results, i.e. mortar with basalt powder of less specific surface area, the tendency is more or less the same. The increase of the amounts of basalt decreases the compressive strength.

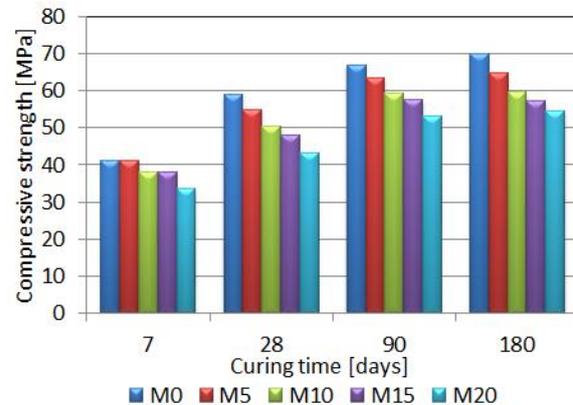


Fig. 9. Compressive strength of mortars with ground basalt powder addition.

The compressive strength of a mortar with the addition of ground basalt powder is higher as compared to a mortar prepared with basalt powder of lesser specific surface area. The influence of mechanical activation of basalt powder is particularly visible after 7, 28 and 90 days, while after 180 days only little influence of the specific surface area on the compressive strength is observed. The flexural strength as a function of the amount of ground basalt powder and time is shown in Fig. 10.

The decrease is observed after 7 days, while at a later point in time, i.e. after 28, 90 and 180 days, the flexural strength does not differ much when compared to the control mortar. An exception is a mortar with 10% addition of basalt powder when the flexural strength after 180 days increases of about 10% as compared to the control mortar.

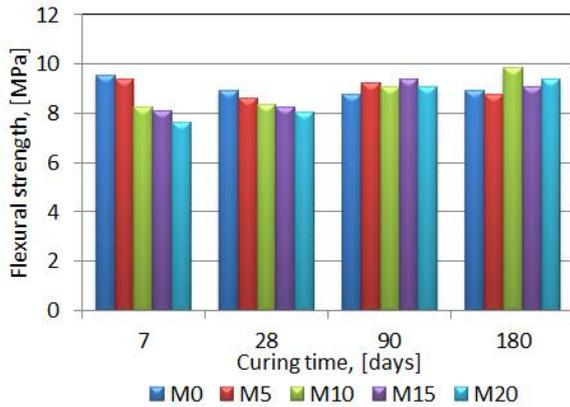


Fig. 10. Flexural strength of mortars with ground basalt powder addition.

Fig. 11 and Fig. 12 present the comparison of compressive and flexural strength as a function of basalt powder content of different specific surface area.

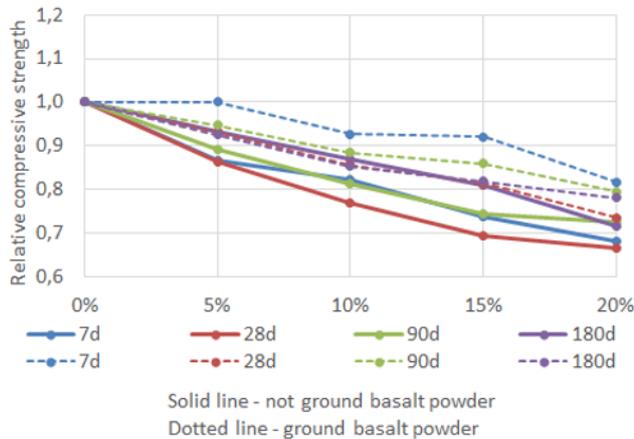


Fig. 11. Relative compressive strength of mortars with basalt powder addition.

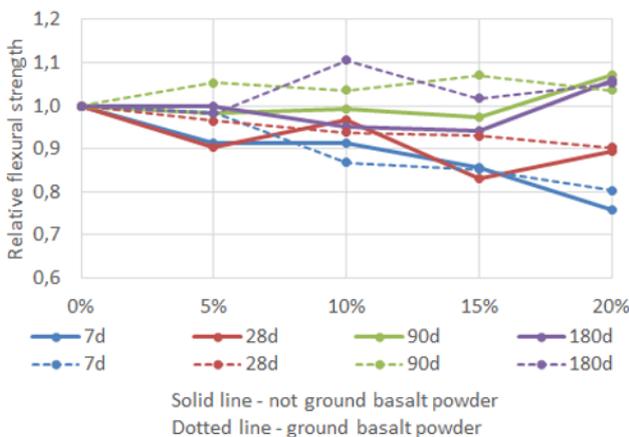


Fig. 12. Relative flexural strength of mortars with basalt powder addition.

The strength of mortar with ground basalt powder is higher as compared to these with addition of basalt powder of lesser specific surface area. This is due to physical nature of better packing. Mechanically

activated basalt powder is the finest material in all the mixtures. The addition of finer than cement basalt powder particles leads to a denser matrix and better dispersion of cement grains. Despite the lower cement content, the decrease of the compressive strength is not so visible as compared to the strength of a mortar with less fine basalt powder.

5 Conclusions

The following conclusions can be drawn from the work presented in this paper:

1. The addition of basalt powder results in a delay of the cement hydration. The dormant period in blended cement is slightly extended as compared to the pure cement paste. The main peak of heat evolution curve decreases with the increase of the amount of basalt powder.
2. The percentage decrease of cumulative heat is smaller than the reduction of cement content. It indicates a slight pozzolanic reaction of basalt powder and heteronucleation of C-S-H phase on basalt powder particles.
3. The second reaction of aluminate C_3A appears earlier and is much more visible in the blended system than in plain cement. It is related to the lower concentration of sulfate in the solution as compared to plain cement.
4. The addition of basalt powder as the replacement of cement affects the compressive strength of mortar negatively. It is mainly due to the dilution of cement. Basalt powder only acts like inert mineral admixtures reducing the compressive strength. Regarding the flexural strength, only a small difference can be observed as compared to the reference mortar. This is probably mainly due to the large irregularity and roughness of the basalt grains surface which have the ability to mechanical wedging in the cement matrix.
5. The increase in the fineness of basalt powder only slightly influences the hydration kinetics, as well as mechanical properties of mortar.

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