

# Investigating the Influence of Waste Basalt Powder on Selected Properties of Cement Paste and Mortar

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**Abstract.** Concrete is the most widely used man-made construction material in civil engineering applications. The consumption of cement and thus concrete, increases day by day along with the growth of urbanization and industrialization and due to new developments in construction technologies, population growing, increasing of living standard. Concrete production consumes much energy and large amounts of natural resources. It causes environmental, energy and economic losses. The most important material in concrete production is cement. Cement industry contributes to production of about 7% of all CO<sub>2</sub> generated in the world. Every ton of cement production releases nearly one ton of CO<sub>2</sub> to atmosphere. Thus the concrete and cement industry changes the environment appearance and influences it very much. Therefore, it has become very important for construction industry to focus on minimizing the environmental impact, reducing energy consumption and limiting CO<sub>2</sub> emission. The need to meet these challenges has spurred an interest in the development of a blended Portland cement in which the amount of clinker is reduced and partially replaced with mineral additives – supplementary cementitious materials (SCMs). Many researchers have studied the possibility of using another mineral powder in mortar and concrete production. The addition of marble dust, basalt powder, granite or limestone powder positively affects some properties of cement mortar and concrete. This paper presents an experimental study on the properties of cement paste and mortar containing basalt powder. The basalt powder is a waste emerged from the 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 also. The present study shows the results of the research concerning the modification of cement paste and mortar with basalt powder. The modification consists in that the powder waste was added as partial replacement of cement. Four types of common cement were examined, i.e. CEM I, CEM II/A-S, CEM II/A-V and CEM II/B-V. The percentages of basalt powder in this research are 0%, 1%, 2%, 3%, 4%, 6%, 8% and 10% by mass. Results showed that the addition of basalt powder improved the strength of cement mortar. The use of mineral powder as the partial substitution of cement allows the effective management of industrial waste and improves some properties of cement mortar.

## 1. Introduction

Concrete is one of the most important construction materials and it is widely used in many civil engineering applications. Concrete, thereby cement production consumes much energy and large



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amounts of natural resources. It causes environmental, energy and economic losses as it exploits 50% of raw material, 40% of total energy, as well as generates 50% of total waste [1, 2]. Cement industry contributes to production of about 7% of all CO<sub>2</sub> generated in the world [3]. Every ton of cement production releases nearly one ton of CO<sub>2</sub> to atmosphere [4]. Thus the concrete and cement industry changes the environment appearance and influences it very much. Therefore, it has become very important for construction industry to focus on minimizing the environmental impact, reducing energy consumption and limiting CO<sub>2</sub> emission. The need to meet these challenges has spurred an interest in the development of a blended Portland cement in which the amount of clinker is reduced and partially replaced with mineral additives – supplementary cementitious materials (SCMs). Supplementary cementitious materials are mainly by-products of industrial production, such as silica fume (SF), fly ash (FA), granulated blast furnace slag (GBFS), stone powders and others. As a SCMs can be also used natural minerals like zeolite [5]. The average amount of clinker in cement declined from 85% in 2003 to 77% in 2010, and it is expected to decrease further to 71% in the future. At the same time the use of SCM is increasing [6].

Concrete industry is one of the major consumers of natural resources. On the other hand, large quantities of fine material (dust) are generated as by-products of stone crushers in quarries and during processing rocks into aggregate used in concrete industry. This fine material can be emitted into the surrounding atmosphere. The handling and disposal of dust is a severe environmental problem since it is detrimental to environment: it contributes to a great extent to the accumulation and harmful dispersion in air, water and soil of fine solid particles [7]. Many researchers have studied the applicability of waste mineral powder in mortar and concrete production. The addition of marble dust [8, 9], basalt powder [10-15], limestone powder [14-17] or granite powder [17, 18] or positively affects the strength of cement mortar and concrete as well as durability of concrete.

Previous studies have shown that the use of waste powder as partial replacement for natural sand improves some properties of mortar and concrete, thus allows for the effective management of industrial waste. The present study shows the results of the research concerning the modification of cement paste and mortar with basalt powder. The modification consists in that the powder waste is added as partial replacement of cement. The physical properties and chemical compositions were firstly studied. Next, the normal consistency and setting time were tested for the cement paste with basalt powder addition. Finally, the compressive and flexural strength as well as shrinkage of cement mortar were analysed.

## **2. Experimental program**

### *2.1. Materials*

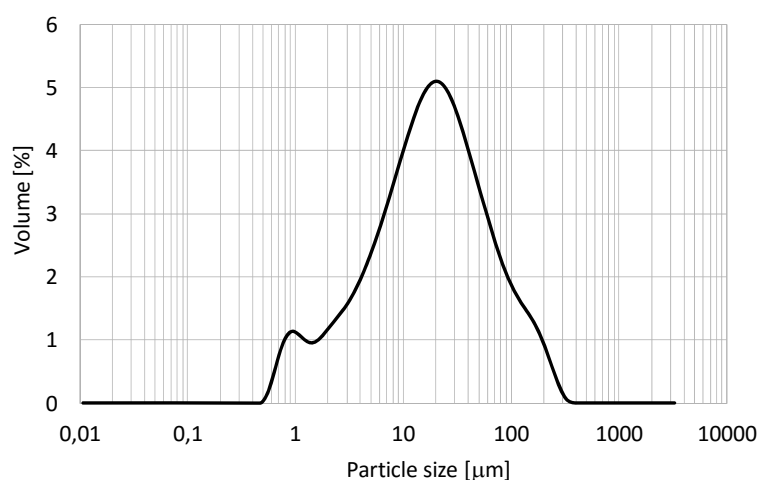
To investigate the potential of basalt powder as cement replacement, four types of common cement were used, i.e. ordinary Portland cement CEM I 42.5R; Portland-slag cement CEM II/A-S 42.5; Portland-fly ash cement CEM II/A-V 42.5R and Portland-fly ash cement CEM II/B-V of two strengths classes 32.R and 42.5R. All cements used in this study conform to the requirements of EN 197-1:2011 [19]. The standard quartz sand CEN was used in all mortar mixtures.

Waste basalt powder was obtained from Asphalt Batch Mix Plant. Asphalt mixture production leads to formation of significant amounts of by-product in the form of mineral powder. Mineral aggregate used in asphalt mixture production is dried at the temperature of about 200°C. An exhaust leaves the dryer with a particles of powder. Coarser fractions of powder are collected in a special separator but very fine fractions deposit 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 production of asphalt mixture. It can be estimated that about 25-30 thousand tons of waste powder has been produced per year in Kuyavian-Pomeranian Voivodeship in Poland. Mineral powder used in this study is the origin of basalt hence it is defined as a basalt powder. The chemical composition of powder basalt is presented in table 1. The grading curve of basalt powder is shown in figure 1. The

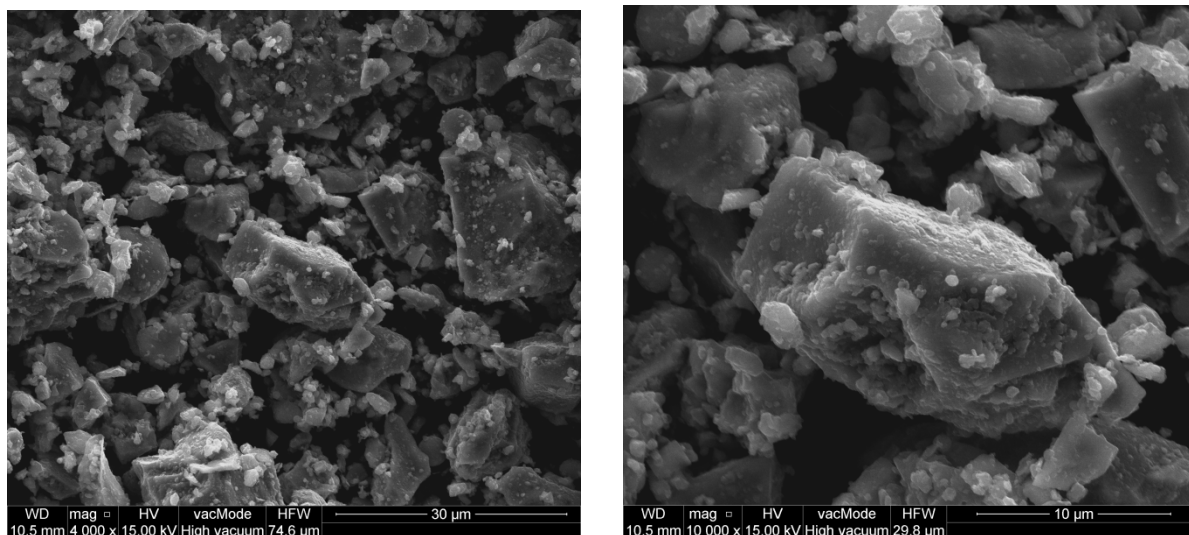
particle diameters are in the range of 1.5 to 200  $\mu\text{m}$ . The largest volume, ie. ca. 51%, are occupied by particles of about 19.89  $\mu\text{m}$  in diameter. The specific gravity of powder is 2.99  $\text{g}/\text{cm}^3$  and Blaine specific surface is 3500  $\text{cm}^2/\text{g}$ . Chemical composition is typical for basalt rock, ie. silica and alumina oxide dominate, which is in about 51% and calcium and iron oxide.

**Table 1.** Chemical composition of basalt powder BP

|    | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | CaO   | MgO  | SO <sub>3</sub> | K <sub>2</sub> O | Na <sub>2</sub> O | Cl <sup>-</sup> | P <sub>2</sub> O <sub>5</sub> | LOI  |
|----|------------------|--------------------------------|--------------------------------|-------|------|-----------------|------------------|-------------------|-----------------|-------------------------------|------|
|    |                  |                                |                                |       |      | [%]             |                  |                   |                 |                               |      |
| BP | 38.16            | 12.68                          | 15.88                          | 15.16 | 7.66 | 0.2             | 0.83             | 2.91              | 0.07            | 1.02                          | 4.16 |

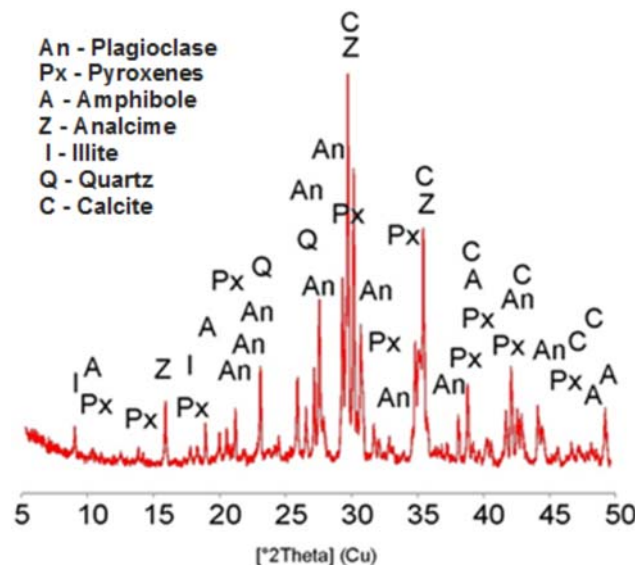


**Figure 1.** The grading curve of powder basalt



**Figure 2.** Scanning electron microscope image of basalt powder, mag. x4000 (left), x10000 (right)

The scanning electron microscope (SEM) image of the basalt powder and XRD diffractogram are presented in figure 2 and figure 3, respectively. Basalt powder particles have rough surface and angular shape. XRD spectrum indicates that in mineralogical composition, the plagioclase, pyroxene and amphibole dominate.



**Figure 3.** XRD diffractogram of the basalt powder

### 2.2. Mixture proportion and methods

The study is conducted on cement pastes and mortars made without and with basalt powder used as partial replacement of cement. P0 and M0 abbreviations were used to name reference paste and mortar respectively. The percentages of basalt powder are 1%, 2%, 3%, 4%, 6%, 8% and 10% mass of cement. Paste and mortar specimens containing basalt powder were named by using the abbreviations of P1-P10 and M1-M10 where the numbers indicate the percentage of replacements. All mortar mixtures were prepared in accordance with EN 196-1:2005 [20]. The water-binder ratio equals 0.5 was kept constant for all mortars.

Normal consistency test and determination of initial setting time (IST) and final setting time (FST) were conducted in accordance with EN 196-3:2011 [21]. The cement mortars were cast into 40x40x160 mm prisms steel molds and compacted through external vibration. The specimens were cured at 20°C and at 100% relative humidity. The EN 196-1:2005 [20] was employed to determine the compressive and flexural strength after 2 and 28 days of curing. Shrinkage was studied on specimens of 40x40x160 mm cured at 20°C and at relative humidity over 95%. The prisms were equipped with metallic bolts which allowed to measure the linear expansion using Graf-Kaufmann apparatus. Length change of mortar made from CEM I 42.5R were determined until 90 days of curing time.

### 3. Results and discussion

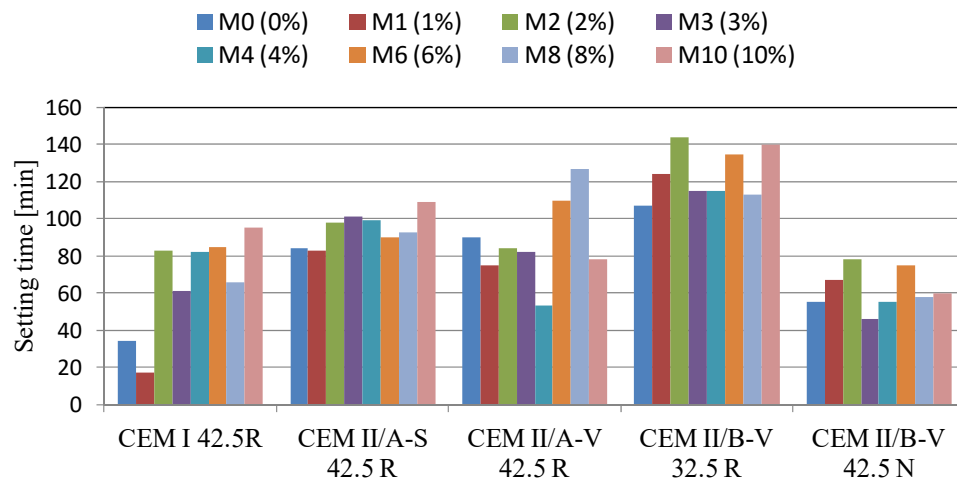
The replacement of cement by basalt powder does not affect the normal consistency of binder cement paste. The amounts of water required to obtain a cement paste of normal consistency were found as 29%, 27%, 27%, 28% and 30% for CEM I 42.5R, CEM II/A-S 42.5R, CEM II/A-V 42.5R, CEM II/B-V 32.5R and CEM II/B-V 42.5N respectively. The powder basalt has comparable specific surface to cement so the increase of powder content does not change the normal consistency.

Effects of basalt powder as the cement replacement on initial (IST) and final setting time (FST) of blended cement paste are presented in table 2. Figure 4 shows the changes in setting time of cement paste with different amount of basalt powder. As seen in table 2, the initial and final setting time were generally prolonged for cement pastes with addition of basalt powder with some exceptions. The initial setting time was shortened for CEM II/A-S 42.5R, CEM II/A-V 42.5R, CEM II/B-V 32.5R and CEM II/B-V 42.5N with replacement ratios of 3%, 6 and 8%, 1 and 2%, 1 and 2%, respectively. The

final setting time was shortened for CEM I 42.5R with 1% addition of basalt and for CEM II/A-V 42.5R with 1-6% addition of basalt powder. However, the initial setting time of all blended cement pastes comply with the limits prescribed by EN 197-1:2011 [19], i.e. over 75 minutes for 32.5 strength class and over 60 minutes for 42.5R and 42.5N strength class. Similar observation on the setting time of cement paste with basalt powder addition was demonstrated in former study presented by Laiboa et al. [10].

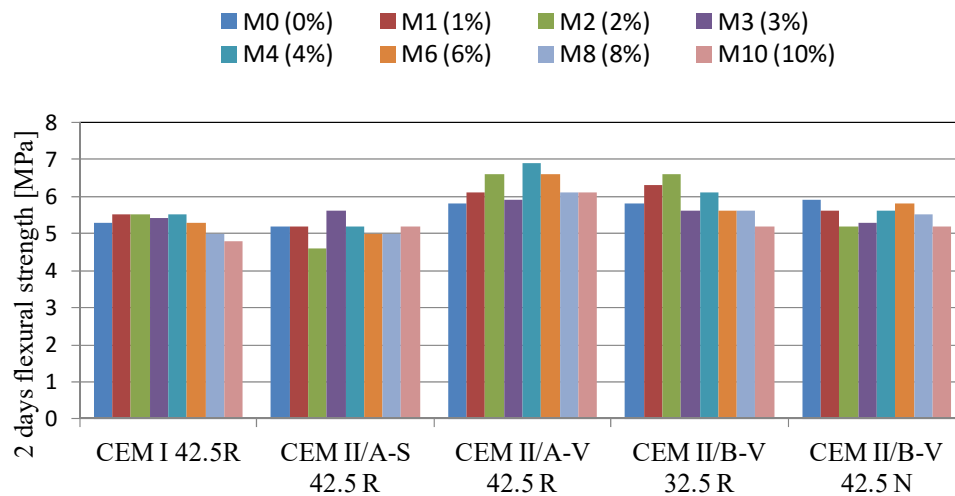
**Table 2.** Initial and final setting time of blended cement paste with powder basalt.

|                  | Paste | Setting time [min] |     |                  | Paste | Setting time [min] |     |                  | Paste | Setting time [min] |     |
|------------------|-------|--------------------|-----|------------------|-------|--------------------|-----|------------------|-------|--------------------|-----|
|                  |       | IST                | FST |                  |       | IST                | FST |                  |       | IST                | FST |
| CEM I 42.5R      | P0    | 140                | 174 | CEM II/A-V 42.5R | P0    | 221                | 311 | CEM II/B-V 42.5N | P0    | 191                | 246 |
|                  | P1    | 150                | 167 |                  | P1    | 230                | 305 |                  | P1    | 185                | 252 |
|                  | P2    | 142                | 225 |                  | P2    | 226                | 310 |                  | P2    | 180                | 258 |
|                  | P3    | 164                | 225 |                  | P3    | 226                | 308 |                  | P3    | 207                | 253 |
|                  | P4    | 146                | 228 |                  | P4    | 235                | 288 |                  | P4    | 205                | 260 |
|                  | P6    | 164                | 249 |                  | P6    | 192                | 302 |                  | P6    | 192                | 267 |
|                  | P8    | 166                | 232 |                  | P8    | 203                | 330 |                  | P8    | 207                | 265 |
|                  | P10   | 170                | 265 |                  | P10   | 246                | 324 |                  | P10   | 202                | 262 |
| CEM II/A-S 42.5R | P0    | 188                | 272 | CEM II/B-V 32.5R | P0    | 215                | 322 |                  |       |                    |     |
|                  | P1    | 193                | 276 |                  | P1    | 205                | 329 |                  |       |                    |     |
|                  | P2    | 190                | 288 |                  | P2    | 200                | 344 |                  |       |                    |     |
|                  | P3    | 186                | 287 |                  | P3    | 220                | 335 |                  |       |                    |     |
|                  | P4    | 190                | 289 |                  | P4    | 225                | 340 |                  |       |                    |     |
|                  | P6    | 201                | 291 |                  | P6    | 218                | 353 |                  |       |                    |     |
|                  | P8    | 203                | 296 |                  | P8    | 236                | 349 |                  |       |                    |     |
|                  | P10   | 202                | 311 |                  | P10   | 232                | 372 |                  |       |                    |     |



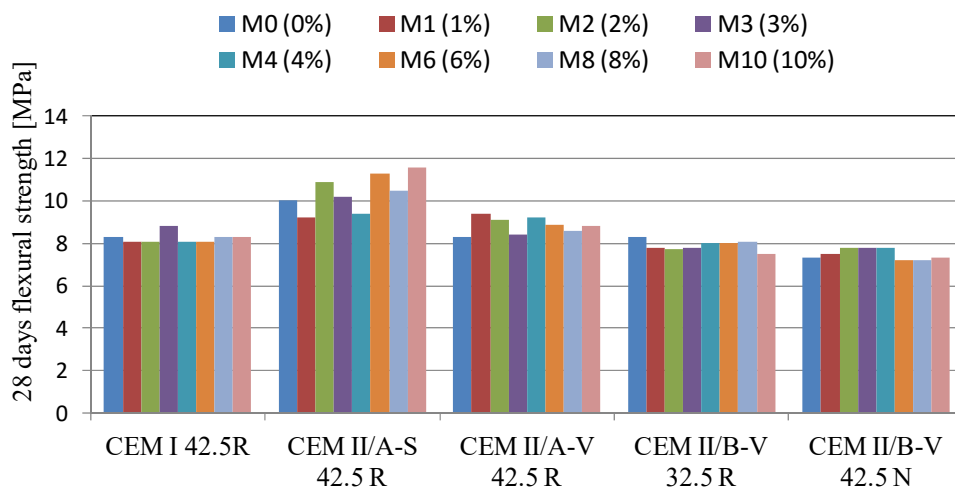
**Figure 4.** The setting time of cement paste with basalt powder.

The relationship between the early (2-days) and normal (28-days) flexural strength of mortar and the basalt powder content is presented in figure 5 and 6, respectively.



**Figure 5.** The early flexural strength of mortar at 2 days with different basalt powder content.

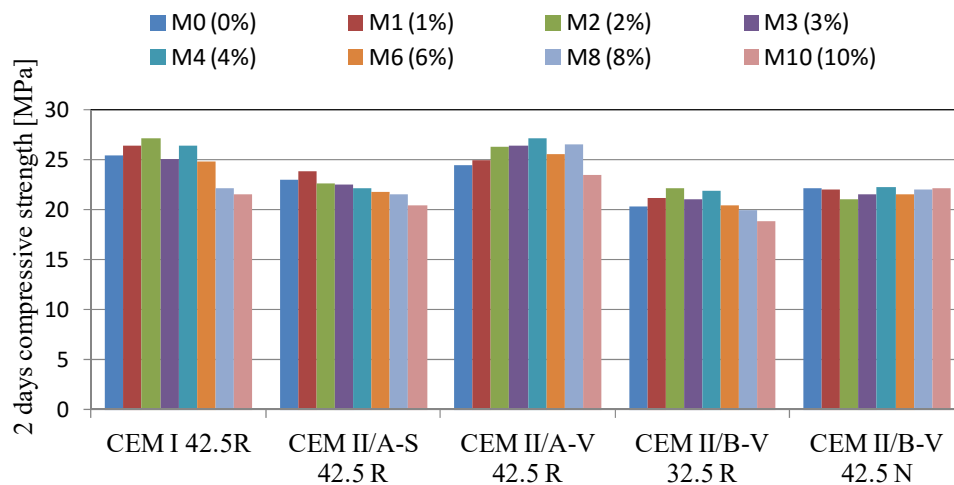
It can be seen that the addition of powder basalt as a replacement of cement affects flexural strength. The result indicates that the more powder basalt was added to mortar made from CEM II/A-V 42.5R, the higher flexural strength was observed in all curing time in comparison to control mortar. The highest increase in early flexural strength, i.e. 19% was attained for 4% addition of basalt powder to CEM I 42.5R. The highest increase in 28-days flexural strength, i.e. 18% was attained for 1% addition of basalt powder to CEM II/A-V 42.5R. The addition of powder basalt as replacement of cement leads also to decrease of flexural strength in some cases. The maximum decrease of early flexural strength, at about 12% was observed in the case of mortar made from CEM II/B-V 32.5R and CEM II/B-V 42.5 N with 10% addition of basalt powder. The decrease of normal flexural strength was lower than 2%.



**Figure 6.** The normal flexural strength of mortar at 28 days with different basalt powder content.

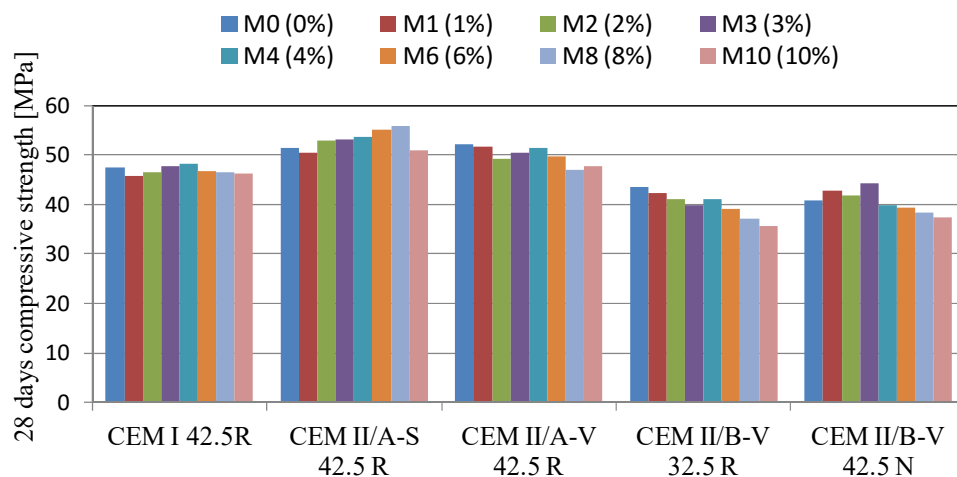
The variation of 2-days and 28-days compressive strength of cement mortar with respect to replacement of basalt powder is presented in figure 7 and 8.





**Figure 7.** The early compressive strength of mortar at 2 days with different basalt powder content.

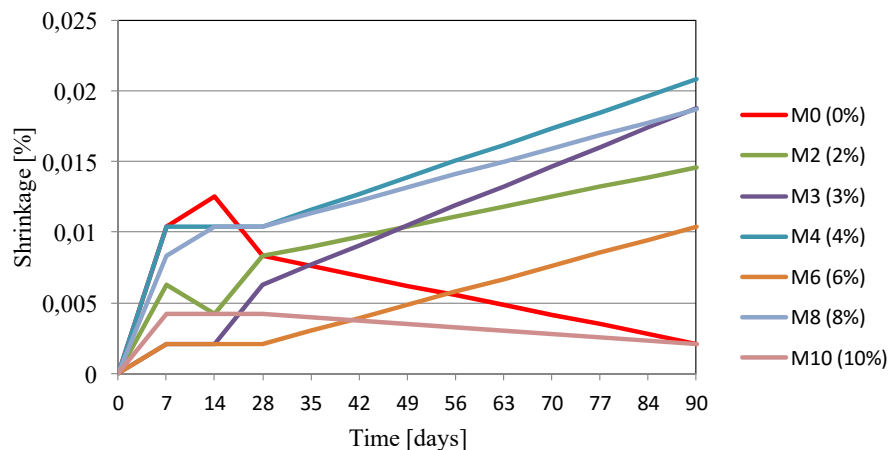
It was observed an increase of early and normal compressive strength of mortar made from CEM II/A-V 42.5R and CEM II/A-S 42.5R respectively with the addition of basalt powder up to 8%. The highest increment of early compressive strength at about 11% was observed in the case of mortar made from CEM II/A-V 42.5R with 4% content of basalt powder. However, in some cases it was observed detrimental effect of basalt powder on compressive strength. Mortar made from CEM II/B-V 32.5 R with 10% addition of basalt attained the highest decrease in normal compressive strength i.e., 18%. The loss of early compressive strength, by about 15 %, was observed in the case of CEM I 42.5R with 10% cement replacement by basalt powder.



**Figure 8.** The normal compressive strength of mortar at 28 days with different basalt powder content

The addition of powder basalt positively affects the flexural and compressive strength of cement mortar. The strength of almost all examined mortars made with addition of basalt powder is higher or is closely to the control mortar made without basalt. This phenomenon may be attributed to the nucleation effect of the basalt particles in the early hydration, which affects the early strength and pozzolanic activity of the basalt [10, 11, 22]. It is worth noticing that compressive strength of all mortars, with exception of CEM II/B-V 42.5N, conforms to the requirements specified in the EN 197:

2011 [19]. Value of early compressive strength is higher than 10 MPa and 20 MPa for mortar of strength class 32.5N and 42.5R respectively. The normal 28-days compressive strength of mortars of strength class 32.5N and 42.5R is between 32.5-52.5 MPa and 42.5-62.5 MPa respectively. The control mortar M0 (without basalt powder) made from cement CEM II/B-V 42.5N does not conform standard requirements since its compressive strength is 40.8 MPa. The requirements have been met after replacement of cement by basalt powder on a level till 3% and then compressive strength reached a value of 44.3 MPa.



**Figure 9.** Shrinkage cement mortar with addition of basalt powder.

The replacement of cement by basalt powder leads to increase of effective water-cement ratio from the value 0.5 for control mortar to 0.56 for mortar with 10% addition of basalt powder. It has been supposed to be a possible cause for greater drying shrinkage due to increased water demand. This is reflected by the test results which are presented in figure 9. After 14 days of curing shrinkage strain of all mortars with addition of basalt powder was lower than control mortar. But with the passing time the shrinkage of all mortars with basalt exceeds that of control mortar.

#### 4. Conclusions

Growing demand for natural resources used for building materials production led to intensification of research concerning the possibility of using by-products. The review of the literature shows that waste stone powder i.e., marble, limestone, granite and basalt powder can be used as a replacement of cement in mortar and concrete production. In this research, partial replacement of basalt powder to CEM I, CEM II/A-S, CEM II/A-V and CEM II/B-V types of cement were studied as experimentally. Experiments were applied to basalt powder blended cement both in the form of paste and mortar. According to the findings obtained experimentally, the following conclusions can be drawn written;

- 1) The addition of basalt powder to a cement paste does not affect a water demand to obtain a normal consistency. Both, basalt and cement particles have similar finesses so replacement of cement by basalt powder does not make a significant impact on specific surface area of the grains. It is a main reason that normal consistency has not changed with the increase of the basalt powder content.
- 2) Basalt powder has retardation effect on the hydration process of cement paste. The initial and final setting time were prolonged with the increase of the basalt content. The replacement of cement by basalt powder leads to dilution effect on cement in blended pastes and the reduction of tricalcium silicate  $C_3S$  which gives the hardening at early age of cement paste [23].



- 3) Replacement of cement by basalt powder positively affects the mechanical properties of cement mortars i.e., flexural and compressive strength at 2 and 28 days of curing time. The addition up to 8% of basalt powder leads to increase of both, flexural and compressive strength. The review of the literature shows that the effect of basalt powder on the properties of cementitious materials is physical as well as chemical, ie. basalt has potential pozzolanic activity [10, 11].
- 4) The increase in basalt powder content leads to increase of shrinkage of mortar. Until 14 days the shrinkage of mortars with addition of basalt powder was lower than shrinkage of control mortar. As curing time progressed from 14 days to 90 days, the results changed inversely. At 90 days of curing the shrinkage of mortars with basalt was found higher than that of control mortar. Greater shrinkage can be attributed to increase of water-cement ratio of mortar with basalt powder content.
- 5) All pastes and mortars made with powder basalt addition conform to the requirements of EN 197-1:2011 [19].

Incorporation of waste basalt powder into cement mortar as a partial substitution of cement is environmentally friendly and economically feasible. It enables for the effective management of industrial waste and improves some properties of cementitious mortar.

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