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# Comparison of the strength development of binary and ternary cements containing perlite powder

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**Abstract**
Currently, the consumption of blended cements is increasing all over the world. This is due to environmental, technical and economic reasons. Among the additives mixed with ordinary Portland cement, ground granulated blast furnace slag and fly ash are of particular significance. However, some regions may lack standard additives, and vice versa, may be rich in natural pozzolans. This paper is focused on the perlite as a natural pozzolanic material which is locally available. This study presents the results of the application of perlite as a component of blended cements in different proportions, representing binary and ternary compositions, and compares it with standard additives (fly ash and ground granulated blast furnace slag). The time development of both compressive and flexural strength, including results of 2, 7, 28 and 90-day testing, is analyzed. Perlite binders show acceptable time development of strengths, which is comparable to conventional blended binders based on ground granulated blast furnace slag and fly ash and do not constitute a technological barrier. With a higher dose of perlite, the time increase in flexural strength is slower, but the rate of increase in compressive strength does not change substantially. Flexural strength of 4.1–6.2 MPa and compressive strength of 18.8–38.5 MPa are sufficient for a number of practical applications and are expected to meet the required limits. An improvement of strengths in the later period (90 days) was also confirmed.

**Key words:** blended cements, perlite, blast furnace slag, fly ash, flexural strength, compressive strength

## 1 Introduction

Cement can currently be considered the most widely used binder in the construction sector. Several kinds of cement, as for the composition, are standardly used. The basic level is represented by Ordinary Portland Cement (OPC), and then different additives are considered to substitute the part of it, creating various blended cements. The standard range of such additives and compositions is given in STN EN 197-1 [1]. However, only a few types of all the defined options of cement compositions are commonly manufactured and used, like cements with blast furnace slag (CEM II/A-S or B-S, CEM III).
Currently, the consumption of blended cements is increasing all over the world. This is due to

three basic aspects [2, 3, 4]:

- energy saving and air quality: The cement industry contributes significantly to the imbalances of the environment; in particular, due to air quality and energy use. Partial substitution of cement clinker by other materials can help with this issue.
- conservation of natural resources: in case the used mineral additives are the waste products. By using these products, natural minerals like lime stone, clay and silica are saved.
- quality of cement-based products, like concrete: improvement of workability, mechanical properties and durability due to fineness and chemical actions.

Among the additives, ground granulated blast furnace slag (GGBFS) and fly ash (FA) are of particular significance throughout the world [2, 5].

**Fly ash** used in the production of cement and concrete is an inorganic product produced by the combustion of solid, usually finely ground, fuels in coal-fired power plants. Due to its fine particle size and generally non-crystalline character, fly ash usually has satisfactory pozzolanic properties or, in the case of a high lime content, both pozzolanic and latent hydraulic properties [6]. Oxide analysis is traditionally used to describe chemical composition in fly ash. The chemical composition can vary considerably, e.g. its mineralogical composition depending on the type and quantity of impurities present in the coal, method of combustion and method of collection. Fly ash obtained from anthracite is rich in silica ($SiO_2$), alumina ($Al_2O_3$) and iron oxide ($Fe_2O_3$). The mineralogical parameters of the fly ash are of decisive impact on pozzolanic reaction, microstructure and nature of the hydrated products [6].

**Ground granulated blast furnace slag** is a by-product of the production of iron in a blast furnace. In terms of use in cement and concrete, the most important parameter is the glass-phase content. In almost completely glassy form, obtained by rapid cooling, GGBFS reaches a latent hydraulic and pozzolanic properties [6].

The effects of both FA and GGBFS on cement-based mixtures can generally be listed as follows [7-11]:

- on fresh mixtures: reduction of segregation and bleeding, better workability,
- on heat of hydration: additives reduce the heat of hydration in concrete. A substitution of 30 per cent fly ash may result in a reduction of 50-60% heat of hydration. This helps reduce the risk of thermal cracking,
- on setting time: setting time is typically longer; a 30 per cent substitution of fly ash may result in an increase of initial setting time up to 2 hours,
- on strength: since the pozzolanic action is slow, the early strengths at 7 and 28 days are lower, but may be about equal at 3 months and may further increase at ages greater than 3 months provided curing is continued,
- on durability: on addition of fly ash or GGBFS to cement, concrete is less permeable and chemically more stable than concrete from OPC. 28 days old concrete may be three times as permeable as ordinary concrete. It provides high resistance to attack by sulphates, chlorides and other chemicals thus durability is improved. High resistance to chloride ingress also reduces the risk of reinforcement corrosion.

However, some regions may lack standard additives, such as GGBFS due to high demand and consequent difficulties in securing supplies, or FA due to a lack of one that meets standard limits for concrete production. And vice versa, some regions or countries may be rich in natural pozzolans but do not generate substantial amounts of artificial pozzolans [12].

Therefore, other types of additives are increasingly being tested, like lime, perlite, artificial pozzolans (glass powder, brick powder…) and others [13 - 18].

**Perlite** (P) is amorphous volcanic glass, which has a relatively high-water content, usually formed by the hydration of obsidian. It occurs naturally and has the unusual property of expanding significantly when heated sufficiently. A typical perlite sample consists of 71% to 75% silicon dioxide, 12.5% to 18.0% alumina, 4% to 5% potassium oxide, 1% to 4% of sodium and calcium oxides and trace amounts of metal oxides [19]. Partial replacement of cement with perlite powder (PP) significantly reduces the initial strength of cement mortars during the first 7-28 days compared to CEM I samples. The optimal rate of cement substitution by perlite is declared in the values of 10% and 20%. This reduces sorptivity and porosity and also increases strength over time, due to the pozzolanic activity of perlite, which is slow at an early age and develops over time [20]. PP as a natural pozzolan is considered to be beneficial due to its low price and availability (depending on the region), as well as its ability to reduce the hydration heat and control the shrinkage of concrete mixtures. Nevertheless, its influence on the properties of concrete, including the reactivity (specifically in the early ages), strength, durability and so on, is still a concern [21]. There is also little information on how perlite interacts with other additives. With the trend of higher amounts of additives present in blended cements, different combinations need to be tested and optimized to achieve satisfactory performance.

This study presents the results of the application of perlite as a component of blended cements in different proportions, representing binary and ternary compositions, and compares it with standard additives (FA and GGBFS). The time development of both compressive and flexural strength, including results of 2, 7, 28 and 90-day testing, is analyzed. Testing was performed according to STN EN 196-1 [22].

## 2 Materials and methods

To verify the effect of perlite on the strength development of blended binders, binder mixtures were designed in different compositions, including the reference one with no any additive. Perlite (P) was applied as a component of OPC (CEM I) in three different percentage proportions:

- CEM/P = 70/30; the binder represents the CEM II/B-P type of cement according to STN EN 197-1 [1],
- CEM/P = 50/50; the binder represents the CEM IV/B type of cement according to STN EN 197-1,
- CEM/P/Ad = 70/15/15; the binder is of ternary composition and it represents the CEM II/B-M type of cement according to STN EN 197-1.

To compare the effect of perlite, two standard additives, FA and GGBFS, were used in such compositions, too. Ten compositions were tested in this way, including a reference sample – see table 1.

Table 1: Composition of blended binders

| Samples | Components [%] | | | |
|---|---|---|---|---|
| | CEM I 42.5 R | Perlite (P) | Slag (S) | Fly ash (F) |
| **REF** | 100 | - | - | - |
| **C70P30** | 70 | 30 | - | - |
| **C70S30** | 70 | - | 30 | - |
| **C70F30** | 70 | - | - | 30 |
| **C50P50** | 50 | 50 | - | - |
| **C50S50** | 50 | - | 50 | - |
| **C50F50** | 50 | - | - | 50 |
| **C70/P15/S15** | 70 | 15 | 15 | - |
| **C70/S15/F15** | 70 | - | 15 | 15 |
| **C70/P15/F15** | 70 | 15 | - | 15 |

For testing the properties, standard mortars according to STN EN 196-1 [22] were prepared using following materials:

- Sand (S): CEN Standard sand according to STN EN 196-1 [22],
- Cement (C): CEM I 42,5 R (CRH Turňa nad Bodvou, Slovakia),
- Mixing water (W): tap water,
- Mineral additives (Ad):
  - Ground granulated blast furnace slag (S): US Steel Košice, Slovakia,
  - Fly ash (F): energy segment of steel making factory, US Steel Košice, Slovakia,
  - Perlite (P): natural, finely ground perlite, Lehôtka pod Brehmi, Slovakia.

The powdery materials are characterised in table 2, including the presence of main oxides and grain size characteristics.

Table 2: Properties of cement, perlite, slag and fly ash

| | **$SiO_2$** | **$Al_2O_3$** | **$Fe_2O_3$** | **CaO** | **Others** | **d (0.5)** | **d (0.9)** |
|---|---|---|---|---|---|---|---|
| | | | **(%)** | | | | |
| CEM I 42.5 R | 20.3 | 4.0 | 3.0 | 64.1 | 8.6 | 26.7 | 67.9 |
| P | 53.9 | 9.3 | 1.3 | 1.3 | 34.2 | 33.7 | 78.0 |
| S | 41.3 | 6.3 | 0.4 | 36.0 | 16.0 | 19.0 | 111.5 |
| F | 56.4 | 19.9 | 7.3 | 4.4 | 12.0 | 19.1 | 94.8 |

Binders were prepared according to the proposed percentage composition by dry mixing. Furthermore, mixtures of standard composition (450 ± 2 g of binder, 1 350 ± 5 g of CEN standard sand and 225 ± 1 g of water) were prepared in accordance with STN EN 196-1 [20]. In the fresh state, differences in consistency were visually detected (with the presence of perlite powder and at higher amounts, the mixtures tended to be stiffer); however, for all mixtures, the

principle of a constant w/b ratio was kept to maintain the prescribed composition for testing the strength of binders. Following the moulding of the samples (40x40x160 mm), and after the appropriate curing time, the samples were tested for both flexural and compressive strength.

# 3 Results and discussion

To declare the flexural and compressive strength development of binders, results of 2, 7, 28 and 90-day values are given in tables 3 and 5. Results are next evaluated and discussed in two ways:

- as a percentage of the values of the reference sample, and
- as a percentage of 90-days values.

Data are given in tables 4 and 6.

## 3.1 Flexural strength

Table 3: Results of flexural strength of blended binders

| | **$R_f$ [MPa]** | | | |
|---|---|---|---|---|
| | 2 days | 7 days | 28 days | 90 days |
| **REF sample** | 4.4 | 4.7 | 7.0 | 7.8 |
| **C70 P30** | 3.6 | 4.8 | 5.3 | 5.9 |
| **C70 S30** | 3.9 | 5.6 | 7.2 | 8.1 |
| **C70 F30** | 3.6 | 4.9 | 5.9 | 6.7 |
| **C50 P50** | 2.4 | 3.5 | 4.1 | 5.3 |
| **C50 S50** | 2.7 | 5.1 | 5.7 | 9.1 |
| **C50 F50** | 2.8 | 4.2 | 5.0 | 5.7 |
| **C70 P15 S15** | 3.8 | 5.4 | 5.9 | 6.8 |
| **C70 S15 F15** | 4.3 | 5.9 | 6.8 | 7.0 |
| **C70 P15 F15** | 3.6 | 5.2 | 6.2 | 6.2 |

Table 4: Expression of flexural strength as a percentage of the values of the reference sample and the values of 90 days, respectively

| | **2 days** | | **7 days** | | **28 days** | | **90 days** | |
|---|---|---|---|---|---|---|---|---|
| | share of REF value | share of 90- day value | share of REF value | share of 90- day value | share of REF value | share of 90- day value | share of REF value | share of 90- day value |
| | | | | **%** | | | | |
| **REF sample** | 100 | 56 | 100 | 60 | 100 | 90 | 100 | 100 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **C70 P30** | 82 | 61 | 102 | 81 | 76 | 90 | 76 | 100 |
| **C70 S30** | 89 | 48 | 119 | 69 | 103 | 89 | 104 | 100 |
| **C70 F30** | 82 | 54 | 104 | 73 | 84 | 88 | 86 | 100 |
| **C50 P50** | 55 | 45 | 74 | 66 | 59 | 77 | 68 | 100 |
| **C50 S50** | 61 | 30 | 109 | 56 | 81 | 63 | 117 | 100 |
| **C50 F50** | 64 | 49 | 89 | 74 | 71 | 88 | 73 | 100 |
| **C70 P15 S15** | 86 | 56 | 115 | 79 | 84 | 87 | 87 | 100 |
| **C70 S15 F15** | 98 | 61 | 126 | 84 | 97 | 97 | 90 | 100 |
| **C70 P15 F15** | 82 | 58 | 111 | 84 | 89 | 100 | 79 | 100 |

The reference sample has the highest flexural strength after 2 days (4.4 MPa), but over time some of the blended binders acquire better strengths. After 90 days, C50S50 achieved the highest strength (9.1 MPa).

*Comparison of time development of flexural strength:*

- all samples show an increase over time, but to varying degrees,
- the fastest increase is in samples C70P30, C70S15F15 and C70P15F15, which in 2 days reach 61%, 61% and 58% of their 90-day strength, and in 7 days they reach 81%, 84% and 84% of 90-day strength,
- the slowest increase is in C50S50 and C50P50, which in 2 days have only 30% and 45% of their 90-day strength, and in 28-days only 63% and 77% of 90-day strength.

*Comparison with the reference sample:*

- at 2 days of setting, the blended cement samples reach from 55% (C50P50) to 98% (C70S15F15) of the value of the reference sample. In later times, some of the blended cements even exceed the value of the reference sample; e.g. after 7 days of setting and hardening, this is the case for all samples except C50P50 and C50F50,
- after 90 days of hardening, the samples of blended cements reach from 73% (C50F50) up to 104% (C70S30), and 117% (C50S50) of the value of the reference sample.

*Evaluation of perlite samples:*

- standard 28-day values of flexural strength of blended binders with perlite are in the range of 4.1 - 6.2 MPa, the best value being in combination with fly ash (C70P15F15),
- with a higher dose of perlite, the increase in flexural strength is slower; at 28 days, C70P30 has 90% of its 90-day strength, but C50P50 has only 59% of its 90-day strength. In combination with slag (C70P15S15) the value is at the level of 30% perlite, but in combination with fly ash (C70P15F15) the hardening is accelerated and the 28-day strength reaches the level of 90-day strength.
- perlite samples achieve lower strength than that of the reference sample; after 90 days of curing, the closest value to the reference sample is 87% (C70P15S15),
- perlite achieves the best results in combination with slag or fly ash.

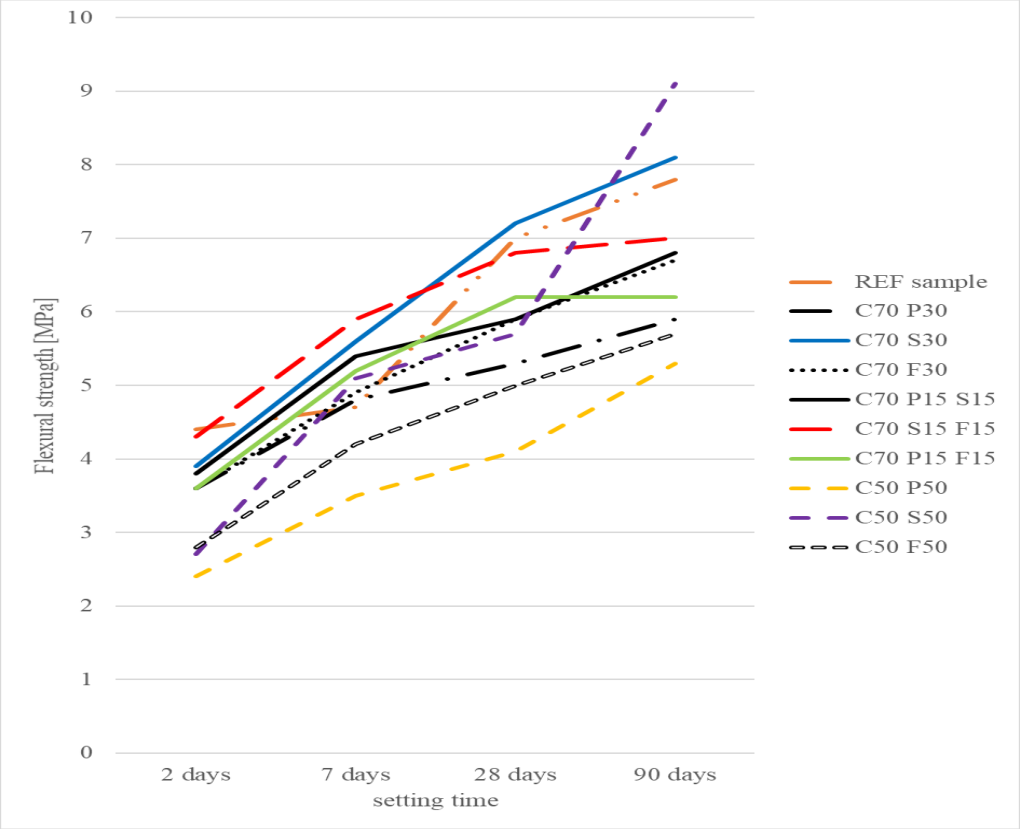



Figure 1: Development of flexural strength of blended binders

## 3.2 Compressive strength

Table 5: Results of compressive strength of blended binders

| | $R_c$ [MPa] | | | |
|---|---|---|---|---|
| | 2 days | 7 days | 28 days | 90 days |
| **REF sample** | 26.3 | 46.0 | 54.5 | 55.4 |
| **C70 P30** | 16.1 | 24.4 | 31.0 | 35.3 |
| **C70 S30** | 17.3 | 29.8 | 41.5 | 48.0 |
| **C70 F30** | 17.7 | 26.1 | 39.0 | 46.9 |
| **C50 P50** | 9.4 | 15.3 | 18.8 | 23.5 |
| **C50 S50** | 10.9 | 21.3 | 34.9 | 48.7 |
| **C50 F50** | 12.2 | 19.6 | 27.0 | 34.0 |
| **C70 P15 S15** | 16.8 | 29.2 | 38.0 | 42.9 |
| **C70 S15 F15** | 17.4 | 29.6 | 44.5 | 49.1 |
| **C70 P15 F15** | 16.5 | 25.3 | 38.5 | 41.4 |

Table 6: Expression of compressive strength as a percentage of the values of the reference sample and the values of 90 days, respectively

| | **2 days** | | **7 days** | | **28 days** | | **90 days** | |
|---|---|---|---|---|---|---|---|---|
| | share of REF value | share of 90- day value | share of REF value | share of 90- day value | share of REF value | share of 90- day value | share of REF value | share of 90- day value |
| | | | | **%** | | | | |
| **REF sample** | 100 | 47 | 100 | 83 | 100 | 98 | 100 | 100 |
| **C70 P30** | 61 | 46 | 53 | 69 | 57 | 88 | 64 | 100 |
| **C70 S30** | 66 | 36 | 65 | 62 | 76 | 86 | 87 | 100 |
| **C70 F30** | 67 | 38 | 57 | 56 | 72 | 83 | 85 | 100 |
| **C50 P50** | 36 | 40 | 33 | 65 | 34 | 80 | 42 | 100 |
| **C50 S50** | 41 | 22 | 46 | 44 | 64 | 72 | 88 | 100 |
| **C50 F50** | 46 | 36 | 43 | 58 | 50 | 79 | 61 | 100 |
| **C70 P15 S15** | 64 | 39 | 63 | 68 | 70 | 89 | 77 | 100 |
| **C70 S15 F15** | 66 | 35 | 64 | 60 | 82 | 91 | 89 | 100 |
| **C70 P15 F15** | 63 | 40 | 55 | 61 | 71 | 93 | 75 | 100 |

The reference sample has the highest compressive strength at all tested times (26.3 - 55.4 MPa). Of the blended binders, they are C70S30 and C70S15F15, which have values at the same level (17.3 - 48.0 MPa) and (17.4 - 49.1 MPa) respectively.

*Comparison of time development of compressive strength:*

- all samples show an increase over time, but to varying degrees,
- the reference sample has the fastest increase. In the case of blended binders, the sharpest increase is in C70P30, C50P50 and C70P15F15, which in 2 days reach 46%, 41% and 40% of their 90-day strength,
- the slowest increase is in C50S50, which in 2 days has only 22% of 90-day strength, and in 28 days only 72% of 90-day strength.

*Comparison with the reference sample:*

- at 2 days of setting, the blended cement samples reach from 36% (C50P50) to 67% (C70F30) of the reference sample value. It can be stated that all blended binders with combinations at the level of 30% of additives have in principle the same result,
- after 90 days of hardening, the samples of blended cements reach from 42% (C50P50) up to 89% (C70S15F15) and. 88 %% (C50S50) of the reference sample value.

*Evaluation of perlite samples:*

- standard 28-day values of compressive strength of blended binders with perlite are in the range of 18.8 - 38.5 MPa, with the best value in combination with fly ash (C70P15F15),
- with a higher dose of perlite, the increase in strength does not change substantially, even in combinations with slag and fly ash. The strength after 2 days of setting reaches the level of about 40% of 90-day strength, in 7 days about 67% and in 28 days about 90% of 90-day strength.

- perlite samples achieve lower strengths than the reference sample; after 90 days of curing, sample C70P15S15 was found to be closest to the reference sample by 77%,
- perlite achieves the best results in combination with slag or fly ash.

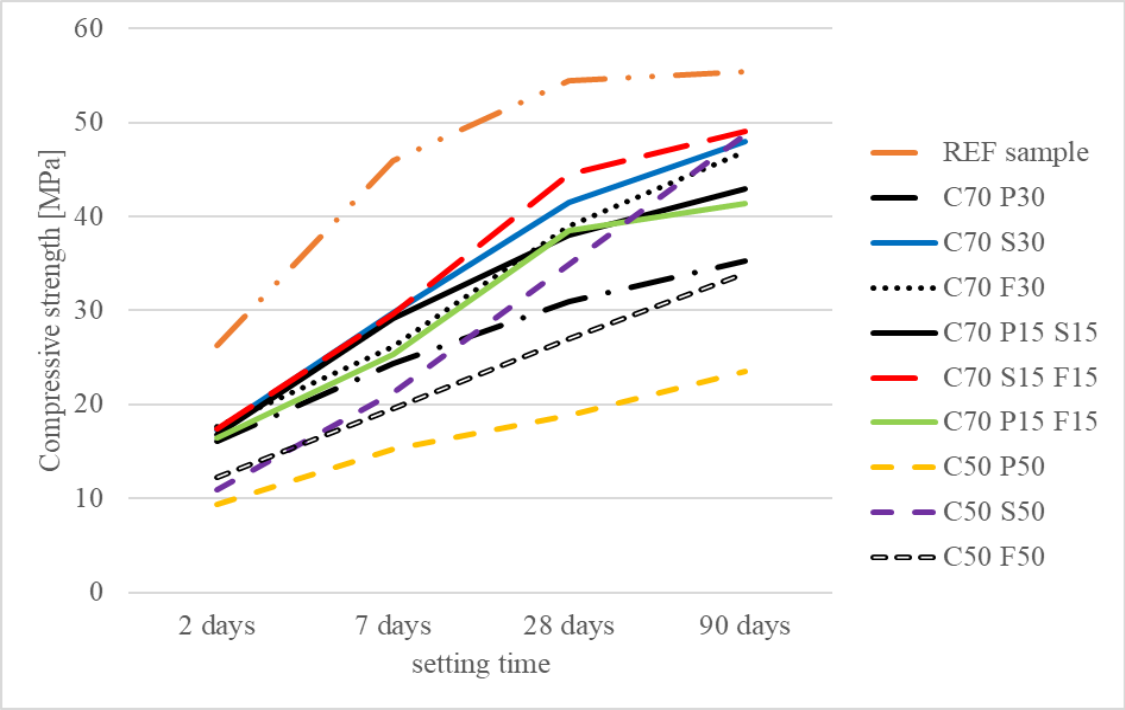



Figure 2: Development of compressive strength of blended binders

## 4 Conclusion

Perlite powder, a natural material with pozzolanic properties that is locally available, was the subject of the presented testing. The aim was to compare perlite performance with conventional additives (GGBFS and FA), while they were used in different compositions representing binary and ternary blended cements. Following percentage ratios of CEM I and additives (Ad) were tested: CEM I/Ad = 70/30, 50/50, and CEM I/Ad1/Ad2 = 70/15/15, while all possible combinations of three additives were applied. For testing the properties, standard mortars according to STN EN 196-1 were prepared. The time development of both the compressive and flexural strength, including results of 2, 7, 28 and 90-day testing, was evaluated. The following findings can be formulated:

- blended binders with different % of perlite, slag and fly ash show different rates of strength increase in the range of 90 days of setting and hardening,
- the fastest increases after 2 days of curing were found at the level of 61% and 58% of the 90-day flexural strength and at the level of 46% and 40% of 90-day compressive strength – this applies to samples C70P30 and C70P15F15,
- sample C50S50 has the slowest increases in strength: after 2 days of curing it was found at

the level of 30% of the 90-day flexural strength and at the level of 22% of the 90-day compressive strength; after 28 days at the level of 63% of the 90-day tensile strength and only 72% of the 90-day compressive strength,
- with a higher dose of perlite, the time increase in flexural strength is slower, but the rate of increase in compressive strength does not change substantially,
- perlite binders show acceptable time development of strengths, which is comparable to conventional blended binders based on GGBFS and FA and do not constitute a technological barrier,
- standard 28-day values of blended binders with perlite are in the range of 4.1 - 6.2 MPa (flexural strength), and 18.8 - 38.5 MPa (compressive strength), the best values being achieved in combination with fly ash (C70P15F15),
- perlite samples achieve lower strengths than the reference sample; after 90 days of hardening, the sample C70P15S15 is closest to the reference sample - it reached 87% of the reference flexural strength and 77% of reference compressive strength.
By comparing the results, it is generally possible to conclude that although perlite blended binders achieve lower strengths compared to conventional binders, they have a promising potential. Flexural strength of 4.1–6.2 MPa and compressive strength of 18.8–38.5 MPa are sufficient for a number of practical applications and are expected to meet the required limits. Also, their improvement in the later period (90 days) was confirmed.

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## References

[1] STN EN 197-1. (2012). Cement. Part 1 Composition, specifications and conformity criteria for common cements.

[2] Sivakumar A., Nair Nithya, Sounthararajan V.M. (2013). Hydration Characteristics of Pozzolanic Substitutes in Cementitious Binder. *World Applied Sciences Journal* 25.8, 1166-1170. ISSN 1818-4952.

[3] DEVI K. Syamala, LAKSHMI V. Vijaya, ALAKANANDANA A. (2017). Impacts of cement industry on environment-an overview. *Asia Pac. J. Res.* 1, 156-161.

[4] NACERI A., HAMINA M. Chikouche, GROSSEAU P. (2009). Physico-Chemical Characteristics of Cement Manufactured with Artificial Pozzolan (Waste Brick). *World Academy of Science, Engineering and Technology*. 52, 41-43.

[5] ZHAO Feng-Qing, et al. (2007). Activated fly ash/slag blended cement. *Resources, Conservation and recycling*. 52 (2), 303-313.

[6] TOKYAY Mustafa. (2016). *Cement and concrete mineral admixtures*. CRC Press.

[7] PAYA J., et al. (2000). Mechanical treatment of fly ashes: Part IV. Strength development of ground fly ash-cement mortars cured at different temperatures. *Cement and Concrete Research*. 30 (4), 543-551.

[8] CHOI Young Cheol, KIM Jiyoung, CHOI Seongcheol. (2017). Mercury intrusion porosimetry characterization of micropore structures of high-strength cement pastes incorporating high volume ground granulated blast-furnace slag. *Construction and Building Materials*. 137, 96-103.

[9] SURESH D., NAGARAJU K. (2015). Ground granulated blast slag (GGBS) in concrete–a review. *IOSR journal of mechanical and civil engineering*. 12(4), 76-82.

[10] PANDEY Rajesh Kr, KUMAR Abhishek, AFAQUE KHAN M. (2016). Effect of ground granulated blast furnace slag as partial cement replacement on strength and durability of concrete: a review. *Int Res J Eng Technol (IRJET)*. 3 (2), 1662-1666.

[11] KAGADGAR Sarfaraz Ahmed, SAHA Suman, RAJASEKARAN C. (2017). Mechanical and durability properties of fly ash based concrete exposed to marine environment. *Selected Scientific Papers-Journal of Civil Engineering*. 12 (1), 7-18.

[12] ERDOĞAN Sinan Turhan, SAĞLIK Aslı Ünsal. (2013). Early-age activation of cement pastes and mortars containing ground perlite as a pozzolan. *Cement and Concrete Composites*. 38, 29-39.

[13] BHEEL Naraindas, et al. (2019). Use of rice husk ash as cementitious material in concrete. *Engineering, Technology & Applied Science Research*. 9 (3), 4209-4212.

[14] BHEEL Naraindas. et al. (2019). Effect of Tile Powder Used as a Cementitious Material on the Mechanical Properties of Concrete. *Engineering, Technology & Applied Science Research*. 9.5, 4596-4599.

[15] ESFANDIARI J., LOGHMANI P. (2019). Effect of perlite powder and silica fume on the compressive strength and microstructural characterization of self-compacting concrete with lime-cement binder. *Measurement*. 147, 106846.

[16] KAREIN S., Mahmoud Motahari, et al. (2018). Effects of the mechanical milling method on transport properties of self-compacting concrete containing perlite powder as a supplementary cementitious material. *Construction and Building Materials*. 172, 677-684.

[17] FEDERICO L. M., CHIDIAC S. E. (2009). Waste glass as a supplementary cementitious material in concrete–critical review of treatment methods. *Cement and concrete composites*. 31 (8), 606-610.

[18] SOBOL Khrystyna, MARKIV Taras, HUNYAK Oleksii. (2017). Effect of mineral additives on structure and properties of concrete for pavements. *Selected Scientific Papers-Journal of Civil Engineering*. 12 (2), 95-100.

[19] SAMAR Mueena, SAXENA Shweta. (2016). Study of chemical and physical properties of perlite and its application in India. *Int J Sci Technol Manag*. 5, 70-80.

[20] GUENANOU Farida, KHELAFI Hamid, AATTACHE Amel. (2019). Behavior of perlite-based mortars on physicochemical characteristics, mechanical and carbonation: Case of perlite of Hammam Boughrara. *Journal of Building Engineering*. 24, 100734.

[21] KAREIN S. Mahmoud Motahari, et al. (2018). Effects of the mechanical milling method on transport properties of self-compacting concrete containing perlite powder as a supplementary cementitious material. *Construction and Building Materials*. 172, 677-684.

[22] STN EN 196-1. (2019). Methods of testing cement. Part 1 Determination of strength.