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Reuse of stone working enterprise slurry in geopolymer and concrete products

Volodymyr Shamrai [1*], Iryna Leonets [1], Viktoriia Melnyk-Shamrai [1], Iryna Patseva [1], Yaroslav Naumov [1]

[1] *Zhytomyr Polytechnic State University, Zhytomyr, Ukraine*
**Corresponding author: e-mail kgt_shvi@ztu.edu.ua*

Abstract

Purpose is to assess influence by fine stone working refuse (FSWR) on physicomechanical characteristics of geopolymer and concrete materials for future development of efficient methods of the FSWR reuse.

Methods. Geopolymer mixtures and concrete samples differing in FSWR proportions were applied for the research. Mechanical compression testing was performed with the samples, which helped assess influence by different number of FSWR on material strength. Totally, 16 polymer and 18 concrete samples were prepared.

Findings. The research has analyzed the possibility of FSWR application while manufacturing concrete and geopolymer materials to reuse industrial waste, and mitigate its environmental impact. The research is intended to identify FSWR effect on physicomechanical characteristics of materials, and develop techniques for their reuse. FSWR addition loses geopolymer strength: if content is 25% then strength is 20 MPa; if the content is 50% then strength drops down to 5.3 MPa. As for concrete, partial sand replacement by FSWR decreases strength insignificantly (from 37.42 to 36.6 MPa if FSWR content is 20%). Geopolymers with 25% of FSWR are suitable for low-load structures; in turn, concrete mixtures containing FSWR can be applied without significant strength decrease.

Originality. For the first time, optimal fine refuse concentration of strong natural stone from Zhytomyr Region has been identified. The concentration is up to 25%. It provides acceptable compression strength with no significant decrease in technical characteristics.

Practical implications are as follows. Compliance with optimal FSWR proportions in composition of geopolymer and concrete mixtures makes it possible to reduce cost of raw materials; decrease FSWR amount; and support the closed economy principles in the construction industry.

Keywords: *geopolymers, concrete, fine refuse, stone working, waste utilization, strength*

1. Introduction

1.1. The problem formulation

Under the current conditions of intensive industrial development and significant increase in construction activities, the problem of materials recovery becomes extremely topical. Environmental issues resulting from accumulation and insufficient utilization of industrial waste need both prompt and efficient solution. Reuse of stone working enterprises slurry often remained unutilized or put on the scrapheap is very important problem among such issues [1], [2]. The slurry resulting from natural stone dressing has a significant potential for processing and further use while manufacturing both concrete and geopolymer products [3]-[5]. Nevertheless, today the possibility is not generated adequate industrial interest depending upon numerous technical and economic factors.

Scientific research in the field is important from the viewpoint of several reasons. First, in view of the current environmental challenges being the global warming, atmospheric pollution, and reduction of natural resources study of new ways of industrial waste reuse becomes critically needed [5], [6]. Second, accumulation of such stone working waste as slurry within territories of enterprises may result in serious soil and water pollution involving severe soil and water pollution which needs heavy expenses to utilize the waste, and liquidate negative environmental impact [7], [8]. Moreover, the majority of countries including Ukraine face the necessity to develop and implement innovative procedures for the waste processing which will reduce environmental risks and create new possibilities for economic growth.

Zhytomyr Region located in the northern part of Ukraine, is among the most important industrial areas of the country. It especially concerns natural stone excavation and processing. The region is known by its rich deposits of magmatic rocks, being significant potential for mining industry. Extraction of the minerals provides raw materials for numerous enterprises engaged in stone dressing for furnishing and facing works, and manufacturing of various stone products for construction, architecture, and design. In general, there are 92 deposits on natural stone in Zhytomyr Region; its total

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reserves are almost 140 million cubic meters [9]. Owing to such rich resources, the region has become the key centre of stone mining and processing in Ukraine.

However, along with the active industrial activities, numerous environmental problems arise; namely, those ones connected with stone working industry refuse. As in the case of other processing industry branches, stone dressing is followed by generation of considerable waste amount, which becomes more and more serious problem for regional environment. According to some estimates, annual refuse amount generated by enterprises of Zhytomyr Region engaged in natural stone processing, may achieve up to 50 thousand cubic meters. The waste amount is almost equal to 150 thousand tons of fine stone working refuse (FSWR) accumulated annually by the Region areas [10].

Mostly, the waste is generated during stone cutting and its further processing. Studies show that stone mining and processing generate so-called stone slurry being almost 40% of initial amount of the material [11]. Hence, about half of the mined stone transforms into waste rather than the finished product. The situation is complicated by the fact that near 20% of the waste belongs to stone working enterprises delivering stone for furnishing and facing [11].

Nevertheless, despite the environmental problem, projects to utilize stone working refuse are developing actively in Zhytomyr Region. Researchers and entrepreneurs are trying to arrive to solution, which would help reduce waste amount and reuse it. One of the trends of such an activity is to apply fine stone working refuse while manufacturing construction materials (i.e. concrete, asphalt, ceramics, and other building mixtures). Moreover, developments are underway as for the waste use for land improvement or manufacturing of new products for construction industry.

In additions, research in the region is proceeded improving operating stone working procedures to decrease the amount of the generated waste. Use of innovative techniques for stone cutting and polishing may reduce the level of material loss at the processing stage, which will help lessen amount of slurry generated by stone working enterprises. Another promising trend is implementation of systems utilizing and recycling water applied in the processes of stone cutting and polishing. The abovementioned will make it possible to cut waste amount as well as improve environmental situation in the region.

In general, stone refuse may be divided into the two main categories: coarse waste (i.e. crushed stone and other large fragments) and FSWR. Coarse waste is a result of goods chipping and breakage due to fissuring or identification of defects at the surface of parts factoring into rejection of the whole blocks of natural stone. Owing to its dimensions, the waste type may be made additionally into crushed stone for construction. Moreover, if geometry of some natural stones allows, they can be applied to manufacture smaller in size products exceeding their economic merit. The situation is much more difficult in case of FSWR. Currently, there are no rational techniques to process the waste; hence, its majority accumulates within the territories of enterprises causing additional environmental problems.

The important factor making FSWR such a serious problem for Ukraine is its accumulation scale as well as imperfection of environmental standards in the country. The issue is especially acute in Zhytomyr Region where significant amount of FSWR is stockpiled right in large open pits within territories neighbouring producing units. The majority of such territories has no waterproof coating and is used for gravitational FSWR settling and water recirculation. The abovementioned may result in significant pollution of soil and aquifers as well as in other environmental problems being degradation of natural landscapes and negative impact on local ecosystems.

In addition to local environmental problems, it is important to pay attention to the nation-wide statistics. Other mineral wastes generated by mining industry are the key component forming refuse of I-IV classes of hazard in Ukraine. According to the data by the State Statistics Service, in 2023 the waste was about 150 million tons; it is 85% of all hazardous refuse generated in the country. Barren rock resulting from dredging works is another large source of industrial refuse of I-IV classes; together with mineral waste, they are 98% of rejected materials in the country [9].

On the other hand, results of research intended to utilize such waste have the potential for considerable influence on the construction industry growth. Use of fine stone working refuse as a component of concrete and geopolymer products reduces cost of raw materials and improves technical characteristics of the finished goods. Among other things, FSWR can improve strength of a material, its resistance to external influence, and better other physicomechanical characteristics [12], [13]. Use of the refuse may be profitable for construction enterprises since it helps optimize application of natural resources, and minimize dependence upon traditional types of raw materials.

In addition, mitigation of ecological burden on the environment is rather important factor. Use of FSWR to manufacture building materials both favours the decrease in the nation-wide construction waste amount accumulated within landfills and supports the closed economy principles [14]. Moreover, it may contribute to conservation of natural resources, and mitigation of negative environmental impact by construction industry. For example, implementation of methods making it possible to apply refuse as a substitute for traditional materials not only favours economic efficiency but also decreases carbon dioxide emissions. Additionally, recent advancements in energy-efficient technologies, such as the development of sodium silicate production methods, have shown promise in reducing environmental impacts associated with construction materials [15]-[17].

Consequently, the research concerning FSWR utilization in concrete and geopolymer products is extremely important from the viewpoint of ecology as well as in view of economic and industrial potential. Use of the refuse to manufacture building materials opens new opportunities for industrial application of the waste which will favour stable development of construction branch. FSWR-enriched geopolymer materials have the potential to be applied in a wide range of engineering structures including low loaded constructions; insulation materials; and landscape elements. Thus, it helps design new goods with high ecological value, and mitigate environmental impact by construction industry.

Finally, development of techniques and improvement of FSWR utilization processes will influence positively the economy of regions where stone working enterprises operate; Zhytomyr Region is among them. Use of waste for construction will help reduce cost of building materials; create new jobs; and support the circular economy. It may become an important step towards stable development of Ukrainian industries and economy. Hence, the research aimed at analysis of the processes is extremely topical for modern Ukraine.

1.2. Analysis of scientific sources and statement of the problem

Paper [18] demonstrates results of the analysis of granulometric FSWR composition influencing heavily physicomechanical characteristics of cement mixtures and concrete. Fine SWR fractions [19] may increase the need for water to moist binder and support consistency of cement materials since their specific surface is large. To provide the required working capacity of such mixtures, it was proposed to apply high doses of superplasticizers [20]. In this regard, the problem of economic expediency to use the mixtures has remained unsolved. To overcome the difficulties, one can perform partial replacement of cement by fine stone working refuse in concrete, and complete metakaolin replacement by FSWR in geopolymer mixtures.

In addition to granulometric FSWR composition influence on physicomechanical characteristics of cement, paper [21] considered FSWR form granitoid rocks and marble differing greatly in their mineralogical and chemical composition. Papers [19]-[21] have shown that FSWR from carbonate rocks of marble types is the most efficient to be applied. Use of FSWR from granitoid rocks is possible only in small amount (i.e. up to 10%) or in combination with marble FSWR. In this context, such mineral admixtures should contain about 70% of SiO_2. However, the papers did not consider the use of FSWR from gabroid rocks characterized by low SiO_2 content (i.e. almost 50%). Hence, as an alternative to solve the problem, it is possible to apply FSWR from gabroid rocks, or their combination with granitoid rocks; chemical composition should be analyzed.

Paper [22] has proved that fine particles of granite slurry may act as macro fillers in capillary pores and in transition zones, which results in the improved consolidation of cement mixture particles as well as uniform distribution of cement particles. The abovementioned provides better cohesive properties and denser microstructure of cement materials [23]. Nevertheless, the improvements are possible if only granite slurry content is adequate. The matter is that stone working enterprises operate with different rocks and chemical composition of FSWR will vary constantly [24]. The impossibility to control granite slurry content in FSWR factors into variability of physicomechanical characteristics of cement and geopolymer mixtures [25]. While removing FSWR from a slurry tank, averaging of FSWR characteristics obtained during cutting of different rocks takes place [26]. If water purification equipment is applied, flocculants may be added accelerating sedimentation of small particles, and varying chemical composition of FSWR [27]. Hence, a problem of content of certain rock components is solved through FSWR use which composition contains various rocks; chemical composition is analyzed.

Analysis of the available scientific sources demonstrates conflicting results concerning slurry effect as cement substitute for mechanical properties of cement materials. Some studies denote that slurry adding may reduce compression strength as well as other mechanical characteristics [20], and [21]. In turn, other papers emphasize its positive influence on the properties [22]-[24]. That is why the problem needs further research.

1.3. Research purpose and tasks

The research purpose is to assess influence by FSWR on physicomechanical characteristics of geopolymer and concrete materials, and develop efficient techniques of their utilization to mitigate negative impact of industrial waste on the environment.

For the purpose, following tasks have been formulated:

– to identify influence of different FSWR ratios on characteristics of the geopolymer mixtures (namely, on their strength);

– to analyze influence of sand substitution for FSWR in concrete mixtures and assess the possibility of partial sand substitution for FSWR with no significant decrease in the material strength.

2. Research materials and methods

2.1. Research subject

Geopolymer materials and concrete mixtures are analyzed added by FSWR as an alternative filler. The basic research hypothesis is as follows. FSWR adding to composition of building materials may improve their strength characteristics while reducing cost and mitigating environmental load. FSWR effect on the material strength is defined through the particle size and quantitative content in the mixture; microstructural changes by FSWR are the basic factors influencing mechanical properties of materials. The adopted simplifications involve consideration of mixtures where FSWR replaces certain percentage of sand ignoring other possible combinations of the materials.

Generally, stone working enterprises in Ukraine operate with basic and acid rocks (i.e. gabbro, labradorites, and granites). Also, sand is applied for traditional concrete. Table 1 demonstrates chemical composition of sand and FSWR to be applied.

Table 1. X-ray fluorescence analysis of the applied materials

Component	Sand from Oleksandrivske deposit, wt %	FSWR from stone working enterprise NIKA-HRAN Ltd, wt %
SiO_2	96.81 ± 0.24	65.80 ± 0.24
Al_2O_3	1.30 ± 0.06	15.17 ± 0.18
Fe_2O_3	0.17 ± 0.0059	4.35 ± 0.10
K_2O	0.11 ± 0.0060	4.25 ± 0.10
MgO	0.06 ± 0.0024	1.56 ± 0.06
CaO	0.20 ± 0.0021	3.55 ± 0.09
TiO_2	0.05 ± 0.0049	0.579 ± 0.029
Na_2O	0.09 ± 0.0091	3.44 ± 0.09
P_2O_5	–	0.1750 ± 0.0087
MnO	0.09 ± 0.0091	0.0623 ± 0.0031
ZrO_2	–	0.0236 ± 0.0027
V_2O_5	–	–
SrO	0.02 ± 0.0019	0.0499 ± 0.0025
RuO_4	–	–
Rb_2O	–	–
PdO	–	0.0124 ± 0.0047
S	–	–
SO_3	0.09 ± 0.0091	0.0655 ± 0.0037
NiO	–	–
PtO_2	–	–
Cr_2O_3	–	–
Cl	–	0.0621 ± 0.0058

Granulometric composition of raw materials to be used is important for any building material manufacturing. In the context of the research, fine sand takes place to produce geopolymer concrete. Hence, FSWR applicability for geopolymer concrete production has been identified through its granulometric composition (Table 2).

Table 2. Granulometric composition of the materials to be applied

Granulometric composition of materials, um	Raw materials, %	
	Sand from Oleksandrivske deposit	FSWR from stone working enterprise NIKA-HRAN Ltd
0-50	7	14
50-100	15	79
100-140	10	3
140-200	16	1
200-250	10	1
250-500	19	1
> 500	23	1

2.2. Method of geopolymer mixture preparation

Binder was made from FSWR and sand. The obtained compound was mixed with a complex activator solution consisting of sodium silicate (liquid glass) and a two-molar NaOH solution. Samples were formed from the composition; they hardened under normal conditions.

According to papers [5] and [22], ground granulated blast furnace slag, construction waste, and fly ash and sand, which granulometric and chemical composition is similar to FSWR and sand composition, were selected as materials to make geopolymers. Four geopolymer formulas were analyzed during the research depending upon average particle ratio of corresponding fractions in the traditional geopolymer mixtures. Chemical composition regulates percentage ratio of the geopolymer mixture components. Hence, the decision has been made to use sand and FSWR proportions being multiple of 25%:

– sand content is 75%, and FSWR content is 25%;
– sand content is 50%, and FSWR content is 50%;
– sand content is 25%, and FSWR content is 75%;
– sand content is 0%, and FSWR content is 100%.

Four samples were prepared for each formula; consequently, 16 samples were analyzed.

Geopolymer samples for the research have been prepared as follows.

1. Sand and FSWR were dried at 105 ± 2°C temperature.
2. Sand-FSWR mixture was blended up to uniformity. The mixture composition to make a sample 1 was as follows: its total mass was 1000 gr among which corresponding volume fell at FSWR and sand in accordance with the mentioned formulas. For example, if sand content was 75% then 750 gr of the material was applied; if FSWR content was 25% then 250 gr of FSWR was used.
3. 300 ml of 8-molar sodium hydroxide solution (NaOH) was prepared. For the purpose, 32 gr of NaOH were dissolved in 100 ml of the distilled water.
4. Sodium hydroxide solution (NaOH) was added by liquid glass (Na_2SiO_3) at the rate of 48 gr per each 100 ml of the solution. After that, the liquid glass was mixed thoroughly with alkali solution.
5. The uniform dry 1000-gr FSWR-sand mixture was added by 300 ml of alkali solution and liquid glass.
6. The mixture was blended thoroughly and cubic geopolymer samples were shaped with 70×70×70-mm geometry.
7. The geopolymer samples were drying during 8 hours at 80 ± 2°C temperature.
8. The obtained geopolymer samples were tested for strength using a press.

2.3. Method for concrete mixture preparation

Standard composition to make concrete was used for the purpose. The made mixture was added by FSWR in different proportions. Slurry was added in the amount being 0-20% of the total mass of the mixture. Water-cement-sand-crushed stone proportion of the composition was 0.7:1:2.39:4.39 respectively. Reference sample was produced using standard composition of concrete, namely in the proportion 0.7-2.3 l of water; 1.0-3.3 kg of cement; 2.39-7.90 kg of sand; and 4.39-14.50 kg of crushed stone with 5-20 fractions.

In contrast to geopolymer mixture, addition of more than 10% of fine fractions which dimensions are less than 200 um, significant strength decrease is observed [3]. Since FSWR mainly consists of < 200 um fractions, it was proposed to analyze following concrete formulas with FSWR:

– sand content is 100%, and FSWR content is 0%;
– sand content is 90%, and FSWR content is 10%;
– sand content is 80%, and FSWR content is 20%.

6 samples were prepared for each formula; totally, 18 samples were analyzed.

Following procedure was applied to prepare concrete samples for the research.

1. Sand and FSWR were dried at 105 ± 2°C temperature.
2. Concrete mixture in correct proportions was blended to its uniformity.
3. Cubic concrete samples were shaped with 70×70×70-mm geometry.
4. Concrete samples were hardening during 56 days at 20°C temperature.
5. The obtained concrete samples were tested for strength using a press.

2.4. Compression strength identification

Compression tests took several stages:

Stage 1. Compression test. All samples from one party underwent the compression test at the estimated age being no less than 24 days.

Stage 2. Preparation of samples. Before a sample mounting (Fig. 1), the press was checked for contamination and residual particles left from the previous testing. The selected sample face was placed on ground bed plate centering it along longitudinal axis with the help of lines built into the press plate. After the sample mounting on the bed plates, upper plate of the press was leveled with upper bearing face of the sample in such a way to make complete contact of their surfaces. Then, a process of loading on the press used for compression of samples started.

Stage 3. Measuring scale selecting. Measuring scale of the press force was selected in such a way to provide the expected 20-80% value of destructive load being the maximum permissible load for the chosen scale. MATEST press was applied to test strength of the samples (Fig. 2).

Stage 4. Loading of samples. The samples were loaded permanently with a velocity providing increase in design stress up to their complete destruction. The velocity was (0.6 ± 0.4) MPa/s under compression.

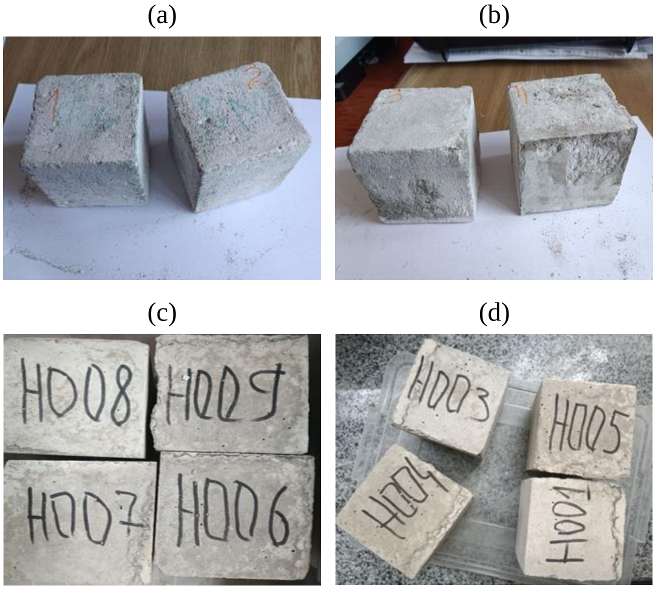

Figure 1. Samples after compression: (a), (b) are geopolymer samples; (c), (d) are concrete ones

Figure 2. MATEST press

Stage 5. Destructive load determination. The maximum force achieved while testing was defined as destructive load and recorded.

Stage 6. Evaluation of the destructed sample. After destruction, the sample was evaluated visually. Following data were recorded: the destruction nature; availability of large cavities (which amount is more than 1 cubic centimeter) inside the sample; lumps; and traces of layering. The identified defects of structure and destruction nature listed at the stage are not taken into consideration in the process of further calculations.

3. Results and discussion

The findings show that increase of stone slurry content in geopolymer material is followed by significant decrease in its compressive strength. Among other things, if FSWR content is 25% then the strength is 20 MPa being rather high value for its use as a component of building structures. However, FSWR content increase up to 50, 75, and 100% decrease strength down to 14.3, 10.0 and 5.3 MPa, respectively (Fig. 3). The results have demonstrated insignificant strength reduction along with increase in FSWR percentage.

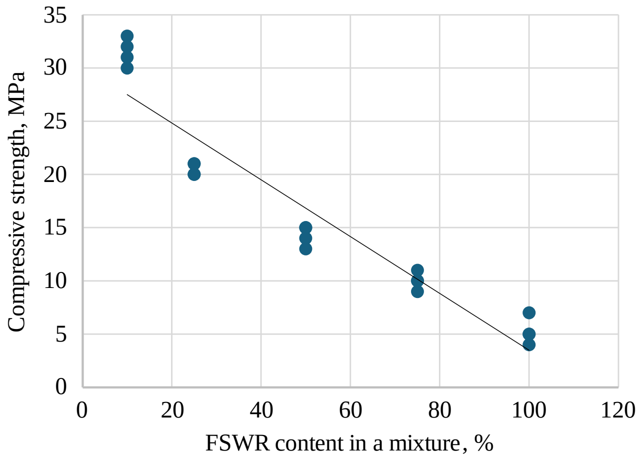

Figure 3. Dependence of the geopolymer sample strength upon the percentage of fine stone working refuse

Hence, it can be applied as partial sand substitute. Geopolymers with up to 25% FSWR content have the potential to be applied in construction industry providing sufficient compressive strength.

Strength decrease in geopolymer samples can be explained by the fact that high slurry concentration reduces amount of active cementing component influencing directly formation of solid microstructure. The idea is supported by [28] research where FSWR acts as a densifier; however, compression strength decreases in terms of high concentrations. In addition, [28] research states that the decrease in sample strength may result from water excess required by a mixture if FSWR percentage increases. However, scientific source [25] have shown that FSWR may be helpful to prolongate life of cement materials owing to decrease in water permeability. Strength reduction depends upon increase in the material porosity and less efficient cohesion of FSWR particles against each other.

To compare with other studies mainly considering FSWR as cement substitute, the research applies slurry as the basic component of geopolymer mixture, which makes it possible to reduce significantly raw material costs as well as negative environmental impact. Analysis of such scientific sources as [23] and [26] demonstrates a wide range of approaches to use FSWR and other industrial waste for building materials; nevertheless, their results differ greatly depending upon methods and application conditions. Research [22] has compared FSWR-based geopolymer materials with traditional concrete mixtures. It has been identified that despite the geopolymers are inferior to traditional materials in terms of strength they are better from the viewpoint of environmental friendliness and cost.

The obtained research results intended to define strength of geopolymer and concrete samples solve directly the problem formulated in the study; namely, the necessity of geopolymer mixture composition optimization to provide their sufficient strength while FSWR applying. The research shows that geopolymers containing up to 25% of FSWR guarantee strength being sufficient for their use in construction. Analysis of the FSWR influence on concrete strength if sand substitution in a concrete mixture is 0, 10, and 20% (Fig. 4).

The testing results (Fig. 4) show that strength of concrete samples with FSWR decreases to compare with reference samples. Specifically, concrete strength without FSWR was 35.42-38.2 MPa.

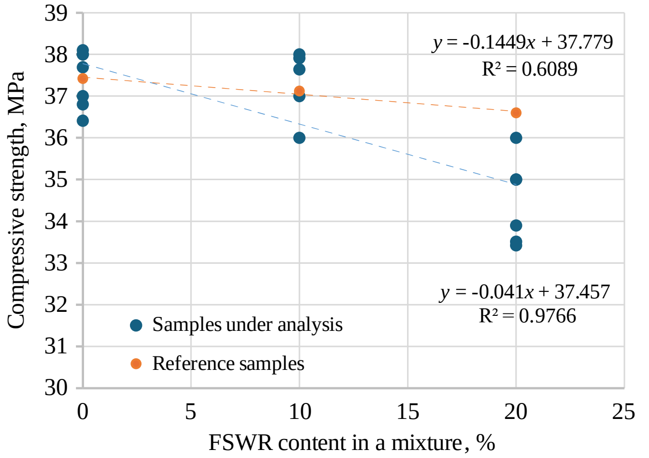

Figure 4. Dependence of the concrete sample strength upon the content of fine stone working refuse

Strength of samples with 10% of FSWR was 36.0-38.2 MPa; and samples with 20% of FSWR demonstrated strength at the level of 33.4-36.0 MPa. If FSWR content is 10% then concrete strength is similar to reference concrete or even higher. The improvement or strength stability may depend upon the fact that minor FSWR percentage increases concrete mixture density decreasing its porosity. In this case, fine FSWR particles may act as an additional filler bettering contact between the mixture components.

Decrease in concrete sample strength resulting from addition of 20% of fine stone working refuse has several explanations. First, excessive saturation of a mixture with fine particles disturbs structure of a cement matrix, and deteriorate contacts between concrete components. Second, the increased water demand due to high surface area of FSWR particles factors into increase in water-cement ratio, and porosity formation. Moreover, FSWR abundance decreases adhesion between cement and filler, and weakens strength of the material. Finally, cement hydration process may be disturbed due to inertia of some slurry particles, which worsens additionally mechanical characteristics of concrete.

To compare with other studies ([23]-[25]), FSWR use in the construction industry helps implement new ways of large-volume stone working waste utilization. The matter is that according to data by the State Statistics Service of Ukraine, Zhytomyr District of Zhytomyr Region generates the largest amount of refuse of I-IV classes of hazard, which corresponds to concentration of numerous stone enterprises. In turn, the abovementioned needs ecologic and economic substantiation since the waste may be used to manufacture building mixtures.

Our results confirm the possibility of partial sand substitution for FSWR with no significant decrease in concrete strength, which solves the problem of sand deficiency and cost reduction. It is achieved owing to optimization of ratio between concrete mixture components. Moreover, it helps mitigate load on natural resources, and provide more stable use of waste. Geopolymer material added by stone slurry has various application possibilities depending upon its composition and the obtained compressive strength. Relying upon the fin-dings, its following application trends can be proposed.

1. Low-load structures. Geopolymers with up to 25% of FSWR content which compressive strength is to 20 MPa may be used to produce such low-load structural units as paving slabs, decorative blocks, partitions, facade panels etc. Moreover, FSWR use as micro filler in mixtures helps improve distribution of particles, and reduce porosity of the materials [23].

2. Building insulation materials. Owing to porous structure and low density, geopolymers with FSWR content (being 50% and more) can be applied in construction as thermal insulation or sound insulation materials.

3. Landscaping materials. Geopolymers with FSWR are applicable for hard landscaping, curbs, and garden walks which need not high compressive strength values.

4. Building units for temporary structures. Geopolymers where FSWR content is up to 50% may be used to manufacture temporary structures, for instance temporary supports, protective barriers or building blocks for temporary buildings.

5. Soil stabilization. Owing to proper cohesion characteristics, geopolymers with high FSWR content can be used for soil stabilization especially in road construction or while protecting banks and slopes.

Consequently, depending upon slurry percentage and corresponding strength, the geopolymer material is applicable for different constructing and landscaping projects where strength requirements vary from average down to low ones.

One of the key restrictions is the fact that the proposed geopolymer materials where FSWR content is more than 25% cannot provide sufficient strength to be applied in bearing structures. In such a way, their potential is limited by low-load structures. Moreover, the research was carried out only in a lab environment, which do not take into consideration influence by such external factors as temperature and moisture on the material properties.

The basic disadvantage of the research is the restricted scale of the experiment involving only five formulas. In addition, such long-term material characteristics as cold resistance and water resistance were ignored. The abovementioned may restrict practical use of the results.

Further research development should involve greater number of formulas, and testing for durability of the materials. It is also worth analyzing modification potential of FSWR to improve its cohesion properties or develop combination methods with other waste types for formulation of new materials differing in the improved characteristics.

4. Conclusions

It has been identified for the first time that use of fine refuse of natural stone from Zhytomyr District as a sand substitute in concrete and geopolymer materials preserves acceptable physicomechanical characteristics of materials. If FSWR concentration in geopolymer mixtures is up to 25% then compressive strength is 20 MPa, being quite sufficient to be applied in low-load structures.

It has been defined that increase in more than 25% FSWR concentration factors into significant strength reduction of geopolymers: in terms of 50% strength is 14.3 MPa; and in terms of 75% it is only 10 MPa. In such a way, use of the materials in high-strength structures is restricted.

It has been determined that partial sand substitution for FSWR in concrete mixture reduces the material strength insignificantly. 20% sand substitution for FSWR results in concrete strength reduction from 37.42 MPa down to 36.6 MPa which is permissible for the construction industry.

Practical significance of the research is the possibility to apply geopolymer materials with FSWR for the production of various structural units, i.e. paving slabs, decorative blocks, insulation materials, and landscape structures.

Author contributions

Conceptualization: VS; Formal analysis: IL; Funding acquisition: VS, IL, VMS, IP, YN; Investigation: VS, IL, YN; Methodology: YN; Project administration: VS; Resources: YN; Supervision: IP; Validation: VMS; Visualization: VMS; Writing – original draft: VS, IL, YN; Writing – review & editing: VMS, IP. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Утилізація шламу каменеобробних підприємств в геополімерних та бетонних виробах

В. Шамрай, І. Леонець, В. Мельник-Шамрай, І. Пацева, Я. Наумов

Мета. Оцінка впливу дрібнодисперсних відходів каменеобробки (ДВК) на фізико-механічні властивості геополімерних і бетонних матеріалів для подальшої розробки ефективних методів утилізації ДВК.

Методика. Для дослідження використовувалися геополімерні суміші та бетонні зразки з різними пропорціями ДВК. Зразки піддавалися механічним випробуванням на стиск, що дозволило оцінити вплив різної кількості ДВК на міцність матеріалів. Всього було підготовлено 16 геополімерних та 18 бетонних зразків.

Результати. У дослідженні проаналізовано можливість використання ДВК у виробництві бетонних і геополімерних матеріалів для утилізації промислових відходів та зменшення їх впливу на довкілля. Дослідження спрямоване на визначення впливу ДВК на фізико-механічні властивості матеріалів і розробку методів їх утилізації. Додавання ДВК знижує міцність геополімерів: при 25% вмісті міцність становить 20 МПа, а при 50% зменшується до 5.3 МПа. Для бетону часткова заміна піску на ДВК зменшує міцність незначно (з 37.42 до 36.6 МПа при 20% ДВК). Геополімери з 25% ДВК підходять для низьконавантажених конструкцій, а бетонні суміші з ДВК можуть використовуватися без значного зниження міцності.

Наукова новизна. Вперше встановлено оптимальну концентрацію дрібнодисперсних відходів з міцного природного каменю з родовищ Житомирської області до 25%, що забезпечує прийнятну міцність на стиск без значного зниження технічних характеристик.

Практична значимість. Полягає у тому, що за умов дотримання оптимальних пропорцій ДВК у складі геополімерних та бетонних сумішей можливо знизити витрати на сировину, зменшити обсяг ДВК та підтримати принципи економіки замкненого циклу в будівельній індустрії.

Ключові слова: *геополімери, бетон, дрібнодисперсні відходи, каменеобробка, утилізація відходів, міцність*

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