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PRELIMINARY RESULTS VALIDATION ON THE THEORETICAL AND EXPERIMENTAL APPROACH FOR USING SPENT GARNET RESIDUES OF ROMANIAN LOCAL INDUSTRIES IN CONSTRUCTION MATERIALS

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Abstract

Waterjet cutting is an industrial method that uses high-pressure water jets to cut a variety of materials such as metals, concrete, wood, ceramic, stone, rubber, foams, plastic, etc. For improving the procedure performance, in terms of speed and cutting accuracy, abrasive agents like red garnet sand is mixed with the water, generating the Abrasive Water Jet (AWJ) methodology. This is known to present environmental drawbacks, including the production of wastewater, garnet sludge and corresponding dried wastes, and microscopic particles from the cut materials, still disposed in household landfills, which generate severe environmental issues. Using Garnet Sand (SG) wastes in cementitious materials (mortars and concrete) as partial aggregate substitution is an innovative approach to enhance sustainability in construction, offering several benefits like increased strength, durability performance, etc., reduced production costs due to the re-using material approach and ecological protection as well. Preliminary studies in this direction were conducted in the last years within NIRD URBAN – INCERC, Timişoara branch, showing encouraging results in the proposed aggregate substitution proposal in the regular mortar mixes, in accordance with initial international studies in the field. The current paper aims to confirm the initial results by specific extension of the research area, reaching some critical parameters, like SG material source variation, as a mandatory validation procedure of preliminary conclusion and foundation of further specific studies regarding the viability of the SGs recycling opportunities in construction products and their effective use.

Keywords: *aggregate substitution, Circular Economy (CE), green building design, recycling, Spent Garnet (SG).*

INTRODUCTION

Abrasive waterjet (AWJ) cutting is an advanced, non-thermal machining technique that utilizes a high-pressure jet of water mixed with abrasive particles - primarily Garnets - to cut a wide range of materials with precision. The AWJ cutting technique is widely used in various industries due to its ability to accurately process a diverse range of materials (metals, ceramics and glass, composites, stone and marble, metals and other hard materials, etc.) without inducing thermal damage or structural distortion (Figure 1). Garnets, the most versatile abrasive material for the AWJ process, represents a group of silicate minerals known for their crystalline structure and diverse chemical compositions; the general chemical formula is $X_3Y_2(SiO_4)_3$, where X and Y are various metal cations, such as calcium, magnesium, aluminium, iron, and manganese (Chassé et al., 2018). The chemical composition flexibility of Garnets determines their wide range of varieties, each with distinct physical and optical properties. The most common colour of Garnets is red (reddish-pink range of colours), but they can also be green, orange, yellow, or even black, depending on their specific type (Figure 2). Garnet varieties include (Bucher et al., 2019; Usman et al., 2021; Skanavi & Dovydenko, 2018; Vasile et al., 2024):

- Almandine (iron - aluminum, $Fe_3Al_2(SiO_4)_3$, of red to reddish-brown colour, represents the most widespread of Garnets, with a wide range of use in abrasive applications;
- Pyrope (magnesium - aluminum, $Mg_3Al_2(SiO_4)_3$), of deep red colour;
- Spessartine (manganese - aluminum): Orange to reddish-brown;
- Grossular (calcium - aluminum): Green, yellow, or colorless;
- Andradite (calcium - iron): Green, yellow, or black, etc.

Garnets are preferred for AWJ cutting procedures due to their hardness (6.5-7.5 on the Mohs scale), angular particle shape, and chemical stability, which facilitate efficient cutting while minimizing equipment wear (Baeră et al., 2023; Cornelia B. et al., 2023; Vasile et al., 2024). Garnet production varies globally, with several countries, like India, Australia, United States, China, South Africa, etc., leading the extraction and processing and also dominating the global Garnet market, as raw materials suppliers for industries such as waterjet cutting and sandblasting (https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-garnet.pdf). According to Precision Business Insights (https://www.precisionbusinessinsights.com/market-reports/garnet-market) "the global Garnet market size was valued at approximately $892.8 million in 2024 and is projected to grow at a compound annual growth rate (CAGR) of 7.2% from 2025 to 2031", which predicts a corresponding growth of the industries connected to AWJ processes.

a)  b) 

Figure 1. Abrasive waterjet cutting device for material processing: a) specific AWJ equipment (Vasile et al., 2024); b) metal piece processed by AWJ operations (TimCut SRL, Timisoara, Romania)

a)  b) 

Figure 2. Garnet sands: a) Garnet sand deposits, Long Island Sound in Madison, Connecticut, USA; b) Garnet sand grains (aspect and colour variation) (https://fredmhaynes.com/2021/03/11/a-sea-of-garnet-sand/)

In abrasive waterjet (AWJ) cutting operations utilizing Garnets (Figure 1), the process produces Garnet slurries as the initial waste, consisting of a liquid suspension of water mixed with smaller, altered Garnet particles of varying size distribution (Cornelia B. et al., 2023; Vasile et al., 2024). Typically gathered in a container positioned beneath the cutting equipment, the Garnet slurries are periodically removed at irregular intervals and, through natural drying, form waste piles (Figure 3). Discarding spent Garnet sands (SGs) in landfills generates environmental pollution and increases waste management costs. Integrating sustainable materials and innovative techniques in civil engineering contributes to environmental protection while enhancing resource efficiency and structural reliability, which requires sustainable solutions (Longobardi et al., 2024; Olinic et al., 2024). Research performed in the last decade shows the potential of SG materials as a fine aggregate replacement in construction materials, mortar and concrete. This can be seen as an eco-friendly alternative to natural sand, which represents an exhaustible, natural resource. In this context, garnet waste, a byproduct of abrasive waterjet cutting in the material processing industry, can be effectively repurposed in the construction sector. It holds significant potential for use in cement-based (Budiea et al., 2021; Ab Kadir et al., 2019; Kanta & Ponnada, 2021; Lim et al., 2020; Kunchariyakun & Sukmak, 2020; Jamaludin et al., 2021) or alkali-activated concrete (Huseien et al., 2019; Muttashar et al., 2018a; 2018b) and mortars, plaster, fibre-reinforced composites, and other building materials (Cornelia B. et al., 2023; Vasile et al., 2024). The use of SG waste as a replacement for fine aggregates in cement-based materials, such as mortar and concrete, has been explored to enhance sustainability in construction. Experimental studies performed worldwide indicated that incorporating spent Garnets (SGs) in the concrete or mortar mixture can improve their physical and mechanical properties, such as densities and workability, flexural and compressive strength, while also contributing to environmental sustainability.

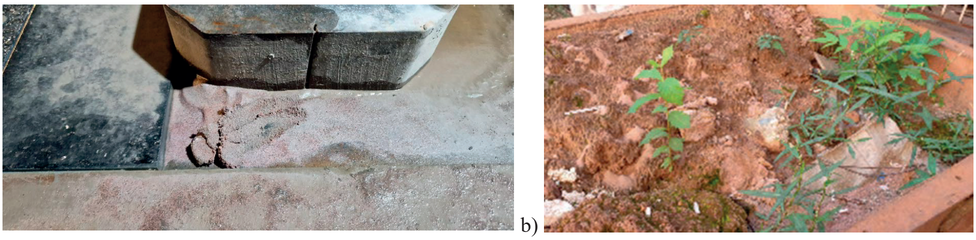
a) b)


Figure 3 . AWJ processes waste generation: a) Waterjet sludge collected in recipients (TimCut SRL, Timisoara); b) Garnet waste dry slurry collected in outside recipients for medium-term storage (National Research & Development Institute for Welding and Material Testing - ISIM Timisoara, Romania) (Vasile et al., 2024)

Overview of ongoing research

Over the past decade, the rapid growth of the AWJ industry and the associated waste generation have driven an increasing need for research on SG waste management, particularly its integration into construction materials. This demand has led to a proportional rise in studies focused on repurposing SG in the building materials industry, in accordance with the Circular Economy approach: innovative transformation of potential waste into new products with distinct life cycles. In this context, SGs generated from abrasive waterjet material processing can be repurposed as a valuable by-product through improved industrial process control. The SG wastes can therefore be effectively integrated into various building materials, mortar and concrete as well (Baeră et al., 2023). Early studies conducted by Malaysian researchers explored the potential of garnet waste in alkali-activated mortars and concrete (Muttashar et al., 2018a; 2018b), while parallel research efforts investigated its application in cementitious composites as part of spent Garnet valorisation (Budiea et al., 2021; Ab Kadir et al., 2019; Kanta & Ponnada., 2021; Lim et al, 2020; Kunchariyakun & Sukmak, 2020; Jamaludin et al., 2021; Huseien et al., 2019). A common methodology in these studies involves developing a reference mortar or concrete mix, followed by testing variations with incremental sand replacement levels of

25%, 50%, 75%, and 100%. The findings consistently highlight the viability of sand substitution by SG material for cement-based mixes.

The present study was developed within the research project PN 23 35 04 01 of Nucleu Programme of the National Research Development and Innovation Plan 2022-2027, "ECODIGICONS", supported by the Ministry of Research, Innovation and Digitalization, with focus on waste management implementation, environmental protection and natural resources saving (Baeră et al., 2023; Cornelia B. et al., 2023; Vasile et al., 2024) and is consistent to the previously mentioned experimental methodology: a standard cementitious mortar was first developed as the reference mix (R). Subsequently, the conventional sand was partially replaced with SG waste material, sourced from two local companies. The first stages of the study (Baeră et al., 2023; Cornelia B. et al., 2023; Vasile et al., 2024) evaluated as favourable the compatibility of Garnet waste material with cement-based materials, by the means of comparative analysis of fresh and hardened state properties (fresh state appearance, cohesivity of the mixture, material consistency and fresh state density, etc., together with hardening age and typical mechanical performance, 7-day and 28-day flexural and compressive strength, etc.) in substitution mortars relative to the reference. The focus of this phase is the validation of the previous conclusion and evaluation of its consistency, with respect to the viability of the proposed substitution procedure. The current natural aggregate substitution was conducted by weight, following guidelines from previous studies on the subject, with replacement levels of 10%, 30% and 50% of the sand (S) content in the reference mix.

MATERIALS AND METHODS

The current experimental procedures are performed to validate the previous conclusions of the initial stages of the study. Consequently, the SG material used in this study, derived from two local providers: SG 1 and SG 3 were provided from the National Research & Development Institute for Welding and Material Testing (ISIM) (Ionescu et al., 2014; Perianu et al., 2017), but they were collected at different times - SG 1 in April 2022 and SG 3 in August 2023, over a year apart (Vasile et al., 2024). This time gap is considered significant for assessing the consistency of preliminary findings, as it allows for an evaluation of waste dynamics in terms of both material properties and compositional performance when integrating SG 1 and SG 3. Additionally, another SG source is considered, namely the local company SC Tim Cut SRL Timisoara, Romania, specializing in AWJ material processing technology (https://www.timcut.ro/); the material they provided is denoted SG 5.

The comparative evaluation is performed in terms of mechanical behaviour, of the modified mortars with respect to the reference, namely flexural and compressive strength recorded at early ages (7 days) and also the regular age of 28 days. The control mixes (R1 and R2) consist of conventional mortars, while the test mixes incorporate SG materials (SG 1, SG 3 and SG 5) as a partial replacement for sand in the reference mix (R). The substitution is performed at 10%, 30% and 50% by mass, following the standard methodology established in previous studies, and the mixing procedure is in accordance with EN 196-1 and 1015-11.

Raw materials

The Reference and the SG mixes were produced with locally available raw materials (Figure 4):

- Portland Cement, CEM II/A-LL 42.5 R (C) (Figure 4a);
- granular class 0/4 Natural sand (S), (Figure 4b);
- Spent Garnet sand (SG), from by two distinct local sources: SG 1 (Source 1 (ISIM), sampling: April 2022), (Figure 4c); SG 3 (Source 1 (ISIM), sampling: August 2023, (Figure 4d); e) SG 5 (Source 2 (Tim Cut SRL) (Figure 4c), sampling: 2023, (Figure 4e);
- Water (tap water);
- Free additives mixtures.

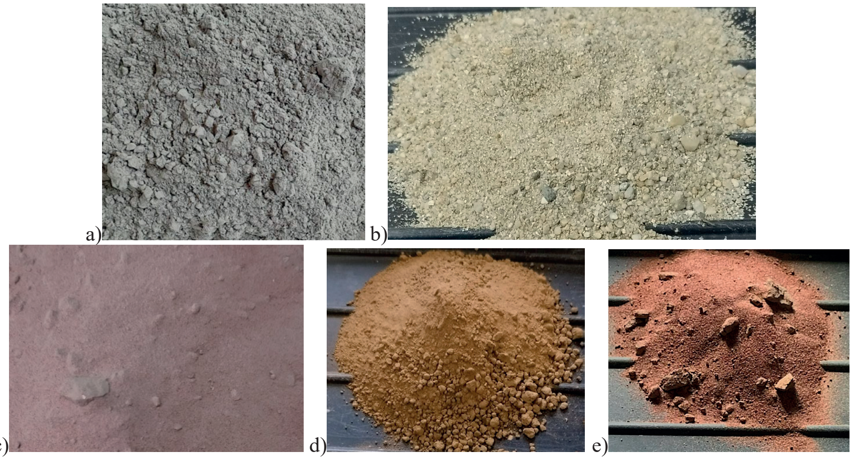
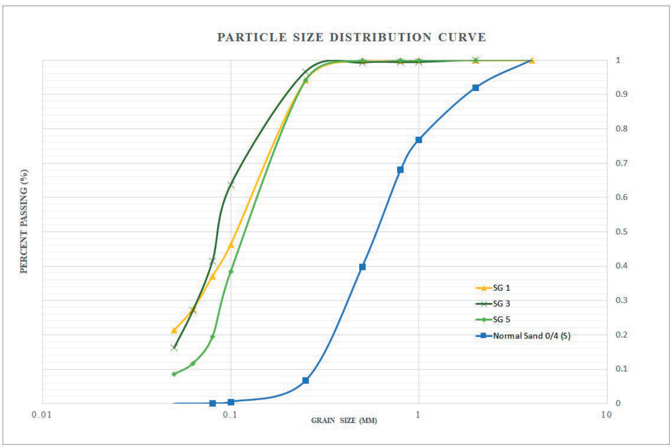


Figure 4. Raw materials: a) Portland Cement; b) Natural sand (0/4), S; c); SG 1 (Source 1 (ISIM), sampling: April 2022); d) SG 3 (Source 1 (ISIM), sampling: August 2023); e) SG 5 (Source 2 (Tim Cut SRL), sampling: 2023)

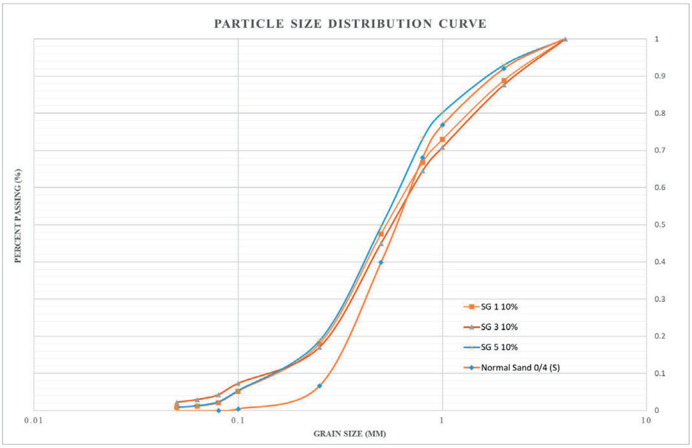
Preliminary experimental procedure - Granulometric analysis

The sieving analysis is performed according to EN 933-1 method for the usual sand 0/4 (S), for the considered substitution SG materials, SG 1, SG 3 and SG 5 and additionally for the S+SG blended aggregate, containing 10%, 30% and 50% replacement levels of the sand (S). The graphical representation of the sieving analysis is presented in Figures 5 and 6 (Vasile et al., 2024).

Figure 5. Determination of particle size distribution for SG 1 50% mixture: a) component materials, S+ SG 1, before mixing; b) S+SG 1, after mixing; c) particle size fractions (retained on sieve) resulting from the sieving operation



a)



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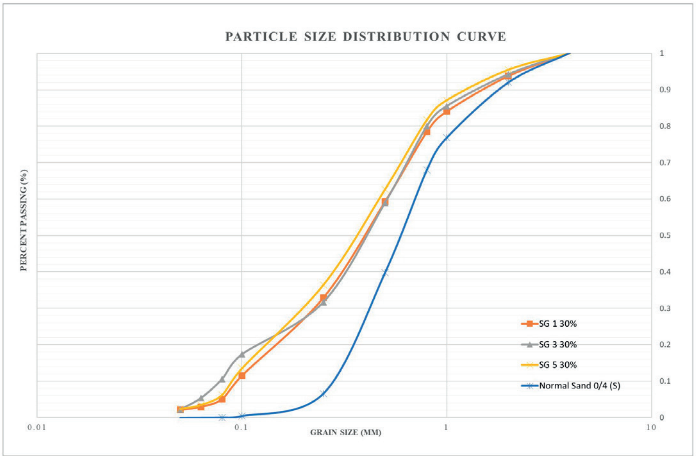

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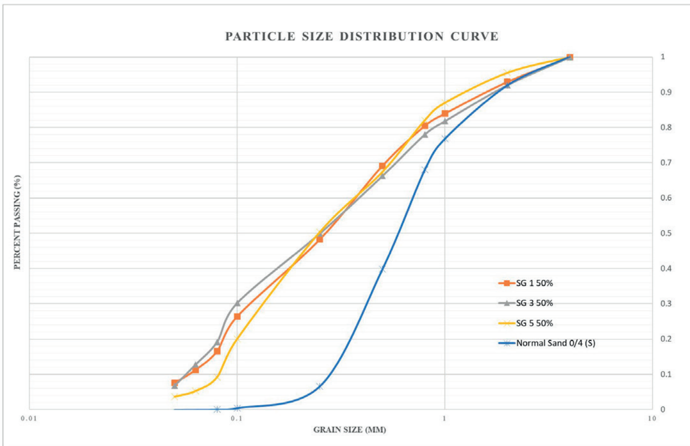

d)

Figure 6. Aggregate grading: a) Natural sand 0/4 (S), SG 1, SG 3 and SG 5; b) Natural sand 0/4 (S), blended aggregate mixture of S+SG (1, 3 or 5) (10%); c) Natural sand 0/4 (S), blended aggregate mixture of S+SG (1, 3 or 5) (30%); d) Natural sand 0/4 (S), blended aggregate mixture of S+SG (1, 3 or 5) (50%)

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Mix proportion and specimen preparation

The reference mortar mixes, R1 ((W/C) 0.61) and R2 ((W/C) 0.56), were developed with classic raw materials: regular sand 0/4 (S), cement and water are produced (Cornelia B. et al., 2023; Vasile et al., 2024). The S+SG mortar mixes were produced by SG material incremental replacement, by mass, of the usual aggregate (S), with SG additions (10%, 30% and 50%). The 10% sand replacement presents reduced economic significance for real use purposes, but it serves as important data for completing the perspective regarding the incremental growth and the corresponding mortar performance.

The mortar mix design follows the approach used in the preliminary studies (Cornelia B. et al., 2023; Vasile et al., 2024), the mixing process performed in accordance with the SR EN 196-1 and SR EN 1015-11 standards. Similarly, the casting of prismatic specimens (40 × 40 × 160 mm) and their conditioning before mechanical testing remain consistent with previous research (Baera et al., 2021; 2022; 2023; Vasile et al., 2024). The SG mortars incorporate blended aggregate mixes, with SG materials replacing the natural 0/4 sand at predetermined substitution levels of 10%, 30% and 50%. The water-to-cement (W/C) ratio for SG mortars is maintained at 0.56, aligning with R2. The mix proportions for both the reference mortars (R1 and R2) and the SG-modified mixes are standardized relative to the cement content (C = 1.0) and are detailed in Table 1. Figure 7 emphasises some relevant stages of the mortar specimen development process and testing procedures, as well.

Table 1. Mix proportions of the considered mortar mixtures: References and SG mixtures

Ingredients / Mixtures	C	S 0/4	SG	W/C	A/C
R1-1	1	3	-	0.56	3
R2-1	1	3	-	0.61	3
SG 1-1 10%	1	2.10	0.90	0.56	3
SG 1-1 30%	1	2.70	0.30	0.56	3
SG 1-1 50%	1	1.50	1.50	0.56	3
R1	1	3	-	0.56	3
R2	1	3	-	0.61	3
SG 1 10%	1	2.10	0.90	0.56	3
SG 1 30%	1	2.70	0.30	0.56	3
SG 1 50%	1	1.50	1.50	0.56	3
SG 3 10%	1	2.10	0.90	0.56	3
SG 3 30%	1	2.70	0.30	0.56	3
SG 3 50%	1	1.50	1.50	0.56	3
SG 5 10%	1	2.10	0.90	0.56	3
SG 5 30%	1	2.70	0.30	0.56	3
SG 5 50%	1	1.50	1.50	0.56	3

Figure 7. Specimen preparation and testing: a) fresh state aspect of the mortar during mixing sequences; b) fresh mortar casted in the prismatic mold; c) SG 5 50% mix specimen after removal from the mold, 24 h after casting and specific conditioning (air, high moisture (>95%)); d) Specimen placement in the 3PB testing equipment; e) Compression testing; f) Specimens after 3PB and compressive testing

After mixing and fresh state evaluation, the mortars were cast into the 40 x 40 x 160 (mm) prismatic, metallic molds (Figure 7b), cured for 24 h at the temperature T (20±1)°C and relative humidity RH (90±5)%. The hardened specimens (Figure 7c) were removed from the molds after 24 hours, visually evaluated and placed in water at the temperature T (20±1)°C, until the testing age, 7days and 28 days, respectively.

Hardened state evaluation of the SG mixes: validation of early and regular age mechanical performance

The validation stage of the SG substitution mortars (Table 1) is performed based on the mechanical characteristics of the developed mixes, namely the compressive and flexural strength, at early age (7 days) and regular age of 28 days.

The mechanical performance of the mortars is evaluated via bending tensile strength (three-point bending, 3PB) and compression strength, determined on the 40 x 40 x 160 mm prismatic specimens (Figure 7d), at early age (7 day-strength) and further at 28 days, in accordance with EN 1015-11 and EN 196-1 specifications. The flexural strength was determined using the three-point bending (3PB) test performed on whole specimens (Figure 7d), followed by the compression test on the resulting half-prism specimens (Figure 7e).

RESULTS AND DISCUSSIONS

Aggregate grain size distribution

The natural sand 0/4 (S) has a lower fine grain content, as anticipated. Replacing 10% natural sand (S) with SG material does not influence the overall grain size distribution (Figure 6b), but 30% and 50% sand replacement by SG (Figure 6c and 6d) helps balance the aggregate grading curve. All SG materials exhibit a consistent grain size distribution pattern (Figure 6a, Figure 8), with minimal variation, enhancing the reliability of the proposed substitution.

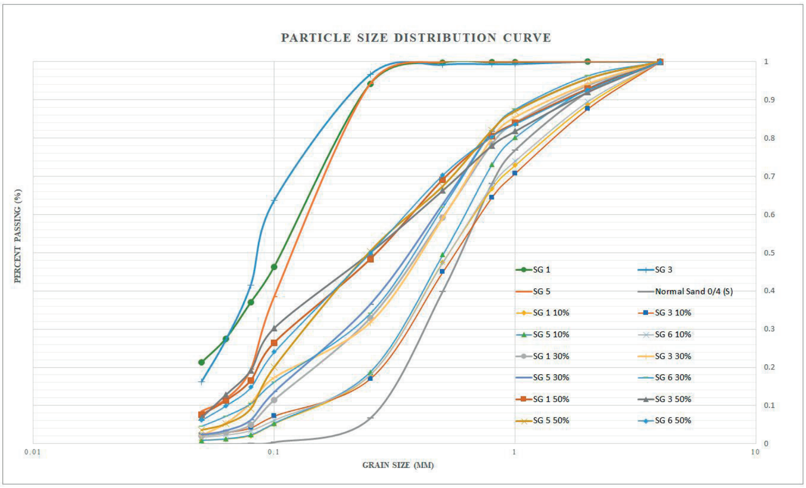


Figure 8. Aggregate grading: Natural sand 0/4 (S), SG 1, SG 3, SG 5 and blended aggregate mixture of S+SG (1, 3 or 5) (10%, 30% and 50%)

Mechanical performance

The physico-mechanical performances at early ages (7 days), bending tensile strength (3PB) and compressive strength, respectively, are essential parameters in evaluating the primary compatibility of the considered SG admixture with the cementitious matrix. Their evaluation, highlighted in Table 2, confirms the previously identified trends of overall improvement in material performance by using SG inert mineral aggregate as a partial aggregate substitute.

Table 2. Mechanical performances of SG mortars and References at young age (7 days) and regular, 28 days: flexural strength and compressive strength

Mechanical strength	7-day 3PB Flexural resistance				7-day 3PB Flexural resistance			
Age	Early age (7-day strength)		28-day strength		Early age (7-day strength)		28-day strength	
Mixtures	Strength (MPa)	Strength gain/loss vs R2 (%)	Strength (MPa)	Strength gain/loss vs R2 (%)	Strength (MPa)	Strength gain/loss vs R2 (%)	Strength (MPa)	Strength gain/loss vs R2 (%)
R1-1	5.9	-15.7	7.2	-14.3	22.0	-7.6	32.2	-11.3
R2-1	**7.0**	**0.0**	**8.4**	**0.0**	**23.8**	**0.0**	**36.3**	**0.0**
SG 1-1 10%	6.6	-5.7	8.0	-4.8	24.2	1.7	38.2	5.2
SG 1-1 30%	7.9	12.9	8.3	-1.2	29.5	23.9	40.6	11.8
SG 1-1 50%	7.6	8.6	8.5	1.2	33.0	38.7	39.5	8.8
R1	**5.7**	**-5.0**	**6.6**	**-4.3**	**25.4**	**-8.6**	**33.0**	**-3.8**
R2	***6.0***	***0.0***	***6.9***	***0.0***	***27.8***	***0.0***	***34.3***	***0.0***
SG 1 10%	6.3	5.0	6.6	-4.3	29.2	5.0	35.1	2.3
SG 1 30%	6.1	1.7	7.6	10.1	32.4	16.5	45.6	32.9
SG 1 50%	6.7	11.7	7.4	7.2	36.4	30.9	38.5	12.2
R1	**5.7**	**-5.0**	**6.6**	**-4.3**	**25.4**	**-8.6**	**33**	**-3.8**
R2	***6.0***	***0.0***	***6.9***	***0.0***	***27.8***	***0.0***	***34.3***	***0.0***
SG 3 10%	5.5	-8.3	7.2	4.3	28.7	3.2	37.2	8.5
SG 3 30%	6.4	6.7	6.8	-1.4	33.2	19.4	40.7	18.7
SG 3 50%	7.1	18.3	7.3	5.8	35.2	26.6	38.9	13.4
R1	**5.7**	**-5.0**	**6.6**	**-4.3**	**25.4**	**-8.6**	**33**	**-3.8**
R2	***6.0***	***0.0***	***6.9***	***0.0***	***27.8***	***0.0***	***34.3***	***0.0***
SG 5 10%	5.6	-6.7	7.7	11.6	29	4.3	39.6	15.5
SG 5 30%	6.8	13.3	6.6	-4.3	36.3	30.6	31.5	-8.2
SG 5 50%	7.3	21.7	7.7	11.6	34.5	24.1	43.5	26.8

Legend:
- **R1-1 and R2-1:** Reference mortars produced during the initial mechanical testing of SG 1 material (source 1, ISIM Timisoara, initial sampling) – PRELIMINARY STAGE
- **SG 1-1 10%, SG 1-1 30%, SG 1-1 30%:** Substitution mortars produced during the initial mechanical testing of SG 1 material (source 1, ISIM Timisoara, initial sampling) – PRELIMINARY STAGE
- **R1 and R2:** Reference mortars produced during the secondary mechanical testing of SG 1 material (source 1, ISIM Timisoara, initial sampling), SG 3 (source 1, ISIM Timisoara, secondary sampling); SG 5 (source 2, Tim Cut SRL, Timisoara, initial sampling) – VALIDATION STAGE
- **SG 1, SG 2, SG 3 (10%, 30%, 50 %)**: Substitution mortars produced during secondary mechanical testing of SG 1 material (source 1, ISIM Timisoara, initial sampling), SG 3 (source 1, ISIM Timisoara, secondary sampling); SG 5 (source 2, Tim Cut SRL, Timisoara, initial sampling) – VALIDATION STAGE.

The validation phase of the research confirms the initial results and implicitly the derived conclusions regarding the viability of the concept of partial substitution of fine aggregate (sand) in usual cement-based mortars by SG waste derived from AWJ processes. The credibility of the initial studies is confirmed in the secondary stage by the comparative analysis of the R1-1, R2-1 and SG1-1 samples, with similar compositions, developed with the same raw material, but more than 1 year later. The variation of the R1-1 vs R1 and R2-1 vs. R2, respectively, is sensitive for both 3PB flexural strength and compressive strength, at 7 and 28 days, and is within the usual variational limits, typical of cementitious composites, characterized by heterogeneity (Table 2, Figure 9). Simultaneously, the performance of the substitution mortars (SG1-1, SG 1 and SG 3), developed considering the percentage variation of the substitution of 0/4 natural sand 0/4 by SG material, from 10%, to 30% and 50%, confirms the trend traced by the R references, through sensible variations in the comparative analysis in Figure 8. At the same time, the results confirm the similarity of the SG material performance in cement-based material, considering the two distinct sampling procedures (SG 1 and SG 3), sourced from the same AWJ cutting operator. The variation of the AWJ cutting operations (processed material, equipment processing, conditioning, etc.) seems to produce a negligible effect on the SG waste performance when added to usual mortars. The SG grading curve (SG1 vs SG3), (Figure 6a and Figure 8) also confirms this assumption, in terms of physical characteristics.

The validation conclusions can be further expanded by including the SG 5 material, sourced from Tim Cut SRL Timisoara (Table 2, Figure 10). A common behavior pattern of SG waste in cement-based materials as partial sand replacement can be sketched, due to small variations recorded while comparative analyses are extended by SG 5 mortar inclusions.

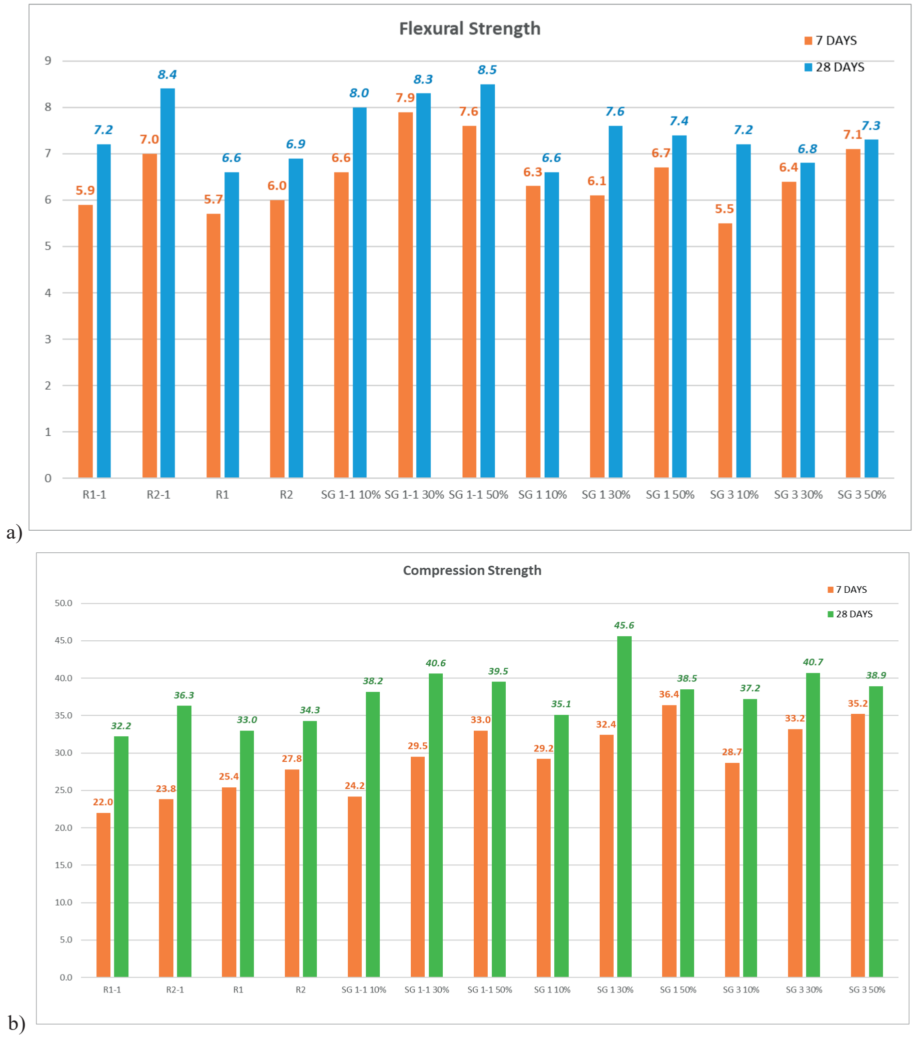
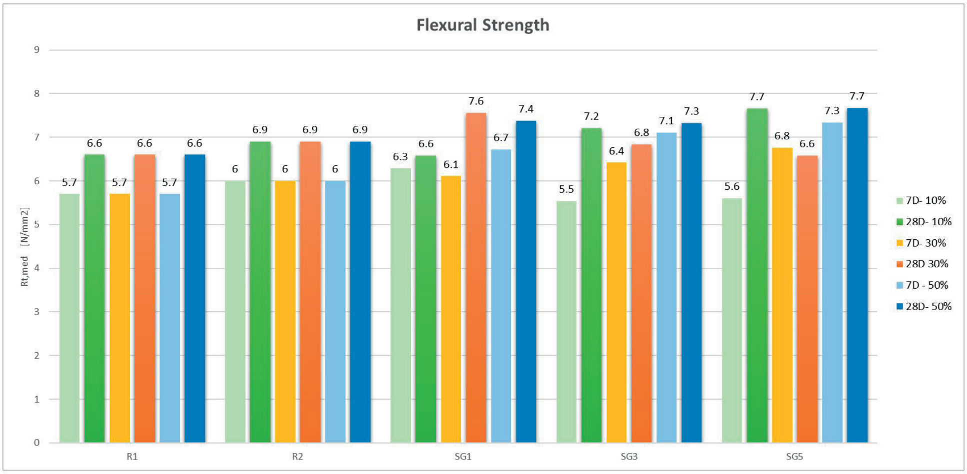
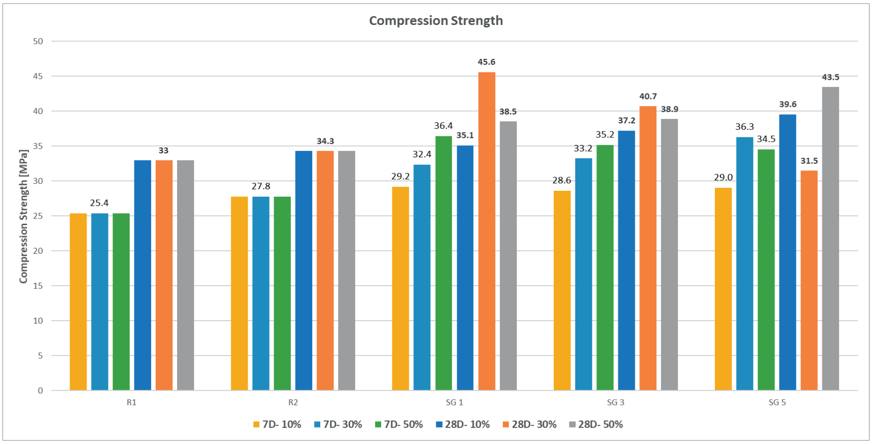


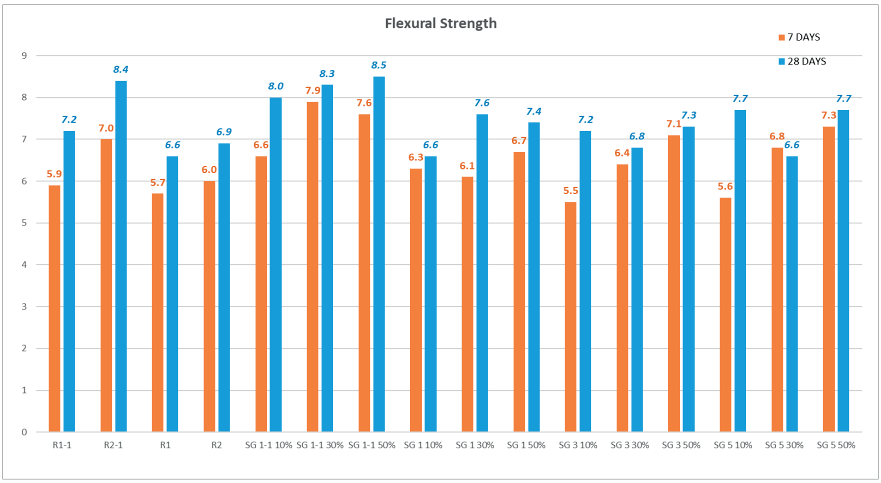
Figure 9. Validation stage - mechanical strength evaluation for the SG material sourced 1 (SG1 and SG 3) and Reference: a) 7-day and 28-day flexural strength; b) 7-day and 28-day compression strength


Flexural Strength
Rt,med [N/mm2]
R1
R2
SG1
SG3
SG5
7D- 10%
28D- 10%
7D- 30%
28D 30%
7D - 50%
28D- 50%

a)


Compression Strength
Compression Strength [MPa]
R1
R2
SG 1
SG 3
SG 5
7D- 10%
7D- 30%
7D- 50%
28D- 10%
28D- 30%
28D- 50%

b)


Flexural Strength
7 DAYS
28 DAYS
R1-1
R2-1
R1
R2
SG 1-1 10%
SG 1-1 30%
SG 1-1 50%
SG 1 10%
SG 1 30%
SG 1 50%
SG 3 10%
SG 3 30%
SG 3 50%
SG 5 10%
SG 5 30%
SG 5 50%

c)

d)

Figure 10. Comparative analysis of mechanical strength evaluation for the SG material sourced 1 (SG 1 and SG 3), sourced 2 (SG 5) and Reference: a), c) 7-day and 28-day flexural strength; b), d)7-day and 28-day compression strength

CONCLUSIONS

The experimental research program of compositional development of SG partially substituted preliminary mixtures, established in line with previous studies, conducted internationally (Muttashar et al., 2018a; 2018b) as well as in the laboratory (Cornelia B. et al., 2023; Vasile et al., 2024), generated 9 SG compositions, considering the operation of a specific screening in the area of substitution percentages used in the initial studies. This leads to the identification of the following as relevant values for assessing the efficiency of the substitution process:

a) 10% substitution;

b) 30% substitution;

c) 50% substitution.

Hardened state determinations and comparative performance evaluation lead to the identification of SG 30% and SG 50% compositions as prototype SG Mortar. The SG 10% compositions do not offer dramatic changes, and the percentage of substitution, 10% substitution is reduced to generate potential for technology transfer in the compositional area of common mortars and micro mortars. The SG 10% type compositions, though, have the role of confirming the identified trend and identifying possible compositional anomalies that may occur in the mix design.

In addition, the initial SG waste source is extended to a second one. (source 2). At the same time, new samplings are made from the original source 1 (ISIM Timisoara), thus extending the investigation area towards the validation of the initial conclusion and insurance of the robustness of the proposed concept. Ongoing research is offering valuable data regarding the compositional drawbacks and optimisation possibilities, related to the considered direct field of applicability, namely development of paving blocks for the innovative integration of SG into concrete mixes. Development of prefabricated paving products is considered an initial, practical, and more accessible use of SG substitution, with lower health risks for the population due to the outdoor placement of the products.

This field of application is particularly promising given the growing demand for paving products in the local Romanian market, driven by current infrastructure needs in both urban and rural areas. The approach also aligns with Circular Economy principles, by preventing Garnet sand waste and reintegrating it into new life cycles - specifically in building materials and products - while also contributing to the conservation of natural resources such as natural aggregates.

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REFERENCES

Ab Kadir, M. A., Khiyon, M. I., Sam, A. R. M., Kueh, A. B. H., Lim, N. H. A. S., Mastor, M. N. M. A., Zuhan, N., & Mohamed, R. N. (2019). Performance of spent garnet as a sand replacement in high-strength concrete exposed to high temperature, *Journal of Structural Fire Engineering, 10*(4), 468-481, 10.1108/JSFE-10-2018-0025

Budiea, A. M. A., Sek, W. Z., Mokhatar, S. N., Muthusamy, K., & Yusoff, A. R. M. (2021). Structural Performance Assessment of High Strength Concrete Containing Spent Garnet under Three Point Bending Test, IOP Conference Series: *Materials Science and Engineering 1144*(1), 10.1088/1757-899X/1144/1/012018.

Bucher, K., Weisenberger, T. B., Klemm, O., & Weber, S. (2019). Decoding the complex internal chemical structure of garnet porphyroblasts from the Zermatt area, *Western Alps. Journal of metamorphic Geology, 37*(9), 1151-1169, https://doi.org/10.1111/jmg.12506.

Baera, C., Gruin, A., Enache, F., Bolborea, B., Chendes, R. V., Ciobanu, A., ... & Corbu, O. (2023). Opportunities regarding the innovative conservation of the Romanian vernacular urbanistic heritage. *International Journal of Conservation Science, 14*(3), 913-936, DOI: 10.36868/IJCS.2023.03.09.

Chassé, M., Griffin, W. L., Alard, O., O'Reilly, S. Y., & Calas, G. (2018). Insights into the mantle geochemistry of scandium from a meta-analysis of garnet data. *Lithos, 310-311*, 409-421, 10.1016/j.lithos.2018.03.026.

Cornelia, B., Gruin, A., Bolborea, B., Chendeş, R., Burduhos-Nergiş, D. D., & Varga, L. (2023). Experimental Approach Regarding the Potential of Spent Garnets Use as Mineral Addition in Cement-Based Construction Products. *In Olympiad in Engineering Science (pp. 566-584). Cham: Springer Nature Switzerland.*

EN 196-1. Methods of testing cement - Part 1: Determination of strength.

EN 1015-11. Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar.

Huseien, G. F., Sam, A. R. M., Shah, K. W., Budiea, A. M. A., & Mirza, J. (2019). Utilizing spent garnets as sand replacement in alkali-activated mortars containing fly ash and GBFS, *Construction and Building Materials, 225,* 132-145, 10.1016/j.conbuildmat.2019.07.149.

Ionescu D., Serbanescu S. I., Perianu, I. A. - Patent No. 1. 129363 of 2014, Procedure for obtaining a mortar-type construction material from abrasive material waste, Oficiul de Stat pentru Mărci și Invenții, București, România BOPI 12 (2016).

Jamaludin, N. F. A., Muthusamy, K., Isa, N. N., Jaafar, M. F. M, & Ghazali, N. (2021) Use of spent garnet in industry: A review. *Materials Today: Proceedings, 48*(9), 10.1016/j.matpr.2021.02.210.

Kanta, N. R., & Ponnada, M. R. (2021). Performance of spent garnet sand and used foundry sand as fine aggregate in concrete, World *Journal of Engineering,* 10.1108/WJE-10-2020-0514.

Lim, N. H. A. S., & Alladin, N. F. N, Mohammadhosseini, H., Ariffin, N.F., Mazlan, A. N. (2020). Properties of Mortar Incorporating Spent Garnet as Fine Aggregates Replacement, *International Journal of Integrated Engineering 12*(9), 96-102. 10.30880/ijie.2020.12.09.012.

Longobardi, G., Moșoarca, M., Gruin, A., Ion, A., & Formisano, A. (2024). An innovative, lightweight, and sustainable solution for the integrated seismic energy retrofit of existing masonry structures, *Sustainability 16(11),* https://doi.org/10.3390/su16114791

Kunchariyakun, K., & Sukmak, P. (2020). Utilization of garnet residue in radiation shielding cement mortar, *Construction and Building Materials, 262,* 10.1016/j.conbuildmat.2020.120122.

Muttashar, H. L., Ariffin, M. A. M., Hussein, M. N., Hussin M. W., & Ishaq, S. B. (2018a). Self-compacting geopolymer concrete with spent garnet as sand replacement. *Journal of Building Engineering, 15,* 85-94, https://doi.org/10.1016/j.jobe.2017.10.007.

Muttashar, H. L., Ali, N. B., Ariffin, M. A. M., & Hussin, M. W. (2018b). Microstructures and physical properties of waste garnets as a promising construction material, *Case studies in construction materials, 8*, 87-96, https://doi.org/10.1016/j.cscm.2017.12.001.

Olinic, T., Olinic, E. D., & Butcaru, A. C. (2024). Integrating Geosynthetics and Vegetation for Sustainable Erosion Control Applications. *Sustainability, 16*(23), https://doi.org/10.3390/su162310621.

Perianu I. A., D. Ionescu, & V. Verbitchi. (2017) Method of measuring the abrasive-water jet diameter, for the cutting process control, *Welding and Material Testing – BID, 1.*

Skanavi, N., & Dovydenko, T. (2018, June). The use of waterjet cutting wastes in the production of building materials. In *IOP Conference Series: Materials Science and Engineering*, *365*(3), 10.1088/1757-899X/365/3/032025.

Usman, K. R., Hainin, M. R., Satar, M. K. I. M., Warid, M. N. M., Usman, A., Al-Saffar, Z. H., & Bilema, M. A. (2021). A comparative assessment of the physical and microstructural properties of waste garnet generated from automated and manual blasting process, Case Studies in *Construction Materials, 14* e00474.

Vasile, A. C., Baeră, C., Gruin, Perianu, I. A., Petrisor K.I. & Ion A. (2024). Experimental Study on Spent Garnets for Fine Grain Aggregate, a Partial Substitution in Cement Based Mortars: Validation of Preliminary Research. *Condferece Proceedings of "Innovative Technologies for Joining Advanced Materials" TIMA25, November 06-07, 2025 Timişoara, Romania (accepted for publication)*

https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-garnet.pdf (accesesed at 15.03.2025);

https://fredmhaynes.com/2021/03/11/a-sea-of-garnet-sand/ (accesesed at 15.03.2025);

https://www.precisionbusinessinsights.com/market-reports/garnet-market (accesesed at 15.03.2025);