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O. Djezairi[*1],
orcid.org/0009-0007-2829-8186,
S. Kherbache[2],
orcid.org/0009-0005-7206-3363,
N. Bouzidi[1],
orcid.org/0000-0002-9154-5895,
L. Perez-Villarejo[3,4],
orcid.org/0000-0002-6912-9844,
B. Ayaden[1],
orcid.org/0009-0006-1643-6572

1 – University of Bejaia, Faculty of Technology, Department of Mines and Geology, Laboratory of Materials Technology and Process Engineering (LTMGP), Bejaia, Algeria
2 – University of Bejaia, Faculty of the Technology, Laboratory of Construction Engineering and Architecture (LGCA), Bejaia, Algeria
3 – University of Jaén, Department of Chemical, Environment and Materials Engineering, Jaén, Kingdom of Spain
4 – University of Jaén, Center for Advanced Studies in Earth Sciences, Energy and Environment (CEACTEMA), Jaén, Kingdom of Spain
* Corresponding author e-mail: omar.djezairi@univ-bejaia.dz

EXPLORING PROPERTIES, DURABILITY, AND ENVIRONMENTAL IMPACT OF BARITE REJECTS AGGREGATES IN CONCRETE

Purpose. To study the use of rejected barite aggregates (BRA) from the Boucaïd mine as a partial substitute for quarry sand in concrete.

Methodology. The concrete was prepared by replacing quarry sand (QS) with rejected barite aggregates (BRA) of fraction 0/4 mm, at (0, 5, 10, 15, and 20 wt%). The mechanical properties and durability of the concrete were studied. Durability was assessed using leaching tests, in which concrete monoliths were immersed in water, an acid solution, and a sulfate solution. The leachates obtained were then subjected to chemical analysis to determine the heavy metal (Fe, Zn, and Pb) content.

Findings. A significant improvement in the properties of the concrete was observed, particularly in terms of compressive strength. The addition of 10 wt% of BRA led to optimal performance, with a compressive strength of 56.44 MPa. Durability of the best concrete exposed to water, acid and sulfate attacks show a good resistance, since loss in mass of the concretes is stabilized after 48 hours of immersion. As regards environmental sustainability, chemical analysis of the concrete containing 10 wt% of barite rejects aggregate reveals that the levels of heavy metals (Fe, Zn, Pb) from leaching tests remain low and within regulatory limits (USEPA) since they are trapped and immobilized in the concrete structure.

Originality. The novelty of this study lies in justifying the feasibility of the use of barite mine rejects as a partial substitute for quarry sand in concrete. The study highlights both an improvement in mechanical properties, particularly compressive strength and durability, and a sustainable environmental approach. This type of recovery has never been reported before for this type of mine reject.

Practical value. This study proposes a sustainable and applicable approach to materials for the construction industry, which enables the recycling of mining rejects adding value to them and providing an effective method for rehabilitating mining sites.

Keywords: *barite rejects aggregate, concrete, durability, leaching test, environmental impact*

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Introduction. The extraction of mineral substances generates significant amounts of solid reject, which constitute a source of danger and environmental degradation. The extent of the risk becomes significant, particularly when it comes to the extraction of polymetallic substances or non-metallic industrial minerals rich in sulfides and sulfates [1]. The various fields of use of barite, such as civil engineering, hydrocarbons, and the pharmaceutical industry, are continuously increasing the national and international demand for this material.

The barite ore ($BaSO_4$) in Algeria mainly comes from the Boucaïd mine (Tissemsilt region), the Ain Mimoun mine (Khenchla region), and the Ichmoul mine (Batna region). To meet the national demand, Algeria has increased barite production by opening new mines, namely the Koudiet Safia mine (Medea region) and the Draissa mine (Bechar region). As a result, these new

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mining activities will generate solid mining reject that may worsen the environmental situation, which requires their immediate management and valorization in the industry. The exploitation and processing of barite at the Boucaïd mine began in 1976, after the depletion of its polymetallic ore reserves (lead and zinc) that were exploited during the colonial era. Large quantities of gravity processing reject are accumulating, putting the region at risk of pollution [2]. To address the environmental impacts of these reject materials, their valorization has become an urgent necessity.

The valorization of these rejects in construction materials, such as cement, ceramics, and concrete, is part of contemporary solutions. The use of these reject products in these fields is essentially based on a thorough understanding of their physic-chemical characteristics and properties [3]. Indeed, barite reject aggregates increase the physical and mechanical properties of concrete, such as compressive strength and tensile strength [3, 4]. In order to protect the environment from heavy metal pollution caused by mining waste, recycling it in concrete manufacturing is a contemporary solution, subject to conducting an impact study of these metals on the durability of concrete [3, 4].

Barite reject containing heavy metals is currently used in the manufacture of heavy concrete for nuclear power plants and hospitals [5], due to the high density of baryte, which reaches approximately 4.2 g/cm^3, thus allowing for the attenuation of gamma radiation [4, 6]. Although, these additions negatively affect the mechanical properties of the obtained concretes [7]. These studies have shown the feasibility of substituting conventional aggregates with barite aggregates [8], or even using mixtures with other minerals or slag, magnetite [9], colemanite, hematite [10], combined with tungsten oxide [11], lead-zinc mine reject [12] and nanosilica [13].

According to the work by Badarloo and Esen [14, 15], the mass ratio of aggregate/barite rejects modifies the physical and mechanical properties of concrete; however, the compressive and tensile strengths decrease with the increase in barite content. The best result was obtained with a 10 % ratio of barite aggregates. The study carried out by Saidani [8] on the influence of replacing sand with powdered barite on the mechanical properties of concrete indicated that, at a maximum rate of 10 wt% of barite, the compressive strength of the concrete is optimal. The addition of powdered barite allowed filling the voids left by conventional aggregates, but it decreased the durability of the concrete.

Table 1

Labeling of concrete samples with the rate of barite rejection introduced, wt%

Sample code	BS0	BS5	BS10	BS15	BS20
% BRA	0	5	10	15	20

The study of the durability properties of concrete obtained with barite additions or barite residues is of vital importance, since according to Mostofinejad (2012) [16], barite concrete does not exhibit satisfactory durability when exposed to atmospheric conditions. According to Aksogan [17], the durability of the concrete expresses its endurance and service for many years without losing its strength.

Knowing that the Boucaïd mining region (Tissemsilt, Algeria) is exposed to pollution risks due to mining activity, generating waste likely to contain toxic elements [2], as is the case in several mining regions around the world. The aim of this study is to contribute to the environmental protection of this mining region by reducing the quantities of barite processing rejects through their recycling and recovery as a raw material to substitute quarry sand in concrete production.

Various properties of concrete were studied, particularly its physical and mechanical properties. Durability was assessed through leaching tests, during which concrete monoliths were exposed to aggressive environments, namely acid and sulfate attacks. The leachates obtained were then subjected to chemical analysis to quantify the concentrations of iron (Fe), zinc (Zn), and lead (Pb).

Material and methods. ***Materials.*** The rejects used in this study were recovered from the barite ore gravimetric treatment unit of the Boucaïd mine (Tissemsilt, Algeria) at a particle size of less than 16 mm. The barite rejects (BRA) were then dried in an oven for 24 hours at 105 °C. After this operation, they were separated using laboratory sieves into three size fractions the 0/4 mm fraction, 4/8 and 8/16 mm. For this work, only the fraction below 4 mm was used in concrete as a substitute for quarry sand (QS) from the El M'hir quarry (Bordj Bou Arreridj region) in different weight proportions: 0, 5, 10, 15, and 20 % (Fig. 1). The cement used in this study is a blended Portland cement type (CEM I 42.5R), manufactured according to the European standard EN 197-1,

a *b*

Fig. 1. Preparation of samples of barite rejects:
a – raw sample; b – sample of 0/4 mm

a *b* *c*

Fig. 2. Concrete samples:

a – immersed in water; b – subjected to compressive strength test; c – excavated for leaching test)

with a dosage of 350 kg/m^3. The mixing water used is tap water with 175 l/m^3, for a water/cement (W/C) ratio of 0.5 to obtain a slump value of 11 cm.

The concrete samples obtained were named as follows (BS0, BS5, BS10, BS15 and BS20) (Table 1).

Methods. The densities of the different granulometric fractions of aggregates used for making concrete were determined by the helium pycnometer method, using a Micromeritics ACCUPYS 1,330 pycnometer, in accordance with the European standard NF EN 1097-6. The quantity and quality of fines contained in QS and BRA were determined by the sand equivalent test, in accordance with standard NF EN 933-8, and by the methylene blue test, in accordance with standard NF EN 933-9, respectively. The chemical composition of the materials used in this study, such as BRA and QS, was determined by X-ray fluorescence using an instrument (PANalytical X'Pert Pro), while their mineralogical nature was determined by XRD using an X-ray diffractometer (Bruker D2 Phaser).

Concrete formulation. The formulation method used in this study is the Dreux Gorisse, which is suitable for concretes based on industrial rejects. The mixtures (aggregates/reject) were prepared using a 30-liter capacity mixer at a medium rotation speed for 10 minutes. Cement and water were added afterwards, 3 minutes after the mixing operation. The mixtures of obtained products were molded to prepare samples in the form of cubic test specimens with dimensions of 15 × 15 × 15 cm^3, subjected to vibrations using a vibrating rod according to the NF P 18-400 and NF P18-422 standards. Three concrete samples were prepared for each mixture, and then they were stored in a water basin at room temperature for 28 days (Fig. 2, *a*). The fresh density of concrete is determined as the ratio between the mass of compacted concrete in a mold and its nominal volume. Hardened density is calculated after 28 days of curing, by dividing the mass of hardened specimens by their actual volume.

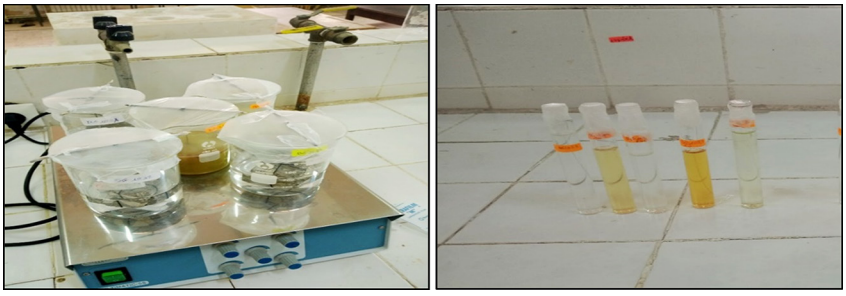
The compressive strength was determined using a 65-L11M2 type press following the UNE-EN-12390-3 (Fig. 2, *b*). The obtained results were compared with the reference sample (BS0) of 0 wt.% barite reject aggregates (BRA). Concrete samples with the highest compressive strength (BS10) were drilled and sawn into concrete blocks measuring of 40 × 40 × 20 cm^3 (Fig. 2, *c*).

Each sample was subjected to a Leaching Test (TLM) according to the UNE-EN 7375:2004 keeping them in two different solutions for a total duration of 28 days.

Three different preservation media were used for the leaching tests. These included distilled water, representing a neutral medium; a sulfate medium prepared with a (5 % $Na_2SO_4 \cdot 10H_2O$) solution; and an acidic medium consisting of a (5 % HCl) solution.

The pH and the mass losses were measured from the preservation solution after leaching periods of 6, 18, 24, 48, 120, 168, 480 and 672 hours.

An environmental study was conducted to examine the leaching of heavy metals such as iron (Fe), zinc (Zn), and lead (Pb) contained in the BS10 monolith during 28 days of immersion. This test was performed according to method TCLP 1311-1 (1992) (Fig. 3), and the amount of metals in the leachates was determined by inductively coupled plasma mass spectrometry (ICP-



a *b*

Fig. 3. Concrete leaching test in an agitator:

a – agitation test; b – solution collected for chemical analysis

MS) using an Agilent 7500 instrument equipped with Ar plasma ionization and a quadrupole detector.

Results and discussions. ***Physico-chemical characterization of the raw materials. Physical characterization.*** The particle size distribution curves illustrated in Fig. 4 show that quarry sand (QS) and the barite reject (BRA) have similar shapes, where the distribution is spread out. This distribution can improve some concrete properties, such as strengthening the cohesion between sand and gravel grains by reducing the size of the pores in the concrete, which can improve the cracking resistance.

The barite reject Aggregates (BRA) has a fairly high absolute density (Table 2) of around 3,338 kg/m^3 compared to that of the quarry sand (QS) of 2,734 kg/m^3. This is explained by the high content of barium sulfate $BaSO_4$ in the barite reject aggregates (BRA). This suggests that the barite aggregates are considered as heavy aggregates since its absolute density is greater than 3,000 kg/m^3. In addition, the absolute density of different fractions of aggregates is almost constant with an average value of 2,740 kg/m^3.

The sand equivalent test shows that BRA has a lower fine content (64 %) compared to QS (67 %). These values indicate that both sands are within the range generally considered acceptable for the production of normal quality concrete, according to standards such as ASTM D2419 or NF P18-598.

Furthermore, the results obtained with methylene blue show a significant difference between the two sands. BRA sand has a higher methylene blue value (2.49 mg/g), indicating the presence of a considerable amount of fine clay or silt particles, while QS has a very low value (0.5 mg/g), which indicates a clean sand, but with fewer fine particles.

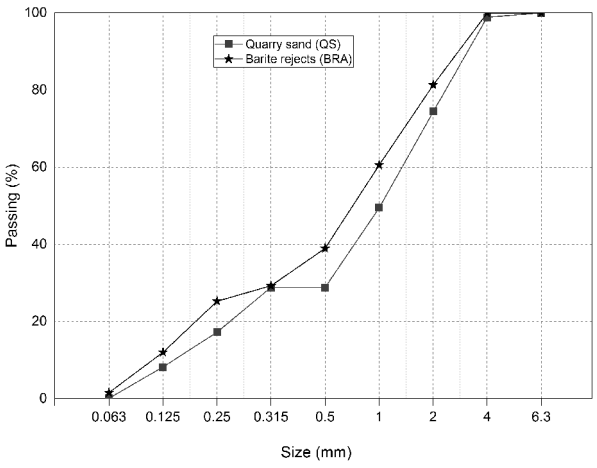


Fig. 4. Size distribution of quarry sand (QS) and barite reject aggregates (BRA)

Table 2

The density of raw materials

Products/fraction	BRA	QS	3/8 mm	8/15 mm	15/25 mm
Absolute density, kg/m^3	3,338	2,734	2,736	2,747	2,759
Real dried density, kg/m^3	3,102	2,643	2,680	2,680	2,698
Real saturated density, kg/m^3	3,172	2,677	2,701	2,704	2,720

Table 3

Sand cleanliness

Cleanliness	Quarry sand (QS)	Barite reject sand (BRA)
Sand equivalent, %	67	64.17
Methylene blue, mg/g	0.5	2.49

These results suggest that, although BRA meets the requirements of the sand equivalent, its higher methylene blue index reflects a higher clay content, which may influence its performance in concrete mixes (Table 3).

Mineralogical characterization. The result of the X-ray diffraction analysis of BRA and the quarry sand is shown in Fig. 5. The mineralogical composition shows that the main crystalline phases constituting BRA are calcite, barite and quartz; these phases are similar to the aggregates used in the manufacture of concrete. On the other hand, the quarry sand is mainly composed of dolomite and calcite.

Chemical compositions of materials. As shown in Table 4, BRA is mainly composed by (CaO, SiO_2, BaO and Fe_2O_3), which is quite similar to the compositions of aggregates and construction materials commonly used in concrete. The high content of calcium oxide (CaO) at 13.51 % is due to the host rock (limestone) of the barite deposit, which is beneficial for the manufacture of concrete. Moreover, the high content of BaO (13.37 %) is very useful for the manufacture of concrete; it will increase the density and compressive strength of concrete, and can also improve the overall durability of concrete by reducing permeability and increasing chemical resistance. Besides, SiO_2 (8.42 wt.%), which is the source of quartz in the barite reject deposit, could contribute to the increase in mechanical properties of the concrete. The loss on ignition (LOI) of the raw materials (~40 % wt%) is attributed to the decomposition of carbonates in the QS material (calcite and dolomite) as well as that of carbonates and sulfides in the BRA material, respectively related to the presence of calcite, dolomite, barite and pyrite. This loss mainly corresponds to CO_2 released by the carbonates. The chemical composition reveals significant amounts of Fe_2O_3, ZnO, and PbO, which also contribute to increasing the

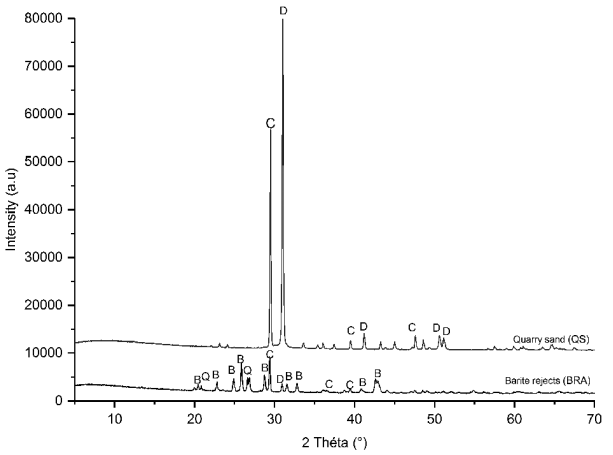


Fig. 5. X-ray diffraction patterns of Barite Reject and Quarry Sand aggregates (BRA and QS):
Q – quartz; C – Calcite; D – Dolomite; B – Barite

density of concrete, similar to BaO. However, these oxides can also represent a potential source of heavy metal leaching (Zn, Pb, and Fe) into the environment. The chemical composition of the quarry sand (QS) presented in Table 4 shows significant CaO and MgO contents attributed to the carbonate and dolomitic origin of sedimentary rock, with a CaO/MgO ratio = 1.7. Dolomitic aggregates have high compressive strength due to reduced porosity and water absorption, which can reduce the possibility of cracking and freeze/thaw damage. Dolomite can also improve the durability of concrete by making it more resistant to freeze-thaw cycles, and chemical attack.

Characterization of the prepared concrete. The composition of the concrete according to the Dreux-Gorisse method is presented in Fig. 6. Table 5 presents the proportions of the different concrete compositions necessary to produce three test specimens of 15 × 15 × 15 cm^3.

The reference granular curve must be plotted on the same graph as the particle size curves of the component aggregates. We then draw the dividing lines between each of the aggregates, by joining the 95 % point of the granular curve of the first, to the point at 5 % of the curve of the next aggregate, and so on. We will then read on the reference curve at the point of intersection with the straight line(s) of sharing, the absolute volume percentage of each of the aggregates (Sand, gravel 3/8, gravel 8/15 and gravel 15/25).

Table 4

Chemical composition of raw materials

Oxides	BRA	QS	Cement
B_2O_3	3.25	–	–
Na_2O	0.36	0.29	0.143
MgO	1.67	19.11	1.54
Al_2O_3	3.05	<0.05	4.26
SiO_2	10.07	0.27	19.93
SO_3	6.38	0.03	2.14
K_2O	0.39	<0.05	0.32
CaO	13.51	33.35	61.56
Fe_2O_3	4.98	0.26	4.65
CuO	0.01	<0.05	–
ZnO	1.31	0.02	–
SrO	0.27	0.03	–
BaO	13.37	0.06	–
PbO	0.88	<0.05	–
LOI*	40.15	40.47	3.88

* LOI, loss on ignition

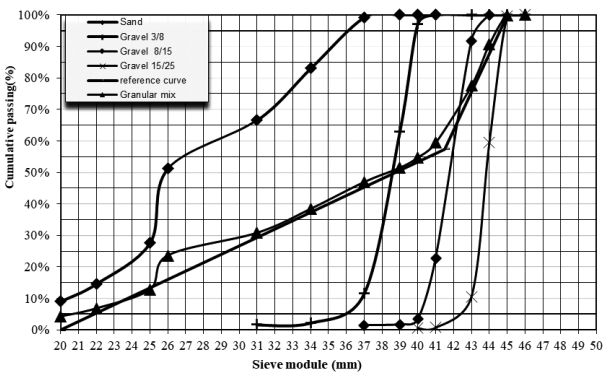


Fig. 6. Concrete mixing curve using the Dreux-Gorisse method

Table 5

Compositions of the concrete mix for one m^3 and for three test specimens

Constitute	kg/m^3	Three test pieces, g
Quarry Sand	871	8,823.87
Gravel 3/8	153	1,546.02
Gravel 8/15	441	4,462.66
Gravel 15/25	443	4,482.14
Cement	350	3,543.75
Water	175	1,771.88

Concrete densities. According to Fig. 7, the densities of fresh concrete produced with 5, 10, and 15 wt% BRA are lower than those of the reference concrete (BS0). This decrease is probably due to the presence of voids and pores in the structure, resulting in part from a lower initial compactness related to the granulometry of the barite aggregates (BRA). However, when the mixture contains 20 wt% of BRA, the density increases after 28 days of curing, which is explained not only by the progressive filling of voids, but also by better hydration of the cement and a reduction in capillary porosity. The effect of the high density of the barite-rich BRA ($BaSO_4$, ~4.2–4.5 g/cm^3) also contributes to this increase in density compared to quarry sand, which has a lower density (~2.6–2.7 g/cm^3). Thus, even at a low substitution rate of 10 wt%, the hardened concrete exhibits a higher final density after curing.

The maximum density of the hardened concrete is achieved with 10 wt% BRA, reaching 2.508 g/cm^3, suggesting an optimal substitution rate where compactness and density are prioritized. Beyond 15–20 wt%, the density stabilizes or decreases slightly, probably due to the increase in internal porosity despite the high intrinsic density of the BRA. This increase in density could be correlated with an improvement in certain mechanical properties of concrete, such as compressive strength, although other characteristics, such as fresh workability, may be affected [8].

Compressive strength of the concrete. Compressive strength results were performed on the different concrete compositions at 28 days and the results obtained are shown in Fig. 8. The higher compressive strength

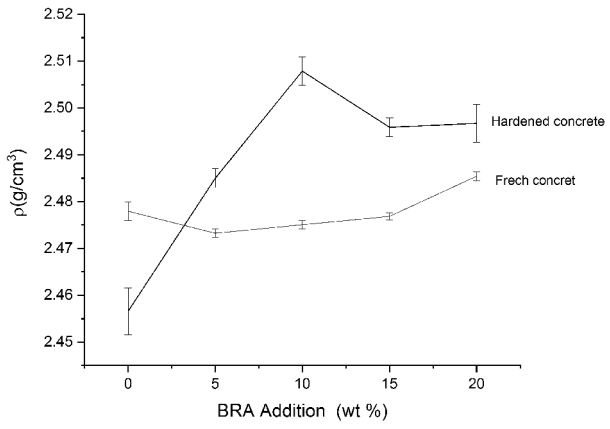


Fig. 7. Average density of fresh and hardened concrete (after 28 of curing days)

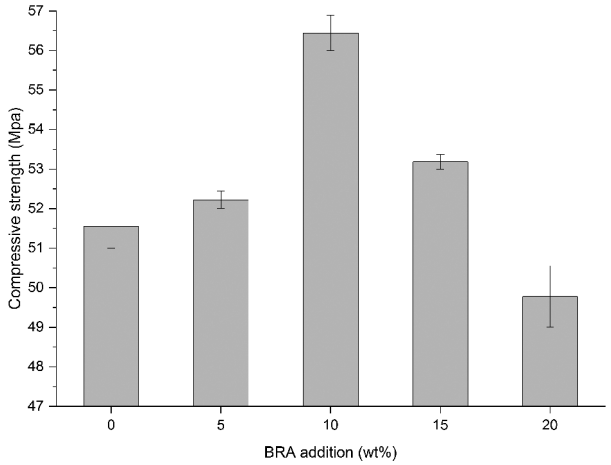


Fig. 8. Compressive strength of concrete a as function of BRA additions

was recorded to the concrete sample BS10 with a value of 56.44 MPa, this is due to the increase in the density of the concrete caused by the addition of high-density barite residue (3,338 kg/m^3). These results have been observed in similar works in the literature [5, 11, 16, 18]. The compressive strengths of BS10 specimens are much higher than those achieved in previous studies [8].

According to the study conducted by Shettima [19], the presence of iron improves the mechanical properties of concrete, particularly its compressive strength, by strengthening the bond between the cement matrix and aggregates. However, according to Liu [20], increasing the Pb content affects cement hydration, which reduces compressive strength. Indeed, Ling [21] states that excessive addition of barite negatively influences compressive strength due to the low mechanical strength of this material. According to Kök [22], the presence of B_2O_3 (3.25 wt% in BRA) contributes to the development of mechanical strength at early ages due to the mitigation the agglomeration of flocks and the increasing tetrahedral network fraction of silicates [SiO_4] and borates [BO_4], respectively. Beyond 10 % of BRA into the mixture, the value of the compressive strength of the concrete begins to decrease, but compared to the BS0 control concrete, it still remains high. This may come down to the cleanliness of the barite rejects and can also be explained by the reduction in the compactness of the concrete, but also the characteristic structure of the barite rejects [15]. Another reason that could explain the mechanical behavior for content higher than 10 % of barite aggregates cause decreasing compressive strength values is that, as indicated by González-Ortega [23], barite has a highly crystalline structure, which makes it very friable, which could cause the concrete to have worse mechanical properties when used as an aggregate. Aksogan [17] points out that the contribution of barite to compressive strength when added in large proportions is that the structure of barite is soft and has hardly any pozzolanic effect.

On the other hand, the compressive strength of the BS20 concrete is reduced below that of the BS0 control concrete and reaches 49.77 MPa. This result is probably due to the excess of the amount of barite existing in the rejects; it can generate a discontinuity of the granular curve of the mixture [8] beside the retarding effect of the heavy metals of lead and zinc existing in the rejects and which lead to the loss of compressive strength [24]. As Saidani [8] points out, the drop in compressive strength can be explained by the double effect of the substitution of the nature of the aggregates (barite residues) and the presence of fines in the barite that results in a more friable material.

In addition, observation of the density values of the hardened concrete (Fig. 7) shows that maximum density is achieved for the sample containing 10 % BRA. Above this level, increasing the BRA content leads to a gradual decrease in the density of the concrete. This decrease in density also explains the observed reduction in compressive strength values.

Mineralogical characterization of concrete. The results of the mineralogical analysis of the concrete presented in Fig. 9 reveal the primary phases composing concrete as calcite, dolomite, and quartz, alongside lower intensity peaks of portlandite and gypsum. Indeed, the intensity peaks of calcite and quartz are correlated with the rate of barite reject amounts. Otherwise, the intensity of the peaks of dolomite decreases and peaks of quartz increase with the increase of BRA additions. This is due to the formation of gypsum, portlandite and CSH phases.

Durability of barite reject based concretes in neutral, hydrochloric acid and sulfate salts environment. In order to see the behavior of the optimal concrete sample (BS10) in neutral, hydrochloric acid (HCl5 %) and sulphate salts (5 %) attacks, the loss in mass of the samples were recorded as function of time (during 28 days (672 hours).

Mass variation of BS10 sample immersed in neutral medium (water). As shown in Fig. 10, the mass loss of concrete cubes immersed in water increases up to 18 hours (2 wt%); this is due to the water filling the cracks and the pores of the samples. After 18 hours of immersion, the mass loss of the monolith samples decreases to ~0.8 wt% and tend to be more stable; this is due to the saturation process and the vacuums occupied by water beside the low water absorption characteristics of barite sand reject [17].

Mass variation of BS10 sample immersed in hydrochloric acid medium. As shown in Fig. 10, the mass loss

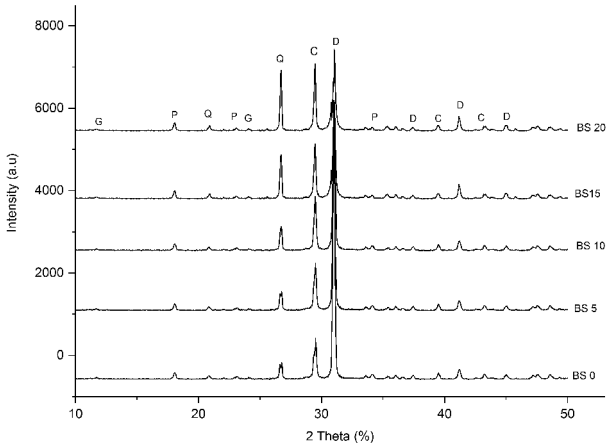


Fig. 9. X-ray diffraction patterns of the concrete samples: Q – quartz; C – Calcite; D – Dolomite; P – Portlandite; G – Gypsum

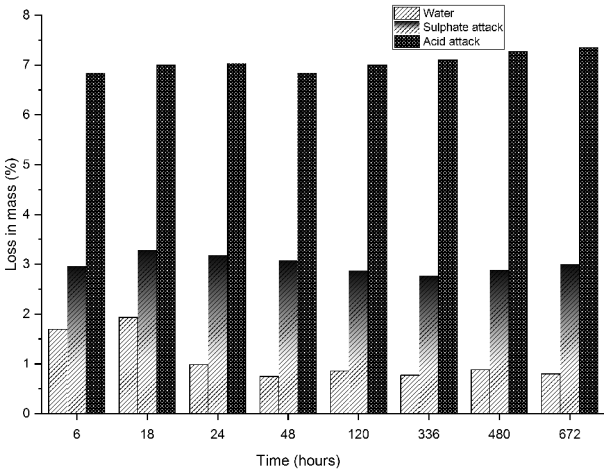


Fig. 10. Mass loss (wt%) in water, acid, and sulphate mediums

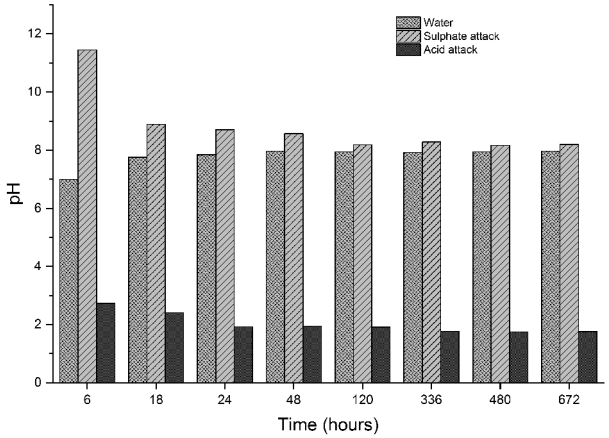


Fig. 11. pH variation of the leachates as function of time in neutral, hydrochloric acid, and sulfate salt environments

of concrete cubes immersed in 5 % of hydrochloric acid increases with the exposure period, reaching an average value of loss of 7 %. The presence of acid increases the rate of attack by reacting with the basic constituents of hydrated cement (alkali hydroxides, calcium hydroxide, calcium silicate hydrates, calcium aluminate, aluminate hydrates, monosulfate and ettringite).

Mass variation of BS10 sample immersed in sulfate (5 % $Na_2SO_4 \cdot 10\,H_2O$). According to Fig. 10, the mass loss of concrete cubes immersed in sulfate salts (5 % $Na_2SO_4 \cdot 10H_2O$) shows an increase in mass loss of the concrete samples, from 2.95 to 3.28 %, at 6 and 18 hours of immersion. This mass loss stabilizes at the end of the immersion period (28 days). Attack by sodium sulfate (alkaline sulfates) reacts with portlandite (CH), monosulfate, and non-tricalcium aluminate (C_3A) to form gypsum (CSH) and ettringite, causing cracks to form and leading to deterioration of the concrete [25].

pH variation of leachates in neutral, hydrochloric acid, and sulfate salt environments. The pH of the leachates of the concrete samples (BS10) in neutral (distilled water), hydrochloric acid and sulfate salt environments was studied, pH measurements were carried out along the analyzed periods of exposure (Fig. 11).

The results related to the leachates obtained in distilled water environment show an increase in the value of pH from 7 after 6 hours on immersions to 8.0 later 672 hours (28 days); after immersion in distilled water, the pH values tend to increase smoothly until stabilizing in the range of pH ~8 to the end of the exposure (672 hours). As the amount of QS replaced by BRA increases, the amount of calcium and magnesium salts decreases, consequently resulting in a smoother increase in pH.

Regarding the pH values of the leachates obtained from the concrete (BS10) immersed in acidic environments (Fig. 11), they tend to be low and vary from 2.73 to 1.76. However, the pH values within the initial day (24 hours) range from 2.73 to 2.40, indicating a high rate of chloride release during the early stages of acid exposure. After that, pH values tend to be stabilized around 1.75 to the end of the exposure (672 hours). In HCl attack, the chloride ions react with calcium ions to form calcium chloride, which is a gel-like state. The decrease in pH values in the acid medium of the leachates is mainly due to the less release of OH^-. Therefore, the C—S—H phase could be destabilized and consequently starts to release calcium ions, which could elevate pH values [26].

When BS10 samples are exposed to sodium sulfate attack (Fig. 11), the pH values of the leachates increase along time and are basic pH > 8. However, the pH values are significantly higher during the first 24 hours (11.45), gradually decreasing to 8.17 thereafter. Hence, higher pH maintains the stability of CSH and ettringite particles.

Toxicity Characteristic Leaching Procedure (TCLP) results. The results of leaching tests conducted on BS10 samples exposed to acid and sulfate salt solutions are summarized in Tables 6 and 7, respectively. The concentrations of Fe, Zn and Pb ions are expressed in ppm (mg/L) after 6, 18, 24, 48, 120, 336, 480 and 672 hours (28 days) of curing.

As shown in Table 6, the concentration of Fe increased as a function of the immersion time. Moreover, the same trend of the concentration of zinc and lead was noticed. This fact suggests that the acid attack releases the metals contained in the concrete [26].

The results presented in Table 7, showed that the concentrations of iron were much higher than those of lead and zinc, which is due to higher content of iron in BRA. Overall, the concentration of the heavy metals in the leachate diminished as the time of immersion was increased showing that these heavy metals are stabilized and immobilized in the concrete matrix. The concentrations of the heavy metals were much lower than the Toxicity Characteristic Leaching Procedure (TCLP) criterion concentration, even after a longer period of leaching (672 hours). It was mentioned that the concentrations of the heavy metals in the leachates are much higher in acid attack than in sulfate attack. However, the concentrations of the heavy metals were much lower than the Toxicity Characteristic Leaching Procedure (TCLP) criterion concentration.

Environmental impact of utilizing barite rejects in concrete production. Barite aggregate is a very high-density aggregate (3.3 g/cm^3). However, replacing part of the sand incorporated into the concrete with barite sand, the obtained samples were 10 % stronger than those made from traditional concrete. On the other hand, the

Table 6

Leaching test on concrete attacked by HCl, 5 %

Time, h	6	18	24	48	120	336	480	672	Limit value, mg/L
Concentration, mg/L									
Fe	9.29	42.21	66.67	206.98	253.11	260.12	267.11	268.20	nd[1]
Zn	3.00	3.43	4.39	6.94	9.46	9.75	9.82	9.90	250
Pb	0.45	0.47	0.49	1.42	1.91	1.99	2.02	2.03	5

[1] not defined

Table 7

Leaching test on concrete attacked by sulfate salts, 5 %

Time, h	6	18	24	48	120	336	480	672	Limit value, mg/L
Concentration, mg/L									
Fe	nd[1]	5.210	2.668	1.980	1.112	0.980	0.910	0.880	nd[1]
Zn	250	0.617	0.448	0.370	0.353	0.317	0.309	0.307	250
Pb	5	0.468	0.415	0.387	0.385	0.372	0.371	0.371	5

[1] not defined

incorporation of a significant quantity of barite aggregates into concrete (beyond 15 %) clearly reduces its mechanical resistance. These barite aggregates therefore offer a large part of the resistance properties, high density, and an absence of abrasiveness and chemical neutrality of concrete.

There are technical problems in adopting recycled aggregates as an alternative material to natural aggregates, such as residual mortar adhesion, porosity and water absorption [27], as well as possessing, in general, a quality [28]. Although from an environmental point of view, as in this case, barite rejects, the main problem in their use is the leaching of heavy metals [29], although one of the factor's governing leaching is pH and this determines that they can be considered as inert or non-hazardous materials, which is not the case with natural aggregates. Another important aspect from an environmental point of view is the depletion of resources, due to the increasing demand for them, as in the case of fine aggregates, and taking into account that around 70–80 % of the volume of concrete is aggregates, taking into account the increase in concrete use, which is expected to be 4.3 % for the period 2022–2030 [30], and the environmental impact of the use of natural aggregates and the need for further efforts for standardization and extension of the use of recycled aggregates is evident.

The heavy concretes thus obtained could be particularly suitable for the construction of long-lasting structures such as tunnels and bridges. They may also be used in nuclear power plants due to their radiation-absorbing properties, as well as in the creation of counterweights.

Thanks to the high weight of these concretes, it allows the structures to be anchored to the ground.

Conclusion. The following conclusions are made from the experimental results.

The mineralogical and chemical analysis results of the barite reject from the Boucaïd mine shows that these rejects are mainly composed of calcite ($CaCO_3$), barite ($BaSO_4$), and quartz (SiO_2), which is characteristic of the casing host rock (limestone) of the barite deposit. The absolute density of barite reject aggregates (BRA) is very large at 3,338 kg/m^3 compared to that of quarry sand (QS), which is 2,734 kg/m^3. The grain size distribution of barite rejects (BRA) presents a spread distribution and close to that of quarry sand. This distribution plays an important role in the quality of the concrete produced, as it reinforces the cohesion between sand and gravel particles by reducing the pore size in the concrete mix, which can improve resistance to cracking.

The results suggest that barite reject aggregates addition should be limited to 10 wt% of the concrete mix to ensure the integrity of compressive strength of 56.44 MPa. However, excessive increase in barite rejects aggregates (BRA > 15 wt%) leads to a significant decrease in the compressive strength of concrete due to increase of porosity and fine particles belonging to BRA.

Mineralogical analysis of the concrete reveals the primary phases composing concrete, as calcite, dolomite, and quartz, alongside lower intensity peaks of portlandite and gypsum. Indeed, the intensity peaks of calcite and quartz are correlated with the rate of barite reject addition. Otherwise, the intensity of the peaks of dolomite decreases and peaks of quartz increase with the increase in BRA additions. This is due to the formation of gypsum, portlandite and CSH phases.

The loss in mass of BS10 samples immersed in water increases to 2 wt% before 18 hours of immersion in distilled water. After 18 hours, this parameter decreases (0.8 wt%) and tends to be more stable. This is due to the saturation process and the fact that the vacuums are occupied by water beside the low water absorption characteristics of barite sand reject (10 wt). An increase is achieved in loss in mass of the BS10 concrete when it is exposed to sulfate attack (~3 %); after 48 hours of immersion, the loss in mass is stabilized. However, the mass loss of the concretes in acid attacks is higher (~7 %) but tend to be stabilized after 48 hours of immersion.

The leachates obtained in distilled water environment show an increase in pH from 7 (after 6 hours of immersion) to 8.0 (later after 672 hours (28 days). This is due to the release of calcium and magnesium salts which consequently increase slightly pH of the leachate. When exposed to acid attack, pH values of the leachates vary from 2.73 to 2.40 in the first 24 hours, then they decrease until 1.76 in the end of immersion (672 hours), this is due to the less release of OH^-. Besides, the chlo-

ride ions react with calcium ions to form calcium chloride, which is a gel-like state. When BS10 samples are exposed to sodium sulfate attack, the pH values of the leachates increased along time and are basic pH > 8. However, the pH values are significantly higher during the first 24 hours (11.45), gradually decreasing to 8.17 thereafter. Hence, higher pH maintains the stability of CSH and ettringite particles, whereas the decrease in pH affects the stability of the CSH particles.

The result of Leaching Test on Concrete Monoliths (TML) indicates that the concentrations of Zn, Pb, and Fe in the leachate are acceptable and do not exceed the regulatory limit for heavy metals established by USEPA. The use of barite rejects from the Boucaïd mine can be successfully employed as an aggregate additive in concrete formulation, substituting quarry sand. In addition to its economic advantage, this natural reject material generates appreciable compressive strength, durability and immobilization of the heavy metals. This can avoid the risk of pollution in the mining area and protect the environment.

References.

1. Gallala, W., Hayouni, Y., Gaied, M. E., Fusco, M., Alsaied, J., Bailey, K., & Bourham, M. (2017). Mechanical and radiation shielding properties of mortars with additive fine aggregate mine waste. *Annals of nuclear energy, 101*, 600-606. https://doi.org/10.1016/j.anucene.2016.11.022

2. Attoucheik, L., Jordanova, N., Bayou, B., Lagroix, F., Jordanova, D., Maouche, S.,..., & Boutaleb, A. (2017). Soil metal pollution from former Zn–Pb mining assessed by geochemical and magnetic investigations: case study of the Bou Caid area (Tissemsilt, Algeria). *Environmental Earth Sciences, 76*, 1-17. https://doi.org/10.1007/s12665-017-6622-9

3. Gou, M., Zhou, L., & Then, N. W. Y. (2019). Utilization of tailings in cement and concrete: A review. *Science Engineering of Composite Materials, 26*(1), 449-464. https://doi.org/10.1515/secm-2019-0029

4. Zayed, A., El-Khayatt, A., Petrounias, P., Shahien, M., Mahmoud, K., Rashad, A. M.,..., & Masoud, M. (2024). From discarded waste to valuable products: Barite combination with chrysotile mine waste to produce radiation-shielding concrete. *Construction Building Materials, 417*, 135334. https://doi.org/10.1016/j.conbuildmat.2024.135334

5. Topçu, İ. B. (2003). Properties of heavyweight concrete produced with barite. *Cement Concrete Research, 33*(6), 815-822. https://doi.org/10.1016/S0008-8846(02)01063-3

6. Akkurt, I., Akyildirim, H., Mavi, B., Kilincarslan, S., & Basyigit, C. (2010). Gamma-ray shielding properties of concrete including barite at different energies. *Progress in Nuclear Energy, 52*(7), 620-623. https://doi.org/10.1016/j.pnucene.2010.04.006

7. Sakr, K., & El-Hakim, E. (2005). Effect of high temperature or fire on heavy weight concrete properties. *Cement Concrete Research, 35*(3), 590-596. https://doi.org/10.1016/j.cemconres.2004.05.023

8. Saidani, K., Ajam, L., & Ouezdou, M. B. (2015). Barite powder as sand substitution in concrete: Effect on some mechanical properties. *Construction Building Materials, 95*, 287-295. https://doi.org/10.1016/j.conbuildmat.2015.07.140

9. Gunoglu, K., & Akkurt, İ. (2021). Radiation shielding properties of concrete containing magnetite. *Progress in Nuclear Energy, 137*, 103776. https://doi.org/10.1016/j.pnucene.2021.103776

10. Shams, T., Eftekhar, M., & Shirani, A. (2018). Investigation of gamma radiation attenuation in heavy concrete shields containing hematite and barite aggregates in multi-layered and mixed forms. *Construction Building Materials, 182*, 35-42. https://doi.org/10.1016/j.conbuildmat.2018.06.032

11. Al-Ghamdi, H., Elsafi, M., Sayyed, M., Almuqrin, A. H., & Tamayo, P. (2022). Performance of newly developed concretes incorporating WO_3 and barite as radiation shielding material. *Journal of Materials Research Technology, 19*, 4103-4114. https://doi.org/10.1016/j.jmrt.2022.06.145

12. Çullu, M., & Bakırhan, E. (2018). Investigation of radiation absorption coefficients of lead-zinc mine waste rock mixed heavy concrete at 662–1460 keV energy range. *Construction Building Materials, 173*, 17-27. https://doi.org/10.1016/j.conbuildmat.2018.03.175

13. Janković, K., Stanković, S., Bojović, D., Stojanović, M., & Antić, L. (2016). The influence of nano-silica and barite aggregate on properties of ultra high performance concrete. *Construction Building Materials, 126*, 147-156. https://doi.org/10.1016/j.conbuildmat.2016.09.026

14. Badarloo, B., Lehner, P., & Bakhtiari Doost, R. (2022). Mechanical properties and gamma radiation transmission rate of heavyweight concrete containing barite aggregates. *Materials, 15*(6), 2173. https://doi.org/10.3390/ma15062173

15. Esen, Y., & Yilmazer, B. (2010). Investigation of some physical and mechanical properties of concrete produced with barite aggregate. *Scientific Research and Essays, 5*(24), 3826-3833. https://doi.org/10.5897/SRE.9000040

16. Mostofinejad, D., Reisi, M., & Shirani, A. (2012). Mix design effective parameters on γ-ray attenuation coefficient and strength of normal and heavyweight concrete. *Construction Building Materials, 28*(1), 224-229. https://doi.org/10.1016/j.conbuildmat.2011.08.043

17. Aksoğan, O., Binici, H., & Ortlek, E. (2016). Durability of concrete made by partial replacement of fine aggregate by colemanite and barite and cement by ashes of corn stalk, wheat straw and sunflower stalk ashes. *Building Materials Construction, 106*, 253-263. https://doi.org/10.1016/j.conbuildmat.2015.12.102

18. Bouali, E., Abdelhak, K., Ayadi, A., & Soualhi, H. (2019). Effet de l'ajout de la Barytine BaSO4 dans la formulation des bétons lourds. *Academic Journal of Civil Engineering, 37*(1), 147-150. https://doi.org/10.26168/acje.37.1.31

19. Shettima, A. U., Hussin, M. W., Ahmad, Y., & Mirza, J. (2016). Evaluation of iron ore tailings as replacement for fine aggregate in concrete. *Construction Building Materials, 120*, 72-79. https://doi.org/10.1016/j.conbuildmat.2016.05.095

20. Liu, H., Shi, J., Qu, H., & Ding, D. (2019). An investigation on physical, mechanical, leaching and radiation shielding behaviors of barite concrete containing recycled cathode ray tube funnel glass aggregate. *Construction Building Materials, 201*, 818-827. https://doi.org/10.1016/j.conbuildmat.2018.12.221

21. Ling, T.-C., & Poon, C.-S. (2012). Feasible use of recycled CRT funnel glass as heavyweight fine aggregate in barite concrete. *Journal of cleaner production, 33*, 42-49. https://doi.org/10.1016/j.jclepro.2012.05.003

22. Kök, S., Türetken, M., Öksüzer, N., & Gökçe, H. (2023). Effect of elevated temperature on radiation shielding properties of cement and geopolymer mortars including barite aggregate and colemanite powder. *Materialia, 27*, 101693. https://doi.org/10.1016/j.mtla.2023.101693

23. González-Ortega, M. A., Cavalaro, S., & Aguado, A. (2015). Influence of barite aggregate friability on mixing process and mechanical properties of concrete. *Construction Building Materials, 74*, 169-175. https://doi.org/10.1016/j.conbuildmat.2014.10.040

24. Kundu, S., Aggarwal, A., Mazumdar, S., & Dutt, K. B. (2016). Stabilization characteristics of copper mine tailings through its utilization as a partial substitute for cement in concrete: preliminary investigations. *Environmental Earth Sciences, 75*, 1-9. https://doi.org/10.1007/s12665-015-5089-9

25. Achour, R., Zentar, R., Abriak, N.-E., Rivard, P., & Gregoire, P. (2019). Durability study of concrete incorporating dredged sediments. *Case Studies in Construction Materials, 11*, e00244. https://doi.org/10.1016/j.cscm.2019.e00244

26. Usman, J., & Sam, A. M. (2017). Acid resistance of palm oil fuel ash and metakaolin ternary blend cement mortar. *Sustainable Environment Research, 27*(4), 181-187. https://doi.org/10.1016/j.serj.2017.02.003

27. Arandara, K., Paranavithana, G., Priyadarshana, S., Pitawala, H., & Dissanayake, R. (2024). Evaluation of coconut shell biochar on recycled aggregate concrete through petrographic studies. *Construction Building Materials, 428*, 136342. https://doi.org/10.1016/j.conbuildmat.2024.136342

28. Paleari, M., Lavagna, M., & Campioli, A. (2016). The assessment of the relevance of building components and life phases for the environmental profile of nearly zero-energy buildings: life cycle assessment of a multifamily building in Italy. *The International Journal of Life Cycle Assessment, 21*, 1667-1690. https://doi.org/10.1007/s11367-016-1133-6

29. Galvín, A. P., Ayuso, J., Agrela, F., Barbudo, A., & Jiménez, J. R. (2013). Analysis of leaching procedures for environmental risk assessment of recycled aggregate use in unpaved roads. *Construction Building Materials, 40*, 1207-1214. https://doi.org/10.1016/j.conbuildmat.2011.12.091

30. Sabbrojjaman, M., Liu, Y., & Tafsirojjaman, T. (2024). A comparative review on the utilisation of recycled waste glass, ceramic and

rubber as fine aggregate on high performance concrete: Mechanical and durability properties. *Developments in the Built Environment, 17*, 1-18. https://doi.org/10.1016/j.dibe.2024.100371

Дослідження властивостей, довговічності та впливу на навколишнє середовище заповнювачів із відходів бариту в бетоні

О. Джезаірі[*1], *С. Хербаш*[2], *Н. Бузіді*[1], *Л. Перез-Вільярехо*[3,4], *Б. Аяден*[1]

1 – Університет Беджая, Технологічний факультет, кафедра гірничої справи та геології, лабораторія матеріалознавства й технологічних процесів (LTMGP), м. Беджая, Алжир

2 – Університет Беджая, Технологічний факультет, Лабораторія будівельної інженерії та архітектури (LGCA), м. Беджая, Алжир

3 – Університет Хаена, Кафедра хімічної, екологічної та матеріалознавчої інженерії, м. Хаен, Королівство Іспанія

4 – Університет Хаена, Центр передових досліджень у галузі наук про Землю, енергетики та навколишнього середовища (CEACTEMA), м. Хаен, Королівство Іспанія

[*] Автор-кореспондент e-mail: omar.djezairi@univ-bejaia.dz

Мета. Дослідження можливості використання відвальних баритових заповнювачів (BRA) із родовища Букаїд як часткової заміни кар'єрного піску в бетоні.

Методика. Бетонні суміші виготовляли шляхом заміщення кар'єрного піску (QS) відвальними баритовими заповнювачами (BRA) фракції 0/4 мм у кількості 0, 5, 10, 15 та 20 мас.%. Досліджені механічні властивості й довговічність бетону. Довговічність оцінювали методом вилуговування, за якого бетонні моноліти занурювали у воду, кислотний і сульфатний розчини. Отримані фільтрати (елюати) піддавали хімічному аналізу для визначення вмісту важких металів (Fe, Zn, Pb).

Результати. Встановлено суттєве покращення властивостей бетону, зокрема його міцності на стиск. Додавання 10 мас.% BRA забезпечило оптимальні показники із міцністю на стиск 56,44 МПа. Дослідження довговічності зразків, підданих впливу води, кислотного й сульфатного середовища, показало їх високу стійкість, оскільки втрата маси бетону стабілізувалася після 48 годин занурення. Щодо екологічної безпечності, хімічний аналіз бетону з 10 мас.% баритових відходів засвідчив, що концентрації важких металів (Fe, Zn, Pb) у результатах тестів на вилуговування залишаються низькими й не перевищують нормативні межі (USEPA), оскільки вони фіксуються та іммобілізуються у структурі бетону.

Наукова новизна. Полягає в обґрунтуванні доцільності використання відходів баритових рудників як часткової заміни кар'єрного піску в бетоні. Робота демонструє одночасне підвищення механічних характеристик, зокрема міцності на стиск і довговічності, а також екологічну доцільність такого підходу. Подібний напрям утилізації цього типу гірничих відходів раніше не висвітлювався.

Практична значимість. Запропоновано сталий і прикладний підхід щодо матеріалів для будівельної галузі, який дозволяє залучити відвальні відходи у вторинний обіг, підвищити їхню додану вартість і сприяти екологічній реабілітації гірничих територій.

Ключові слова: *відвальні баритові заповнювачі, бетон, довговічність, тест на вилуговування, вплив на довкілля*