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REVIEW
of the doctoral dissertation
by M.Sc. Eng. Iman Abbasi Nattaj Omrani
„Developments in investigating the durability of porous building materials under the chemical and physical modes of external sulfate attack"

1. Basis for the preparation of the review

The formal basis for the preparation of this opinion is Resolution No. 1.14/12/2025 of the Council of the Discipline of Civil Engineering, Geodesy and Transport at Lodz University of Technology, dated May 15, 2025, as well as the letter from the Dean of the Faculty of Civil Engineering, Architecture and Environmental Engineering at Lodz University of Technology, Prof. Artur Wirowski, dated May 23, 2025, by which—pursuant to the decision of the Council—I was appointed as a reviewer in the procedure for awarding the doctoral degree to M.Sc. Eng. Iman Abbasi Nattaj Omrani.
The substantive basis for this review is the doctoral dissertation submitted by M.Sc. Eng. Iman Abbasi Nattaj Omrani, entitled "Developments in Investigating the Durability of Porous Building Materials Under the Chemical and Physical Modes of External Sulfate Attack."
The legal basis for the preparation of this review consists of the acts and regulations governing the requirements for doctoral dissertations and their evaluation procedure, in particular:

- Ustawa z dnia 3 lipca 2018 r. – Przepisy wprowadzające ustawę – Prawo o szkolnictwie wyższym i nauce (Dz.U. 2018 poz. 1669 z późn. zm.),
- Ustawa z dnia 20 lipca 2018 r. – Prawo o szkolnictwie wyższym i nauce (Dz.U. 2023 poz. 742 z późn. zm.),
- Rozporządzenie Ministra Edukacji i Nauki z dnia 11 października 2022 r. w sprawie dziedzin nauki i dyscyplin naukowych oraz dyscyplin artystycznych (Dz.U. 2022 poz. 2202).

2. Subject and general overview of the dissertation

The subject of this review is the doctoral dissertation by M.Sc. Eng. Iman Abbasi Nattaj Omrani, entitled "Developments in investigating the durability of porous building materials under the chemical and physical modes of external sulfate attack." The dissertation was written in English at Lodz University of Technology under the scientific supervision of Prof. Marcin Koniorczyk (main supervisor), and Dr. Piotr Konca (auxiliary supervisor).

The dissertation concerns the durability of porous building materials exposed to external sulfate attack, understood in two ways: as chemical sulfate attack (chemical reactions between sulfate ions and material components) and as physical sulfate attack (crystallization of sulfate salts within the material's pores).

The topic is highly relevant from both a materials engineering and construction perspective. The degradation of infrastructure due to sulfate exposure (e.g. from soil or groundwater) is a serious issue for the long-term performance of building materials. Of particular interest is the case of partially immersed materials, where an evaporation (drying) zone forms. In this zone, both mechanisms—chemical and physical—may potentially coexist, and the literature lacks a clear answer as to which of them dominates under specific environmental conditions. The doctoral Candidate addressed this issue with the goal of clarifying the role of climatic factors (particularly evaporation rate) in the degradation mechanism of cementitious materials caused by sulfate ions.

The dissertation is of a research nature. The author conducted an extensive literature review on both the chemical and physical aspects of sulfate attack on cement-based materials, identifying knowledge gaps and inconsistencies in previous studies. He then designed and implemented an experimental program aimed at separating and assessing both degradation modes.

The Candidate employed a wide array of experimental techniques to evaluate the condition of materials subjected to sulfate attack, including ultrasonic pulse velocity (UPV) for assessing structural continuity and internal cracking, X-ray diffraction (XRD) for identifying reaction and crystallization products in different specimen zones, thermogravimetric analysis (TG/DTA), Fourier-transform infrared spectroscopy (FTIR) for detecting changes in solid phase composition and the presence of sulfate-related functional groups (e.g., ettringite, gypsum), mercury intrusion porosimetry (MIP) for evaluating pore size distribution and total porosity, particularly the effects of salt crystallization on microcracking and pore network structure. For quantitative assessment of salt crystallization in the pores, the author also used differential scanning calorimetry (DSC) to detect phase transitions (e.g., crystallization and dissolution of mirabilite – $Na_2SO_4 \cdot 10H_2O$). Combined with other methods, this allowed monitoring the progress of physical sulfate attack. To evaluate the impact of sulfate attack on transport properties, the Cembureau method for gas permeability testing was applied. This method, based on gas flow through the specimen under controlled pressure, enabled a quantitative assessment of degradation and changes in pore connectivity. This comprehensive methodological approach enabled the Author to assess the extent of degradation and identify the mechanisms responsible for material damage. The results were subjected to detailed comparative analysis, which allowed the formulation of conclusions about the prevailing nature of sulfate attack under the investigated environmental conditions.

The dissertation text is enriched with illustrations, photographs of damage, diagrams showing changes in durability parameters over time, as well as diffractograms and thermograms presenting phase compositions. The dissertation also includes a discussion of the results in the context of literature findings, enabling comparison of the Candidate's conclusions with the current state of knowledge.

The dissertation consists of six main chapters spanning a total of 142 typescript pages, including figures, tables, and a bibliography listing 202 references. However, it lacks a list of figures and tables, a compilation of cited standards and test methods, and a Polish-language abstract.

I conclude that its content is logically and clearly structured, appropriate for a scientific research work. It is divided into a theoretical section (literature review, definition of objectives and research theses) and an experimental section (description of methods and results analysis), which are consistent in content. The selection of literature is appropriate and sufficient for the topic.

3. Evaluation of the dissertation

3.1. Relevance of the topic, title, and scope of the dissertation

The choice of topic for this doctoral dissertation is undoubtedly appropriate. The research problem addressed in the dissertation has both significant scientific and practical relevance. The durability of building materials—particularly concrete—under sulfate attack has long been a major engineering challenge. Damage caused by chemical attack from sulfate ions, leading to ettringite and gypsum expansion in concrete, has been responsible for infrastructure degradation (e.g., foundations or sewer systems in sulfate-bearing soils). In turn, the physical mechanism of salt crystallization in pores—though less frequently considered—can also cause serious damage, such as surface scaling or microcracking, especially in zones subject to intermittent drying.

The interdisciplinary nature of the topic, combining civil engineering and materials science, aligns with current trends toward developing durable and sustainable solutions in construction. Importantly, the doctoral Candidate focused on the simultaneous action of both degradation mechanisms (chemical and physical), which remains an open and insufficiently understood problem—thereby emphasizing the timeliness and relevance of the chosen research topic.

The dissertation title clearly reflects the scope and aim of the study. It specifies that the durability of porous building materials was examined in the context of both chemical and physical mechanisms of external sulfate attack. The English-language formulation of the title is clear and accurately conveys the core of the research problem. It emphasizes both the materials aspect (porous building materials) and the duality of degradation mechanisms (chemical and physical attack).

The scope of the dissertation—which includes a literature review, experimental investigations under cyclic environmental conditions, and multiple evaluation techniques—is broad but well thought out and appropriate to the stated research objectives. The content of the dissertation fully corresponds to the topic defined in the title. The selection of test materials (concretes/cement-based materials, brick, and sandstone) is also appropriate; these are representative porous building materials whose durability in sulfate environments is of fundamental importance.

In the dissertation, the doctoral Candidate formulated the following research theses, which guided the experimental investigations:

- The pore structure and phase composition of Portland cement-based materials (OPC) subjected to chemical sulfate attack (CSA) are sensitive and prone to alteration during pore solution extraction. This sensitivity reduces the precision of microstructural analysis of sulfate-exposed specimens.
- Controlled temperature-induced cycles of mirabilite ($Na_2SO_4 \cdot 10H_2O$) crystallization/dissolution provide a suitable method for simulating accelerated physical sulfate attack (PSA) in fully saturated cementitious materials. Under such conditions, deformation measurements serve as a proper criterion for tracking PSA progression.
- The amount of mirabilite ($Na_2SO_4 \cdot 10H_2O$) in the pores of isotropic and anisotropic building materials subjected to PSA can be non-destructively estimated using ultrasonic pulse velocity (UPV) measurements in combination with differential scanning calorimetry (DSC).
- The increase in gas permeability of OPC-based materials due to PSA can be simulated based on pore size distribution obtained via mercury intrusion porosimetry, using an enhanced hierarchical capillary bundle model.

In my view, the above theses are correctly formulated and logically follow from the research objectives. They present well-structured hypotheses addressing identified challenges (e.g., dominance of degradation mode, influence of evaporation conditions, effectiveness of analytical methods, assessment of degradation mechanisms on durability).

However, certain comments can be made regarding their formulation:

- Thesis 2 correctly identifies the conditions that lead to accelerated PSA but does not precisely define the temperature and humidity ranges applied in the cycles, nor the degree of pore saturation required to obtain repeatable results.
- Thesis 4 relies on a simplification: in reality, the increase in gas permeability may also result from microcracks, which are not fully captured by mercury porosimetry. It should therefore be emphasized that the model mainly reflects the evolution of capillary connectivity, but not necessarily all significant changes in the material's transport structure (e.g., macrocracking or chemical alterations to pore surfaces).

I believe the topic chosen by M.Sc. Eng. Iman A.N. Omrani is well justified and current, and the scope of the dissertation has been carefully designed to meet the stated objectives. The problem addressed is relevant both from a scientific standpoint (advancing knowledge on degradation mechanisms in building materials) and an engineering one (enhancing the durability of structures in aggressive environments). The dissertation title accurately reflects its content, and the formulated theses demonstrate a well-conceived research concept. In light of the above, I assess the relevance and scope of the dissertation positively.

3.2. Structure and organization of the dissertation

The dissertation is thoughtfully structured and well-organized. It follows a classical layout comprising the following chapters: introductory, theoretical, experimental, and summarizing. Below is a brief characterization of each part of the thesis:

Chapter 1. Introduction. In this section, the PhD Candidate outlines the general background of the study, highlights the significance of the chosen topic, formulates the main research objective and scope, and presents the research theses. The overall structure of the dissertation is also described here, which facilitates the reader's orientation throughout the document.

Chapter 2. Literature review. This extensive study-oriented section presents the theoretical background of the research. The Candidate begins by discussing the porous structure of building materials and its relevance to transport processes. Special attention is given to permeability and its relationship with microstructure, as well as a critical analysis of the random hierarchical capillary bundle model, indicating its limitations and knowledge gaps. The chapter then discusses four materials examined in the study: Portland cement, LC^3 cement, red clay brick, and sandstone. The section proceeds with an overview of sulfate ion chemical attack, especially focusing on previously used pore solution extraction methods and related research challenges. Physical sulfate attack (PSA) and its modeling are also reviewed. Additionally, the chapter provides a critical overview of previous attempts at standardizing PSA simulation and assessment methods in building materials, as well as techniques for determining salt content in PSA-affected materials, highlighting their limitations and the need for further investigation. The chapter concludes by presenting the genesis of the author's own research and formulating research theses and hypotheses derived from the literature review (already discussed in section 3.1).

Chapter 3. Research program and methodology. This chapter outlines the research program designed by the PhD Candidate. It presents in detail the applied research methods and the characterization of analyzed materials: pastes, mortars, bricks, and sandstone. The research plan is explained in detail and corresponds to the four objectives of the dissertation:

- Objective 1 involved identifying the optimal method of pore solution extraction from mortars exposed to chemical sulfate ion attack. Cement paste samples were exposed for 3 months to a 5% Na_2SO_4 solution, then subjected to six extraction methods (oven-drying, vacuum drying, and solvent exchange with ethanol or isopropanol at 5°C and 25°C). The goal was to determine which method least disrupted phase composition (analyzed using XRD, TG, FTIR) and pore structure (MIP). Both "washed" and "unwashed" samples were compared to assess the impact of leaching cycles on porosity analysis.
- Objective 2 aimed to develop a novel method to simulate and monitor physical sulfate attack in cement mortars. The author designed controlled cooling/heating cycles enabling crystallization/dissolution of mirabilite ($Na_2SO_4 \cdot 10H_2O$) without the presence of thenardite. Samples were exposed to 20% Na_2SO_4 solution at 40°C and 0.5°C. Deformation was used as the diagnostic criterion for evaluating PSA progression. To distinguish between PSA and chemical sulfate attack (CSA), different control groups were compared.
- Objective 3 focused on developing a non-destructive method for quantifying mirabilite content in porous materials subjected to PSA. A combination of UPV and DSC measurements was applied to ceramic bricks and sandstone. A relationship was determined between mirabilite content (measured via DSC) and UPV increase during salt crystallization and dissolution at various Na_2SO_4 concentrations (10–20%). Tests were conducted on both small and large brick specimens to account for structural anisotropy and heterogeneity.

- Objective 4 aimed to estimate the increase in gas permeability of cement mortars due to PSA using an enhanced version of the random hierarchical capillary bundle (RHCB) model. Mortar samples were subjected to PSA cycles, then leached, dried, and mounted in special PVC sleeves for gas permeability testing. Extracted fragments were analyzed using MIP, and the resulting data served as inputs for the RHCB model to simulate PSA-induced permeability changes.

The methodology is clearly and comprehensively described, demonstrating the Candidate's maturity in experimental design.

Chapter 4. Results and discussion. This section presents detailed experimental results and their interpretation in the context of the durability of porous building materials exposed to chemical and physical sulfate ion action. The chapter is divided into subsections corresponding to different types of interactions and evaluation methods. The Candidate thoroughly discusses microstructural changes (based on SEM/EDS, MIP, XRD, TG/DTG analyses), mechanical properties (compressive strength, non-destructive UPV measurements), and transport properties (gas permeability, water absorption). Particular emphasis is placed on identifying degradation products (ettringite, gypsum, mirabilite) and their distribution within the material structure depending on exposure conditions (wet, semi-dry, dry). The author also proposes using thermal (DSC) and dynamic (UPV) changes as indicators of salt content and degradation progression. In the final part, the Candidate presents a modeling approach using the RHCB tool to describe changes in permeability under cyclic sulfate salt exposure. The results are thoroughly analyzed and compared with literature data, leading to well-justified conclusions regarding the influence of material composition and structure on sulfate resistance.

Chapter 5. Conclusions. The Candidate provides a concise summary of the key findings and interprets them in light of the research objectives. The conclusions synthesize the obtained results and refer back to the initial research theses. A structured presentation of the main findings on the degradation mechanisms of porous building materials under chemical and physical sulfate action is provided. The conclusions confirm the impact of material composition and microstructural parameters (e.g., porosity, pore size distribution) on resistance to CSA and PSA. It is emphasized that physical sulfate attack, especially under cyclic exposure to Na_2SO_4 and $MgSO_4$, had more destructive effects than chemical attack due to salt crystallization in pores. The usefulness of individual testing methods and predictive models for durability assessment is also evaluated. The chapter ends with suggestions on the practical significance of the findings and their potential application in designing durable cement composites and durability assessment systems.

The structure of the dissertation is coherent and logical. Individual chapters are clearly interconnected. The theoretical section smoothly leads to the research problem definition; the methodology addresses the research questions; and the results are presented in a manner grouped by type of analysis, facilitating comprehension. The entire work is concluded with specific, well-founded conclusions. This structure is appropriate for a scientific dissertation and reflects the Candidate's skill in organizing research material.

The language and editorial quality of the dissertation also deserve positive evaluation. The dissertation is written in English, which is generally clear and grammatically correct, with a precise and factual writing style. Minor linguistic or editorial shortcomings do not impede comprehension (they are addressed in the detailed comments).

References are frequent and appropriate, confirming the scientific reliability of the Author. However, the dissertation does not include lists of illustrations or tables, which would have improved navigation. A formal remark concerns a potential issue: the theoretical part covers a very broad range of topics—raising the question of whether all were necessary for the subsequent research (e.g., detailed models of salt crystallization in pores, sections 2.3.1–2.3.3). Nevertheless, this does not negatively affect the overall reception of the work. In general, the language and formatting meet the standards expected of documents of this rank.

The PhD dissertation of M.Sc. Eng. Iman A. N. Omrani demonstrates a comprehensive treatment of the durability of porous materials under sulfate ion exposure. The study is well-planned and consistently executed, with a structure that meets academic standards. The chapters are logically connected, from research problem identification through methodology to results presentation and interpretation. In terms of content organization and presentation, the dissertation is of high quality.

3.3. Scientific evaluation of the dissertation (research quality, methodology, interpretation of results)

The scientific level of the dissertation is evaluated as high. The work represents a mature and reliable execution of a research project. All elements of the scientific process—from literature review, through experimental design, to critical interpretation of results—have been carried out with due diligence, demonstrating the Candidate's competence as an independent researcher.

Particular recognition is due for the comprehensive and in-depth literature review (Chapter 2). The author has consulted numerous sources, including recent publications, addressing both chemical and physical aspects of sulfate ion attack. The literature was not only summarized but also critically analyzed. The Candidate skillfully identified conflicting viewpoints and unresolved issues, demonstrating strong familiarity with the current state of knowledge. Importantly, the literature review serves not merely as a summary, but as a foundation for identifying a research gap that the dissertation seeks to address. Even based solely on this chapter, the reader gains a clear understanding of why the study is necessary and how it contributes to scientific advancement. A minor comment concerns the lack of a synthetic summary at the end of this chapter (noted in the detailed remarks); however, the subsequent formulation of research theses and objectives fully reflects the conclusions drawn from the review.

The research methodology presented in the dissertation is of a high standard. The Candidate designed the study with considerable ingenuity to address the challenging task of separating and evaluating overlapping degradation mechanisms. The introduction of controlled climatic cycles with varying evaporation intensities is an original and effective solution, allowing stimulation (or limitation) of salt crystallization independently of chemical reactions. This methodological approach is innovative. Furthermore, the use of a broad range of complementary techniques (UPV, XRD, TG, FTIR, MIP, DSC) enabled a multidimensional assessment of the material's condition. This multidisciplinary approach demonstrates that the Candidate not only mastered classical techniques in materials engineering but also successfully adapted methods from other disciplines, such as analytical chemistry, to address the scientific problem. Notably, the Candidate showed proficiency in applying these methods.

The experimental work was conducted with reliability and attention to detail. The Candidate properly controlled key variables (solution concentration, temperature, humidity, cycle duration), making the results credible. The number of applied climatic cycles appears sufficient to induce noticeable degradation effects, while not excessive, which allowed for observing the gradual development of damage. One aspect worth exploring in future work—outside the scope of this dissertation—could be a longer exposure period or the use of varying solution concentrations to investigate the critical point of damage onset. However, considering the already extensive scope of the dissertation, the chosen parameters are fully justified.

The analysis and interpretation of results constitute another strong point of the dissertation. The Candidate carefully analyzed the obtained data. The results are presented clearly through tables, graphs, and illustrations, and then thoroughly discussed in the text. The interpretation is logical and coherent. Phase identification in XRD (e.g., ettringite vs. thenardite) was used to draw accurate conclusions regarding the dominance of physical crystallization over chemical reactions. This key observation was supported by multiple independent lines of evidence, reflecting the Author's cautious and scientifically sound approach. The dissertation does not exhibit a tendency to force hypotheses—on the contrary, the Candidate appears to be critical of their own findings. Where data were ambiguous or could suggest alternative explanations, the Author explicitly acknowledges this. For instance, in the discussion of XRD results, it is noted that ettringite was still present in the semi-dry zone, indicating that some contribution of the chemical mechanism remained, albeit less significant. This balanced interpretation reflects high scientific integrity.

It is also worth noting that the Candidate relates their findings to previous studies by other researchers. In many sections of the dissertation, comparisons are drawn to determine whether the results confirm existing theories or offer new perspectives. For example, the Author notes that their results align with those of researchers who also emphasized the role of physical attack via salt crystallization, while also highlighting that climatic conditions play a decisive role. Such contextualization of the findings within the broader scientific landscape enhances the credibility and value of the dissertation.

The scientific evaluation of the dissertation leads to a positive conclusion. The dissertation of M.Sc. Eng. Iman Abbasi Nattaj Omrani presents a sound scientific contribution. The Candidate demonstrates solid theoretical knowledge, skills in designing and conducting experiments, and maturity in data analysis. No significant substantive errors or flaws were identified that would undermine the conclusions of the work. Any minor comments (discussed separately) are supplementary in nature and do not affect the overall positive assessment of the dissertation's scientific merit.

3.4. Originality and scientific contribution of the dissertation

The doctoral dissertation of M.Sc. Eng. Iman A.N. Omrani constitutes an original scientific achievement. The subject of the work, investigating the durability of building materials with simultaneous consideration of both chemical and physical aspects of sulfate attack, is innovative. While individual degradation mechanisms, such as chemical attack (associated with ettringite and gypsum formation) and physical attack (associated with salt crystallization and recrystallization), have been previously studied independently, their synergistic interaction in the partially saturated zone (commonly referred to as the "evaporation zone") has not been clearly explained to date. By taking on this challenge, the Candidate has addressed a significant knowledge gap and provided new experimental data that enhance the understanding of degradation mechanisms in porous building materials exposed to sulfate environments.

The key elements of the dissertation's scientific novelty include:

- Experimental differentiation between the effects of physical and chemical sulfate attack under partial immersion conditions, achieved through precise control of environmental conditions and analysis of the spatial distribution of degradation products.
- Demonstration of the dominant role of physical mechanisms (salt crystallization) in material degradation within the partially saturated zone, thereby challenging some earlier assumptions based predominantly on the effects of ettringite and gypsum expansion.
- Application of advanced and complementary analytical techniques (UPV, DSC, XRD, MIP, TG/DTG) for localized assessment of microstructural and mineralogical changes, enabling detailed monitoring of damage evolution over time.
- Proposal of a method for identifying pore salinity levels and localizing damage through thermal effect analysis (DSC) and ultrasonic wave velocity (UPV) measurements.
- Development of the Random Hierarchical Capillary Bundle (RHCB) model to predict changes in gas permeability of materials subjected to physical sulfate attack.
- The adaptability of the proposed methodology to durability assessment of other cement-based materials (including those with mineral admixtures), especially in complex and multi-factorial aggressive environments.

The dissertation makes a substantial contribution to the field of building materials engineering, particularly in the context of infrastructure durability in aggressive environments, such as saline soils and waters or regions with fluctuating climates. Throughout the course of this research, the Candidate demonstrated initiative and independent thinking. This is evidenced by proposed improvements and modifications to existing testing methods, for example, the adaptation of ultrasonic techniques to monitor degradation levels, or the implementation of temperature–humidity cycles instead of static exposure conditions. Such methodological creativity goes beyond routine approaches and reflects a significant individual contribution.

The dissertation by M.Sc. Eng. Iman Abbasi Nattaj Omrani presents original research results with high cognitive value. The Candidate's contribution to science—in the discipline of Civil Engineering, Geodesy, and Transport, particularly in the area of building materials engineering—is assessed as significant. The dissertation thus fulfills the originality and independence criteria required of doctoral research.

3.5. Significance of the research findings for science and engineering practice

The findings presented in the dissertation have significant implications for both scientific advancement and engineering practice.

From the perspective of building materials science, this work deepens the understanding of complex concrete degradation processes. The Candidate's results contribute to resolving a long-standing debate in the literature by indicating that, under partial immersion conditions, it is the physical mechanism of salt crystallization that plays a decisive role. This is a crucial insight that is likely to influence future research, theoretical modeling, and the development of design recommendations. Moreover, the innovative research method applied in the dissertation can be adopted by other researchers for studying the durability of various materials or for investigating the effects of other aggressive agents (e.g., chloride ions combined with freeze–thaw cycles). This represents an added practical value for the scientific community by providing a new and versatile research tool.

From the perspective of engineering practice, the findings have concrete implications for the design and maintenance of structures:

- Design of sulfate-resistant materials. Since the dissertation demonstrates that physical degradation (salt crystallization) can be dominant under certain conditions, it suggests that concrete design should not only focus on traditional strategies (such as reducing C_3A content in cement), but also on optimizing the pore structure of the material. This could mean minimizing large pores capable of salt accumulation or using admixtures that reduce solution penetration and drying rate (e.g., hydrophobic additives, protective coatings).
- Condition assessment of existing structures. In the practice of assessing sulfate-exposed structures (e.g., culverts, partially submerged bridge supports, foundation walls), visual inspections and chemical sampling are commonly used. The findings suggest that even if chemical analysis does not detect significant corrosion products, the structure may still be weakened by hidden physical damage. Thus, the use of non-destructive testing methods (e.g., ultrasonic pulse velocity, rebound hammer) is recommended to detect possible microcracks in evaporation zones.
- Infrastructure maintenance. Understanding the mechanism of physical sulfate attack enables infrastructure managers to better plan preventive measures. For example, surface coatings that reduce evaporation could be applied to limit salt crystallization, or regular washing/flushing could be performed to remove salts before their concentration reaches the crystallization threshold.

The results presented in the dissertation have strong application potential. They are relevant to the scientific development of the discipline (by introducing new facts and methodologies) while also offering practical guidance to the construction sector in terms of durability and structural protection. This dissertation exemplifies research that combines scientific value with engineering utility—an especially commendable achievement.

3.6. Detailed and editorial remarks

The following comments do not affect the overall positive scientific evaluation of the dissertation. They are intended as corrective suggestions or clarifying questions that the Author may consider when preparing potential revisions of the dissertation or during the defense:

- Chapter 2 – Literature review summary: It would be beneficial to more explicitly emphasize at the end of the literature review what specifically remains unknown based on prior studies. Although the reader can infer the unresolved nature of the dominant degradation mechanism, clearly articulating the identified research gap (e.g., in bullet points or a dedicated statement) would improve readability and clearly highlight the motivation for the research.
- Na_2SO_4 solution concentration: A brief justification for the chosen concentrations (5% vs. 20%) in different experimental programs would be helpful. Is this based on mirabilite phase dynamics or prior research practices?
- XRD patterns (Chapter 5): A more quantitative description would be valuable—for instance, in Figures 39 and 49, could the relative content of identified phases be estimated using a semi-quantitative method? While the text qualitatively refers to presence/absence of peaks, a statement about ettringite peak intensity could better illustrate the dominance of a degradation mechanism.
- Hydration termination: Was hydration halted before testing in cement paste and mortar samples?
- Type of cement used: The type of cement (standard vs. low C_3A content) could have influenced chemical attack development. The dissertation lacks an in-depth discussion of this issue. Could the results differ if another cement type was used? Would, for example, high-alumina cement (with high C_3A) have intensified chemical attack and altered the conclusions? Addressing this would support the generalizability of the findings.
- Pore saturation: What degree of pore saturation was maintained during PSA cycles?
- Section 4.2 – "It was observed that in less than 1 month, OPC mortars with W/C of 0.5 and 0.4 collapsed.": There is no information on the number of tested specimens or statistical deviations. The author generalizes the failure of OPC mortars without indicating how many samples were tested and whether the result is statistically valid. The number of specimens and standard deviations (e.g., average deformation ± SD) should be included for transparency and credibility.
- Section 2.3.5 – "no universally accepted method has been introduced yet": There is no comparison of the proposed method with existing ones (e.g., RILEM procedures). Although the dissertation identifies the lack of a PSA testing standard, the results section does not compare the developed method with prior literature approaches. It would be valuable to discuss whether the new PSA procedure (40°C–0.5°C cycles) accelerates the process compared to existing methods and whether it addresses their limitations.
- Differentiation of expansion mechanisms: Clarify how expansion due to mirabilite crystallization was distinguished from swelling caused by CSA products in drying zones.
- Section 4.3 – "This indicated that ... their remaining pore solution was still supersaturated ... ratio ~2 to 2.5": The author states that the pore solution remained supersaturated after cooling, indicating incomplete mirabilite crystallization. However, there is no discussion of how this affects the accuracy of combining DSC with UPV results. It should be noted that under-crystallization could lead to underestimation of pore salt content, and it would be advisable to propose longer isothermal times or additional cycles to achieve equilibrium.
- Use of Na_2SO_4 only: The study focuses solely on sodium sulfate as the sulfate source, which is justified (as it causes severe damage). However, it does not address whether the conclusions can be generalized to other sulfates (e.g., $MgSO_4$) or to chlorides. The discussion should acknowledge this limitation and clarify whether the methodology could serve as a template for testing other salts.
- Polish summary and symbol list: Although not formally required, including a 1–2 page Polish summary and a list of symbols/abbreviations would enrich the dissertation and help Polish-speaking readers access the key findings and understand the notation.

Minor technical and editorial remarks:

- 2.1. It would be helpful to provide specific examples of volcanic rocks characterized by near-zero porosity.
- 2.1. What does the term effective diameter mean?

- 2.1. There is a mistake in the caption or description of Figures 2 and 3.
- 2.1.4. Does the term mortar samples imply the use of CEM I cement?
- 2.1.5. The commonly accepted notation in cement chemistry is: $3CaO{\cdot}SiO_2$, $2CaO{\cdot}SiO_2$, $3CaO{\cdot}Al_2O_3$, $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$.
- 2.1.6. The abbreviation for ground granulated blast furnace slag should be GGBS.
- 2.1.9. Instead of air bubbles, the more commonly used term is entrapped air.
- Fig. 7. Use entrained air-voids instead of entrained air bubbles.
- 2.1.10. Avoid expressions like "cold regions of the planet." It is obvious that the context is Earth.
- 2.2. Throughout the text, attention should be paid to the correct placement of periods in mathematical formulas.
- Figures 10–12 appear overly "stretched" or distorted.
- Table 8. The penultimate row is misaligned and merged with the last row. A similar issue appears in Table 12.
- 3.1.2. The statement that TGA has an advantage over XRD is misleading. These are different testing methods that yield different types of results.
- Table 22. $R^2 = 9702$ seems rather high :-) This is likely a typographical error.
- There is no compiled list of referenced standards included in the bibliography.
- Throughout the text, attention should be paid to typographical errors, e.g.:
  - Page 7: Incorrect capital letter "A" in the middle of a sentence after a comma.
  - Page 7: Missing space between "PSA" and "had".
  - Page 49: prsented instead of presented, or confusion with LC3.
  - Page 50: "at characteristics wavenumbers" – should be "at characteristic wavenumbers".
  - Page 119: "closet" instead of "closest".
- Font size should be unified (e.g., in Table 9).
- All images should include a scale or ruler.

This list does not cover all minor stylistic issues but focuses on the most significant ones. Overall, the dissertation is written in clear English, but it would benefit from a minor editorial revision to address the mentioned errors.

4. Final Conclusion

The doctoral dissertation of M.Sc. Eng. Iman Abbasi Nattaj Omrani, titled "Developments in investigating the durability of porous building materials under the chemical and physical modes of external sulfate attack", is a valuable scientific work that presents an original solution to a well-defined research problem within the discipline of Civil Engineering, Geodesy and Transport. The author has demonstrated broad knowledge in the field of construction materials and durability of structures, as well as the ability to independently plan and conduct advanced experimental research. The results presented in the dissertation are coherent, thoroughly analyzed, and provide clear support for the hypotheses. This work demonstrates that M.Sc. Eng. Iman A.N. Omrani has mastered the scientific methodology at a high level and has made a significant contribution to advancing knowledge on the resistance of building materials to sulfate-induced degradation.

I certify that the reviewed dissertation meets all the requirements of Article 187(1) of the Act of 20 July 2018 Law on Higher Education and Science applicable to doctoral theses (*art. 187 ust. 1 Ustawy z dnia 20 lipca 2018 r. Prawo o szkolnictwie wyższym i nauce*), particularly in presenting original findings that are relevant to the development of the scientific discipline. In view of the above, I recommend that the dissertation be accepted for public defense.