World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Review Article)

Criteria for specifying rocks in facades

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World Journal of Advanced Research and Reviews, 2023, 20(01), 1187–1195

Publication history: Received on 16 September 2023; revised on 24 October 2023; accepted on 26 October 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.20.1.2176

Abstract

The choice of natural rock for cladding building facades is an ancient practice that concerns not only functionality but also architectural aesthetics. Natural rock comes in a variety of colors, textures, and patterns that can add a unique and sophisticated touch to your building. Additionally, it is durable and weather-resistant, making it ideal for external use. The use of natural rock in facades also contributes to sustainability as it is an abundant material in nature and does not require complex manufacturing processes. The methodology adopted is characterized by a qualitative approach, using bibliographic research as the investigative procedure, allowing for an in-depth analysis of the essential topics related to this theme. The overall objective of this work is to provide a contribution to construction professionals, architects, and engineers by offering information and guidance for the use and specification of natural rocks in facades. The study highlighted that understanding the specific characteristics of natural rocks is essential to ensure the longevity, aesthetics, and integrity of facades constructed with ornamental rocks. Finally, it is recommended that the specified material should meet the minimum performance required by ASTM C-615 standards. It is also important to verify if the supplying company has the capacity to meet your needs within the volume and timeframe of each specific project.

Keywords: Natural rock; Facade; Sustainability; Architectural aesthetics.

1. Introduction

The selection of natural stones for cladding building facades is an age-old practice, associated with not only functionality but also architectural aesthetics. Natural stones, due to their diversity in color, texture, durability, and physical-mechanical properties, offer numerous design and performance possibilities. However, the proper specification of these materials is crucial to ensure that facades meet both technical and aesthetic requirements. Errors in selection and specification can lead to significant issues in the future, ranging from premature deterioration to safety concerns.

The methodology adopted is characterized by a qualitative approach, using literature research as the investigative procedure, allowing for an in-depth analysis of essential topics related to this subject.

The general objective of this work is to provide a contribution to construction professionals, architects, and engineers, offering information and guidance for the use and specification of natural stones in facades. The specific objectives are as follows: to present definitions of natural stones, the physical and mechanical properties of rocks, to conduct technological characterization of these materials, and to discuss the standards and minimum requirements governing their application.

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This article is structured into four sections, and the main themes addressed in this work include definitions of natural stones, the physical and mechanical properties of rocks, technological characterization of these materials, and the standards and minimum requirements governing their application. By understanding the definitions, evaluating the properties, mastering characterization techniques, and adhering to standards, professionals can ensure not only the desired aesthetics but also the quality, safety, and durability of facades constructed with these materials.

2. Material and methods

The methodology employed for the development of this scientific article followed a qualitative approach with investigative resources focused on a literature search aimed at locating theoretical references published in books, scientific articles, documents, etc., to gain a deeper understanding of the primary criteria for specifying natural rocks in facades, in light of pre-existing scientific contributions.

Several scientific contributions on the use of ornamental rocks in facades were analyzed. In this manner, numerous citations were extracted and analyzed from various works authored by different individuals, with notable mentions Alencar (2013), Antoniazzi (2019), Barbosa, Costa, and Oliveira (2019), and Zagôto (2023).

Hence, the significance of bibliographic research in the investigative process cannot be denied. Fachin (2001, p. 125) succinctly captures the importance of bibliographic research, stating that "[...] it forms the foundation for other research and can be said to be a constant in the life of those who engage in studying [1]."

3. Literature Review

The theoretical foundation of this work encompasses a set of topics related to the specification of natural rocks in facades. Initially, definitions of the primary materials used in facade cladding are presented, highlighting their geological origin, main characteristics, and mineralogical diversity. Subsequently, the focus shifts to the physical and mechanical properties of rocks, emphasizing the importance of criteria such as density, water absorption, compressive strength, and flexural strength in evaluating their performance in facade applications. The technological characterization of rocks, including laboratory tests and petrographic analysis techniques, is explored as a crucial tool for understanding their mineralogical composition and assessing their suitability for use in facades. Finally, the discussion extends to national and international standards and minimum requirements that establish criteria and guidelines for the selection and specification of these materials in facades, ensuring the quality, safety, and durability of these architectural applications [2]; [3].

3.1. Rock Definitions

Ornamental Rocks are types of natural rocks, such as marble, granite, slate, and many others, extracted from the Earth and used in decorative and architectural applications due to their aesthetic beauty and durability. They are often polished and cut into various shapes to create decorative elements, flooring and facade cladding, sculptures, and a variety of other products.

According to Alencar (2013, p. 23),

The Brazilian Association of Technical Standards - ABNT, in accordance with standard 15.012:2003, defines ornamental rock as: natural rock material, subjected to various degrees or types of processing, used for aesthetic purposes. Rock for cladding corresponds to natural rock that, after undergoing various processing methods, is used in the finishing of surfaces, especially floors, walls, and facades in construction works. Cladding stone corresponds to natural rock material selected, processed, and finished in specific shapes and sizes to meet dimensional requirements for structural or architectural purposes [4].

Ornamental rocks are commonly referred to as marble and granite, regardless of their specific geological characteristics. This is because these terms are widely used and recognized in the industry, simplifying communication, even though the rocks may have different mineral compositions when examined in greater detail from a geological perspective.

3.1.1. Marble

Marbles are metamorphic rocks formed from limestone. Limestone is a sedimentary rock composed primarily of calcium carbonate. When limestone is exposed to high temperatures and pressure, it transforms into marble.

The composition of marble varies depending on the original limestone composition. However, marble is generally composed mainly of calcium carbonate ($CaCO_3$) and other minerals such as dolomite [$CaMg(CO_3)_2$] and quartz (SiO_2) [5].

The quantity and distribution of these minerals determine the color and texture of marble. For example, white marble is primarily composed of calcium carbonate, while black marble is mainly composed of magnesium carbonate.

In the ornamental and cladding stone industry, the term "marble" is commercially used to refer to all carbonatic rocks capable of receiving polish and luster [4].

The use of marble dates back to ancient civilizations, such as Greece and Rome. Ancient Greeks used marble in iconic temples, such as the Parthenon in Athens, where the columns were made of marble. In Rome, marble was used to construct grand structures like the Colosseum and the Arch of Constantine.

3.1.2. Granite

Granites are intrusive igneous rocks that form when magma cools and solidifies within the Earth's crust. Magma is a mixture of molten rock, gases, and minerals that is expelled from the Earth's interior through volcanoes or underwater eruptions.

Granites are primarily composed of quartz, feldspar, and mica. Quartz is a hard and resilient mineral that imparts strength to granite. Feldspar is a mineral responsible for granite's coloration. Mica is a mineral that provides granite with its luster and durability.

For the ornamental and cladding stone industry, granite deposits represent a wide range of silicate rocks, with the most common mineralogical association comprising quartz, feldspars, and micas. The recent increase in the relative use of granites has been, at least in part, determined by their greater durability and resistance compared to marbles, as well as their distinct aesthetic patterns and possibilities for use in flooring and facades [4].

The use of granite in construction and various applications is timeless, owing to its durability, strength, and appealing aesthetics. Its versatility makes it suitable for projects ranging from historical structures to modern buildings and contemporary works of art.

3.1.3. Quartzites

Quartzites are metamorphic rocks that originate from sandstones (sedimentary rocks primarily composed of quartz sand grains) subjected to high pressures and temperatures.

During the metamorphic process, the quartz grains in sandstone are recrystallized and compacted, resulting in a very hard and resilient rock with a high percentage of quartz. Quartzites are renowned for their durability, wear resistance, and a wide range of colors.

Quartzite is primarily composed of quartz, but it may also contain small amounts of other minerals. Its primary composition consists of approximately 90% or more of quartz, making it an exceedingly quartz-rich rock. In some cases, quartzite may contain traces of minerals like feldspar, mica, hematite, and others, but these minerals are generally present in very small quantities.

3.2. Physical and Mechanical Properties of Rocks

The physical and mechanical properties of rocks play a pivotal role in the selection and performance of rocks for facades. According to Barbosa, Costa, and Oliveira (2019, p. 17),

The physical and mechanical properties of rocks are crucial factors to consider in the specification of rocks for facades. Physical properties such as density, water absorption, and wear resistance affect the durability of the rock, while mechanical properties such as compressive strength, flexural strength, and impact resistance influence the rock's ability to withstand loads and resist damage [6].

Understanding the properties of rocks is essential for the proper specification of facade cladding, as these characteristics determine not only the facade's durability and aesthetics but also the structural safety and long-term maintenance of the building.

3.2.1. Physical Properties of Rocks

The physical properties of rocks are intrinsic characteristics that describe the composition, structure, and physical behavior of these materials. These properties are fundamental for understanding how rocks behave in different contexts, including applications such as building facades.

The following are the primary physical properties:

- Porosity: Rock porosity refers to the amount of empty spaces within them. In facades, low porosity is desirable to prevent water absorption, which could lead to issues such as efflorescence, staining, and premature wear [7].
- Density: Density is the mass of a rock per unit volume. Rocks with high density are generally more resistant to physical and chemical damage [7].
- Water Absorption: Water absorption is related to porosity and indicates how much water a rock can retain. For facades, it is crucial to select rocks with low water absorption to prevent deterioration [7].
- Weathering Resistance: Rocks for facades need to withstand weathering, including exposure to sunlight, rain, atmospheric pollutants, and temperature variations. This resistance is linked to physical properties such as porosity and water absorption [7].

In summary, understanding the physical properties of rocks is essential to ensure that the choice is durable, safe, and compliant with standards. Ignoring these properties can lead to performance and maintenance issues in the future, as well as compromise the overall quality of the project.

3.2.2. Mechanical Properties of Rocks

The mechanical properties of rocks pertain to characteristics related to the strength and mechanical behavior of these materials when subjected to external forces. These properties are crucial in determining how rocks will behave under load and in response to various types of efforts.

Let's discuss each of these properties:

- Compressive Strength: Compressive strength is the ability of a rock to withstand loads applied toward its center. For facades, high compressive strength is essential to ensure structural stability and safety [8].
- Flexural Strength: Flexural strength is important when rocks are subject to loads that bend them, such as strong winds. This property prevents fractures and fissures. Santos et al. (2018) stated that bending forces are applied to the pieces during the transportation and fixation of decorative stones. The minimum necessary thickness is calculated to prevent breakage or fissures in the panel. To do this, flexural strength must be determined by loads at four points. These supports are similar to those used during the transportation and after the fixation of facade pieces [9].
- Shear Strength: Shear strength is the ability of a rock to resist forces attempting to cut it at right angles to its grains. It is important for slope stability and structures [10].
- Thermal Expansion: Thermal expansion refers to the variation in size of the rock with temperature changes. Significant variations can cause stress in rocks.

Zagôto (2023, p. 28) demonstrates a specific application of knowledge regarding thermal expansion:

Due to its significant influence on the stability of mortar-set stone slabs and the sizing of expansion joints, this property is important. Additionally, since the coefficient of thermal expansion of rocks differs from that of mortars, there may be detachment of the slabs due to relative movement caused by temperature oscillation. In slabs fixed by the system of metal inserts in exterior cladding, this issue is minimized by establishing a certain spacing between the slabs and by the fact that the devices allow for the accommodation of the façade [10].

Understanding the mechanical properties of rocks is essential to ensure the safety, stability, and durability of facades during construction. This allows for the selection of appropriate materials and an appropriate structural design, ensuring that the facade will perform its function effectively and safely over an extended period.

3.3. Technological Characterization Tests

The technological characteristics of rocks are obtained through analyses and tests performed according to rigorous procedures standardized by national and international entities, including the Brazilian Association of Technical

Standards (ABNT), the American Society for Testing and Materials (ASTM), the Deutsch Institut für Normung (DIN), and the Association Français du Normalisation (AFNOR).

As per Alencar (2013, p. 34),

In Brazil, the main technological characterization tests required for rocks intended for use as cladding materials for buildings, except for slates, are standardized by ABNT NBR 15.845:2010, which establishes methods for the following tests: Petrographic analysis Physical indices Apparent density Apparent porosity Water absorption Uniaxial compression Freeze and thaw resistance Three-point bending (modulus of rupture) Four-point bending Linear thermal expansion coefficient Hard body impact resistance [4].

Due to their natural characteristics, ornamental rocks require knowledge of their mineral composition and petrographic, chemical, and mechanical properties for their use. This provides essential information about the properties of rocks, ensuring their quality, safety, and durability in architectural and construction projects.

3.3.1. Petrographic Analysis - NBR 12.768

Petrographic analysis of a rock is a scientific method involving laboratory processes that entail the detailed study of the mineralogical composition, texture, and structure of a rock sample under a petrographic microscope.

Petrographic analysis is the only laboratory investigation method that enables a detailed visualization of the rock's constituents, allowing for an assessment of the implications of its properties on the subsequent behavior of applied products.

3.3.2. Physical Indices - NBR 12.766

The physical indices of ornamental rocks are measurements and physical characteristics that describe the properties of a particular rock, as previously discussed in section 2.1.1.

The indices that are most useful for the qualification of ornamental rocks include:

- Apparent Density: The study of a rock's apparent density is conducted to determine the amount of mass contained in a given volume of the rock. Apparent density is often expressed in kilograms per cubic meter (kg/m^3) or grams per cubic centimeter (g/cm^3).
- Apparent Porosity: Apparent porosity is a measure of the amount of empty space or pores present in a material relative to its total volume. It is calculated by dividing the volume of pores by the total volume of the sample and expressed as a percentage. Apparent porosity can vary from 0% (no porosity) to 100% (the material is entirely porous).
- Water Absorption: The water absorption index of a rock is calculated to determine the amount of water a rock sample can absorb. It is calculated using the formula: IAA (%) = [(Mf - Mi) / Mi] x 100 Where: Mf is the final mass (weight of the wet sample after immersion). Mi is the initial mass (weight of the dry sample before immersion).

For example, in humid climates, it is important to choose rocks with low water absorption to avoid deterioration problems due to prolonged exposure to moisture. The durability of rocks is a critical factor, especially in facade applications that are constantly exposed to the elements.

Physical indices help predict how rocks will respond to adverse environmental conditions over time, allowing for the selection of materials that resist degradation.

3.3.3. Uniaxial Compression - NBR 15846-1 / NBR 12.767

This test aims to find the highest load per unit area that a rock can support without breaking. In other words, it allows for the determination of the rock's rupture stress when subjected to compressive forces. Its purpose is to assess the rock's strength when used as a structural element and obtain an indicative parameter of its physical integrity for use as cladding in buildings [4].

The uniaxial compression test is used to determine the material's compressive strength. Compressive strength is crucial for the safety of the facade, as it determines the maximum load the material can bear before breaking. Compressive strength is expressed in megapascals (MPa) or newtons per square millimeter (N/mm^2).

3.3.4. Freeze and Thaw Resistance - NBR 12769

The purpose of this test is to assess the rock's resistance to the repeated freezing and thawing, simulating adverse weather conditions that may occur in regions where temperatures drop below the freezing point. A performance index of 100% indicates that the test specimen did not experience any deterioration. A performance index of 0% indicates complete disintegration of the test specimen.

3.3.5. Three-Point Bending - NBR 15846-2 and 12763

Flexural strength, also known as the modulus of rupture, is a laboratory test that assesses a material's ability to withstand bending or flexing before breaking.

When applied to natural rocks for use in facades, this test is relevant in determining the material's capacity to support bending loads and the stresses it will undergo in building cladding applications.

The main objective is to evaluate the granite's ability to withstand bending, which is important in facade cladding applications where the rock may be subjected to wind forces, vibrations, and other loads.

The test results are used to calculate the rock sample's modulus of rupture, which is a measure of the material's resistance to flexure. This is typically expressed in pascals (Pa) or megapascals (MPa).

3.3.6. Four-Point Bending - ASTM C-880

This test guides the calculation of the thickness in relation to the area of rock slabs that undergo bending stresses, both during transport and after their installation in facades using metallic anchoring systems for fixation [4].

Four-point bending, as specified by ASTM C880, is a standardized test used to determine flexural strength. The primary objective of the test is to determine the material's resistance to flexure, i.e., its ability to withstand loads that cause bending deformation before failure.

During the test, data are recorded, including the applied load, sample deformation (bending), and the point of failure. The test results are used to calculate the material's flexural strength, typically expressed in pascals (Pa) or megapascals (MPa).

3.3.7. Linear Thermal Expansion Coefficient - NBR 15845-3/15

The coefficient of linear thermal expansion, measured for various types of cladding, allows for the determination of the recommended minimum spacing between plates to prevent them from coming into contact, causing lateral compression [11].

Given that rocks expand and contract when subjected to continuous and sudden temperature changes, it's important to characterize the reaction of the rock material to this parameter.

During the test, data is recorded, including the dimensional variations (changes in length, width, and thickness) of the sample in response to temperature changes.

3.3.8. Hard Body Impact Resistance - NBR 12.764

This test involves measuring the rock's resistance to impact, determined by measuring the height from which a solid body is dropped to cause the test specimen to fracture [4].

Impact resistance is a critical property in facade cladding materials, as it helps ensure the material's durability and safety when exposed to real-world conditions. A facade cladding material with good impact resistance will be less prone to cracking, chipping, or breaking when subjected to impact forces. The measure of hard body impact resistance is the energy absorbed by the material during impact. The absorbed energy is typically expressed in joules (J) or megajoules per cubic meter (MJ/m^3).

3.4. Standards and Required Performance

The specification of rocks for facades requires strict adherence to well-defined standards and performance criteria to ensure quality, safety, and durability in these applications. In Brazil, technical standards from ABNT (Brazilian Association of Technical Standards) play a fundamental role. ABNT NBR 15845 sets performance requirements for ornamental rocks used in facades, addressing criteria such as weather resistance, wear resistance, and other relevant attributes. It also covers the classification of rocks for cladding and can be applied to the specification of rocks for facades, defining criteria such as mineral composition, porosity, and flexural strength.

For international references, ASTM International (formerly known as the American Society for Testing and Materials) provides valuable guidelines. ASTM C615 deals with the specification of rocks used in construction and cladding. It is titled "Standard Specification for Granite Dimension Stone" and primarily focuses on granite, one of the most widely used rocks for facades.

Table 1 Properties and Tests for the Specification of Granite for Facade Cladding - ABNT NBR 15844

Properties/Tests	**Norm**	**Acceptance Criteria**
Petrographic Analysis	ABNT NBR 15845 – 1	-
Apparent Density (kg/m³)	ABNT NBR 15845 – 2	≥ 2550
Apparent Porosity (%)	ABNT NBR 15845 – 2	≤ 1,0
Water Absorption (%)	ABNT NBR 15845 – 2	≤ 0,40% (granite)
Linear Thermal Expansion Coefficient (10^{-3} mm/(m x °C))	ABNT NBR 15845 – 3	≤ 8,0
Uniaxial Compressive Strength (MPa)	ABNT NBR 15845 – 5	≥ 100
Flexural Strength (3-Point Bending)	ABNT NBR 15845 – 6	≥ 10
Four-Point Flexural Strength (MPa)	ABNT NBR 15845 - 7	≥ 8,0
Hardness Impact Resistance (m)	ABNT NBR 15845 - 8	≥ 0,3

Source: [12]

Table 1 presents the physical and mechanical properties that should be determined through tests for the correct specification of ornamental rocks for facade cladding. This table also provides suggested acceptance criteria for granites, as proposed by the ABNT NBR 15844 standard.

By considering properties such as weather resistance, durability, and water absorption, we can choose rocks that are suitable for the specific site conditions and performance expectations. This helps ensure that facades remain visually and structurally sound over time. Table 2 illustrates a comparison between the Brazilian ABNT 15844 and American ASTM 615 standards for minimum granite property requirements.

Table 2 Comparison between Brazilian and American Standards

Property	**Norm**	
	ABNT NBR 15844	**ASTM C 615**
Apparent Density (kg/m³)	> 2.550	≥ 2.560
Apparent Porosity (%)	1,0	n.e.
Water Absorption (%)	< 0,4	≤ 0,4
Uniaxial Compressive Strength (MPa)	> 100	≥ 131
Flexural Strength (3-Point Bending)	> 10,0	≥ 10,34
Four-Point Flexural Strength (MPa)	> 8,0	≥ 8,27
Linear Thermal Expansion Coefficient (10^{-3} mm/(m x °C))	< 8,0	n.e.
Hardness Impact Resistance (m)	> 0,3	n.e.
Amsler Wear (mm/1000 m)	< 1,0	n.e.

Source: [13]

In summary, the combination of search criteria and standards ensures that the selected rocks not only meet minimum requirements but also address the specific demands of the project.

4. Conclusion

In this research, we have examined key definitions to assist in the accurate specification of natural stone for use in facades. We initiated our exploration by delving into the fundamental definitions of ornamental rocks, thus comprehending their geological origins.

Furthermore, we conducted an in-depth investigation into the physical and mechanical properties of these rocks, acknowledging the diverse array of characteristics that have a direct bearing on their durability and performance in facades.

Our research has underscored the significance of detailed laboratory analyses, highlighting the critical importance of parameters such as porosity, compressive strength, water absorption, among others.

The technological characterization of these rocks has emerged as a pivotal stage in the meticulous selection of these materials, offering a robust foundation for making well-informed decisions. The study has unequivocally demonstrated that an understanding of the specific attributes of natural rocks is imperative to ensure the longevity, aesthetic appeal, and structural integrity of facades constructed with ornamental rocks.

Conclusively, it is recommended that the specified material should meet the minimum performance requirements as stipulated by ASTM C-615. Moreover, it is considered crucial to ascertain whether the supplying company possesses the capacity to fulfill your project-specific needs within the designated volume and timeframe.

Compliance with ethical standards

Acknowledgments

The authors would like to thank Ana Zuleika Mendes Bastos Tavares Education and Career Analyst II at Instituto Euvaldo Lodi - IEL/CE and Prof. Spec. Carlos Rubens Araújo Alencar Coordinator of the MBA Course in Use of Rocks in Civil Construction and also Professor M. Sc. Rosilda do Rocio do Vale Coordinator of the Graduate Courses at the Faculty of Industry and the Euvaldo Lodi Institute (IEL) for all the attention given.

Disclosure of conflict of interest

The authors assure that there is no conflict of interest with the publication of the manuscript or an institution or product mentioned in the manuscript and/or important for the result of the presented study.

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