

Article

Standardization of Böhme Abrasion Testing: Effects of Abrasive Type and Particle-Size Distribution on Test Repeatability

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Abstract

The Böhme abrasion test (EN 14157) is widely used to evaluate the wear resistance of natural stones; however, the abrasive powder specified by TS 699 requiring 70–80 wt.% crystalline Al_2O_3 is not commercially available in the Turkish market. Commercially supplied abrasives deviate substantially from both the prescribed chemical composition and the grain-size distribution of TS 699, introducing a recognized but unresolved source of variability in Böhme abrasion measurements. This study evaluates the influence of abrasive type and particle-size distribution on Böhme abrasion performance with the aim of identifying which available abrasive material yields the most reliable and reproducible test results. The emphasis is therefore metrological—on test repeatability and standardization—rather than on ranking the abrasion resistance of the stones. Six natural stones representing contrasting lithologies—four crystalline marbles, one limestone, and one granite—were tested using five abrasive powders: two locally produced natural emery abrasives (Emery-1 and Emery-2), silicon carbide (SiC), white corundum, and brown corundum. Each abrasive was evaluated under both standardized graded conditions prepared in accordance with TS 699 and heterogeneous ungraded conditions reflecting common industrial practice. Chemical analyses confirmed that both emery abrasives deviate markedly from TS 699 specifications, with Al_2O_3 contents (~57.7 wt.%) well below the required range and Fe_2O_3 (~24 wt.%) considerably exceeding the standard limit. Sieve analyses further revealed substantial particle-size deviations in several commercial abrasives. One-way ANOVA demonstrated that abrasive type exerts a statistically significant influence on abrasion performance ($F = 8.99$, $p < 0.05$, $\eta^2 = 0.297$). SiC consistently produced the highest abrasion values, followed by corundum-based abrasives, while emery abrasives showed comparatively lower but stable performance. Independent-samples *t*-tests showed that particle-size grading significantly affected abrasion performance only for brown corundum ($p < 0.05$), attributable to its markedly elevated coarse particle fraction. Petrographic analysis, XRD, and SEM–EDS characterization of the investigated rocks confirmed that abrasion response is additionally modulated by rock mineralogy and microstructure. Under standardized grading conditions, SiC provided the most consistent and reproducible results across all lithologies, supporting its suitability as the reference abrasive for inter-laboratory Böhme testing. Locally produced emery abrasives, despite their chemical non-compliance with TS 699, yielded stable and reproducible outcomes under controlled grading, supporting their potential as cost-effective alternatives for routine testing.

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1. Introduction

Natural stones are widely used in architectural and civil engineering applications owing to their durability, mechanical performance, and aesthetic properties [1–3]. Among the durability-related characteristics relevant to service life, abrasion resistance is of particular importance in flooring, paving, and other high-traffic environments, where progressive surface wear governs long-term performance. Reliable laboratory assessment of abrasion resistance is therefore essential for material selection, quality control, and durability classification [4,5].

The Böhme abrasion test, standardized by EN 14157 [6], is among the most widely applied methods for evaluating the wear resistance of natural stones and is routinely employed in both laboratory and industrial settings [7–9]. The standard specifies not only the test procedure but also the chemical composition and particle-size distribution of the abrasive powder, the latter being detailed in TS 699 [10]. According to TS 699, the abrasive powder used in Böhme testing should consist predominantly of crystalline Al_2O_3 (corundum; 70–80 wt.%), with $\text{SiO}_2 \leq 5$ wt.%, $\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO} + \text{MgO} \leq 2$ wt.%, and only trace Fe_2O_3 . However, an abrasive powder meeting these chemical specifications is not commercially available in the Turkish market [11]. Commercially supplied abrasives frequently deviate from both the prescribed chemical composition and the grain-size distribution defined by TS 699, raising a fundamental question for routine testing practice: which available abrasive material produces the most reliable and reproducible Böhme abrasion results? Recent studies further underscore the sensitivity of standardized abrasion testing to method and procedural factors: Strzałkowski et al. [12] documented implementation and interpretation problems in the Böhme procedure under EN 14157, while Çelik et al. [13] reported systematic differences between EN 14157 and ASTM C1353 abrasion results across a large sample set, highlighting the importance of standardized test conditions for inter-laboratory comparability.

This question has practical consequences. Abrasion resistance values reported in stone catalogues and technical databases are laboratory-dependent, since they reflect the properties of the abrasive material used rather than an absolute material characteristic [11]. Small differences in abrasive particle-size distribution have been shown to produce measurable changes in abrasion loss [11], and achieving compositional homogeneity in naturally sourced abrasives is inherently constrained by the heterogeneous nature of natural emery deposits. These sources of variability undermine the inter-laboratory comparability of Böhme abrasion results and highlight the need for systematic evaluation of abrasive materials under controlled conditions. Earlier work by Bağcı and Bozkurt [11] identified these issues and recommended that abrasion test reports should specify both the type of abrasive used and its particle-size distribution; however, this recommendation has not been formally incorporated into standard practice, and the problem remains unresolved [14].

Previous studies have examined abrasion resistance primarily in relation to rock properties, including mineralogical composition, texture, porosity, and mechanical strength [15–19]. Comparatively little attention has been directed toward abrasive-related variables—such as abrasive type, chemical composition, and particle-size grading—despite their direct influence on material removal during testing and on the reproducibility of results across laboratories and testing conditions. Abrasion response is also conditioned by the mineralogical and microstructural properties of the tested rock. Mineral hardness,

grain size, intergranular bonding, and textural heterogeneity collectively govern resistance to abrasive wear [20,21]. Carbonate rocks, dominated by calcite, generally exhibit lower abrasion resistance, whereas silicate-rich lithologies such as granite show comparatively higher resistance owing to the presence of harder mineral phases including quartz and feldspar [22,23]. Understanding how rock properties modulate abrasion response under varying abrasive conditions is necessary for a complete interpretation of Böhme test results.

This study addresses these issues by evaluating the influence of abrasive type and particle-size distribution on Böhme abrasion performance using six natural stones with contrasting lithological characteristics—four crystalline marbles (Kaplanpostu, Afyon Sugar, Afyon Honey, and Akşehir Black), one limestone (Gölpazarı Beige), and one granitic rock (Balaban granite). Five abrasive powders—locally produced natural emery (Emery-1 and Emery-2), silicon carbide (SiC), white corundum, and brown corundum—were tested under both standardized graded conditions prepared in accordance with TS 699 and heterogeneous ungraded conditions reflecting common industrial practice. Sieve analyses and chemical characterization were used to quantify deviations from TS 699 specifications, while petrographic observations, X-ray diffraction (XRD), and SEM-EDS analyses provided mineralogical and microstructural characterization of the investigated rocks. The specific objectives of this study are to: (i) quantify deviations of commercially supplied abrasives from TS 699 chemical composition and particle-size specifications; (ii) evaluate which abrasive type yields the most reliable and reproducible Böhme abrasion results under standardized grading conditions; and (iii) assess the role of rock mineralogical and microstructural characteristics in modulating abrasion response under different abrasive conditions. The overarching aim is metrological: to improve the repeatability and inter-laboratory comparability of the standardized Böhme procedure rather than to rank the abrasion resistance of the stones.

2. Materials and Methods

2.1. Natural Stone Materials

Six natural stones commonly used in architectural and engineering applications were selected to represent contrasting lithological, mineralogical, and textural characteristics relevant to abrasion behavior. The investigated rock suite comprised four crystalline marbles (Kaplanpostu, Afyon Sugar, Afyon Honey, and Akşehir Black), one limestone (Gölpazarı Beige), and one granitic rock (Balaban granite), representing lithologies widely used in flooring, paving, cladding, and decorative construction where abrasion resistance is an important selection criterion (Figure 1). The investigated rocks exhibit contrasting lithological and petrographic characteristics. Kaplanpostu, Afyon Sugar, and Afyon Honey marbles (Afyon-İscehisar, Paleozoic) share a granoblastic to polygonal calcite fabric with minor sericite and trace quartz. Akşehir Black marble (Konya-Akşehir, Triassic) displays a cataclastic texture with banded calcite grains (0.19–1.90 mm) and white calcite veins, together with minor dolomite. Gölpazarı Beige limestone (Bilecik-Gölpazarı, Middle Jurassic–Early Cretaceous) consists of a micritic calcite matrix ($<5\ \mu\text{m}$) with sparitic calcite filling fractures and voids. Balaban granite (Kırklareli-Dereköy, Paleozoic) is a hypidiomorphic granular monzonitic rock comprising orthoclase, oligoclase–andesine plagioclase, quartz, biotite, hornblende, pyroxene, sphene, and accessory apatite. The selected lithologies were intended to capture variations in mineralogical composition, grain size, texture, and intergranular relationships that may influence abrasion performance. The carbonate rocks represent contrasting crystalline and sedimentary fabrics, whereas Balaban granite was included as a silicate-rich, polymineralic reference lithology containing mechanically resistant mineral phases (Table 1). It should be emphasized that these six stones are the test specimens, not candidate abrasives: TS 699 governs the composition

and grain size of the abrasive powder (Section 2.2), so conformity to it is not a selection criterion for the stones. The suite was chosen to span a wide range of mineralogy, hardness, and texture so that the repeatability of the standardized procedure could be assessed across contrasting matrices.

This lithological diversity enabled comparative assessment of abrasion responses across contrasting mineralogical and microstructural settings. Representative block samples were obtained from commercially active quarries. Test specimens were prepared in accordance with EN 14157 to ensure dimensional consistency and comparability. Prior to abrasion testing, petrographic analysis, X-ray diffraction (XRD), and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDS) were conducted to characterize the mineralogical and microstructural framework of the investigated rocks and support interpretation of abrasion behavior.

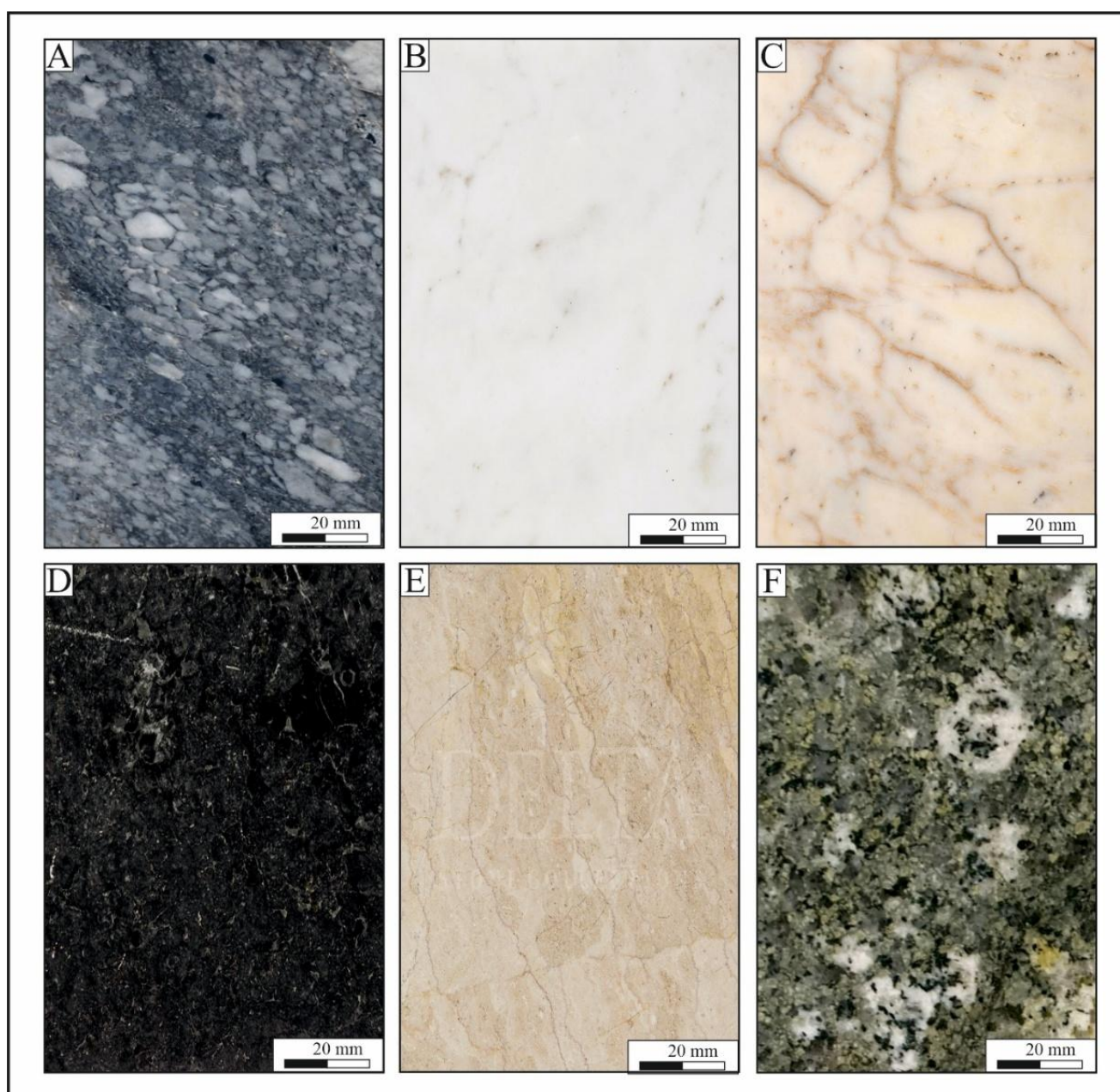


Figure 1. Polished slab surfaces of the investigated natural stones: (A) Kaplanpostu marble (KP); (B) Afyon Sugar marble (AS); (C) Afyon Honey marble (AH); (D) Akşehir Black marble (AB); (E) Gölpa-zarı Beige limestone (GB); (F) Balaban granite (BG).

Table 1. Lithological, mineralogical, and engineering characteristics of the investigated natural stones.

Sample	Commercial Name	Lithology	Location	Geological Age	Dominant Mineralogy	Petrographic Summary	General Texture/Fabric
KP	Afyon Kaplanpostu	Marble	Afyon–İscehisar	Paleozoic	Calcite-dominated	Granoblastic calcite (500–750 µm) with pressure twinning; minor cataclastic calcite (40–300 µm)	Granoblastic
AS	Afyon Sugar	Marble	Afyon–İscehisar	Paleozoic	Calcite-dominated	Granoblastic to polygonal texture; minor sericite and trace quartz	Granoblastic to polygonal
AH	Afyon Honey	Marble	Afyon–İscehisar	Paleozoic	Calcite-dominated	Granoblastic to polygonal texture; minor sericite and trace quartz	Granoblastic to polygonal
AB	Akşehir Black	Marble	Konya–Akşehir	Triassic	Calcite ± dolomite	Cataclastic texture; banded calcite (0.19–1.90 mm); white calcite veins	Cataclastic–banded
GB	Gölpazarı Beige Limestone	Limestone	Bilecik–Gölpazarı	Middle Jurassic–Early Cretaceous	Calcite-dominated	Micritic calcite (<5 µm matrix); sparitic calcite in fractures and voids	Micritic to sparitic
BG	Balaban Granite	Granite	Kırklareli–Dereköy	Paleozoic	Quartz + plagioclase + orthoclase + mica	Hypidiomorphic granular; orthoclase, oligoclase–andesine plagioclase, quartz, biotite, hornblende, pyroxene, sphene, apatite	Hypidiomorphic granular

2.2. Abrasive Materials

Five abrasive powders with contrasting mineralogical compositions, hardness characteristics, and particle-size distributions were selected to evaluate their influence on Böhme abrasion performance. These comprised two locally produced natural emery abrasives (Emery-1 and Emery-2) and three synthetic abrasives: silicon carbide (SiC), white corundum, and brown corundum (Figure 2).

The natural emery abrasives were included as locally available and economically accessible materials with potential applicability as alternatives to imported synthetic abrasives. Mineralogically, these abrasives consist predominantly of corundum with subordinate opaque minerals, principally magnetite and hematite, resulting in compositional heterogeneity that may influence abrasion efficiency.

Silicon carbide and corundum-based abrasives were included as reference materials due to their widespread use in abrasion testing, relatively homogeneous composition, and high hardness. Silicon carbide is characterized by sharp grain morphology and very high hardness, whereas white and brown corundum are commonly used in industrial grinding applications because of their mechanical durability and abrasion efficiency.

Each abrasive was evaluated under two preparation conditions: (i) standardized graded conditions prepared according to TS 699 particle-size specifications and (ii) heterogeneous ungraded conditions representing the original commercial grain-size distributions. This approach enabled assessment of abrasion performance under both standard-compliant conditions and particle-size variability commonly encountered in industrial practice.

The chemical compositions of the two locally produced natural emery abrasives are presented in Table 2, alongside the chemical specifications defined by TS 699. Both Emery-1 and Emery-2 exhibit nearly identical compositions, with Al₂O₃ as the dominant component (~57.7 wt.%), followed by Fe₂O₃ (~24 wt.%) and SiO₂ (~13 wt.%). Comparison with TS 699 specifications reveals substantial deviations: the Al₂O₃ content of both emery abrasives falls markedly below the required 70–80 wt.% range, while SiO₂ and Fe₂O₃ contents considerably exceed the prescribed limits. These deviations confirm that locally produced natural emery abrasives do not meet the chemical composition requirements of TS 699, reflecting the inherent mineralogical heterogeneity of natural emery deposits. The com-

positional similarity between Emery-1 and Emery-2 suggests that both originate from the same or mineralogically equivalent emery source.

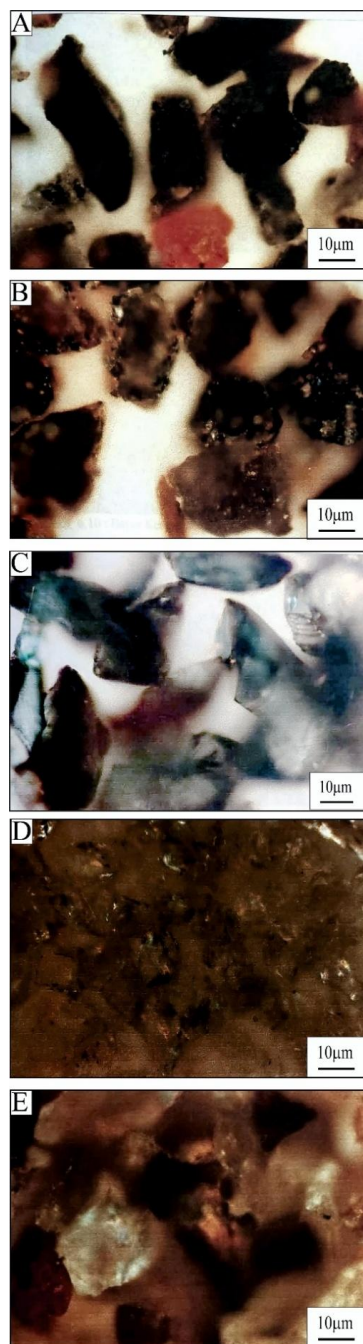


Figure 2. Optical microscope images of the abrasive powders used in Böhme abrasion experiments. (A) Emery-1, (B) Emery-2, (C) silicon carbide (SiC), (D) white corundum, and (E) brown corundum.

Table 2. Chemical composition of locally produced natural emery abrasives (wt.%) compared with TS 699 specifications.

Component	TS 699 Specification	Emery-1	Emery-2
Al ₂ O ₃ (corundum)	70–80 wt.%	57.75	57.66
SiO ₂	≤5 wt.%	12.90	13.10
Na ₂ O + K ₂ O + CaO + MgO	≤2 wt.%	1.06	1.06
Fe ₂ O ₃	Trace	24.15	23.98
SO ₃	—	0.38	0.38
LOI	—	2.89	3.04

2.3. Sieve Analysis and Abrasive Grading

Particle-size analyses were conducted to characterize the grain-size distributions of abrasive powders and assess their compliance with TS 699 specifications. Representative 100 g samples were prepared by quartering to minimize segregation and ensure sample homogeneity. Sieve analyses were performed using an mechanical sieve shaker (ELE International, Leighton Buzzard, UK) equipped with square-mesh sieves of 0.160, 0.125, 0.100, and 0.071 mm aperture sizes. Each abrasive was initially characterized in its commercially supplied (ungraded) state.

Standardized graded mixtures were subsequently prepared by adjusting sieve-fraction mass proportions to conform to TS 699 particle-size specifications (Table 3). Ungraded abrasives were tested in their original commercial form to represent particle-size heterogeneity commonly encountered in routine practice. Deviations from TS 699 specifications were quantified by comparing measured grain-size distributions with the target standard, with particular emphasis placed on coarse particle fractions that may influence abrasion efficiency and test repeatability.

Table 3. Target particle-size distribution of graded abrasives per TS 699.

Particle-Size Interval (mm)	Target Mass Percentage (%)
−0.160 + 0.125	6
−0.125 + 0.100	55
−0.100 + 0.071	35
<0.071	4
Total	100

2.4. Böhme Abrasion Test Procedure

Böhme abrasion tests were performed in accordance with EN 14157. Prior to testing, specimen thickness (71 mm × 71 mm × 71 mm) was measured at nine predefined locations uniformly distributed across the test surface using a digital caliper (Horex, Bad Homburg, Germany) with a precision of ±0.01 mm. The arithmetic mean of these measurements was recorded as the initial thickness (d_0). Specimens were mounted in the holding frame and subjected to abrasion under standardized loading conditions. During each abrasion period, 20 ± 0.5 g of abrasive powder was uniformly distributed onto the friction track. A vertical load of 30 ± 0.3 kgf (294 ± 3 N) was applied through a steel lever system, corresponding to a contact pressure of approximately 0.06 N/mm². Displaced abrasive particles were periodically redistributed using a soft brush to maintain uniform abrasive contact throughout testing.

The test consisted of 20 successive abrasion periods of 22 revolutions each, corresponding to a total of 440 revolutions. After each interval, residual abrasive and detached material were removed, a fresh 20 ± 0.5 g abrasive charge was applied, and the specimen was rotated by 90° around its vertical axis to minimize directional abrasion effects. Following completion of the test, specimens were cleaned and remeasured at the same nine locations, and the arithmetic mean was recorded as the final thickness (d_1). In contrast to the graded condition, for which each stone–abrasive combination was tested in triplicate ($n = 18$ per abrasive across the six lithologies), the ungraded condition was assessed using a single determination per stone–abrasive combination as a screening-level comparison ($n = 6$ per abrasive). This difference in replication is carried through to the sample sizes used in the subsequent statistical analyses.

The experimental workflow is illustrated in Figure 3. Böhme abrasion loss was calculated according to Equation (1):

$$A_b = (d_0 - d_1) \times 50 \quad (1)$$

where A_b is the Böhme abrasion loss ($\text{cm}^3/50 \text{ cm}^2$), d_0 is the mean initial thickness (cm), and d_1 is the mean final thickness (cm).

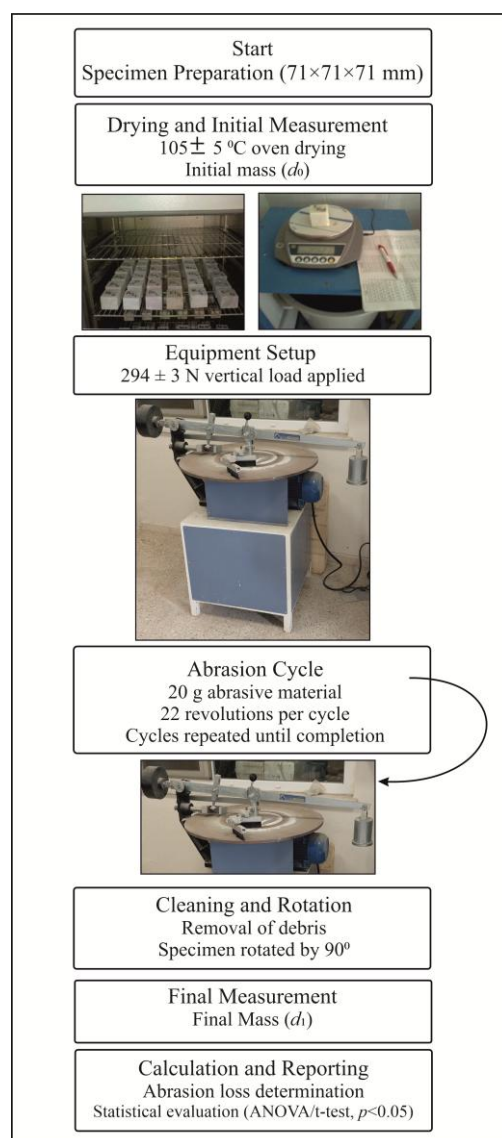


Figure 3. Schematic workflow of the Böhme abrasion test procedure applied in this study. The sequence includes specimen preparation (71 mm × 71 mm × 71 mm), oven drying and initial mass measurement (m_0), equipment setup under a $294 \pm 3 \text{ N}$ vertical load, abrasion cycling ($20 \pm 0.5 \text{ g}$ abrasive, 22 revolutions per cycle), inter-cycle cleaning and 90° specimen rotation, final mass measurement (m_1), and abrasion loss calculation with statistical evaluation (ANOVA/ t -test, $p < 0.05$).

2.5. Petrographic Analysis

Petrographic analyses were conducted on standard polished thin sections ($\sim 30 \mu\text{m}$) prepared at the General Directorate of Mineral Research and Exploration (MTA), Türkiye.

Thin sections were examined using a Nikon LV100POL research polarizing microscope equipped with transmitted and reflected light systems, a trinocular observation head, and a digital imaging system. Petrographic observations were supported by image analysis using Clemex Vision Lite software (version 5, Clemex Technologies Inc., Longueuil, QC, Canada) to examine mineralogical composition, textural characteristics, grain-size relationships, and microstructural features relevant to abrasion performance.

2.6. X-Ray Diffraction (XRD) Analysis

X-ray diffraction (XRD) analyses were performed using a Shimadzu XRD-6000 diffractometer equipped with a Cu X-ray tube and CuK α radiation ($\lambda = 1.544 \text{ \AA}$). Analyses were conducted on powdered and flat-surface specimens over a scanning range of $2\theta = 2\text{--}70^\circ$. Powdered samples were prepared at grain sizes below 100–200 μm to ensure analytical consistency. Qualitative mineralogical phase identification was performed by comparison with ICDD reference patterns. XRD was primarily used to verify dominant mineral phases identified petrographically and support mineralogical and lithological characterization of the investigated rocks.

2.7. SEM–EDS Analysis

Scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM–EDS) was carried out using a Zeiss LEO 1430 VP scanning electron microscope equipped with a W (tungsten) filament, secondary electron (SE) and backscattered electron (BSE) detectors, and a RÖNTEC QX2 XFlash energy-dispersive X-ray spectroscopy (EDX) detector at Afyon Kocatepe University Technology Application and Research Center (AKU TUAM). Fresh fracture surfaces prepared from representative rock specimens were coated with carbon prior to imaging to ensure electrical conductivity. It is acknowledged that EDS analyses performed on unpolished fracture surfaces are semi-quantitative in nature and subject to surface topography effects; the results are therefore interpreted as indicative of elemental composition rather than precise mineral stoichiometry.

SEM observations focused primarily on mineral associations, textural relationships, and microstructural heterogeneity relevant to abrasion performance. Semi-quantitative EDS analyses, including point and area measurements, were used to support mineral phase identification and elemental characterization rather than precise mineral chemical determination.

2.8. Statistical Analysis

Descriptive statistics are reported as mean $\pm$ standard deviation (SD). All statistical analyses were conducted at a significance level of $p < 0.05$.

One-way ANOVA was used to assess whether abrasion loss values differed significantly among abrasive types under comparable experimental conditions. Independent-samples *t*-tests were applied to evaluate the effect of particle-size grading (graded versus ungraded conditions) on abrasion performance for each abrasive type.

Effect size was quantified using eta squared (η^2), calculated as follows:

$$\eta^2 = \frac{SS_{\text{between}}}{SS_{\text{total}}} \quad (2)$$

where SS_{between} is the sum of squares between groups and SS_{total} is the total sum of squares. Values of approximately 0.01, 0.06, and 0.14 correspond to small, medium, and large effect sizes, respectively [24]. For the graded-versus-ungraded comparisons, effect sizes were additionally quantified using Cohen's *d*, with $|d|$ values of approximately 0.2, 0.5, and 0.8 denoting small, medium, and large effects, respectively [24].

3. Results

3.1. Particle-Size Characteristics of Abrasives and Compliance with TS 699

The particle-size distributions of commercially supplied abrasive powders exhibited substantial deviations from the target grain-size specifications defined by TS 699 (Table 3). Sieve analysis results revealed marked variability among abrasive types, indicating that commercially available abrasives frequently differ from standardized grading specifica-

tions and may therefore introduce an important source of variability into Böhme abrasion measurements.

The coarse particle fraction ($-0.160 + 0.125$ mm; 6%) specified by TS 699 showed considerable variation among the investigated abrasives. The greatest deviation was observed for brown corundum, where the coarse fraction reached 27.5%, exceeding the standard specification by more than fourfold. Similarly, Emery-2 exhibited a relatively elevated coarse fraction (13.4%), whereas silicon carbide (SiC) contained the lowest proportion (1.1%), reflecting comparatively finer particle characteristics. Marked differences were also observed within intermediate and fine particle-size fractions. The dominant grain-size interval defined by TS 699 ($-0.125 + 0.100$ mm; 55%) ranged from 31.8% to 70.2% among abrasives. Emery-2 exhibited the highest proportion within this interval (70.2%), whereas white corundum displayed the lowest (31.8%). In contrast, the fine fraction ($-0.100 + 0.071$ mm; 35%) reached 59.9% in white corundum, indicating enrichment in finer particles relative to the standardized target distribution.

These findings demonstrate that commercially supplied abrasive powders may substantially deviate from TS 699 particle-size specifications, potentially affecting the repeatability and comparability of Böhme abrasion measurements. In particular, the pronounced enrichment of coarse particles in certain abrasives, especially brown corundum, may contribute to increased abrasion efficiency and material removal during testing. The results therefore emphasize the importance of standardized particle-size grading for minimizing grain-size-related variability and improving the reproducibility of Böhme abrasion testing.

3.2. Abrasion Performance Under Different Abrasive Conditions

Böhme abrasion results obtained under graded and ungraded abrasive conditions are presented in Tables 4 and 5, respectively, and reveal substantial variation associated with both abrasive type and particle-size condition. Under standardized graded conditions, silicon carbide (SiC) consistently produced the highest abrasion values across nearly all investigated stone types ($0.26\text{--}0.78$ cm³/50 cm²). In contrast, natural emery abrasives (Emery-1 and Emery-2) yielded the lowest abrasion values, whereas white and brown corundum exhibited intermediate to relatively high abrasion performance. Based on mean abrasion values obtained under graded conditions, the overall abrasion efficiency ranking is:

$$\text{SiC} > \text{Brown Corundum} \approx \text{White Corundum} > \text{Emery-1} \approx \text{Emery-2}$$

The comparatively high abrasion performance of SiC and corundum-based abrasives is plausibly related to their greater hardness and more effective abrasive characteristics. In contrast, the lower abrasion values obtained for Emery-1 and Emery-2 may reflect their comparatively heterogeneous mineralogical composition and broader particle-size variability. Differences between graded and ungraded conditions were most pronounced for brown corundum, which exhibited substantially higher abrasion values under ungraded conditions. This pattern is consistent with sieve analysis results (Section 3.1), which demonstrated marked enrichment of coarse particle fractions in commercially supplied brown corundum. The observed increase in abrasion performance therefore suggests that deviations from standardized particle-size distributions may measurably influence material removal during Böhme testing. The distribution of abrasion loss values across all abrasive types and grading conditions is illustrated in Figure 4. Among the investigated lithologies, carbonate rocks consistently exhibited higher abrasion losses than Balaban granite across all abrasive types and grading conditions. This carbonate–silicate hardness contrast is long established and is not treated here as a result; it is retained only as a controlled

matrix variable against which the abrasive- and grading-related effects are evaluated (see Section 4.1).

To determine whether the observed differences among abrasive types and grading conditions were statistically significant, abrasion data were further evaluated using one-way ANOVA and independent-samples *t*-tests.

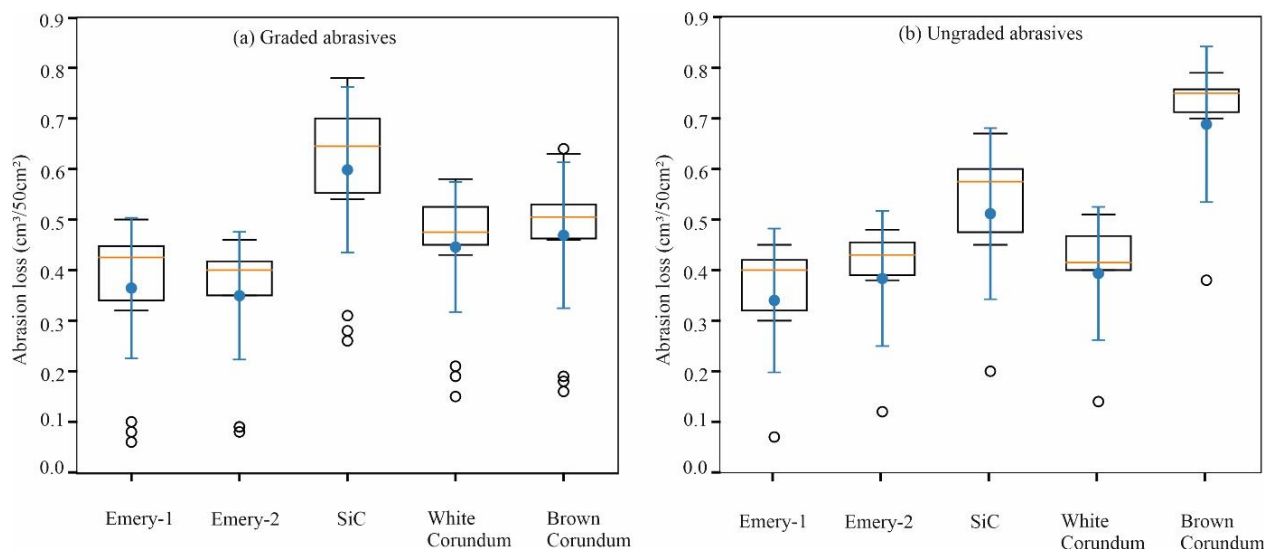


Figure 4. Box plots of Böhme abrasion loss values ($\text{cm}^3/50 \text{ cm}^2$) for the five investigated abrasive types under (a) graded and (b) ungraded conditions. Orange lines indicate medians; blue circles indicate means, with blue bars denoting mean ± 1 SD; black whiskers mark the Tukey limits; open circles denote outliers. Box construction: the box spans the interquartile range (Q1–Q3) with the median; whiskers follow the Tukey convention, extending to the most extreme value within $1.5 \times$ IQR of the nearer hinge. Whisker lengths therefore differ between panels and are not symmetric about the box or median; where a lower whisker is absent (e.g., Emery-2; white corundum), the hinge coincides with the extreme value, and the whisker length is zero. Axis ticks were rechecked and corrected.

Table 4. Experimental abrasion loss values obtained using graded abrasive powders ($\text{cm}^3/50 \text{ cm}^2$); each stone–abrasive combination was tested in triplicate ($n = 3$).

Abrasive	Emery-1	Emery-2	SiC	White Corundum	Brown Corundum
Kaplanpostu	0.50	0.46	0.78	0.55	0.61
	0.47	0.46	0.77	0.58	0.64
	0.47	0.46	0.76	0.56	0.63
Afyon Sugar	0.44	0.41	0.69	0.46	0.53
	0.43	0.40	0.70	0.49	0.52
	0.44	0.41	0.70	0.48	0.50
Afyon Honey	0.45	0.43	0.71	0.56	0.51
	0.46	0.42	0.70	0.51	0.50
	0.43	0.40	0.69	0.53	0.53
Akşehir Black	0.40	0.40	0.60	0.49	0.54
	0.42	0.35	0.59	0.47	0.51
	0.39	0.35	0.58	0.43	0.47
Gölpazarı Beige	0.37	0.37	0.55	0.45	0.46
	0.32	0.36	0.54	0.46	0.50
	0.33	0.35	0.56	0.45	0.46
Balaban Granite	0.08	0.09	0.31	0.15	0.19
	0.06	0.08	0.28	0.21	0.16

	0.10	0.09	0.26	0.19	0.18
Table 5. Experimental abrasion loss values obtained using ungraded abrasive powders (cm ³ /50 cm ²).					
Abrasive	Emery-1	Emery-2	SiC	White Corundum	Brown Corundum
Kaplanpostu	0.45	0.44	0.67	0.51	0.75
Afyon Sugar	0.42	0.48	0.60	0.43	0.79
Afyon Honey	0.42	0.46	0.60	0.48	0.76
Akşehir Black	0.38	0.42	0.55	0.40	0.70
Gölpazarı Beige	0.30	0.38	0.45	0.40	0.75
Balaban Granite	0.07	0.12	0.20	0.14	0.38

3.3. Statistical Evaluation of Abrasion Differences

3.3.1. Effect of Abrasive Type

One-way ANOVA revealed statistically significant differences in abrasion loss among graded abrasive types ($F = 8.9857$, $p < 0.05$; Table 6), indicating that abrasive type exerts a statistically significant influence on Böhme abrasion performance.

Effect size analysis yielded $\eta^2 = 0.297$, indicating that approximately 30% of the total variance in abrasion loss can be attributed to abrasive type. According to conventional effect size thresholds ($\eta^2 > 0.14$), this corresponds to a large effect, confirming that abrasive type represents an important controlling factor in abrasion performance under standardized Böhme testing conditions. The remaining unexplained variance suggests that additional factors may contribute to abrasion response, most notably differences in rock mineralogy and microstructural characteristics.

The influence of particle-size grading was further evaluated using independent-samples t -tests, presented in Section 3.3.2.

Table 6. ANOVA results for abrasion values obtained under graded conditions.

Source	SS	df	MS	F
Between Groups	0.7146	4	0.1786	8.9857
Within Groups	1.6895	85	0.01988	—
Total	2.4042	89	—	—

3.3.2. Independent-Samples t -Test: Graded vs. Ungraded Abrasives

To evaluate the influence of particle-size grading on abrasion performance, independent-samples t -tests were conducted to compare abrasion values obtained under graded and ungraded conditions (Table 7). Because the two conditions differed in replication ($n = 18$ for graded versus $n = 6$ for ungraded), the independent-samples t -tests were performed on unequal sample sizes; accordingly, the panel (b) distributions in Figure 4 are based on six observations per abrasive and should be interpreted with this in mind.

For most abrasives, abrasion values obtained under graded and ungraded conditions did not differ significantly ($p > 0.05$). Emery-1, Emery-2, silicon carbide (SiC), and white corundum exhibited statistically comparable abrasion performance despite differences in particle-size distributions. These findings suggest that moderate deviations from standardized grain-size specifications may have limited influence on abrasion performance under the tested conditions. The mean values in Table 7 are reported solely as the inputs required for the independent-samples t -test and are not intended as performance descriptors; they are pooled across all six lithologies and therefore characterize each abrasive rather than any individual stone. Outliers were retained for transparency rather than removed: in the graded condition each stone–abrasive combination was measured in tripli-

cate ($n = 3$), so discarding individual replicates is not statistically justified, whereas the ungraded values are single determinations per stone–abrasive combination; both are shown in Figure 4 only for completeness.

In contrast, brown corundum exhibited a statistically significant difference between graded and ungraded conditions ($p < 0.05$). The mean abrasion value increased from 0.47 cm³/50 cm² under graded conditions to 0.69 cm³/50 cm² in the ungraded state, indicating a substantial increase in abrasion performance.

This behavior is consistent with sieve analysis results (Section 3.1), which demonstrated that commercially supplied brown corundum contained a markedly elevated coarse particle fraction relative to TS 699 specifications. The greater abundance of coarse particles in the ungraded material may therefore have enhanced material removal during testing, resulting in increased abrasion loss.

Overall, these findings indicate that particle-size grading does not uniformly influence abrasion performance across all abrasive materials. However, substantial deviations from standardized particle-size specifications may significantly affect abrasion performance under specific conditions, particularly in abrasives enriched in coarse particle fractions such as brown corundum. Effect sizes computed alongside the significance tests confirm this pattern: the grading effect is negligible to medium and statistically non-significant for Emery-1 ($d = 0.14$), Emery-2 ($d = 0.38$), white corundum ($d = 0.39$), and SiC ($d = 0.55$), whereas brown corundum shows a large effect ($d = 1.50$; $p = 0.004$). The standardized Böhme outcome is therefore largely insensitive to grading variation for four of the five abrasives, with brown corundum—the only abrasive carrying a markedly elevated coarse fraction—identified as the sole measurable source of grading-related bias.

Table 7. Comparison of abrasion performance between graded and ungraded abrasive conditions. Values are group means used as t -test inputs (pooled across lithologies), not performance descriptors.

Abrasive	Graded Mean	Ungraded Mean	Cohen's d	Statistical Interpretation
Emery-1	0.36	0.34	0.14	No significant difference
Emery-2	0.35	0.40	0.38	No significant difference
SiC	0.60	0.51	0.55	No significant difference
White Corundum	0.44	0.39	0.39	No significant difference
Brown Corundum	0.47	0.69	1.50	Significant difference

3.4. Petrographic Characteristics of Investigated Rocks

Petrographic analysis of thin sections revealed marked differences in mineralogical composition, grain size, and textural organization among the investigated lithologies (Figure 5).

The three crystalline marbles—Kaplanpostu (KP), Afyon Sugar (AS), and Afyon Honey (AH)—are composed predominantly of calcite, displaying granoblastic to interlobate textures with sutured grain boundaries. Kaplanpostu marble exhibits a medium- to coarse-grained granoblastic fabric with well-developed twin lamellae in calcite grains (Figure 5a). Afyon Sugar marble is characterized by a coarser crystalline texture with elongated calcite grains showing pronounced mechanical twinning (Figure 5b). Afyon Honey marble displays a fine- to medium-grained granoblastic texture with uniformly interlocking calcite grains and subordinate accessory phases (Figure 5c).

Akşehir Black marble (AB) exhibits a markedly heterogeneous microstructure consisting of coarser calcite grains set in a fine-grained to microcrystalline carbonate matrix, with scattered opaque minerals (Figure 5d).

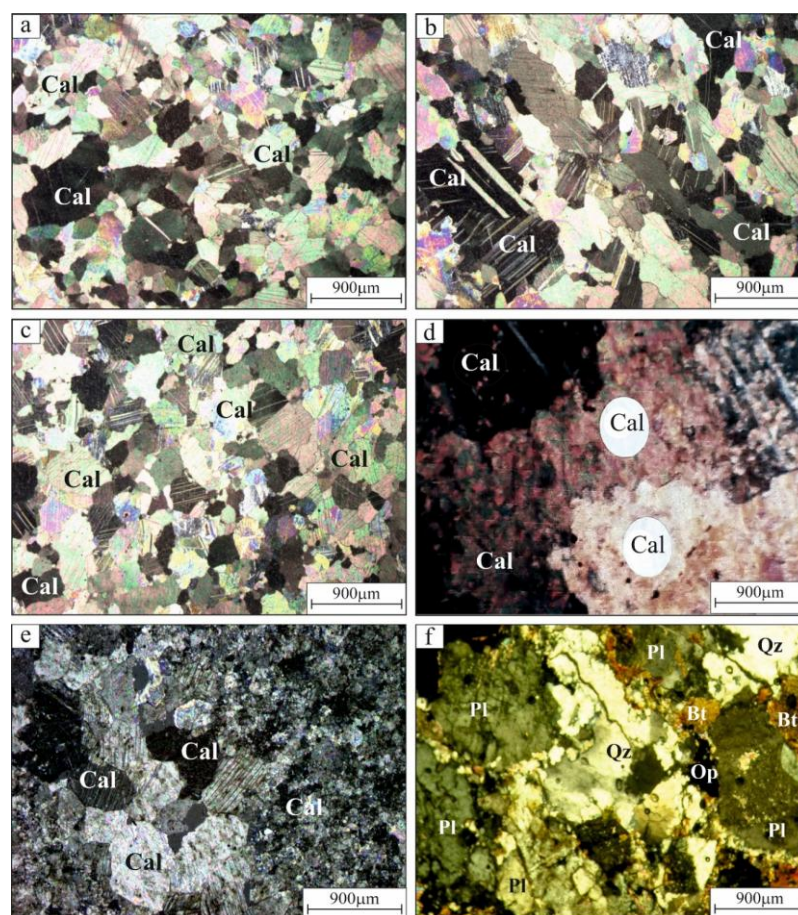


Figure 5. Polarizing microscope images of the investigated natural stones under crossed nicols. Mineral abbreviations follow Whitney and Evans [25]. (a) Kaplanpostu marble (KP): medium- to coarse-grained granoblastic calcite (Cal) fabric with sutured grain boundaries. (b) Afyon Sugar marble (AS): coarse-grained calcite with pronounced mechanical twinning. (c) Afyon Honey marble (AH): fine- to medium-grained granoblastic calcite texture. (d) Akşehir Black marble (AB): coarser calcite (Cal) grains set in a fine-grained to microcrystalline carbonate matrix. (e) Gölpazarı Beige limestone (GB): micritic matrix with sparitic calcite grains and fossil fragments. (f) Balaban granite (BG): poly-mineralic granular texture comprising plagioclase (Pl), quartz (Qz), mica (Bt), and opaque minerals (Op).

This bimodal grain-size distribution reflects a complex recrystallization history and represents a microstructurally distinct carbonate lithology relative to the other marbles.

Gölpazarı Beige limestone (GB) is characterized by a micritic to microsparitic matrix containing larger sparitic calcite grains and fossil fragments, consistent with a biomicritic fabric (Figure 5e). The fine-grained matrix and intergranular porosity distinguish this lithology texturally from the recrystallized marbles.

Balaban granite (BG) is a polymineralic crystalline rock comprising plagioclase, quartz, mica (Bt), and opaque minerals (Op), with a granular interlocking texture (Figure 5f). The coexistence of mechanically resistant silicate phases and well-developed grain boundary contacts distinguishes this lithology from the carbonate rocks in terms of microstructural framework.

3.5. Mineralogical Characterization by XRD

X-ray diffraction analyses confirmed the dominant mineral phases identified petrographically and revealed systematic compositional differences among the investigated lithologies (Figure 6).

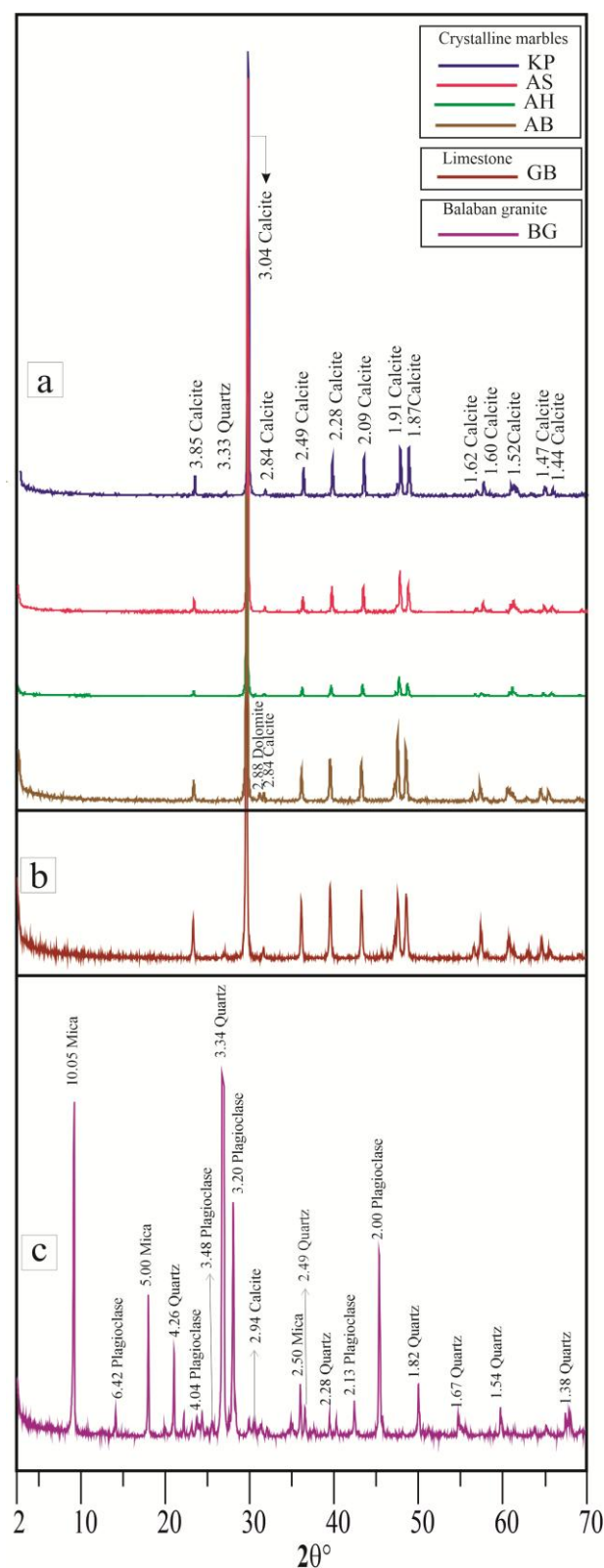


Figure 6. X-ray diffraction (XRD) patterns of the investigated natural stones. (a) Crystalline marbles: KP, AS, and AH showing calcite-dominated patterns with the diagnostic reflection at $d = 3.04 \text{ \AA}$; AB displaying additional dolomite peak at $d = 2.88 \text{ \AA}$. (b) Gölpaazarı Beige limestone (GB), exhibiting a calcite-dominated pattern. (c) Balaban granite (BG), displaying reflections corresponding to quartz, plagioclase, mica, and minor calcite.

The crystalline marbles KP, AS, and AH yielded diffraction patterns dominated by sharp calcite peaks, with the diagnostic $d = 3.04 \text{ \AA}$ reflection dominant across all three

specimens, and a minor quartz peak at $d = 3.33 \text{ \AA}$ visible in KP (Figure 6a). No additional mineral phases were detected in AS and AH, confirming predominantly monomineralic calcite composition.

Akşehir Black marble (AB) displayed calcite reflections together with a dolomite peak at $d = 2.88 \text{ \AA}$, indicating a mixed carbonate mineralogy distinct from the other marbles. XRD data for Akşehir Black marble were sourced from Gürcan [26].

Gölpazarı Beige limestone (GB) similarly exhibited a calcite-dominated diffraction pattern; however, differences in peak intensity ratios and background character relative to the marbles are consistent with the finer crystallinity and micritic fabric observed petrographically (Figure 6b).

Balaban granite displayed a markedly different diffraction pattern, with prominent reflections corresponding to quartz ($d = 3.34, 4.26, 2.49 \text{ \AA}$), plagioclase ($d = 3.20, 3.48, 4.04, 6.42 \text{ \AA}$), mica ($d = 10.05, 5.00, 2.50 \text{ \AA}$), and a minor calcite peak at $d = 2.94 \text{ \AA}$ (Figure 6c). The identification of mica via the basal 001 reflection at $10.05 \text{ \AA}$ is consistent with a mica phase. The minor calcite signal likely reflects secondary carbonate along grain boundaries or microfractures.

3.6. Microstructural Observations by SEM–EDS

SEM observations on fresh fracture surfaces revealed microstructural features consistent with petrographic and XRD results and provided additional textural detail relevant to abrasion behavior (Figure 7).

In Kaplanpostu marble (KP), SEM imaging revealed coarse calcite (Cal) grains with well-developed cleavage surfaces alongside subordinate mica (Ms) flakes occupying intergranular positions (Figure 7a). The presence of mica at grain boundaries represents a mechanically weak locus susceptible to preferential wear during abrasion.

Afyon Sugar marble (AS) exhibited a dense interlocking fabric of calcite grains with irregular fracture surfaces and occasional intergranular voids (Figure 7b). The absence of subordinate phases and tight grain packing suggest a comparatively homogeneous microstructural framework.

In Afyon Honey marble (AH), SEM images showed calcite grains with irregular boundaries and localized mica /muscovite (Ms) inclusions within the carbonate matrix (Figure 7c). The spatial association of mica with calcite grain boundaries introduces microstructural heterogeneity consistent with petrographic observations.

Akşehir Black marble (AB) displayed a fine-grained calcite matrix with scattered mica/muscovite (Ms) flakes oriented subparallel to the foliation plane (Figure 7d). This fabric introduces textural anisotropy that may influence directional abrasion response, and is consistent with the dolomite detected by XRD indicating mixed carbonate mineralogy. SEM–EDS data for Akşehir Black marble were sourced from Gürcan [26].

Balaban granite (BG) exhibited a coarse interlocking assemblage of plagioclase (Pl), quartz (Qz), and mica/Biotite (Bt), with well-defined grain boundaries and minimal intergranular porosity (Figure 7e). The tight interlocking of hard silicate phases is consistent with the comparatively high abrasion resistance of this lithology observed in abrasion testing.

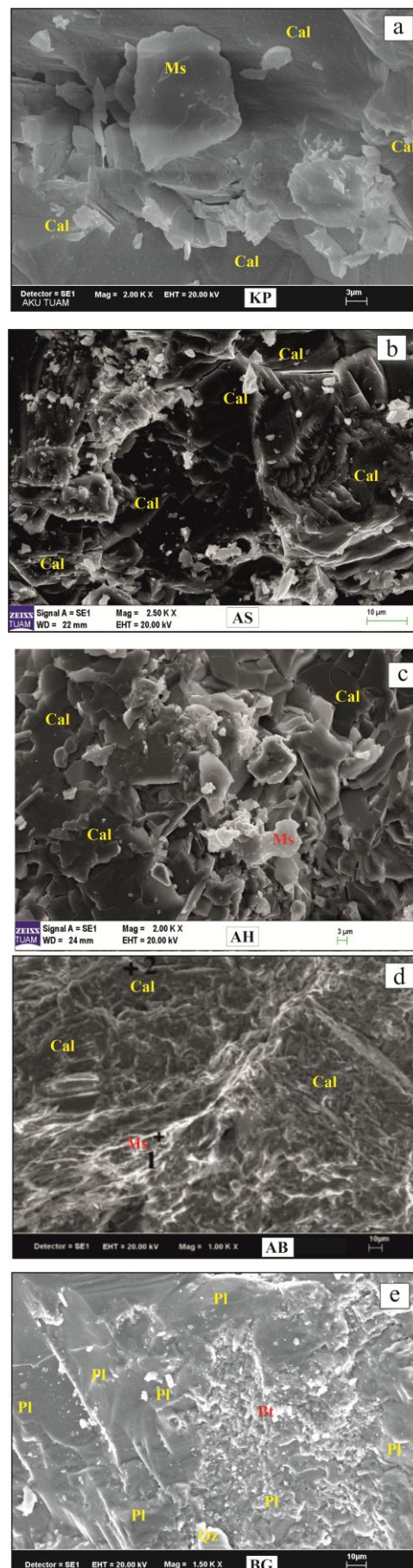


Figure 7. SEM images of fresh fracture surfaces of the investigated natural stones. (a) KP: coarse calcite (Cal) grains with well-developed cleavage surfaces and intergranular mica (Ms). (b) AS:

dense interlocking calcite fabric with intergranular voids. (c) AH: calcite grains with localized mica (Ms) inclusions. (d) AB: fine-grained calcite matrix with foliation-parallel mica (Ms) flakes. (e) BG: interlocking plagioclase (Pl), quartz (Qz), and mica (Bt).

4. Discussion

4.1. Mineralogical and Microstructural Context of Abrasion Performance

The abrasion trends observed in this study indicate that abrasion performance is influenced not only by abrasive characteristics but also by the mineralogical composition and microstructural properties of the investigated rocks. Petrographic observations, X-ray diffraction (XRD) analyses, and SEM–EDS data collectively suggest that variations in mineral composition, grain size, textural relationships, and microstructural heterogeneity are associated with differences in abrasion response among the investigated lithologies.

The carbonate lithologies investigated in this study, including Kaplanpostu, Afyon Sugar, and Afyon Honey marbles together with Akşehir Black marble and Gölpazarı Beige limestone, generally exhibited higher abrasion losses than Balaban granite. This pattern may reflect the predominance of calcite, a relatively soft mineral phase (Mohs hardness = 3), in carbonate rocks [27–30]. Although abrasion performance varied among carbonate lithologies, the overall response suggests that calcite-dominated mineralogy is broadly associated with comparatively lower abrasion resistance. This hardness-controlled contrast is long established and is treated here as a controlled variable rather than as a result of the present study; it is invoked only to explain why the abrasive-related effects differ across matrices of contrasting hardness.

Differences among carbonate rocks may additionally reflect variations in texture and mineralogical composition. Petrographic and SEM–EDS observations indicate differences in grain size, accessory mineral content, textural relationships, and microstructural heterogeneity among the investigated lithologies. In particular, compositional variability and the presence of accessory phases in certain rocks may have contributed to localized differences in abrasion performance.

In contrast, Balaban granite consistently exhibited the lowest abrasion loss values regardless of abrasive type or grading condition [28]. This comparatively higher abrasion resistance may be associated with its polymineralic composition, dominated by quartz and feldspar together with mica-bearing phases. The relatively greater hardness of silicate minerals compared with calcite may therefore contribute to increased resistance against abrasive wear.

Overall, the results indicate that abrasion performance reflects the combined influence of abrasive characteristics and rock mineralogical–microstructural properties. While abrasive type represents a statistically significant influencing factor, the mineralogical framework of the tested rocks appears to modulate the magnitude of abrasion response under Böhme test conditions. The inclusion of low-hardness carbonate lithologies alongside the harder granite was a deliberate design choice rather than an attempt to rank the stones: because a standardized test procedure must perform reliably across the full range of material hardness to which it is applied, evaluating repeatability at both the soft (carbonate) and hard (silicate) extremes provides a more demanding and informative test of the method than hard rocks alone.

4.2. Implications for Standardization of Böhme Testing

The findings of this study have important implications for the standardization and reproducibility of Böhme abrasion testing. Although EN 14157 and TS 699 define target particle-size specifications for abrasive powders, sieve analyses demonstrated that commercially supplied abrasives may substantially deviate from these standards. Such devi-

ations indicate that abrasive particle-size characteristics represent a potentially underrecognized source of variability capable of affecting the comparability of abrasion measurements across laboratories and testing conditions.

Statistical analyses indicate that particle-size distribution does not uniformly influence abrasion performance across all abrasive materials. For most abrasives, differences between graded and ungraded conditions were not statistically significant, suggesting that moderate deviations from standardized grain-size specifications may have limited practical influence under certain conditions. However, the statistically significant increase in abrasion performance observed for brown corundum under ungraded conditions demonstrates that substantial enrichment of coarse particles may introduce measurable bias into Böhme abrasion measurements.

These findings emphasize the importance of particle-size control in abrasion testing, particularly for abrasives characterized by broad or heterogeneous grain-size distributions [31,32]. The results further suggest that the use of standardized graded abrasives may improve test repeatability and reduce variability associated with commercially supplied materials [33]. These observations are consistent with the earlier findings of Bağcı and Bozkurt [11], who demonstrated that even small differences in abrasive particle-size distribution produce measurable changes in abrasion loss, and recommended that both the type of abrasive and its sieve analysis data be reported alongside abrasion test results. The present study provides statistical evidence supporting this recommendation and extends it to a broader range of abrasive types under controlled experimental conditions.

Overall, the results demonstrate that reliable abrasion characterization depends not only on the intrinsic properties of the tested rock but also on the standardization of abrasive materials. Improved control of abrasive particle-size distributions may therefore substantially enhance the reliability, repeatability, and inter-laboratory comparability of Böhme abrasion measurements. A further limitation concerns the asymmetric replication between conditions. Because the ungraded condition was evaluated with a single determination per stone–abrasive combination, within-condition test repeatability could not be quantified for that case; the repeatability evidence reported here therefore pertains primarily to the graded condition. In addition, the dispersion bars in Figure 4 are pooled across the six lithologies and thus reflect combined material and procedural variability rather than pure within-specimen test repeatability.

4.3. Applicability of Locally Produced Natural Emery Abrasives

Chemical analyses revealed that both Emery-1 and Emery-2 deviate substantially from the chemical composition prescribed by TS 699 (Table 2). Their Al_2O_3 content (~57.7 wt.%) falls well below the required 70–80 wt.% range, while Fe_2O_3 (~24 wt.%) and SiO_2 (~13 wt.%) considerably exceed the standard limits. These compositional deviations reflect the inherent mineralogical heterogeneity of natural emery deposits, which cannot be eliminated by commercial processing. The near-identical compositions of Emery-1 and Emery-2 further suggest a common or mineralogically equivalent source, explaining their comparable abrasion performance.

Despite their chemical non-compliance with TS 699, both emery abrasives exhibited comparatively stable abrasion performance across graded and ungraded conditions. For most stone types, abrasion values did not differ significantly between grading states ($p > 0.05$), indicating that the particle-size distributions of these abrasives are inherently less variable than those of synthetic abrasives such as brown corundum. This behavioral stability is a practically important characteristic: it suggests that even without rigorous grading control, emery abrasives introduce less bias into Böhme measurements than abrasives with broad or heterogeneous grain-size distributions.

Under controlled grading conditions, locally produced emery abrasives yielded consistent and reproducible abrasion results across all tested lithologies. Although their abrasion efficiency is lower than that of SiC or corundum-based abrasives—a consequence of their lower Al_2O_3 content and the presence of softer mineral phases—this characteristic may be advantageous for standardization purposes, as it reduces the risk of excessive or variable material removal. Their local availability and lower procurement cost relative to imported synthetic abrasives further support their potential as cost-effective alternatives for routine Böhme abrasion testing, provided that particle-size grading is controlled in accordance with TS 699. A quantitative cost comparison supporting this statement is provided in Section 4.4 (Table 8).

Table 8. Retail procurement and per-test cost of the investigated abrasives (25 kg pack, VAT included; quotations mid-2026).

Abrasive	Grade	Unit Price (TL kg ⁻¹)	Per-Test Cost (TL, 0.40 kg)	Source
Natural emery (local)	F120	84	33.6	Zımaş (producer) [34]
White corundum	F60–F180	430–492	172–197	sanayideposu/EGE NANOTEK [35]
Silicon carbide (black)	P400	887	355	sanayideposu/EGE NANOTEK [35]
Brown corundum	F220	quote on request	—	sanayideposu/EGE NANOTEK [35]

4.4. Procurement-Cost Considerations

The standardization advantages of an abrasive must be weighed against its procurement cost, particularly for routine, high-throughput testing. Under EN 14157, 20 g of abrasive is applied per period over 20 periods, giving 0.40 kg of abrasive per specimen test. Retail unit costs (25 kg pack, VAT included, mid-2026) are summarized in Table 8. Locally produced natural emery is by far the least expensive abrasive at approximately 84 TL kg⁻¹, corresponding to about 33.6 TL per test. The imported synthetic abrasives are substantially more costly: white corundum approximately 430–492 TL kg⁻¹ (about 172–197 TL per test) and black silicon carbide approximately 887 TL kg⁻¹ (about 355 TL per test); brown corundum is supplied on a quotation basis. Emery is therefore roughly one-fifth to one-tenth of the per-test cost of the synthetic abrasives. These are indicative retail prices that vary with supplier, pack size, grit, and exchange rate; emery is quoted by a domestic producer of natural emery [34], whereas the synthetic abrasives are priced through an industrial supplier [35]. Taken together with the abrasion and repeatability results, this comparison supports a practically meaningful conclusion. Locally sourced emery, although chemically non-compliant with TS 699 and lower in abrasion efficiency, combines domestic availability with the lowest procurement cost of the abrasives tested and, as shown in Sections 3.3.2 and 4.3, delivers stable and reproducible results under controlled particle-size grading. It therefore represents a cost-effective option for routine, standardization-compliant Böhme testing where maximum abrasion efficiency is not required, whereas SiC remains the preferred reference abrasive for the highest repeatability.

5. Conclusions

This study investigated the influence of abrasive type and particle-size distribution on Böhme abrasion performance of six natural stones under graded and ungraded conditions. The key findings are as follows.

Abrasive type was the dominant factor controlling abrasion performance. Silicon carbide produced the highest abrasion values across all tested lithologies, followed by corundum-based abrasives, while locally produced natural emery powders (Emery-1 and Em-

ery-2) exhibited comparatively lower efficiency. This hierarchy is consistent with differences in abrasive hardness and grain morphology.

Sieve analyses revealed that commercially supplied abrasives frequently deviate from TS 699 particle-size specifications. Particle-size grading had no statistically significant effect on abrasion performance for most abrasives; however, brown corundum showed a significant increase under ungraded conditions, attributable to its markedly elevated coarse particle fraction. This finding identifies non-standardized particle-size distributions as a measurable source of variability in Böhme testing. This insensitivity is a property of the test and the abrasives—quantifying how strictly the abrasive specification must be controlled—rather than a consequence of the particular stones tested.

Abrasion response also reflected the mineralogical and microstructural characteristics of the tested rocks. Carbonate lithologies consistently exhibited higher abrasion losses than Balaban granite, a contrast attributable to differences in mineral hardness, grain boundary cohesion, and textural complexity. This hardness-driven ranking is well established and is not presented as a new result; it is noted only to explain the matrix-dependent behavior of the test.

Under controlled grading conditions, locally produced natural emery abrasives yielded consistent and reproducible results, supporting their viability as cost-effective alternatives to imported synthetic abrasives for routine standardization-compliant testing. (Quantified in Section 4.4, emery is approximately 84 TL kg^{−1} versus approximately 430–887 TL kg^{−1} for the synthetic abrasives—roughly one-fifth to one-tenth of the per-test cost). These findings reinforce the recommendation of Bağcı and Bozkurt [11] that abrasion test reports should specify both the type of abrasive used and its particle-size distribution, and further suggest that SiC under standardized graded conditions provides the most reliable basis for inter-laboratory comparison of Böhme abrasion results.

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Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request.

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Abbreviations

The following abbreviations are used in this manuscript:

EN	European Norm
TS	Turkish Standard
SiC	Silicon carbide
XRD	X-ray diffraction
SEM	Scanning electron microscopy
EDS	Energy-dispersive X-ray spectroscopy
IQR	Interquartile range
ANOVA	Analysis of variance
SD	Standard deviation
KP	Kaplanpostu marble

AS	Afyon Sugar marble
AH	Afyon Honey marble
AB	Akşehir Black marble
GB	Gölpazarı Beige limestone

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