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Assessment of the suitability of clayey and sandy gypsum deposits from the Çankırı region (Türkiye) for plaster production

Çankırı (Türkiye) Bölgesindeki killi ve kumlu jips yataklarının sıva üretimi için uygunluğunun değerlendirilmesi

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Abstract

This study evaluates the suitability of clayey and sandy gypsum deposits from the Çankırı region of Türkiye for use in plaster production. Samples were collected in their natural state, without beneficiation or additives, to reflect realistic field conditions. Chemical compositions were determined by XRF, mineralogical phases were identified using XRD and Raman spectroscopy, and textural features were assessed by thin-section petrography. Results show that most samples contained SO_3 and CaO levels consistent with high-purity gypsum. One sample exhibited elevated SiO_2 and Al_2O_3 contents, as well as accessory phases such as quartz, calcite, and clays, and was therefore excluded from further evaluation. Petrographic observations indicated that most of the samples displayed homogeneous fabrics comparable to the industrial reference, while only one sample exhibited more heterogeneous features. Mechanical tests demonstrated that the uniaxial compressive strength increased from 1.51 MPa at 7 days to 2.84 MPa at 90 days, whereas the flexural strength rose dramatically from 0.62 MPa at 28 days to 1.52 MPa at 90 days. These results indicate that even without pre-treatment or reinforcement, natural clayey and sandy gypsum from Çankırı can achieve mechanical performance comparable to conventional plaster materials, highlighting their potential for cost-effective and sustainable construction applications.

Keywords: Çankırı, gypsum, plaster, material strength, sustainable product.

Öz

Bu çalışma, Çankırı bölgesinde yaygın olarak bulunan killi ve kumlu jips yataklarının sıva üretiminde kullanılabilirliğini değerlendirmektedir. Arazi koşullarına uygun şekilde, örnekler herhangi bir ön saflaştırma veya katkı işlemi uygulanmadan alınmış ve doğrudan laboratuvar analizlerine tabi tutulmuştur. Kimyasal bileşimler XRF ile belirlenmiş, mineralojik özellikler XRD ve Raman spektroskopisi ile incelenmiş, ayrıca ince kesit petrografisi ile dokusal özellikler gözlemlenmiştir. Sonuçlar, çoğu örneğin SO_3 ve CaO içerikleri bakımından yüksek saflıkta jips ile uyumlu olduğunu göstermektedir. Ancak bir örnek, yüksek SiO_2 ve Al_2O_3 seviyeleri ile birlikte kuvars, kalsit ve kil mineralleri varlığı nedeniyle farklılaşmış ve sıva üretiminden dışlanmıştır. Petrografik incelemeler, örneklerinin büyük çoğunluğunun referans endüstriyel jipse oldukça benzer homojen dokular sergilediğini, sadece bir örneğin ise daha heterojen bir yapı gösterdiğini ortaya koymuştur. Mekanik deneylerde, 7 günde 1.51 MPa olan tek eksenli basınç dayanımı 90 günde 2.84 MPa'a ulaşmıştır. Eğilme dayanımı ise 28 günde ortalama 0.62 MPa iken 90 günde 1.52 MPa'a yükselmiştir. Elde edilen sonuçlar, katkısız ve saflaştırılmamış bu doğal jipslerin dahi sıva üretiminde kullanılabilecek performans sunduğunu göstermektedir.

Anahtar kelimeler: Çankırı, jips, sıva, materyal dayanımı, sürdürülebilir ürün.

1 Introduction

Gypsum ($CaSO_4 \cdot 2H_2O$) is a widely available sulfate mineral that has been utilized in construction for millennia due to its fast-setting properties, ease of application, and natural abundance [1],[2]. It typically forms in evaporitic environments through the precipitation of calcium and sulfate ions under arid climatic conditions. The physical and chemical characteristics of gypsum, such as purity, grain size, siliciclastic inputs, and impurity content, directly influence its suitability for plaster and cement production. In modern construction, gypsum-based plasters continue to be highly valued for their fire resistance, acoustic insulation, and smooth surface finish [3]. Traditionally, industrial production relies on relatively pure deposits processed to strict granulometric and compositional standards. However, the growing demand for sustainable and locally sourced building materials has prompted increasing interest in the use of unrefined or minimally processed gypsum resources.

Türkiye, especially the Çankırı Basin, represents areas rich in evaporitic units. These evaporitic units are important raw material potential because of their huge usage areas, such as plaster, cement, mortar, ceramic, chemical products, etc. In Türkiye, particularly within the Central Anatolian province of Çankırı, natural gypsum deposits commonly occur in association with sandy and clayey impurities. These heterogeneous materials are often overlooked in favor of purer varieties, yet they hold considerable potential for cost-effective and sustainable plaster production if their chemical and mineralogical properties are well understood and optimized.

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The effective utilization of such deposits can reduce processing costs and promote resource efficiency, contributing to the sustainability goals of the construction sector.

The structural behavior of gypsum is central to its performance as a binder. Crystallographically, gypsum belongs to the monoclinic system (space group A2/a), with its framework consisting of calcium ions coordinated by sulfate tetrahedra and interlayer water molecules [4]-[6]. Upon heating, gypsum undergoes stepwise dehydration:

- Gypsum → Bassanite (~100-200 °C)
- Bassanite → Anhydrite (>200-1000 °C)
- Structural collapse and densification (>1000 °C)

These transformations profoundly affect the setting behavior and durability of gypsum products. For instance, bassanite (**$2CaSO_4{\cdot}(H_2O)$)** is metastable and highly reactive, whereas anhydrite ($CaSO_4$) crystallizes in the orthorhombic system (**space group Cmcm**), exhibiting significantly different physical and chemical properties [6],[7]. Such phase transitions not only alter mechanical performance but also yield distinct diffraction and spectroscopic signatures. Gypsum displays strong Raman bands near 1014 cm^{-1} (ν1 SO_4^{2-} symmetric stretch), while anhydrite produces sharper and shifted bands due to its denser, water-free lattice [5]. These differences highlight the utility of X-ray diffraction (XRD) and Raman spectroscopy as complementary techniques for phase identification and for monitoring dehydration processes.

Beyond crystal chemistry, the role of natural impurities is also crucial. Within this context, the sedimentological evaluation of evaporite materials (gypsum, anhydrite), the characterization of their facies, the assessment of their spatial distribution, and the construction of a basin model to optimize production will contribute to clarifying the fundamental issues [8]-[11]. Gypsum deposits often contain accessory minerals, including quartz, clay minerals (such as illite and smectite), carbonates, and minor sulfate phases. The presence of such impurities directly influences setting time, water demand, and long-term strength development [12]. For example, clayey and sandy gypsum varieties display different workability and pozzolanic reactivity [13]. While pure gypsum often ensures high early strength, mixed-texture deposits may provide long-term durability through micro-filling effects and secondary reactions.

Comprehensive characterization of these heterogeneous deposits requires a multi-method approach. Elemental analysis via X-ray fluorescence (XRF) provides information on chemical composition [14], while XRD and Raman spectroscopy allow for detailed phase identification and crystallinity assessment [4], [15]. Additionally, thin-section petrography under polarized light microscopy remains a fundamental tool for assessing textures, fabric, and diagenetic features that bulk analytical methods may not capture. The integration of these techniques provides a robust framework for correlating mineralogical features with the performance of plaster products.

Calcination represents a critical stage in plaster production. Conventional plasters are typically produced at 130-180 °C, generating bassanite, whereas higher temperatures (>800 °C) promote the formation of denser anhydrite phases with reduced reactivity [5]. Milling, water-to-powder ratios, and curing conditions further influence the microstructure and strength development of the final product. Numerous studies have shown that curing duration, water content, and the presence of additives significantly affect compressive and flexural strength [3],[13].

In this context, the present study examines the suitability of unseparated clayey and sandy gypsum deposits from Çankırı for use in plaster production. Chemical, mineralogical, and petrographic analyses were conducted to characterize the raw material, while plaster mortars were prepared by calcining selected mixed samples, grinding them, and mixing with water. Mechanical performance was evaluated through uniaxial compressive strength (UCS) and flexural strength tests conducted after 7, 28, and 90 days of curing. By combining analytical characterization with mechanical evaluation, this study aims to determine whether mixed-texture gypsum deposits can achieve comparable performance to conventional construction plasters without the need for pre-separation or additional additives.

2 Materials and methods

The raw materials used in this study were collected from natural gypsum outcrops located between the Çankırı city and Şabanözü town in the Central Anatolia, Türkiye. Samples were taken from relevant units in the areas between Çankırı province and Şabanözü. A total of six clayey and sandy gypsum samples were collected from the study area. The sampling sites are located within the Bozkır Formation, which is characterized by evaporitic successions dominated by clayey and sandy gypsum [16]. The Bozkır Formation is Upper Miocene-aged and characterized by intercalations of gypsum, mudstone, sandstone, and tuffite [17]. Gypsums are laminated and white in color. Mudstones are gray-green and contain gypsum crystals. Sandstones are yellowish and thinly bedded. Tuffites are white and rare [17]. The Bozkır Formation is transitional with the Hançili Formation, which consists of sandstone, siltstone, and marl [17]. To reflect realistic field conditions and ensure economic applicability, the samples were used in their naturally mixed form without preliminary separation or beneficiation.

The geomechanical properties of the gypsum used in this study were investigated in accordance with the test standards prepared by the Turkish Standards Institute. The applied test standards and methods are summarized below.

2.1 Chemical and mineralogical analyses

The characterization and chemical analysis were conducted at the Earth Sciences Application and Research Center (YEBİM) laboratories of Ankara University. Elemental composition was determined through X-ray fluorescence (XRF) spectroscopy with the Spectro branch X-Lab 2000 model machine. The details of the sample preparation and measurement conditions were given by Deniz and Kadioglu [15]. Mineralogical composition and phase identification were carried out using X-ray diffraction (XRD) with Co-Kα radiation over a 2θ range of 5°-70°. Raman spectroscopy measurements were performed using a confocal Raman microscope equipped with a 633 nm laser, enabling the detection of sulfate and silicate phases. Additionally, petrographic thin sections were examined under a polarizing microscope to assess textural features, impurity distribution, and mineral fabric.

2.2 Calcination and grinding

The selected samples (Çankırı 1, 3, 5, and 6), whose composition is dominantly gypsum, were mixed, and then the selected gypsum samples were subjected to calcination in a laboratory furnace (Electric Heat Treatment Furnace) at 850 °C for 24 hours in order to achieve complete dehydration and transformation into anhydrite. The calcined material was subsequently ground in a ball mill until a powder fineness suitable for mortar preparation was obtained.

2.3 Mortar preparation

The powdered, calcined gypsum was mixed with distilled water at a solid-to-liquid ratio of 3:1 (by weight) to form plaster mortars. The mixtures were cast into standardized prismatic molds (40 × 40 × 160 mm) (nine samples) and cylindrical (r=15 mm) (twenty-three samples) molds, then allowed to set under ambient laboratory conditions (≈20 °C, ~50% RH). Identification of gypsum binders and gypsum plasters was carried out according to the TS EN 13279-1 (2009) [19] standard. The shape, dimensions, and other requirements of the samples and molds for various experiments were prepared according to the TS EN 12390-1 (2002) [19] standard.

2.4 Curing procedure

After demolding, the specimens were stored under room conditions (≈20 °C, ~50% RH) and tested after 7, 28, and 90 days of curing. No artificial humidity or temperature control was applied during curing, in order to simulate realistic field conditions. Sample preparation and curing for the strength tests were carried out according to the TS EN 12390-2 (2019) [20] Standard.

2.5 Mechanical testing

Each prepared prismatic and cylindrical test samples were only used for one uniaxial compressive strength (UCS) and flexural strength test. Mechanical performance was evaluated using UCS and flexural strength tests, as specified in the relevant Turkish Standards (*TS EN 13279-1: TSE-2009)* [18]. UCS and FS tests were conducted using a UTEST-branded UTCM-3742 model cement compression and flexure test frame with 0.01 kN/s (0.023 MPa/s) loading speed configuration. First, using a three-point bending configuration, the resulting halves were subjected to UCS testing. The uniaxial compressive strength (UCS) of the test samples was determined according to the TS EN 12390-3 (2019) [21] standard, and the flexural strength of the test samples was determined according to the TS EN 12390-5 (2010) [22] standard.

3 Results

3.1 Chemical analysis results

X-ray fluorescence (XRF) analysis was employed to determine the chemical composition of the gypsum samples and to evaluate their suitability for plaster production based on oxide content. As expected for gypsum-rich materials, the dominant oxides were sulfur trioxide (SO_3) and calcium oxide (CaO), both of which are primary indicators of gypsum purity and reactivity (Table 1).

For all analyzed samples, except for the anomalous sample Çankırı-4, SO_3 concentrations ranged between 39.19% and 42.09%, while CaO contents varied from 30.23% to 31.82%. These values are in close agreement with the theoretical composition of high-purity gypsum ($CaSO_4 \cdot 2H_2O$), demonstrating that the majority of the field samples are chemically suitable for binder-based applications, such as plaster.

The reference material, commercially sourced and used as a baseline, contained 39.15% SO_3 and 30.16% CaO, aligning closely with the field samples (Table 1). This compositional similarity reinforces the compatibility of the natural deposits with industrial-grade gypsum, supporting their potential integration into standardized plaster formulations.

One sample (Çankırı-4) deviated significantly from this overall trend. Its chemical profile was characterized by an unusually high CaO content (40.27%), accompanied by elevated levels of aluminum oxide (Al_2O_3, 4.93%), silicon dioxide (SiO_2, 20.16%), and a loss-on-ignition (LOI) value of 29.00% (Table 1). Such values suggest a heterogeneous composition dominated by accessory phases such as calcite ($CaCO_3$), quartz (SiO_2), and clay minerals, rather than pure gypsum. Owing to its divergent geochemical character, this sample was excluded from further stages of plaster preparation to maintain consistency and comparability in performance evaluation.

In addition to the major oxides, the remaining samples contained only trace levels of iron oxide (Fe_2O_3), titanium dioxide (TiO_2), and other minor constituents (Table 1). The very low concentrations of these impurities confirm the mineralogical purity of the majority of samples and further support their suitability for industrial plaster production, where consistency and chemical stability are critical for setting behavior and mechanical performance.

3.2 Mineralogical and petrographic investigations

3.2.1 Thin section examinations

Polarized light microscopy was employed to examine the mineralogical textures and microstructures of selected gypsum samples from the Çankırı region, together with a commercial reference specimen. The petrographic observations provided complementary insights into the purity, homogeneity, and overall mineral fabric of the materials, which are critical parameters for assessing their suitability in plaster production.

The examined thin sections revealed variations in grain size, crystal morphology, and the distribution of accessory phases. Samples with a more uniform fabric and limited impurity content displayed higher optical clarity and fewer textural heterogeneities, indicating a higher degree of purity.

Table 1. Major oxide ratios provided from XRF results of the samples (LOI: Loss on ignition).

Element	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	V_2O_3	Cr_2O_3	MnO	Fe_2O_3	LOI
Dimension	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Cankırı-1	0.13	0.727	0.611	2.929	0.1239	41.0	0.03367	0.1821	31.02	0.1544	0.0018	0.00215	0.00362	0.242	22.05
Cankırı-3	0.14	0.93	0.401	2.242	0.1151	39.54	0.03683	0.1556	30.48	0.1362	0.0016	0.00279	0.00337	0.168	25.02
Cankırı-4	0.04	1.255	4.928	20.16	0.0471	35.82	0.03386	0.9047	40.27	0.2383	0.0102	0.00395	0.0331	2.442	29.002
Cankırı-5	0.13	0.46	0.351	1.464	0.1085	42.09	0.02992	0.1475	31.82	0.1678	0.0018	0.00264	0.00264	0.1351	23.01
Cankırı-6	0.13	1.016	0.722	4.509	0.1313	39.19	0.0392	0.2485	30.23	0.1852	0.0018	0.0048	0.00795	0.3137	23.1
Reference	0.13	1.23	0.463	2.24	0.1048	39.15	0.03487	0.1767	30.16	0.1409	0.0017	0.0058	0.00468	0.2546	25.5

In contrast, some specimens exhibited irregular grain boundaries, localized clay inclusions, or fine quartz particles dispersed within the gypsum matrix. These features suggest that while most deposits are suitable for binder applications, certain textural and compositional differences may influence water demand, setting behavior, and long-term mechanical performance.

Compared with the commercial reference sample, the majority of the Çankırı specimens showed broadly similar microstructural characteristics, confirming their potential as alternative sources of raw material. However, samples displaying pronounced heterogeneity or abundant inclusions may require selective use or blending strategies to ensure consistent plaster performance.

Sample Çankırı-1 exhibits a compact and fine-grained fabric dominated by equigranular gypsum crystals displaying low-order interference colors (Figure 1a, b). The dense packing and overall textural uniformity suggest minimal detrital contamination, indicating a relatively pure sulfate composition. Similarly, Çankırı-6 exhibits a homogeneous microstructure characterized by finely crystalline gypsum with slight grain alignment and sutured contacts, indicating limited post-depositional modification and a high degree of suitability for binder applications (Figure 1j, k).

In contrast, Çankırı-3 presents a more heterogeneous appearance, with loosely arranged gypsum grains and the presence of elongated to fibrous crystal habits (Figure 1c, d). These features may reflect depositional variability and weak preferred orientation, potentially associated with subaqueous sedimentation. Minor opaque inclusions were also observed, which may correspond to iron oxides or fine-grained clay minerals.

According to the mineralogical and petrographical investigation of the most heterogeneous sample (Çankırı-4), the magnesian calcite and quartz are the main mineral compositions with a minor amount of gypsum (Figure 1e, f).

Among the field samples, Çankırı-5 exhibited the highest degree of petrographic heterogeneity (Figure 1g, h). The sections contained coarse, angular grains embedded within a finer-grained gypsum matrix, along with localized zones of elevated birefringence. These optical variations, together with irregular grain boundaries, suggest partial recrystallization and the presence of accessory silicate phases. The compositional complexity observed in Çankırı-5 indicates possible mixing with non-sulfate detrital materials such as quartz or clay, which may influence its plaster performance.

The reference sample, used as an industrial benchmark, displayed a well-ordered gypsum texture composed of tabular to prismatic grains with minimal impurities (Figures 1l, m). The structural similarity between the reference and samples, such as Çankırı-1 and Çankırı-6, reinforces the interpretation that these natural deposits are suitable for industrial plaster production.

Figure 1. Microphotos of the samples under plane-polarized (PPL) and cross-polarized light (XPL), (a): Çankırı-1 PPL, (b): Çankırı-1 XPL, (c): Çankırı-3 PPL, (d): Çankırı-3 XPL, (e): Çankırı-4 PPL, (f): Çankırı-4 XPL, (g): Çankırı-5 PPL, (h): Çankırı-5 XPL, (j): Çankırı-6 PPL, (k): Çankırı-6 XPL, (l): Reference commercial sample PPL, (m): Reference commercial sample XPL.

Conversely, the pronounced heterogeneity observed in Çankırı-5 warrants careful consideration due to its potential impact on setting behavior and mechanical strength. Nevertheless, to evaluate the performance of local deposits under realistic conditions, this sample was also incorporated into the mortar preparation stage.

3.2.2 X-ray diffraction data interpretation

X-ray diffraction (XRD) was performed to determine the mineralogical composition and assess the phase purity of the gypsum samples collected from the field (Çankırı-1, 3, 4, 5, and 6) alongside the commercial reference material. The diffraction patterns are presented in Figure 2, where the characteristic reflections of the dominant crystalline phases are identified, and their relative intensities are indicated. These results provide the basis for evaluating the mineralogical variability among the field samples and for comparing their degree of purity with that of the industrial benchmark.

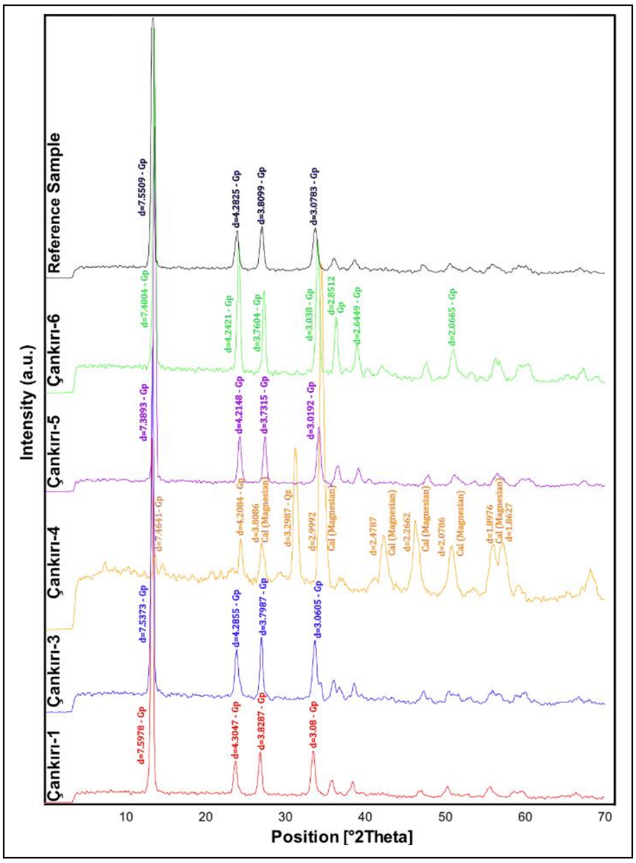

Figure 2. XRD patterns of the samples, starting with Çankırı-1 at the bottom and ending with the reference sample at the top. D values are shown over and next to the peaks (Cal: Calcite (magnesian, Gp: Gypsum, Qz: Quartz).

The diffractograms of Çankırı-1, Çankırı-3, Çankırı-5, Çankırı-6, and the reference sample consistently exhibit sharp, well-defined reflections corresponding to gypsum ($CaSO_4 \cdot 2H_2O$) (Figure 2). The most prominent peaks occur at ~11.7°, 20.7°, 23.4°, and 29.1° 2θ, which are characteristic of gypsum's basal planes. These diffraction features indicate a high degree of crystallinity and overall mineralogical purity in the majority of the analyzed samples.

In contrast, Çankırı-4 displays a distinctly different pattern (Figure 2). Alongside gypsum reflections, the profile exhibits significant peaks attributable to quartz (SiO_2), calcite ($CaCO_3$), and minor clay phases. The presence of these accessory minerals is consistent with the elevated SiO_2 and LOI values identified by XRF, confirming the heterogeneous nature of this sample. Such mineralogical complexity implies a detrital contribution, indicating that Çankırı-4 does not represent pure evaporitic gypsum, thereby limiting its suitability for plaster production.

The diffraction profile of Çankırı-5 also shows subtle deviations, including slightly broadened peaks and weak indications of secondary phases (Figure 2). These features align with the heterogeneity observed in thin-section petrography. Nevertheless, gypsum remains the dominant crystalline phase in this sample.

The reference sample exhibits a pattern typical of high-grade industrial gypsum, characterized by minimal background noise and the absence of detectable impurities (Figure 2). Its strong resemblance to Çankırı-1 and Çankırı-6 reinforces the interpretation that these natural deposits possess comparable quality and can serve as viable raw materials for plaster applications without beneficiation.

Overall, the XRD results validate the predominance of high-purity gypsum in most field samples, while also corroborating the exclusion of Çankırı-4 due to its mineralogical divergence.

3.2.3 Confocal Raman spectroscopy data interpretation

Raman spectroscopy was employed to characterize the vibrational signatures of sulfate minerals and to complement the mineralogical data obtained from XRD and petrographic observations. This technique provided additional confirmation of the crystalline phases present, particularly in distinguishing between gypsum, bassanite, and anhydrite, as well as detecting minor accessory phases. The spectra of the field samples and the commercial reference are presented in Figure 3, where the diagnostic Raman bands associated with gypsum and secondary components are indicated. These results validate the diffraction data and provide further insights into the structural integrity and compositional variability of the studied materials.

All analyzed samples, including the commercial reference, exhibit intense and well-defined Raman bands centered at ~1014 cm^{-1}, ~1140 cm^{-1}, ~430 cm^{-1}, and ~495 cm^{-1} (Figure 4). These bands are diagnostic of gypsum ($CaSO_4 \cdot 2H_2O$) and are consistent with previously reported spectra (Antunes et al., 2014). The dominant peak at ~1014 cm^{-1} corresponds to the symmetric stretching vibration (ν1) of the SO_4^{2-} group, while the bands around ~1140 cm^{-1} and ~430 cm^{-1} are assigned to asymmetric stretching (ν3) and bending (ν2) modes, respectively. Collectively, these features confirm the presence of crystalline gypsum as the major phase in all samples, with the exception of Çankırı-4.

The Raman spectra of Çankırı-1, Çankırı-3, and Çankırı-6 are highly consistent with the commercial reference, indicating strong spectral purity and minimal interference from non-sulfate phases (Figure 3). The sharpness and intensity of the gypsum-related bands further confirm the dominance of well-crystallized sulfate minerals in these specimens.

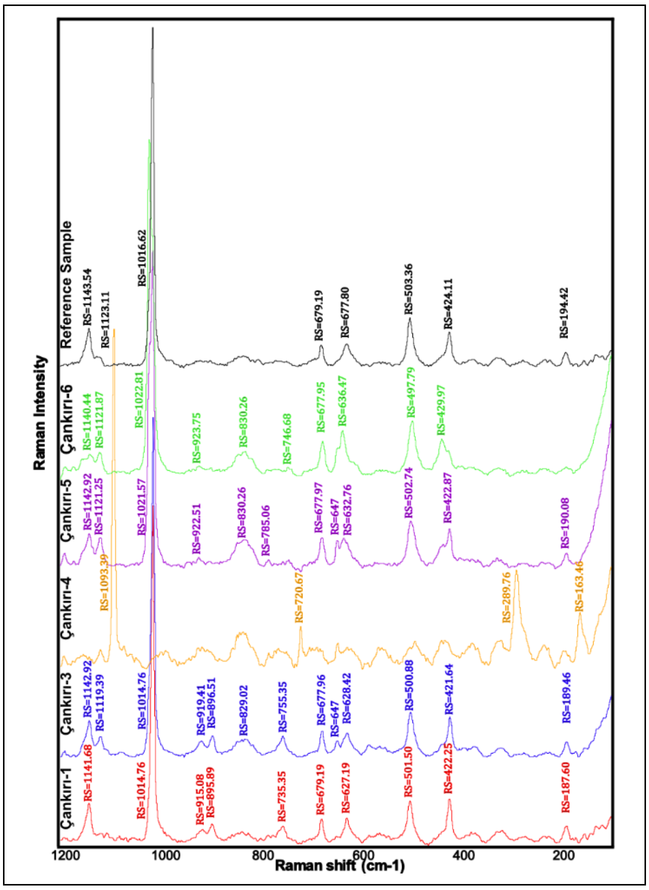

Figure 3. Raman spectra of the samples, starting with Cankiri-1 at the bottom, ending with the reference sample at the top. Raman shift values are shown over and next to peaks.

In contrast, Çankırı-4 displays broadened and suppressed sulfate signals, together with minor additional bands likely attributable to quartz (SiO_2) and clay minerals (Figure 3).

This spectral behavior corroborates the XRD evidence for non-gypsum phases and the XRF-detected enrichment in SiO_2 and Al_2O_3 (Table 1), confirming the heterogeneous character of this sample and its unsuitability for plaster production.

Çankırı-5 exhibits intermediate characteristics: although gypsum bands remain dominant, the presence of minor shoulders and band broadening indicates compositional mixing or structural disorder (Figure 3). This spectral complexity is consistent with the heterogeneity revealed by petrographic and XRD analyses.

Overall, the Raman data validate the presence of structurally ordered gypsum in most field samples and demonstrate their mineralogical compatibility with the industrial reference. The spectral divergence observed in Çankırı-4, and to a lesser extent in Çankırı-5, reinforces the rationale for excluding or cautiously considering these materials in plaster formulation.

3.3 Mechanical test results

To assess the performance of gypsum-based plasters produced from natural, unprocessed materials, uniaxial compressive strength (UCS) and flexural strength tests were performed following curing periods of 7, 28, and 90 days (Figure 4a, b). The results of these mechanical evaluations are summarized in Tables 2 and 3, providing a comparative basis for understanding the development of strength over time and for evaluating the suitability of the raw materials for plaster applications.

(a)

(b)

Figure 4. (a): UCS test on a sample. (b): Flexural strength test on a sample.

As presented in Table 2, the UCS values ranged from 1.51 MPa at 7 days to a maximum of 2.84 MPa at 90 days. The average strength was 1.90 MPa after 28 days of curing and 1.81 MPa after 90 days of curing. Due to the test sample availability, the test results of 7-day curing was only obtained one test sample. According to the Turkish Standards [16], the commonly referenced minimum compressive strength for gypsum plasters is 2.0 MPa. While the 7-day results fall slightly below this benchmark, the 28- and 90-day tests indicate progressive strength development, with several specimens exceeding the reference value.

This trend is particularly significant given that no additives, fiber reinforcements, or pre-separation of clay and sand fractions were applied to the raw materials. The favorable performance can therefore be attributed to the intrinsic mineralogical quality of the Çankırı gypsum and the efficiency of the adopted calcination and curing procedure.

Flexural strength results demonstrate a pronounced increase between 28 and 90 days of curing (Table 3). At 28 days, the average strength was 0.62 MPa, slightly below the 1.0 MPa benchmark defined in plaster standards. At 90 days, the average strength was 1.52 MPa (Table 3).

Table 2. UCS test results of the prepared test samples

Sample	7 Days (MPa)	28 Days (MPa)	90 Days (MPa)
Test Sample 1	1.51	1.93	1.65
Test Sample 2	-	2.02	1.8
Test Sample 3	-	1.8	2.84
Test Sample 4	-	1.9	2.71
Test Sample 5	-	1.93	1.9
Test Sample 6	-	1.84	1.6
Test Sample 7	-	-	1.6
Test Sample 8	-	-	1.71
Test Sample 9	-	-	1.2
Test Sample 10	-	-	1.1
Minimum	1.51	1.8	1.1
Maximum	1.51	2.02	2.84
Average	1.51	1.9	1.81

Table 3. Flexural strength test results of the prepared prismatic test samples

Sample	28 Days (MPa)	90 Days (MPa)
Test Sample B	0.64	1.05
Test Sample C	0.64	2.0
Minimum	0.6	1.05
Maximum	0.64	2.0
Average	0.62	1.52

This substantial strength gain suggests progressive densification of the plaster matrix and the possible development of secondary bonding mechanisms during prolonged curing. The attainment of such high flexural values, particularly in the absence of fiber reinforcement or chemical additives, underscores the promising long-term durability of the prepared gypsum plasters.

4 Conclusions

This study evaluated the chemical, mineralogical, petrographic, and mechanical properties of natural gypsum deposits from the Çankırı region (Türkiye) in comparison with a commercial reference material. The following conclusions can be drawn:

1. Chemical composition (XRF): The majority of samples (Çankırı-1, 3, 5, and 6) exhibited SO_3 and CaO contents consistent with high-purity gypsum, aligning closely with the commercial reference. One sample (Çankırı-4) deviated significantly due to elevated SiO_2, Al_2O_3, and LOI, reflecting a heterogeneous composition dominated by quartz, calcite, and clay minerals.
2. Mineralogical characterization (XRD & Raman): XRD and Raman analyses confirmed the dominance of crystalline gypsum in most samples, with sharp and well-defined peaks comparable to the reference material. Çankırı-4 exhibited strong signals of accessory phases, while Çankırı-5 showed minor deviations consistent with petrographic evidence of heterogeneity.
3. Petrographic observations: Thin-section microscopy revealed compact and homogeneous textures in Çankırı-1 and Çankırı-6, similar to the reference, indicating minimal impurities and high suitability for plaster production. Çankırı-3 and especially Çankırı-5 displayed more heterogeneous fabrics, with inclusions and irregular grain boundaries that may influence performance.
4. Mechanical performance:
   - Compressive strength (UCS): Values ranged from 1.51 MPa at 7 days to 2.84 MPa at 90 days. Average strengths approached or exceeded the 2.0 MPa benchmark after 28 and 90 days, despite the absence of additives or beneficiation.
   - Flexural strength: Average values increased from 0.62 MPa at 28 days to 1.52 MPa at 90 days, with peak results as high as 2.0 MPa. This pronounced improvement indicates progressive matrix densification and secondary bonding over time.
5. Overall assessment: The majority of Çankırı gypsum samples are mineralogically pure and mechanically competent, demonstrating comparable performance to industrial reference material. The findings highlight the potential for utilizing unprocessed, mixed-texture gypsum deposits in plaster production without requiring prior separation of clayey and sandy fractions. However, highly heterogeneous samples such as Çankırı-4 should be excluded due to their divergent geochemical and mineralogical characteristics. Although the total extent of gypsum-bearing horizons within the Bozkır Formation has not been quantitatively determined, field observations indicate that thin to moderately thick gypsum layers occur intermittently throughout the formation. This suggests that the evaporitic facies are regionally widespread, offering a continuous but heterogeneous distribution of gypsum. From an economic standpoint, such lateral continuity indicates a promising potential for local plaster-grade gypsum resources, even though detailed reserve assessments have yet to be conducted.

In conclusion, the results demonstrate that local gypsum resources can be effectively used in binder applications, supporting both economic efficiency and sustainable construction practices.

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6 Author contribution statement

Within the scope of this study, Ali Osman Taş contributed to the project design, literature review, field sampling, sample analyses, evaluation and comparison of analytical results, selection of suitable samples for further stages, preparation of samples for mechanical tests, participation in mechanical tests, evaluation and comparison of mechanical test results, and manuscript writing. Kıymet Deniz Yağcıoğlu contributed to the project design, field sampling, sample analyses, evaluation and comparison of analytical results, and critical revision of the manuscript. Yusuf Kağan Kadıoğlu contributed to idea generation, project design, field sampling, and provision of reference samples. Turgay Beyaz contributed to the preparation of samples for mechanical tests, participation in mechanical tests, evaluation and comparison of mechanical test results, and critical revision of the manuscript.

7 Ethics committee approval and conflict of interest statement

"Ethical approval was not required for the preparation of this manuscript". "The authors declare that there is no conflict of interest with any individual or institution in the preparation of this manuscript".

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