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Using Moss Extract on Cementitious Mixture with Enhanced Workability and Mechanical Properties

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Keywords

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Abstract

The negative environmental effects of cement and concrete additives, as well as the carbon emissions generated during the fabrication of cement and other required concrete components, have come into increasing focus in recent years. Cement-based construction materials, which often originate from plant extracts and agricultural residue, have gained a lot of interest lately due to their low energy requirements, affordability, and environmentally friendly characteristics. Within this context, the present study explores the application of synthesized moss extract (ME)-based nanoparticles (NPs) to enhance the mechanical performance of cement, mitigate environmental impacts, and reduce carbon emissions. Surface characterization of the NPs was carried out using Transmission Electron Microscopy (TEM), which revealed moss extract-based nanoparticles (ME-NPs) with particle sizes below 100 nm and irregular needle-like shapes. The effects of ME-NPs on the physical and mechanical properties of cement mortar were investigated by testing water absorption, compressive strength, flexural strength, and microstructure. The experimental results showed that extracts of Homalothecium sericeum and Dicranum scoparium specifically enhanced compressive strength. Overall, the findings reveal that MEs can be utilized to develop eco-friendly, workable cementitious composites with improved mechanical properties.

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1. INTRODUCTION

The taxonomic group known as bryophytes—mosses included—shows variances throughout several systematic frameworks, with 1,036 genera and 18,409 species. Mosses comprise a significant percentage of this group, with about 13,000 species found globally. Three categories are commonly used to examine

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bryophytes: liverworts (Marchantiophyta), hornworts (Anthoceratophyta), and mosses (Bryophyta). (Buck et al., 2009). Since the beginning of bryophyte research in Turkey in 1829, about 1030 species have been found, including 7 endemic mosses, 3 endemic liverworts, and 4 hornworts (Ursavaş & Işin, 2019). Several studies have shown that bryophytes are used for a variety of purposes in the US, Russia, Japan, China, India, and several European countries. Results show that bryophytes are useful non-seed plants for a variety of uses, such as agriculture, fuel generation, industry, construction, and drug studies (Abay, 2006). Mosses are small, simple-structured plants that range in size from a few millimeters to seventy centimeters (Çetin, 1995). Unlike higher plants, bryophytes have significantly weaker morphological characteristics; they lack distinct roots, stem frameworks, and components. However, their shoots are primarily separated into stems and leaves (Abay & Kamer, 2010). Homalothecium sericeum and Dicranum scoparium are among the bryophyte species that have gained attention for their potential applications in sustainable roofing systems and traditional ethnobotanical contexts. Dicranum scoparium, a widespread acrocarpous moss, has historically been employed in construction by Indigenous communities such as the Shuswap in British Columbia, where it was mixed with clay for use as a natural chinking material in wooden structures, valued for its insulating properties and availability (Glime, 2017). Particularly in climates prone to desiccation, its dense mats, rapid regeneration, and drought tolerance make it especially promising for green roof installations. Likewise, Homalothecium sericeum, a pleurocarpous moss frequently found in temperate forest ecosystems, is well-suited to shaded rooftop environments. It has been used traditionally in northern Europe as a filler between logs and around chimneys due to its resilience and structural pliability (Glime, 2017). Both species demonstrate a capacity for nitrogen accumulation and retention of heavy metals, enhancing their ecological services when applied to urban green infrastructure (Glime, 2017; Saxena & Harrinder, 2004). Additionally, their relatively rapid life cycles and ease of propagation support their suitability for engineered moss-based roofing systems, though their annual to biennial persistence may pose limitations for vertical applications requiring perennial coverage (Harris, 2008; Benek et al., 2022).

The negative environmental consequences of chemical additives used in concrete and cement, as well as the carbon emissions produced during the production of cement and other essential components for concrete, have drawn more and more attention from studies (Kockal, 2015; Mahmood & Kockal, 2020). Recently, there has been a lot of interest in cement-based nano-construction materials.

In recent years, the use of natural admixtures has been increasing in order to improve the mechanical and durability properties of concrete. Nyabuto et al. (2024) studied the effect of an Aloe Vera-based superplasticizer in enhancing the consolidation of concrete with limestone-calcined clay cement, while Mahmood et al. (2021) conducted a comparative analysis of chemical and natural admixtures (grape and mulberry extracts). Similarly, Long and Wang (2021) investigated the effect of pine needle fibers on the mechanical properties of concrete, revealing the potential of natural admixtures in building materials.

Extracts obtained by processing plants in various ways are used in cementitious mixtures for different purposes. Some researchers used the certain plant extracts (Phyllanthus muellerianus, Cymbopogon citratus, Ricinus communis) as a corrosion inhibitor and, also they reported that these extracts enhanced the mechanical properties of concrete (Okeniyi et al., 2017; 2018; Palanisamy et al., 2018). In addition, some studies have found that plant extracts increase hydration and thus improve the mechanical properties. Malathy et al. (2020) added bio materials namely Spincea oleracea and Calatropis gigantea as internal curing agents to concrete. These biomaterials increased hydration without using any curing method and contributed to the mechanical properties. One of the scientific studies, Aloe barbadensis miller and Musa x para-disiaca extracts were used in the self-curing concrete as chemical admixtures substituted polyethylene glycol (Malathy et al., 2023). It was found that Aloe barbadensis miller significantly increased the compressive strength of the concrete containing polyethylene glycol at the ratio of %23.36.

The effects of plant extracts on the setting time of cementitious materials were investigated by certain researchers (Diquélou et al., 2015; Hazarika et al., 2018; Delannoy et al., 2020; Wang et al., 2023). On the one of this research (Hazarika et al., 2018) the use of extract shortened the setting time, on the other hand the other ones delayed the setting time. The use of Opuntia ficus-indica extracts was increased the compressive and flexural strength in the later ages in the other study (Aquilina et al., 2018).

The cement-based nano-construction materials are inexpensive, energy-efficient, and often derived from plant extracts and agricultural leftovers. With the technological advances of recent decades, nanomaterials have garnered significant attention due to their potential in the health, transportation, electronics, food, and construction sectors. The application of nanotechnology in construction is emerging as an important future direction, particularly considering the limitations of traditional materials. The wide-ranging use of nano formulation/cement-based products could play a major role in helping underdeveloped nations overcome obstacles, especially those brought on by a lack of resources, shortages of water, poor hygienic conditions, and other emergencies. For this reason, a natural material was used as a component instead of a synthetic one in this study. The renewable nature of natural materials provides minimal consumption of energy. By reducing synthetic additives, CO_2 emissions and toxicity risks are reduced. Within this context, this research focuses on using ME - NPs to enhance mortar mechanical characteristics, reduce adverse environmental effects, and carbon emissions. Transmission electron microscopy (TEM) was used to analyze the surface of the prepared ME-NPs. TEM analysis revealed the successful observation of ME-NPs with particle sizes below 100 nm, exhibiting irregular needle-shaped shapes. Despite the promising potential of plant-derived nanomaterials in construction, the application of moss extracts in cementitious mixtures remains largely uninvestigated. Mortar/concrete testing studies on moss extract as a sustainable additive are notably scarce, underscoring a significant knowledge gap and an uninvestigated avenue for novel, eco-friendly building materials. This study, therefore, aims to bridge this gap by investigating the effects of synthesized ME-NPs on the physical and

mechanical properties of cement mortar in order to eliminate lack of the studies on the use of moss extract in the cementitious mixtures.

2. MATERIAL AND METHOD

2.1. Materials of ME-NPs

The material for this study, *Homalothecium Philippinum* and *Dicranum Seoprium* (Hedw.) M. Fleisch. was collected from the boundaries of the Research and Application Forest of Çankırı Karatekin University, Faculty of Forestry, located on Eldivan Mountain in the Eldivan district of Çankırı province, at coordinates *40° 30′ 13.80″ N and 33° 26′ 05.64″ E,* at an altitude of 1400 meters. The moss samples were transported to the laboratory and air-dried for 2-3 days in a shaded environment. Identification of the moss was performed using light microscopy and consulted floristic reference texts from various countries (Lawton, 1971; Smit, 2004).

2.2. Materials Used in Mortar Production

Portland cement (CEM IV /B (P) 32.5 N) from Adoçim Antalya Çimento Beton San. ve Tic. A.Ş. was used as the binder in this study. Crushed stone with origin of $CaCO_3$ and a size of 0-4 mm, sourced from the Antalya region, was used as an aggregate. Four species of bryophyte extracts were used instead of water in mortars.

Mortars prepared with 15 % extract ratio of cement by weight were prepared according to EN 196-1 (2016). The proportions of these mixtures are given in detail in Table 1. In addition, to determine the fresh properties of the mortars, flow tests were applied according to ASTM C 1437 (2009).

Table 1. *The quantities of the materials in mortars (g/dm^3)*

Sample Code	Description of the Sample	Cement	Aggregate	Water	Extract
K-0	*Control Sample*	866	2592	433	----
A-1	*Brachytheciaceae Homalothecium philippeanum (Spruce) Schimp.*	866	2592	302.1	129.9
B-1	*Dicranceace Dicranum scoparium Hedw.*				
C-1	*Brachytheciaceae Homalothecium lutescens (Hedw.) H.Rob.*				
D-1	*Thuidiaceae Abietinella abietina (Hedw.) M.Fleisch.*				

2.3. Preparation and Characterization of ME-NPs

The same procedure was applied to both samples, labeled as A-1 and B-1. To obtain the moss extract, the sample was first purified using Type I ultrapure water. It was then dried in a vacuum oven at 50°C for five

hours, or until a constant weight was reached. Subsequently, 1.5 g of the dried sample was mixed with 40 mL ultrapure water and 40 mL ethanol, and the mixture was kept in a dark environment at 25°C for two days. Following this, the mixture was sonicated under controlled conditions: 30% amplitude, 100 W power, 30 minutes duration, 20 kHz frequency, and a constant temperature of 25°C. Finally, the extract was carefully filtered using sterile syringe filters with pore sizes of 0.45 µm and 0.22 µm.

High-resolution TEM was conducted with the JEM-2100 Plus instrument from JEOL, operating at 200 kV.

2.4. Preparation of Mortars and Experimental Study

According to ASTM C 1437 (2009), fresh state properties of mortars, including flow and unit weight tests were performed. During the flow test, the largest diameter of fresh mortars and the diameter perpendicular to it were measured and the arithmetic average of these measurements was recorded as the test result. After the fresh state tests, mortars were placed in molds in accordance with EN 196-1 (2016). The placed samples were wrapped and kept for 24 hours. After removing the samples from the mold, they were cured in a water bath at 20±1°C for 7 and 28 days.

At the end of the 7th and 28th days, the mortars removed from the curing water were weighed under saturated surface dry conditions in water and air and then oven dry weights were determined. The physical test results of the samples were calculated according to ASTM C 1437.

In order to determine the mechanical properties of the samples, tests were carried out at the end of both the 7th and 28th days. First, the samples were subjected to a three-point bending strength test, followed by a compressive strength test for two parts of the sample that broke during this test. Using the load and displacement data recorded during the tests, the bending and compressive strengths of the samples were calculated according to the EN 196-1.

3. RESULTS AND DISCUSSION

3.1. TEM Analysis of ME-NPs

The A-1 and B-1 samples' shape, distribution, and particle size were examined using the TEM technique. The TEM images of A-1 and B-1 at magnifications of x6.0k and x20.0k are shown in Figure 1 and 2, respectively. Uniformly distributed nanoparticles with a diameter of approximately 60 nm were observed in sample A-1 and approximately 120 nm in sample B-1. There are morphological differences between samples A-1 and B-1. While type A-1 is more uniform and rounded, sample B-1 occasionally agglomerates and exhibits regularly defined structures. This suggests that the synthesis conditions (extract preparation and operation with cementitious ions) directly enhance the flexible nucleation and growth process. In B-1, nanodroplets may continue to coalesce during drying. These findings suggest that the ME allows the formation of nanoparticles with variable morphologies and sizes.

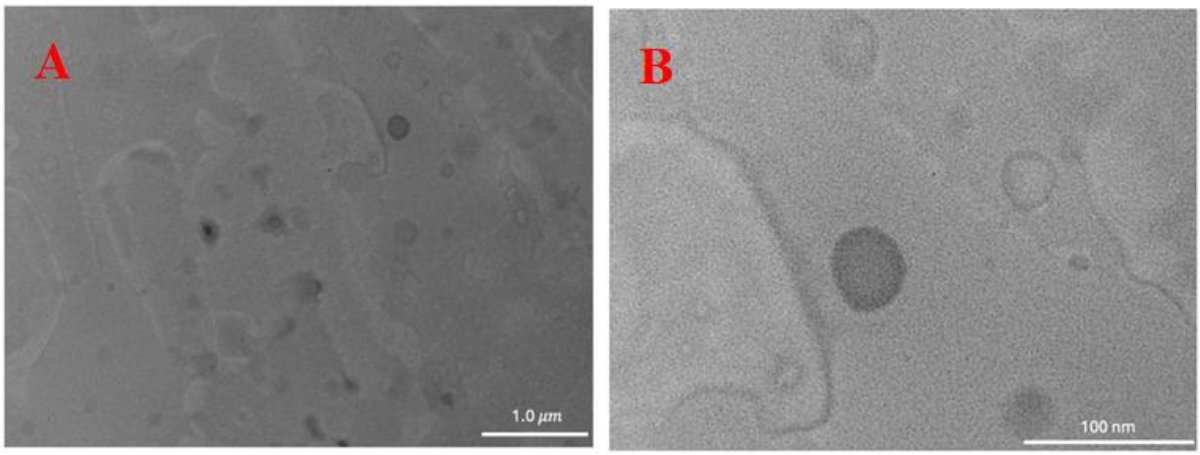


Figure 1. *TEM images of A-1 at different magnifications;* ***A)*** *x6.0k and* ***B)*** *x20.0k*

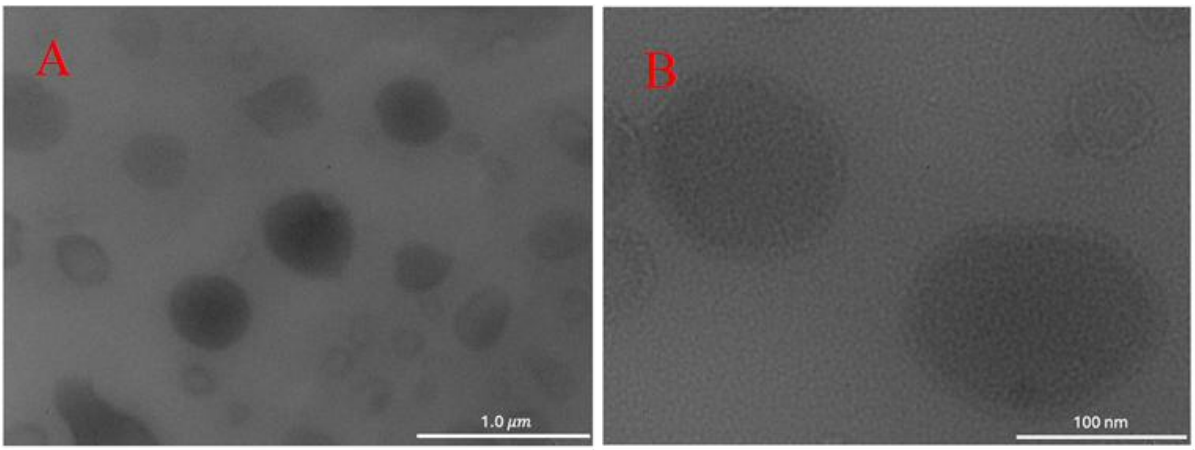


Figure 2. *TEM images of B-1 at different magnifications;* ***A)*** *x6.0k and* ***B)*** *x20.0k*

3.2. The Fresh Properties of Mortars

The flow test results of the mortars indicated an increase in consistency compared to the control sample. The highest flow diameter was observed in sample A-1, demonstrating slightly greater fluidity than the other mixtures.

Subsequent fresh unit weight measurements yielded values ranging from 2111 to 2268g/dm³, with the lowest unit weight recorded for sample C-1. The remaining mortars exhibited values close to those of the control sample. The flow diameter and unit weight test results are summarized in Table 2.

Table 2. *Fresh properties of the mortars*

Sample Code	Flow Diameter (mm)	Fresh Unit Weight (g/dm³)
K-0	107.5	2268.1
A-1	122.5	2267.6
B-1	117.5	2264.2
C-1	115.0	2111.6
D-1	115.0	2261.0

Previous studies have reported similar trends in the workability of cementitious materials modified with bio-based additives. Nyabuto et al. (2024) observed a significant increase in the flowability of fresh mortar incorporating aloe vera mucilage extract, with spreading values rising proportionally with dosage. Similarly, Mahmood et al. (2021) demonstrated that fruit-derived additives, such as grape and mulberry extracts, enhanced concrete workability, as evidenced by increased slump values.

Wang et al. (2023) investigated the influence of Opuntia ficus-indica (cactus) and mulberry leaf extracts on cement mortar consistency. Their findings indicated that higher additive ratios improved mortar consistency, attributed to the electrostatic repulsion and dispersion effects induced by active functional groups in the extracts. In a related study, Shelar et al. (2021) reported a dosage-dependent increase in slump values for concrete containing Sapindus mukorossi (Rita) seed extract, further supporting the role of plant-based additives in enhancing workability.

3.3. Physical Properties

The physical test results and unit weight analyses demonstrated minimal variation between the modified samples and the control, with unit weight values deviating by less than 5% across all specimens (Table 3 and 4). This negligible difference primarily stems from the comparable specific gravities of the extracts to that of water.

Porosity, a critical microstructural characteristic governing mechanical performance, exhibited a direct correlation with water absorption capacity. At 7 days curing, the water absorption rates (8.91%-9.49%) exhibited a consistent increase of 1-8% relative to the control specimen (8.82%), indicating the extract's influence on pore structure development. This trend persisted at 28 days, where absorption values (8.65%-8.86%) remained elevated compared to the reference mixture (7.98%). Regarding open porosity, the 7-day results indicated a maximum value of 0.196% for sample D-1, while other formulations-maintained values within 0.186-0.193%, comparable to the control (0.218%). By 28 days, all specimens achieved porosity values (0.182-0.184%) approaching the reference value (0.169%), demonstrating progressive microstructural densification.

Table 3. *Physical test results of mortars (7 days)*

Sample Code	Water Absorption (%)	Dry Unit Weight	Sds Unit Weight	Apparent Unit Weight	Open Porosity (%)
K-0	8.815	2.480	2.698	3.230	0.218
A-1	9.257	2.076	2.268	2.570	0.192
B-1	8.918	2.090	2.276	2.568	0.186
C-1	9.312	2.073	2.266	2.568	0.193
D-1	9.468	2.075	2.721	2.582	0.196

Table 4. *Physical test results of mortars (28 days)*

Sample Code	Water Absorption (%)	Dry Unit Weight	Sds Unit Weight	Apparent Unit Weight	Open Porosity (%)
K-0	7.976	2.118	2.287	2.548	0.169
A-1	8.651	2.099	2.280	2.564	0.182
B-1	8.650	2.113	2.296	2.586	0.183
C-1	8.858	2.082	2.267	2.553	0.184
D-1	8.676	2.099	2.281	2.567	0.182

Previous studies on bio-based additives have reported varying effects on water absorption and porosity. Mahmood et al. (2021) observed reduced water absorption in cement paste modified with grape extract, attributing this to microstructural refinement and pore segmentation, which enhanced compressive strength. Conversely, Wang et al. (2023) found that mulberry leaf and *Opuntia ficus-indica* (cactus) extracts altered hydration kinetics, leading to dosage-dependent variations in water absorption.

In the present study, the use of ME - NPs increased water absorption and porosity relative to the control. However, these effects may be adjustable by optimizing the extract dosage, suggesting potential for tailored performance in future work.

3.4. Mechanical properties

Within the scope of mechanical tests, firstly, higher values were observed in 7-day bending strengths compared to the control sample. The highest values were obtained in A-1 and D-1 samples with 10.75 MPa, respectively. In 28-day samples, the bending strength values remained at levels closer to the control sample. The highest bending strength value compared to other samples was determined in B-1 sample (Figure 3). According to the Figure 4, the gain of bending strengths (7 to 28 days) of control sample was higher than the other ones. In the light of these results, there is no advantageous effect of using the plant extracts to enhance the bending strength of the traditional mortars.

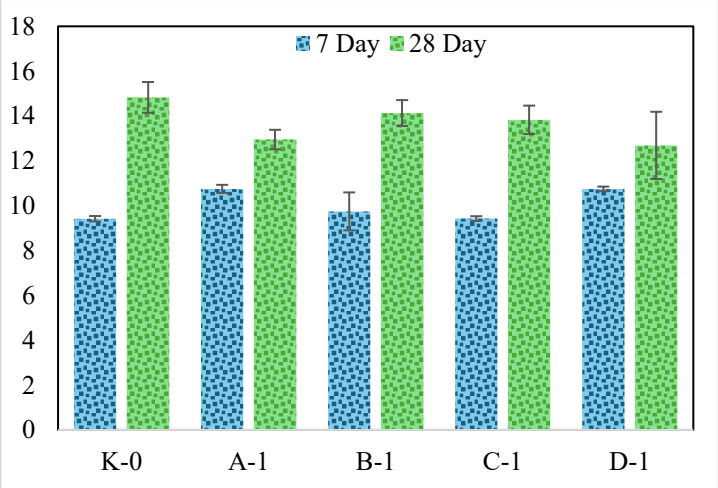


Figure 3. *The Bending Strength Results (MPa)*

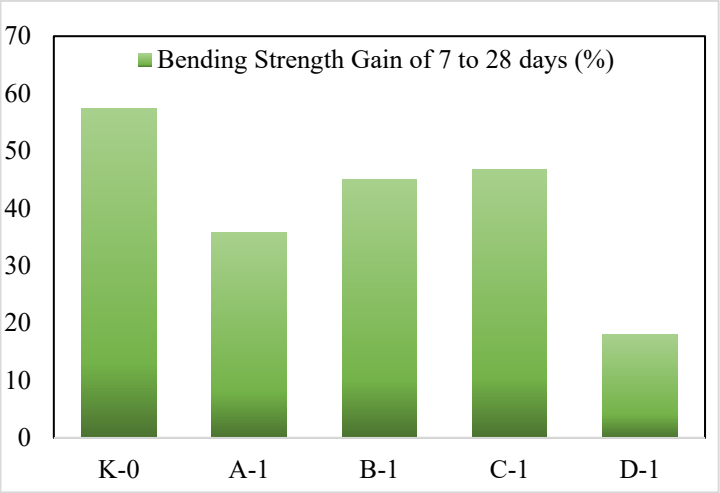


Figure 4. *The Bending Strength Gain of Mortars 7 to 28 days (%)*

In compressive strength tests, values close to the control sample were obtained in the 7-day results. However, in the 28-day test results, higher values than the control sample were observed in A-1 and B-1 samples with 37.6 MPa and 35.55 MPa, respectively. The lowest compressive strength value was determined in D-1 sample with 32.66 MPa (Figure 5). Similarly, Aquilina et al. (2018) studied with concrete mixtures including the extract of *Opuntia ficus-indica,* and lower strength values than the control samples were detected at early ages and these values were increased at 28 days. It was observed that these increments were up to 19% at 28 days (Aquilina et al., 2018). In the another study, samples containing S.oleracea extracts instead of polyethylene glycol as an internal curing agent, reached the highest compressive strength values at 28 days compared to the samples with dissimilar extracts and the control samples (Malathy et al., 2020).

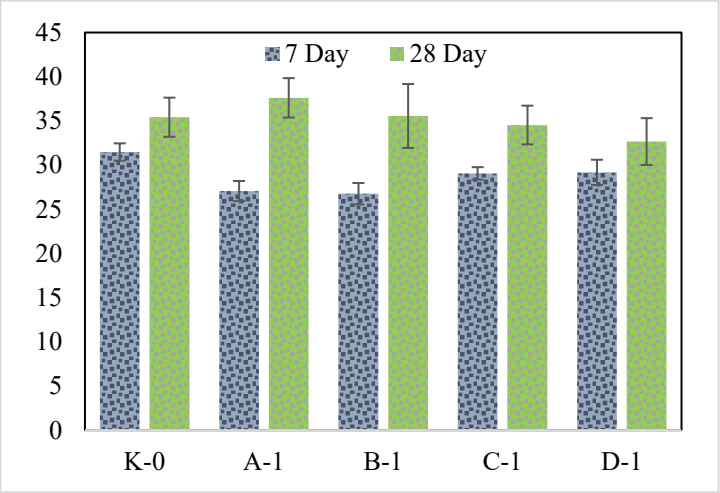


Figure 5. *The Compressive Strength Results (MPa)*

According to the changes in the compressive strength of the mortars from 7 to 28 days at Figure 4, it could be seen that the mixtures containing plant extracts have a higher rate of strength increase compared to the control sample. It is said that these extracts act as an additive material that effect the compressive strength at later ages, not at early ages. Ravi et al. (2016) studied *Opuntia ficus-indica* as a bio-admixture in hydraulic lime mortars

for restoration, the later ages of 90 days the mechanical properties of the mortars including opuntia ficus-indica exctracts highly increased than the control samples.

The increment of the bending and compressive strengths were different for the samples (Figure 4 and 6), because the failure mechanisms of the concrete subjected to compressive and bending load are different. The concrete subjected to compressive load firstly vertically compressed and the sample began to shorten on its axis and to expand on the lateral direction. But the bending (3 point bending load) load applied on one point of the up surface and two points of the underside of the samples. Moreover tensile stress is effective for bending strength test that's why, the compressive strength values are higher than the bending ones.

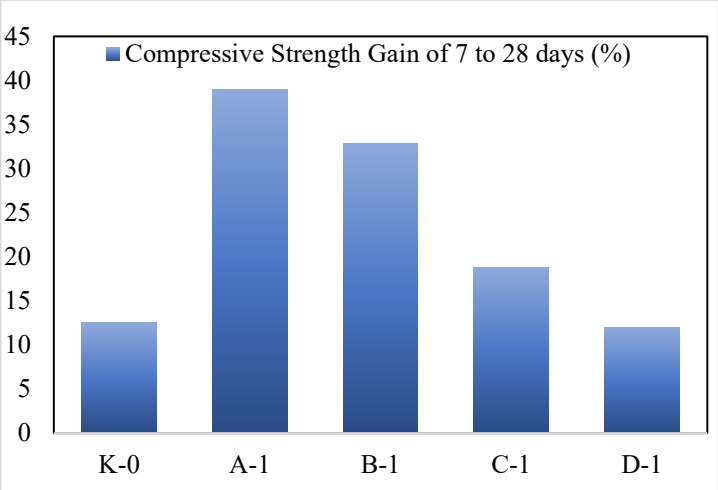


Figure 6. *The Compressive Strength Gain of Mortars 7 to 28 days (%)*

3.5. Microstructures of the Mortars

The microstructural evaluation through the SEM images of mortars confirmed that the physical and mechanical test results of the mortars containing ME-NPs correlate with their microstructures. The EDX analysis also revealed a characteristic lime-based composition, with elemental distribution showing Ca (30.63 wt.%), O (40.63 wt.%), followed by C (17.63 wt.%) as primary components and Si (10.89 wt.%) and along with trace amounts of Mg and Al (each <0.20 wt.%). While significant morphological differences, such as drastic changes in hydration product morphology or widespread microcracks, were immediately evident between the mortars containing ME-NPs and the control samples at the observed magnifications, the overall integrity and compactness of the cement paste matrix were maintained. The interface quality exhibited comparable performance, indicating no detrimental effects from the incorporation of moss extracts. Importantly, the micrographs consistently showed a relatively void-free morphology with no detectable severe microstructural defects that would negatively influence the observed mechanical properties. This suggests an appropriate and stable development of the hydration reaction in the presence of ME-NPs, contributing to the enhanced strength and workability. These observations collectively indicate that while ME-NPs may not substantially alter the fundamental macro-microstructure in a visually dramatic manner, their judicious use effectively maintains and

potentially optimizes the structural integrity of the cementitious composite, thereby supporting the improved mechanical performance.

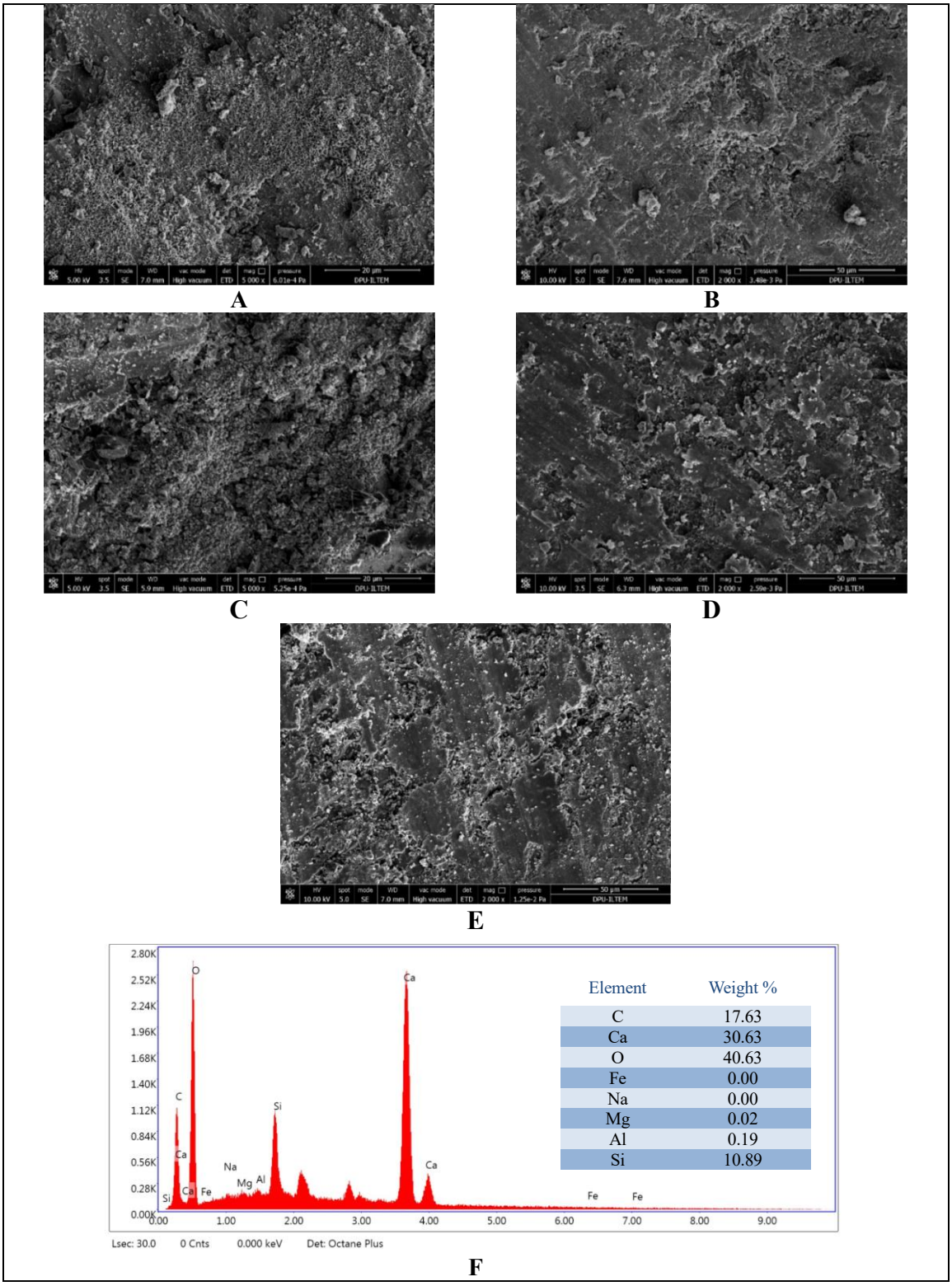


Figure 7. *SEM Images of Mortars*
A) *A-1,* ***B)*** *B-1,* ***C)*** *C-1,* ***D)*** *D-1,* ***E)*** *K-0, and* ***F)*** *EDX spectrum of Mortar C-1*

4. CONCLUSION

The significant findings of this study could be concluded as follows:

- The mortars including moss extracts had nearly the same fresh unit weight with control samples.
- The extracts increased the workability of mortars within the range of 7-14%. A similar increase in workability was observed in mortars using various plant-based extracts.
- The samples containing extracts had slightly high-water absorption ratio at early and later ages.
- The highest bending strength was 14.13 MPa at 28 days belonged to *the Dicranum scoparium* sample.
- The higher compressive strength values were 37.61, 35.56 MPa at 28 days belonged to the *Homalothecium sericeum* and *Dicranceace Dicranum Seoprium* samples respectively.
- It was observed that the use of plant extracts positively affected the mechanical properties, especially the compressive strength. The fact that the increase in 7 to 28 days was higher than the control sample showed that the moss extracts influenced later age strength rather than the early strength.
- It has been observed that environmentally friendly and more workable cementitious mixtures with high mechanical properties could be obtained by using moss extracts and without chemical admixtures.

AUTHOR CONTRIBUTIONS

Conceptualization, S.K. and N.T.; methodology, N.U.K., S.K. and N.T.; title, S.K.; validation, S.T. and N.İ.K.G.; laboratory work, N.U.K, S.T., N.İ.K.G., S.K., S.U. and G.G., ; formal analysis, S.T., N.İ.K.G. and S.K.; research, S.T., N.İ.K.G. S.K., S.U., G.G. and N.T.; sources, S.T., N.İ.K.G., S.U., and G.G.,; manuscript-original draft, N.U.K. S.T., N.İ.K.G. S.K. and N.T.; manuscript-review and editing, N.U.K, S.T., N.İ.K.G., S.K., and N.T.; visualization, S.T. and N.İ.K.G; supervision, N.U.K, S.T. All authors have read and legally accepted the final version of the article published in the journal.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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