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Osman Hansu
Gaziantep Islam Science and Technology University
osman.hansu@gibtu.edu.tr, Gaziantep-Türkiye
Zeynep Pınar Emrullah
Gaziantep University, zpinaremrullah@hotmail.com, Gaziantep-Türkiye
Mehmet Tolga Göğüş
Gaziantep University, mtgogus@gantep.edu.tr, Gaziantep-Türkiye

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ORCID ID	0000-0003-1638-4304	0009-0000-6649-1912	0000-0002-9150-2537
Corresponding Author	Osman Hansu		

MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF SELF-COMPACTING MORTAR PRODUCED USING RECYCLED POLYURETHANE PARTICLES AS AGGREGATE

ABSTRACT

Since sand/aggregate is one of the most intensively used natural resources for the production of concrete and its derivatives, the destruction of nature for its supply is increasing rapidly. As a result, the disposal of natural resources and CO_2 emissions are increasing rapidly in parallel. This situation plays a fundamental role in the substitution of waste for aggregate or sand. In this study, polyurethane-based recycled materials (PUW), which are frequently used in industrial or domestic wastes, were substituted with aggregate in self-compacting mortar. In the mixtures used in the study, the water/binder ratio was 0.45 and the binder dosage was 500 kg/m^3. PUW was substituted with aggregate at 5%, 10%, 15%, 20% and 25% by volume. The fresh (slump flow and V-funnel), microstructural (XRD, EDX and SEM) and mechanical (axial compressive and flexural tensile strength) properties of the self-compacting mortar mixtures were comparatively evaluated to assess the basic requirements. The data obtained from the mechanical tests of the SCM showed that the compressive strength of the PUW substitute within the relevant mix specifications of 20% PUW substitution by volume remained above 30MPa in the 28th day tests, which gives a basic information about its mechanical suitability for use.

Keywords: Polyurethane-based, Recycled Materials, Self-compacting Mortar, Mechanical Properties, Microstructure

1. INTRODUCTION

The construction industry relies heavily on essential building materials such as sand, cement, bricks, and steel, which are primarily sourced from natural reserves. The continuous extraction and utilization of these resources inflict substantial harm on the environment, causing ecological disruption and resource depletion. Furthermore, the production of key building materials, most notably cement, has been identified as a significant contributor to greenhouse gas emissions, which are known to exacerbate climate change. Recognizing the pressing need to curtail environmental damage, conserve natural resources, and address the carbon footprint associated with construction, this study was initiated with a multifaceted objective. At its core, this research aims to explore the recycling potential of waste materials derived from specific components used in construction, particularly polypropylene fiber, which is a factory byproduct [1].

Waste fiber fabric has been steadily accumulating, constituting approximately 30% of the total waste volume. While some organizations

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have implemented used clothing collection bins to mitigate the influx of discarded fiber fabric into landfills, the impact of such initiatives remains limited due to the staggering volume of this waste category. Consequently, researchers are actively exploring recycling methods and technology development to address the challenges associated with its accumulation, making this a topic of great interest [2].

By delving into the recycling of waste polypropylene fiber from factory wastement, this research aspires to achieve several interconnected goals. Firstly, it seeks to reduce the detrimental impact of resource depletion by repurposing these materials rather than relying solely on new extraction. Secondly, by diverting these waste materials from landfills and incineration, it aims to minimize environmental pollution and reduce the burden on waste disposal systems. Furthermore, the study seeks to contribute to the reduction of carbon dioxide emissions associated with the production of building materials by promoting the sustainable use of recycled materials. In essence, this research endeavors to present a holistic approach to addressing the environmental challenges posed by conventional construction practices. The recycling of polypropylene fibre waste not only provides a more sustainable alternative but also paves the way for a greener, more resource-efficient, and environmentally responsible construction industry. This objective is consistent with the overarching goal of cultivating a more sustainable and environmentally conscious approach to construction, thereby concurrently contributing to the global efforts to combat climate change. To provide a concrete example, the extensive utilization of natural aggregates, encompassing both fine and coarse varieties, serves as a predominant factor exacerbating the scarcity of these resources in many countries worldwide. These natural aggregates, typically sourced from riverbeds, quarries, and other natural deposits, are fundamental constituents in the production of concrete and various construction materials. The escalating demand for these aggregates, driven by the ever-expanding construction industry and infrastructure development, has led to over-exploitation and depletion of these finite resources. Consequently, many regions face a growing challenge in securing an adequate and sustainable supply of natural aggregates to meet their construction needs. This scarcity has far-reaching implications, including increased transportation costs to import aggregates from distant sources, environmental disruption from excessive extraction, and a heightened urgency to explore alternative materials and recycling methods to alleviate the strain on these finite natural resources. Consequently, it underscores the pressing need for sustainable practices and innovative solutions within the construction sector to address this critical issue and ensure a more responsible use of these valuable materials [3].

Cement holds the distinction of being the most massive product produced on Earth [4]. Portland cement was the primary ingredient that contributed to the early hardness of the mortar that was utilised in construction projects. Conversely, the Portland cement concrete industry has undergone substantial growth in recent years. Furthermore, concrete is recognised as a material of simplicity in form, yet of complexity in nature. Concrete is characterised by its internal complexity, durability, and economy, which collectively serve to establish it as the most widely used construction material in the world [5].

Mortar is a key construction material made from a mixture of cement, sand, and water. It serves various functions, including binding construction elements together, surface smoothing, waterproofing, and insulation. Mortar is a material that is available in a variety of types, each of which is designed to meet specific construction needs. It is an essential component for ensuring the stability and longevity of

structures. Its tensile strength is a critical quality indicator. The utilisation of synthetic fibres, such as polypropylene, in concrete has been predominantly prevalent since the late 1960s [6]. The special qualities of polypropylene fibers (PF) make them appropriate for use in concrete matrices; they are stable and chemically inert in the alkaline environment of concrete, have a relatively high melting point with inexpensive raw materials, and have a hydrophobic surface that prevents them from absorbing water [5 and 7].

The construction industry is constantly advancing, with a growing emphasis on innovation and the improvement of building materials. Enhancing the durability and longevity of structures is becoming increasingly crucial. In this context, polymer-based materials are gaining prominence in the construction sector. This study specifically investigates the effects of different appearances and ratios of polypropylene fibers on mortar properties. Polypropylene fibers, when added to construction materials, can enhance structural integrity, and possess various physical characteristics. Therefore, understanding the influence of different aspects (such as shape, size, and surface properties) and ratios of polypropylene fibers on the mechanical strength, tensile strength, crack formation, and other properties of mortar mixtures is essential in the construction industry. Fiber-reinforced mortar is a specialized construction material characterized by the inclusion of fibrous elements, which serves to augment its structural integrity and mechanical properties. These fibrous elements are typically in the form of short, discrete fibers that are methodically dispersed throughout the mortar mixture. The orientation of these fibers is entirely stochastic, meaning they assume random angles within the mortar matrix, contributing to the material's enhanced performance. A noteworthy feature of fiber-reinforced mortar is the diversity of fiber materials available for incorporation. Steel fibers, known for their high tensile strength, offer improved crack resistance and load-bearing capacity. Glass fibers provide durability and corrosion resistance. Synthetic fibers, such as polypropylene, offer increased ductility and impact resistance. Natural fibers, like sisal or jute, can be environmentally friendly and cost-effective options. It's essential to recognize that the properties of fiber-reinforced mortar are not fixed but rather subject to variation based on a multitude of factors. The behaviour and performance of the composite material are influenced by a number of factors. These include the specific combination of mortar types, the choice of fibre materials, the geometrical characteristics of the fibres (length and diameter), the distribution pattern of fibres within the mortar mix, the orientation of these fibres, and the density of their inclusion. Therefore, engineering and construction professionals must carefully select and fine-tune these parameters to achieve desired structural characteristics and performance outcomes in each application [8].

As a result, there is a plethora of studies in the extant literature that are focused on the reduction of natural resources utilised and the minimisation of CO_2 emissions. In some of these studies, ground waste vehicle tires used instead of aggregate [9, 10, 11 and 12], studies aiming to eliminate chemicals by impregnating organic wastes [13], studies examining the substitution of glass wastes with cement or sand [14 and 15], studies examining the use of PVC wastes in concrete derivatives [16], or studies aiming to use fly ash or silica fume [17, 18 and 19], which are industrial wastes, in concrete and its derivatives have been and continue to be carried out. The study aimed to evaluate the use of polyurethane material (PUW) obtained from recycled materials in mortar. PUW was substituted with sand in mortar considering the similarity in the grain size of the PUW used and the grain size of the

sand used. Substitution rates were evaluated as 6 sets of 0%, 5%, 10%, 15%, 15%, 20% and 25%. The samples produced from the mixtures were first analyzed for workability properties (slump-shedding and V-funnel) and then for micro properties (SEM, EDX and XRD) in accordance with EFNARC. The experimental data and the evaluation of the results are described under the following headings.

2. RESEARCH SIGNIFICANCE

The global construction industry faces increasing pressure to reduce its environmental footprint due to the excessive consumption of natural resources, particularly sand and aggregate, which are essential components in concrete production. This unsustainable demand contributes to significant ecological degradation, resource depletion, and greenhouse gas emissions. In this context, the integration of recycled materials into cement-based composites is not only an environmentally responsible approach but also a critical pathway toward sustainable construction practices. The present study investigates the use of polyurethane-based waste (PUW)—a material that is commonly discarded in both industrial and domestic sectors—as a partial volumetric replacement for natural aggregate in self-compacting mortar (SCM). The research provides a comprehensive understanding of the feasibility of PUW as a functional construction material by evaluating the fresh, microstructural and mechanical properties of SCM mixtures incorporating PUW. The findings demonstrate that up to 20% volumetric substitution of aggregate with PUW can yield compressive strengths above 30 MPa at 28 days, meeting basic structural performance criteria. This highlights the potential of PUW to be utilized in non-structural or semi-structural cementitious applications, offering a dual benefit: minimizing environmental harm caused by aggregate extraction and promoting circular economy principles by repurposing polymeric waste. This research contributes to the growing body of knowledge on sustainable concrete technologies by introducing a novel application of PUW, and offers practical implications for the development of eco-efficient construction materials.

Highlights:

- Polyurethane-based waste (PUW) was successfully used as a partial aggregate replacement in self-compacting mortar (SCM) at up to 25% by volume.
- PUW substitution up to 20% maintained compressive strength above 30MPa at 28 days, meeting fundamental mechanical performance criteria.
- The study supports sustainable construction by reducing natural aggregate consumption and promoting the reuse of industrial/domestic polyurethane waste.

3. EXPERIMENTAL METHOD-PROCESS

The contents of the materials used in the materials used in the study and the details related to the research-study in the experimental-theoretical studies applied are explained in subheadings.

3.1. Materials

The contents of the materials used in the materials used in the study and the details related to the research-study in the experimental-theoretical studies applied are explained in subheadings. For the experimental studies, CEM I 42,5 R type cement product produced by the Cement Factory located in Gaziantep province and produced with TS EN 197-1 [20] standard was used. The results of the analysis of the chemical

and physical properties of the cement provided by the production facility are given in Table 1.

Table 1. Chemical composition of portland cement

Chemical composition (%)	Portland Cement
CaO	63.35
SiO_2	19.36
Al_2O_3	3.79
Fe_2O_3	4.11
MgO	3.1
SO_3	3.15
K_2O	0.81
Na_2O	0.41
Loss of ignition	1.92
Blaine (m^2/kg)	367

The sand used in SCM production was obtained from sand plants producing crushed sand using natural rock reserves in Gaziantep province. The sand obtained directly from the plant is in the size range of 0-5.6mm. This natural crushed sand (CNS) material was screened with a 4mm sieve. After sieving, it was used in the designed SCM mixtures. The calculated specific gravity of the CNS used is 2.60. Furthermore, the sand granulometry curve was measured as shown in Figure 1.

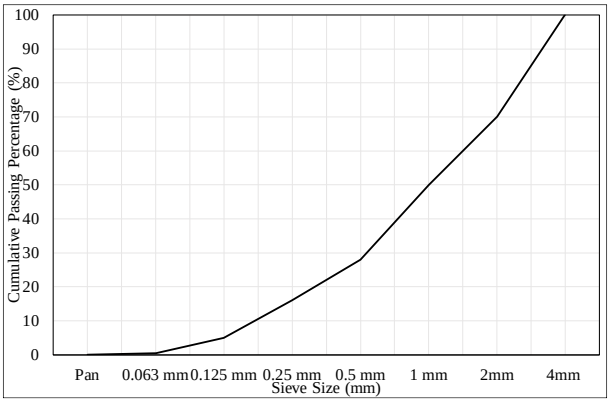

Figure 1. Sand sieve analysis

To ensure the fresh state properties of the mixtures in accordance with EFNARC [27], a highly water reducing chemical additive (HRWR) produced in accordance with TS EN 934-2 [22] was included in the mixtures within the scope of the experimental study. The HRWR chemical used was selected as Sika Visco Crete Hi-Tech-28 HRWR coded polycarboxylate based product and the chlorine free density 1.055-1.095kg/l stated in the catalog provided by the manufacturer company for HRWR was used in the calculations. In addition, water supplied from the city drinking water was used for mixing water during production in SCM mixtures.

3.2. Materials

A total of 6 different SCM mixtures consisting of CNS and PUW substitutes, including the control mixture SCM, were calculated and produced. PUW substitution rates of the mixtures were evaluated as 0%, 5%, 10%, 15%, 15%, 20% and 25% and a laboratory type mortar mixer with a capacity of 5 m^3 was used to produce SCM mixtures with the recipe designed using the relevant rates. The water/binder ratio for the designed SCMs was based on 0.45 and 500kg/m^3 was used for binder content. During the production of the SCMs, different proportions of HRWR were

used in each mix to ensure that the workability properties were within the limits of the SCMs when substituting CNS with PUW.

Sand, cement and PUW substitute were used to prepare the mixtures produced as SCM. Cement and sand (PUW content according to the characteristics of the respective mix) were mixed as a dry mix in a mixer for 1 minute at the mix proportions obtained from the mix recipe. Then 1/3 of the mix water was added to the dry mix and the mortar mixer was operated for another 1 minute. Then the HRWR and the remaining mix water (2/3 of the mix water) were mixed in a container and added to the mix. At this stage, the mixture was continued to be mixed for another 1 minute. The fresh SCM mixtures produced were allowed to rest in the mixer for 1 minute at the end of the time. After visual inspection, the rested mixture was mixed for another 1 minute. The preparation time of the SCM mixtures in the mortar mixer was 5 minutes in total for each casting within the scope of the study. The materials and quantities used for the design of the SCM mixtures in the study are given in Table 2. The mixtures were tested by slump flow test and V-funnel test using the EFNARC standard EFNARC (EFNARC and The European Project Group, 2005) to determine the suitability of the mixtures for classification as SCM (Figure 2).

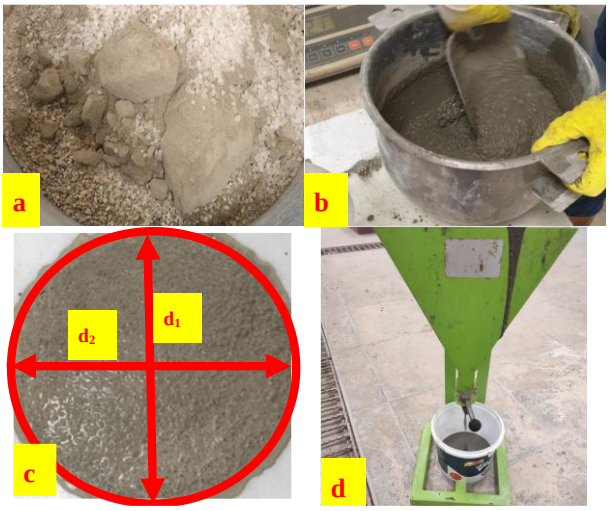

Figure 2. Laboratory fresh mixing and testing stages: a) dry mix, b) fresh mix, c) slump-flow, and d) V-funnel test

Table 2. Mixture designs

MIX ID.	Cement (kg/m^3)	PUW	HRWR	Water	Sand
SCM1	500	0	5	225	1638
SCM2	500	30.5	5	225	1556
SCM3	500	57.8	4.6	225	1474
SCM4	500	81.8	4.5	225	1392
SCM5	500	102.7	4.4	225	1310
SCM6	500	120.3	3.9	225	1229

To determine the mechanical and micro properties of the produced SCM mixtures, 36 specimens produced as 40×40×160mm^3 prismatic specimens for hardened concrete tests were used in mechanical tests. The prismatic specimens were produced after verification by fresh state tests that the SCM mixtures meet the adequate properties for SCM according to EFNARC [21]. After the SCM blends met the relevant fresh property criteria, these prism specimens produced with fresh SCM placed in prismatic metal molds with dimensions of 40×40×160mm^3. The specimens produced with fresh SCM were placed in the relevant molds in metal molds free from

intervention and kept in the molds for 24 hours for setting and hardening. At the end of the time, the specimens were removed from the molds and placed in curing tanks containing lime-saturated water. All specimens were cured in these tanks at 20±2°C for 28 days. For the tests of the mechanical properties in the hardened state, the specimens taken from the curing tanks were tested on the 7th and 28th days. The specimens were first subjected to tensile tests in flexure and then to compressive strength tests on the fractured prism fragments (Figure 3).

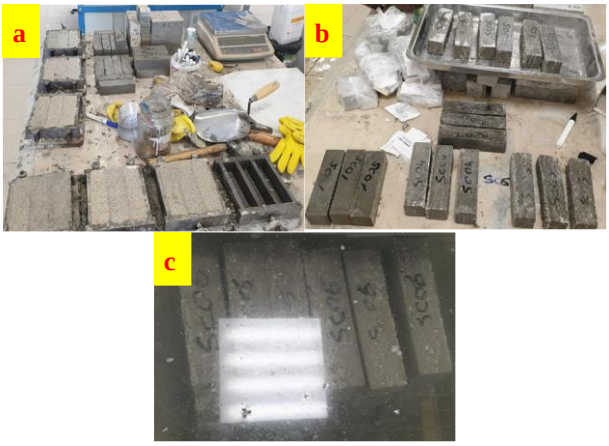

Figure 3. Sample preparation stages: a) casting, b) demolding, and c) curing

3.3. Test Procedures

The results of fresh properties (workability), microstructure (EDX, SEM and XRD) and mechanical properties (flexural tensile strength and compressive) of SCM blends produced during the experimental studies were evaluated. A study was designed to determine the variation of the effects of PUW substitution rates in SCMs on these properties.

3.3.1. Workability Test

The workability properties obtained from the slump-flow and V-funnel experiments were selected for each mix in accordance with EFNARC [21] to remain within the basic limits of the SCM principle. EFNARC [21] standard dimensions and drawings of the relevant experimental apparatus are given in Figure 4. The values obtained from these two experiments for EFNARC [21] are between 24 and 26cm spreading diameter value and 7- and 11-seconds V-Funnel flow time.

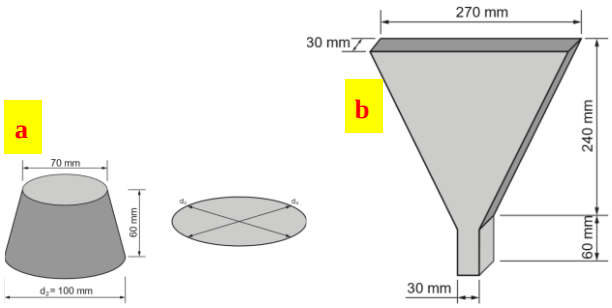

Figure 4. Workability tests: a) mini slump and b) v-funnel

3.3.2. Flexural Strength Test

Prism specimens with dimensions of 40×40×40×40×160mm was produced to be used for flexural tensile strength and tested in accordance with ASTM C348 [23] when the relevant curing periods were completed (Figure

5). In these tests performed in accordance with ASTM C348 [23], a universal testing machine with a loading capacity of 250kN was used to evaluate the tensile strength capacities in bending. The specimens were tested on the universal testing machine using the loading rate specified in ASTM C348 [23]. Compression tests were also conducted on the specimens in question, employing the broken prism specimens that had been obtained following the tensile strength testing in flexure. To confirm the repeatability or accuracy of the data obtained from the sample groups, three prism specimens were used in each mix and in each age group. These experimental results were averaged to determine the flexural tensile strength capacity of the SCM blends (Figure 5).

3.3.3. Compressive Strength Test

The compressive strengths of 40×40×160mm prisms produced using the mixtures prepared by substituting CNS for PUW in SCM mixtures and the control mixture were tested in accordance with ASTM C349 [24] on broken prisms obtained after flexural tensile strength test. In the study, compressive strength tests were carried out on 3 SCM 40×40×160mm prisms in each age and test group for all mixtures tested within the scope of specimens obtained from SCM mixtures. For the execution of these experiments, a universal compressive strength test press with a capacity of 250kN was utilised within the scope of the experimental study. ASTM C109 [25] states that for compressive strength loading rate, the specimen can be loaded for testing with a loading rate between 900 and 1800N/s. The specimens produced in this study were tested with a compressive load of 1kN/s during the test (Figure 5b).

Figure 5. Compressive and flexural strength: a) flexural strength test and b) compressive strength tested on broken prisms

3.3.4. EDX, XRD and SEM Analysis

Characterization of natural cement hydrates is one of the main challenges towards a complete understanding of hydration processes. Analytical electron microscopy is one of the promising methods to characterize cement hydrates using imaging, spectroscopic and diffraction information [26]. The use of SEM is a common practice in the field of micro-scale topography and elemental composition analysis. Furthermore, the process is characterised by its surface sensitivity, with the transfer of electrons from occupied states to unoccupied states

being pivotal. For this purpose, SEM employs a high-energy electron beam in a scanning pattern to produce images of the surface topography of a sample. The high-energy electron beam is directed towards the sample surface, where electrons interact with surface atoms. The signals generated from these interactions have been shown to provide information on surface topography, composition, and other properties, including electrical conductivity [26] (Figure 6b). EDX is used to determine the elemental composition of a material by measuring the characteristic X-rays emitted from core electrons transitioning from higher energy levels to the ground state. The basis of this study is the interaction between an X-ray excitation source and a sample. The instrument's ability to characterise materials is predicated on the fundamental principle that each element possesses a distinct atomic structure, resulting in a unique set of peaks in the X-ray spectrum [27] (Figure 6b). The measurement of characteristic X-rays emitted by the sample surface allows for the discrimination of its elemental composition [28]. X-ray diffraction (XRD) is a technique used for the characterisation and identification of crystalline phases, polycrystalline phases, and residual stresses. In the context of X-ray interactions with crystalline phases, the phenomenon of Bragg diffraction is observed, resulting in the formation of a characteristic diffraction pattern. It is important to note that this is unique to each phase, akin to a fingerprint, and can thus be utilised for the identification of the substance [28] (Figure 6a).

Figure 6. Microstructure test in Munzur University laboratory a) XRD, and b) SEM and EDX

4. FINDINGS AND DISCUSSIONS

4.1. Fresh State Test Results

The results of slump-flow and V-funnel tests, which are fresh concrete tests used to check workability, are shown for the SCM mixes produced in the study. The slump-flow for all SCM mixes met the EFNARC boundary conditions (≥240 mm, ≤260 mm) EFNARC (EFNARC and The European Project Group, 2005). The results of the flow times calculated because of the V-funnel, which is another workability test, produced different results with the change of PUW replacement ratios used. The experimental data obtained are within the slump-flow and V-funnel limits given in EFNARC [21] as shown in Figure 7.

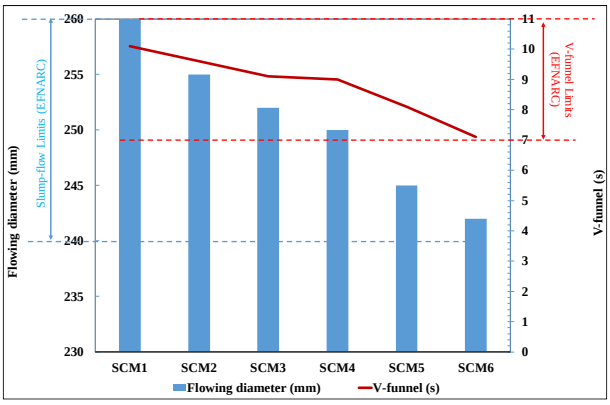

Figure 7. Flowing diameter and v-funnel results

4.2. Flexural Strength Test

First, flexural tensile tests were performed on the specimens at 7 and 28 days of age. At 7 days of age, the flexural tensile strength of SCM specimens was 7.78 MPa for specimens produced from the control mix. At 28 days of age, the flexural tensile strength reached 8.43 MPa for the control mix. At PUW substitution rates of 5%, 10%, 15%, 20% and 25%, the flexural tensile strength of 7-day-old specimens decreased by 8%, 10%, 17.2%, 30.5% and 35.3%, respectively, compared to the control mix. At 28 days of age, the flexural tensile strength of SCM specimens was 8.43 MPa. At 5%, 10%, 15%, 20% and 25% PUW substitution rates, the flexural tensile strength of 28-day old specimens decreased by 10.6%, 11%, 14.6%, 29.9% and 33.6%, respectively, compared to the control mix. On the other hand, in the flexural tensile tests performed at the end of the 7th and 28th days, at 0%, 5%, 10%, 15%, 20% and 25% PUW substitution rates, the results of the 28th day test results are 8%, 5%, 7.6%, 11.7%, 9.3% and 11% higher than the 7th day (Figure 8).

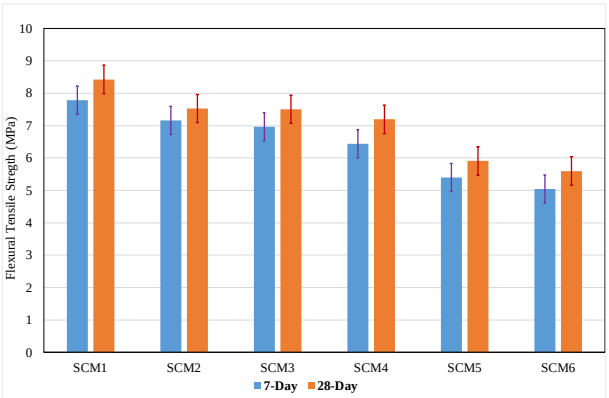

Figure 8. Flexural tensile strength test results

4.3. Compressive Strength Test

During the flexural tensile strength, the broken prism pieces formed by splitting the 40x40x160mm prismatic specimens into two pieces were used to determine the compressive strength. For the evaluated specimens, standard compressive tests were performed for the 7th and 28th days as in flexural tensile. On days 7 and 28, the compressive strengths obtained for the control mix were calculated as 55.6 and 59.1MPa, respectively. The compressive strengths of the mixtures with 5%, 10%, 15%, 20% and 25% PUW substitution were calculated as 37.4, 33.7, 30.9, 26.9 and 26.2MPa at the end of the 7th day, respectively. On the 28th day, the compressive strengths of the mixtures with 5%, 10%, 15%, 20% and 25% PUW substitution were calculated as 27.8%, 28.2%, 34.4%,

35.1% and 55.5% lower than the control mixture, respectively. At day 28, compared to the compressive strengths obtained at day 7, mixtures with 5%, 10%, 15%, 20% and 25% PUW substitution increased by 6.2%, 14.3%, 26.1%, 26.1%, 25.7%, 42.7% and 3.5%, respectively (Figure 9).

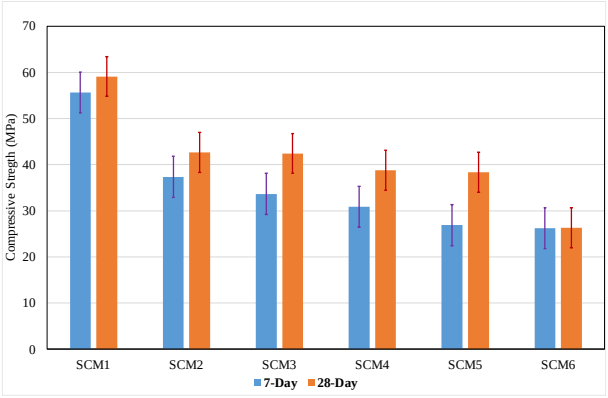

Figure 9. Compressive strength test results and porosity values

4.4. EDX, XRD and SEM Analysis

The samples taken from the samples of each mixture produced were examined by SEM analysis. The SEM images obtained are presented in Figure 10. In the frames captured for PUW in the images, the magnitudes of the cross-sectional properties of the PUW material are marked. Especially for the high compressive strength losses in PUW substituted mixtures, the PUW cross-sections in Figure 10 and the PUW and cement paste interface in Figure 10 (d)-(e) can be clearly seen.

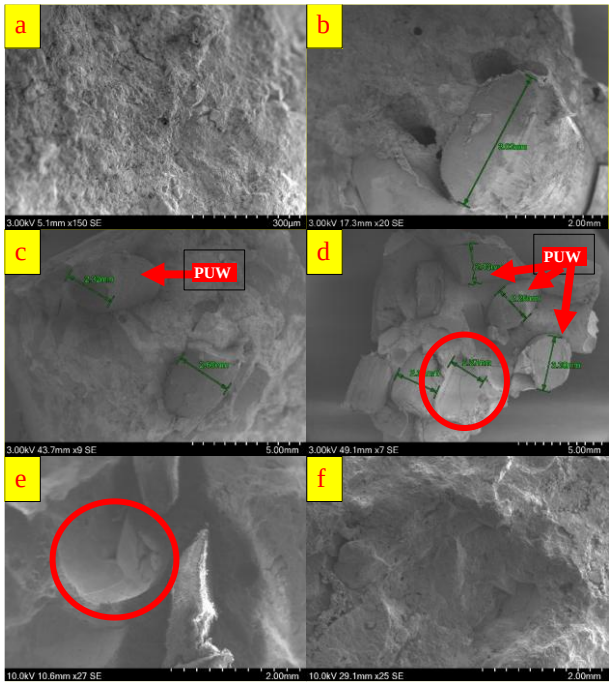

Figure 10. SEM images of a) control SCM, b) 5%, c) 10%, d) 15%, e) 20% and f) 25% PUW substitution

EDX analysis was performed to evaluate the elemental concentrations in the mixtures. C, O, Mg, Al, Si, Ca, K, K, Na, and Fe atoms are present in the obtained analysis results. In the results obtained from EDX analysis, on average, C, O, Mg, Al, Si, Ca, K, Na, and

Fe atoms are 35.3%, 50.1%, 0.58%, 1.08%, 3.06%, 8.10%, 0.24%, 0.35%, and 1.17% in atomic %, respectively (Figure 11).

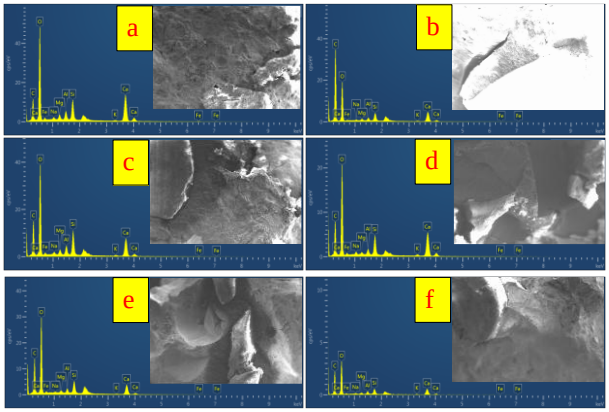

Figure 11. EDX of a) control SCM, b) 5%, c) 10%, d) 15%, e) 20% and f) 25% PUW substitution

Polyurethane is a polymer consisting of a chain of organic units joined by carbamate linkages. These materials are utilised in the production of flexible and non-stretchable foams, durable elastomers and high-performance adhesives, synthetic fibres, gaskets, carpet backing and rigid plastics. The presence of a carbon bond is a key characteristic of organic-based products, and as such, they can be readily identified through the use of C bond density mapping techniques, which utilise electron diffraction (EDX) analysis. For the purposes of illustration, examples of EDX mapping on samples taken from the samples are presented in Figure 12.

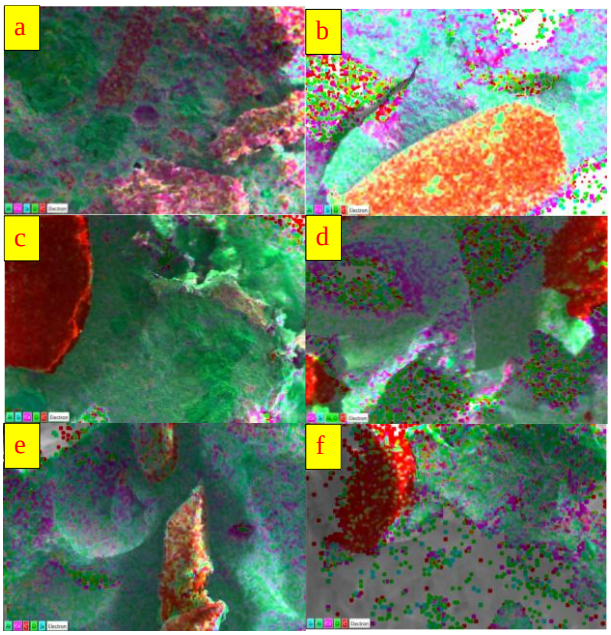

Figure 12. EDX mapping of a) control SCM, b) 5%, c) 10%, d) 15%, e) 20% and f) 25% PUW substitution

The XRD analysis results of the cement paste and PUW material sent to Munzur University laboratory for XRD analysis are given in Figure 13. As a result of XRD in Figure 13, the mineral phase of PUW material was determined as C10H18. It is understood that the chemical differences

between cement paste and PUW as well as the phase separation of the two materials can be easily obtained by XRD (Figure 13).

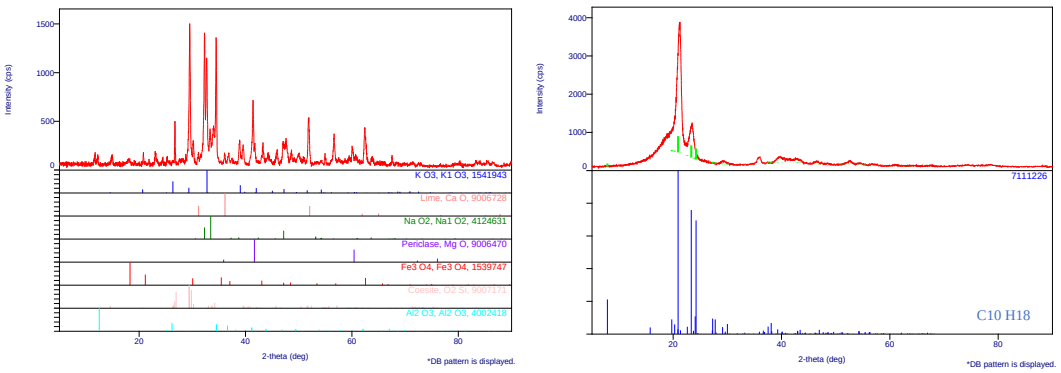

Figure 13. XRD of a) cement and b) PUW

5. CONCLUSION AND RECOMMENDATIONS

In this study, PUW substitution for naturally occurring sand in SCM was evaluated. The effect of PUW substitution on fresh, mechanical, and micro properties of SCM was evaluated. In the SCMs obtained within the remit of the study, PUW was utilised as a PUW substitute at 0%, 5%, 10%, 15%, 15%, 20% and 25% by volume. The binder dosage in SCM mixtures was determined as 500kg/m^3 at the design and production stages. Mechanical tests were evaluated on the 7th and 28th days. The results can be summarized as follows.

- PUW substitution was found to be effective in flexural tensile strength values compared to the control mix. In addition, at 10% PUW substitution rate, flexural tensile strength values decreased by 10-11% on the 7th and 28th day. At 25% PUW replacement rate, these losses increased to 33-35%.
- After PUW substitution, PUW substitution was found to be more effective in compressive strength values compared to tensile strength in flexure. At 10% PUW substitution rate, compressive strength values decreased by 28-40% on the 7th and 28th days compared to the control mix. At 25% PUW substitution rate, these losses increased to 53-55%.
- In the images obtained from SEM analysis, it can be said that the reason for the rapid increase in the basic losses in flexural and compressive strength is that the connection interface to form adherence at the PUW and cement paste interface is very flat.
- The results obtained by EDX and XRD are an important indication that possible PUW contents in the cement matrix can be detected. Furthermore, an example of how the method can be easily used in case studies for detection purposes is presented.

CONFLICT OF INTEREST

The authors declare that they have no known financial interests or personal relationships that could have influenced this work.

FINANCIAL DISCLOSURE

The author(s) declared that they received no financial support for this study.

DECLARATION OF ETHICAL STANDARDS)

The author(s) of the article declare that the materials and methods used in this study do not require ethics committee approval and/or legal-special permission.

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