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Araştırma Makalesi / Research Article

Physical, Mechanical, Radiation Shielding Properties of Self-Compacting Heavy Concrete

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Abstract

The purpose of this research is to ascertain the radiation, mechanical, and physical characteristics of self-compacting concrete with barite aggregate that has been prepared with various additives. Experiments were carried out on self-compacting heavy concrete samples produced using different additives to determine their physical and mechanical properties such as V-funnel, slump-spreading, collapse, compressive strength, air gap, density values of the samples, and radiation shielding values. The highest linear attenuation coefficient was 0.2859 cm^{-1}, observed in the concrete sample with CNT 4 additive. The lowest value (0.2775 cm^{-1}) was measured in the sample containing CNT 2. For CNT 1 and CNT 3, the linear attenuation coefficients were recorded as 0.2794 cm^{-1} and 0.2818 cm^{-1}, respectively. Among the polycarboxylic ether-based additives, CNT 3 demonstrated the best radiation shielding properties.

Keywords: Barite, Heavy Concrete, Radiation Shielding Properties, Self-Compacting Concrete.

Kendiliğinden Yerleşen Ağır Betonun Fiziksel, Mekanik, Radyasyon Tutuculuk Özellikleri

Öz

Bu araştırmanın amacı, çeşitli katkı maddeleri ile hazırlanan barit agregalı kendiliğinden yerleşen betonun radyasyon, mekanik ve fiziksel özelliklerini belirlemektir. Farklı katkı maddeleri kullanılarak üretilen kendiliğinden yerleşen ağır beton numuneleri üzerinde V hunisi, çökme-yayılma, çökme, basınç dayanımı, hava boşluğu, numunelerin yoğunluk değerleri, radyasyon zırhlama değerleri gibi fiziksel ve mekanik özelliklerinin belirlenmesi amacıyla deneyler yapılmıştır. En yüksek lineer soğurma katsayısı, CNT 4 katkılı beton numunesinde 0,2859 cm^{-1} olarak belirlenmiştir. En düşük değer (0,2775 cm^{-1}), CNT 2 içeren numunede ölçülmüştür. CNT 1 ve CNT 3 için lineer soğurma katsayıları sırasıyla 0,2794 cm^{-1} ve 0,2818 cm^{-1} olarak kaydedilmiştir. Polikarboksilik eter esaslı katkı maddeleri arasında CNT 3 en iyi radyasyon tutuculuk özelliği göstermiştir.

Anahtar Kelimeler: Kendiliğinden Yerleşen Beton, Ağır Beton, Radyasyondan Koruma Özellikleri, Barit.

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1. Introduction

Self-compacting concrete (SCC) is a unique kind of concrete that doesn't require additional compaction or vibration to flow and solidify under its own weight. SCC was created in the early 1980s and early 1990s to address the entire compaction need brought on by the substantial reinforcing (Kılıçarslan and Conkusu, 2022; Demirel and Öz, 2017; Okamura and Ouchi, 2003; Brouwers and Radix, 2005). When mixed with admixtures like fillers, superplasticizers, and viscosity modifying agents, SCC gives concrete the desired qualities of improved compaction and workability (Mohan and Mini, 2018; Singh and Siddique, 2016; Sharma and Khan, 2017; Silva and DeBrito, 2017; Goodier, 2003). Concrete mixes that are homogenous and free of honeycombing can be created using SCC. Applications of SCC in the construction industry have increased due to the characteristics (Adhikary et al., 2022; Lilesh et al., 2022; Sun et al., 2020).

SCC can be costly despite having several advantages over traditional concrete since it requires extra supplies and testing during use (Revilla-Cuesta et al., 2020; Neelam and Rafat, 2012). The final qualities of SCC strength, durability, and serviceability are greatly influenced by the properties and caliber of the materials that make up SCC (Hisham, 2018; Faraj et al., 2020; Rajakarunakaran et al., 2022). Determining the measured fractions of the components of SCC cement, fine aggregate, coarse aggregate, water, and admixtures is necessary to create the proportional mix. The main component used in the production of SCC, aggregate makes for 70% of the bulk of the product. The characteristics of the concrete mix are influenced by the quantity and kind of sand used in its production. Concrete becomes stronger as fine aggregate fills in the gaps and holes in the material. Natural river sand can be substituted with manufactured sand, sometimes referred to as M sand in the building business. While M sand is thought to be a more environmentally benign alternative to natural sand, its creation is a labor-intensive and energy-intensive process that uses a lot of water, raw materials, and trash (Stelmakh et al., 2022; Meko et al., 2021; Ashish and Verma, 2019).

Concrete is an environmentally friendly alternative that may reduce building material prices and preserve natural resources by being made from industrial waste. Researchers claim using industrial waste as an aggregate in self-compacting concrete. SCC production proved to be the best concrete mix when up to 30% of the cement was replaced with ground ferronickel slag and 50% of the sand was substituted with the same slag (Md et al., 2022; Belalia et al., 2017; Alhussainy et al., 2016). Ferronickel slag, which can substitute fine aggregate up to 40% in composition, may provide long-lasting, high-strength SCC while maintaining environmental balance in lieu of natural sand (Md et al., 2020; Pelisser et al., 2018).

Barite has a special place in concrete due to its high density and radiation protection properties. Especially preferred in the production of heavy concrete, barite is used in special applications such as radiation protection structures and nuclear facilities. Barite is a natural mineral with the chemical formula $BaSO_4$ (barium sulfate) and is usually white, gray, yellow, brown or colorless. It attracts attention due to its high density (4.3-4.6 g/cm³), which makes it a popular material in various industries (Goyal and Goyal, 2018; Saidani et al., 2015; Kilincarslan et al., 2016; Kilincarslan et al., 2018; Akkurt et al., 2015). The main characteristics of barite are its inertness, cleanliness, nontoxicity, and ability to block gamma radiation (Goyal and Goyal, 2018). Barite finds application in the chemical industry and radiation protection, despite its global usage being centered on the oil and gas sector (Saidani et al., 2015). In the concrete industry, it is generally considered a heavy-weight aggregate (Topçu, 2003, Sakr K and El-Hakim, 2005; Khan et al., 2020). Even though barite is often utilized in the industry as a powder, research on concrete mostly employ it as aggregate. Its application in powder form requires more investigation. Damiche et al. (2020) studied the rheological characteristics of mixes made with barite powder; Saidani et al. (2015) made mixtures using barite powder rather than sand and investigated their mechanical characteristics. Cemalgil (2020) looked on how barite powder affected the self-compacting mortars' mechanical characteristics. Binici et al. (2012) developed anti-corrosion paint for reinforced concrete rebars using barite powder. Conversely, Sevinc et al. (2017) examined the engineering characteristics of concretes made with barite powder and other mineral admixtures. There aren't many studies in the literature that look at how resistant concretes with barite powder are to the impacts of high temperatures. Esen and Kurt (2018) looked at the high-temperature resistance and certain technical qualities of concretes that contained up to 40% barite powder. The findings demonstrated that when heated to 400 °C, the compressive strength of every sample containing barite rose somewhat. The strength of the samples containing barite powder was significantly less than that of the reference sample, even though the reference sample lost a large portion of its strength at 800 ◦C. When literature studies were examined, it was determined that there were very few studies on the production of self-compacting heavy concretes and that radiation retention tests were not carried out on these samples. In this study, the mechanical, physical and radiation shielding properties of barite aggregate self-compacting concrete produced using different additives were determined. As a result of the experiments, it is expected that the radiation shielding properties of self-compacting heavy concretes will increase significantly. Following is the remainder of the article. The materials and methods utilized in the study are described in Section 2. The application and assessment of machine learning techniques on the experimental study data are described in Section 3. The paper's conclusion is presented in the last part.

2. Materials and Methods

The barite used in this study was supplied from Sarkikaraagac/Isparta region. The specific gravity of barite is 4 g/cm^3. Aggregate granulometry curve is given in Figure 1.

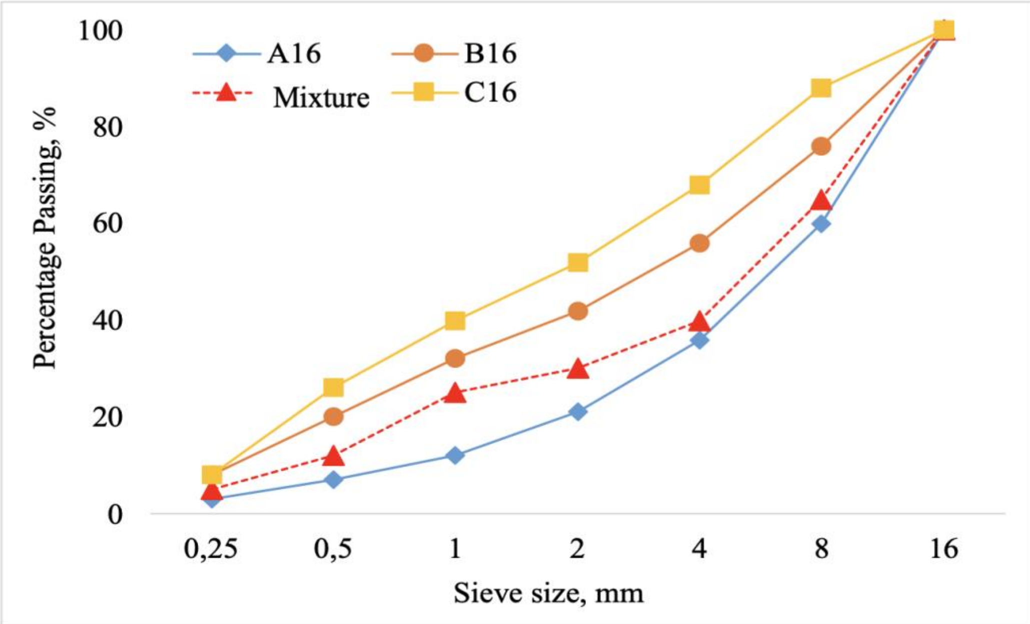

Figure 1. Granulometry curves of aggregates.

In the experiments, CEM I 42.5 R type cement produced at Goltas Cement Factory, which continues its production activities within the borders of Isparta province, was used. The properties of cement and fly ash are shown in Table 1. The unit weight of the fly ash used is 2.05 g/cm^3 and its surface area is 3305 cm^2/g.

Four distinct BASF-obtained additives were utilized in the studies. RHEO 1000 is based on naphthalene sulfonate and polycarboxylic ether, two of the additives (MG 51, SKY 608, RMC 303) that are employed. The technical specifications of the additives used are given in Table 2. The additives used in the experiments were produced in accordance with TS EN-934-2 (2002) standards.

Table 1. Chemical properties of CEM I 42.5 R cement and fly ash.

Component	CEM I 42,5 R (%)	Fly ash (%)
MgO	1.91	1.41
Al2O3	6.2	21.89
SiO2	20.6	58.59
CaO	61.4	4.43
Fe2O3	3.01	9.31
SO3	2.53	0.41
K2O	1.03	1.81
Na2O	0.19	0.24
Cl	0.007	-
S+A+F	-	89.79
Loss of Glow	1.35	1.39
Insoluble Residue	1.773	-

Table 2. Technical specifications of the additives used.

Contribution Type	MG 51 (CNT 1)	SKY 608 (CNT 2)	RMC 303 (CNT 3)	RHEO 1000 (CNT 4)
Material Structure	Polycarboxylic Ether Based	Polycarboxylic Ether Based	Polycarboxylic Ether Based	Naphthalene Sulfonate Based
Colour	Brown	Brown	Green	Brown
Intensity (kg/L)	1.082-1.142	1.069-1.109	1.0-1.1	1.17-1.23
PH value	6-7	5-7	5-8	6-8
Chlorine Content (%)	≤ 0,1	≤ 0,1	≤ 0,1	≤ 0,1
Alkali Content (%)	≤ 3	≤ 3	≤ 3	≤ 10

The water/cement ratio of the concrete to be produced can affect the strength of the concrete. Suleyman Demirel University potable tap water was used in the concrete samples produced for the experiments.

2.1. Concrete production

The quantities of aggregate (barite), cement, fly ash, water, and various chemical additives used in the mixture were measured with a scale, and the sample production recipes were prepared accordingly. A total of four groups of concrete were produced with the use of different additives. The mixing ratios of the produced concrete are given in Table 3.

Table 3. Mixing ratios of produced concrete (1 m^3).

Concrete group	Cement	Fly Ash	Aggregate	Plasticizer	Water
CNT 1	350	50	2750	2.8	190
CNT 2	350	50	2750	4.2	190
CNT 3	350	50	2750	4.2	190
CNT 4	350	50	2750	4.2	190

The mixture calculations were arranged so that the aggregate grain diameter was 16 mm. The concrete to be produced is required to have a fluid consistency. The mixture obtained with the help of a concrete mixer was placed in cube molds with dimensions of 15x15x15 cm. Concrete samples removed from the molds were kept in the curing pool for 7 and 28 days.

2.2. Experimental Methodology

The air meter device in SDU DEYMAM was used to determine the amount of air contained in concrete samples created with different additives. Determination of air amount was applied according to TS EN 12350-7 (2010) standard. To carry out the fresh concrete slump test, fresh concrete was filled into the cone called Abrams cone in 3 stages, after each stage the concrete was skewered 25 times and the concrete was compacted. After the last bottling, it was waited for a while and the funnel was then removed, the distance between the collapsed concrete and the funnel was measured, and the measured value provided the slump value of the concrete. The high slump value obtained indicates that the workability of the concrete is good. It was applied according to the TS EN 206 (2002) standard. Since there was no need for compression in the SCC in performing the spreading test from fresh concrete, bottling was not done, and the concrete was filled into the cone through a container. A strong pressure was applied to the funnel during filling. The purpose of the pressure is to prevent the concrete from leaking while the funnel is lifted. When the filling was completed, the funnel was lifted, and the shaking table was lifted 5 cm and left for the concrete to spread. This process was repeated 15 times. The time until the spreading diameter reached 50 cm was measured. When the spreading process stopped, two diameters perpendicular to each other were measured and the experiment was completed. The test was carried out by TS EN 206 standard. The V funnel is filled to the brim with fresh concrete for the fresh concrete V funnel test. Then, the lid at the lower end of the V funnel is opened and the flow process is started. Flow time was measured with the help of a stopwatch and the classes of concrete samples produced with different additives were determined. Depending on their flow rate, samples are in the VF1 class if they flow in less than 8 seconds, and in the VF2 class if they flow in 9-25 seconds. The test was carried out by TS EN 12350-9 (2010) standard. TS EN 12390-7 (2010) standard was applied in hardened concrete density tests. At the end of 28 days, the hardened density test was applied to the dry surface-saturated samples taken from the curing pool in lime-saturated water at 23 ^{o}C. The scale and electronic caliper in the SDU DEYMAM laboratory were used to carry out this experiment. Hardened concrete compressive strength test. A uniaxial pressure test was carried out according to the TS EN 12390-3 (2010) standard. Visuals of the experiments performed on the samples in the study are given in Figure 2.

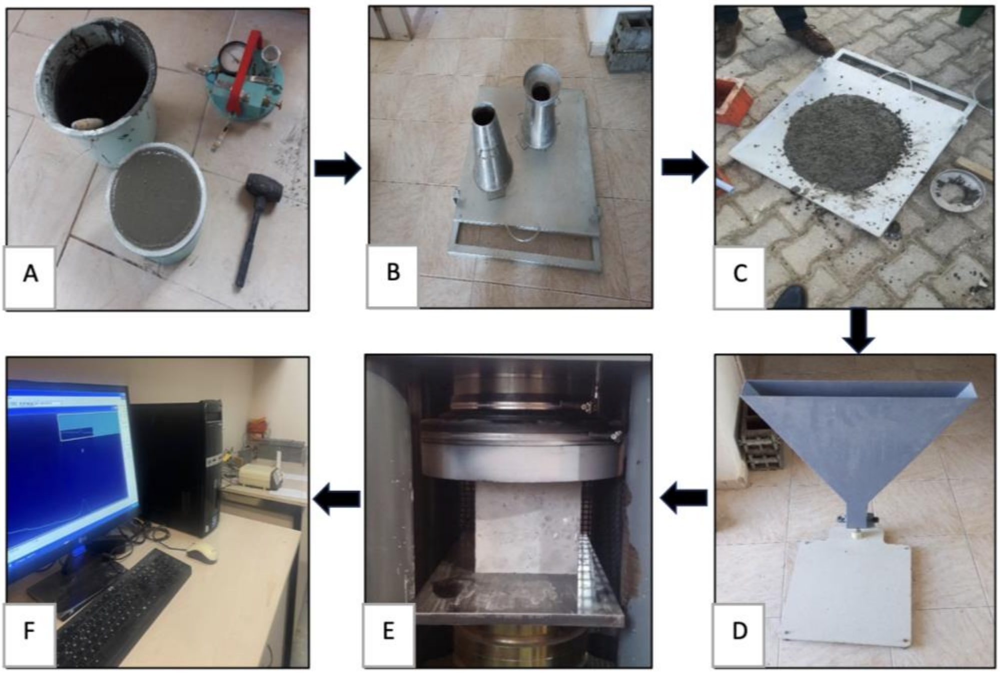

Figure 2. Fresh concrete and hardened concrete tests were performed on the produced samples, A: Air content determination, B: Slump test, C: Diffusion test D: V funnel test, E: Compressive strength test, F: Radiation retention test.

To determine the radiation absorption properties of the samples, radiation absorption values, and radiation coefficients were determined. A gamma spectrometry system was used to determine the coefficients. A gamma spectrometer is a system that can separate gamma rays according to their energy, and NaI(Tl) device was used as a detector in the spectrometer, and gamma-ray values were measured with the help of electronic devices. Radiation detectors can be grouped into three groups according to their material properties: gaseous, semiconductor, and scintillation detectors. The NaI(Tl) detector consists of a scintillating NaI crystal and a photomultiplier tube attached to its back. The high atomic amount of iodine in the NaI scintillator results in very high efficiency in the detection of gamma rays. It is usually activated by adding a small amount of Thallium into the crystal, and this structure is called Nal(TI) crystal. The Beer-Lambert equation was used to determine radiation absorption properties.

$\Delta N = -\mu \cdot N \cdot \Delta x$ ...

$N = N\ e{-}\mu x$

Where;

ΔN : Change in radiation intensity

N_0: Intensity of radiation before interaction with matter, N: Intensity of radiation after interaction with matter,

X: Thickness of the absorbing material,

μ: Linear absorption coefficient

It is defined as (Senli, 2011).

3. Findings and Discussion

Firstly, the air amounts of the 4 different mortar mixtures obtained in the study were determined. The obtained values are given in Figure 3.

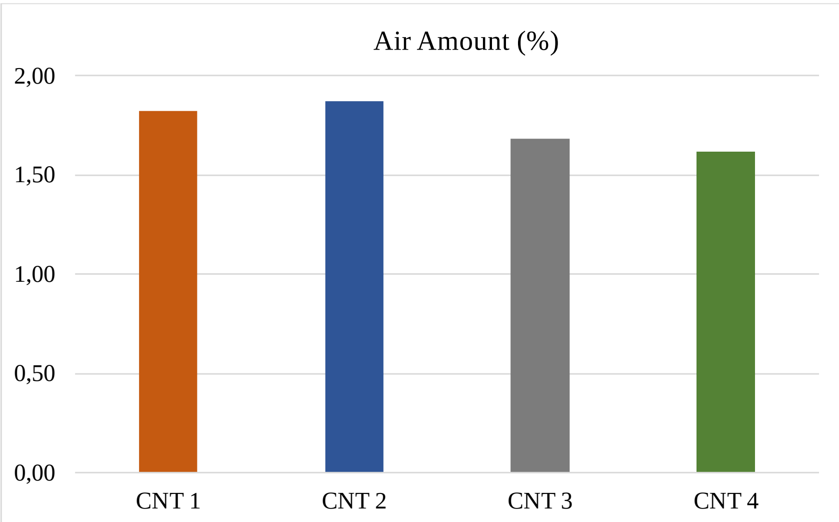

Figure 3. Air content values of mortars.

An air content measurement experiment was carried out to determine the air content of concrete samples produced with polycarboxylic ether-based admixtures and naphthalene sulfonate-based admixtures. As a result of the experiments, it took values between 1.62-1.87%. The highest amount of air content was measured as 1.87% in CNT 2 added concrete. The minimum amount of air content was measured as 1.62% in the CNT 4 added concrete sample. It is seen that there is a difference of approximately 10.7% between the highest and lowest air content values measured in concrete samples. The self-compacting concrete air content, which varied between 5.2% and 9.2%, was higher than what other writers had documented for this kind of concrete (Schankoski et al., 2020; Kostrzanowska-Siedlarz and Gołaszewski, 2015). Superplasticizers based on polycarboxylate may result in additional air-entraining problems, according to Aitcin and Flatt (2016). However, similar results were found in the literature for self-compacting concrete, with no significant negative effects on the material's fresh and hardened properties: Aïssoun et al. (2016) reported 6.0–8.4% air contents; Koura et al. (2020) found 4.2–6.0% air contents; Megid and Khayat (2018) reported 4.6–7.1% air contents; and Hwang and Khayat (2012) found 4.6–8.7% air contents. Finally, it is important to note that a high air content (e.g., up to 9%) may be desired to ensure good freeze-thawing resistance, even though this is not the aim of our work.

The data obtained because of the experiments conducted on self-compacting heavy concrete samples produced with naphthalene sulfonate-based additive CNT 4 and polycarboxylic ether-based additives CNT 1, CNT 2, and CNT 3 are shown in Figure 4.

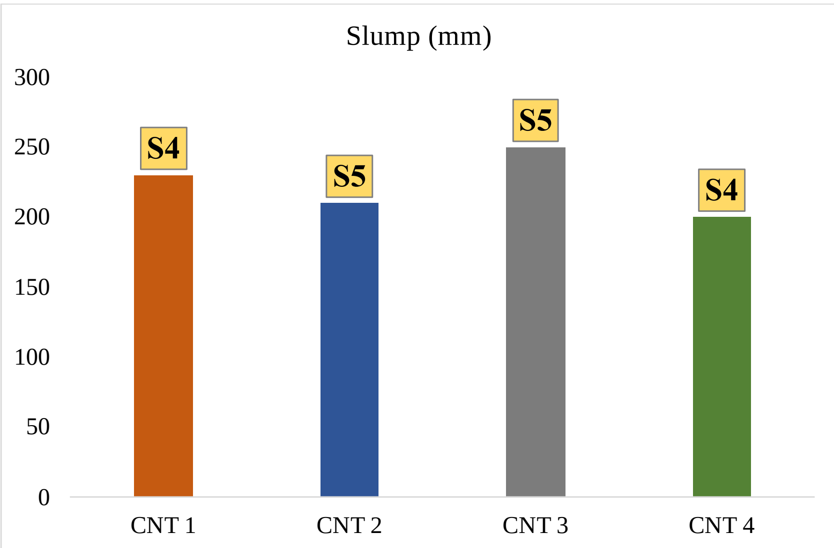

Figure 4. Slump test results of mortar mixtures.

According to the slump value results, it was measured that the slump values of concrete produced with polycarboxylic ether-based additives were higher than the concrete produced with naphthalene sulfonate-based additives. The lowest slump value was measured in the concrete sample produced with CNT 4 additive and the slump value was measured as 200 mm. The highest slump value was measured as 250 mm in the concrete sample produced with the CNT 3 additive. The slump values of CNT 1, CNT 2, and CNT 3, which are polycarboxylic ether-based additives, have values close to each other, these values are between 210-250 mm. Among the additives used, it is thought that the most suitable additive to produce self-compacting heavy concrete will be the CNT 3 additive. The value range of the values found because of the collapse-swelling test is shown in Figure 5.

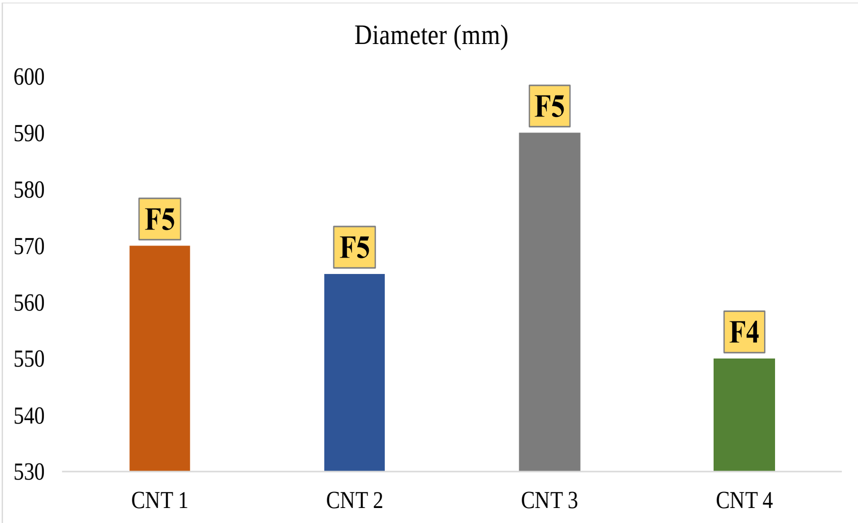

Figure 5. Results of spread test.

The slump and spreading properties of concrete can be shown among the important parameters that can be used to get an idea about its self-compacting ability. As a result of the experiments, the highest spread was measured in CNT 3 added concrete samples and this value was 590 mm. The lowest spread value was measured in the CNT 4 additive and this value is 550 mm. Polycarboxylic ether-based additives have values between 565-590 mm and the highest spreading value is 590 mm measured in the CNT 3 additive, which has the highest spreading value because of the experiments. Ardahanlı et al. (2021) investigated the effect of early preheating on concrete hydration for self-compacting concretes obtained by adding different amounts of fly ash while keeping the water-cement ratio constant. In self-compacting fresh concrete experiments, while the change in spreading diameter decreased slightly as the amount of fly ash increased, the lowest T50 time was observed in the 30UK group. It has been stated that increasing the use of fly ash up to a certain rate positively contributes to the settlement and spreading properties of SCC (Tohumcu and Bingöl, 2013; Zhao et al., 2015; Benli and Karataş, 2019).

The V funnel test was carried out in accordance with TS EN 12350-9 standard. If the flow time of the concrete sample is less than 9 seconds, it is in the VF1 value range class, and if it is 9-25 seconds, it is in the VF2 value range class. The obtained V funnel experiment results are shown in Figure 6.

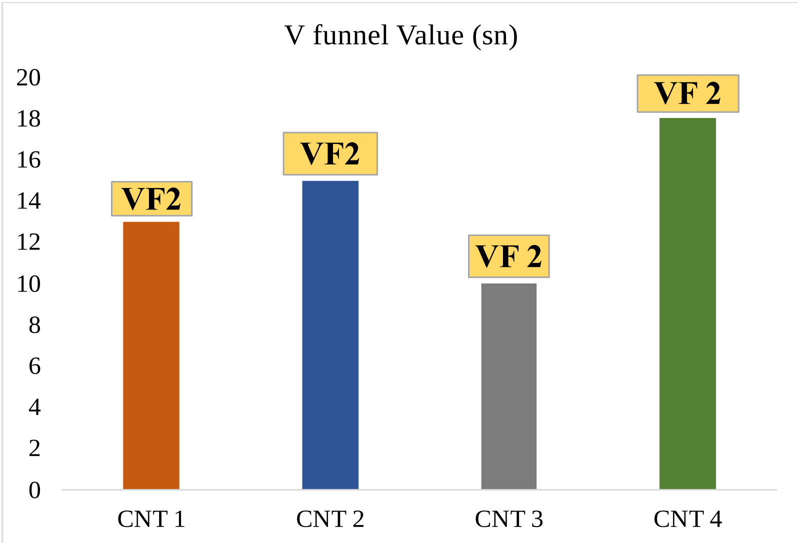

Figure 6. V funnel experiment results.

The V funnel experiment yielded values ranging from 10 to 18 seconds. The additive with the lowest fluidity property was determined as CNT 4. The highest fluidity value belongs to the CNT 3 additive with a flow time of 10 seconds. The flow time of CNT 2 additive was measured as 15 seconds, and the flow time of CNT 1 additive was measured as 13 seconds. Among the additives used, it is thought that the additive that will give the best results to produce self-compacting heavy concrete will be the CNT 3 additive. Gonen and Yazıcıoglu (2021) Gönen and Yazıcıoglu (2021) produced 13 different pumice aggregate self-compacting lightweight concretes using 4 different mineral additives, namely fly ash, silica fume, powder perlite and pumice powder. In the study, it was observed that the increase in the amount of fly ash increased the slump spreading diameter and V-funnel duration. Mahure et al. (2014) examined the fresh and hardened characteristics of self-compacting concrete by partially replacing cement with fly ash at various percentages. The fresh properties of self-compacting concrete were evaluated through measurements such as slump value, V-funnel value, and L-box value. Their findings indicated that the fresh properties remained within acceptable limits when fly ash was used as a replacement for up to 30% of the cement. However, workability tended to decrease as the fly ash content increased. Additionally, Kurt et al. (2015) reported that the V-funnel time for self-compacting concrete rose as the proportion of lightweight aggregates increased. Ryan and O’Connor (2016) observed that incorporating pulverized fuel ash and ground granulated blast furnace slag into self-compacting concrete mixtures led to an increase in viscosity. Mixtures containing pumice powder demonstrated superior slump flow retention compared to other blends. SCC made with pumice powder exhibited adequate flowability, passing ability, and resistance to segregation, although it required higher superplasticizer dosages compared to mixtures with fly ash. Bani Ardalan et al. (2017) found that binary mixtures met the requirements of U-box and V-funnel tests but often failed to comply with EFNARC recommendations for the J-ring test, whereas ternary mixtures achieved satisfactory results across all tests. Benli et al. (2017) further noted that self-compacting mortar with fly ash had better fresh properties than both silica fume and control mixtures. The inclusion of Class C fly ash reduced relative slump values, as fly ash helped disperse cement particles and reduce inter-particle friction. 7-day and 28-day compressive strength values of the produced concrete are given in Figure 7.

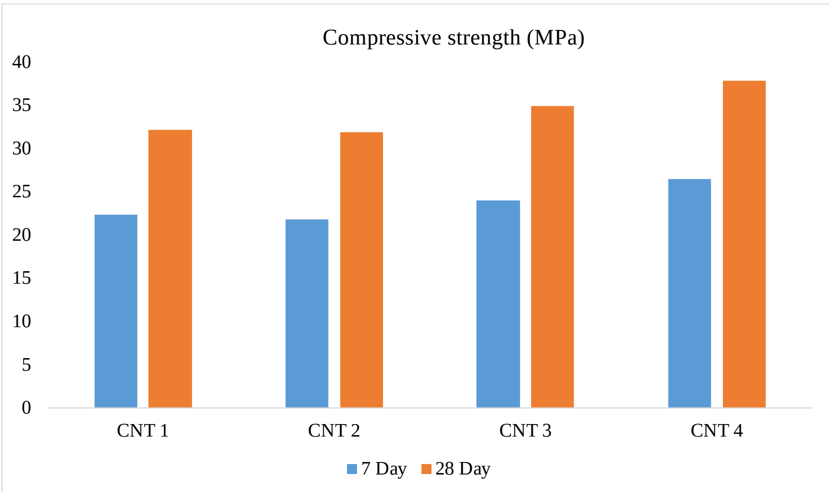

Figure 7. Compressive strength values.

As a result of the experiments, it was determined that the 7-day average compressive strength values were in the range of 21.82-26.47 MPa, and the 28-day average compressive strength values were in the range of 31.88-37.82 MPa. The highest 7-day and 28-day average compressive strength values were obtained from CNT 4, a concrete sample produced with naphthalene sulfonate additive. These values were determined as 26.47 MPa and 37.82 MPa. The lowest 7 and 28-day average compressive strength values were obtained from CNT 2, a concrete sample produced with polycarboxylic ether-based additives. These values were determined as 21.82 MPa and 31.88 MPa. It is seen that the 7 and 28-day average compressive strengths of CNT 1 and CNT 2 additives have very close values to each other. It is seen that there is a difference of approximately 15% between the 7 and 28-day average compressive strengths of the concrete sample with the highest average compressive strength and the concrete samples with the lowest average compressive strength. Among the concrete samples produced using polycarboxylic ether-based additives, the highest 7-day and 28-day average compressive strength values belong to the CNT 3 additive. The 7-day and 28-day average compressive strength values of the admixture are 23.98 MPa and 34.93 MPa. Ardahanlı et al. (2021) aimed to determine the effect of early-age preheating on concrete hydration for self-compacting concretes obtained by adding different amounts of fly ash while keeping the water-cement ratio constant. In the samples produced, one group was kept in water cure (without preheating) for 28 days, while the other group was left under preheating (75°C for 1 day). In the flexural tensile strength test, the best result in both groups was obtained with 30% fly ash addition, while the best result in the splitting tensile strength test was observed in the 30% fly ash-added non-preheated samples. According to the obtained results, the compressive strength of the non-preheated samples was higher than the preheated samples. Wattanalamlerd and Ouchi (2005) explored how fly ash impacts the flowability of self-compacting concrete, particularly by examining mortar flow area and funnel speed. Their findings showed that fly ash acts as a lubricant due to the spherical shape of its particles, which significantly improves the flowability of fresh concrete. As a result, fly ash is commonly used in self-compacting concrete because it is both cost-effective and performs well as a partial cement substitute (Guneyisi et al., 2013). It also helps to prevent the clustering of cement particles, further enhancing the concrete's self-compactability. Similarly, Jalal et al. (2015) observed that the rheological properties of fresh self-compacting concrete benefited from fly ash's ball-bearing-like particles. Additionally, the incorporation of fly ash decreases slump flow times, V-funnel flow times (T20 and T40), L-box flow times, torque, and shear thickening behavior (Guneyisi et al., 2015). Naik et al. (2012) investigated the use of fly ash as a cement replacement in self-compacting concrete and noted that its spherical particles create a ball-bearing effect, which minimizes friction between the paste and aggregate particles. This property reduces the need for superplasticizers and lowers the required amount of cement. Consequently, these studies suggest that incorporating high volumes of fly ash can produce cost-efficient, high-strength self-compacting concrete (Naik et al., 2012).

Linear attenuation coefficient values of concrete produced using different additives are given in Figure 8.

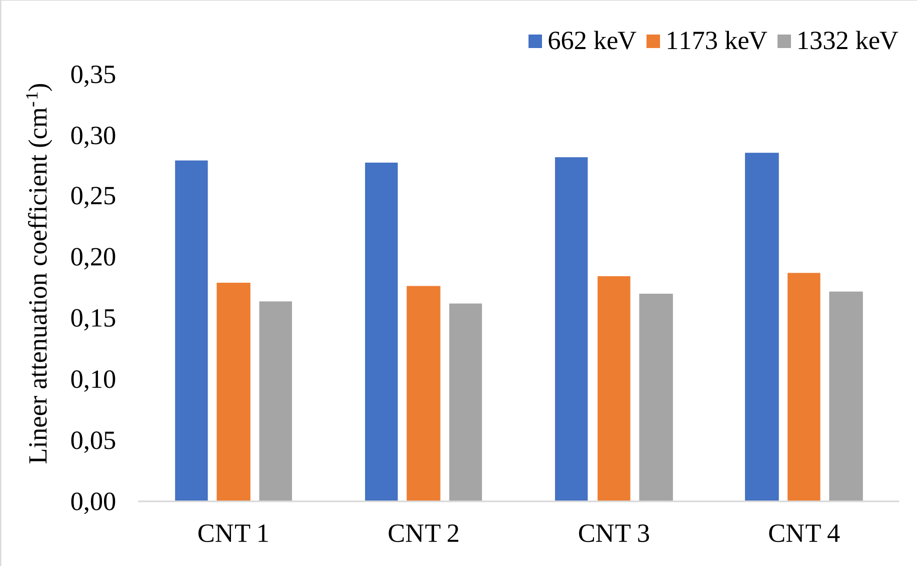

Figure 8. Linear attenuation coefficient values of concrete.

The highest linear attenuation coefficient value was measured as 0.2859 cm^{-1} in the CNT 4 additive. The lowest linear attenuation coefficient value was measured as 0.2775cm^{-1} in the CNT 2 added concrete sample. The linear attenuation coefficient value of CNT 1 added concrete was measured as 0.2794 cm^{-1}. The linear attenuation coefficient value of CNT 3 added concrete was measured as 0.2818 cm^{-1}. The best radiation shielding feature among polycarboxylic ether-based additives was obtained from the CNT 3 series. It has been observed that the additives used do not cause significant differences in the linear attenuation coefficient. Akkurt et al. (2006) examined how the type and quantity of barite and normal-weight aggregates in concrete influenced the linear attenuation coefficient. This coefficient was both directly measured on concrete samples and calculated using the XCOM code. The findings demonstrated that concrete containing barite exhibited a higher linear attenuation coefficient compared to those with ordinary aggregates. Akkurt et al. (2010 and 2012) further explored factors such as the amount of barite, density, water-cement ratio, and corrosion on the linear attenuation coefficient of concrete shielding. Their research concluded that the water-cement ratio and compressive strength had no significant impact on the linear attenuation coefficient. However, it was observed that corrosion led to a decrease in the linear attenuation coefficient of the concrete samples.

4. Conclusions and Recommendations

In the present study, the heavy concrete produced with the barite aggregate was able to self-settle by adding plasticizer additives to minimize the problems such as segregation, among problems (difficulties) encountered during workability and settlement. Four different additives were used for the study, CNT 1, CNT 2, and CNT 3 are polycarboxylic ether-based, and CNT 4 is naphthalene sulfonate-based. As a result of the compressive strength tests, the concrete sample with naphthalene sulfonate-based admixtures had a higher compressive strength than concrete with polycarboxylic ether-based admixtures, but there were no significant differences between the compressive strength values of polycarboxylic ether-based admixtures. It was also determined that the concrete sample with CNT 4 added was in the F4 class due to its higher viscosity compared to other admixtures, while the samples with CNT 1, CNT 2, and CNT 3 added were in the F5 class in the standard. According to the slump test results, the slump consistency classes of the additives were determined according to TS EN 206-1. It was also determined that CNT 4 and CNT 2 additives were in the S4 class, and CNT 1 as well as CNT 3 additives were in the S5 class. Based on the V funnel test results, all the additives stand the VF2 class. In line with the data obtained from dispersion, slump, and V funnel experiments, polycarboxylic ether-based superplasticizers have a lower viscosity than naphthalene sulfonate-based superplasticizers. According to the result of the radiation permeability experiment, there were no significant differences between polycarboxylic ether-based superplasticizers and naphthalene sulfonate-based superplasticizers.

As a result, it can be concluded that it would be more appropriate to use polycarboxylic ether-based superplasticizers instead of naphthalene sulfonate-based superplasticizers in the production of heavy concrete with self-compacting barite aggregate. Although polycarboxylic ether-based superplasticizers have lower viscosity values than naphthalene sulfonate-based superplasticizers, they had better results than naphthalene sulfonate-based additives in the consistency, dispersion, and V funnel tests performed for the present study. Therefore, it would be more appropriate to use polycarboxylic ether-based superplasticizers in self-compacting heavy concretes. When compared to viscosity, compressive strength, and radiation shielding properties, the best results were obtained in the CNT 3 additive. Based on the findings of this study, it is recommended to prioritize the use of polycarboxylic ether-based superplasticizers for producing self-compacting heavy concrete with barite aggregates. These superplasticizers demonstrated superior performance in terms of consistency, dispersion, and viscosity compared to naphthalene sulfonate-based alternatives, making them more suitable for ensuring optimal workability and settlement properties. Among the polycarboxylic ether-based admixtures tested, CNT 3 exhibited the most favorable results, combining high viscosity with excellent compressive strength and radiation shielding capabilities. Consequently, CNT 3 should be considered the preferred additive for applications where high-performance heavy concrete with self-compacting properties is required.

Authors' Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

References

Adhikary, S.K., Ashish, D.K., Sharma, H., Patel, J., Rudžionis, Ž., Al-Ajamee, M., Khatib, J.M. (2022). Lightweight self-compacting concrete: A review. *Resources, Conservation & Recycling Advances.* 15: 200107.

Aïssoun, B., Khayat, K., Gallias, J.L. (2016). Variations of sorptivity with rheological properties of concrete cover in self-consolidating concrete, Constr. Build. Mater. 113, 113–120, https://doi.org/10.1016/j.conbuildmat.2016.03.006.

Aïtcin, P., Flatt, R.J. (2016). Science and Technology of Concrete Admixtures, Woodhead Publishing Limited, https://doi.org/10.1016/C2015-0-00150-2.

Akkurt, I. Akyildirim, H., Karipçin, F., Mavi, B. (2012). Chemical corrosion on gamma-ray attenuation properties of barite concrete, J. Saudi Chem. Soc. 16: 199– 202.

Akkurt, I. Akyildirim, H., Mavi, B., Kilincarslan, S., Basyigit, C. (2010). Photon attenuation coefficients of concrete includes barite in different rate, Anna. Nucl. Energy 37: 910–914.

Akkurt, I., Basyigit, C., Kilincarslan, S., Mavi, B., Akkurt, A. (2006). Radiation shielding of concretes containing different aggregates, Cem. Concr. Compos. 28 (2): 153–157.

Akkurt, I., Emikönel, S., Akarslan, F., Günoğlu, K., Kilincarslan, S., Uncu, I. (2015). Barite effect on radiation shielding properties of cotton-polyester fabric. *Acta Physica Polonica A.* 128(2B).

Alhussainy, F., Hasan, H.A., Rogic, Sheikh, M.N., Hadi, M.N. (2016). Direct tensile testing of self-compacting concrete. *Construction and Building Materials.* 112: 903-906.

Ardahanlı, M., Oltulu, M., Alameri, I. (2021). The Effect of Preheating on the Properties of the Fly Ash Self-Compacting Concrete. *Black Sea Journal of Engineering and Science*, *4*(3), 81-88.

Ardahanlı, M., Oltulu, M., Alameri, I. (2021). Uçucu Küllü Kendiliğinden Yerleşen Betonun Özellikleri Üzerine Ön Isıtmanın Etkisi. *Black Sea Journal of Engineering and Science*, *4*(3), 81-88.

Ashish, D.K., Verma, S.K. (2019). An overview on mixture design of self-compacting concrete. *Structural Concrete*. 20(1), 371-395.

Bani Ardalan, R., Joshaghani, A., Hooton, R.D., 2017. Workability retention and compressive strength of self-compacting concrete incorporating pumice powder and silica fume. Constr. Build. Mater. 134, 116–122.

Belalia, D.O., Boukhatem, B., Ghrici, M., Tagnit-Hamou, A. (2017). Prediction of properties of self-compacting concrete containing fly ash using artificial neural network. *Neural Computing and Applications.* 28, 707-718.

Benli A, Karatas M. 2019. Durability and strength properties of self-compacting mortars produced from triple mixtures with fly ash and silica fume substitutes. DUMF Engineering Journal10: 335-345.

Benli, A., Karatas ̧, M., Gurses, E., 2017. Effect of sea water and MgSO4 solution on the mechanical properties and durability of self-compacting mortars with fly ash/silica fume. Constr. Build. Mater. 146, 464–474.

Binici, H., Aksogan, O., Durgun, M.Y. (2012). Corrosion of basaltic pumice, colemanite, barite and blast furnace slag coated rebars in concretes. *Construct. Build. Mater.* 37:629-637.

Brouwers, H.J.H., Radix, H.J. (2005). Self-compacting concrete: theoretical and experimental study. *Cement and concrete research*, 35(11): 2116-2136.

Cemalgil, S. (2020). Mechanical properties of barite powder modified self-compacting mortars. *DUMF Engineering Journal.* 11: 817–823.

Damiche, Z., Lounis, M., Hamadache, M., Maachou, H., Chaib, O. (2020). Rheological study of heavy cement grouts with physical and chemical characterization of barite powder. *Asian J. Civ. Eng.* 21: 805–813.

Demirel, S., Öz, H.Ö. (2017). Effect of waste materials on performance of self compacting concrete: a review. *KSU Journal of Engineering Sciences*, 20(3):40-48.

Esen, Y., Kurt, A. (2018). Effect of high temperature in concrete for different mineral additives and rates. *KSCE J. Civ. Eng.* 22, 1288–1294.

Faraj, R.H., Ali, H.F.H., Sherwani, A.F.H., Hassan, B.R., Karim, H. (2020). Use of recycled plastic in self-compacting concrete: A comprehensive review on fresh and mechanical properties. *Journal of Building Engineering.* 30:101283.

Gonen, T., Yazıcıoğlu, S. (2021). The Effect of Mineral Admixtures on Freeze-Thaw Resistance of Self-Compacting Lightweight Concrete with Pumice Aggregate. *El-Cezeri*, *8*(1), 94-101.

Goodier, C.I. (2003). Development of self-compacting concrete. *Proceedings of the Institution of Civil Engineers-Structures and Buildings.* 156(4): 405-414.

Goyal, M., Goyal, H. (2018). A review paper on use of recycled aggregates in concrete, *Int. J. Eng. Res. Technol.* 6: 113–119.

Güneyisi, E., Gesoglu, M., Al-Goody, A., İpek, S., 2015. Fresh and rheological behavior of nano-silica and fly ash blended self-compacting concrete. Constr. Build. Mater. 95, 29–44.

Güneyisi, E., Gesoğlu, M., Algin, Z., 2013. Performance of self-compacting concrete (SCC) with high-volume supplementary cementitious materials (SCMs). Eco- Efficient Concrete, 198–217.

Hisham, Q. (2018). Fresh properties of green SCC made with recycled steel slag coarse aggregate under normal and hot weather. *J. Clean. Prod.* 204: 980–991.

Hwang, S.D., Khayat, K.H. (2012). Comparison of in situ properties of wall elements cast using self-consolidating concrete, Mater. Struct. Constr. 45, 123–141, https://doi.org/10.1617/s11527-011-9755-4.

Jalal, M., Pouladkhan, A., Harandi, O.F., Jafari, D., 2015. Comparative study on effects of Class F fly ash, nano silica and silica fume on properties of high performance self compacting concrete. Constr. Build. Mater. 94, 90–104.

Khan, M.U., Ahmad, S., Naqvi, A.A., Al-Gahtani, H.J. (2020). Shielding performance of heavy-weight ultra-high-performance concrete against nuclear radiation. *Progress in Nuclear Energy.* 130: 103550.

Kilincarslan S, Akkurt I, Uncu I, Akarslan F. (2016). Determination of radiation shielding properties of cotton polyester blend fabric coated with different barite rate. *Acta Physica Polonica A*, 129(4), 878-879.

Kilincarslan, S., Iskender, A., Uncu, I.S. (2018). Investigation of the effect of coating method on the radiation shielding properties of terry cotton fabric. *The Journal of Medical Research.* 18(1).

Kılınçarslan, S., Coskunsu, A. (2022). Investigation of physical properties of heavy concrete with self compacting produced by using different additives. *Journal of Technical Science*. 12(2): 6-13.

Kostrzanowska-Siedlarz, A., Gołaszewski, J. (2015). Rheological properties and the air content in fresh concrete for self compacting high performance concrete, Constr. Build. Mater. 94, 555–564, https://doi.org/10.1016/ j.conbuildmat.2015.07.051.

Koura, B.I.O., Hosseinpoor, M., Yahia, A., Kadri, E.H., Kaci, A. (2020). A new proportioning approach of low and normal binder self-consolidating concrete based on the characteristics of fine mortar and granular skeleton, Constr. Build. Mater. 239, 117892, https://doi.org/ 10.1016/j.conbuildmat.2019.117892.

Kurt, M., A.C. Aydin, M.S. Gül, R. Gül, and T. Kotan, The effect of fly ash to self- compactability of pumice aggregate lightweight concrete. Sadhana, 2015. 40(4): p. 1343-1359.

Lilesh, G., Jinendra, K.J., Abhishek, J., Pawan, K. (2022). Recycling of bone China ceramic waste as cement replacement to produce sustainable self-compacting concrete. *Structures.* 37: 364-378.

Mahure, S.H., Mohitkar, V., Ravi, K., 2014. Effect of Fly Ash on Fresh and Hardened Properties of Self Compacting Concrete. I JESRT International Journal of Engineering Sciences & Research Technology 3 (2), 944–948.

Md, N., Jhutan Chandra, K., Jhanssen, O., Camargo, C., Prabir, K.S. (2020). Fresh and hardened properties of high strength self-compacting concrete using by-product ferronickel slag fine aggregate. *J. Build. Eng.* 32.

Md, N., Jhutan Chandra, K., Prabir, K.S.(2022). Strength, permeability and microstructure of self-compacting concrete with the dual use of ferronickel slag as fine aggregate and supplementary binder. *Construct. Build. Mater.* 318, 125927.

Megid, W.A., Khayat, K.H. (2018). Effect of concrete rheological properties on quality of formed surfaces cast with self-consolidating concrete and superworkable concrete, Cem. Concr. Compos. 93, 75–84, https://doi.org/10.1016/j. cemconcomp.2018.06.016.

Meko, B., Ighalo, J.O., Ofuyatan, O.M. (2021). Enhancement of self-compactability of fresh self-compacting concrete: A review. *Cleaner Materials*, 1: 100019.

Mohan, A., Mini, K.M. (2018). Strength and durability studies of SCC incorporating silica fume and ultra-fine GGBS. *Construct. Build. Mater.* 171: 919–928.

Naik, T.R., Kumar, R., Ramme, B.W., Canpolat, F., 2012. Development of high-strength, economical self-consolidating concrete. Constr. Build. Mater. 30, 463–469.

Neelam, P., Rafat, S. (2012). Effect of elevated temperatures on properties of self-compacting-concrete containing fly ash and spent foundry sand. *Construct. Build. Mater.* 34: 512–521.

Okamura, H., Ouchi, M. (2003). Self-compacting concrete. Journal of advanced concrete technology, 1(1): 5-15.

Pelisser, F., Vieira, A., Bernardin, A.M. (2018). Efficient self-compacting concrete with low cement consumption. *Journal of Cleaner Production.* 175, 324-332.

Rajakarunakaran, S.A., Lourdu, A.R., Muthusamy, S., Panchal, H., Alrubaie, A.J., Jaber, M.M., Ali, S.H.M. (2022). Prediction of strength and analysis in self-compacting concrete using machine learning based regression techniques. *Advances in Engineering Software*, 173:103267.

Revilla-Cuesta, V., Skaf, M., Faleschini, F., Manso, J.M., Ortega-López, V. (2020). Self-compacting concrete manufactured with recycled concrete aggregate: An overview. *Journal of Cleaner Production*. 262, 121362.

Ryan, P.C., O'Connor, A., 2016. Comparing the durability of self-compacting concretes and conventionally vibrated concretes in chloride rich environments. Constr. Build. Mater. 120, 504–513.

Saidani, K., Ajam, L., Ben Ouezdou, M. (2015). Barite powder as sand substitutionin concrete: effect on some mechanical properties, *Construct. Build. Mater.* 95, 287–295,

Sakr K, El-Hakim E. 2005. Effect of high temperature or fire on heavy weight concrete properties. Cement and concrete research, 35(3): 590-596. https://doi.org/10.1016/j.cemconres.2004.05.023.

Schankoski, R.A., de Matos, P.R., Pilar, R., Prudêncio, L.R., Ferron, R.D. (2020). Rheological properties and surface finish quality of eco-friendly self-compacting concretes containing quarry waste powders, J. Clean. Prod. 257 (2020), https://doi.org/ 10.1016/j.jclepro.2020.120508 120508.

Senli, G. (2011). Investigation of the Effect of Chemical Additives on the Radiation Permeability of Heavy Concrete. Süleyman Demirel University Technical Education Faculty, B.Thesis, 27s, Isparta.

Sevinç, A.H., Durgun, M.Y., Eken, M. (2017). A Taguchi approach for investigating the engineering properties of concretes incorporating barite, colemanite, basaltic pumice and ground blast furnace slag. *Construct. Build. Mater.* 135: 343-351.

Sharma, R., Khan, R. (2017). Durability assessment of self-compacting concrete incorporating copper slag as fine aggregates. *Construct. Build. Mater.* 155: 617–629.

Silva, P., DeBrito, J. (2017). Experimental study of the mechanical properties and shrinkage of self-compacting concrete with binary and ternary mixes of fly ash and limestone filler, *Eur. J. Environ. Civ. Eng.* 21 (4): 430–453.

Singh, G., Siddique, R. (2016). Strength properties and micro-structural analysis of self-compacting concrete made with iron slag aspartial replacement of fine aggregates. *Construct. Build. Mater.* 127: 144–152.

Stelmakh, S.A., Shcherban, E.M., Beskopylny, A., Mailyan, L.R., Meskhi, B., Beskopylny, N., Zherebtsov, Y. (2022). Development of high-tech self-compacting concrete mixtures based on nano-modifiers of various types. *Materials.* 15(8): 2739.

Sun, C., Chen, Q., Xiao, J., Liu, W. (2020). Utilization of waste concrete recycling materials in self-compacting concrete. Resources. *Conservation and Recycling.* 161, 104930.

Tohumcu İ, Bingöl AF. 2013. Fresh concrete properties and compressive strengths of self-compacting concretes with silica fume and fly ash additives. DUMF Engineering Journal, , 15(2): 31-44.

Topçu, I.B. (2003). Properties of heavy weight concrete produced with barite, *Cement Concr. Res.* 33, 815–822.

TS 12350-7. 2010. Fresh Concrete Tests - Part 7: Air Content Determination Test, Turkish Standards Institute, Ankara.

TS 12350-9. 2010. Fresh Concrete Tests - Part 9: V Funnel Test, Turkish Standards Institute, Ankara.

TS 12390-3. 2010. Hardened Concrete Tests - Part 3: Determination of Compressive Strength, Turkish Standards Institute, Ankara.

TS 12390-7. 2010. Hardened Concrete Tests - Part 7: Density Determination Test, Turkish Standards Institute, Ankara.

TS EN 197-1. 2002. Cement - Part 1: General Cements - Composition, Properties and Compatibility Criteria, Turkish Standards Institute, Ankara.

TS EN 206-1. 2002. Concrete, Property, Performance, Manufacturing, Conformity, Turkish Standards Institute, Ankara.

TS EN 934-2. 2002. Chemical Additive for Concrete, Mortar and Grout. Recipes, Requirements, Conformity, Marking and Labeling, Turkish Standards Institute, Ankara.

Wattanalamlerd, C., Ouchi, M. Flowability of fresh mortar in self-compacting concrete using fly ash. in SCC'2005-China: 1st International Symposium on Design, Performance and Use of Self-Consolidating Concrete. 2005. RILEM Publications SARL..

Zhao H, Sun W, Wu X, Gao B. 2015. The properties of the self- compacting concrete with fly ash and ground granulated blast furnace slag mineral admixtures. J Cleaner Prod, 95: 66-74.