

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

**THE EFFECT OF CEMENT AND NATURAL SAND
REPLACEMENTS BY WASTE GLASS POWDER ON THE
COMPRESSIVE STRENGTH OF CONCRETE**

EBUBEKİR SİDDİK YEŞİL

**A THESIS OF MASTER OF SCIENCE
DEPARTMENT OF CIVIL ENGINEERING**

ADVISOR: ASSOC. PROF. DR. TAYFUN ALTUĞ SÖYLEV

JULY 2024

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T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

ATIK CAM TOZU İLE ÇİMENTO VE DOĞAL KUM
İKAMELERİNİN BETON BASINÇ DAYANIMINA
ETKİSİ

EBUBEKİR SİDDİK YEŞİL

YÜKSEK LİSANS TEZİ
İNŞAAT MÜHENDİSLİĞİ ANABİLİM DALI

DANIŞMAN: DOÇ. DR. TAYFUN ALTUĞ SÖYLEV

JULY 2024



MASTER of SCIENCE JURY APPROVAL FORM

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ABSTRACT

The increasing volume of waste materials has emerged as a major environmental problem. Using waste materials from one industry as raw materials in another industry can be a viable strategy to reduce environmental impact. This strategy can also be an effective way to reduce costs, energy consumption, and pollution. The incorporation of waste materials into concrete has been successfully implemented, and waste glass is among the materials used as a substitute for aggregate or cement. Despite its potential, the application of waste glass in concrete is relatively new and requires further research to thoroughly understand its effects. Powdered waste glass has good potential as a cement substitute material due to its rich silica content. In addition, it can also be used as a substitute for fine aggregate. This thesis investigates the effect of waste glass powder (WGP) on the compressive strength of concrete by using it as a substitute for both cement and aggregate. Experiments were conducted with three different cement replacement rates (0%, 10% and 15%) and four different natural sand replacement rates (0%, 25%, 50% and 75%) using WGP. The results showed a decrease in compressive strength at 10% and 15% cement replacement rates, which was attributed to lower cementing efficiency of WGP compared to Portland cement, as supported by previous studies.

In this study, it was observed that the use of glass powder as a substitute for aggregate contributes to an increase in strength. It was found that the strength loss observed when glass powder is used as a cement substitute can be partially regained through substitution with sand. Experiments conducted on concrete with three distinct water/cement ratios revealed that the most favorable results were obtained with concrete having a 0.45-w/c ratio and 75% sand substitution. This optimal ratio varied for the 0.55-w/c ratio, where it was determined to be various, and for concrete with a 0.65-w/c ratio, it was determined to be 25%.

Keywords: Waste Glass Powder, Concrete, Cement Replacement, Sand Replacement, Compressive Strength.

ÖZET

Atık malzemelerin artan hacmi önemli bir çevre sorunu olarak ortaya çıkmıştır. Bir endüstrinin atık malzemelerinin başka bir endüstride hammadde olarak kullanılması çevresel etkiyi azaltmak için uygun bir strateji olabilir. Bu strateji aynı zamanda maliyeti, enerji tüketimini ve kirliliği azaltmanın da etkili bir yolu olabilir. Atık malzemelerin betona dahil edilmesi başarıyla uygulanmıştır ve atık cam, agrega veya çimento yerine kullanılan malzemeler arasındadır. Potansiyeline rağmen, atık camın betonda uygulanması nispeten yenidir ve etkilerini iyice anlamak için daha fazla araştırma yapılmasını gerektirmektedir. Toz halindeki atık cam, zengin silika içeriğinden dolayı çimento ikame malzemesi olarak iyi bir potansiyele sahiptir. Ek olarak, ince agrega ikamesi olarak da kullanılabilir. Bu tez, atık cam tozunun (WGP) hem çimento hem de agrega yerine kullanılarak betonun basınç dayanımı üzerindeki etkisini araştırmaktadır. Deneyler, WGP kullanılarak üç farklı çimento değiştirme oranı (%0, %10 ve %15) ve dört farklı doğal kum değiştirme oranı (%0, %25, %50 ve %75) ile yürütülmüştür. Sonuçlar, önceki çalışmalarla desteklendiği üzere, WGP'nin Portland çimentosuna kıyasla daha düşük çimentolama verimliliğine atfedilen %10 ve %15 çimento değiştirme oranlarında basınç dayanımında bir düşüş olduğunu göstermiştir.

Bu çalışmada cam tozunun agrega ikamesi olarak kullanıldığı durumlarda dayanım artışı sağladığı görüldü. Cam tozunun çimento ikamesi olarak kullanıldığı durumlarda görülen dayanım kaybının, kum ikamesi yoluyla kısmi olarak geri kazanıldığı tespit edildi. 3 farklı su/çimento oranına sahip betonlarda yapılan çalışmalarda en ideal sonuçların 0.45 su/çimento oranına sahip betonlarda %75 kum ikamesi durumunda olduğu tespit edildi. Bu ideal oran 0.55 su/çimento oranına sahip betonlarda çeşitli iken, 0.65 su/çimento oranına sahip betonlarda %25 olarak tespit edildi.

Anahtar Kelimeler: Atık Cam Tozu, Beton, Çimento İkamesi, Kum İkamesi, Basınç Dayanımı.

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LIST OF SYMBOLS AND ABBREVIATIONS

μm	: Micrometer
C. Sand	: Crushed Sand
CSI	: Crushed Stone One
CSII	: Crushed Stone Two
CT	: Glass Powder
N. Sand	: Naturel Sand
OD	: Oven Dried
SP	: Superplasticizer
W/C	: Water/Cement Ratio
WG	: Waste Glass
WGP	: Waste Glass Powder

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1. INTRODUCTION

Sustainability is of great importance for the survival of future generations. Most research done in this field aims to save energy, reduce maintenance and repair costs, prevent contraction problems, reduce waste and pollution. In addition, they aspire to make building materials more efficient, comfortable, durable and flexible. Considering that humans are in constant contact with buildings, it is vital for human health that building materials get maintenance or renewal at regular intervals. Following a sustainable approach requires selecting building materials that effectively utilize the limited local resources, are environmentally friendly, save energy and meet economic expectations. Materials that successfully meet these criteria throughout their life cycle make more positive contributions to human health and the environment.

Recycling is a process that is becoming increasingly important as resources become scarcer around the world. Recycling waste into the production process is an increasing necessity day by day. Incorporating waste materials into concrete production has emerged as a worldwide trend, increasingly embraced to foster the development of sustainable and eco-friendly concrete. As the significance of sustainable construction practices continues to grow, the construction sector is progressively prioritizing the integration of waste materials into concrete. Substituting waste materials for natural resources represents one of the most efficacious strategies for enhancing the sustainability of the concrete industry. Glass, one of the recycled materials, has become a preferred binding agent in the building materials and construction industries because it attracts attention with the color, texture and shape alternatives it offers.

Glass can be ground to micron level to make it reusable. The similarity between glass and cement in their chemical properties, enables the ground glass powder to be compatible with cement reactions. Studies are being carried out on using glass instead of cement or as aggregate or a mixture of both. Research shows that silica-rich glass provides positive effects on the environmental durability of the building structures. Therefore, the use of glass as a sustainable building material not only increases environmental sustainability but also provides economic and technical advantages. Considering the requirements for energy saving and waste management, the use of recycled glass as a building material finds wider application in the construction

industry. Reusing glass directly reduces natural resource consumption and thus minimizes the environmental footprint. The development and use of building materials that comply with sustainability principles is of critical importance for a more viable world in the future. In this context, the use of recycled glass in concrete production provides both environmental and economic benefits. The primary objectives of the "green" approach to concrete are to reduce greenhouse gas emissions, minimize the consumption of natural resources, and integrate waste materials into the concrete composition.

In this way, renewable building materials play an important role in improving both environmental sustainability and user health. Thanks to their benefits such as energy efficiency, reduction in maintenance costs and preservation of natural resources, these materials have an important place in the future of the construction industry. Especially with the gradual decrease of natural resources, the use of innovative materials such as recycled glass will continue to be one of the cornerstones of sustainable construction. Recycled materials both reduce the environmental impact of construction projects and provide a cost-effective solution. Recycling processes and innovative material use will play a significant role in achieving sustainability goals in the future of the construction industry.

1.1. Purpose of The Study

In recent years, the use of glass powder plays an important role in concrete technology. The use of glass powder in concrete at different rates has an important place in terms of concrete performance.

The most important purpose of using glass powder in concrete is to provide versatile contributions by obtaining more cost-effective, environmentally friendly and energy-saving concrete.

Within the scope of this thesis, in the second chapter, starting from the recycling of urban wastes, the use of waste glass as fine aggregate and coarse aggregate in concrete, and its use as a substitute for cement, this study presents the findings of researchers' investigations and incorporates literature information on these studies.

In the third section, the methods used in experimental studies are discussed. Information about the materials and their properties, in the fourth section, data on

experimental results were given and brief comments were made, and finally, in the fifth section, the study was completed by writing the most general version of the comments.



2. LITERATURE REVIEW

2.1. Recycling Urban Waste

Waste is solid, liquid or gaseous substances that are produced as a result of production or consumption processes and are no longer wanted to be used. According to an alternative definition, waste is materials that no longer have any value for the owner and are intended to be disposed of [Christensen, 2011].

According to a more comprehensive definition, waste; It includes liquid, solid and gaseous substances and waste energy that arise as a result of production and consumption activities, which may change the natural structure and usage potential of the receiving environments with their physical, chemical and bacteriological properties, and may cause direct or indirect harm [Ünal at al., 1998].

When we look at the definition of waste in terms of legislation in Turkey, "waste is stated in the Waste Management Regulation published in the Official Gazette dated 02.04.2015 and numbered 29314; It is defined as any substance or material that is thrown or released into the environment by its manufacturer or the real person or legal entity that actually possesses it, or that has to be thrown away."

Urban solid waste is one of the serious problems faced by cities due to high costs and insufficient attention. This is not just a technical issue, but a complex problem that interacts with political, legal, socio-cultural, environmental and economic factors [Henry at al., 2006].

Municipalities, which in the past years needed a large land area to remove and collectively store all urban solid waste, today use a complex and integrated system consisting of recycling, composting, energy recovery and storage for solid waste [Hung at al., 2007].

The amount of solid waste per capita has risen due to economic development and increasing living standards and the increase in demand for products and services. With the combination of increasing population, growing economy, rapid urbanization and rising living standards, urban solid waste has become a bigger problem, especially in developing countries.

Solid wastes, defined by Palabıyık and Altunbaş as "substances generated as a result of domestic, commercial and/or industrial activities and thrown away by users on the grounds that they are no longer useful, but need to be disposed of regularly due to environmental and human health as well as other social benefits" **[Palabıyık and Altunbaş,2004]**, are divided into four categories according to their sources. can be grouped:

- Domestic Solid Waste,
- Industrial Solid Wastes (Hazardous and Non-Hazardous Wastes),
- Medical Solid Waste,
- Special Solid Wastes.

This concept encompasses a wide array of waste materials, excluding solid waste, hazardous waste, liquid waste, and atmospheric emissions. Municipal solid waste is generated from residential, commercial, institutional, construction and demolition activities, as well as urban services **[Bardan and Haggar,2006]**.

According to data from the China Resources Recycling Association, 22.75 million tons of waste glass was produced in China in 2021, but only 10.05 million tons of this amount was recycled. The disposal of substantial quantities of glass results not only in the inefficient use of resources and energy but also contributes to land utilization and environmental degradation. Due to its inert nature, glass cannot be incinerated in landfills, naturally decomposed, or treated using conventional physical and chemical methods [Warnphen at al.,2019]. The recycling and repurposing of waste glass mitigate production energy requirements and raw material usage, while also averting the land occupation associated with indiscriminate disposal **[Khan at al., 2020]**.

Recycling and reusing waste glass reduces the consumption of energy and raw materials required for production, while also preventing land occupation caused by random disposal. Waste glass has different types and components, and the recycling process is complex. In the recycling process, stages such as transportation, separation, crushing, removal of foreign substances, screening and classification may cause environmental pollution. For example, heavy metals used as special performance

enhancers in glass production can be released into the environment during recycling [Pant and Singh, 2020].

2.2. The Use of Waste Glass in Concrete Mix

Large amounts of waste glass powder (WGP) are produced in the world, and there are approximately 200 million tons of solid waste, approximately 7% of which is waste glass [Chindaprasirt et al., 2022].

The precise time, location, and method by which humans acquired the knowledge to produce glass remain uncertain. It is estimated that handmade glass was found in Iraq and Egypt 4000 years ago [Al Jburi et al., 2019]. The increased use of glass products in recent years has caused the amount of waste glass to increase significantly. A large portion of waste glass is thrown into landfills, and this causes serious damage to the environment and has negative effects on people and animals [Kumar and Nagar, 2017]. Additionally, glass is not biodegradable, causing these wastes to cause global environmental concerns [Salahaddin et al., 2022].

It is integral to the manufacturing of various materials commonly utilized in everyday life, including glassware, bottle glass, window glass, light bulb glass, and glass ornaments. The waste glass resulting from the use of these materials can be used instead of aggregate, in cement production, as a filling material and as a mineral additive [Özkan, 2007].

Glass structurally consists of SiO_2 , Na_2O and CaO components. After reaching the facilities from recycling companies, waste glass is separated according to specific usage areas. " Waste glass can be integrated into concrete in three ways: as a substitute for aggregate (coarse and fine), as a cement substitute" [Kavas et al., 2004].

Before being used in concrete production, waste glass is washed and cleaned of foreign substances and ground to the desired size, then classified according to grain size. Large pieces are used as aggregates in mortar and concrete, and powdered materials are used as mineral additives or filling materials instead of cement [Baradan ,2003].

Glass is highly favored in construction due to its attributes including optical clarity, chemical inertness, exceptional structural integrity, minimal gas permeability, and resilience to high temperatures [Lu et al., 2017].

In the context of hardened concrete properties, variations exist in the impact of glass powder on the compressive strength of concrete at different levels of glass powder content. Kumarappan and Khatib observed enhancements in compressive strength when incorporating up to 10.0% glass powder as a replacement for cement. **[Kumarappan,2013, Khatip at al.,2012]**. Vandhiyan examined the replacement of cement with waste glass powder and observed a significant increase in early strength gain, especially in the sample containing 15% glass powder; While this increase provided a 29% increase compared to the control sample in 7 days, this difference decreased to 23% on the 28th day. It was determined that the strength increase was most optimal at 10% replacement **[Vandhiyan at al.,2013]**. Dali and Tande investigated the impact of glass powder screened through a 600 μm sieve and noted that the compressive strength demonstrated an increment with varying proportions of glass powder up to 25%. However, the maximum enhancement occurred at a proportion of 20% **[Dali and Tande, 2012]**. Patil and Sangle utilized glass powder with particles smaller than 90 μm in their experimental investigation. They observed an enhancement in the compressive strength of concrete when substituting cement with glass powder up to 10.0% **[Patil and Sangle,2013]**. Vasudevan's test results showed that the use of glass powder up to 20.0% increased the compressive strength of concrete **[Vasudevan and Pillay,2013]**. Furthermore, Chikhalikar and Tande observed that using glass powder instead of cement up to 20.0% increases the compressive strength of concrete **[S.M. Chikhalikar and S.N. Tande, 2012]**, and Vijayakumar concluded that using 75 μm sieved glass powder up to 40.0% content increases the compressive strength of concrete **[G. Vijayakumar at al.,2013]**.

2.2.1. The Use of Waste Glass as an Aggregate in Concrete Mix

Topçu and Canbaz observed a decrease of up to 0.3% in the unit weight of concrete without waste glass powder compared to concrete with waste glass powder. The addition of waste glass powder was found to reduce the slump value by up to 0.2%. The inclusion of waste glass powder reduced the air content by up to 27%. Furthermore, the addition of water glass (WG) increased workability and flow table values by up to 4% due to its non-absorptive nature and thinner water layer on the surface. Based on VeBe test results, VeBe values typically range from 4.5 to 7 seconds. Incorporating 60% waste glass powder increases VeBe values by 19%. The irregular

geometry of waste glass prolongs the placement time of fresh concrete, especially with high levels of waste glass content [Topçu and Canbaz,2002].

The compressive strength of concrete samples without waste glass (WG), after curing for 28 days, ranged from 2.04 to 23.50 MPa. It was observed that compressive strength diminished as the proportion of WG in the concrete increased. Specifically, with a 15% WG addition, there was an 8% reduction in compressive strength, while a 30% WG content resulted in a 15% reduction. When the WG proportion reached 45%, the compressive strength decreased by 31%. A further increase to 60% WG led to a 49% reduction in compressive strength. The high brittleness of WG caused cracks, resulting in incomplete adhesion between the WG and the cement paste interface. Additionally, the non-ideal geometry of waste glass prevents achieving a uniform distribution of aggregates. Consequently, increasing the amount of WG in concrete led to a reduction in compressive strength [Topçu and Canbaz,2002]. A study by Tuncan indicated that incorporating 15% WG in crushed form into concrete increased the compressive strength by up to 13%. In this study, the WG was finely divided and exhibited pozzolanic activity, thus enhancing the compressive strength of the concrete [Tuncan et al.,2001]. In another study by Parka 30% WG addition resulted in a 4% decrease in compressive strength, which aligns with our findings [Park et al.,2002]. Additionally, research by Kısacık showed that the compressive strength of concrete without WG increased with dosage, but when WG was incorporated, the compressive strength decreased by as much as 19% [Kısacık,2002].

2.2.1.1. The Use of Waste Glass as a Fine Aggregate

The significant demand for concrete necessitates the extensive use of river sand as a fine aggregate, contributing to the excessive depletion of natural resources and the lowering of water levels in rivers. Consequently, there is a growing imperative to recycle or reuse more waste materials instead of further depleting natural resources. Efforts have been made to substitute glass waste for natural river sand [Salahaddin et al.,2022]. In addition to conserving materials and energy, recycling certain solid wastes can enhance concrete performance in various aspects. For instance, using glass waste as a fine aggregate improves concrete's resistance to chloride penetration [Ling et al.,2011].

2.2.1.2. The Use of Waste Glass as a Coarse Aggregate

Topçu and Canbaz investigated the impact of using glass aggregates (GA) to replace coarse aggregates sized between 4–6 mm, varying the replacement levels from 0% to 60%. Their findings indicated that increasing GA content resulted in decreased air content, slump value, and density [Topçu and Canbaz, 2004]. Afshinnia and Rangaraju utilized waste glass (WG) as a replacement for cement and coarse aggregate at different levels. They concluded that higher GA content led to a reduction in concrete strength [Afshinnia and Rangaraju, 2016]. Additionally, WG with sizes ranging from 4–16 mm was investigated as a replacement for coarse aggregate in concrete production, with replacement levels from 0% to 60% [Topçu and Canbaz, 2004]. The results showed minimal influence on concrete workability and a slight decrease in strength [Ducman et al., 2002].

Waste glass shows potential as a coarse aggregate in concrete, providing aesthetic advantages, yet it may lead to a loss in mechanical properties. Studies indicate that substituting natural coarse aggregate with waste glass notably diminishes compressive and splitting tensile strengths, with a substantial 38% decrease in compressive strength observed [Afshinnia and Rangaraju, 2016]. This assertion is corroborated by studies conducted by Topçu and Canbaz, as well as Kou and Poon, which found that substituting traditional coarse aggregate with waste glass had minimal impacts on workability but significantly compromised compressive and splitting tensile strengths. The smooth surface of glass aggregates inhibits the formation of a strong bond with the cement paste, thereby compromising the overall strength development [Topçu and Canbaz, 2004] and [Kou and Poon, 2009]. Gerges observed that as the replacement ratio of coarse waste glass increased, both the 7-day and 28-day compressive strengths decreased. Samples containing coarse waste glass exhibited a more pronounced difference in 7-day compressive strength compared to 28-day strength, relative to the control, suggesting a delayed strength development in the waste glass samples [Gerges, 2018]. Terro discovered that substituting coarse aggregate with up to 10% waste glass could result in higher compressive strengths at temperatures above 150 °C. However, increasing the replacement ratio beyond 10% led to a reduction in compressive strength at elevated temperatures. Additionally, he found that using waste glass as fine aggregate yielded more promising results compared to its use as coarse aggregate [Terro, 2006]. Topcu and Canbaz found that

increasing the waste glass aggregate content increased the Ve-Be consistency test values [Topçu and Canbaz,2004]. Considering the decrease in slump, the increase in consistency indicates that adding waste glass had negligible effects on workability. In this context, the increase in slump attributed to the smooth surface of the glass suggests that it provided weak interference in the mix [Terro, 2006].

2.2.2. The Use of Glass Cement Replacement in Concrete

Cement, the principal ingredient in concrete, generates a substantial quantity of greenhouse gases during its production, thereby contributing to global warming. It is reported that the production of 1 ton of Portland cement in the 2000s emitted almost 870 kg of CO₂ and that cement production constituted 5% of the global total of 30 gigatons of CO₂ emissions [Naik and Moriconi, 2005].

The production of cement entails multiple stages, including fuel consumption, calcination, and electricity utilization, rendering this sector a significant emitter of CO₂. By 2021, Portland cement is widely acknowledged as an energy-intensive industry, responsible for roughly 5-8% of global anthropogenic CO₂ emissions [İbrahim,2021]. The production of one ton of cement clinker is estimated to emit between 0.9 and 1.0 tons of CO₂, contingent on the type of fuel utilized [Olutoge,2016] . Utilizing waste glass powder as a cement substitute can significantly contribute to CO₂ emission reduction and energy savings, marking an important advance toward viable production.

Glass powders can enhance the mechanical properties of concrete thanks to the pozzolanic activity [Du and Tan,2013]. It is noteworthy that waste glass powder, with particles sized 100 micrometers or smaller, displays a reactive property akin to the pozzolanic reaction observed in concrete [Ali at al.,2017].

Moreover, the use of waste glass powder in concrete can lessen ASR expansion due to the earlier depletion of alkali in the C-S-H structure during the pozzolanic reaction [Matos and Coutinho,2012]. Cassar and Camilleri demonstrated that replacing 10-20% of cement with glass powder resulted in concrete with high resistance to chloride ion penetration [Cassar and Camilleri,2012]. Kamali and Ghahremaninezhad also noted that using glass powder instead of cement improved the compressive strength and resistance to chloride permeability of concrete, achieving minimal chloride

permeability at a maximum substitution level of 20% **[Kamali and Ghahremaninezhad,2015]**.

In addition to chemical admixtures, mineral admixtures used in concrete, such as pozzolans, do not exhibit binding properties on their own. However, due to their high silica content, pozzolans react with calcium hydroxide to gain binding properties. Pozzolans are used to increase the workability of fresh concrete, reduce bleeding and segregation, lower the heat of hydration, and improve the mechanical properties of hardened concrete, such as compressive, flexural, and tensile strength. They also enhance durability properties by reducing porosity, water permeability, drying shrinkage, and expansions, and increase resistance to freeze-thaw cycles, acids, sulfates, and chlorides, thus leading to the production of more economical concrete.

Pozzolans can be classified into three groups based on their sources:

Naturel materials (volcanic ash, tuffs, diatomaceous earth)

Materials obtained as industrial by-products not directly related to concrete production (fly ash, silica fume, granulated blast furnace slag)

Heat-treated materials (calcined clay, calcined shale) **[Erdoğan,2013]**.

3. EXPERIMENTAL STUDY

In this study, the effect of glass powder on concrete strength was investigated. For this purpose, 25%, 50%, and 75% of the sand in the concrete were replaced with glass powder. Additionally, 10% and 15% of the cement in the concrete were replaced with glass powder. The replacement ratios were tested in combination. While different concrete mixtures were obtained, the amount of water in all mixtures was kept constant and the amount of cement was changed. Generally, the workability of concrete is proportional to the amount of water. Three different strength classes were tried to be obtained by changing the amount of cement while keeping the amount of water constant. In these three different mixture designs, cement and sand were substituted with glass powder in various ratios to see the effect of glass powder on the mechanical properties of concrete. Three different water/cement ratios were determined to obtain different strength classes. In concrete with these three different w/c ratios, the ratio of glass powder replaced by three different cements and the ratio of glass powder replaced by three different sands were determined. The mixtures were examined over two stages. The impact of waste glass powder (WGP) on the compressive strength of concrete will be examined by substituting both cement and aggregate. Each concrete mixture was compared with control concrete with a similar water/cement ratio in terms of concrete compressive strength performance.

3.1. Materials and Their Properties

3.1.1. Cement

In the experiments, Portland cement type classified as CEM I 42.5 R according to TS EN 197-1 produced by Nuh Çimento Sanayi A.Ş. was used. Physical analysis results, chemical analysis results and mineralogical compositions of this material obtained from the manufacturer are given in **Table 3.1**, **Table 3.2** and **Table 3.3**, respectively. Enough cement for the number of samples to be used in the experiments was taken from the factory at once. In this way, it was tried to prevent standard changes that may occur in the physical and chemical properties of cement.

Table 3.1: CEM I 42.5 R physical analysis results.

Physical analysis results	Value
Specific Gravity	3,15 (gr/cm ³)
Freezing time	90/165 (minute)
Volume constancy	1-10 (mm)
Normal Consistency	29.80 (%)

Table 3.2: CEM I 42.5 R chemical analysis results.

Chemical analysis results	Value (%)
Si O ₂	19.80
Al ₂ O ₃	4.49
Fe ₂ O ₃	3.77
Ca O	63.63
Mg O	1.91
SO ₃	2.63
Insoluble Residue	0.38
Chloride	0.0089
Total contribution	0.47

Table 3.3: CEM I 42.5 R mineralogical composition.

Mineralogical composition	Value (%)
C ₃ S	64.09
C ₂ S	7.57
C ₃ A	4.9
C ₄ AF	11.32

3.1.2. Glass Powder

The experiment utilized waste glass powder supplied by Akcihan Madencilik. The chemical analysis results for this material are detailed in **Table 3.4**, while **Table 3.5** presents the corresponding physical analysis results provided by the manufacturer.

Table 3.4: WGP chemical analysis.

Parameters	Value (%)
SiO ₂	69.42
Fe ₂ O ₃	0.48
Ca O	8.27
Al ₂ O ₃	1.09
Mg O	4.25
Na ₂ O	12.31

Table 3.5: Physical analysis.

Parameters	Value
Specific weight	2.58 (Gr/cm ³)
Bulk density	1.56 (Gr/cm ³)
Melting point	720 (C)
Water absorption	2 (%)
Grain size(Average)	10 (µm)

3.1.3. Aggregates

In this study, Crushed stone I (11,2 mm) and Crushed stone II (22,4 mm) were used as coarse aggregates to be used in concrete mixtures. Moreover, crushed sand and natural sand were used as fine aggregates.



Figure 3.1: Coarse Aggregates.



Figure 3.2: Fine Aggregates.

Table 3.6: Coarse aggregate specific weight (oven dried-OD) and water absorption rate values.

	Specific weight (OD) (t/m ³)	Water Absorption (%)
N. Sand	2,59	2
C. Sand	2,65	1,5
CSI	2,69	0,67
CSII	2,71	0,51

The water absorption rate results of the dry aggregate used in the mixtures and oven dried density values are given in **Table 3.6**.

The coarse aggregates used in the concrete mixture were laid on a smooth surface and dried in the laboratory environment.

Natural sand and crushed sand used in the concrete mixture were dried in an oven at $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$ for 24 hours until completely dry. It was then cooled to room temperature in plastic containers with lids to prevent moisture and stored in these containers until mixed.



Figure 3.3: Lab oven.

The aggregates underwent granulometric examination using the sieve analysis method to determine their particle size distribution, with the results tabulated in **Table 3.7**. Subsequently, suitable mixing ratios were established based on these findings.

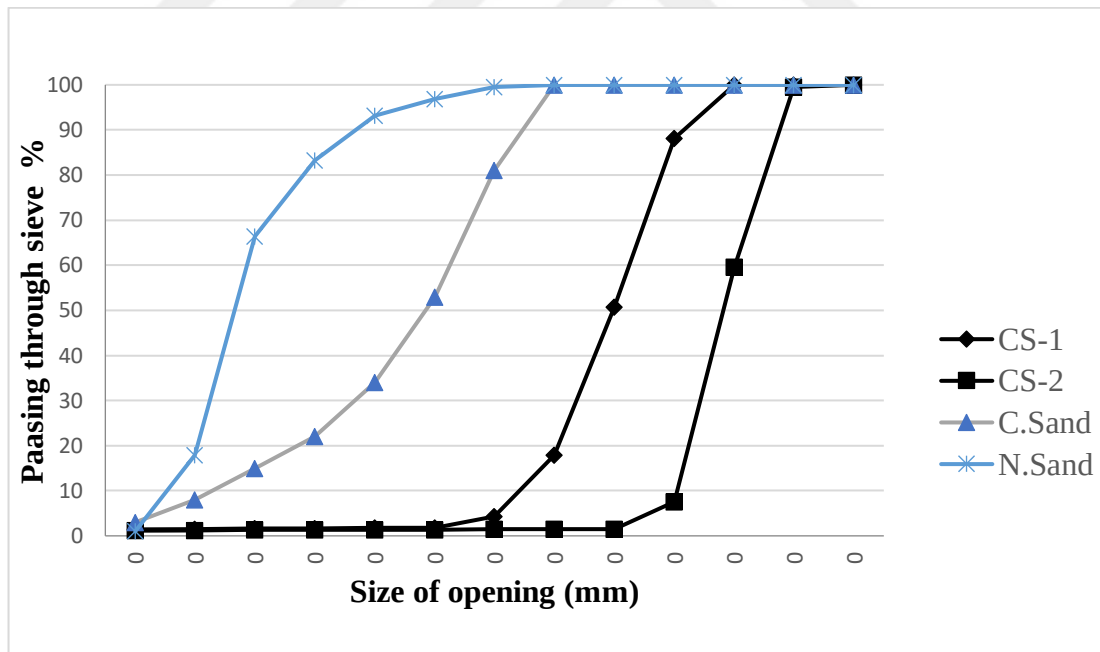
To obtain the sieve analysis results specified in **Table 3.7**, the shaking table and sieves in **Figure 3.4** were used.



Figure 3.4: Sieve and sieve shaker.

Table 3.7: Sieve analysis test results.

Cumulative Passing (%)				
Sieve	N. Sand (0,22)	C. Sand (0,22)	CSI (0,3)	CSII (0,26)
22,4	100	100	100	98,57
16	100	100	100	30,865
11,2	100	100	99,04	1,295
8	100	100	80,33	0,19
5,6	99,97	99,87	40,1	0,125
4	99,47	97,71	14,9	0,12
2	96,79	68,34	0,925	0,12
1	93,19	46,16	0,76	0,12
0,5	83,21	30,53	0,75	0,12
0,25	66,43	20,72	0,735	0,12
0,125	17,93	15,07	0,72	0,12
0,063	1,01	8,02	0,62	0,12

Table 3.8: Sieve analysis.

3.1.4. Superplasticizer

MasterGlenium sky 675 product was used in this study. The technical data sheet of the product is as stated in the table below. The reason for using the product in this study is to rise the workability of concrete mixtures with a high fine material ratio.

Table 3.9: Technical specifications of the superplasticizer.

Technical Specialty	
Material Structure	Polycarboxylic Ether Based
Appearance	Dark Brown - Liquid
Specific Weight (20 ⁰ C)	1.058 – 1.098 kg/lt
Solid Content	% 27

3.2. Concrete Mixes

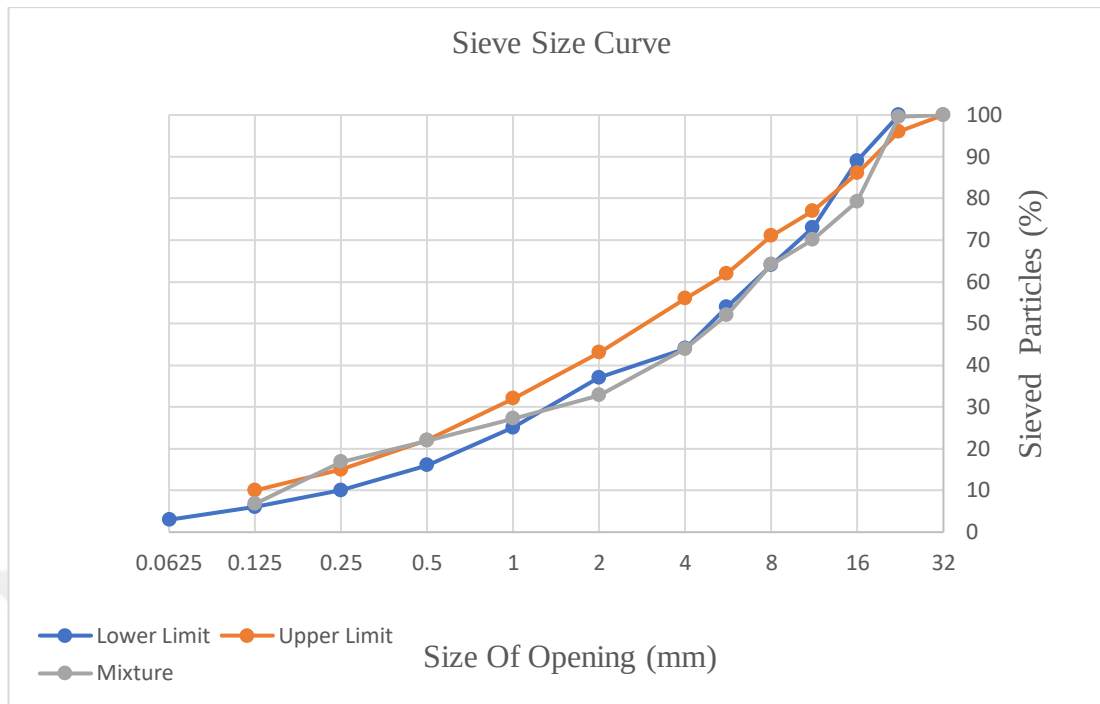
The TS 802 standard was used as the main guide for the concrete mix design. In this study, a total of 27 samples were prepared for hardened concrete tests for each concrete mixture. Three different w/c ratios (0.45, 0.55, 0.65), three different glass powder replacement rates with cement (%0, %10, %15), and three different glass powder replacement rates with sand (%25, %50, %75) were determined. While naming the samples, firstly the water/cement ratio (0.45, 0.55, 0.65), the number written next to CT (Glass powder) indicates the substitution ratio for glass powder to portland cement. Finally, K indicates the natural sand replacement rate. The code was created by writing that glass powder was added instead.

(Examples: C45-CT10-K25, C55-CT15-K75)

In these mixes, the mixing ratios of the aggregates were first determined. The chart in table 3.10 was used when determining the mixing ratios of the aggregates. The aggregate mixes consist of 12% sand, 23% crushed sand, 32% crushed stone I(11,2 mm), and 33% crushed stone II (22,4 mm).

Chemical additives were used in concrete samples with 0.45, 0.55 and 0.65 water/cement ratios and their workability was measured. While calculating the chemical additive, it was decided to add chemical additives at the rate of 0.5%, 0.7% and 0.9% of the cement mass, respectively, to the productions with serial numbers K25, K50 and K75, which indicate the natural sand replacement ratio.

Table 3.10: Sieve analysis of the aggregates used.



Then the amount of water was determined. The most appropriate amount of water for the workability of concrete was determined to be 220 kg/m³. Finally, the w/c ratio was considered to be 0.45, 0.55 and 0.65. Based on this, concrete mixture designs were obtained.

Table 3.11: Concrete mixes in kg for 1m³ concrete at 0.45-w/c.

Concrete Mixes	Water	Cement	Glass P.	SP	N.Sand	C.Sand	CSI	CSII
C45-CT0-K0	220	488,89	-	2,44	194,13	372,08	517,67	533,85
C45-CT0-K25	220	488,89	48,53	2.20	145,60	372,08	517,67	533,85
C45-CT0-K50	220	488,89	97,06	3,42	97,06	372,08	517,67	533,85
C45-CT0-K75	220	488,89	145,60	4,40	48,53	372,08	517,67	533,85
C45-CT10-K0	220	440,00	48,89	2,44	185,25	372,08	517,67	533,85
C45-CT10-K25	220	440,00	95,20	2.20	138,94	372,08	517,67	533,85
C45-CT10-K50	220	440,00	141,51	3,42	92,62	372,08	517,67	533,85
C45-CT10-K75	220	440,00	187,82	4,40	46,31	372,08	517,67	533,85
C45-CT15-K0	220	415,56	73,33	2,44	180,81	372,08	517,67	533,85
C45-CT15-K25	220	415,56	118,53	2,44	135,60	372,08	517,67	533,85
C45-CT15-K50	220	415,56	163,74	3,42	90,40	372,08	517,67	533,85
C45-CT15-K75	220	415,56	208,94	4,15	45,20	372,08	517,67	533,85

Table 3.12: Concrete mixes in kg for 1m³ concrete at 0.55-w/c.

Concrete Mixes	Water	Cement	Glass P	SP	N.Sand	C.Sand	CSI	CSII
C55-CT0-K0	220	400	-	2,00	203,19	389,44	541,83	558,76
C55-CT0-K25	220	400	50,80	2,00	152,39	389,44	541,83	558,76
C55-CT0-K50	220	400	101,59	2,80	101,59	389,44	541,83	558,76
C55-CT0-K75	220	400	152,39	3,60	50,80	389,44	541,83	558,76
C55-CT10-K0	220	360	40	2,00	195,92	389,44	541,83	558,76
C55-CT10-K25	220	360	88,98	2,00	146,94	389,44	541,83	558,76
C55-CT10-K50	220	360	137,96	2,80	97,96	389,44	541,83	558,76
C55-CT10-K75	220	360	186,94	3,60	48,98	389,44	541,83	558,76
C55-CT15-K0	220	340	60	2,00	192,29	389,44	541,83	558,76
C55-CT15-K25	220	340	108,07	2,00	144,21	389,44	541,83	558,76
C55-CT15-K50	220	340	163,83	2,80	96,14	389,44	541,83	558,76
C55-CT15-K75	220	340	204,21	3,60	48,07	389,44	541,83	558,76

Table 3.13: Concrete mixes in kg for 1m³ concrete at 0.65-w/c.

Concrete Mixes	Water	Cement	Glass P	SP	N.Sand	C.Sand	CSI	CSII
C65-CT0-K0	220	338,46	-	1,69	209,46	401,46	558,55	576,00
C65-CT0-K25	220	338,46	52,36	1,69	157,09	401,46	558,55	576,00
C65-CT0-K50	220	338,46	104,73	2,37	104,73	401,46	558,55	576,00
C65-CT0-K75	220	338,46	157,09	3,05	52,36	401,46	558,55	576,00
C65-CT10-K0	220	304,62	33,85	1,69	203,31	401,46	558,55	576,00
C65-CT10-K25	220	304,62	84,67	1,69	152,48	401,46	558,55	576,00
C65-CT10-K50	220	304,62	135,50	2,37	101,65	401,46	558,55	576,00
C65-CT10-K75	220	304,62	186,33	3,05	50,83	401,46	558,55	576,00
C65-CT15-K0	220	287,69	50,77	1,69	200,23	401,46	558,55	576,00
C65-CT15-K25	220	287,69	100,83	1,69	150,18	401,46	558,55	576,00
C65-CT15-K50	220	287,69	158,90	2,37	100,12	401,46	558,55	576,00
C65-CT15-K75	220	287,69	200,94	3,05	50,06	401,46	558,55	576,00

In the mix, first the aggregates (crushed stone I, crushed stone II, natural sand and crushed sand) were placed in the mixer and mixed for 2 minutes. After adding cement and glass powder, the mixture was completed by adding water to the mixture. Water was added all at once at the end of the second minute. Fresh concrete tests were made. After the mixing was completed, the concrete produced in the proportions determined

in the calculation was mixed by a concrete mixer and poured into pre-lubricated molds and compacted. When the molds were filled halfway, they rodded 25 times, and when the remaining half was filled, this process was repeated. Care was taken to ensure that the rod did not penetrate the lower part of the mold during compaction (TS EN 12350-1). The molds with dimensions of 150mm * 150mm * 150mm were generously lubricated. After the samples were kept in the molds for two days, they were removed from the mold and placed in a water-filled curing pool prepared according to the curing conditions. Tap water was added at $20\pm3^{\circ}\text{C}$ for 28 days. The granulometry test results of the aggregates used are given in **Table 3.10**.

3.3. Fresh Concrete Tests

3.3.1. Workability

To determine the consistency after mixing, a slump test was performed according to the TS EN 12350-2 standard. Chemical additives were used in concrete samples with 0.45, 0.55 and 0.65 water/cement ratios and their workability was measured. (Table 4.1)

3.3.2. Unit Weight

According to the TS EN 12350-6 standard, during the production phase, after the mixing process was completed by the concrete mixer, the fresh concrete was placed in the mold with a volume of 7 liters and a certain weight in three layers, by 25 bottling operations in each layer, and its total weight was weighed. Data regarding unit weight results are given (**Table 4.2, Table 4.3, Table 4.4**).

3.4. Hardened Concrete Tests

The specimens, which were kept in the curing tank until saturated with water at the 28th day, were subjected to compressive strength testing according to the EN 12390-3 standard. The average of the obtained results is according to the different water/cement ratios of the mixtures, glass powder replaced with cement and glass powder replaced with sand as given in the tables below (**Tables 4.5, 4.6 and 4.7**).

4. EXPERIMENTAL RESULTS

4.1. Fresh concrete test results

4.1.1. Workability

Table 4.1: Slump results of fresh concrete.

Concrete Mixes	Slump (mm)	Concrete Mixes	Slump (mm)
C45-CT0-K0	160	C55-CT10-K50	170
C45-CT0-K25	140	C55-CT10-K75	215
C45-CT0-K50	210	C55-CT15-K0	230
C45-CT0-K75	220	C55-CT15-K25	165
C45-CT10-K0	170	C55-CT15-K50	170
C45-CT10-K25	170	C55-CT15-K75	115
C45-CT10-K50	110	C65-CT0-K0	185
C45-CT10-K75	215	C65-CT0-K25	190
C45-CT15-K0	175	C65-CT0-K50	215
C45-CT15-K25	150	C65-CT0-K75	85
C45-CT15-K50	185	C65-CT10-K0	165
C45-CT15-K75	200	C65-CT10-K25	180
C55-CT0-K0	200	C65-CT10-K50	140
C55-CT0-K25	170	C65-CT10-K75	65
C55-CT0-K50	180	C65-CT15-K0	185
C55-CT0-K75	155	C65-CT15-K25	200
C55-CT10-K0	155	C65-CT15-K50	190
C55-CT10-K25	165	C65-CT15-K75	110

As the w/c ratio increased, the slump value increased. According to water/cement ratios, the lowest slump values are seen in 0.45-w/c ratio concrete mix.

The average slump value was obtained in 0.55-w/c ratio concrete mix compared to other series.

More slump values were obtained in 0.65-w/c ratio concrete mix compared to other series. The addition of super plasticizer generally increased the slump value.

While the replacement rate of glass powder with cement in 0.45-w/c ratio concrete mix was constant, the slump value increased as the replacement rate with sand increased. However, the only reason for this may be that the amount of superplasticizer has increased, not the change in the glass powder ratio. However, the same relationship was not seen in 0.55-w/c ratio and 0.65-w/c ratio concrete mixes.

In 0.65-w/c ratio concrete mixes, it has not been possible to increase the amount of superplasticizer as the amount of glass powder replacing sand increases. The reason for this is the disruption of the concrete form when the amount of superplasticizer is increased. Therefore, the slump amount for 0.65-w/c ratio concrete mixes are relatively low at 75% (k75) compared to other mixes.

4.1.2. Unit weight

Table 4.2: Fresh concrete unit weight test results of the C45 series.

Concrete Mixes	Fresh concrete unit weight (kg/m ³)
C45-CT0-K0	2383
C45-CT0-K25	2361
C45-CT0-K50	2363
C45-CT0-K75	2348
C45-CT10-K0	2355
C45-CT10-K25	2342
C45-CT10-K50	2345
C45-CT10-K75	2332
C45-CT15-K0	2357
C45-CT15-K25	2340
C45-CT15-K50	2334
C45-CT15-K75	2348

Table 4.3: Fresh concrete unit weight test results of the C55 series.

Concrete Mixes	Fresh concrete unit weight (kg/m ³)
C55-CT0-K0	2360
C55-CT0-K25	2363
C55-CT0-K50	2357
C55-CT0-K75	2340
C55-CT10-K0	2370
C55-CT10-K25	2354
C55-CT10-K50	2342
C55-CT10-K75	2344
C55-CT15-K0	2361
C55-CT15-K25	2348
C55-CT15-K50	2336
C55-CT15-K75	2338

Table 4.4: Fresh concrete unit weight test results of the C65 series.

Concrete Mixes	Fresh concrete unit weight (kg/m ³)
C65-CT0-K0	2372
C65-CT0-K25	2367
C65-CT0-K50	2359
C65-CT0-K75	2341
C65-CT10-K0	2363
C65-CT10-K25	2362
C65-CT10-K50	2342
C65-CT10-K75	2331
C65-CT15-K0	2367
C65-CT15-K25	2350
C65-CT15-K50	2343
C65-CT15-K75	2319

Generally, unit weight decreased as the replacement rate of glass powder with sand increased. This result may be associated with the lower unit weight of glass powder compared to sand.

4.2. Hardened concrete test results

The data taken tables were used in the drawing of **Figures 4.1** and **4.2**. The 28-day compressive strength of 0.45-w/c ratio concrete mix varies between 49.10 MPa and 59.11 MPa. The compressive strength results of 0.45-w/c concrete mixes displayed graphically in **Figure 4.1**.

Table 4.5: Strength results of samples 0.45-w/c ratio concrete mixes.

Concrete Mixes	Average Strength (MPa)
C45-CT0-K0	57,14
C45-CT0-K25	56,50
C45-CT0-K50	57,18
C45-CT0-K75	59,11
C45-CT10-K0	52,19
C45-CT10-K25	51,26
C45-CT10-K50	53,66
C45-CT10-K75	54,85
C45-CT15-K0	50,41
C45-CT15-K25	49,10
C45-CT15-K50	50,78
C45-CT15-K75	54,11

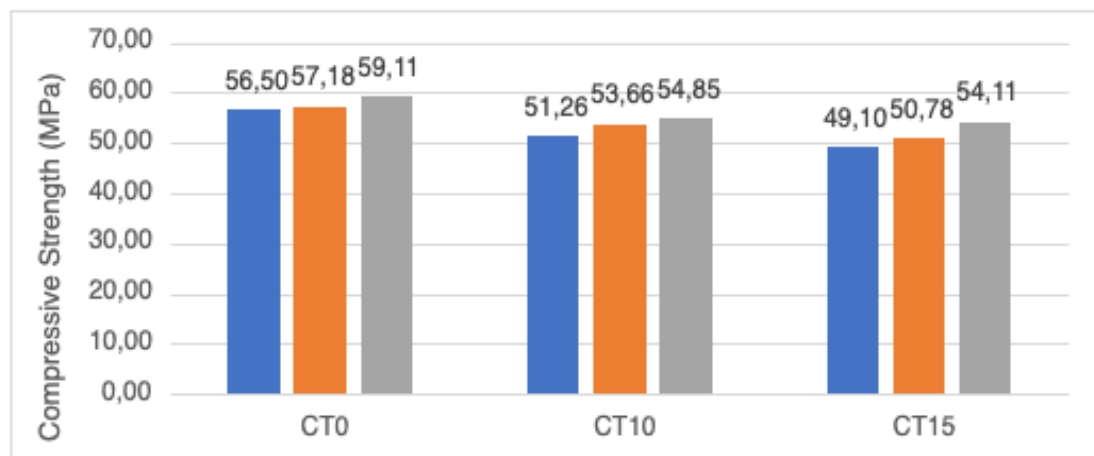


Figure 4.1: Concrete strength results of 0.45-w/c ratio.

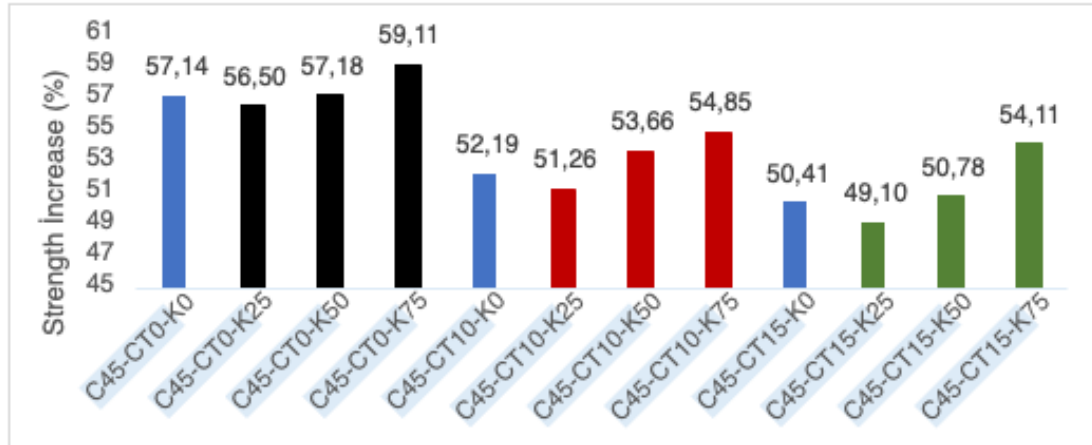


Figure 4.2: Concrete strength increase rates for 0.45-w/c ratio.

In 0.45-w/c ratio concrete mixes, a loss of strength was observed in all mixtures where glass powder was used solely as a cement replacement. Conversely, when used solely as a replacement for sand, a partial decrease was observed at a ratio of 0.25, similar strength was get at a ratio of 0.50, and an increase in strength was observed at a ratio of 0.75. In concretes where the cement replacement ratio was 10%, the strength loss was around 10%, while in cases where 75% of the sand was replaced with glass powder, the strength loss decreased to around 4%. Similarly, in concrete where the glass powder replacement ratio for cement was 15%, the strength loss was around 12%, while in cases where 75% of the sand was replaced with glass powder, the strength loss decreased to around 5%. No improvement in compressive strength was observed when only 25% of the sand was replaced with glass powder.

In 0.45-w/c ratio concrete mixes, while the glass powder ratio was constant, the compressive strength increased as the sand substitution rate changed. While the replacement rate with sand was constant, as the replacement rate with cement increased, the compressive strength decreased.

It has been observed that there is a decrease in compressive strength when glass powder is used as a cement replacement in concrete. The decrease in compressive strength due to the substitution of sand with glass powder could be partially or fully compensated.

Table 4.6: Strength results of samples 0.55-w/c ratio concrete mixes.

Concrete Mixes	Average Strength (MPa)
C55-CT0-K0	49,28
C55-CT0-K25	48,26
C55-CT0-K50	49,16
C55-CT0-K75	49,27
C55-CT10-K0	43,55
C55-CT10-K25	42,83
C55-CT10-K50	42,23
C55-CT10-K75	43,66
C55-CT15-K0	42,58
C55-CT15-K25	40,00
C55-CT15-K50	39,37
C55-CT15-K75	43,69

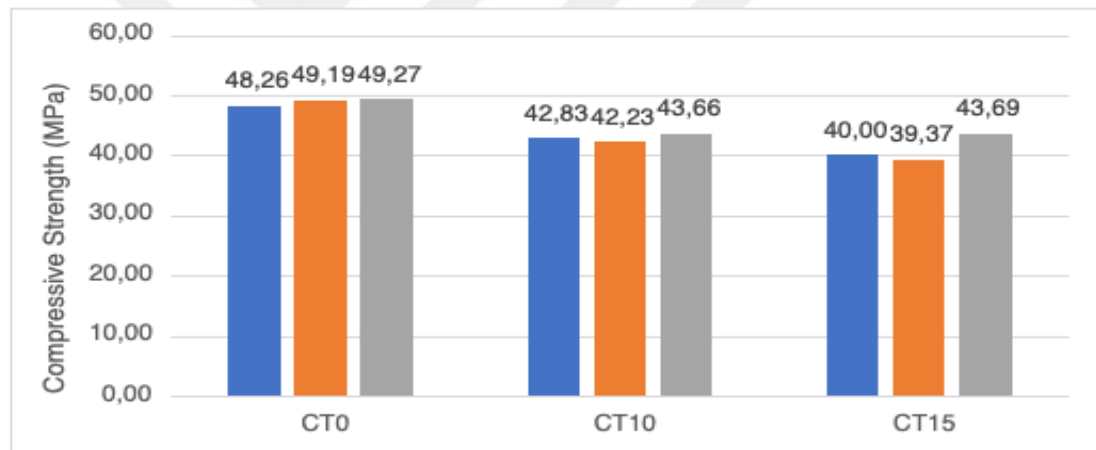


Figure 4.3: Concrete strength of 0.55-w/c ratio.

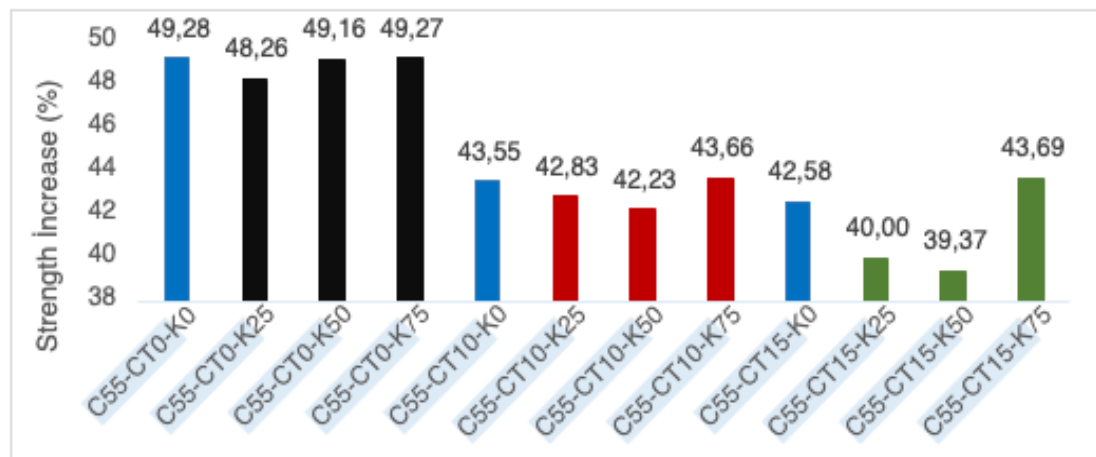


Figure 4.4: Concrete strength increase rates for 0.55-w/c ratio.

In 0.55-w/c ratio concrete mixes, no mixture in which glass powder replaced sand achieved a strength increase compared to the control sample. Only in the concrete coded C55-CT0-K75 was the strength equal to that of the control sample. In concretes with a 10% glass powder replacement, the strength loss could not be mitigated by using glass powder as a replacement for sand. In concretes with a 15% replacement ratio, the strength loss, which was around 19%, decreased to approximately 11% when 75% of the sand was replaced with glass powder. Unlike concretes with a water/cement ratio of 0.45, a decrease in strength was observed in concretes with a 50% sand replacement ratio compared to the control sample of the same class.

In 0.55-w/c ratio concrete mixes, while the glass powder ratio was constant, the compressive strength increased as the sand substitution rate changed. As an exception, compressive strength decreased when passing from C55-CT10-K25 concrete mix to C55-CT10-K50 and from C55-CT15-K25 to C55-CT15-K50. While the replacement rate with sand was constant, as the replacement rate with cement increased, the compressive strength decreased.

Table 4.7: Strength results of samples 0.65-w/c ratio concrete mixes.

Concrete Mixes	Average Strength (MPa)
C65-CT0-K0	40,50
C65-CT0-K25	41,27
C65-CT0-K50	42,60
C65-CT0-K75	41,89
C65-CT10-K0	36,20
C65-CT10-K25	38,07
C65-CT10-K50	36,58
C65-CT10-K75	36,53
C65-CT15-K0	32,37
C65-CT15-K25	33,48
C65-CT15-K50	35,48
C65-CT15-K75	34,09

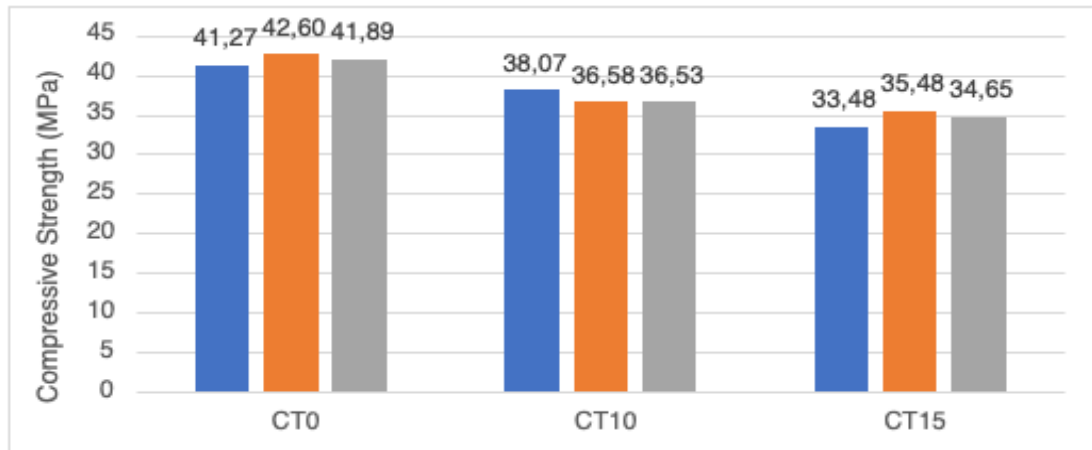


Figure 4.5: Concrete strength of 0.65-w/c ratio.

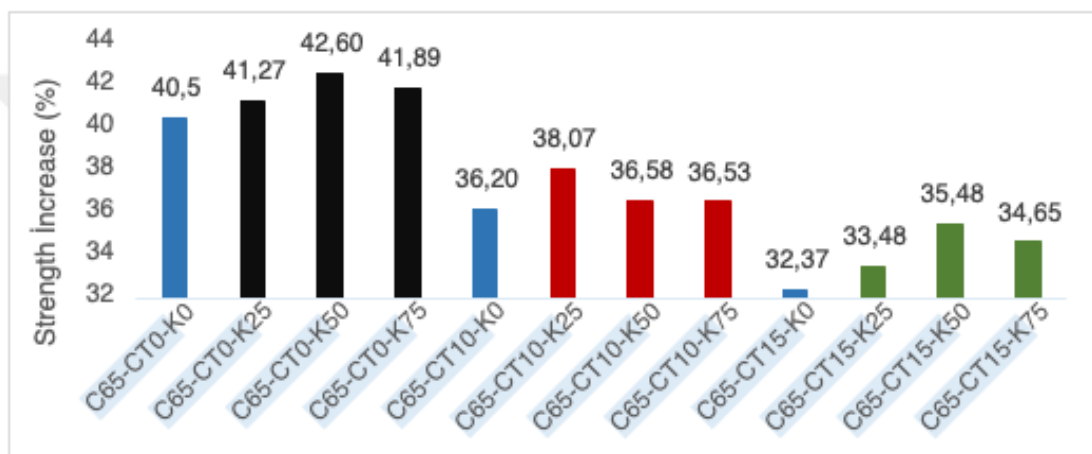


Figure 4.6: Concrete strength increase rates for 0.65-w/c ratio.

In 0.65-w/c ratio concrete mixes, an increase in strength was observed in all cases where glass powder was used solely as a replacement for sand. Unlike concrete with other water/cement ratios, the highest strength in 0.65 ratio concrete was observed in the mixture where 50% of the sand was replaced with glass powder. In concretes with a 10% replacement ratio, the strength loss was around 10%, while the strength loss decreased to 6% when 25% of the sand was replaced with glass powder. In concretes with a 15% replacement ratio, the strength loss was around 20%, while the strength loss decreased to approximately 12% in concretes where 50% of the sand was replaced with glass powder.

5. CONCLUSIONS

- **0.45 w/c Ratio:**

- Using WGP as a cement replacement led to a reduction in compressive strength across all mixtures.
- As a sand replacement, WGP showed varying effects: a decrease at 25% replacement, similar strength at 50%, and an increase at 75%.
- When 75% of sand was replaced with WGP, the strength loss observed in cement replacement (10% and 15%) was significantly mitigated, highlighting the potential of WGP to compensate for strength reduction when used as a sand replacement.

- **0.55 w/c Ratio:**

- No significant increase in strength was achieved in any mixture where WGP replaced sand, except when 75% of sand was replaced, which showed similar strength to the control sample.

- **0.65 w/c Ratio:**

- All mixtures where WGP replaced sand showed an increase in strength, with the highest increase observed at 50% replacement.
- Strength loss observed at 10% and 15% cement replacement ratios was mitigated by the partial replacement of sand with WGP, showing an overall improvement in compressive strength.
- The ideal replacement ratio for sand with WGP varied across different w/c ratios.
- For 0.45 w/c ratio, the best results were obtained at 75% sand replacement.
- For 0.55 w/c ratio, optimal ratios varied, but no clear ideal replacement ratio was identified.
- For 0.65 w/c ratio, the optimal replacement ratio was identified as 25%, with significant improvements in strength observed.

The study illustrates that WGP can be utilized as a viable alternative to cement and sand in concrete mixtures, with different impacts on compressive strength depending on the water-to-cement ratio and the amount of replacement. The key observation is that when WGP is used as a substitute for cement, it often decreases compressive strength. However, this negative effect can be offset or even enhanced when WGP is used as a substitute for sand, especially at greater substitution rates.

Additional research is advised to enhance the composition of the mixtures and gain a comprehensive understanding of the enduring consequences of including WGP in concrete. The encouraging findings suggest that WGP have the capacity to serve as a durable and effective substance in the construction sector, so aiding in waste reduction and the preservation of natural resources.

Ultimately, the study offers a thorough examination of the impacts of WGP on concrete characteristics, thereby facilitating the adoption of more eco-friendly and cost-effective methods for producing concrete. The incorporation of waste glass powder (WGP) into concrete mixes is in line with worldwide initiatives aimed at promoting sustainable construction and preserving resources, making it a significant field for ongoing research and implementation.

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BIOGRAPHY

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APPENDICES

Table 1: Results of sample C45-CT0-K25 Concrete Mix.

C45-CT0-K25		
Sample 1	MPa	57,03
Sample 2	MPa	54,93
Sample 3	MPa	57,55
Average	MPa	56,50
C. of Variation	(-)	2,45
Slump	mm	140
Unit Weight	kg/m ³	2361

Table 2: Results of sample C45-CT0-K50 Concrete Mix.

C45-CT0-K50		
Sample 1	MPa	59,30
Sample 2	MPa	55,26
Sample 3	MPa	56,98
Average	MPa	57,18
C. of Variation	(-)	3,55
Slump	mm	210
Unit Weight	kg/m ³	2363

Table 3: Results of sample C45-CT0-K75 Concrete Mix.

C45-CT0-K75		
Sample 1	MPa	58,27
Sample 2	MPa	60,96
Sample 3	MPa	58,09
Average	MPa	59,11
C. of Variation	(-)	2,72
Slump	mm	220
Unit Weight	kg/m ³	2348

Table 4: Results of sample C45-C10-K25 Concrete Mix.

C45-CT10-K25		
Sample 1	MPa	50,21
Sample 2	MPa	51,57
Sample 3	MPa	51,99
Average	MPa	51,26
C. of Variation	(-)	1,82
Slump	Mm	170
Unit Weight	kg/m ³	2342

Table 5: Results of sample C45-CT10-K50 Concrete Mix.

C45-CT10-K50		
Sample 1	MPa	55,33
Sample 2	MPa	51,63
Sample 3	MPa	54,02
Average	MPa	53,66
C. of Variation	(-)	3,50
Slump	mm	110
Unit Weight	kg/m ³	2345

Table 6: Results of sample C45-CT10-K75 Concrete Mix.

C45-CT10-K75		
Sample 1	MPa	55,48
Sample 2	MPa	55,87
Sample 3	MPa	53,21
Average	MPa	54,85
C. of Variation	(-)	2,62
Slump	mm	215
Unit Weight	kg/m ³	2332

Table 7: Results of sample C45-CT15-K25 Concrete Mix.

C45-CT15-K25		
Sample 1	MPa	48,16
Sample 2	MPa	50,88
Sample 3	MPa	48,26
Average	MPa	49,10
C. of Variation	(-)	3,14
Slump	mm	150
Unit Weight	kg/m ³	2340

Table 8: Results of sample C45-CT15-K50 Concrete Mix.

C45-CT15-K50		
Sample 1	MPa	50,93
Sample 2	MPa	49,26
Sample 3	MPa	52,16
Average	MPa	50,78
C. of Variation	(-)	2,87
Slump	mm	185
Unit Weight	kg/m ³	2334

Table 9: Results of sample C45-CT15-K75 Concrete Mix.

C45-CT15-K75		
Sample 1	MPa	51,65
Sample 2	MPa	51,54
Sample 3	MPa	56,56
Average	MPa	54,11
C. of Variation	(-)	6,42
Slump	mm	205
Unit Weight	kg/m ³	2348

Table 10: Results of sample C55-CT0-K25 Concrete Mix.

C55-CT0-K25		
Sample 1	MPa	46,75
Sample 2	MPa	48,79
Sample 3	MPa	49,25
Average	MPa	48,26
C. of Variation	(-)	2,76
Slump	mm	170
Unit Weight	kg/m ³	2363

Table 11: Results of sample C55-CT0-K50 Concrete Mix.

C55-CT0-K50		
Sample 1	MPa	50,51
Sample 2	MPa	47,79
Sample 3	MPa	49,19
Average	MPa	49,16
C. of Variation	(-)	2,77
Slump	mm	180
Unit Weight	kg/m ³	2357

Table 12: Results of sample C55-CT0-K75 Concrete Mix.

C55-CT0-K75		
Sample 1	MPa	48,85
Sample 2	MPa	48,63
Sample 3	MPa	50,34
Average	MPa	49,27
C. of Variation	(-)	1,89
Slump	mm	155
Unit Weight	kg/m ³	2340

Table 13: Results of sample C55-CT10-K25 Concrete Mix.

C55-CT10-K25		
Sample 1	MPa	42,33
Sample 2	MPa	42,91
Sample 3	MPa	43,25
Average	MPa	42,83
C. of Variation	(-)	1,09
Slump	mm	165
Unit Weight	kg/m ³	2354

Table 14: Results of sample C55-CT10-K50 Concrete Mix.

C55-CT10-K50		
Sample 1	MPa	42,41
Sample 2	MPa	41,57
Sample 3	MPa	42,72
Average	MPa	42,23
C. of Variation	(-)	1,41
Slump	mm	170
Unit Weight	kg/m ³	2342

Table 15: Results of sample C55-CT10-K75 Concrete Mix.

C55-CT10-K75		
Sample 1	MPa	42,89
Sample 2	MPa	43,95
Sample 3	MPa	44,15
Average	MPa	43,66
C. of Variation	(-)	1,55
Slump	mm	215
Unit Weight	kg/m ³	2344

Table 16: Results of sample C55-CT15-K25 Concrete Mix.

C55-CT15-K25		
Sample 1	MPa	39,51
Sample 2	MPa	40,76
Sample 3	MPa	39,74
Average	MPa	40,00
C. of Variation	(-)	1,66
Slump	mm	165
Unit Weight	kg/m ³	2348

Table 17: Results of sample C55-CT15-K50 Concrete Mix.

C55-CT15-K50		
Sample 1	MPa	38,77
Sample 2	MPa	39,32
Sample 3	MPa	40,02
Average	MPa	39,37
C. of Variation	(-)	1,59
Slump	mm	170
Unit Weight	kg/m ³	2336

Table 18: Results of sample C55-CT15-K75 Concrete Mix.

C55-CT15-K75		
Sample 1	MPa	43,15
Sample 2	MPa	42,32
Sample 3	MPa	45,59
Average	MPa	43,69
C. of Variation	(-)	3,89
Slump	mm	245
Unit Weight	kg/m ³	2338

Table 19: Results of sample C65-CT0-K25 Concrete Mix.

C65-CT0-K25		
Sample 1	MPa	40,97
Sample 2	MPa	41,89
Sample 3	MPa	40,95
Average	MPa	41,27
C. of Variation	(-)	1,30
Slump	mm	190
Unit Weight	kg/m ³	2367

Table 20: Results of sample C65-CT0-K50 Concrete Mix.

C65-CT0-K50		
Sample 1	MPa	43,31
Sample 2	MPa	43,14
Sample 3	MPa	41,35
Average	MPa	42,60
C. of Variation	(-)	2,55
Slump	mm	215
Unit Weight	kg/m ³	2359

Table 21: Results of sample C65-CT0-K75 Concrete Mix.

C65-CT0-K75		
Sample 1	Mpa	41,18
Sample 2	Mpa	42,87
Sample 3	Mpa	41,61
Average	Mpa	41,89
C. of Variation	(-)	2,10
Slump	mm	85
Unit Weight	kg/m ³	2341

Table 22: Results of sample C65-CT10-K25 Concrete Mix.

C65-CT10-K25		
Sample 1	MPa	38,07
Sample 2	MPa	38,11
Sample 3	MPa	38,03
Average	MPa	38,07
C. of Variation	(-)	0,11
Slump	mm	180
Unit Weight	kg/m ³	2362

Table 23: Results of sample C65-CT10-K50 Concrete Mix.

C65-CT10-K50		
Sample 1	MPa	35,84
Sample 2	MPa	37,05
Sample 3	MPa	36,85
Average	MPa	36,58
C. of Variation	(-)	1,77
Slump	mm	140
Unit Weight	kg/m ³	2342

Table 24: Results of sample C65-CT10-K75 Concrete Mix.

C65-CT10-K75		
Sample 1	MPa	36,03
Sample 2	MPa	37,00
Sample 3	MPa	36,55
Average	MPa	36,53
C. of Variation	(-)	1,45
Slump	mm	65
Unit Weight	kg/m ³	2331

Table 25: Results of sample C65-CT15-K25 Concrete Mix.

C65-CT15-K25		
Sample 1	MPa	33,27
Sample 2	MPa	33,20
Sample 3	MPa	33,96
Average	MPa	33,48
C. of Variation	(-)	1,25
Slump	mm	200
Unit Weight	kg/m ³	2350

Table 26: Results of sample C65-CT15-K50 Concrete Mix.

C65-CT15-K50		
Sample 1	MPa	35,73
Sample 2	MPa	34,98
Sample 3	MPa	35,72
Average	MPa	35,48
C. of Variation	(-)	1,21
Slump	mm	190
Unit Weight	kg/m ³	2343

Table 27: Results of sample C65-CT15-K75 Concrete Mix.

C65-CT15-K75		
Sample 1	MPa	34,78
Sample 2	MPa	35,07
Sample 3	MPa	34,09
Average	MPa	34,65
C. of Variation	(-)	1,45
Slump	mm	110
Unit Weight	kg/m ³	2319

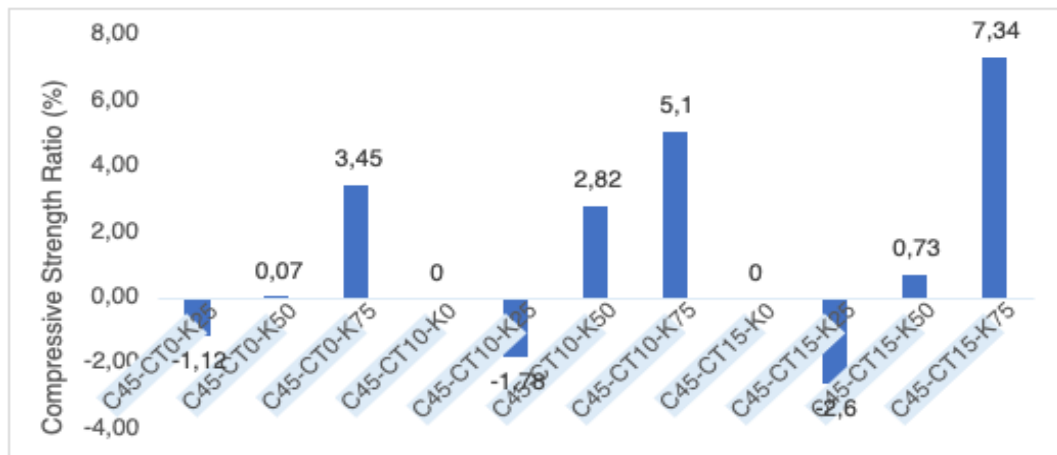


Figure 1: Results of Compressive Strength Ratio at 0.45-w/c.

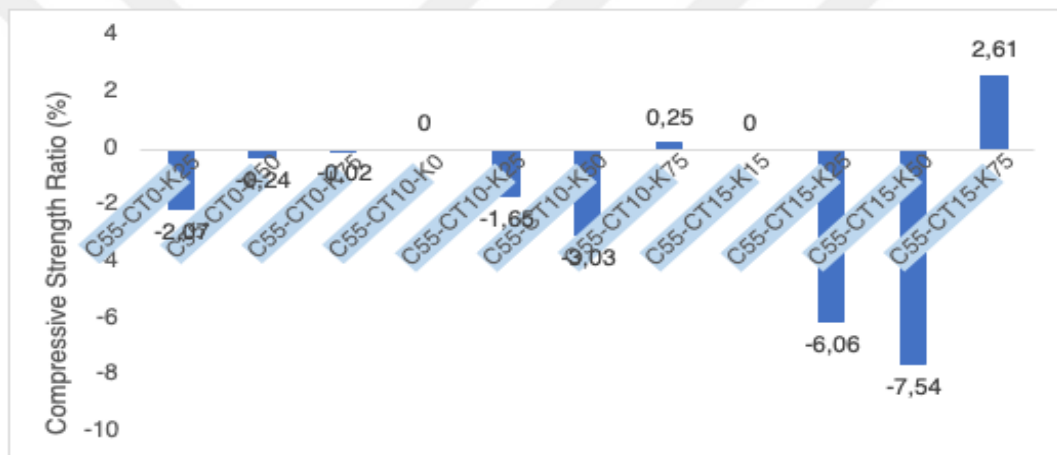


Figure 2: Results of Compressive Strength Ratio at 0.45-w/c.

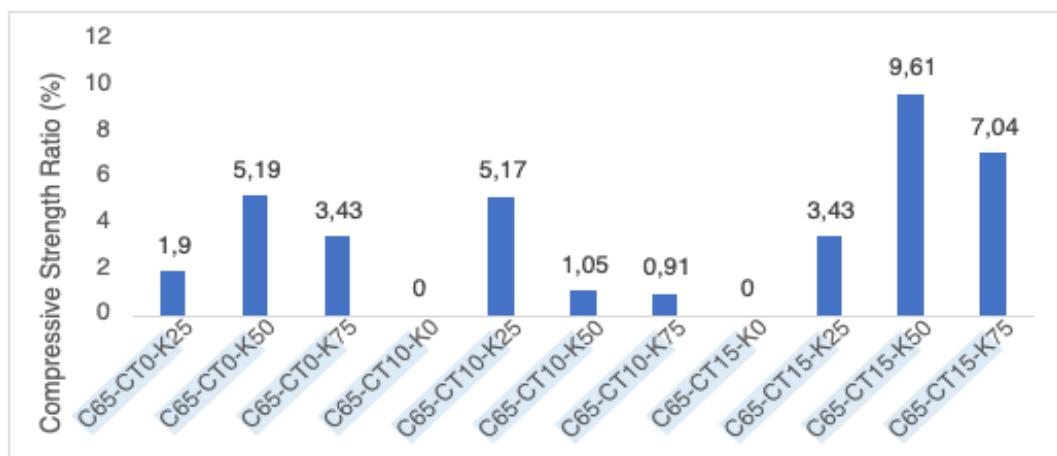


Figure 3: Results of Compressive Strength Ratio at 0.65-w/c.



Figure 4: Concrete Samples.



Figure 5: Concrete Test Pres.



Figure 6: Samples Unit weight.



Figure 7: Concrete slump value.



Figure 8: Concrete Molds.



Figure 9: Covered Concrete Molds.



Figure 10: Curing Pool.



Figure 11: Concrete mixer.



Figure 12: Naturel and Crushed sand.



Figure 13: Lab oven.