Kaunas University of Technology

Faculty of Civil Engineering and Architecture

Various Types of Waste Glasses Utilization in Portland Cement and Properties Research

Master's Final Degree Project

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Construction Structures and Products Engineering (6211EX008)

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Summary

The circular economy is gaining more and more popularity in the field of construction. One of the unexploited niches could be the use of the municipal waste stream in the production of construction products, which would allow to reduce not only the amount of waste thrown into landfills, but also allow to save a significant amount of energy, that could reduce the amount of greenhouse gases (CO_2) emitted into the environment. Waste glass extracted from the municipal waste stream could be an excellent material that could be used in the production of a new generation of binder, which could be used to produce various types of concrete. Waste glass has unique properties that not only go well with Portland cement, but also make it possible to obtain concrete products with better physical, mechanical and durability properties. The experimental study examined two types of waste glass extracted from the municipal waste stream: unwashed and washed. In the research the glass powder were prepared from glass shards by milling process, and the microstructure of waste glass powder was analyzed by scanning electron microscope. The influence of waste glass on Portland cement binder processes was examined by semi-adiabatic calorimetry test method, the influence of ground glass on concrete density, compressive strength, porosity was determined, and the resistance of concrete with ground glass to surface freezing was determined. During the study, a binder was developed that used about 150 kg/m^3 of Portland cement and utilized up to 1000 kg/m^3 of waste glass powder from municipal waste stream. A new generation of binder can be produced with the newly developed concrete, which has the compressive strength vary from 90 MPa to 160 MPa. These values could correspond to the strengths of high performance and ultra-high performance concrete, and would be characterized by a particularly high resistance to salt-scaling. Master‘s thesis consists of 60 pages of text, 10 tables, 50 figures, 42 references.

Siavash Salehi. Įvairių Rūšių Stiklo Atliekų Panaudojimas Portlandcementyje ir Savybių Tyrimai. Magistro baigiamasis projektas / doc. Dr. Evaldas Šerelis; Kauno technologijos universitetas, Statybos ir architektūros fakultetas.

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Santrauka

Žiedinė ekonomika įgauna vis didesnį populiarumą statybos srityje. Viena iš neišnaudotų nišų galėtų būti komunalinių atliekų srauto panaudojimas gaminant statybinius produktus, tai leistų sumažinti ne tik į sąvartynus išmetamų atliekų kiekį tačiau taip pat leistų sutaupyti ir ženklų kieki energijos, o tai sumažintų į aplinką išmetamų šiltnamio efektą sukeliančių dujų (CO_2) kiekį. Maltas stiklas išgautas iš komunalinių atliekų srauto galėtų būti puiki medžiaga, kuri galėtų būti panaudota gaminant naujos kartos rišiklį, su kuriuo būtų galima gaminti įvairių rūšių betonus. Maltas stiklas pasižymi unikaliomis savybėmis, kuri ne tik puikiai dera su portlandcemenčiu tačiau taip leidžia išgauti geresnių fizikinių, mechaninių ir ilgalaikiškumo savybių betoninius gaminius. Eksperimentiniame tyrime buvo nagrinėtas dviejų rūšių maltas stiklas išgautas iš komunalinių atliekų srauto: neplautas ir išplautas. Tyrimuose parodyta malto stiklo parengimo metodika, atlikta plauto ir neplauto malto stiklo skenuojančio elektroninio mikroskopo analizė, nagrinėta malto stiklo įtaka portlandcemenčio rišimosi procesams, nustatyta malto stiklo įtaka betono tankiui, gniuždymo stipriui, poringumui, nustatytas betono su malto stiklo atsparumas paviršiniam šaldymui. Tyrimo metu buvo sukurtas rišiklis, kuriame panaudota apie 150 kg/m^3 portlandcemenčio ir utilizuota iki 1000 kg/m^3 malto stiklo atliekos išgautos ir komunalinių atliekų srauto. Su nauju sukurtu rišikliu galima pagaminti naujos kartos betoną, kurio gniuždymo stipris gali kisti nuo 90 MPa iki 160 MPa, tai atitiktų stipriojo ir ypač stipraus betono stiprius, bei pasižymėtų ypatingai dideliu atsparumu šalčio ardomajam poveikiui. Baigiamojo darbo apimtis – 60 psl., 10 lentelių, 50 paveikslų, 42 literatūros šaltinis.

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List of Abbreviation

MSW - Municipal solid waste

SDG - Sustainable Development Goal

SEM - Scanning electron microscope

EDX - Energy Dispersive X-Ray

WGP - Waste glass powder

SSA - Specific surface area

ASR - Alkali-Silica Reaction

OPC - Ordinary performance concrete

UHPC - Ultra-high performance concrete

SF - Silica fume

LCD - Liquid crystal display

LGP - LCD waste glass powder

XRD - X-ray diffraction

HSC - High-Strength Concrete

GP - Glass powder

TOC - Total organic carbon

NS - Nano silica

MS - Micro silica

FEG - Field emission gun

EDS - Energy-dispersive X-ray spectrometer

INTRODUCTION

Every day, technological developments make daily living better. We attempt to use the raw resources around us to have a better life and discard waste into it since each technology requires certain elements from the environment. We require energy to produce materials and goods, which necessitate the use of fuel and other environmental resources. Higher fuel use results in more CO_2 emissions, which is a serious threat to the environment and global warming. We must treat waste because it is not permitted to leave it in the wild where it will get polluted. Thus, it follows that we should consume energy. We should concentrate on sustainable development Plan to decrease all raw materials consumption and waste generated quantity Sustainable development is a concept and a new way of doing things that meets today's demands while also preserving the environment for the needs of future generations, and it is also known as "sustainable development".

One of the biggest examples is the cement manufacturing companies, which their emission of CO_2 gases is significant. A majority of glass waste from industries is not processed or recycled which causes serious environmental problems. We can reduce such adverse environmental effects by making more eco-friendly materials.

European commission website, ec.europa.eu, shows that 35% of all European Union trash can be attributed to the construction industry. The EU's waste rules target to promote the new method, circular economy, through maximising the recycling of trash. It also seeks to reduce municipal garbage landfilling to 10% by 2035. This makes it clear that recycling waste glass from landfills would be a better choice than using it as a raw materials.

Because glass is amorphous, it may produce a pozzolanic reaction if used in the cement base binder. Glass may theoretically be substituted for cement by some parts if it is crushed into a fine powder. A significant amount of Na_2O is found in glass powder, which could cause an alkali-silica reactions. We can identify glass powder by the following contentious truth. It contains big amount of SiO_2, which is considered as amorphous. Water and CaO can bond with it to produce low basicity C–S-H. It is unclear how glass could impact concrete's microstructure due to its high alkali level. Many experts have discussed these facts. Recycling waste glass for construction reduces greenhouse gas emissions and helps alleviate landfill shortages.

Aim of work: Research the characteristics of Portland cement base binder by utilizing waste glass micro-filler from municipal dumpsites and determine the hydration, physical and mechanical impacts.

Objectives:

1. To make municipal waste glass into a useful microfiller and use it as a raw materials.
2. Learn how Portland cement hydration is affected by waste glass micro-filler.
3. Analyze the waste glass micro-filler effects on the physical and mechanical parameters of cement.
4. Research on the impact of salt-scaling concrete made from powdered waste glass.

1. LITERATURE REVIEW

As a result, the generated municipal waste has accelerated steadily around the globe due to urbanization, trade expansion and population growth[1]. For the disposal of MSW, landfilling remains normal, especially in emerging and impoverished nations [2]. The most crucial element of municipal waste is household trash, which is consist of all kind of plastics, food wastes, paper, bottles, jars, metals, remain foods and etc, etcarbage contains a sizable quantity of animal waste, including bones and pieces of meat. Fruit peels and veggies are included as well. These materials are referred to as wet wastes. Books, cardboards, old books, newspapers, paper, and paper used for wrapping make up a sizable component of the garbage found at landfills. Other types of garbage include toys, plates, mugs, tin cans, and wooden sticks[3]. Open dumps produce a harmful liquid known as landfill leachate because of the moisture level in the MSW and seasonal parameters[1]. This landfill leachate may penetrate the soil and contaminate groundwater.

Statistics, from the Eurostat data website, indicate that since 2013, more waste glass has been produced annually (Fig.1). On the other hand, the volume of recycled glass that has been treated, is increased as well, but the difference between these two parameters has remained approximately constant. Trash glass includes all sorts of glass produced in the municipality, including household waste glass (bottles, jars, etc.), industrial waste glass and construction waste glass (demolishing old buildings). Municipal solid waste (MSW) dumpsites contain a significant amount of glass, including drinking glasses, pickle and paste jars, wine bottles, cosmetic containers, and containers for additives and other products.[4].

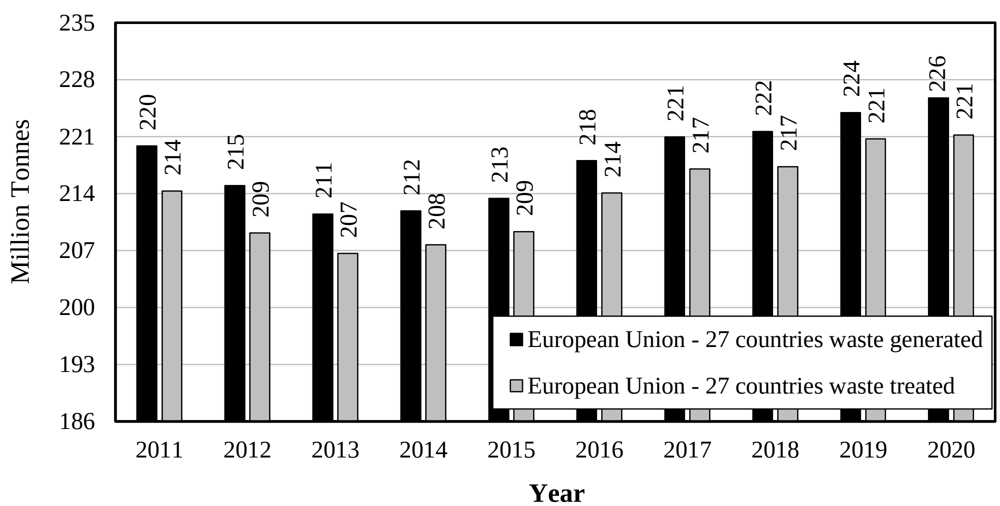

Fig. 1. Eurostat statistic generated and treated of waste glass in Europe*[4]*

Eurostat data shows that the Lithuanian section saw an increase in waste each year, but a decrease in treated waste glass since 2018 (Fig.2). There is a huge difference between these two parameters. This distinction indicates that we lost a significant quantity of waste resources that were or might be reused in the past, went beyond the circle of consumption, and all of this trash was dumped, which is bad for the environment. However, due to the waste glass produced, additional raw materials are consumed every year.

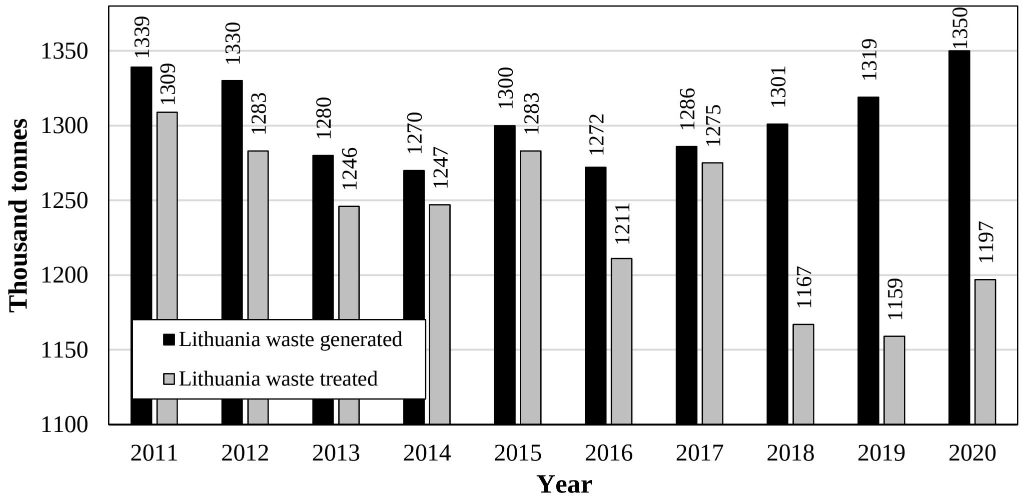

Fig. 2. Statistic of generated and treated waste glass in Lithuania*[4]*

The Sustainable Development Goals (SDGs), a global plan for reducing poverty and protecting the environment, were established by the United Nations in 2015. In 2030, they further want to provide peace and prosperity to everybody. There must be a balance between environmental, social, and economic development, as shown by the 17 goals of sustainable development. These three factors all influence one another[5].

Fig. 3. Sustainable development goals*[5]*

Goal 12 demonstrates the need to modify how resources are used in order to impact the environment and increase economic and sustainability at the same time. This goal promotes responsible consumption and production. Two essential components of achieving this aim are how to manage resources effectively and how to get eliminate of pollution and hazardous waste. By encouraging businesses and industries to minimize and recycle waste, and assisting developing countries in switching, by 2030, to more sustainable consumption patterns[5].

According to the statistic of the Europe Union and Lithuania (Fig.4) from the Eurostat database[4], the indicator counts the amount of municipal garbage that is recycled and divides that amount by the total amount of municipal waste generated over the years. Composting, anaerobic digestion, and material recycling are all forms of recycling. Municipal garbage is mostly created by homes; however, it may also contain wastes of a similar nature produced by businesses and public organizations that the city's municipal government gathered all.

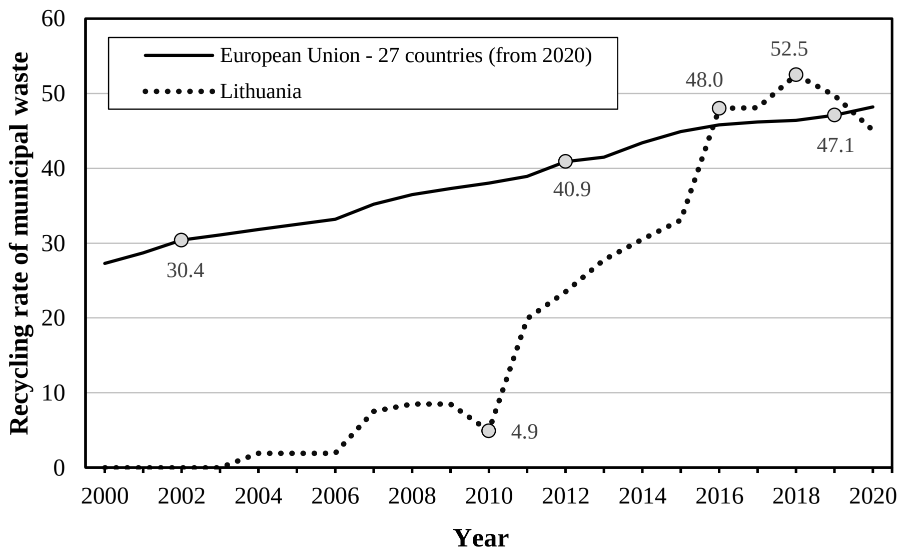

Fig. 4. Recycling rate of municipal waste*[4]*

In the other goal, 13-climate action, every country impacted by climate change, for instance, had a 50% increase in greenhouse gas emissions since 1990. Issues with climate change cost hundreds of billions of dollars every year and will do so unless anything is done to tackle it. They should develop a strategy to stop CO2 emissions and, therefore, global warming. Additionally, the human costs of geophysical catastrophes resulted 1.3 million fatalities, 4.4 billion injuries in between 1998 and 2017[5].

The figure (Fig.5) shows that greenhouse gas emissions fall each year in European Union nations, although Lithuania's position is different. It first rose quickly, dropped off dramatically until 2009, and is now growing once more.

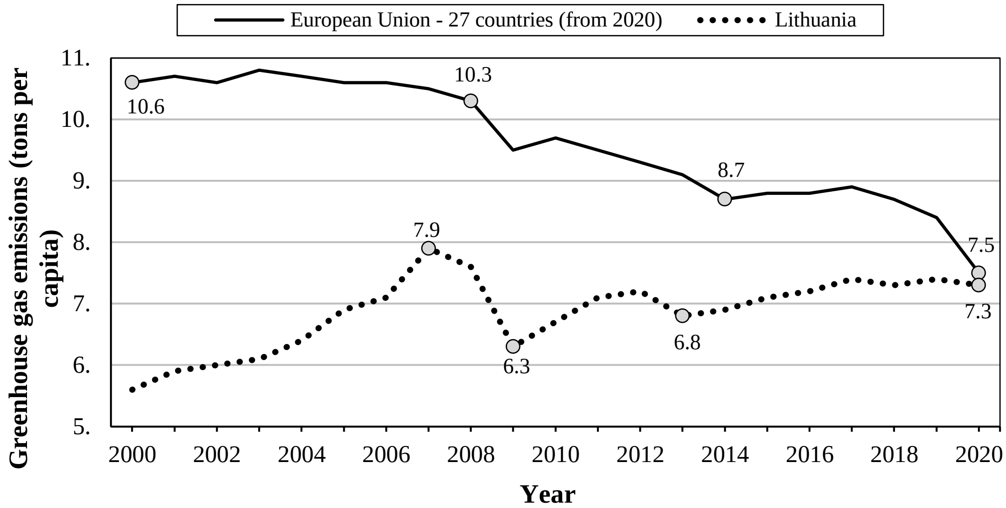

Fig. 5. Greenhouse gas emissions per capita*[4]*

Industry, innovation and infrastructure, goal 9, indicate that invest on infrastructure investing in infrastructure and innovation can help economic growth and These days more than 50% of world's population moving to the cities and it effects to massively increase the transit, renewable energy, new industries, information and communication technologies. Energy efficiency is important for long-term solution. We should consider not only the economic, but also the environmental problems too for long-term point of view. There are so many areas which they may help sustainable development such as sustainable industries, research budget and development[5].

1.1. Glass manufacture procedure

This is a very basic explanation of the manufacturing process for new glass. All the materials are mixed and heated to the point of melting. Refining and then rapidly cooled to preserve its liquid clarity characteristic. Limestone and soda ash, which are both made of natural elements, are additional components. The process of making new glass uses a lot of water and energy since it must be heated to 1700 degrees Celsius, the temperature at which sand melts.

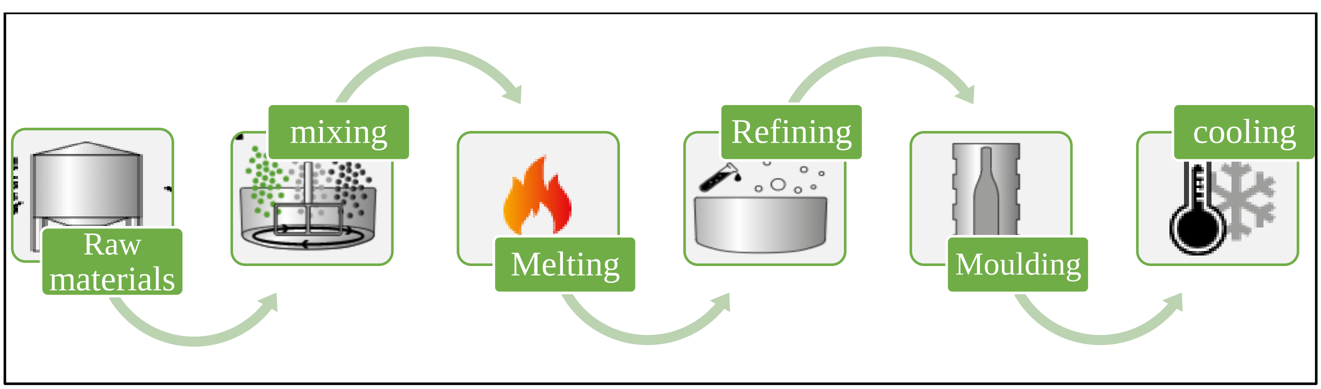

Fig. 6. Glass manufacture procedure (made by author)

A few disadvantages to this process also exist. A hazardous gas called sulfur oxides is created when the temperature is raised and the glass melts. Nitrogen oxides may be released if the heating method uses gas combustion. The manufacture of glass is not environmentally friendly, despite what many people believe[6].

One approach is to recycle used glass. Glass may be recycled and utilized to create new products without losing any of its quality. A new product may be produced with less energy if glass is used in place of sand. Less sand from the ecosystem is also required, which reduces the reducing humans' impacted on cities. Another benefit of using glass in place of sand in the process is that productivity will rise. The following may be saved for every 1,000 tons of recycled glass:

1. Thousand tons of waste eliminated from landfill
2. Saving 1.200 tons virgin materials
3. Reduce CO2 emissions by 314 tons
4. Save 345.000 kWh of using energy

which is significant for environment[6].

In order to solve challenges and conserve energy, recycled and solid waste materials are being used more and more in concrete. Engineers are now concerned with the sustainability of concrete as a building material to consider the significance environmental protection and resource conservation. Additional research into green concrete technology is inspired by the improvement in concrete properties and the environmental benefits of using waste materials. Utilizing glass trash would promote sustainable waste management, preserving environment and cementitious products and assisting in environmental protection. Many investigations have been done on using used glass to substitute for cement and aggregate[7].

You can make a product that is more environmentally friendly by replacing some of the cement with waste powder in concrete mortars. Because waste glass powder can be used in concrete mortars and concrete, it is less expensive and more environmentally-friendly than cement. It also reduces the product's density. Mixing ground-up waste powder with cement in concrete can affect the structure and the shape of the ultra-high performance concrete's microstructure. If the aggregate size of the waste powder is identical to that of cement, it can assist this structure by forming calcium-silicate hydrate (C-S-H) via a favorable reaction during cementing.[8].

1.2. Main properties and prepration of waste glass

Table 1 lists the results from SEM (Scanning electronic microscope) and EDX, which are both analytical methods that analyze the physical properties and formulas of waste glass material. SiO_2 had the greatest content (71.30–73.04%), followed by Na_2O and K_2O. According to the color of the trash glasses, a little change in their chemical characteristics was found. Additionally, without concentrate on the color, the majority grain form was angular, which, in our opinion, has a negative impact on their workability[9].

Table 1. Chemical composition of waste glass[9]

Type	Emerald green glass (%)	Amber glass (%)	Flint glass (%)
SiO_2	71.300	72.10	73.04
Al_2SO_3	2.180	1.74	1.81
$Na_2O + K_2O$	13.07	14.11	13.94
CaO + MgO	12.18	11.52	10.75
SO_3	0.053	0.13	0.22
Fe_2O_3	0.596	0.31	0.04
Cr_2O_3	0.44	0.01	–
Grain shape	Angular	Angular	Angular

Fig.7 shows the impact of grniding on the waste glass powder distribution line of particle, and Table 2 lists the typical particle size as and its relationship with grinding time. From Fig.7 we can understand that there is only one peak that can be seen for the produced waste glass powder, and that peak gradually moves to the left as the grinding time increases. It is implied that waste glass powder particles are refined since the mean particle size of continuously decreases and the particle distribution tends toward normal distribution. The refining effect is more pronounced the longer the milling period is. Table 2 shows that wet milling action greatly reduces the d_{50} and d_{90} for waste glass powder while little change is made to the d_{10} value[10].

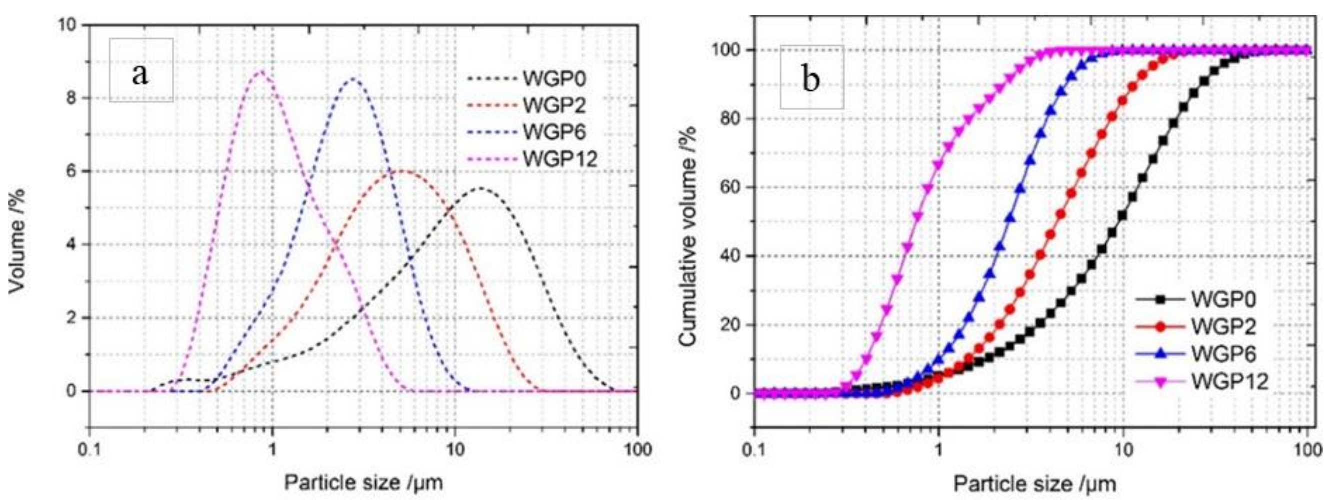

Fig. 7. The particle size distribution of WGP: a) Particle size distribution and b) cumulative volume.[10]

Table 2. Characteristic WGP ground particle size for different duration *[10]*

Waste glass powder Name	Grinding duration (min)	d_{10}	d_{50}	d_{90}
WGP0	0	2.16	10.50	60.34
WGP2	20	1.62	4.96	13.00
WGP6	60	1.14	2.71	5.53
WGP12	120	0.46	0.90	2.51

The morphology of both wet-milled and received waste glass powder is shown in Fig.3. There are no spherical WGP0 particles present, and the particles have smooth surfaces, sharp edges, and huge length-to-diameter ratios. The particles range in size from 5 to 20 μm. The particle size is significantly decreased and the form of the particles improves after 20 minutes of wet grinding. In comparison to WGP2, it is evident that WGP6 and WGP12 contain more tiny particles in the 0.5–5 μm range and superior dispersancy, which will be demonstrated in the following[10].

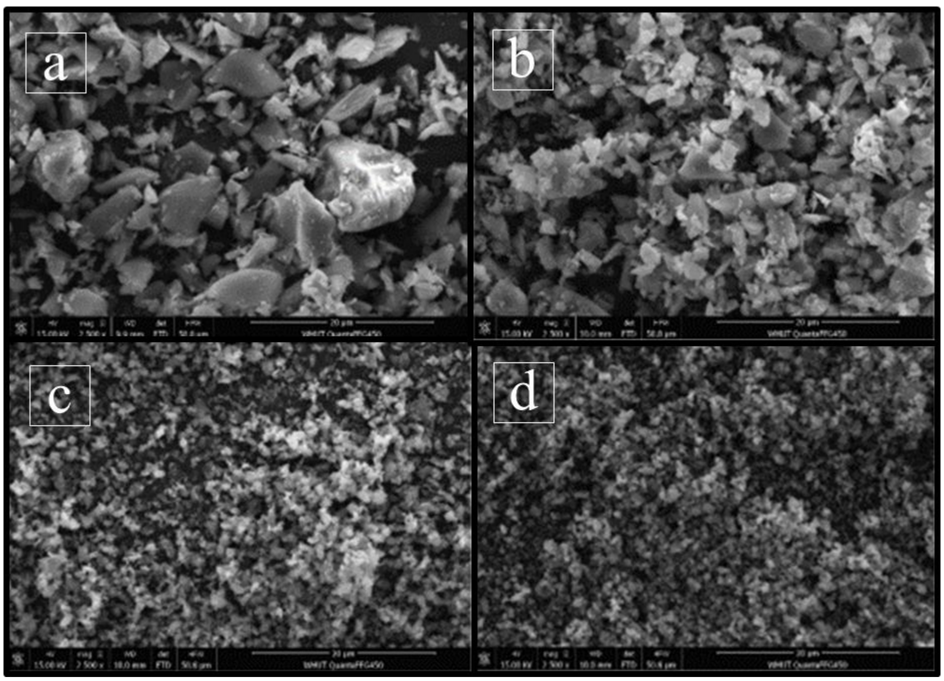

Fig. 8. Morphology of waste glass powder: a) WGP at 0 min b) WGP at 20 min c) WGP at 60 min d) WGP at 120 min.*[10]*

Particle size and logarithm milling time have a good linear connection, according to an experiment from the Blaine apparatus (Fig.10). Another fact is that there is a linear link between specific surface area (SSA) and double logarithm[11].

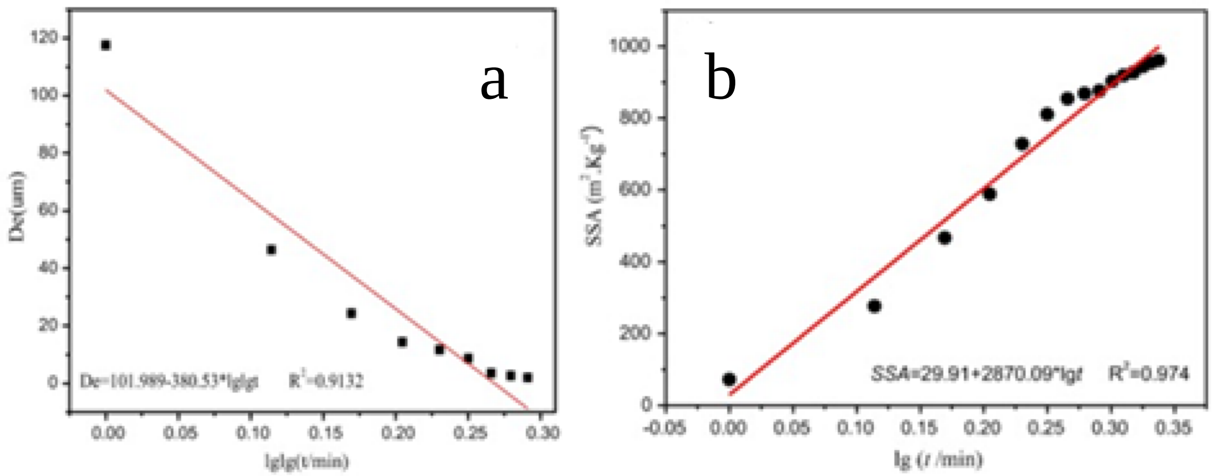

Fig. 9. Glass powder grinding for the different time: a) Size particle b) Specific surface area *[11]*

1.3. Cement hydration process

The important parameter for the property the building of cement-based material properties as a function in time is the hydration reaction between water and cement. To understand the kinetics and stages of these reactions, it is essential to know the details. Monitoring the concrete's temperature over time can help determine the strength of concrete. Temperature can affect the rate at which cement hydrates. This is a good tool to monitor the process. The cement temperature after mixing with water has five different periods, each with a time period as shown in Fig.10[12].

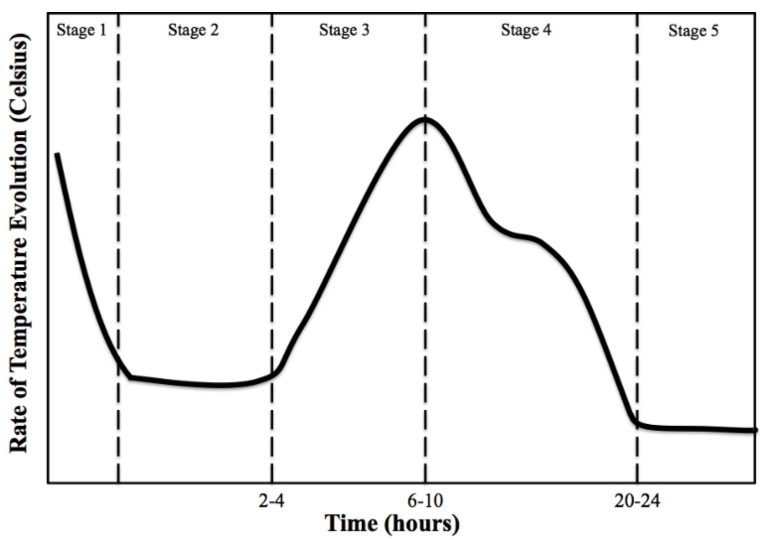

Fig. 10. Five different stages of cement hydration process associated with heat release and Time. Stages are: 1) Mixing the cement with water, 2) Dormancy, 3) Acceleration of hydration, 4) Deceleration of the hydration, 5) Densification of paste *[12]*

Table 3 lists the common names and abbreviations for the mineral bonds that are involved in hydration. Tri-calcium silicates (C_3S) and di-calcium silicates (C_2S) are the two most significant chemical components in the Portland cement paste during the hydration process. There is more C_3S than

C_2S in the cement and water mixture; the amounts range from 50% to 70% for tri-calcium silicates and from 15% to 30% for di-calcium silicates[12], [13]. Due to its hexagonal shape, C_3S may respond significantly more quickly than C_2S when water first appears and while preparing to create a structure. As a result, its structure facilitates the process by allowing water to be absorbed.[13].

When H_2O is added, ettringite is formed initially and then CH precipitates. These two factors combine to create a morphology that resembles a crystalline structure, which can create a wall around cement particles to keep water away from it and remain fully unaffected.[13]. As a result, the temperature of the mixture rises during Stage 1 (Fig.11). Concrete's strength and endurance against ASR is not affected by the strength of these products. Tri-calcium aluminate reacts with water to create cubic (C_3AH_6) and hexagonal (C_4AH_{12}), crystalline structures. (Equation 1)

$$3(C_3A) + 6(H_2O) \rightarrow 3Ca.Al_2O_3.6H_2O\text{(Ettringite)} \quad (1)$$

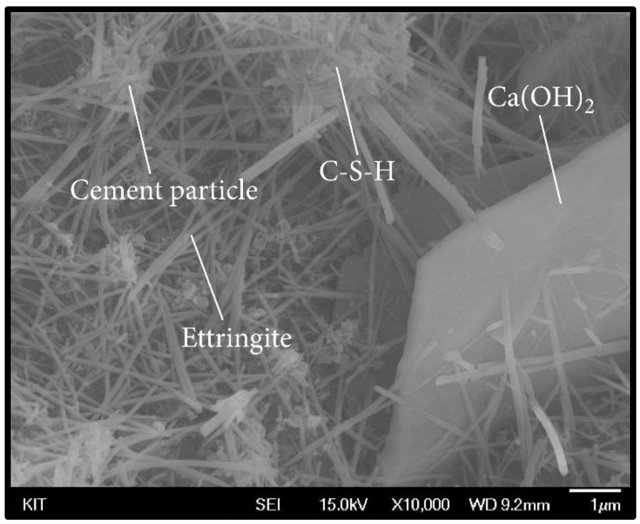

Fig. 11. SEM image of ordinary performance concrete (OPC) after 3 days *[14]*

The microstructure of OPC after three days is seen in the SEM picture in Fig.11. During a usual OPC hydration, C-S-H and Calcium hydroxide were produced, but the darker areas of the picture show that there was also a significant quantity of air or water present in the pores.

Table 3. Abbreviated cementitious compounds*[12]*

Compound	Abbreviated Formula	Actual Formula
Tri-Calcium Silicate	C_3S	$3CaO.SiO_2$
Di-Calcium Silicate	C_2S	$2CaO.SiO_2$
Tri- Calcium Aluminate	C_3A	$3CaO.Al_2O_3$
Calcium-Silicate-Hydrate	C-S-H	$CaO.SiO_2.H_2O$
Calcium Hydroxide	CH	2(Ca).OH

Phase 2 indicates the germination stage of Stage 1's surface layer. This then covers the cement particles. The hydration process is slowed by the thickening of the layer. The reaction rate inside the surface layer is maintained until the free H_2O closes. Gradually, cement particles' coverings thicken and the reaction rate slows down until cement hydration is almost dormant. Since this is when contractors pour the concrete into molds, the commercial concrete sector must protect its dormancy phase. As the dormancy phases proceed, the number of hydration bonds formed in the outer layer of hydration will rise in comparison to the inner layers. However, the concrete is kept in a fluid state by including the anhydrous product in the top layer[12].

Additional H_2O is combined with more C_3S and C_2As the cement hydrates, it forms two different cementitious components and both have calcium, $Ca(OH)_2$ and C–S-Hs. Calcium silicates don't hydrate in solid state but it is possible that anhydrous silicates create a solution of CH first before reacting to create hydrated silicates, which is less dissolvable. These dissolvent silicates then go down from the saturated solutions. In Richardson research shows this by demonstrating how C-S-H is formed and the CH dissolve, (Equation 2)[15].

$$2(C_3S) + 6(H_2O) \rightarrow C - S - H + 3(CH) \quad (2)$$

$$2(C_2S) + 4(H_2O) \rightarrow C - H - S + CH \quad (3)$$

CH is more likely to be dissolved in water than other hydration products[13]. Stage 2 is where Calcium hydroxide and all the (C-H-S)s are formed through first coat of cement that has hardened. They penetrate the layer that has grown over the anhydrous concrete. After the layer of anhydrous cement has been broken, the remaining cement, which does not come into contact with water and remains dry, may absorb water and once more crystallize. Equation 2's byproducts cause a rise in temperature and the start of the shift to phase 3, which follows phase 2[12].

The cement mix's initial strength is achieved at Stage 3. After the CH precipitates, silica (CaO) and calcium oxide (CaO), supersaturated is the solution. When the calcium to silicate ratio is between 0.3 and 0.7, water begins to absorb in this saturated solution[16]. Each C-S-H layer solidified to form a massive structure that provides all of concrete's strength. There are two different product forms, inner and outer, which are comes from C-S-H solution[15]. When the C-S-Hs were just made, the have a highly pore-dense, impure version of the gel [16]. The remaining H_2O in these pores is responsible for significant strength loss and concrete chemically deteriorating[13].

Heat is decreasing because of the Stage 4 decrease in main cementitious reactions (C_3S). There was a transitional period between phase 3 and phase 4, when most were C_3S. The hydrating cement matrix is composed of leftover water and residual C_3S. However, after some time, most elements in the mix are still from the C_2S [12].

Phase 5 involves densification, which is distinguished by a dramatic decrease in C_3S engagement. This causes a temperature drop that causes a temperature to fall. Fig.11 depicts the process's heat flow diagram. Phase 5's whole chain of reactions can occur until there are enough reactive chemicals and H_2O. C-S-H concentrations and densities increase as samples are allowed to cure in the presence silica and water[12].

According to the Silica Fume Association, Pozzolanic materials won't hydrate and get stronger when combined with water, but cementitious materials will [17]. When CH has reacted with Pozzolanic condition, the Pozzolanic substance aids C-H-S to make a structure in following pattern:

$$SiO_2 + CH \rightarrow C - S - H \quad (4)$$

X.X. Feng[18] examined the impact of unreacted cement's hydration upon the long-term strength and durability of strengthened mixture with low water cement ratio. This cement can react with water in an advanced stage, which is detrimental to its long-term strength. The W/C has a negative correlation with strength development at later ages. It is also negatively can be effected by the level of hydration at an older age[18].

1.4. Main properties of Ultra-high performance concrete

The need toproduce high load capacity and durability, Ultra-high performance concrete blends cutting-edge polymer and cementitious material technologies. The material often has small holes that block the entry of hazardous chemicals including water, gas, and chlorides. Additionally, UHPC may attain tensile strengths of more than 20 MPa and compressive values of more than 200 MPa. Additionally, it exhibits notable hardening and softening tendencies under tensile strain. Due to all of these features, UHPC performs very well, such that it may be a desirable choice for boosting the sustainability of building materials. Although UHPC has excellent mechanical properties, great strength and ductility, and outstanding endurance, a number of obstacles make it difficult to utilize widely. The applications of UHPC are currently facing a number of challenges, including:

1. Several considerations like material properties.
2. Technology to make large amount
3. Facing the low workability.
4. How the durability works for long period of time[19].

Fig. 12. Worldwide UHPC industry demand[24]

The water cement ration from 0.15 to 0.25 count as a low level, are used to generate UHPC [20]. Superplasticizers are needed to enhance the forming of concrete structure and use less water, which increases the mixture's fluidity and workability [21]. One of the important cementitious binder part of UHPC manufacture is silica fume (SF) and regular Portland cement (OPC)[22], [23]. The use of UHPC is expected to rise 7% annually between 2018 and 2022, according to predictions for the worldwide UHPC industry(Fig.12) [24].

Since OPC's significant carbon footprint has become a global issue, the demand for UHPC has expanded, as has the desire for more environmentally friendly cementing binders [25].

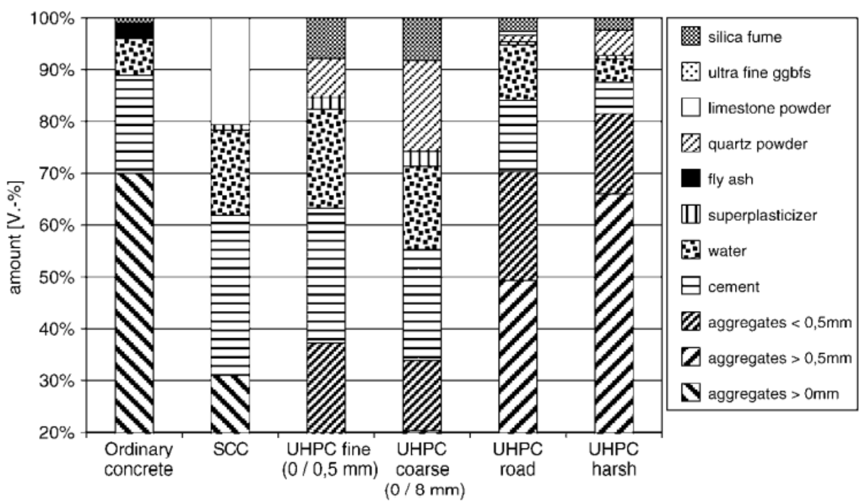

Fig. 13. Different types of concrete with their ingredients overview*[26]*

1.5. Effect of glass on cement

Glass is a convenient natural product that has been utilized in many different ways, although it has a short lifespan if it is compared to other natural resources. Glass has either been dumped in landfills or stacked high after being used to make things. Given that shattered glass is a nonbiodegradable material, landfills may not be the best option. Glass has been tested in the concrete sector since there is a critical demand for landfill alternatives. In order to substitute coarse aggregate, fine aggregate, and cement in the concrete industry, waste glass is mostly tested in these three areas. The substitution of coarse aggregate, however, has had less favorable outcomes in terms of compressive strength. Construction applications have witnessed a similar period of pozzolanic materials. In order to evaluate the pozzolanic effects of fine glass micro-filler in UHPC, In this study, the amount of cement is reduced by using ground glass micro-filler as a binder. Fly ash and silica fume, two substances classified as having a Pozzolanic reaction, are used to experimentally evaluate its performance. Silica fume, fly ash, glass powder, and cement have all been used in the research. They added some glass powder and lowered the amount of cement while using around 15% silica fume and 30% flay ash. The glass powder ranged in size from 150 to 100 μm. In addition to the Pozzolanic reaction that we saw in the experiment, a significant quantity of C-S-H gel was also produced at the start of the process, which improved the cement matrix and enhanced the properties of the concrete. It also enables us to discover that concrete built with glass powder is significantly stronger than concrete manufactured with fly ash[27].

S. K. Kim [14] obtaining the leftover glass from the LCD and TV industries, grinding it into a fine powder, and using it to create new ingredients. After that, an experiment was conducted to determine the effects of this type of glass using the glass powder from LCD, which is now powder and is known as LGP. According to the findings, LGP particles did not engage in the process at first, but after three days, there was a significant level of involvement. This proves that despite the cement's immediate reaction with water, this type of glass takes longer to activate. Additionally, if concrete contains a significant quantity of this glass, the strength of the concrete will be reduced in the short term due to a lack of sufficient Pozzolanic reaction.

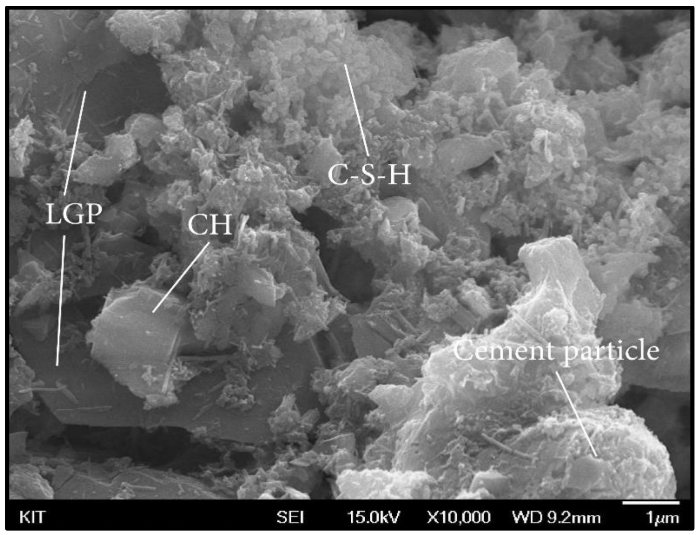

Fig. 14. The LGP image of concrete paste after 3 days from SEM*[14]*

The structure inside the concrete is seen in the SEM picture of the hydrated cement with LGP after 28 days in Fig.15. The LGP particles cannot be distinguished from other portions of the concrete by a visible border. The concrete's darker sides indicate that its pores have decreased compared to three days before. Additionally, it seems that throughout the hydration process, the C-H-Ss and LGP particles create some structure. Three distinct sections in the image can be categorized as black areas, sharp edges, and round surfaces. We know that a sharp type has a greater pozzolanic response. Due to fewer holes and the components of the needle forms that are formed into one another, it looks that the sample has also gotten denser.

A. H. Shalan‘s research [28] By adding various amounts of glass powder, it was hoped to prolong the effects of sulfate on the concrete. They created a way to produce the glass powder for use in the concrete by reducing the 10%, 20%, 40%, and 60% of cement and adding the equal amount of glass powder. Glass powder, which displays a calcium hydroxide reduction, was utilized to quantify the pozzolanic effect using the X-ray diffraction (XRD) test as a performance benchmark. Compressive strength loss results indicate a strong sulfate resistance when they added additional glass shards to the cement paste. Additionally, it demonstrates that the aggregate demonstrates increased resistance to the sulfate when they took half of the sample out of the experiment and used shared glass.

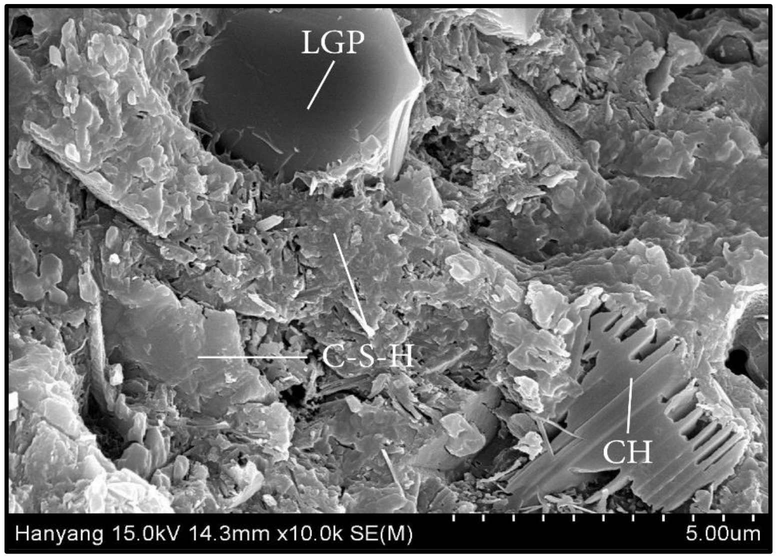

Fig. 15. SEM image of composition paste which contained LGP after 28 days*[14]*

Another research, M. A. El-Mandouh [29], shows that ten deep beams of reinforced High-Strength Concrete (HSC) that were simply supported and statically loaded made up the experimental program. Waste glass powder was present in five beams, but not in the other five. While two reference beams desinged without openings, others had web by the openings characteristic. The impact of employing waste glass powder as well as the position and size of web apertures were the main factors that were investigated. A numerical simulation has been proposed By finite element method to see the difference of the shear strength in three dimensions model. This experiment was carried out to determine the maximum load that can cause beams to break and to compare the failure data between experimental samples and those predicted by the Strut-and-Tie model. The findings showed that utilizing waste glass powder improved the ultimate shear strength (12-41%) Which is in shorter range for cracking strength (17-25%) in comparable the others with web openings. The created concrete microstructures brought on by WGP's extremely fine grains may have contributed to increase the highest load limit to collapse, by causing more gel to form and fewer voids to exist in the concrete matrix.

M. O. Yusuf et al. [30] examine how a glass affects silicon and hydroxyl-based compounds' bond properties, workability, heat resistance, microstructure, and mineral phases. It also looks into how a glass affects C-O vibrations. It provides a mathematical model to determine the strength characteristics of regular Portland cement over a long length of time, which contains glass powder. Additionally, it focuses on the other experiment in which the temperature was raised to 550 °C, a very high temperature, in order to observe the characteristics. It has been discovered that Using glass improves concrete's workability. It also effected density and setting times by reducing. The sample's capacity for heat resistance with 20% glass and 80% cement as a binder is 40%, and a comparison reveals that the OPC is four times more effective on this scale. Another interesting fact is the ideal glass percentage in mortar and concrete is discovered to that after 28 days, that 10% of the weight has a 33 MPa, and after 90 days, that 20% of the weight has a 47 MPa.

In a series of experiments, Y. Wang employed three distinct ways to evaluate the properties of concrete, which is composed of cement and glass powder as a binder. The first one is created in a dry environment and is known as GPd. The second one, known as GPw, is developed underwater. The last product is GPe, which is manufactured that use ethyl alcohol. The outcomes demonstrated that the grinding condition had a substantial impact on the GP's milling efficiency. As long as more water or ethanol was introduced while the grain was being ground, ultrafine GP may be produced. They noticed that when they reduced the size of glass powder's particle size to 300 nm, GP exhibited little pozzolanic reactivity at an early age. The big particle size and its lower absorption characteristic increased the initial strength at the beginning of hydration and workability in the GPd condition, according to the results. However, because of GPd's low pozzolanic reactivity, Compared to the reference samples, the sample's long-term mechanical strength was lower. Both the GPw and GPe samples have a stronger initial strength characteristic than the reference samples due to the GP samples' accelerating effects[31].

Superplasticizers are added WGP to concrete to assure its workability, but their type and dose have a big impact on how well the concrete works. There are a few tests used to examine concrete formed of glass powder and cement, such as the total organic carbon (TOC) test, Zeta potential evaluation, and superplasticizer absorption on the binder particles. The findings showed that when polynaphthalene sulfonate or polycarboxylate were utilized as superplasticizers, the presence of waste glass powder significantly affected some characteristic such as flowability. These superplastisizers exhibit two distinct behaviors depending on how much waste glass powder is added to the mixture. While the polycarboxylate adsorption reduced, the polynaphthalene sulfonate adsorption rose by adding more glass powder[32].

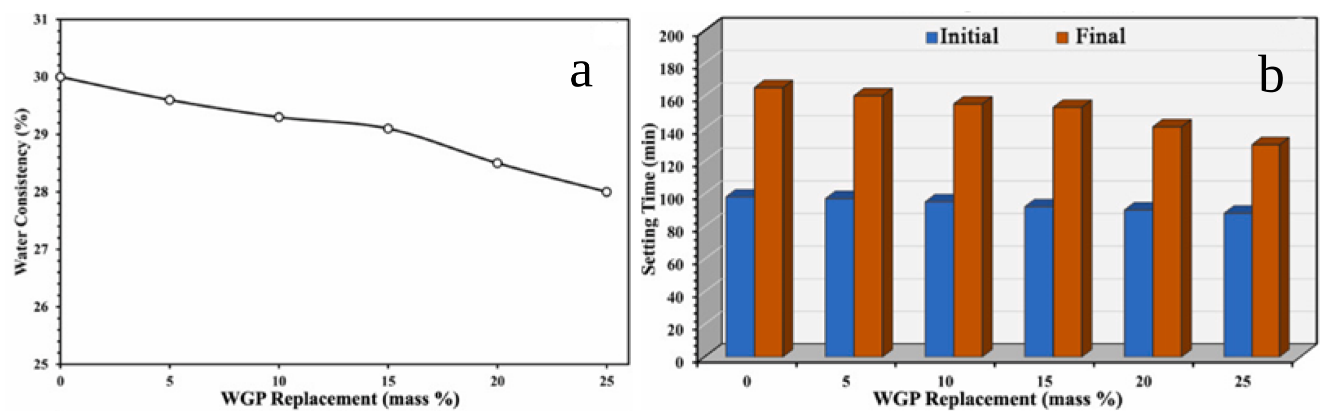

Fig. 16. Effect of replacement percentage of waste glass powder on: a) water consistency b) setting time *[32]*

When we add glass powder in place of less cement in concrete, it can enhance durability-related features while reducing environmental impact in prestressed hollow-core slabs. From an industrial standpoint, concrete's crucial structural component is also one that may be significantly affected by cutting back on cement use[33]. However, in glass-based UHPC, using a breaked glass resulted in mechanical degradation whereas using glass powder in place of 50% of the cement enhanced workability and mechanical qualities. When glass powder and aggregates were used, UHPC's thermal insulation capabilities were greatly improved [34].

There are several factors that have had a significant impact on concrete's characteristics such as size, kind, replacement ratio, mixing, and curing techniques of the waste glass aggregate. Due to its finely tuned pore structure and densified microstructure, the concrete containing glass powder displayed exceptional durability characteristics. The results showed that used glass might perhaps be used as both coarse and fine particles in the making of concrete [35]. In P. Sikora's research, WG fine aggregate was used in place of traditional fine aggregate (river sand) at a ratio of 100% by weight. Additionally, cement mortar had 0, 1, and 3 wt% of NS. The results of the experiment showed that adding WG fine aggregate drastically reduced the cement mortars' thermal conductivity and also reduced their sorptivity coefficient. The results of the study demonstrate that WG fine aggregate may successfully replace by fine sand and it can improve the thermal factors while keeping the mechanical characteristics the same. [36].

1.6. Optimum amount of waste glass powder

Z. Chen's [11] research shows that flowability increases when the grinding period is approximately 45 minutes long and the median particle sizes are around 10mm. Research has shown that mechanical grinding is capable of stimulating WGP activity. WGPs in mortar bars can stimulate WGP activity by using silica fume (SF), which is combined with partial cement. This is a demonstration of the strengthening effect's complementary nature. It was also found that WGPs or SF replacing cement are ideal additions of 27% to 3% in mass. However, this does not take into account other factors such cost, workability etc.[11].

1.7. Heating and adding silica fume impact on UHPC

It was proven by N. Lee and colleagues[37] that, The cement hydration has a great good impact, when it is cured in the oven with high temperature, on Pozzolanic reaction by effectively consuming small amounts of water.

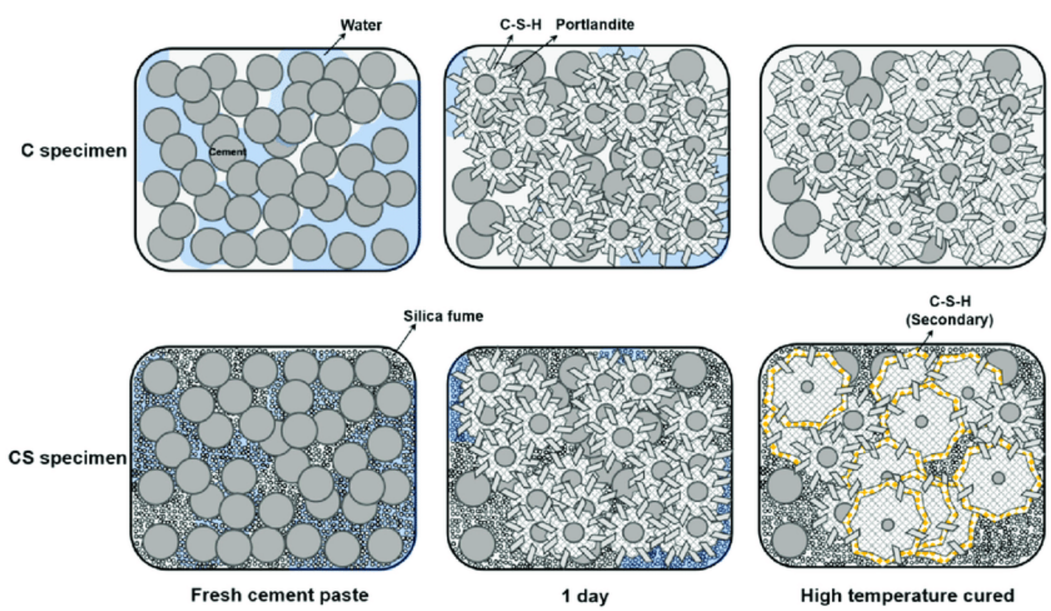

Fig. 17. Process flow model for cement with low water/cement hydration and with and without silica fume appearance*[37]*

Increased cement hydration and pozzolanic reactions sped up the rate at which strength was developed. Because of the small area and the preconsumption water in conditions with low water-to cement ratios, strength growth was limited after high-temperature curing. The anhydrous cement does not require the pozzolanic process. This means that the reaction can be performed under more restricted conditions. It doesn't rely on diffusion to accelerate the reaction. This increases the length of the C-S-H mean chain and makes it easier to produce C-S-H bulks that they have big particle size dimensions. This will help you understand the complex hydration process for ultra-high performance concrete with a low water to cement ratio.

1.8. Conclution of literature review

It is clear from all of these facts that not all cement reacts with water; part of it may still be unreacted. It is not rational to use cement that is not reacted in the concrete and use it only as an aggregate since cement manufacture uses a lot of energy and produces a lot of CO_2. Although it makes sense to utilize glass powder to speed up cement hydration, while the specific surface area is high for glass powder, and is hydrophobic and roughly the same size as cement particles. In previous research, there was so much evidence that a small portion of glass instead of cement can help the properties of concrete and improve it, but there is a potential to use a big amount of glass powder instead of cement, which need to be observed.

The distinction between cleaned waste glass powder and uncleaned is another significant factor that is not taken into consideration. There have been some excellent studies on the use of waste glass, but more attention has to be paid to the differences between cleaned and uncleaned waste glass since contamination can influence the characteristics and behavior of concrete. If their patterns are similar, so it will be good and we can eliminate the effect of waste glass powder without cleaning. But if they do not act like each other, therefore we can not predict the uncleaned waste glass powder.

Although it is clear that silica fume has a positive impact on concrete's qualities, it needs to consider the effects of this substance on concrete's appearance. Although there are many excellent data and studies in this area, they tend to focus on small amounts of glass powder. This has led to a dearth of information on the big portion usage of glass powder in cement replacement.

One significant fact that has not received as much attention is the damage done by frost resistance to concrete with glass powder, especially in Lithuania and other northern European countries cause this parameter is very important in this weather. Numerous research have examined the impact of silica fume on concrete, while others has examined the impact of low amounts of waste glass powder. However, there are several blind spots for concrete that contains a lot of waste glass powder. So, in order to better understand how salt-scaling functions, we are going to perform some study on it.

2. MATERIALS

2.1. Cement

The cement which is used in this experiment is CEM I 42.5 R. It possesses the qualities listed by the following datail: 1) specific surface area which is measured by Blaine apparatus is 3720 cm^2/kg. 2) Compressive strength of samples after 2 and 28 days is 32.3 and 63.1 MPa. 3) Soundness by Le Chatielier is 1.0 mm; 4) Normal consistency is 28.5 percent; 5) Initial setting time is 110 minutes and final setting time is 210 minutes; It consists of the following compositions: C_3S - 68.70% ; C_2S - 8.70%; C_3A - 0.20%; C_4AF - 15.90%. Diversity distribution of CEM I 42.5 R particles is demonstrated in Fig.18.

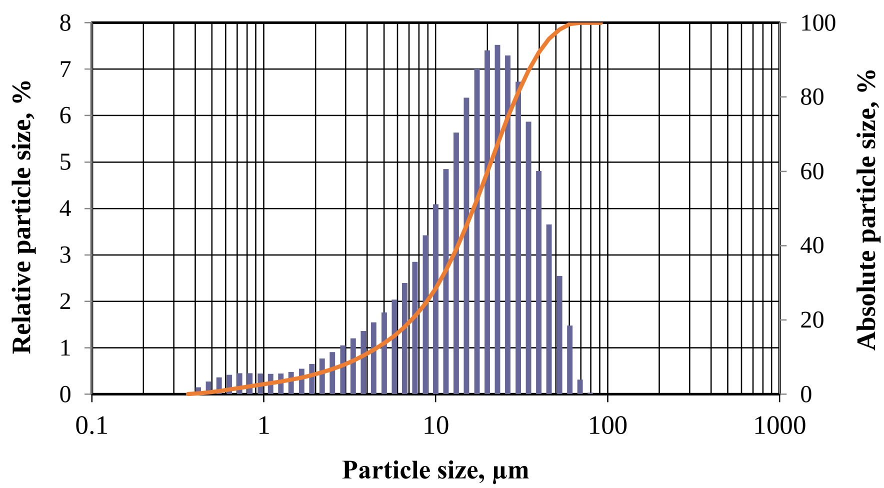

Fig. 18. Diversity distribution of CEM I 42.5 R particles

2.2. Glass powder

In this experiment, we utilized two distinct sorts of glass powders. Glass powders range in impurity content from the least to the most, both contaminated and uncontaminated.

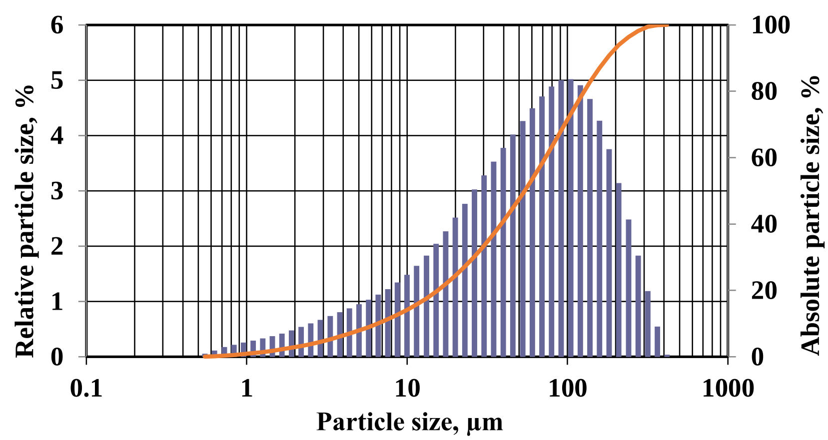

Fig. 19. Particle size distribution of waste glass powder

It possesses the qualities listed by the following datail: 1) Average size of the particles is 25.80 μm; 2) Its Density is 2528 kg/m^3; 3) Specific surface, which is measured by Blaine apparatus is 3350 cm^2/g. Diversity distribution of glass particles is demonstrated in Fig.19.

2.3. Silica fume

When metals and ferro-alloys are burned in the furnace, a byproduct called silica fume is produced. Another name for it is micro-silica (MS). It possesses the qualities listed by the following datail: 1) Its pH is 5.3; 2) Bulk densities is 400 kg/m^3; 3) The density is 2532 kg/m^3. Diversity distribution of glass particles is demonstrated in Fig.20.

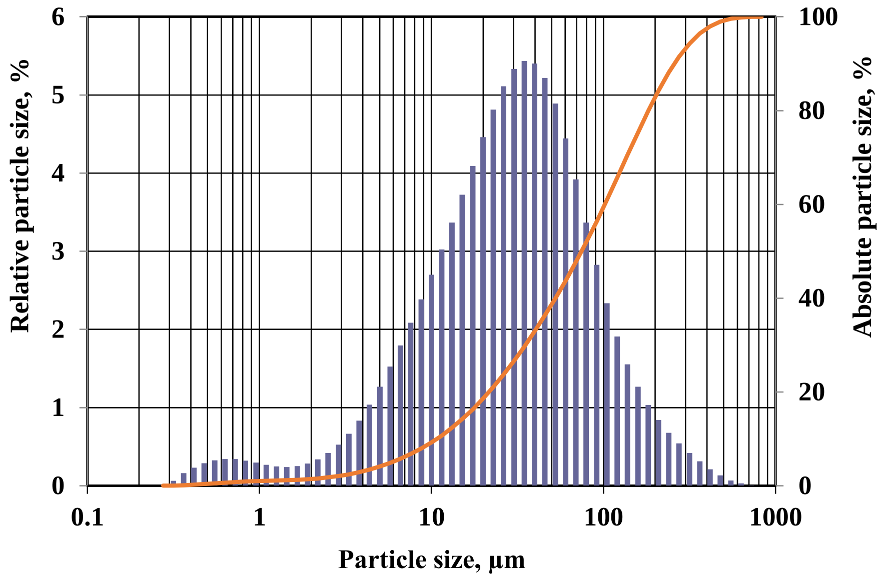

Fig. 20. Particle size distribution of silica fume

2.4. Super plastisizer

The additives used to make high strength concrete are known as superplasticizers. Made up of higher-value, more advanced chemicals than standard and middle-range water reducers. Superplasticizers can reduce the water-cement mix while providing benefits such as higher density. Increased bond strength. Volume stability is improved and shrinkage cracking is reduced. The chemical name is „2-octyl-2H-isothiazole-3-one (OIT)“. It possesses the qualities listed by the following datail: 1) It has light brown Colour; 2)It has liquid appearance ; 3) The PH is 3.5; 4) The pressure of vapour is 23 hPa; 5) It has the density around 1.06 g/cm^3 in 20 °C.

2.5. Quartz Sand

Silica and oxygen are two essential minerals found in abundance in quartz sand. Silicon dioxide makes up the majority of it on a common basis. Quartz sand is sometimes referred to as industrial sand or silica sand and comes in the shape of a hard, solid substance. The chemical composition of quartz sand which is used in this research is: SiO_2 > 98.5 %; Fe_2O_3 < 0.05%; Al_2O_3 < 0.60%. The main properties are: Free flow density - 1.64 t/m^3; Mohs scale – 7; Loose of ignition - <0.2%; Melting temperature - 1650 C^o. Fig.21 displays the range of particle sizes.

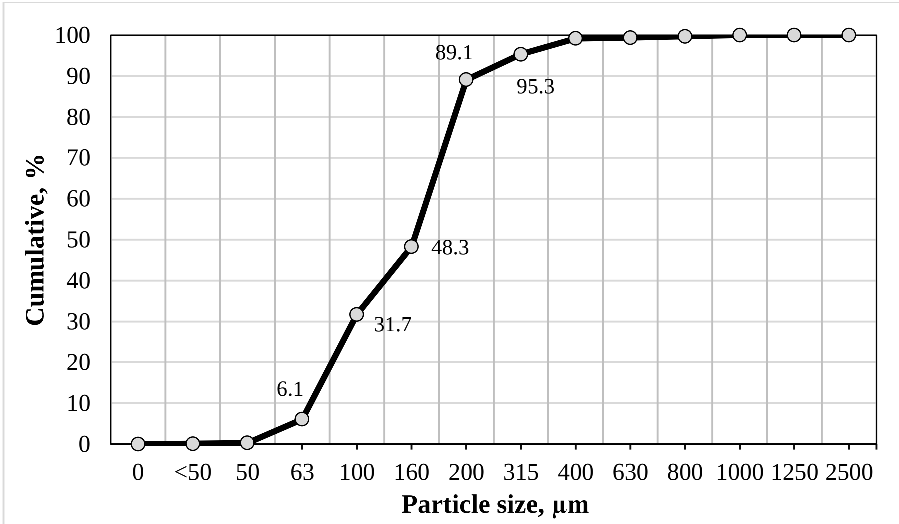

Fig. 21. Particle size distribution of the quartz sand (made by author)

3. METHODS

3.1. Waste glass preparation

Municipal solid waste, which includes home trash and garbage as well as all other types of city trash, is composed of a variety of materials, including leather, wood, all types of plastics, metals, and others.. For the experiment, we gather domestic glass bottles of various types, shapes, and colors. The nearby landfill's municipal sorting facility provided the solid waste for this project (Fig.22).

Fig. 22. Municipal waste glass dumpsite

The garbage in the municipal solid waste dumpsite is separated from the trash that is larger than 40 mm by first going through a trammel screen. To separate the fine shredder and the shredder, they next pass through a wind separator. Then, to separate metal from all other components, the metals stick to the magnet that has been prepared near the screen. The wind separator system uses wind to sweep away the heavier materials while separating the light ones. Up to the conclusion of the device, the heavy materials just pass through the blower screen.

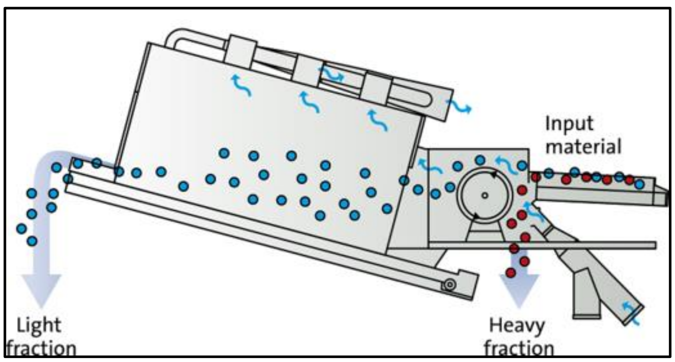

Fig. 23. Scheme of wind separator in the dump site

Two methods were used to prepare waste glass:

1. produced from municipal glass waste, is known as "cleaned waste glass powder." First, wash any waste glass that has a lot of impurities with hot water, then remove any more items. After that, we crush pure glass into a powder using a ball milling machine..
2. We just crush the uncleaned waste glass into "uncleaned waste glass powder" using a ball mill device. The uncleaned waste glass includes certain other items besides glass, such as stone, paper, etc..

Fig. 24. Procedure of glass preparation and steps

The steps inside a site of the recycling waste glass are like the following:

1. Collection & Delivery
2. Sorting Stations
3. Glass Breaking
4. Trommel
5. Fluidized Bed Drier
6. Primary Rotary Screen

Glass is gathered and distributed from all across the city. Glasses of all colors are kept together for storage. All containers are fully examined for contaminants and dangerous items. Sorting out pollutants is the focus of the first two stations. Typical pollutants include cardboard, window frames, mirrors, Pyrex, ceramics, cans, TV's glass and etc. Other stages are used to separate glass, which is not brown, for further new set processing. The glass is broken into rough particles for later optical sorting by hammers, each the size of an arm. When necessary, a gentle water mist is used to reduce airborne particles. Glass shards are separated into 3/8" and 3/4" sizes after being passed through a rotating screen. Paper labels that were cut off during Trommel breaking are propelled into a paper recycling container by fans. Items like corks, caps, lids, and stray labels that don't break and can't pass through the screens are collected and recycled. Glass shards are placed into the dryer in a bed as a smooth ribbon. The particles are moved through the dryer via vibration. Natural gas is used to heat the air to 190 degrees F and propel it through the dryer's bed. Burning sugars and bacteria causes label glue to loosen. The remaining material rises to the top and is removed by our vacuum system. Glass that has been cleaned and dried is screened to extract particular sizes. To create different size classes for different clients, screens are rapidly changed. For instance, all particles must be 12 mesh or smaller for making fiberglass.

Fig. 25. Cleaning process of the Glass: a) Clean the papers with hot water. b) Wash inside and outside of glasses

In the laboratory the Ball Mill machine was used for grinding 8 kg of Cleaned waste glass. It has 130 ball units with diameter of 6.35cm and 1.030 kg weight. The total drum diameter is 70 cm and the length is 52 cm..

Fig. 26. Lab ball mill: a) Drum b) Metal balls

The specific surface area of the glass powder in this observation is from 2119 cm^2/g to 5889 cm^2/g..

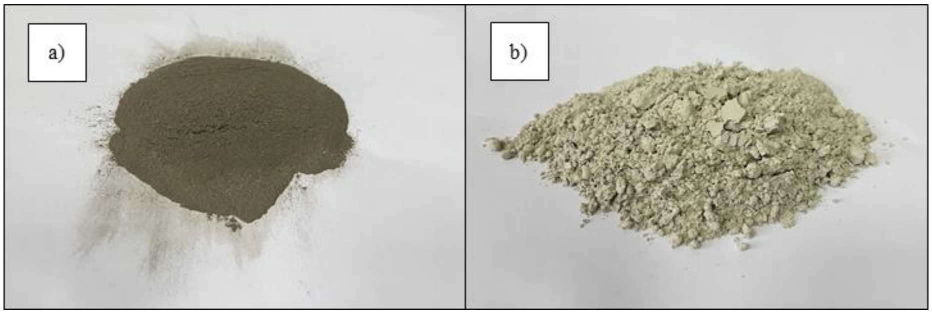

Fig. 27. Final glass powder products: a) uncleaned waste glass powder, b) cleaned waste glass powder

3.2. Specific surface area and particle size distribution

Particle size distribution of all the materials was assessed and controlled by different methods. One of them is the Blaine apparatus (Fig.28) for measuring waste glass powder. In order to determine the precise surface area in the Blaine apparatus, the cleaned waste glasses were milled for various lengths of time, and samples were obtained from the milling machine. Some portions of the samples were stored for further research (Fig.29) Laser granulometry is used to examine Portland cement and sieving for Quartz sand. According to EN 196-6:2018 standard[38], the specific surface area was measured using the Blaine instrument.

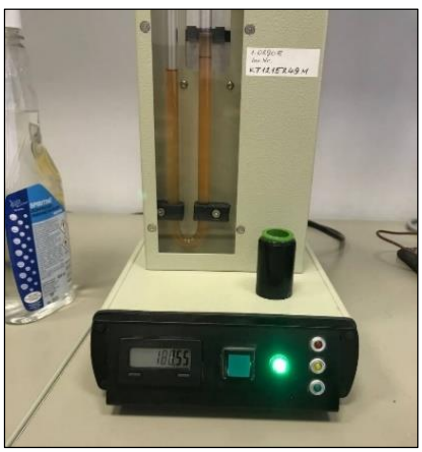

Fig. 28. The Blaine apparatus

Fig. 29. Samples stored in different times from milling machine

3.3. Mix procedure for cement paste

A paste explanation is shown in Table 4 and made using the binder composition shown in Table 5. The experiment was separated into two different phases with two different types of glass: 1) cleaned waste glass powder, 2) uncleaned waste glass powder. Totaly 4 samples for each type of waste glass powder were examined. After being measured for each sample, the cement, waste glass powder, and silica fume were put in separate bowls, stirred, and made homogenous. Start mixing them with water towards the end.

Table 4. Paste composition naming

Notation	Explanation
C100	Reference has 100% cement
C80/G20	Content in mixture involve of 80% cement and 20% glass powder
C60/G40	Content in mixture involve of 60% cement and 40% glass powder
C40/G60	Content in mixture involve of 40% cement and 60% glass powder

Table 5. Binder composition (W/C = 0.25)

Sample	Cement (kg/m^3)	Glass Powder (kg/m^3)	Water (kg/m^3)
C100	735	0	147
C80/G20	588	147	147
C60/G40	441	294	147
C40/G60	294	441	147

3.4. Semi-adiabatic calorimeter

We use semi-adiabatic assess to evaluate the temperature of the specimen at various stages of hydration and the specimen’s setting times include final and initial. The instrument needs to be turned on and connected to a computer where the readings are recorded when the mixture is freshly created. The tube is oiled before the mixture is added so it is simpler to clean after usage. After adding the copper tip to the mix, we begin the computer recording. To prevent air from entering the tube, a rubber cover is placed around it. Polystyrene is placed on top of the semi-adiabatic calorimeter after all the mixtures have been prepared and added. Test method which is used to define the temperature of cement paste hydration is according to EN 196-9:2010 [39]. The semi-adiabatic calorimeter contains 8 channels to place the paste container and a thermocouple (K type) to detect the temperature of each container across a range of -270 °C to +1820 °C.

3.5. SEM analysis

We used the scanning electron microscope to define the formation of hardened UHPC samples. The study made use of An electron microscope with high resolution scanning, FEI Quanta 200 FEG, and field emission gun Schottky. An energy-dispersive X-ray spectrometer (EDS) with a drift droplet detector was used to examine the chemical compositions of samples of ultra-high performance concrete (silicon type).

3.6. Mixing procedure and curing

To characterize the names of the samples in this experiment, we followed Table 6. All of the samples were made in the lab using, Fully Automatic Mortar Mixers, AUTOMIX (Fig.30).

Fig. 30. Fully Automatic Mortar Mixers, AUTOMIX

The main parameters of the mixer are: bowl capacity - 5 liters; 2 different speeds - 140±5 and 285±10 r.p.m; distance from mixer panel to bowl - 3±1 mm during all cycles; weight approximately: 58 kg. The chemical contents of the mix combination with various ammount of waste glass are displayed in Table 7. There are five different mixtures, and we prepared two of them for thermal cured and without thermal cured. Reference has 64% cement and 36% glass powder (C64/G36). Prior to mixing, each component was weighed in a separate container. In a measuring cylinder, we combined 1/3 of the superplastisizer and 1/3 of the water. In the other measuring cylinder, add the remaining 2/3 of the superplasticizer and 1/4 of the water.

Table 6. Concrete composition naming

Notation	Explanation
C64/G36	Binder reference content in mixture consists of 64% cement and 36% waste glass powder
C51/G49	Binder content in mixture consists of 51% cement and 49% waste glass powder
C38/G62	Binder content in mixture consists of 38% cement and 62% waste glass powder
C26/G74	Binder content in mixture consists of 26% cement and 74% waste glass powder
C13/G87	Binder content in mixture consists of 13% cement and 87% waste glass powder

Table 7. Binder mixture of prism samples (W/C = 0.25)

Sample	Cement (kg/m^3)	Silica fume (kg/m^3)	Glass Powder (kg/m^3)	Quartz sand (kg/m^3)	Super plastisizer (kg/m^3)	Water (kg/m^3)
C64/G36	735	99	412	962	36.76	147
C51/G49	588	99	559	962	36.76	147
C38/G62	441	99	706	962	36.76	147
C26/G74	294	99	853	962	36.76	147
C13/G87	147	99	1000	962	36.76	147

To create a homogenous mixture, we first add the dry ingredients to the mixer bowl and mix them for one minute. Mixing the remaining water in the mixture for one minute. The first mixture of super plasticizer is then added, and it is again mixed for a minute. After waiting another minute, add the second portion of the plasticizer and continue mixing the ingredients until the mixer begins to shake.. At this point, the paste is ready. The paste is then added to the previously prepared and greased mold, which is then vibrated until bubbles appear. To stop the water from evaporating, in the end, cover the top with a lid.

After two days, take off the lid and the three prism-containing molds from the samples and submerge them in water. The samples that are supposed to be handled without thermal cured are simply left in the room, and for the others, we cover the bucket with a lid and place it in the oven with temperature 80°C for 48 hours to face thermal cured.

3.7. Flowability test

According to EN 12350-8 [40], We prepared a fresh concrete sample paste and then put it in the mold, which has the shape of a frustum cone. We used a cutter to remove the leftover concrete after pouring the fresh concrete in the cone in one motion. When everything was prepared, we lifted the cone upward without tamping the mixture and let the mixture to spread on the top. We measured the circle's two diameters when the spreading was fully completed, and we took the average of these two diameters. This test is used to check if the amount of water is Consistent with the mix or not because if the amount of water is higher than needed then the mix will segregate and if it’s lower than needed so the mix will be not compact in the shape between the reinforcement.

3.8. Density measurement

We require the weight and the dimensions of the concrete samples in order to determine their density. Vernier calipers were used to measure the measurements, and a digital weight scale was used to measure the weight to two decimal places. Following the measurement of the dimensions, the volume is calculated. The weight is then divided by the volume to obtain the density[41].

3.9. Assess compressive strength

For evaluating the maximum load of each prism that can tolerate, we use testing machine to compress the samples. Sample test piece is in the form of a prism. A compressive test is done to check whether the material can support or carry the load on it with or without any deflection or crack. This test is carried out after the flexural strength, so the prism is in 2 halves. In this case, we use a metallic plate with a known area and dimension (40mm, 40mm), and we put the prism in between the metallic plate and start the test. When the prism breaks, the readings are noted on the screen. This test was done according to the code, EN 196–1:2016 [41].

3.10. Water absorbtion and prosity

The specimens were placed into oven with high temperature, approximately 105°C, and let to evaporate all the water about 48 hours and remain just mass. Turn off the oven and wait for one day until the temperature of the specimens and the room adjust. Take out specimens from the storage container and weigh them. Put them in the bucket full of water and measure their weights after 15, 30, 45, 60 minutes, 1 day, 2 days, 1 week and submerged.

3.11. Salt-scaling resistance and porosity parameters

Following the code EN 13687-1:2002 [42], salt-scaling resistance was applied to the samples. Samples of C64/G36, C38/G62, and C13/G87 were used in the experiment for two alternative curing environments: thermal curing and non-thermal curing. The sample size is: 160mm length, 40mm width, 40mm heigth. The program is operated through salt-scaling and freeze-thaw resistance.. The samples were placed from the length and weight in the 3% NaCl solution, approximately 1 cm of the height covered by the solution, and subjected to 160 cycles of scaling In a chamber that automatically transitions from a frozen state to a thawing state. We consider the mass loss every week and gather them for measuring the weight of them.

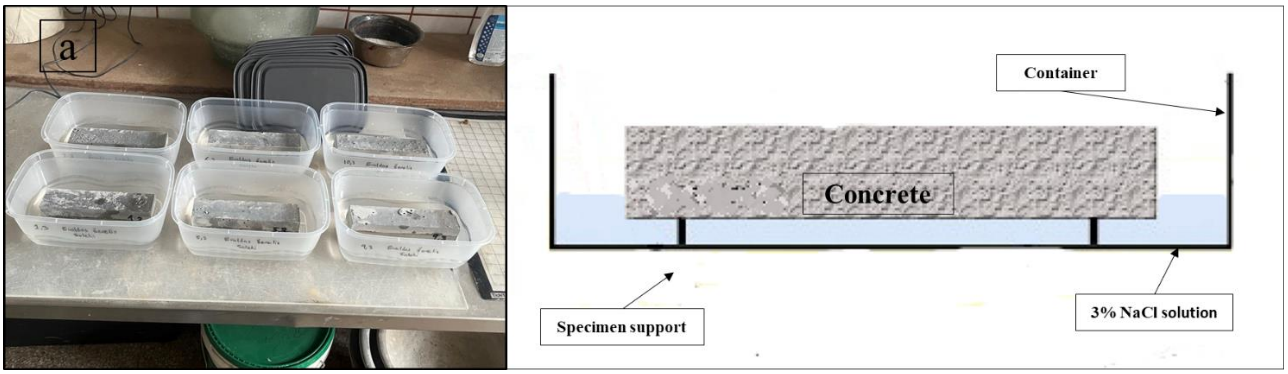

Fig. 31. Preparing samples: a) Place the samples in separate 3% NaCl solution container; b) Scheme of the container, concrete and 3% NaCl solution

4. RESULTS

4.1. Specific surface area of waste glass powder

There are two distinct primary areas with two different slopes as determined by the surface area result (shown in Fig. 32). Between 17 and 75 minutes, the first area's slope is around 40.5, and between 75 and 146 minutes, it is 10.1. It shows that milling is more effective in the first part than in the second. Therefore, with the 3592.45 (cm^2/g) specific surface area, 75 minutes is the ideal milling time.

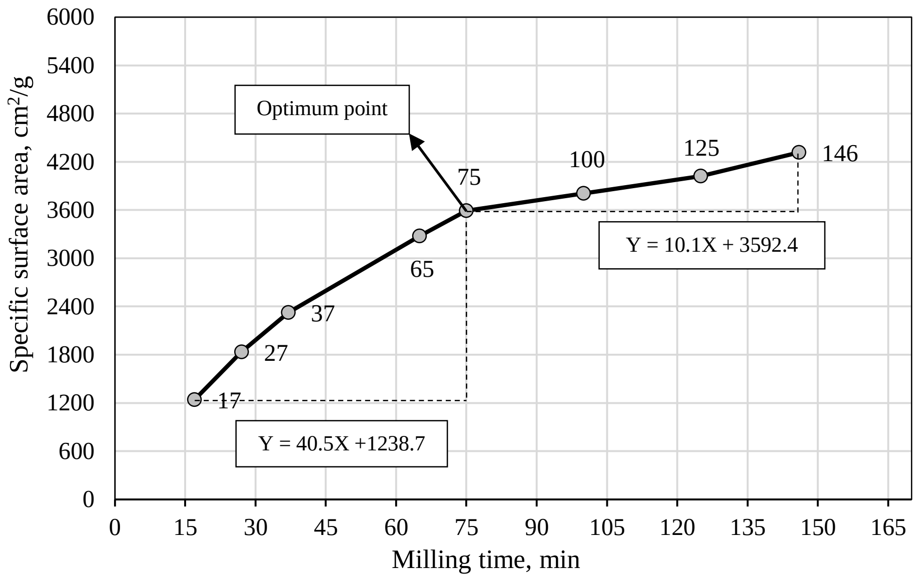

Fig. 32. Relationship between Specific surface area and milling time of cleaned waste glass powder

4.2. SEM and EDX analysis

Spectrometer and the structure of clean and unclean waste glass powder were analysed using a scanning electron microscope. SEM micrographs (Fig.33) show that there are no apparent differences between clean and unclean waste powder. Both types of waste glasses contain long, asymmetrical, sharp edged particles, which come in a variety of sizes. For a mixture to be normal in consistency, it is more difficult for round and smooth-faced particles to absorb water. Materials with a rougher surface will stick better.

Unfortunately, EDX research cannot determine whether the predominant structure of glass powder is crystalline. It is still possible to examine each component individually, however. The EDX analysis revealed the following elements: (O), oxygen,(Si) silica, (C) carbon, (Na) sodium, (Ca) calcium, (Mg) magnesium, (Al) aluminum, (K) potassium, iron (Fe), and (S) sulfur.

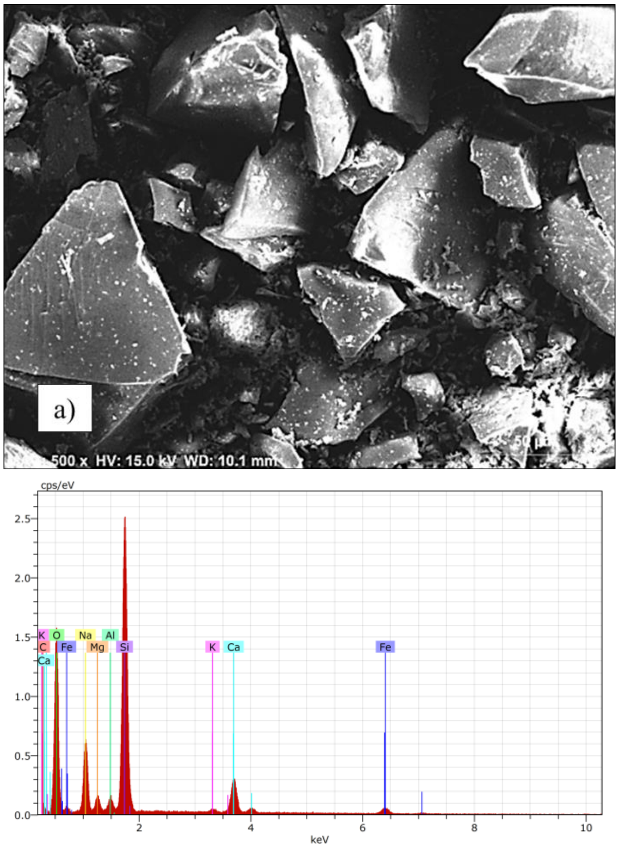

Fig. 33. SEM micrograph and EDX spectrum of cleaned glass powder (a)

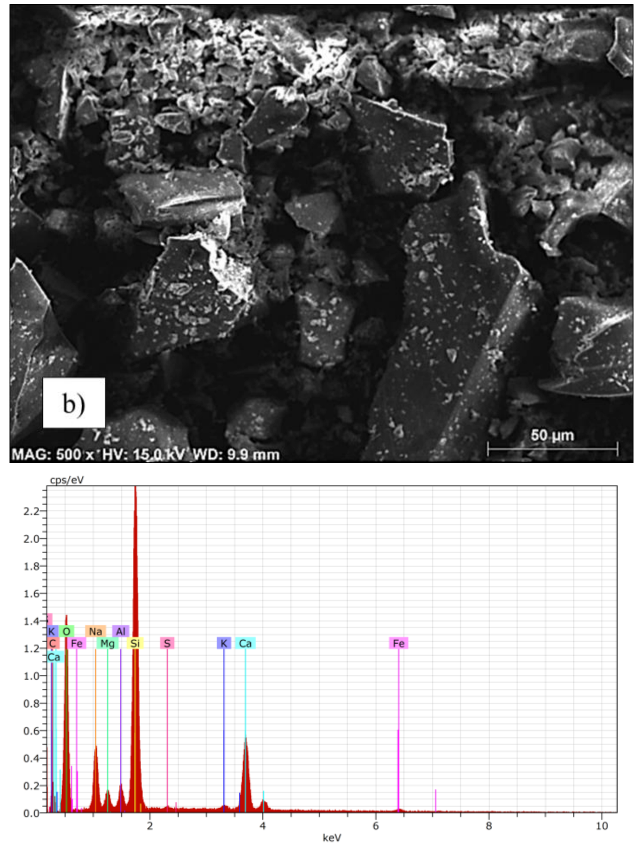

Fig. 34. SEM micrograph and EDX spectrum of uncleaned glass powder (b)

Table 8. EDX spectrum table of elements

Element	Symbol	Cleaned glass powder (wt.%)	Uncleaned glass powder (wt.%)
Carbon	C	0.43	2.83
Oxygen	O	43.88	43.48
Iron	Fe	3.85	1.31
Calcium	Ca	7.73	13.47
Potassium	K	0.63	0.65
Sodium	Na	9.57	6.88
Magnesium	Mn	1.58	1.44
Aluminium	Al	1.28	1.64
Silicon	Si	31.05	28.00
Sulfur	S	0	0.30
Total		100%	100%

The main ingredients in cleaned and unclean WGP are illustrated into Fig.36. This silicon level in cleaned waste glass powder was found to be 11.1% greater, sodium content was 39.1% higher, calcium content was 42.9% lower, magnesium content was 14.2% higher, aluminum content was 18.7% lower, potassium content was 14.2% lower, carbon content was 85.7%, iron content was 3 times more and there was no sulfur.

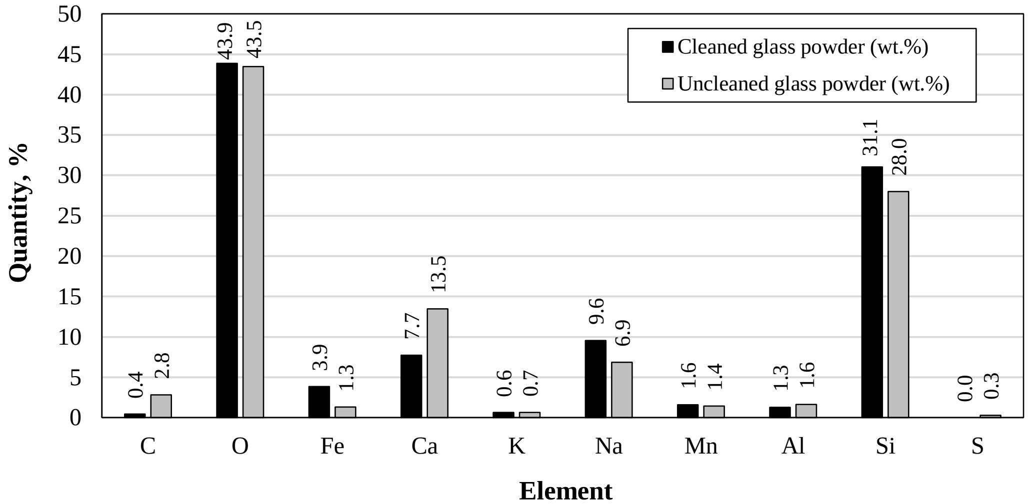

Fig. 35. Diagram of elements of waste glass powder

4.3. Hydration process analysis

We prepare 4 distinct pastes to better understand the starting and end setting times of the paste containing waste glass powder. In our experiment, we used two distinct characteristic of waste glass powder and increased the amount of waste glass powder which is substituted with cement by 20%, 40%, 60%. A semi-adiabatic calorimetry device that utilized a mechanical mechanism was used to monitor the samples. Semi-adiabatic results (Fig. 37 and Fig. 38) indicate that both forms of glass powder have longer final setting times, acting as a retarder as a result. The time is 123 minutes for washed glass and 307 minutes for unwashed glass. On another hand when we add more glass than cement, the temperature of hydration gradually decreases. For washed glass, the temperature fell by 10.8°C, but for unwashed glass, it fell by 13.4°C.

Table 9. Initial and final setting times for paste with cleaned waste glass powder

Specimen		Initial setting Time (Minute)	Initial setting Temperature (°C)	Final setting Time (Minute)	Final setting Temperature (°C)
Cleaned waste glass powder	C100	88	26.85	577	42.72
	C80/G20	87	25.80	606	39.31
	C60/G40	87	24.79	658	35.57
	C40/G60	-	-	700	31.93

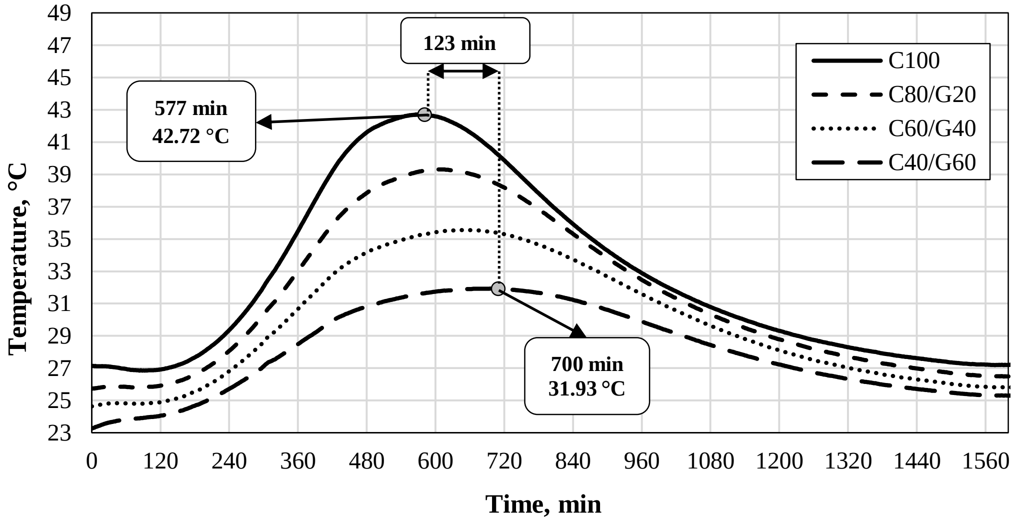

Fig. 36. Effect of cleaned waste glass powder on Portland cement hydration phase

There is a 2.6°C temperature difference between the two samples of 60% glass powder. it indicates that there is less heat generated during hydration, which helps us to understand why the paste made from washed glass is more powerful than the one made from unwashed glass.

Table 10. Initial and final setting times for paste with uncleaned waste glass powder

Specimen		Initial setting Time (Minute)	Initial setting Temperature (°C)	Final setting Time (Minute)	Final setting Temperature (°C)
Uncleaned waste glass powder	**C100**	88	26.85	577	42.72
	C80/G20	137	25.26	649	35.99
	C60/G40	129	25.12	700	32.38
	C40/G60	146	24.92	884	29.30

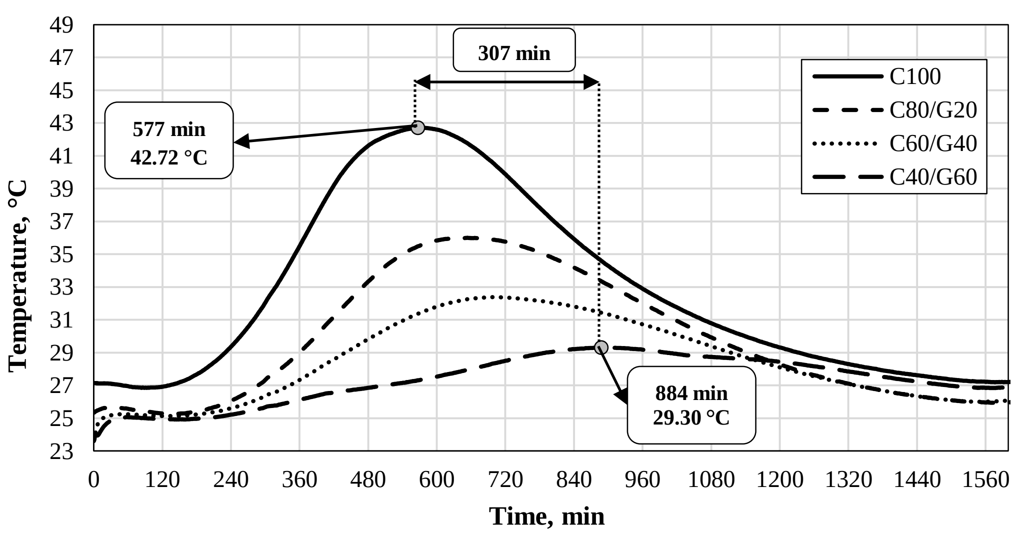

Fig. 37. Effect of uncleaned waste glass powder on Portland cement hydration phase

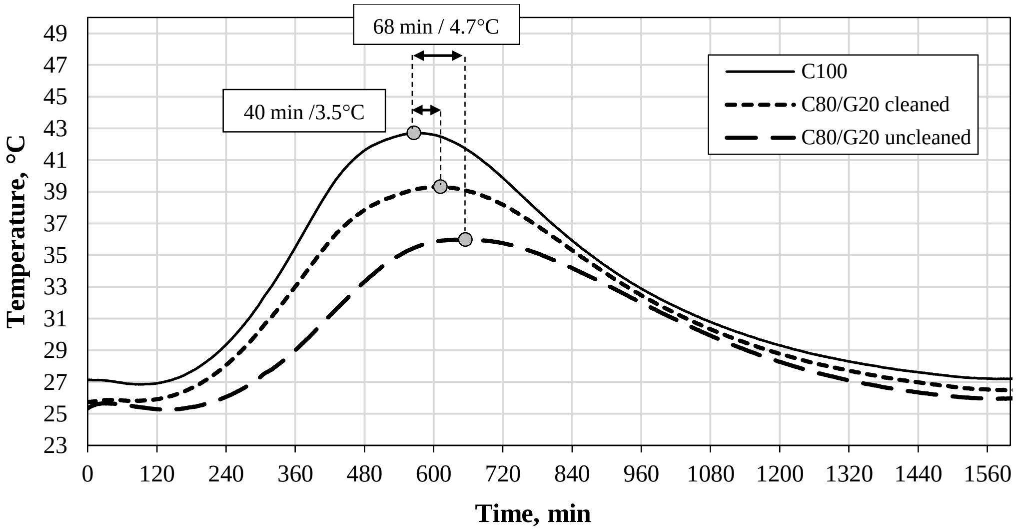

Fig. 38. Comparison the effect cleaned and uncleaned glass on Portland cement hydration phase

4.4. Workability of freshly made concrete

According to Fig.39, the diameter of the flow spread test is gradually expanded by adding additional waste glass powder. The flow diameters for C51/G49 (with 13% more glass powder) to C26/G74 (with 38% more glass powder) are between 20 cm and 24 cm suitable, while the C13/G87 (with 51% more glass powder) paste with a diameter of 26 cm is not.

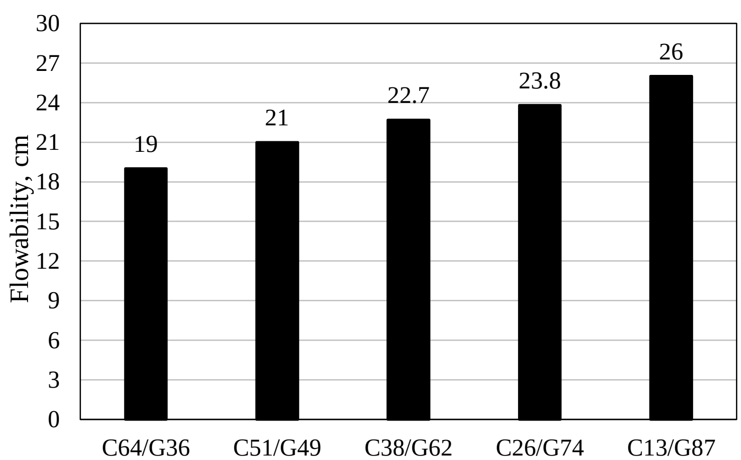

Fig. 39. Effect of waste glass powder on Flow ability

Fig. 40. Measuring the cement paste circle

4.5. Density

According to Fig.41, the density rose in the 13% glass powder paste (C51/G49) during the non-thermal cured duration before beginning to decrease. Therefore, it makes sense that the greatest density, 2324 kg/m^3, is likewise for (C51/G49). However, for thermal cured, it returns to the non-thermal cured pattern, the density first increases on C51/G49 and then reduces from C51/G49, C38/G62, C26/G74 and C13/G87 gradually. Another interesting point is that the density of the reference sample (C64/G36) and the one with 26% more waste glass powder (C38/G62) are almost the same in thermal and non-thermal cured conditions.

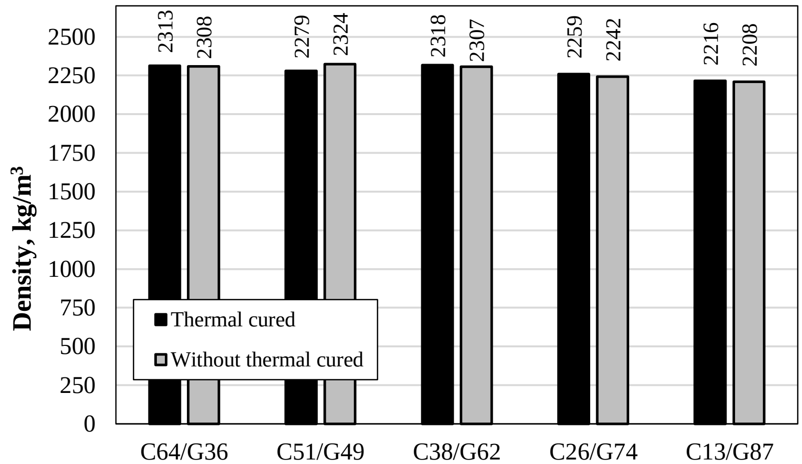

Fig. 41. Glass powder concrete density with and without thermal cured

4.6. Compressive strength of UHPC with glass powder

Mechanical properties are an important factors for construction materials. We performed the compressive strength test to find the highest load, which specimen can bear before it cracks. For Mechanical research, we made 5 different samples. The first one is Reference with 64% cement and 36% waste glass powder, and then we substitute glass powder for 13%, 26%, 38% and 51% of the cement. The first 5 Ultra-high performance concrete samples were cured at 27℃, which is the room temperature in that period of time that experiment is done. After leaving the samples for 28 days, laboratory tests including those for compressive strength and density were undertaken..

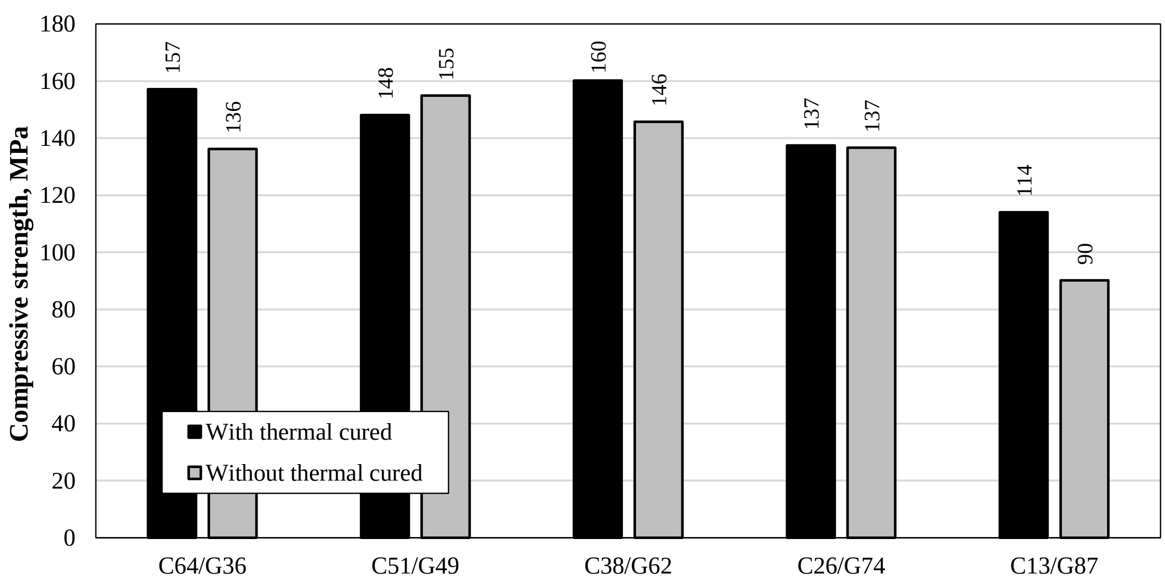

Fig. 42. Compressive strength with thermal cured and without thermal cured

The readings were noted down and calculated manually. According to the outcome (Fig.42), increasing the quantity of waste glass powder substituted causes to grow the strength of samples by 13%–26% before falling in compressive. The strength of samples with 38% less cement, without thermal cured, is roughly equivalent to that of the reference. It implies that we can use 38% less cement while maintaining the same compressive strength. The sample containing 26% more waste glass powder and thermally processed had the maximum compressive strength (160.1 MPa). Additionally, it demonstrates that the sample containing 13% more waste glass powder (154.9 MPa) has almost the same compressive strength as the thermally cured reference (157.1 MPa). Another interesting fact is that even when the composition was substituted with 51% of cement by glass powder, compressive strength reached 90 MPa. It means by having less than 1/6 portion of cement (13%) and 5/6 portion of waste glass powder (87%) as a binder still it has 90 MPa compressive strength. One of this high strength result is glass powder structure, which is high specially compare to cement particle.

4.7. Determines the water absorption rate and porosity

Fig.43 and Fig.44 show that there are generally three phases for water absorption and that nearly all samples follow the same pattern. The first phase begins when we submerge the samples in the water and lasts for 60 minutes, during which time it slightly improves. The second phase is detected between 60 minutes and 24 hours with a significantly increased rate of water absorption. The last phase extends from 24 hours to 1 week, during which the rate of water absorption increases once more but with a less steep slope than in phase 2. For both normal and thermally cured materials, C38/G62 had the greatest water absorption rate at 3.49 and 2.89, respectively. The remaining 4 samples can be divided into two distinct groups with nearly identical behavior during all three phases. The first group consists of the two samples C64/G36 and C51/G49, whereas the second group consists of C26/G74 and C13/G87. In the first group, the rate decreased by around 20% for without thermal cured and 45% for thermal cured, while in the second group, the rate decreased by about 50% for without thermal cured, if we use the sample C38/G62 as a benchmark. For thermal cured, the sample C26/G74 and C13/G87 have dropped by 63% and 77%.

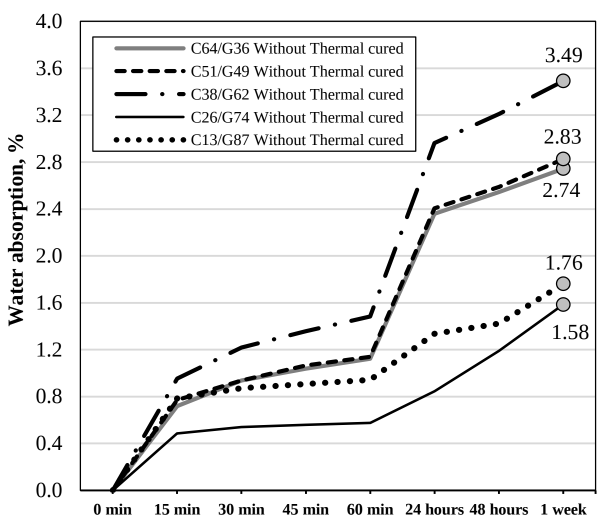

Fig. 43. Water absorption without thermal cured

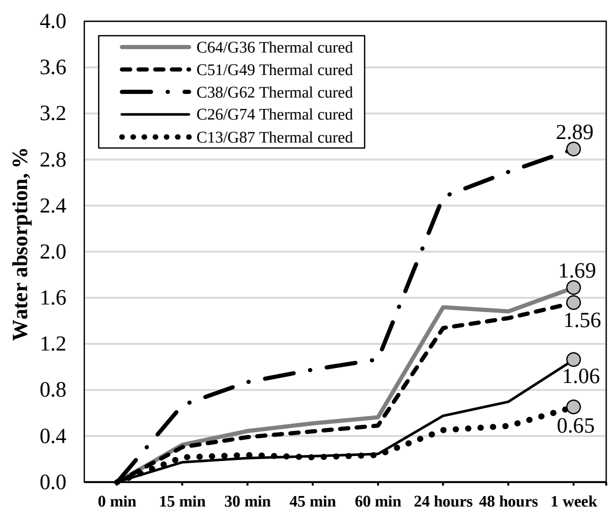

Fig. 44. Water absorption with thermal cured

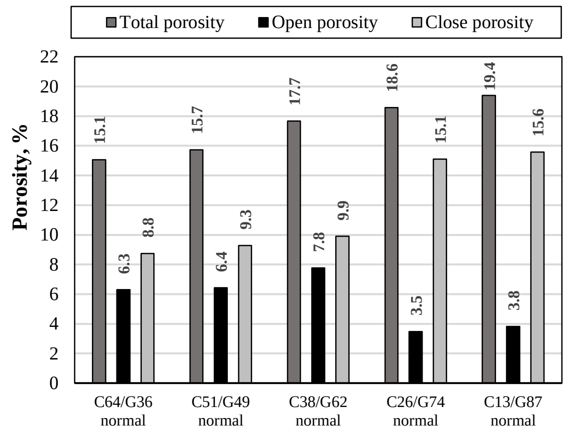

Fig. 45. Porosity of samples without thermally cured (total, open, close)

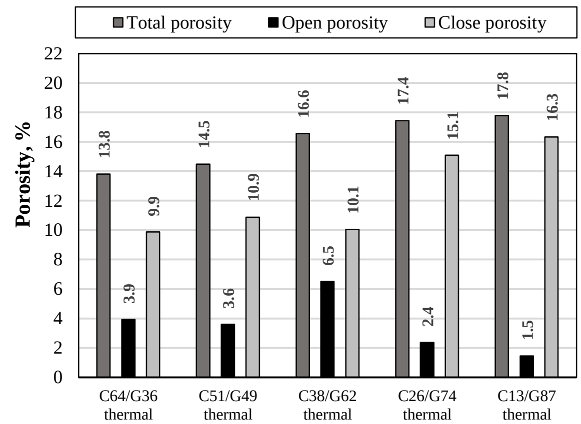

Fig. 46. Porosity of samples with thermally cured (total, open, close)

Fig.45 and Fig.46 make it clear that adding more waste glass powder, instead of the same quantity of cement, increases the overall amount of porosity in both with and without thermally cured samples by 13%, 26%, 38%, and 51%, substituted waste glass powder.

The C13/G87 has the greatest overall porosity, at 19.4. The open porosity of waste glass powder follows the same pattern for thermally and non-thermally cured samples, and it shows almost the same amount for C64/G36 (the reference sample) and C51/G49 (13% more waste glass powder substitution). Following a rise in C38/G62 (with 38% more waste glass powder), there is a sharp decline in 38% and 51%. Open porosity is decreased to half for normal and one-third for thermal. On the other hand, closed porosity displays the same trend as closed porosity, although, for samples made up of more glass powder (38% and 51%), it rose by around a third. From these findings, we understand that the particles of waste glass powder can block all of the routes, which we known them as the micro-cracks, that create the open porosities and considerably reduce their quantity. As a result of the lack of Pozzolanic reaction compared to cement, which caused it to stay an unreacted particle, it also increased the amount of overall porosity.

After all, we can understand A strong linear relationship appears between the two parameters of samples, open porosity and water absorption rate (Fig.47).

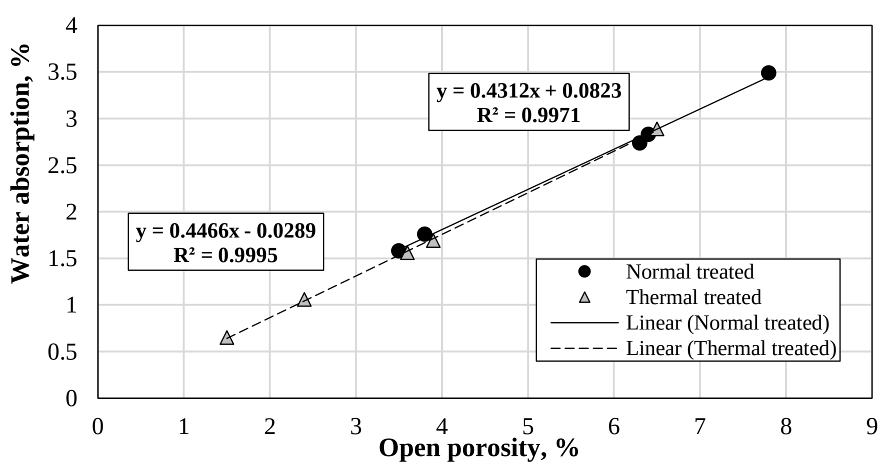

Fig. 47. Relationship between open porosity and water absorption

The total porosity gradually increases by increasing the quantity of waste glass powder in the concrete throughout both with and without thermal processing. It is evident that any sample that has been thermally cured has less overall porosity than a sample that has been without thermally cured. We can see that sample C38/G62 has the highest relative water absorption rate and the maximum open porosity when compared to the other 4 samples. After all, it is clear that the two sample parameters of open porosity and relative water absorption rate have a strong direct linear relationship with a slope of 0.44.

4.8. Resistant to salt-scaling

From spring through winter, samples for the salt-scaling experiment were appropriately checked every week. More than 166 cycles have passed, as indicated in Fig. 48, and all of the samples are still in their original shapes without any cut parts. On sample C38/G62, which was without thermally cured, and sample C13/G87, which was both thermally and normally cured, just a few tiny little microdots are visible. And microscopic dots that even it is not possible to gather and weigh.

The samples C38/G62 with thermal cured have not changed, but the samples without thermally cured have a few tiny small spots, indicating that the samples with thermally cured have more resistance to salt-scaling than the one without thermally cured. Tiny dots in the non-thermally cured sample C13/G87 are obviously more than those with thermally cured, which has the same outcome as the behavior of C38/G62 samples.

The outcome demonstrates that by reducing the amount of cement and increasing the amount of waste glass powder in its instead, the samples' long-term resistance is nearly equal, and they can withstand salt-scaling quite well. There was only a little spot for the samples C13/G87.

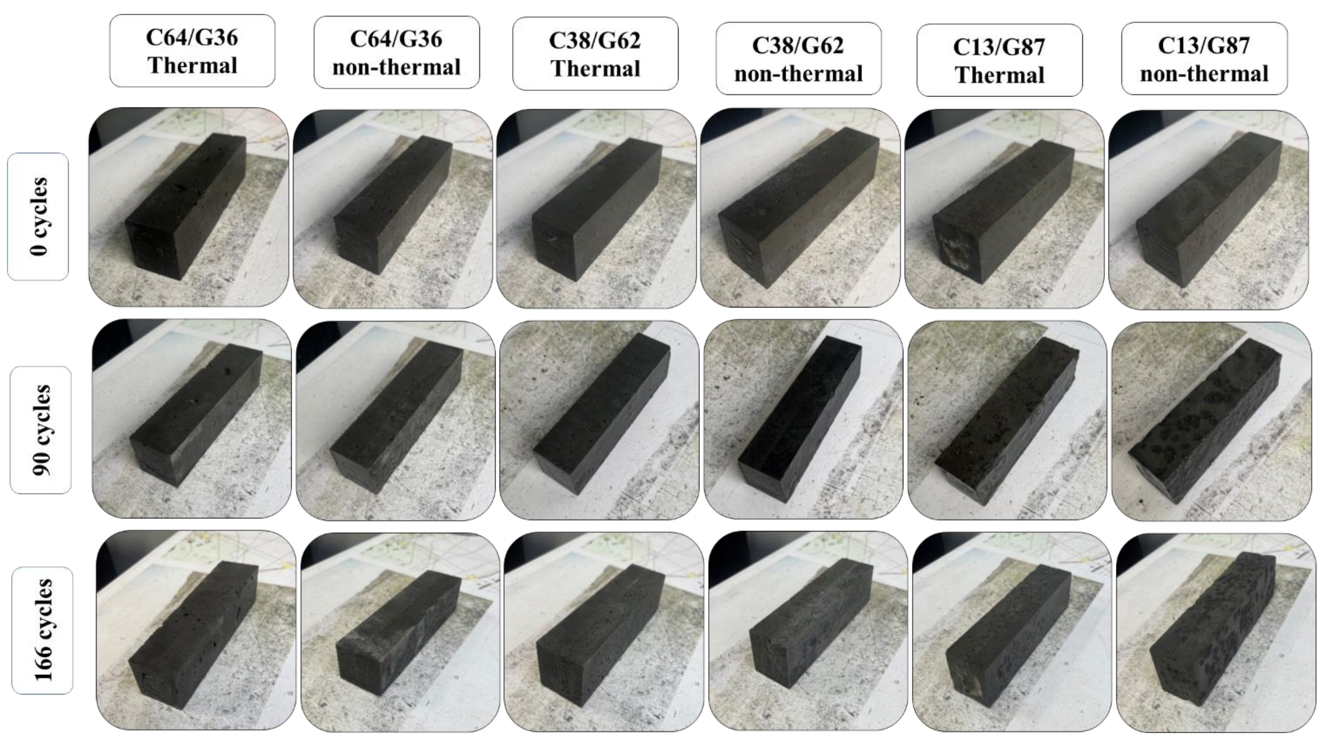

Fig. 48. Samples photo after 90 and 166 cycles of salt-scaling

The examination demonstrates that samples that have been thermally cured have greater resistance to salt-scaling.

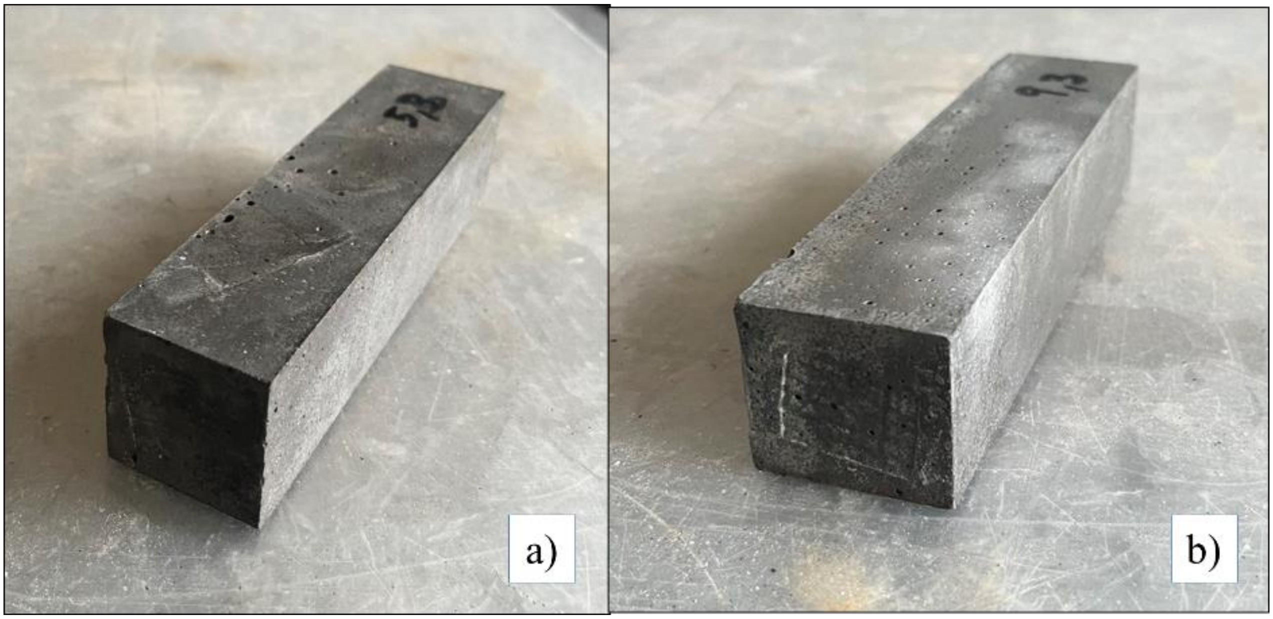

Fig. 49. Pictures of samples with thermal cured in 0 cycles: a) C38/G62, b) C13/G87

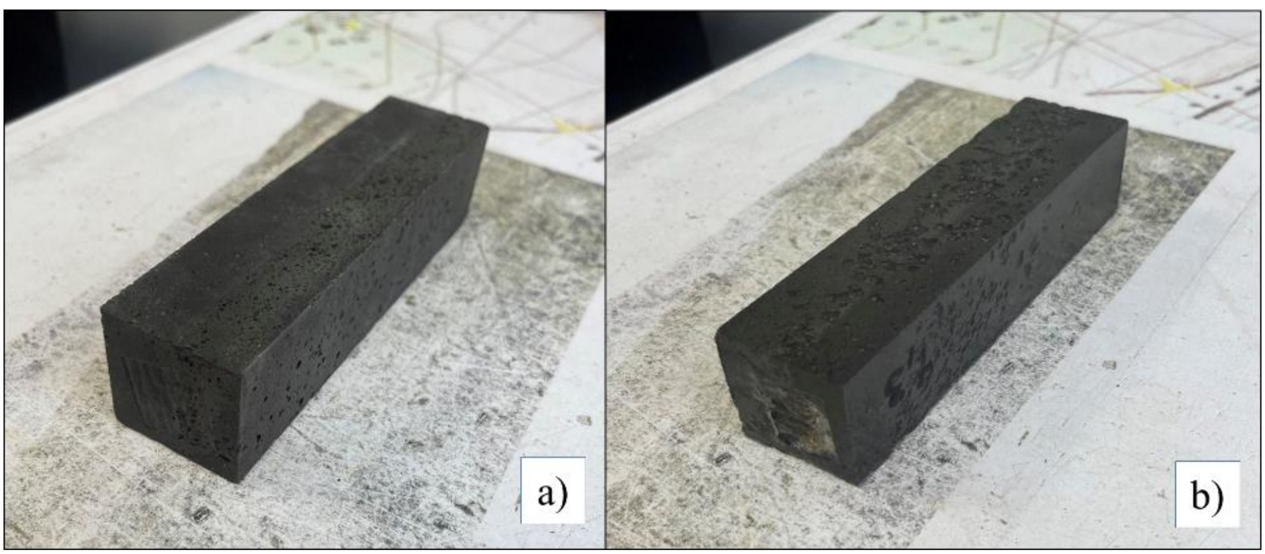

Fig. 50. Pictures of samples with thermal cured in 166 cycles: a) C38/G62, b) C13/G87

Conclusions

After all, we could select the sample with the ideal composition, quantity of waste glass powder, and curing condition. The following information was extracted from two distinct types of waste glass powder with two distinct curing types and varied proportions.

1. The optimum time of milling is at the first area with the highest SSA and time slope with 27.8, which has the endpoint with 75 minutes milling time and 3592.45 (cm^2/g) specific surface area.

2. In the hydration experiment, the temperature dropped by 10.8°C in the washed glass paste during the hydration process, but by 13.4°C in the unwashed glass paste. Therefore, by reducing cement by 60%, the quantity of heat will drop by 25.28 % for washed glass and by 31.36% for unwashed glass. So paste with washed waste glass has better properties.

3.1. The best samples for compressive strength are C51/G49 with 49% waste glass powder by 154.8 MPa, which is cured non-thermal, and C38/G62 with 62% waste glass powder by 160.1 MPa for thermally cured. It indicates that we can achieve 13.6% higher strength by using 13% less cement and 13% waste glass powder.

3.2. In comparison to thermal cured, the rate of water absorption is significantly higher during non-thermal cured. C38/G62 has the greatest water absorption rates of 3.49 and 2.89 for with and without thermal cured, respectively.

4. It is clear from a salt-scaling perspective that all of the samples have a strong resistance to the experiment. There is still no significant physical change when 51% of the cement (total amount of cement in sample is 13%) is replaced with that quantity of cleaned glass powder (total amount of cleaned glass powder in sample is 87%), but there are a few tiny microcracks, that are noticeable. In sample C38/G62, without thermally cured, shows a few small micro-spots that are visible but no significant physical change and the thermally cured one shows no change at all.

Still there are more parameters need to be consider such as shrinkage, and it is suggested to be considered in future researchs.

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Annex

I also particpate during this master program in other activities:

1. Lithuania Language course A1 (6 ECTS).
2. Join the KTU running team.
3. Participate in 2 Lithuanian student sport festival.
4. Participate in 2 Lithuanian student running (LITHUANIAN STUDENT CROSS).
5. Join the KTU Statybos ir architektūros fakulteto studentų atstovybė (FSA) STATIUS.
6. Earn certificate „Introduction to Programming with MATLAB“ from coursera at Varderbilt university by KTU university fund.
7. Earn certificate „Sustainable Regional Principles, Planning and Transportation“ from coursera at Johns Hopkins university.
8. Earn certificate „Sustainable Neighborhoods“ from coursera at Johns Hopkins university.
9. Earn certificate „Lean Six Sigma White Belt“ from Council for six sigma certification.
10. Circular economy for Materials Processing (CircPro for Masters) at Tallin University of Technology in Estonia and funded from European Institute of Innovation and Technolgy (EIT). (6 ECTS)
11. Student scientific conference „SMART BUILD ENVIRONMENT“.

VANDERBILT UNIVERSITY

COURSE CERTIFICATE

Nov 9, 2021

Siavash Salehi

has successfully completed

Introduction to Programming with MATLAB

an online non-credit course authorized by Vanderbilt University and offered through Coursera

Akos Ledeczi, Ph.D.
Professor
Computer Engineering, Computer Science, and Electrical Engineering

J. Michael Fitzpatrick, PhD
Professor Emeritus
Computer Science, Computer Engineering, Electrical Engineering, Neurosurgery, and Radiology

Verify at coursera.org/verify/LKSCSN7DS956

Coursera has confirmed the identity of this individual and their participation in the course.

JOHNS HOPKINS UNIVERSITY

COURSE CERTIFICATE

Dec 20, 2022

Siavash Salehi

has successfully completed

Sustainable Regional Principles, Planning and Transportation

an online non-credit course authorized by Johns Hopkins University and offered through Coursera

William Roper PhD, PE, SES
Professor
Whiting School of Engineering

Verify at:
coursera.org/verify/K6CNGUR7T2VY

Coursera has confirmed the identity of this individual and their participation in the course.

JOHNS HOPKINS UNIVERSITY

COURSE CERTIFICATE

Dec 23, 2022

Siavash Salehi

has successfully completed

Sustainable Neighborhoods

an online non-credit course authorized by Johns Hopkins University and offered through Coursera

William Roper PhD, PE, SES
Professor
Whiting School of Engineering

Verify at:
coursera.org/verify/RE8U2TFCT95H

Coursera has confirmed the identity of this individual and their participation in the course.

LEAN SIX SIGMA WHITE BELT

Certification that

Siavash Salehi

Has satisfactorily completed and has demonstrated proficiency in the curriculum set forth by the Council for Six Sigma Certification to be awarded the title of Certified White Belt.

Managing Director

Certification Number: k3kI9yCBDV
Certification Date: December 21st, 2022

STUDENT SCIENTIFIC CONFERENCE

ktu 1922 faculty of civil engineering and architecture

CERTIFICATE

Siavash Salehi

Has participated in Student scientific conference
„SMART BUILT ENVIRONMENT"
on 25 November 2022

Delivered the presentation:

Methods to Convert Municipal Solid Waste Glass to Beneficial Micro-Fiber and utilize it as a Partial of Cement in Ultra-High Perfomance Concrete

Dean of the Faculty of Civil Engineering and Architecture

Prof. Dr. Andrius Jurelionis