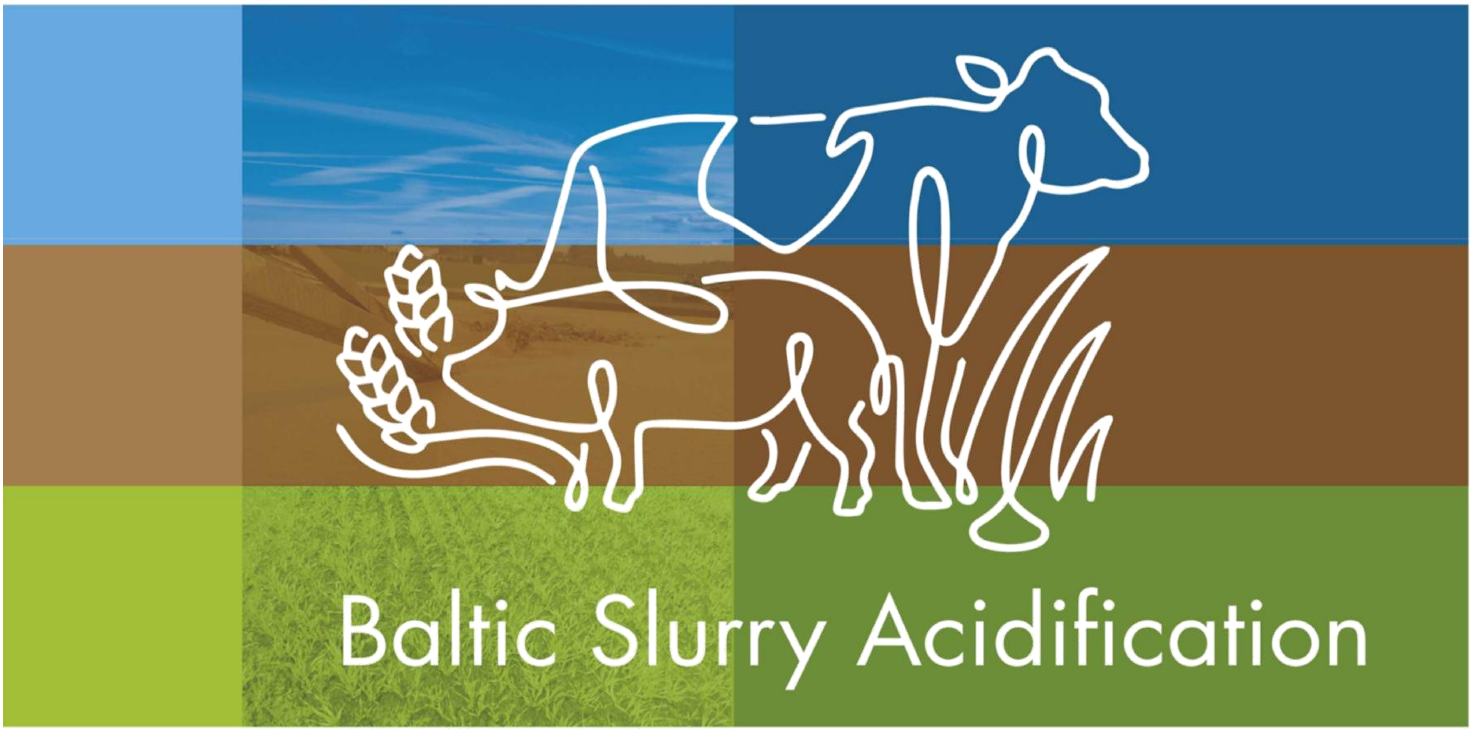

Equipment quality evaluations

Report from WP2, Activity 2

Literature review and evaluation tests of concrete and other materials

Konrad Rudnik, Janusz Młynik, Jan Barwicki, Kamila Mazur, Michał Kuźniar, Bogdan Łochowski, Lena Rodhe

April 2019

Interreg
Baltic Sea Region
Baltic Slurry Acidification

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

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Contents

Preface

Baltic Slurry Acidification is a flagship project in the action plan for EU strategy for the Baltic Sea Region (BSR). The project is being carried out between 2016-2019 with a budget of 5.2 million euros, of which 4 million euros is funded by the EU Regional Development Fund through the Interreg Baltic Sea Region Programme.

The general aims of the project are to reduce ammonia emissions from animal production and create a more competitive and sustainable farming sector by promoting the implementation of slurry acidification techniques (SATs) throughout the Baltic Sea Region. This report falls under Work Package 2, Activity 2.

Implementation of the acidification technique for SATs is associated with materials, from which tanks are made or will be in the future storing slurry, must meet technical requirements, both inside and outside livestock buildings. The purpose of the report is to provide an overview of the equipment being used most often in the countries of the Baltic Sea Region in slurry management systems, in particular in the field of slurry storage. Most often, slurry channels in buildings and separate slurry tanks in Europe and other parts of the world are made of concrete, that's why the research part of the report was devoted mostly to this material.

Experiences gained in the field of these studies will also be used in acidification systems for in-house slurry management - which are in Denmark the most popular, compare to "in field" and "in storage" systems. The report is also an attempt to answer the question whether and to what extent acidified slurry affects the structure of the concrete and how corrosion affects the reinforcement elements compared to non-acidified slurry.

April 2019

Erik Sindhöj
Project Coordinator for Baltic Slurry Acidification

Summary

The report summarize the results of two-year studies on the effect of slurry acidification to pH 5.5 on the quality and structure of concrete classes frequently used in the countries of the Baltic Sea region.

The quality analysis was made as part of the technical feasibility study of the WP2 package, including equipment utilized in the slurry management chain, with special attention on elements heaving contact with acidified slurry, taking into account the lower pH of slurry due to acidification using sulfuric acid.

Analysis of equipment and materials, including concrete testing, offered on the market by producers in the countries of the Baltic Sea region allows to provide statement that they are suitable for acidified use of slurry. In many cases, the elements are made of stainless steel as well as materials resistant to acidic environment, whereas it is recommended for concrete use of sealing additives and the class of concrete must be at least C30/35. The authors recommend the use of materials produced on the basis of synthetic resins, in particular silicone resins, epoxy and polyurethane.

The increase in the strength of concrete samples stored in a wet environment can be attributed to the reaction inducing swelling and filling the open spaces with growing etryngite crystals, the occurrence of which confirmed the results of microscopic examination. Breaking forces in case of strength increase are lower than tensile strength of concrete. After a 21-month test period, samples of concrete class C25/30 placed in acidified slurry environment were still classified as C25 / 30, while samples of concrete class C30 /37 were classified as higher class C45/55. The tests have shown that the compressive strength of concrete of classes C25/30 and C30/35 is increased till 12th month of experiment, then in the following months occurs stabilization of the compressive strength of concrete. This phenomenon applies to concrete samples stored in the environment of water and slurry. For concrete class C25/30 in the period between 18 months and 21 months, concrete samples stored in the acidified slurry environment show a slight decrease in the average compressive strength (2%). With regard to the maximum compressive strength obtained during the entire test period, the decrease is equal 10.9%. For concrete class C30/37, the decrease in compressive strength is 2.8%, with respect to the maximum compressive strength obtained during the entire test period.

For samples with thickness of reinforcement cover 2 mm the strength of concrete on bending in acidified slurry is lower than water (17%) and lower than non-acidified slurry by 6.58 %. For samples with thickness of reinforcement cover 7 mm the strength of concrete on bending in acidified slurry is lower than water (11%) and lower than non-acidified slurry by 15.8%. For samples with thickness of reinforcement cover 17 mm lower than water (10%) and lower than non-acidified slurry 3.14%. Destruction process in concrete reinforcement caused by acidified slurry is larger in by-surface layers compared with non-acidified slurry and water. Bending strength increases with with cover thickness in all environments and for all cases of cover thickness.

The maximum value of strength of C 35/45 concrete for bending was obtained for a 7mm thick cover , which means that this layer provides sufficient protection against corrosion of the concrete-steel contact zone and ensures good adhesion of concrete to steel.

However, to assess the exact risk of negative impact of acidified slurry for concrete used for the construction of slurry channels and slurry tanks, it would be necessary to continue tests for many years in the future.

1. Introduction

Physical properties of the slurry

The physical properties of the slurry have a negligible effect on the corrosion of concrete utilized to build reservoirs or components exposed to direct contact with the slurry. There was no information found in literature about that. An interesting issue can be the ability of the slurry to seal porous materials as concrete. Studies conducted by Nieborowski and Sapała have shown significant differences in the viscosity of the slurry from different farms [1].

The viscosity depends on various factors such as the degree of dilution, animal nutrition, the sampling depth of the tank. The highest slurry viscosity was achieved in the top layer [1]. The average value of the slurry viscosity is equal 10 cP. Slurry as part of a mixture of liquid and solid has a greater coefficient of dynamic viscosity than water. The viscosity of the slurry from pigs is slightly higher than the viscosity of bovine one.

Dynamic viscosity for slurries in particular limitations of dry matter (DM) and particular temperature 20 ^{o}C is calculated based on equations:

For dairy cows: $\mu = 4\cdot 10^{-5} \cdot DM^{4,4671}$

For pigs: $\mu = 4\cdot 10^{-5} \cdot DM^{4,6432}$

Where μ- dynamic viscosity [Pa·s], DM- dry matter [%]

The viscosity of the slurry depends on the solid percentage content, biochemical and isothermal processes. In physical terms, the slurry can be defined as a liquid similar to the composition of water in which solids are dissolved in an amount of up to 10%. Viscosity and solid particules in the slurry have an impact on the material that it filtrates through, which is porous concrete where it seals the pores.

Sealing of the pores of the concrete may be caused by mechanical filling the pores in the surface layer, and because of chemical influence from the slurry on concrete components as shown in the section on chemical impact of slurry on concrete.

Due to the fact that slurry viscosity is greater than waters the filtration will proceed more slowly. A more convincing confirmation of this hypothesis was obtained by the microscopic examination of slurry treated concrete structure and comparison with the concrete structure treated using pure water.

Chemical corrosive effect of influence of slurry components on concrete

On the basis of literature review, it can be stated that the chemical composition and physical slurry properties generally vary in between individual studies [2].

To establish a clear border between the influences of corrosive parameters of slurry on concrete is virtually impossible eg. corrosive slurry was found already in 1972 [3]. An aggressive activity on concrete have the following water-soluble ions:

- sulfide S^{2-}
- sulphate SO_4^{2-}
- chloride Cl^-

- calcium Ca^{2+}
- magnesium Mg^{2+}
- ammonium NH_4^+

In addition to these ions there are aggressive gaseous compounds:

- hydrogen sulfide H_2S
- carbon dioxide CO_2
- ammonia NH_3 .

Hydrogen sulphide, carbon dioxide as anhydride of carbonic acid H_2CO_3 have corrosive properties, because of its acidic nature, which lower the pH of the slurry. Ammonia in the atmosphere of water vapour, aggressively acts on the free calcium Ca, which is present in the concrete, and as a result of this phenomenon, it reduces strength of the concrete. The process can be described by the equation:

$Ca + 2NH_4OH = Ca(OH)_2 + 2NH_4$

Corrosion of the concrete in the environment of slurry occurs because of the reaction of ammonium ions NH_4^+ and chloride Cl^- with calcium oxide contained in the concrete:
$2NH_4^+ + 2Cl^- + CaO = CaCl_2 + 2NH_4OH$

The formed calcium chloride $CaCl_2$, is easily leached from the concrete. According to [4], the fresh slurry has higher pH compared with stored slurry.

With each passing day of storage the pH is lowered at a rate of 0.03 at 20 °C and 0.027 at 18 °C. The process of pH lowering takes place within 25 days [4]. Carbon dioxide in the first stage reacts with calcium hydroxide:

$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O$

to form a sparingly soluble calcium carbonate. The carbon dioxide continues to react with calcium carbonate to form soluble calcium bicarbonate by the formula:

$CO_2 + CaCO_3 + H_2O = Ca(H_2CO_3)_2$

In concrete tank with slurry having a pH below 7, acid corrosion will be present. Such corrosion is the reaction of hydrogen ions of strong mineral acid as HCl, H_2SO_4, according to the reaction:

$Ca(OH)_2 + 2H^+ = Ca^{2+} + 2H_2O$

Calcium ions form salts of acidic residues readily soluble in water. It is followed by leaching of some of components of the cement binder, resulting in an increase of porosity of the concrete and, consequently, decrease of concrete strength what leads to the destruction of the concrete structure.

According to [5], the presence of sulfate ions SO_4^{2-} would cause sulfate corrosion. After exceeding the concentration of sulfate ions in a soluble form above 250 mg / litre, ions react with the components of the cement binder, especially with calcium ion. As a result of this reaction calcium sulfate $CaSO_4$ is produced, and crystallizes as a salt dihydrate or after combining with tricalcium aluminate forms Candlota salt, using formula:

$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$

The first transformation is accompanied by reactions of swelling due to the connection of crystallization water. The increase in the volume of subsurface layers of concrete results in stresses, cracking and chipping. In the first phase of corrosion cracks and scratches appear on the surface and only later are followed by the destruction of the concrete by chipping.
Stages of destruction according to [6] are as follows;

I. Hydrated calcium sulphate

$$Ca(OH)_2 + SO_4^{2-} = CaSO_4 + 2OH^-$$

$$CaSO_4 + 2H_2O = CaSO_4 \cdot 2H_2O$$

II. Forms of monosulfates aluminate

$$3CaO \cdot Al_2O_3 + CaSO_4 \cdot 2H_2O + 10H_2O = 3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O$$

Forms of Candlota salt

III. $3CaO \cdot Al_2O_3 + 3CaSO_4 \cdot 2H_2O + 26H_2O = 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$

Also according to [7] the above reactions lead to the formation of a highly expansive ettringite crystal. During the crystallization, it fills the concrete slits and then exerts on the pore walls the pressure slots leading to the microcracks in the concrete structure. Etryngite leads to damage only in hardened concrete. In fresh concrete, the phenomenon of destruction does not occur due to its ability to accumulate deformation. Sulfate ions cause internal and external corrosion. Internal sulfate corrosion, is caused by calcium sulfate ions $CaSO_4$.

Outer sulfate corrosion occurs when sulfate ions come, for example, from sulfated groundwater, acid rain or acidified sulfuric acid slurry. Sulphate ions present in the environment move deeper into the concrete due to diffusion and react with the concrete components. According to [7], the following conditions have to be met in order for external sulfate corrosion of concrete:

- *high permeability of concrete;*

Under external corrosion conditions, sulfate ions must penetrate deep into the concrete structure. If the concrete will be sealed, the diffusion will be slow and corrosion may not occur,

-*an appropriately high concentration of sulfates in the environment;*

Ettringite crystallizes in capillaries. Until the capillaries fill, the crystals do not pressurize the material. In the case of low sulfate ions, the size of the crystals will be too small to fill the pores and then destroy the concrete.

- *the occurrence of water;*

Concrete is a porous material. Results of works [8, 9] show that greater porosity has an influence on sulfate diffusion velocity and more ettringite can be formed at a certain time leading to faster concrete destruction. Capillary porosity depends on the water-cement ratio. The higher the ratio, the greater is the porosity of the concrete.

Figure 1 shows graphically the combination of conditions for the occurrence of external sulfate corrosion.

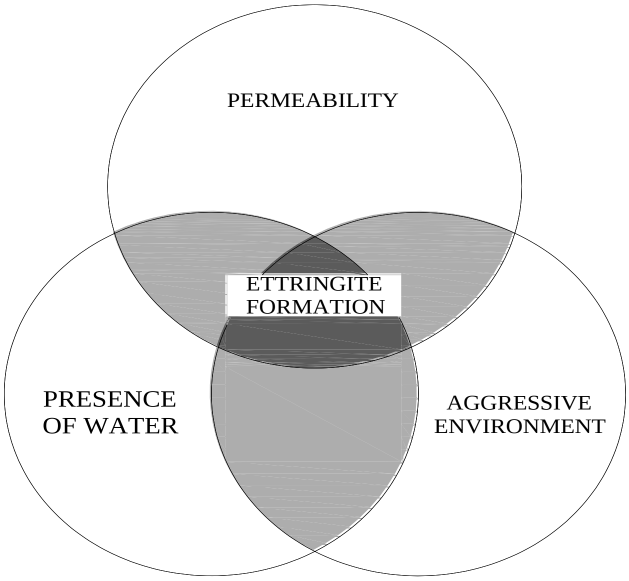


Fig.1. Conditions necessary for the occurrence of sulfate corrosion
Source: [7]

Data on the corrosive action of nitrate ions NO_3^-, which are present in the slurry in an amount comparable to ions NH_4^+, Cl^-, was not encountered in the literature. Ions NO_3^- can interact with calcium oxide CaO contained in the concrete to form calcium nitrate $Ca(NO_3)_2$ compound very soluble in water, which can result in damage of the concrete structure.

$Mg^{2+} + 2NO_3^- + CaO = Ca(NO_3)_2 + MgO$

2. Literature review

2.1. Concrete storage

2.1.1 Legal rules concerning storage of liquid animal manure, Poland example

Storage of liquid manure in Poland is governed by the following rules;

a) The Act of 10 July 2007 concerning fertilizers and fertilization.

Diary of Law of 2007 No. 147 pos.1033

Art.25.1 says "liquid manure and slurry can be stored only in sealed containers with a capacity allowing collection at least four-month of manure collecting. These tanks should be made as closed type".

b) Regulation of the Ministry of Agriculture and Rural Development of 25 March 2013 on the technical conditions to be met by agricultural buildings and their location, **Diary of Law of 2013 pos.472.**

§ 6.1 says, "for removal and storage of animal manure should be applied devices and agricultural buildings suitable for utilization of breeding technology". Closed tanks for liquid manure should have;

- bottom part and walls impermeable,

- sealed cover, with the exception space for liquid manure located under slotted floor and being a part of a livestock building, which forms the technological system of animal breeding,

- ventilation inlet and closed entrance cover.

The procedure for the approval of construction products for marketing or making available on the domestic market is governed by the Act from 2016. Item 1570 on construction products. Production and introduction to sale of tanks or their components may take place on the basis of documents: Declaration of Conformity with the Polish Standard or the Harmonized European Standard.
Where the construction of the tank and materials used are different from those covered by the Standard, the manufacturer must obtain a National Technical Assessment and then issue a Declaration of Conformity. In this case, the National Technical Assessment is a reference document. As of 1.01.2017 a system of placing on the market or making available on the domestic market of products construction is in force. The term Technical Approval replaced the term National Technical Assessment.

According to legal regulations Building Law From 2016, the construction of a liquid manure / liquid manure / slurry reservoir / must be preceded by obtaining a permit for construction. For tanks with a capacity of up to 25 m^3, only an investment application is required.

2.1.2. Storage constructions and associated materials on the example of Poland

Concrete tanks are the most common on the farms in Poland. It can be assumed that 95% of the implemented versions of tanks are prefabricated or monolithic one. The production of monolithic version is carried out on construction site where to the prepared forms, liquid concrete is poured. Prefabricated version means that the components of the tank are produced in the factory and then transported to the site where they are assembled.

Monolithic tanks are constructed by a lot of companies /tens / both on the basis of their own technical documentation and entrusted.

Prefabricated tanks are offered by manufacturers in a variety of construction solutions:

- *Reinforced concrete*

- *Box-shaped tank* divided into two parts of top and bottom. The lower part consists of a bottom plate and four walls. The upper part is a prefabricated reinforced concrete slab with a service hole and ventilation hole. Tank capacity of 8.m^3. with concrete class C 25/30. Producer PH-U Grzegory Grzegorz Zduny.

- *Reinforced concrete tank in the shape of a cylinder* with a vertical longitudinal axis. The elements are manufactured with a groove and tongue on the connector is applied mortar suitable for sealing an appropriate exposure class. The capacity of the tanks is produced from 3,5m^3 to 16,9 m^3. The required capacity is obtained by using the appropriate amount of the intermediate elements in the form of circles. Concrete class is C 40/45. Manufacturer MATBET CONCRETE sp. o.o. Sady. Tarnowo Podgórne.

- *Reinforced concrete wall elements combined with steel connectors and flooded expansive concrete mix*.

Tank consists of prefabricated wall shell to be arranged on a monolithic disc or ring footing. Precast are connected with each other by steel loop connections. The wall elements form closed chambers are poured using expansive concrete. Horizontal lines are made of seals based on EPDM (Ethylene Propylene Diene Monomer) rubber. The capacity of the tanks to be installed depends on the diameter, height, are adapted to the needs of the investor and may be carried out from 30 to 1884 m^3. The concrete class is C 30/37. Manufacturer POOL - POL Wladyslaw Rybak Minsk Mazowiecki.

- *All reinforced concrete elements are combined with the system of screw connections and plugs* that are protected against corrosion. The height of the tank can range from 1m to 3 m. The seal between the elements of the tank provide vertical and horizontal connections and flexible operation of the structure. Offered tank capacity is equal from a few dozen to a few thousand of m^3. The modular buildings allows to configure the tank according to the construction conditions. Manufacturer of the product is Prefabricated Reinforced Concrete Co.in Radomsko.

- Concrete pre-stressed, compressed in two vertical directions, to the circumference of the steel cables, so that they are resistant to such external variable load i. e. temperature. Vertical joints are sealed with EPDM seal. Tanks type ACONTANK C8 are made of concrete class C 40/50, capacity from 145 m^3 to 3100 m^3. Tank height is from 3 m to 8 m. Manufacturer PRECON POLAND Warsaw (part of Swedish company ABetong).

- *Reinforced concrete, flooded locking ring wall elements in the floor* are downloaded by steel cables. The number of cables depends on the height of the tank wall. Tank height ACOTANKTM 6 is from 3 m to 8 m. The tank capacity can vary from 182 m^3 to 7650 m^3. Concrete used for the elements is class C 35/45. Manufacturer is PRECON POLAND from Warsaw.

Storage of slurry in concrete tanks. Materials and construction solutions

Tank shape and level of foundation

The cost of tank construction is the most decisive factor. The shape does not affect the technological processes of filling, storing and emptying the tank but is important in the process of slurry homogenization /mixing/. Due to the statics of the structure, a cylindrical tank with a vertical axis is preferred. In this system there is an uniform distribution of loads which affects the minimum material consumption. Due to the level of foundation, concrete tanks are built as underground, ground or partially underground.

Tank construction

Reinforced concrete tanks are made on the construction site with elements manufactured in a prefabrication facility called prefabricated tanks, while molded preformed formwork on site are called monolithic tanks. In Sweden, however, majority of tanks is made from prefabricated elements. Concrete reinforced tanks are always strenghten with steel rods.

In tanks for animal liquid manure there is always steel in the form of reinforcement, or less often in the form of restressing steel. The task of reinforcing steel is to transfer tensile stress, but the task of concrete is to transfer the compressive stresses that occur in the tank. In the case of pressurized containers, the steel compression elements are designed to pre-squeeze the tank so that there are no tensile stresses during operation.

In prefabricated tanks, the assembly consists in assembling, bringing together and sealing. Transport restrictions /mass, dimensions / cause that tanks with a capacity of up to several m^3 are transported to the place of construction in its complete form, but with higher capacity in the form of components. The class of concrete used in prefabricated tanks is higher than in monolithic tanks and is usually C30/37, C35/45 where the numbers mean the level of strenght on compression. This is for several reasons, such as minimizing the mass, the possibility of damage to the component during transport or assembly.

According to the legal regulations in Poland tanks for liquid animal manure must be covered. On small capacity tanks or underground, a reinforced concrete cover is build. On terraces and larger capacities / larger diameters / roofs are made of elastic materials such as EPDM plastics. In the middle of the tank is mounted wooden or plastic mast on which is based light construction of roof. Both the mast and the roof are resistant to the acidic environment of stored manure. In tanks with a diameter of over 8.0 m with reinforced concrete cover, a reinforced concrete pillar is used. On the column and reinforced concrete wall are prefabricated elements of the roof or reinforced concrete plate.

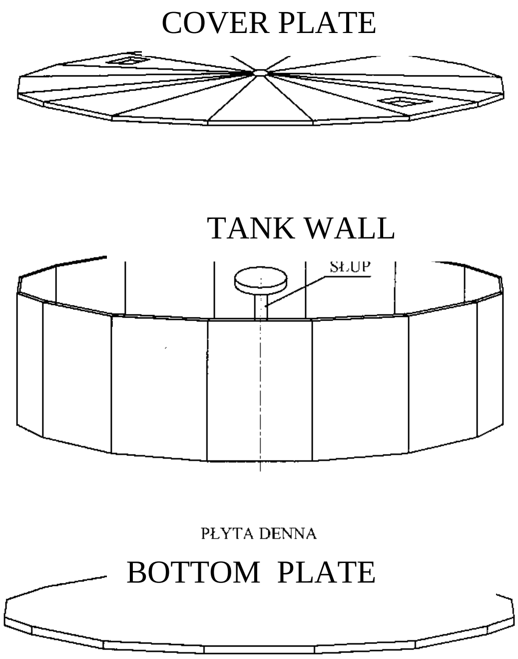


Fig.2. Prefabricated reinforced concrete tank

2.1.3 Methods of corrosion protection of the tank for acidified slurry

Anticorrosion protection of reinforced concrete tanks for acidified slurry

The aggressive medium that is acidified slurry requires that the tank design not only take into account the safe transfer of internal forces, but also takes into account the safe operation of the tank for its intended use [10]. Tightness of the tank is a fundamental characteristic of the tank and is described by an admissible crack width.

Occurrence of cracks

According to [11] the tanks are classified according to leakproof requirements. Slurry storage tanks are designed in 3rd or conditionally in class 2 leak proof. For classes 2 and 3, the value of width of junction Wk_1(width of cracks) is limited to a self-sealing value or special solutions, for example, in the form of lining.

Requirements for admissible width of cracks at designing

The maximum crack width (Wk_1) is defined as the function of the hydrostatic pressure on wall; For $hD \cdot h^{-1} \leq 5$ $Wk_1 = 0.2$ mm

where; h_D- hydrostatic pressure

h - wall / section thickness of the element /

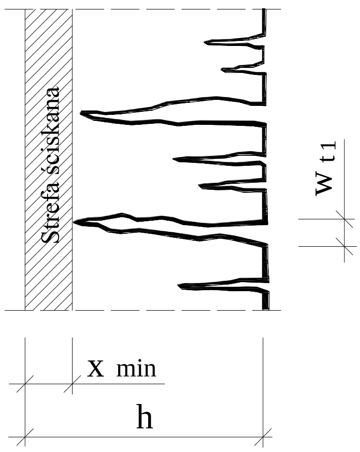
Wk_1-width of the crack

for:

$hd \cdot h^{-1} \leq 35$ $Wk_1 = 0.5$ mm

For intermediate values $hD \cdot h^{-1}$, linear interpolation between values of 0.2 and 0.05 can be used.

For Class 2 and Class 3 structures, we will obtain tank tightness, cracks will not cross the entire section thickness in the case where the computed range of the compression zone if, the x_{min} value is limited to calculated value for the quasi-constant interaction. The recommended xmin value can not be less than 50 mm and 0.2 h at the h-wall thickness / cross section of the element/. Fig.3.



Source: ITP Own study
Fig.3 The occurrence of cracks in a concrete element.

In case of occurrence in the considered cross-section of opposing marks, cracks may occur, covering the full thickness of the element, thereby allowing the tank leakage [11].

The crack width can be calculated from the formula:

Wk = sr, max (εsm-εcm)

where:

$s_{r,max}$- maximum cracks spacing (mm)

ε_{sm}- average deformation of reinforcement (mm)

ε_{cm}- average deformation of concrete between crack (mm)

According to [12], for the sealing class 2, the possibility of crack formation at the entire cross-sectional height should be eliminated unless special solutions in the form of lining, sealing strips are applied. For sealing class 3, special solutions are required in the form of compression presented on figure 4 or sealing linings.

Source: ITP
Fig. 4. Prestressed concrete tank

Waterproof coatings are used in tanks where the integrity and resistance to chemical aggression and corrosion are to be maintained. Material solutions are mainly conditioned by the technology used.

Insulation outside and inside the concrete storage tank
First, priming of concrete should be done under base and external sides of walls. Next, in case of concrete tanks it is very common to use outside on the walls bitumen emulsion with layer of minimum 3 mm**.** Insulation inside the storage tank should protect against chemical and biological corrosion. Bitumen mixtures have high resistance on sulphurs and nitrates and is very tight although only 3 mm thickness is demanded. In places of vertical and horizontal joins very useful are sealing materials and plastificators.

There are three technological groups:

***- Pressure impregnation* [13]**

As an impregnate, multi particulates polymer can be used. In Poland, there are literature cites only, concerning solutions and laboratory research without implementations in production facilities [13].

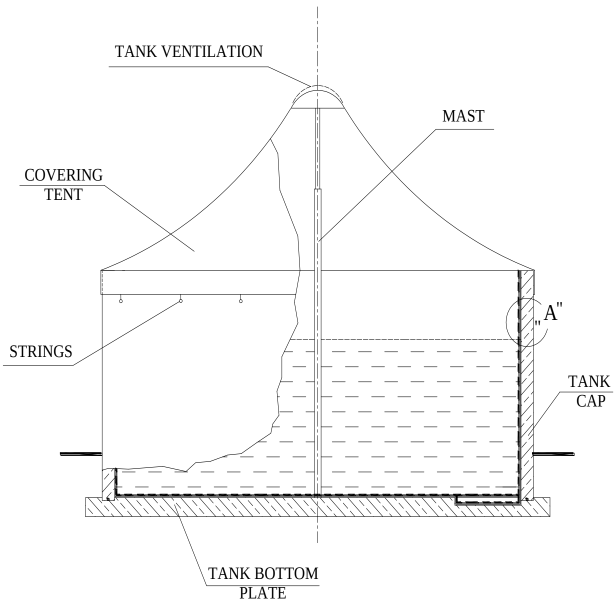
- *Impregnation with surface saturation* [14] [15]

The easy implementation of security and the availability of material resources, have made this method widely used in Poland and abroad. The authors recommend the use of materials produced on the basis of synthetic resins, in particular silicone resins, epoxy and polyurethane.

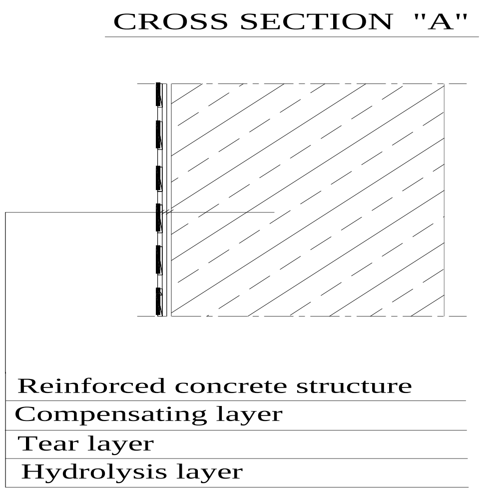
-Chemical resistant cover

The coating formed by impregnation with surface impregnation, for example polyurethane, has bridging properties, does not allow penetration of acidified slurry into the concrete [16].

Figure 5 shows the tank sealing solution used in the XA2 aggressiveness class. The detail of the solution is shown in figure 6.



Source: Own study
Fig.5. Reinforced concrete tank on medium with aggressiveness class XA2



Source: Own study
Fig.6. Sealing coat in concrete tank. Detail of the solution

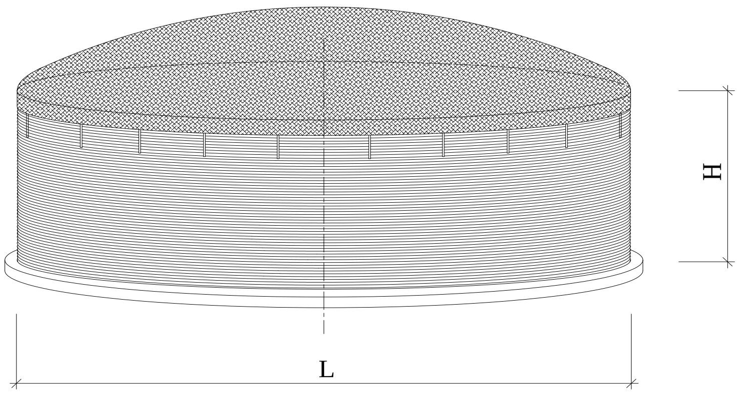
The inner sealing shell of the tank consists of three layers. The first layer, thixotropic epoxy resin cement mortar has the task to level the substrate and the inability to pull moisture under the layer of polyurethane. This 2 mm thick layer is applied directly to the concrete structure. Another layer, is a two-component epoxy resin with quartz sand coating. The purpose of this layer is to primer the substrate and to adjust the absorbency. The third layer, waterproof polyurethane based coating is applied by spraying. The resulting coating is characterized by: tightness / continuity of coating / resistance for chemical aggression, UV resistance, bridging capability, resistance for abrasion [17].

Comparative studies [18] of chemically resistant coatings of concrete elements are described in the literature. Concrete samples were protected by means of water-glass form and epidural 5 epoxy resin with Z-1 hardener. Aggressive factor was 10% acetic acid. Accelerated studies in a pH 3 medium were conducted. The pH has changed spontaneously after 7 days to pH 5 and after 14 days to pH 6. Researchers [18] claim that the reason for the change is concrete showing alkali properties. Another layer, tacky is a two-component epoxy resin with quartz sand coating. The purpose of this layer is to primer the substrate and to adjust the absorbency. The results of the flexural concrete strength test showed the highest values for the secured samples by resin coating, achieved a higher durability of 65% compare to unprotected samples. The losses in surface of samples and protective layer was clearly visible at the time of removal from test medium. Particularly unprotected samples had surface defects, resulting from leaching of soluble salts. After the break, you can see the depth to which it occurred corrosion. Samples impregnated with water glass showed changes in strength 10% higher on bending compared to unprotected samples. On samples with water glass showed corrosion marks, which showed a significant loss in mass and surface damage.

2.2. Storages made of other materials

2.2.1. Steel tanks

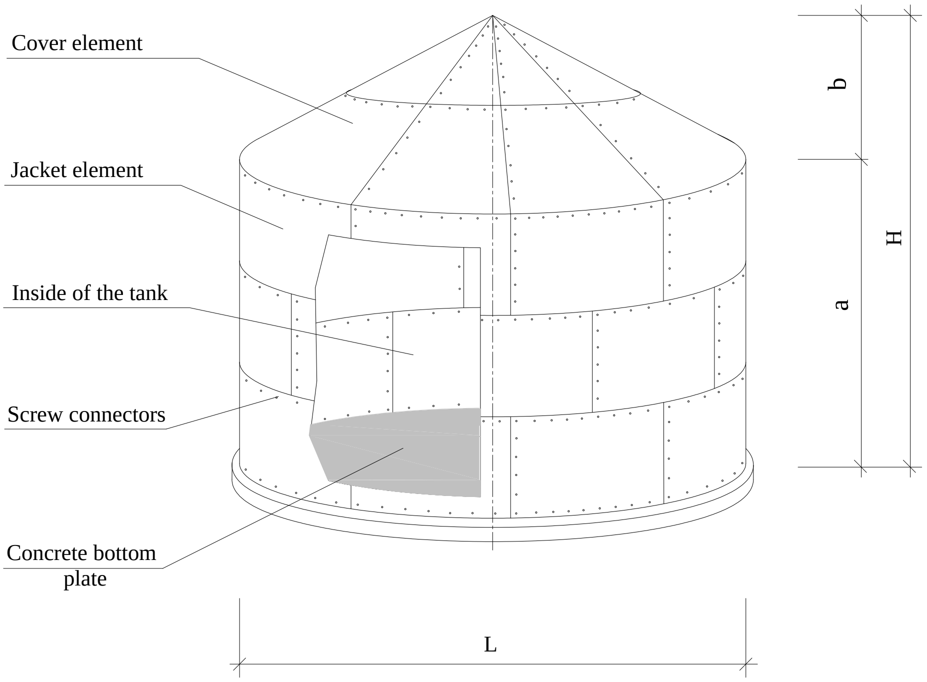
Due to labor-intensive costs, the cost of tile lining, moldings in agricultural media tanks are not applied, whereas the lining in the form of films mechanically bonded to the mantle / wall construction was used for example in BUWATEC steel tanks, (Fig. 7.).



Source: own elaboration
Fig. 7 BUWATEC steel tank with elastic roofing

Tanks are built only on ground version. The walls are made of corrugated steel sheets. The sheets are protected with zinc layer and 200 µm of Plastisol. The plastic coating has a high resistance to mechanical damage, resistance to acids, alcohols and bituminous materials, UV resistance. Wall panels are bolted together on the construction site. Tightness of the membrane is made of 1mm thick PVC or alternatively EX polyolefin EPDM film. The diaphragm prevents the medium from contacting the surface of the sheet metal. PVC as well as other sealing inserts for tanks are resistant to aggressive environmental effects in this acidified slurry. The tank is mounted on a reinforced concrete ring. The bottom of the tank is an even layer of sand on which the geotextile lies, with a membrane such as PVC on it. The tank is covered with a flexible roof made of impregnated fabric or foil. The roofing takes the shape of a dome by forced air from the blower. The roof structure is self-supporting without a support element and is resistant to wind, rain and snow loads. Another solution is to set the plastic pole in the center of the tank. Between the head of the column and the shell of the tank stretches the strings on which the elastic roofing is laid. The capacity of offered tanks is from 151 m^3 to 1776 m^3 while the tanks' diameters range from 7.28 m to 30.95 m.

Steel tank type VITKOVICE



Source: own elaboration
Fig.8 Steel tank type VITKOVICE

The tank [Fig. 8] is characterized by total chemical resistance to media occurring and utilized in agriculture. The casing of the tank is assembled on both sides enamelled steel plates. The enamel is a homogeneous, smooth coating of silicate glass burnt on metal. The enamel is bilayer, fired at temperatures above 800 °C. The sheets are joined with special screws and sealed with a permanently elastic kit. The roof can be constructed in a form of a flexible coating, sheet metal covered with enamel based on construction or in a self-supporting version. Joints and jacket accessories are provided with surface protection. Chemical resistance of the tank is in the pH range of 2-13. The manufacturer guarantees a 40-year shelf life. The capacity of offered tanks is from 21 m^3 to 10218 m^3 and the diameter of tanks varies from 4.29 m to 42.00 m.

2.2.2. Plastic tanks

Plastics are used for the production of tanks; Polyethylene PEHD, polypropylene, fiberglass reinforced resins. These materials are completely resistant to the aggressive effects of agricultural agents including urine and slurry. Because of their physical properties and cost, plastics have found limited use in liquid manure storage systems mainly as drainage wells and tanks with a capacity of up to several dozen m^3.

Companies OLTRANS and POMOT offer fiber glass reinforced tanks (Fig. 9 and 10).

Source: OLTRANS
Fig 9. Transportation of OLTRANS plastic tanks

Source:www.pomot.pl
Fig. 10. Plastic slurry tanker with trailing hoses.

3. Industry and manufacturers views

3.1. Storage

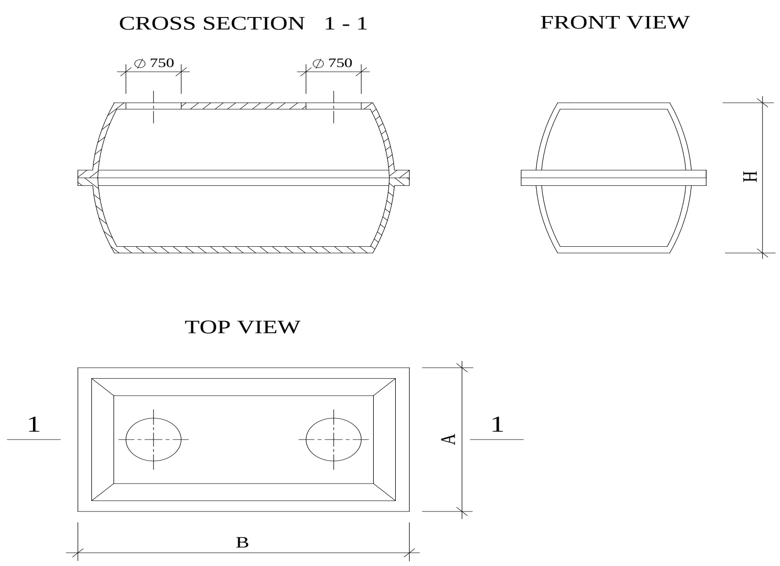
Overview of offers of concrete tank manufacturers

The most popular on farms are concrete tanks. It can be assumed that they represent 95% of the monolithic and prefabricated tanks in Poland. The monolithic version is implemented on the construction site where concrete is poured in the prepared molds. Prefabricated version means that the components of the tank are produced in the plant and then transported to the construction site where they are assembled. Monolithic tanks are made in Poland by a lot of companies, both on the basis of own documentation and developed by specialized offices.

Prefabricated tanks are offered by manufacturers in various construction solutions.

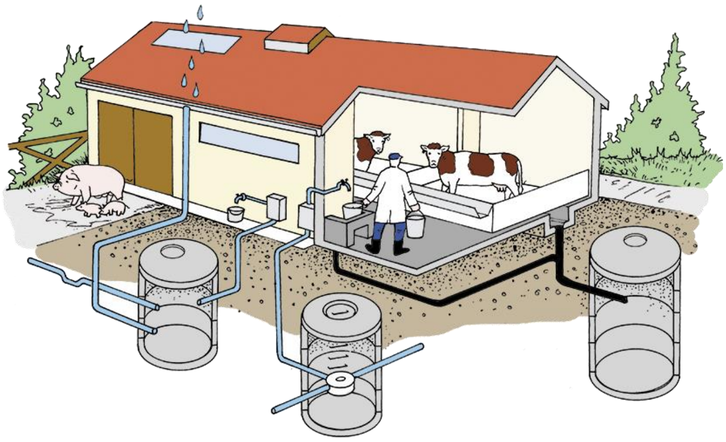
Reinforced concrete with steel

Horizontal hull shaped tank consists of one lower and one upper sections. The upper part is a prefabricated reinforced concrete slab with manhole openings and ventilation opening. The tank elements are sealed and then bolted. Capacity of tank 12-24 m^3. Concrete class C 35/45. Manufacturer: Sienkiewicz MAT-BUD Co. 04-761 Warsaw, Zwoleńska Str. 64a



Source: Manufacturer Mat-Bud
Fig. 11. Reinforced concrete tank ZTB

Reinforced concrete cylinder with vertical longitudinal axis. The components are manufactured with a groove and a tongue, the appropriate sealing mortar suitable for the exposure class is applied to the joints. The capacity of produced tanks, used for temporary slurry storage, is from 3.5 m^3 to 16.9 m^3. The required capacity is obtained by using a number of vertex intermediate components. Concrete class C 40/45. Manufacturer MATBET BETON Co. Rolna Str. 12, SADY, 62-080 Tarnowo Podgórne.



Source: Manufacturer Matbet Beton
Fig. 12. Application of Matbet Concrete tanks in animal production facilities.

Reinforced concrete elements of walls joined by steel connectors and flooded with expansive concrete mix.

The tank consists of prefabricated wall shells set on a monolithic plate or annular footing. Prefabricated items are interconnected by steel loops. The facing wall elements form closed chambers that are flooded with expansive concrete. Horizontal connections are made of EPDM rubber gaskets. The capacity of the mounted tanks depends on the diameter, the height is adapted to the needs of the investor and can range from 30 m^3 to 1884 m^3. Concrete class C 30/37. Manufacturer BASEN – POL, Władysław Rybak, str.Stankowizna 28A, 05-340 Mińsk Mazowiecki.

Reinforced concrete components joined by screws and bolts system, which have factory made corrosion protection.

The height of the tank can range from 1 m to 3 m. Seals between the tank elements guarantee the tightness of vertical and horizontal joints and flexible construction. The capacity of offered tanks ranges from several dozen m^3 to several thousand m^3. Modular construction allows you to configure the tank to suit the installation conditions. Manufacturer KAN Co. Radomsko Reinforced Precast Fabrication Company, str.Główna 142, 97-410 KLESZCZÓW.

- reinforced concrete, prestressed in two directions vertically, circled with steel cables, so that they are resistant to external stress such as temperature. Vertical joints are sealed with an EPDM gasket. ACONTANK C8 tanks are made of C grade 40/50 concrete, capacity from 145 m^3 to 3100 m^3. Tank height ranges from 3 m to 8 m. Manufacturer PRECON POLSKA Co., 00-001Warszawa, str. Domaniewska 47.

Reinforced concrete with steel

The wall elements, flooded in the backing ring in the bottom plate, are tied with steel cables. The number of cables depends on the height of the tank wall. The height of the tank ACOTANKTM C6 is from 3 m to 8 m. The tank capacity can range from 182 m^3 to 7650 m^3. Concrete elements used to make tank are Class C 35/45. Manufacturer PRECON POLSKA Co., 00-001Warszawa str. Domaniewska 47, (Figure 13).

Fig. 13. Reinforced concrete tank with cover. Photo by: B. Łochowski

3.2. Other equipment

Slurry pumps

Nowdays, majority of pumps used for slurry pumping, offered in the BSR countries has proper quality of technical parts that have direct contact with slurry with low pH value. Producers such as: Oberbacher Holzner, Bauer, Meprozet EVAC (series EWS) offer pumps entierly made of stainless steel (class AISI 316), the consequent high price is the only disadvantage. Additional sealing of oil chamber is made from Viton or other material like silicon carbide for high resistance against corrosive media.
Obviously, when taking into account older slurry equipment, sometimes grey cast iron was used for such pumps. New pumps avoid grey cast, which is only resistant against attrition and its weigh is high. Seals in all types of slurry pumps have proper quality.

Slurry tankers

Producers of slurry tankers offer tanks with special protective cover made from plastic, such companies are active on the market in Sweden, Denmark and Poland like Goma (also Goma Poland), Samson. Polish producer of slurry spreaders POMOT Chojna offers tankers with special dedication to wastes with acidic pH, which are fully acid resistant. Other companies (fe. Meprozet) offer tankers with special painted covers, the same like they use for sulphuric-urea solution. Sulphuric-urea solution is supposed to have similar influence on tankers to acidified slurry.

Slurry mixers

Typical slurry mixers have contact with slurry through propeller blades. Popular companys Bauer, Oberbacher Holzner, Meprozet Koscian, Metal-Technik, Stallcamp, offer slurry mixers with strong protection against corrosion from acidified and non-acidified slurry. Their propellers in most cases are made from stainless steel, as well as self-bonded carbides.

Slurry applicators

Slurry applicators should be resistant to lower slurry pH in case of all types of SATs: in-house, in-storage and in-field.

Regarding elements of SAT's equipment, the producers offer under warranty the exchange of most system parts such as pipes, connections, but is only for acidifying elements of equipment.

4. Concrete qualities on market in BSR

Tables 1 and 2 show main characteristics of concrete commonly used for slurry tanks in BSR countries, which were collected during the project.

Table 1. Characteristic of concrete used in BSR countries
Source: own elaboration

Country	**Standard**	**Element**	**Type of cement available on market**	**w/c ratio**	**Additives**	**Concrete density** kg/m3
EE	EVS-EN 206:2014	Wall	Portland	min 0.5	Fly ashes	2400
EE	EVS-EN 206:2014	Base	Portland	min 0.5	Fly ashes	2400
LV	LVS EN1992-1-1:2005	Wall and base	CEM II	0.4 - 0.6	Fly ashes	from 2000 to.2600
PL	PN-EN 206:2014	Wall	CEM IIIA and CEM IIIB	0.45	None	from 2000 to 2600
PL	PN-EN 206:2014	Base	CEM IIIA and CEM IIIB	0.45	None	from 2000 to 2600
SE	SS-EN 206:2013	Storage wall elements	CEM II	0.5	Fly ashes	2400
SE	SS-EN 206:2013	Storage base	CEM II	0.6	Fly ashes	2400

Table 2. Characteristic of concrete used in BSR countries- continuation. Source: own elaboration

Country	Element	Compression strength (cylindrical /cubical), MPa	Exposure class to environment	SO_4 penetration, mg/l (Slurry pH)	Materials for joint/sealing elements
EE	Wall and base	C30/37	XF1, XC4		Rubber sealant
EE	Wall	C30/37	XF3, XC4		Rubber sealant
LV	Base	C30/37	XA1	600 - 3000	Bentonite sealant
PL	Storage wall elements	C 25/30	XA2	200 -600 (pH 6.5-4.5)	Bentonite sealant
PL	Storage base	C 30/37	XA2		Bentonite sealant
SE	Wall	C 35/45	XF1, XC4		Expansive concrete
SE	Base	C 25/30	XC2		Expansive concrete

Clarifications: w/c ratio = water: cement; C 25/30= Classes of compression strength (MPa) for samples cylindrical/cubical form, XA3, Class for exposure to enviroment in soil and groundwater; XF3- Freeze/Thaw attack. Max w/c ratio 0.5, cement content min 320 kg/m^3, min air content 4%, the filling material must have Freeze/Thaw resistance by standard EN 12620; XC4- Corrosion induced by carbonation, max w/c ratio 0.5, cement content min 300 kg/m^3

Cement used for concrete producing should be resistant against SO_4, SR / HSR. The basic satandard in BSR countries, which regulates requirements and describes concrete features for building of slurry tanks is EN-206-1[19]. The pH of stored slurry after acidification should be from 5.5 to 6.0, depending on slurry storage period and techniques “in-house” or „in-storage” **[**20].

If concrete does not fulfill rquirements of EN-206-1 standard, some special solutions should be applied, for example: tightness of the tank or its chemical ressistance could be improved by using special coating preparates.

Differences between particular BSR countries regarding design-building practices result from climate differences. For example in Estonia detailed requirements for aggressive freezing/defrosting without de-icing agents are taken into account- class XF1 for tank’s walls, class XF3 for bottom plate.The common element for Estonia and Sweden is detailed requirement of resistance against carbonatisation of constructions exposed to atmospheric air and building according to class XC4. The overview of tanks available in Poland allows to state, that requirement of classes XC1 to XC4 is not considered at all because of slow process of carbonatisation and lack of significant influence during 30-years period of tanks exploitation. Also impact of freezing is not considered, when planning construction of concrete for special purposes, including slurry storage (classification XF1, XF3). In Poland, particular requirement, which is taken into consideration by designing of slurry tanks is resistance to chemical agrressiveness of construction elements having contact with SO_4^{2}- ions, which are present in the slurry (classification from XA1 to XA3). In particular by pH from 5.5 to 6.0, when acidified slurry is stored, only classification XA1 and XA2 are considered. Also in Estonia such classess are used.

In Poland majority of existing slurry tanks are produced from concrete of class C25/30. These tanks were made during last 20-25 years. Nowdays, new tanks in Poland are made from concrete of higher classes. In Estonia similar reqirement is used, namely for class XA1.

In Estonia, Latvia and Sweden popular additives to concrete are fly ashes. In Poland additives to concrete improving its tightness are available and are used for specific concrete classess.

Non constructional tighting elements before introduction to market by producers/distributors, have to fulfill requirements of national technical assessment. This assessment is a document, in which requirements and usage features of construction products are included.

Concrete production in Poland

In recent years, the concrete productionin Poland tends to increase, and in 2016 it was 20.4 mil m^3. In previous years, the production of concrete is presented in Table 3.

Table 3. Production of concrete in Poland
Source: Own study

Year	Production [million m^3]
2013	18
2014	19,2
2015	19,8
2016	20,4

The main recipients of concrete are:

- development apartment Complexes

- construction of infrastructure / including railway infrastructure, energy and road infrastructure.

The scale of production puts Poland in 5th place in Europe. In Poland there are 530 producers of concrete products with 900 installations of concrete productions plants. There are 2850 concrete tracks and 650 concrete pumps. The average radius of operation of the concrete plant is about 25 km. Polish manufacturers of concrete in terms of equipment and technological preparation are equal to world manufacturers because they use the latest equipment as the leading companies producing concrete, with help of computer software. In the vast majority they are ready to produce even the most technologically advanced assortment of concrete and guarantee delivery to any place in the country.

Concrete production plants equipped with state-of-the-art innovative equipment ensure the production of high quality concrete mixes and guarantee the maintenance of reproducible product parameters. The high standard of production at the leading manufacturers of concrete also supports the quality management system compliant with the ISO 9001 standard and the factory production control system. The leading concrete manufacturers include [21]:

- Ozar Group

-Highland Heidelberg

-RMC Poland

-Dyckerhoff Poland.

Some concrete companies, such as CEMEX, are launching a product targeted at the industry. For customers of the agricultural industry, concrete is produced under the trade name AGRON. AGRON is a concrete characterized by exceptional density and tightness. Elements made of this concrete are waterproof and resistant to biological and chemical agents. Concrete is applicable to construction:

- urine and slurry tanks,

- wells,

- sewage,

- manure plates,

- foundation plates and foundations of buildings and agro technical infrastructure.

The activities of the producers of concrete are based on the basic component of concrete such as cement.

In Poland, all types of cement are produced in country, in 13 cement plants. Total production capacity is equal 24 million tons.

Major cement manufacturers are as follows:

-Górażdże Cement S.A

-Lafarge Cement S.A;

-Ozar Group S.A;

-CEMEX Polska Co.;

-Deckerhoff Polska Co;

-Warta S.A.;

-Odra S.A.;

List of types of cements produced in accordance with PN-EN 197-1: 2002 [21]standard is as follows [22, 23]:

-CEM and Portland cement without additives;

-CEM II Portland cement with additives (slag, silica, pozzolanic fly ash, shale, limestone, multicomponent);

-CEM III metallurgical cement;

-CEM IV pozzolan cement;

-CEM V multi-component cement

Based on the PN-B standard 19707 [24], special cements are produced in accordance with PN-EN 197-1: 2002;

- Low LH warmth element

-SR / HSR sulfate resistant cement

- Low alkaline cement

Sale of concrete in recent years, are presented in Fig. 14.

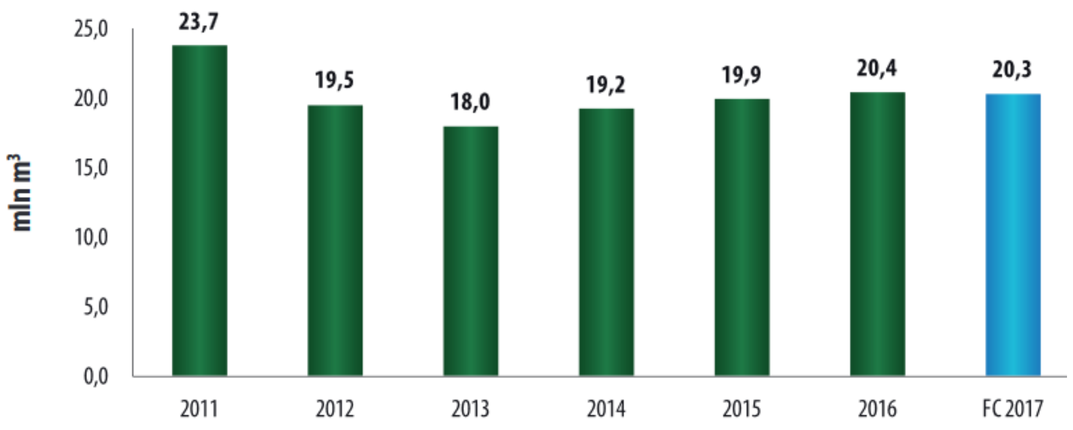


Fig. 14. Concrete sale in Poland, Source: [25].

In Poland cement is produced in bulk way and in bags, from which it is possible to produce all classes of concrete indicated in EN 206-1.

Table 4. List of concrete classes produced in BSR countries
Source: Own study

C 8/10	C 45/55
C 12/15	C 50/60
C 16/20	C 55/67
C 20/25	C 60/75
C 25/30	C 70/85
C 30/37	C 80/95
C 35/45	C 90/105
C 40/50	C 100/115

For concrete production the following aggregates can be utilized in accordance with EN 206: 2014:
- natural/gravel, broken
- activated/generated during the heat treatment of clay materials or raw materials from combustion by-products,
- with recycled/crushed hardened concrete from the structure,
- required/recovered by rinsing or crushing.

For the construction of tanks for liquid animal wastes it is suitable natural aggregates.
The usefulness of concrete aggregates must be determined in accordance with EN 12620 + A1: 2010 Aggregates for concrete [26].
The plants produce designed and formulated concrete according to the customer's instructions. Technology is supervised by certified laboratories [27]. In addition to conventional concrete, special concretes such as self-compacting concrete are also available, which are self-venting and compacting under their own weight. This type of concrete is especially recommended for the production of liquid-pressure tanks and where conventional thickening is difficult or impossible due to the access or large amount of reinforcement.

5. Tests of impact of acidified slurry on concrete. Polish studies

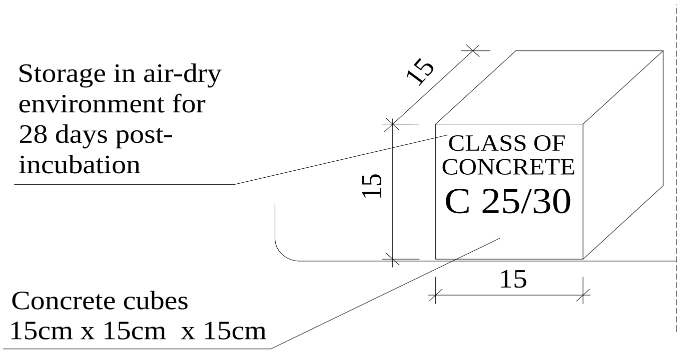
5.1. Concrete compressive strength tests

5.1.1. Introduction

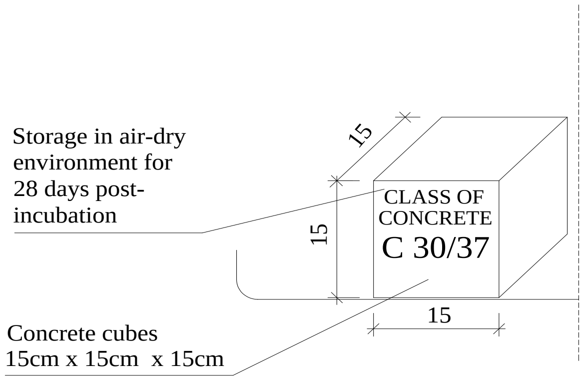
Compressive strength of concrete is a measure of the physical properties of concrete. In concrete samples stored in acidified slurry, chemical processes take place, that affect the quality of the concrete. The measure of the effect of the medium on concrete is the change in the strength of the concrete to the compression.

5.1.2. Goal, method and test program

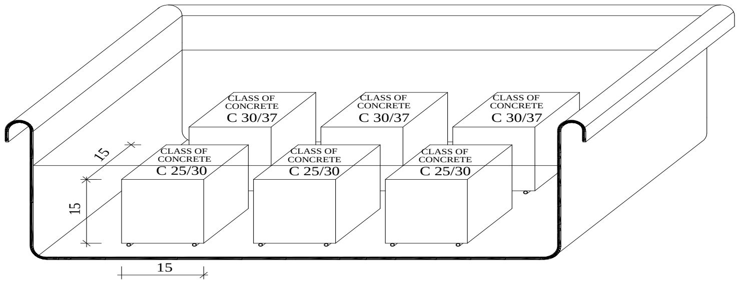
The main objective is to check the effect of acidified slurry on the compressive strength of concrete. The test will be conducted by a comparative method of compressive strength of concrete samples stored in acidified slurry with compressive strength of concrete samples stored in an air-dry environment, in a water environment and in a fresh slurry environment.



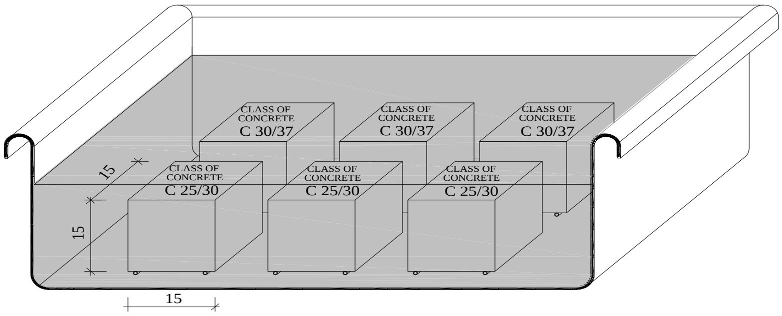
Source: Own elaboration
Fig. 15. Storage of concrete samples C 25/30 in air-dry environment



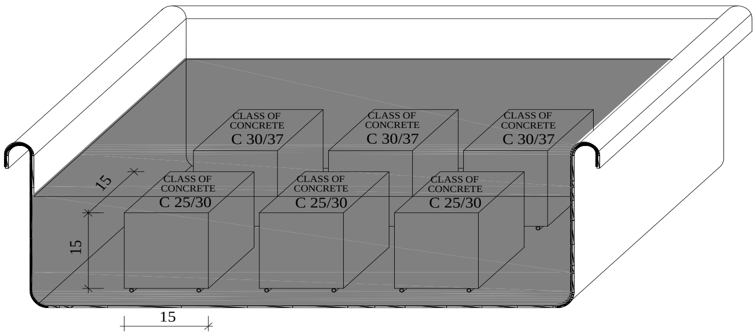
Source: Own elaboration
Fig. 16. Storage of concrete samples C 30/30 in air-dry environment.



Source: Own elaboration
Fig. 17. Storage of concrete samples C 25/30 and C 30/37 in water environment.



Source: Own elaboration
Fig. 18. Storage of concrete samples C 25/30 and C 30/37 in slurry environment.



Source: Own elaboration
Fig. 19. Storage of concrete samples C 25/30 and C 30/37 in acidified slurry environment

The compressive strength test was carried out in accordance with PN-EN 12390-1 standard, on cubic samples measuring 15 cm x 15 cm x 15 cm, made of class C 25/30 and C 30/37 concrete.

Class of concrete C 25/30

1. Concrete samples were made in accordance with PN-EN 206-1: 2006
2. Cement complies with EN 197-1 CEM I 42.5 R
3. Aggregate according to PN-EN 12620: 2000 standard sand 0/2 mm, gravel 2/8 mm
4. Water from water supply system complies with PN-EN 1008: 1997
5. Additive Fluid Optima 185 according to EN 934-2

Table 6. Composition of concrete mix - concrete class C 25/30
Source: Laboratory Hydrobudowa

Composition of concrete mix	Number of components		
	Dry weight components [kg/m^3]	Humidity [%]	Humidity dry components [kg/m^3]
Cement	320	X	320
Aggregate, sand	770	4,0	801
Aggregate, gravel	1080	2.0	1102
Water	128	X	75
Additive	3.2	X	3.2
Sum of components	2301	X	2301

Characteristics of the concrete mix
- consistency S4, according to cone precipitation method, according to EN 12350-2, 17-20 cm, (In laboratory tests of concrete consistency it is height of slump in cm, comparing to its primary height of 30 cm),
- ratio water –to-cement:0.40,
- volumetric density of 2301 kg / m^3.

Concrete class C 30/37

1.Concrete samples were made in accordance with PN-EN 206-1: 2006
2.Cement complies with EN 197-1 CEM I 42.5 R
3.Aggregate according to PN-EN 12620: 2000 standard, sand 0/2 mm, gravel 2/8 mm
4.Water from the water supply system complies with PN-EN 1008: 1997
5.Additive Fluid Optima 185 complies with EN 934-2

Table 7. Composition of concrete mix - concrete class C 30/37
Source: Laboratory Hydrobudowa

Composition of concrete mix	Number of components		
	Dry weight components [kg/m^3]	Humidity [%]	Humidity dry components
Cement	350	X	350
Aggregate, sand	700	4.0	728
Aggregate, gravel	1115	2.0	1137
Water	140	X	90
Additive	3.2	X	3.2
Sum of components	2308	X	2308

Characteristics of the concrete mix

- consistency S4, according to cone precipitation method, according to EN 12350-2, 17-20 cm

- position in w : c 0.40

- volumetric density 2308 kg·m^{-3}

Once the concrete reaches 28 days of age, both samples of concrete C 25/30 and C 30/37 were placed in mediums:

- water (Fig.17),

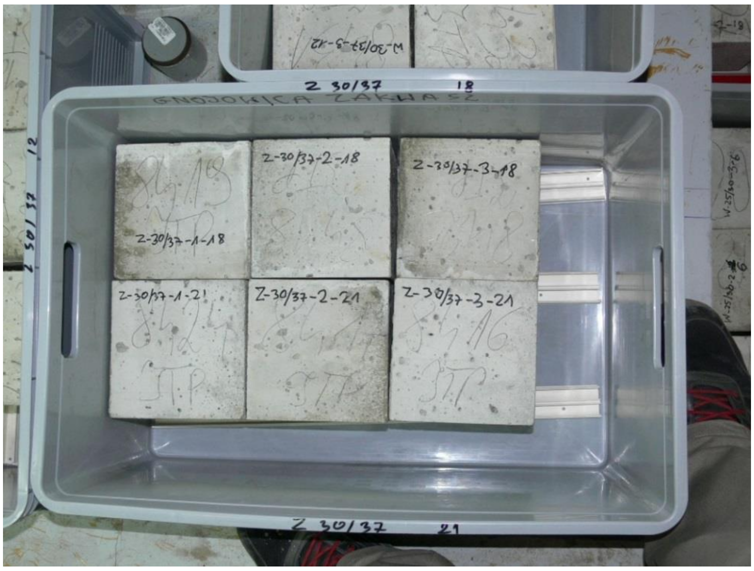
- fresh slurry 6.4, pH 7.18 (Fig.18),

- acidified slurry (Fig.19).

1. Water fulfills requirements of PN-EN 1008:1997 standard.

2. Slurry was checked in laboratory and results were shown in LBR/SPR/ITP/1/2017, results obtained: total sulpfur content 0,52 % of dry matter, acording to procedure PB-186/ICP, sulphuric ions content: 1300 mg/kg of dry matter, what means 87,2 mg/l - test by PN-EN 12457-4:2006 standard, water content 93%, test by PN-EN 12880:2004 Standard.

3. Acidified slurry was tested in laboratory and results were shown in LBR/SPR/ITP/1/2017 Total sulphur content equals 6.59 % f dry matter, according to prcedure PB-186/ICP, sulpuric ions content equals 40000 mg/kg of dry matter, what means 2337 mg/ml complied to PN-EN 12457-4:2006 Standard, water content is 93.9 %, tests complied to PN-EN 12880:2004 standard.



Source: B .Łochowski ITP
Fig.20. Concrete samples prepared to put in acidified slurry.

After determined time shown in Table 8 the samples were rinsed with clean water and in a humid state a compressive strength test was carried out in accordance with PN-EN 12390-3. Measurement is made on the hydraulic press (Fig. 21).

Source: B. Łochowski ITP
Fig.21. Hydraulic press for compressive strength testing of concrete.

Source: B. Łochowski ITP
Fig.22. Destruction of concrete sample during testing / vertical scratches /.

Table 8. Quantities of tested samples stored in different environments and periods
Source: Own elaboration

Environment	period 28 days	period 6 month	period 12 month	period 18 month	period 21 month
Dry-air	3	-	-	-	-
water	-	3	3	3	-
fresh slurry	-	3	3	3	-
acidified slurry	-	3	3	3	3

5.1.3. Results of concrete compressive strength tests

Strength tests after 1 month of maturation in air-dry conditions

Concrete class C 25/30

Table 9. Results of tests of compressive strength of concrete after 1 month of maturation
Source: Own elaboration

No..	Sample identification	Density ± U [kg/m^3]	Max.load when destroyed [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8206	2310±160	729	32.4±2.9	33.9±3.0
2	8207	2290±160	764	34.0±3.0	
3	8208	2300±160	792	35.2±3.1	

U - extension uncertainty of test results at k = 2 and confidence level of 95%

Characteristic strength f_{ck} 30 MPa

Average strength f_{cm} 33.9 MPa

Minimum strength f_{ci} 32.4 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

33,9 < 34

Criterion 2

$f_{ci} > f_{ck} - 4$

32.,4>26

It can be considered that the criteria are met and concrete C 25/30 has been obtained.

Concrete class C 30/37

Table 10. Results of compressive strength testing of concrete after 1 month of maturation under dry-air conditions
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max. load when destroyed [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8405	2330±160	729	52.8±4.7	51.4±4.5
2	8406	2330±160	764	50.0±4.4	
3	8407	2330±160	792	51.4±4.5	

U - extension uncertainty of test results at k = 2 and confidence level of 95%

Characteristic strength f_{ck} 45 Mpa

Average strength f_{cm} 51.4 Mpa

Minimum strength f_{ci} 50.0 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

51.4 > 41

Criterion 2

$f_{ci} > f_{ck} – 4$

50 > 41

It can be considered that the criteria are met and concrete C 30/37 has been obtained.

Tests results of concrete compressive strength after 6 months

Concrete class C25/30

Water environment

Table 11. The results of concrete compressive strength tests. Storage of samples in a water environment for 6 months.
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max.load when destroyed [kN]	f_{ci} ± U [MPa]	f_{cm} ± U [MPa]
1	8209	2320±160	922	41.0±3.6	40.0±3.5
2	8212	2320±160	901	40.0±3.5	
3	8214	2300±160	880	39.1±3.5	

U - extension uncertainty of test results at k = 2 and confidence level of 95%

Characteristic strenght f_{ck} 30 Mpa

Average strength f_{cm} 40.0 Mpa

Minimal strength f_{ci} 39.1 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

40.0 > 34

Criterion 2

$f_{ci} > f_{ck} – 4$

39.1>26

It can be considered that the criteria are met and concrete C-Class 25/30 has been obtained.

Slurry environment

Table 12. The results of concrete compressive strength tests. Storing samples in a slurry environment for 6 months
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max.load when destroyed [kN]	$f_{ci\,\pm}\,U$ [MPa]	$f_{cm\,\pm}\,U$ [MPa]
1	8232	2310±160	980	43.6±3.9	41.9±3.7
2	8234	2260±160	934	41.5±3.7	
3	8228	2280±160	915	40.7±3.6	

U - extension uncertainty of test results at k = 2 and confidence level of 95%

Characteristic strength f_{ck} 37 Mpa

Average strength f_{cm} 41.9 Mpa

Minimal strength f_{ci} 40.7 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

41.9 > 41

Criterion 2

$f_{ci} > f_{ck} - 4$

40.7>33

It can be considered that the criteria are met and concrete C-Class 30/37 has been obtained.

The environment of acidified slurry

Table 13. The results of concrete compressive strength tests. Storage of samples in a slurry environment acidified for 6 months.
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max.load when destroyed [kN]	$f_{ci\,\pm}\,U$ [MPa]	$f_{cm\,\pm}\,U$ [MPa]
1	8223	2280±160	902	40.1±3.5	41.5±3.7
2	8224	2320±160	962	42.8±3.8	
3	8222	2270±160	939	41.7±3.7	

U - extension uncertainty of test results at k = 2 and confidence level of 95%

Characteristic strength f_{ck} 37 Mpa

Average strength f_{cm} 41.5 Mpa

Minimal strength f_{ci} 40.1 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

41,5 > 41

Criterion 2

$f_{ci} > f_{ck} - 4$

40.1>33

It can be considered that the criteria are met and concrete C-Class 30/37 has been obtained

Concrete class C 30/37

Water environment

Table 14. The results of concrete compressive strength tests. Storage of samples in a water environment for 6 months.
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max.load when destroyed [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8426	2310±160	1393	61.9±5.4	63.2±5.6
2	8427	2390±160	1453	64.6±5.7	
3	8432	2360±160	1418	63.0±5.5	

U - extension uncertainty of test results at k = 2 and confidence level of 95%

Characteristic strength f_{ck} 55 Mpa
Average strength f_{cm} 63.2 Mpa
Minimal strength f_{ci} 61.9 MPa
Cryiterion 1
$f_{cm} > f_{ck} + 4$
63.2 > 59
Criterion 2
$f_{ci} > f_{ck} - 4$
61.9>51
It can be considered that the criteria are met and concrete C-Class 45/55 has been obtained

Slurry environment

Table 15. The results of concrete compressive strength tests. Storing samples in a slurry environment for 6 month
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max.load when destroyed [kN]	f_{ci} ± U [MPa]	f_{cm} ± U [MPa]
1	8415	2360±160	1374	61.1±5.4	59.6±5.2
2	8429	2360±160	1285	57.1±5.0	
3	8433	2370±160	1362	60.5±5.3	

U - extension uncertainty of test results at k = 2 and confidence level of 95%

Characteristic strength f_{ck} 50 Mpa

Average strength f_{cm} 59.6 Mpa

Minimal strength f_{ci} 57.1 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

59.6 > 54

Criterion 2

$f_{ci} > f_{ck} – 4$

57.1> 46

It can be considered that the criteria are met and concrete C-Class 40/50 has been obtained.

Acidified slurry environment

Table 16. The results of concrete compressive strength tests. Storage of samples in a acidified slurry environment for 6 months.
Source: Own elaboration

L.p.	Sample identification	Density ± U [kg/m^3]	Max.load when destroyed [kN]	f_{ci} ± U [MPa]	f_{cm} ± U [MPa]
1	8409	2340±160	1415	62.9±5.5	61.5±5.4
2	8410	2330±160	1383	61.5±5.4	
3	8413	2320±160	1349	60.0±5.3	

U - extension uncertainty of test results at k = 2 and confidence level of 95%

Characteristic strength f_{ck} 55 Mpa
Average strength f_{cm} 61.5 Mpa
Minimal strength f_{ci} 60.0 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

61.5 > 59

Criterion 2

$f_{ci} > f_{ck} - 4$

60.0>51

It can be considered that the criteria are met and concrete C-Class 45/55 has been obtained.

Results of concrete compressive strength tests after 12 month

Concrete class C 25/30

Water environment

Table 17. The results of concrete compressive strength tests. Storing samples in water environment for 12 months.
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max. load on destruction [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8213	2280±160	1022	45.4±4.0	45.1±4.0
2	8211	2290±160	994	44.2±3.9	
3	8210	2320±160	1030	45.8±4.0	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Characteristic strength f_{ck} 37 Mpa

Medium strength f_{cm} 45.1 Mpa

Minimum strength f_{ci} 44.2 MPa

Criterion *1*

$f_{cm} > f_{ck} + 4$

45,1 > 41

Criterion *2*

$f_{ci} > f_{ck} - 4$

44.2>33

It can be considered that the criteria are met and the concrete grade has been obtained C 30/37

Slurry environment

Table 18. The results of concrete compressive strength tests. Storing samples in a slurry environment for 12 months.
Source: Own elaboration

No.	Sample indentification	Density ± U [kg/m^3]	Max. load on destruction [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8233	2280±160	997	44.3±3.9	45.1±4.0
2	8235	2270±160	975	43.3±3.8	
3	8229	2330±160	1074	47.7±4.2	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Characteristic strength f_{ck} 37 Mpa

Medium strength f_{cm} 45.1 Mpa

Minimum strength f_{ci} 43.3 MPa

Criterion *1*

$f_{cm} > f_{ck} + 4$

45.1 > 41

Criterion *2*

$f_{ci} > f_{ck} - 4$

43.3>33

It can be considered that the criteria are met and the concrete grade has been obtained C 30/37

Acidified slurry environment

Table 19. The results of concrete compressive strength tests. Storing samples in acidified slurry environment for 12 months..
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max. load on destruction [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8218	2300±160	1006	44.7±3.9	44.8±4.0
2	8219	2320±160	973	43.3±3.8	
3	8216	2280±160	1042	46.3±4.1	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Characteristic strength f_{ck} 37 Mpa

Medium strength f_{cm} 44.8 Mpa

Minimum strength f_{ci} 43.3 MPa

Criterion *1*

$f_{cm} > f_{ck} + 4$

44,8 > 41

Criterion *2*

$f_{ci} > f_{ck} - 4$

43.3 > 33

It can be considered that the criteria are met and the concrete grade has been obtained C 30/37

Concrete class C 30/37

Water environment

Table 20. The results of concrete compressive strength tests. Storing samples in water environment for 12 months.
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max. load on destruction [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8428	2360±160	1510	67.1±5.9	67.4±5.9
2	8430	2370±160	1511	67.2±5.9	
3	8431	2360±160	1525	67.8±6.0	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Characteristic strength f_{ck} 60 MPa

Medium strength f_{cm} 67.4 MPa

Minimum strength f_{ci} 67.1 MPa

Criterion *1*

$f_{cm} > f_{ck} + 4$

67.4 > 64

Criterion *2*

$f_{ci} > f_{ck} - 4$

67.1>56

It can be considered that the criteria are met and the concrete grade has been obtained C 50/60

Slurry environment

Table 21. The results of concrete compressive strength tests. Storing samples in a slurry environment for 12 months.
Source: Own elaboration

No.	*Sample identification*	*Density ± U [kg/m^3]*	*Max. load on destruction [kN]*	*f_{ci} ± U [MPa]*	*f_{cm} ± U [MPa]*
1	*8435*	*2350±160*	*1432*	*63.4±5.3*	*64.1±5.6*
2	*8436*	*2390±160*	*1444*	*64.2±5.6*	
3	*8420*	*2380±160*	*1526*	*67.8±5.9*	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Characteristic strength f_{ck} 60 MPa

Medium strength f_{cm} 64.1MPa

Minimum strength f_{ci} 63.4 MPa

Criterion *1*

$f_{cm} > f_{ck} + 4$

64.1 > 64

Criterion *2*

$f_{ci} > f_{ck} – 4$

63.4> 56

It can be considered that the criteria are met and the concrete grade has been obtained C 50/60

Acidified slurry environment

Table 22. The results of concrete compressive strength tests. Storing samples in acidified slurry environment for 12 months.
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max. load on destruction [kN]	f_{ci} ± U [MPa]	f_{cm} ± U [MPa]
1	8414	2350±160	1406	62.5±5.5	63.8±5.6
2	8422	2340±160	1500	66.7±5.9	
3	8423	2330±160	1400	62.2±5.5	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Characteristic strength f_{ck} 55 MPa

Medium strength f_{cm} 63.8 MPa

Minimum strength f_{ci} 62.2 Mpa

Criterion *1*

f_{cm} > f_{ck} + 4

63.8 > 59

Criterion *2*

f_{ci} > f_{ck} – 4

62.2 > 51

It can be considered that the criteria are met and the concrete grade has been obtained C 45/55

Results of concrete compressive strength tests after 18 months

Concrete class C 25/30

Water environment

Table 23. The results of concrete compressive strength tests. Storage of samples in a water environment for 18 months.
Source: Own elaboration:

No.	Sample identification	Density ± U [kg/m^3]	Max.load at destruction [kN]	f_{ci} ± *U* [MPa]	f_{cm} ± *U* [MPa]
1	8225	2280±160	993	44.1±3.9	44.6±3.9
2	8220	2280±160	1038	46.1±4.1	
3	8227	2290±160	980	43.6±3.9	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Strength characteristic f_{ck} 37 Mpa

Everage strength f_{cm} 44.6 Mpa

Minimal strength f_{ci} 43.6 MPa

Criterion *1*

f_{cm} > f_{ck} + 4

44.6 > 41

Criterion 2

f_{ci} > f_{ck} – 4

43.6 > 33

It can be considered that the criteria are met and the concrete grade has been obtained C 30/37

Slurry environment

Table 24. The results of concrete compressive strength tests. Storing samples in a slurry environment for 18 months.
Source: Own elaboration

No	Sample indentification	Density ± U [kg/m^3]	Max. load at destruction [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8230	2320±160	1036	46.0±4.1	44.9±4.0
2	8231	2300±160	1017	45.2±4.0	
3	8215	2280±160	977	43.4±3.8	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Strength characteristic f_{ck} 37 Mpa

Everage strength f_{cm} 44.9 Mpa

Minimal strength f_{ci} 43.4 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

44,9 > 41

Criterion 2

$f_{ci} > f_{ck} - 4$

43.4 > 33

It can be considered that the criteria are met and the concrete grade has been obtained C 30/37

Acidified slurry environment

Table 25. The results of concrete compressive strength tests. Storing samples in a slurry environment for 18 months.
Source: Own elaboration

No	Sample identification	Density ± U [kg/m^3]	Max.load at destruction [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8217	2280±160	809	36.0±3.2	40.7±3.6
2	8221	2280±160	952	42.3±3.7	
3	8226	2290±160	986	43.8±3.9	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%
Strength characteristic f_{ck} 37 Mpa

Everage characteristic f_{cm} 40.7 Mpa
Minimal stregth f_{ci} 36.0 MPa
Criterion 1
$f_{cm} > f_{ck} + 4$
40.7 < 41
Criterion 2
$f_{ci} > f_{ck} – 4$
36.0 > 33
It can be considered, that the criteria are not met and obtained concrete grade lower class than C 30/37, it means obtained conrete class C 25/30

Concrete class C 30/37

Water environment

Table 26. The results of concrete compressive strength tests. Storing samples in a water environment for 18 months.
Source: Own elaboration

No	Sample identification	Density ± U [kg/m^3]	Max.load at destruction [kN]	$f_{ci\,\pm}\,U$ [MPa]	$f_{cm\,\pm}\,U$ [MPa]
1	8434	2360±160	1485	66.0±5.8	8434
2	8407	2340±160	1480	65.8±5.8	8407
3	8408	2350±160	1502	66.8±5.9	8408

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Strength charactristic f_{ck} 60 Mpa

Everage characteristic f_{cm} 66,2 Mpa

Minimal strength f_{ci} 65.8 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

66.2 > 64

Criterion 2

$f_{ci} > f_{ck} – 4$

65.8>56

It can be considered, that the criteria are met and obtained concrete class C 50/60

Slurry environment

Table 27. The results of concrete compressive strength tests. Storing samples in slurry environment for 18 months.
Source: Own elaboration

No	Sample identification	Density ± U [kg/m^3]	Max.load at destruction [kN]	$f_{ci\,\pm}\,U$ [MPa]	$f_{cm\,\pm}\,U$ [MPa]
1	8421	2360±160	1446	64.3±5.7	64.8±5.7
2	8411	2390±160	1499	66.6±5.9	
3	8412	2360±160	1428	63.5±5.6	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Strength characteristic f_{ck} 60 MPa

Average characteristic f_{cm} 64.8 MPa

Minimal strength f_{ci} 63.5 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

64.8 > 64

Criterion 2

$f_{ci} > f_{ck} – 4$

63.5> 56

It can be considered, that the criteria are met and obtained concrete class C 50/60

Acidified slurry environment

Table 28. The results of concrete compressive strength tests. Storing samples in a slurry environment for 18 months
Source: Own elaboration

No	Sample identification	Density ± U [kg/m^3]	Max.load at destruction [kN]	$f_{ci\,\pm}\,U$ [MPa]	$f_{cm\,\pm}\,U$ [MPa]
1	8419	2360±160	1318	58.6±5.2	60.9±5.4
2	8422	2340±160	1414	62.8±5.5	
3	8423	2360±160	1381	61.4±5.4	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Strength characteristic f_{ck} 55 Mpa
Everage strength f_{cm} 60.9 Mpa
Minimal strength f_{ci} 58.6 MPa
Criterion 1
$f_{cm} > f_{ck} + 4$
60.9 > 59
Criterion 2
$f_{ci} > f_{ck} - 4$
58.6 > 51
It can be considered, that the criteria are met and obtained concrete class C 45/55.

Results of concrete compressive strength tests after 21 months

According to the research methodology and the schedule, after 21 months, concrete samples were only stored in the acidified slurry environment.

Concrete class C 25/30

Acidified slurry environment

Table 29. The results of concrete compressive strength tests. Storage of samples in an acidified slurry environment for 21 months
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max. load on destruction [kN]	f_{ci} ± U [MPa]	f_{cm} ± U [MPa]
1	8236	2280±160	850	37.8±3.4	39.9±3.5
2	8237	2270±160	912	40.5±3.6	
3	8238	2300±160	932	41.4±3.7	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

fci 37.8 MPa

Characteristic strength fck 30 MPa

Strength average fcm 39.9 MPa

Minimum strength fci 37.8 MPa

Criterion 1

fcm > fck + 4

39.9 > 34

Criterion 2

fci > fck – 4

37.8 > 26

It should be recognized that the criteria are met and concrete class 25/30 has been obtained.

Concrete class C 30/37

Environment of acidified slurry

Table 30. The results of concrete compressive strength tests. Storage of samples in a slurry environment acidified for 21 months.
Source: Own elaboration

No.	Sample identification	Density ± U [kg/m^3]	Max. load on destruction [kN]	$f_{ci} \pm U$ [MPa]	$f_{cm} \pm U$ [MPa]
1	8424	2350±160	1385	61.6±5.4	62.0±5.4
2	8417	2360±160	1370	60.9±5.1	
3	8416	2350±160	1430	63.6±5.8	

U - extended uncertainty of the test result with the extension factor k = 2 and the confidence level of 95%

Characteristic strength f_{ck} 55 Mpa
Strength average f_{cm} 62.0 Mpa
Minimum strength f_{ci} 60.9 MPa

Criterion 1

$f_{cm} > f_{ck} + 4$

62.0 > 59

Criterion *2*

$f_{ci} > f_{ck} - 4$

60.9 > 51

It should be recognized that the criteria are met and concrete class C 45/55`has been obtained.

5.1.4. Summary and conclusions of strenght tests during experiment (21 months)

Summary after 6 months of storage of concrete samples in different environments

Concrete class C25/30

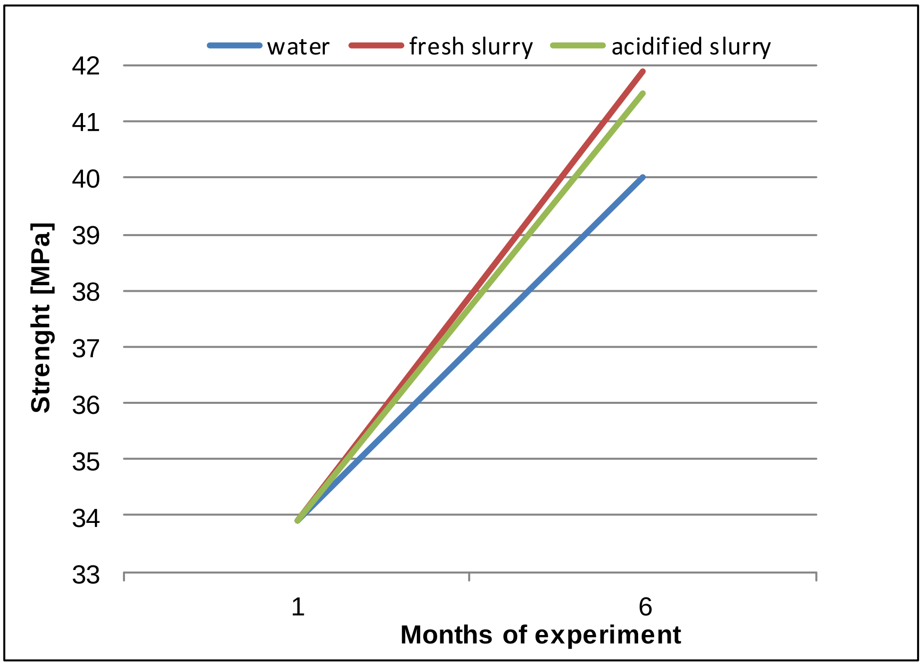


Fig.23 Graph of compressive strength changes of concrete C 25/30 stored in various environments for a period of 6 months

On the basis of the obtained results of concrete compressive strength tests after 6 months we can conclude;

- there is an increase in compressive strength of concrete stored in the water environment

by (40.0 MPa – 33.9 MPa): 33.9MPa · 100% = 18%.

- there is an increase in compressive strength of concrete stored in slurry by (41.9 MPa - 33.9 MPa): 33.9 MPa · 100% = 23.6%.

- there is an increase in compressive strength of concrete stored in the acidified slurry environment by (41.5 MPa – 33.9MPa): 33.9 MPa · 100% = 22.4%.

Concrete class C 30/37

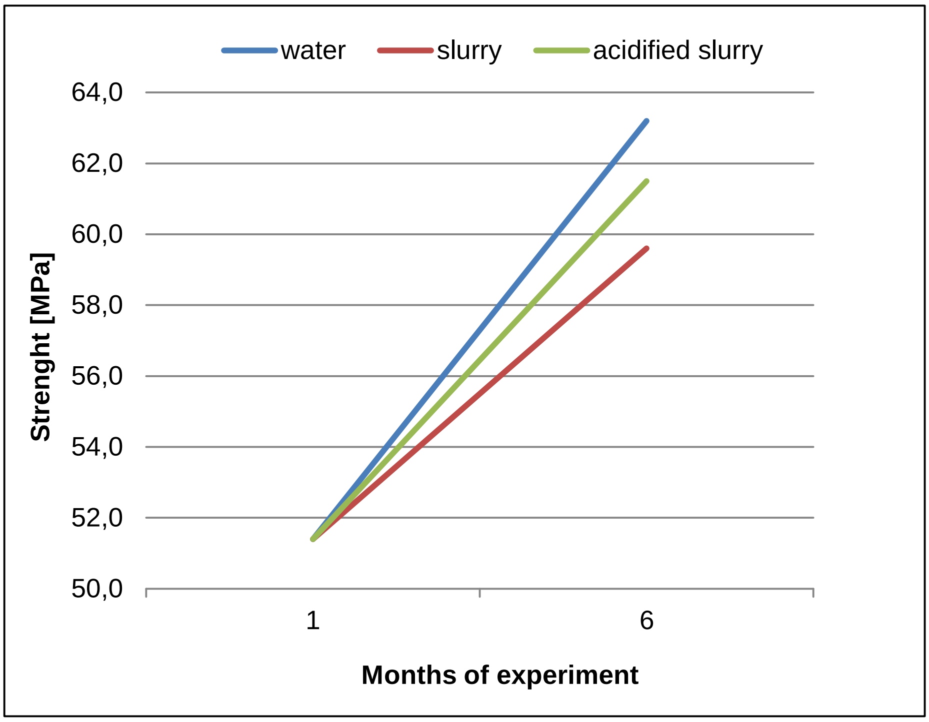


Fig. 24. Graph of compressive strength changes of C 30/37 concrete stored in various environments for a period of 6 months

On the basis of the obtained results of concrete compressive strength tests after 6 months we can conclude:

- there is an increase in compressive strength of concrete stored in the water environment

by (63.2MPa - 51.4MPa): 51.4MPa · 100% = 23.0%

- there is an increase in compressive strength of concrete stored in slurry

by (59.6MPa - 51.4MPa): 51.4MPa · 100% = 16.0%

- there is an increase in compressive strength of concrete stored in the acidified slurry environment by (61.5MPa - 51.4MPa): 51.4MPa · 100% = 19.6%

Summary and conclusions after 12 months of storage of concrete samples in different environments

Concrete class C 25/30

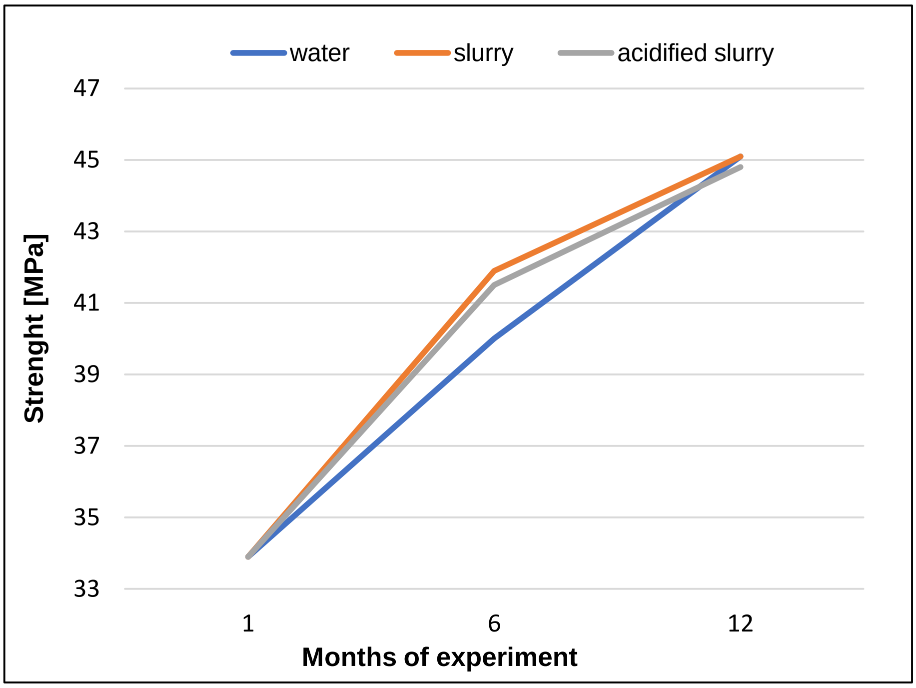


Fig. 25. Graph of compressive strength changes of concrete C 25/30 stored in various environments for 12 months

On the basis of the obtained results of concrete compressive strength tests we can conclude;- there is an increase in compressive strength of concrete stored in the water environment by (45.1 MPa - 33.9MPa): 33.9MPa · 100% = 33.0%

C 25/30 concrete after 12 months of storage in a water environment meets the criteria of C 30/37 concrete

- there is an increase in compressive strength of concrete stored in slurry by (45.1 MPa - 33.9MPa): 33.9MPa · 100% = 33.0%

Class C 25/30 concrete after 12 months of storage in a slurry environment meets the criteria of C 30/37 concrete

- there is an increase in compressive strength of concrete stored in the acidified slurry environment by (44.8 MPa - 33.9MPa): 33.9MPa · 100% = 32.2%

C 25/30 concrete after 12 months of storage in an acidified slurry environment meets the criteria of C 30/37 concrete

Concrete class C 30/37

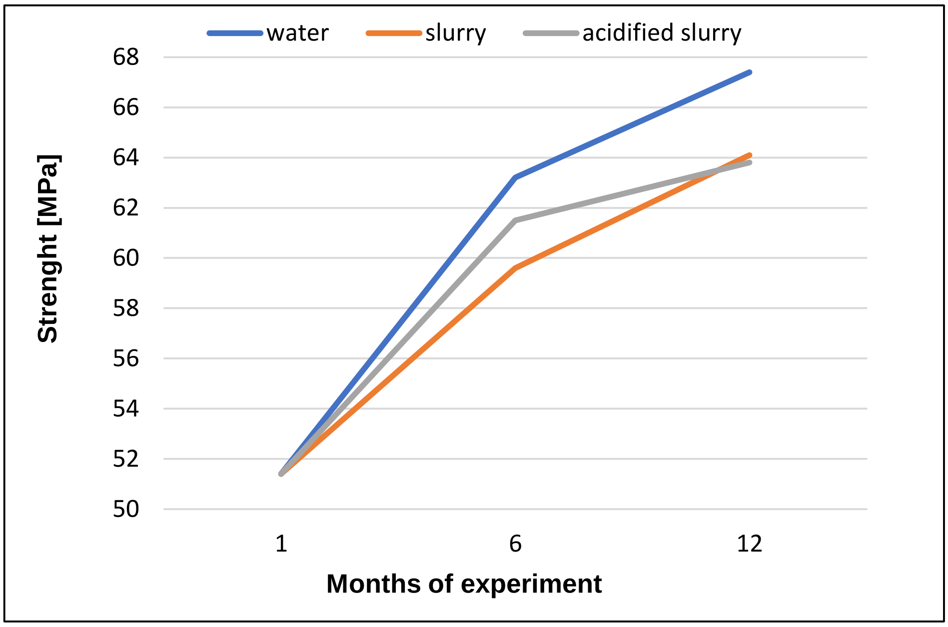


Fig.26. Graph of compressive strength changes of concrete C 30/37 stored in different environments for a period of 12 months

On the basis of the obtained results of concrete compressive strength tests we can conclude:

- there is an increase in compressive strength of concrete stored in the water environment by (67.4MPa - 51.4MPa): 51.4MPa · 100% = 31.1%

C 35/45 concrete after 12 months of storage in a water environment meets the criteria of C 50/60 concrete

- there is an increase in compressive strength of concrete stored in slurry

by (64.1MPa - 51.4MPa): 51.4MPa · 100% = 24.7%
Class C 35/45 concrete after 12 months of storage in a slurry environment meets the criteria of C 50/60 concrete

- there is an increase in compressive strength of concrete stored in the acidified slurry environment by (63.8MPa - 51.4MPa): 51.4MPa · 100% = 24.1%

C 35/45 concrete after 12 months of storage in an acidified slurry environment meets the criteria of C 45/55 concrete.

Summary and conclusions after 18 months of storage of concrete samples in different environments

Concrete C 25/30

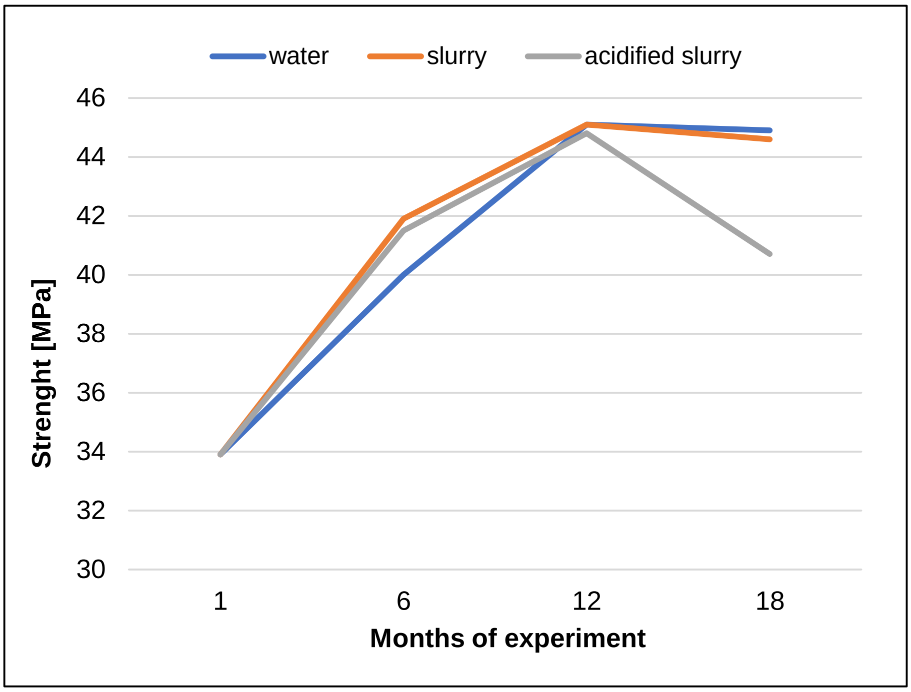


Fig. 27. Graph of compressive strength changes of concrete C 25/30 stored in various environments for a period of 18 months

On the basis of obtained results of concrete compressive strength tests we can conclude:

- in the period between 12 months and 18 months, concrete samples stored in water environment show stabilization of the average compressive strength at 45 Mpa

- concrete C 25/30 after 18 months of storage in a water and slurry environment meets the criteria of concrete C 30/37

- also concrete samples stored in the slurry environment show stabilization of the average compressive strength at 45MPa

- in the period between 12 months and 18 months, concrete samples stored in acidified slurry environment show decrease in the average compression strength. With respect to the maximum compressive strength obtained, the drop is (44.8-40.7): 44.8 · 100% = 9.15%

- concrete C 25/30 after 18 months of storage in an acidified slurry environment meets the criteria of concrete C 25/30.

- compressive strength of cocrete samples stored 18 months in acidified slurry decreased by 9,15 % andfor samples stored in slurry it decreased by only 0,44 %with respect to the maximum compressive strength obtained.

Concrete C 30/37

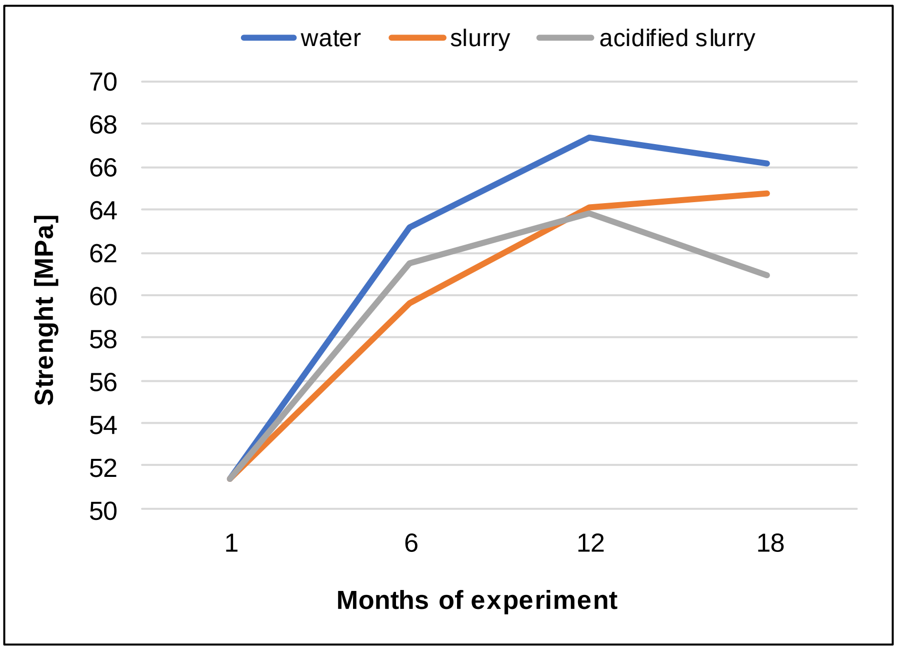


Fig. 28. Graph of compressive strength changes of concrete C 30/37 stored in various environments for a period of 18 months

On the basis of obtained results of concrete compressive strength tests we can conclude;- compressive strength of concrete stored in water environment is stabilized,

- concrete C 30/37 after 18 months of storage in a water environment meets the criteria of concrete C 50/60

- the compressive strength of concrete stored in slurry is stabilized,

- concrete C 30/37 after 18 months of storage in a slurry environment meets the criteria of concrete C 50/60

- the compressive strength of concrete stored in the acidified slurry environment decreases with respect to the maximum compressive strength and fall is

(63.8MPa – 60.9MPa): 63.8MPa · 100% = 4.5%

- concrete C 30/37 after 18 months of storage in an acidified slurry environment meets the criteria of concrete C 45/55.

- compressive strength of cocrete samples stored 18 months in acidified slurry decreased by 4,54% and for samples stored in slurry it increased by 1,08 % with respect to the maximum compressive strength obtained.

Summary and conclusions after 21 months of storage of concrete samples in an acidified slurry environment concrete C 25/30

Concrete C 25/30

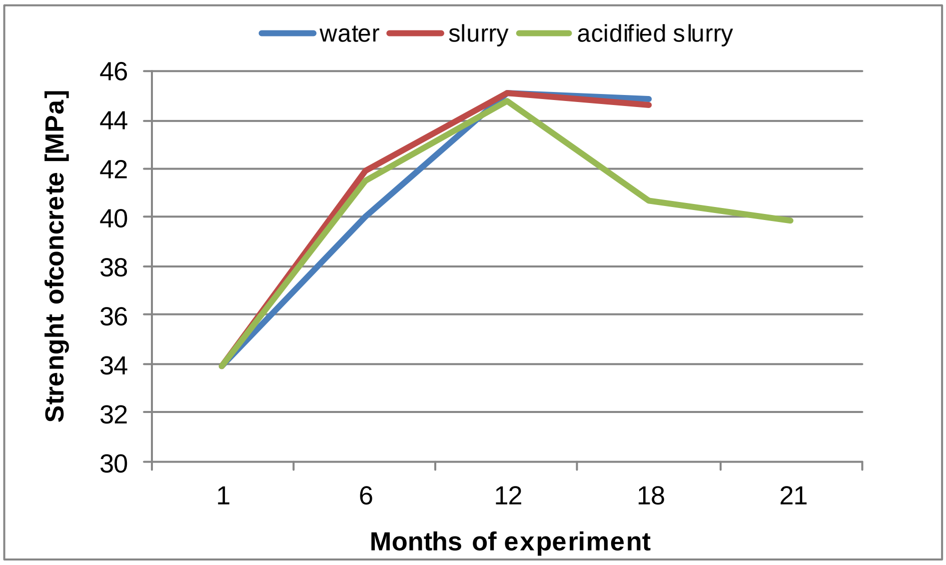


Fig. 29.Graph of compressive strength changes of concrete C 25/30 stored in acidified manure during different research periods.

On the basis of the obtained results of compressive strength tests of concrete, we can conclude:

- in the period between 18 months and 21 months, concrete samples stored in the acidified slurry environment show a slight decrease in the average compressive strength (40.7-39.9):

40.7 · 100% = 2%. With regard to the maximum compressive strength obtained during the entire test period, the decrease is equal (44.8 - 39.9): 44.8 · 100% = 10.93%.

- C 25/30 concrete after 21 months of storage in an acidified slurry environment meets the criteria of C 25/30 concrete. The average compressive strength of concrete samples stored in the acidified slurry environment after 21 months is higher by (33.9 to 49.9): 33.9 100% = 17.7% on the strength of the concrete / reference samples / tested after 28 days from test start.

Concrete C 30/37

On the basis of the obtained results of compressive strength tests of concrete, we can conclude;

- in the period between 18 months and 21 months, concrete samples stored in the acidified slurry environment show a slight increase in the average compressive strength (62.0-60.9): 60.9 · 100% = 1.8%. With respect to the maximum compressive strength obtained during the entire test period, the decrease is (63.8-62.0): 63.8 · 100% = 2.8%.

- C 30/37 concrete after 21 months of storage in the environment of acidified slurry meets the criteria of concrete C 45/55. The average compressive strength of concrete samples stored in acidified slurry environment after 21 months is higher (51.4-62.0): 51.4 · 100% = 20.6% on the strength of the concrete / reference samples / tested after 28 days from test start.

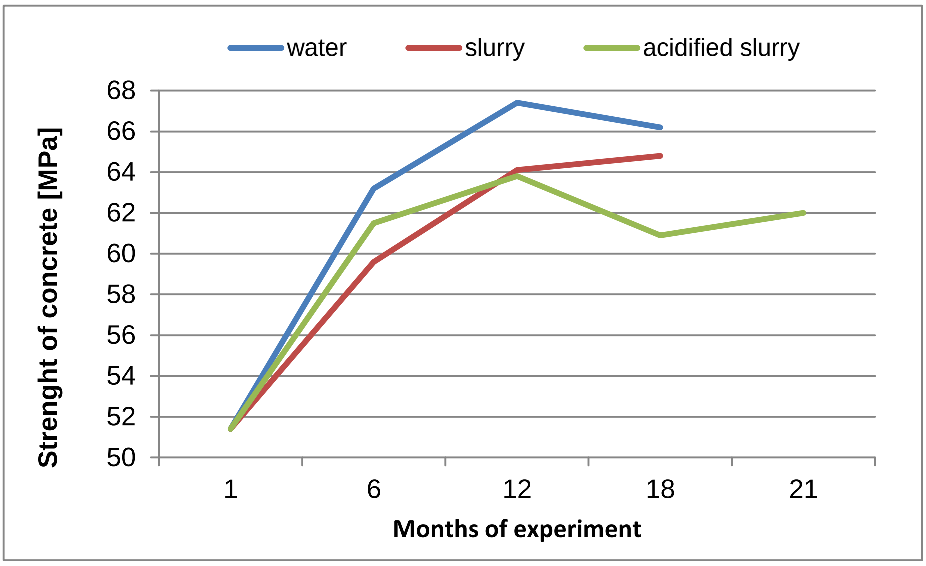


Fig. 30. Graph of compressive strength changes of C 30/37 concrete stored in various environments during research periods

Final conclusions from compressive strenght tests

The tests have shown that the compressive strength of concrete increases in the first 12 months of the experiment, in the following months stabilization of the compressive strength of concrete occurs. This phenomenon applies to concrete samples stored in the environment of water and slurry. The batch samples in the acidified slurry environment show a slight decrease in strength after 18 months. After a 21 month test period, samples of concrete class C25/30 placed in acidified slurry environment were still classified as C25/30, while samples of concrete class C30/37 were classified as higher class C45/55.

The increase in the strength of concrete samples stored in a wet environment can be attributed to the reaction inducing swelling and filling the open spaces with growing etryngite crystals, the occurrence of which are confirmed by the results of microscopic examination. Breaking forces, in case of resistance increase are lower than tensile strength of concrete.

Acidified slurry environment during the research period negatively affected the concrete parameters in terms of compressive strength. For concrete samples class C25/30 compressive strength after 21 months of storage in acidified slurry decreased by 10.93 % and for non-acidified slurry (after 18 months) decreased by 0.44 %, comparing to maximum strength obtained in testing period.

For concrete samples class C30/37 compressive strength after 21 months of storage in acidified slurry decreased by 2.82 % comparing to maximum strength obtained in testing period and for non-acidified slurry, after 18 months, it increased by 1.08%, comparing to former testing period (after 12 months)

5.2. Studies on determining the protective performance of concrete cover for reinforcing steel

5.2.1. Introduction

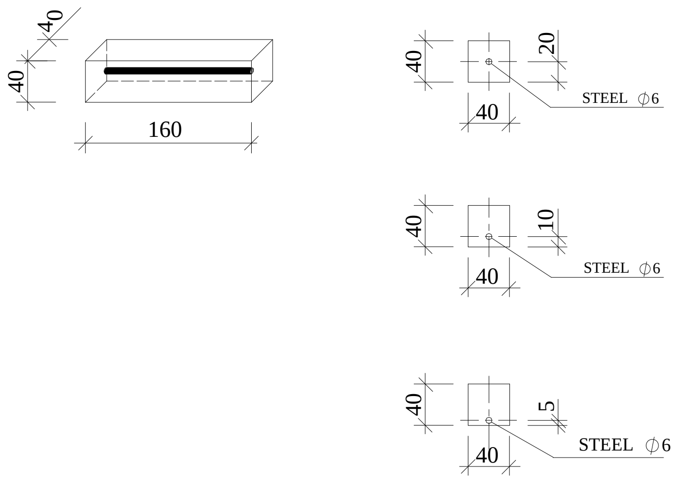
Elements of the tank prepared for slurry storage work in aggressive environments both for concrete and reinforcing steel. The durability and safety of structures made of reinforced concrete is usually determined by the thickness and tightness of the concrete cover. The PN-EN 1992-1-1: 2008 standard defines the minimum cover thicknesses for reinforced concrete elements.

5.2.2. The goal, the method and the test program

The main purpose is to check the effect of the acidified slurry environment on reinforced concrete samples. The above-mentioned check will be conducted by a comparative method of samples stored in acidified slurry with samples stored in the environment of-air-dry,-water,-slurry.

In order to determine the impact of the environment, we will use a break strength test for samples with standard dimensions of 4cm x 4cm x 16cm and an assessment of the surface condition of the reinforcing bar. In the conducted research works, it was assumed that concrete tightness is a function of the concrete class. The samples were made of C 30/37concrete based on Portland cement CEM I and natural aggregate. In practice, concrete of class C35/C45 was obtained.

The reinforcing bar was placed at different heights, thus the reinforcement cover in the tested samples is 2mm, 7mm and 17mm thick. Figure 31 shows the position of the bar axis.



Source: Own elaboration
Fig. 31. Position of the rod axis in concrete samples

After reaching 28 days concrete samples were placed in the environment of:
- water,

- fresh slurry,

- acidified slurry.

The samples were stored in containers with a capacity of approx. 90 dm^3. Samples after removal from individual environments according to the schedule were rinsed with clean water and in the wet state measurement of bending strength of the concrete was performed on a hydraulic press equipped with an attachment for breaking bars 4cm x 4cm x16cm (Fig. 32). During bars breaking, the location of the samples ensures reinforcement in the tensile zone (Fig. 33). Samples were also subjected to macroscopic evaluation. The flexural strength Rf was calculated according to the formula $R_f = 1{,}5 \times F_f \times l \times b^{-3}$

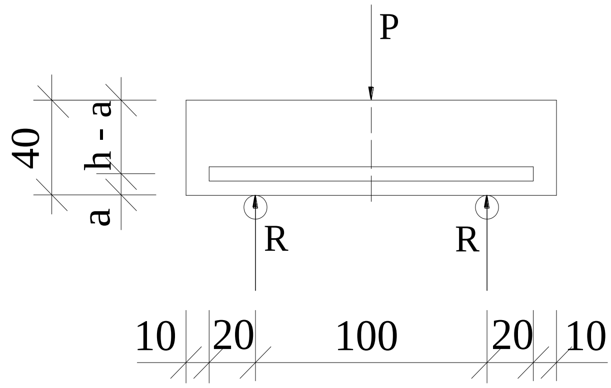
where; R_f - compressive strength, MPa

F_f - breaking load in the center of the bar, kN

l - distance between supports, mm

b - side length of the bar section, mm

Source: B. Łochowski
Fig. 32. Press with an attachment for testing the bending strength of concrete



Source: Own elaboration
Fig .33. Scheme of concrete bar load

5.2.3. Materials

1. Concrete samples were made of C 30/37 concrete according to the standard PN-EN 206-1:2006

2. Cement in accordance with the standard PN-EN 197-1 CEM I 42.5 R

3.Aggregate in accordance with the standard PN-EN 12620:2000 sand 0/2mm , gravel 2/8mm

4. Water from the water supply network in accordance with the standard PN-EN 1008:1997

5. Admixture of Fluid Optima 185 according to the standard PN-EN 934-2

6. Reinforcing steel Ø 6mm grade St3S

Table 31. The composition of concrete mix
Source: Elaboration by Hydrobudowa

The composition of the concrete mix	Number of components		
	Weight dry ingredients [kg/m^3]	Humidity [%]	Weight wet ingredients [kg/m^3]
Cement	350	X	350
Aggregate sand	700	4.0	728
Aggregate gravel	1115	2.0	1137
Water	140	X	90
Additive	3.2	X	3.2
Sum of components	2308	X	2308

Characteristic of concrete mix

- consistency S4, according to the cone fall method, according to EN 12350-2, 17-20 cm

- ratio w:c 0.40

- volume density 2308 kg/m^3

5.2.4. Samples testing

Samples for testing were collected and stored in accordance with PN-EN 12350-1: 2011 and PN-EN 12390-2: 2011. During the tests, the samples were stored in the laboratory in containers with water, slurry and acidified slurry, the temperature in the room is constant and is equal 20 °+/- 2° C. The temperature of the liquids in the containers was equal to the temperature in the room and was equal 20 ° C with an amplitude of 2 ° C. The temperature was measured every 7 days. The acidified slurry was subject to a pH test. Due to the changing degree of acidification, pH was measured every other day until stabilization /about 1 month /. The pH level of the slurry was adjusted to upkeep the slurry acidity level at 5.5.

Source: B. Łochowski
Fig. 34. Prepared containers with samples for pouring in a suitable medium. Tiles on the left side of the container.

Source: B. Łochowski
Fig. 35. Container with samples and acidified slurry

During experiment, the samples were periodically inspected to determine any changes occurring as a result of the corrosion process. Macroscopic and strength tests were carried out in the period of:

- 1 month after the samples were formed / samples stored in air-dry conditions /
- 6 months storage in water
- 6 months storage in fresh slurry
- 6 months storage in acidified slurry
- 12 months storage in water
- 12 months storage in fresh slurry
- 12 months storage in acidified slurry
- 21 months storage in water
- 21 months of storage in slurry
- 21 months storage in acidified slurry

Three samples taken from each medium in each period were subject to testing.

5.2.5.Results of bending strength tests and macroscopic evaluation of reinforcing steel

Test of samples stored in a air-dry conditions after 1 month

Table 35. The results of bending strength tests of concrete samples after 1 month (air-dry conditions)
Source: Own elaboration

No	Sample description according to:		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	104/C	P-5-1	12.3	2
2	116/C	P-10-1	13.3	7
3	138/C	P-20-1	16.0	17

Source:B. Łochowski
Fig. 36. Concrete sample after bending strength test. Side view of the sample

Source:B. Łochowski
Fig. 37. Concrete sample after bending strength test. Side view of the sample

As a result of tests, the samples were destroyed in a characteristic way, the reinforcing bar moves in the concrete after breakage of adhesion between steel and concrete, this phenomenon occurs only in one part of the bar, in the other part of the bar, adhesion forces effectively prevent the steel rod from displacing in the concrete.

Evaluation of reinforcing steel after 28 days. Maturing of concrete in an air-dry environment

Source:B. Łochowski
Fig. 38. Condition of the reinforcing bar with a 2 mm cover.

Source: B. Łochowski
Fig. 39. Condition of the reinforcing bar with a 7 mm cover.

Source: B. Łochowski
Fig. 40. Condition of the reinforcing bar with a 17 mm cover.

Source: B. Łochowski
Fig. 41. Recess in concrete, trace of the rod without corrosion

Reinforcing bars in concrete samples, after a period of one month storage in air-dry laboratory conditions, do not show any corrosion changes in the form of rusty deposits. The condition of bars with 2 mm, 7 mm and 17 mm cover is practically the same as at the time of forming the samples.

Bending tests after 6 months

Table 33. The results of bending test of concrete samples after 6 months stored in water
Source: Own elaboration

No	Sample description according to:		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	108/C	W-5-6	12.5	2
2	122/C	W-10-6	15.6	7
3	137/C	W-20-6	17.7	17

Table 34. The results of bending test of concrete samples after 6 months stored in fresh slurry
Source: Own elaboration

No	Sample description according to:		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	96/C	G-5-6	13.7	2
2	111/C	G-10-6	14.6	7
3	124/C	G-20-6	16.0	17

Table 35. The results of bending test of concrete samples after 6 months stored in acidified slurry
Source: Own elaboration

No	Sample description according to:		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	102/C	Z-5-6	12.9	2
2	114/C	Z-10-6	14.4	7
3	127/C	Z-20-6	16.1	17

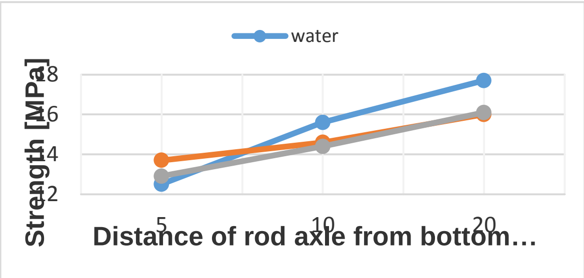


Fig. 42. The influence of the environment and the position of the steel rod on bending strength

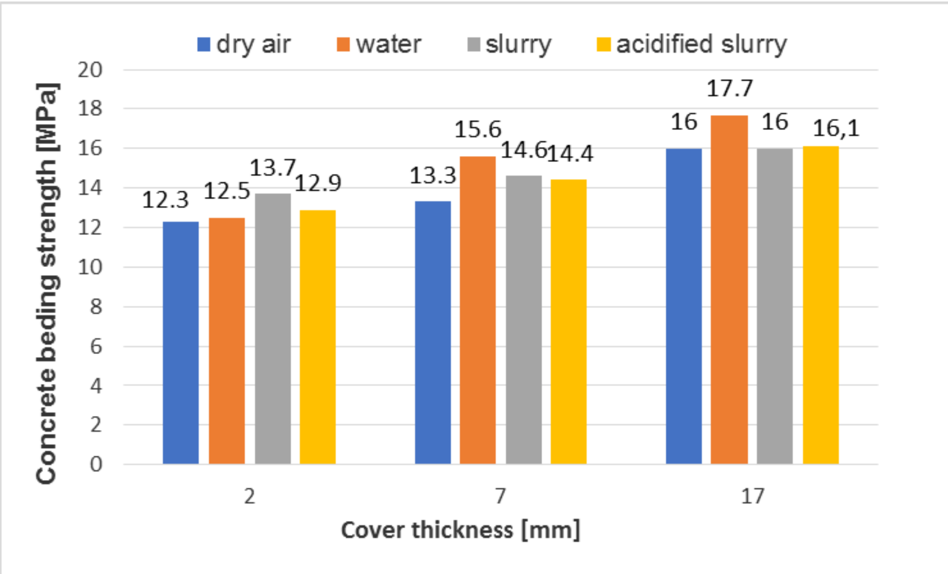


Fig. 43. The influence of environment and thickness of reinforcement cover on strength of concrete on bending after 6 months

Macroscopic evaluation of concrete samples 4cm x 4cm x 16cm reinforced with steel rod after 180 days (6 months).

All samples, stored for 180 days / 6 months / in medium- water,- fresh slurry,- acidified slurry, did not show visible damage on the surface. Cracking, scratches indicating corrosive effect of the environment or change in the volume of reinforcing steel was not revealed.

Evaluation of reinforcing steel after 6 months, samples stored in water environment

Source: B. Łochowski
Fig. 44. The sample after bending test. Cover 2 mm. Environment – water

Source: B. Łochowski
Fig. 45. The sample after bending test. Cover 7 mm. Environment - water

Source: B. Łochowski
Fig. 46. The sample after bending test. Cover 17 mm. Environment – water

Reinforcing bars in concrete samples, after 6 months of storage in water environment, do not show any corrosion changes in the form of rusty deposits. The condition of bars with 2mm, 7mm and 17mm cover is practically the same as at the time of forming the samples.

Evaluation of reinforcing steel after 6 months, samples stored in fresh slurry environment.

Source: B. Łochowski
Fig. 47. The sample after bending test. Cover 2 mm. Environment – fresh slurry

Source: B. Łochowski
Fig. 48. The sample after bending test. Cover 7 mm. Environment – fresh slurry

Source: B. Łochowski
Fig. 49. The sample after bending test. Cover 17 mm. Environment – fresh slurry

Reinforcing bars in concrete samples, after 6 months of storage in fresh slurry environment, do not show any corrosive changes in the form of rusty deposits. The condition of bars with 2mm, 7mm and 17mm cover is practically the same as at the time of forming the samples.

Evaluation of reinforcing steel after 180 days, samples stored in acidified slurry environment

Source: B. Łochowski
Fig. 50. The sample after bending test. Cover 2 mm. Environment – acidified slurry

Source: B. Łochowski
Fig. 51. The sample after bending test. Cover 7 mm. Environment – acidified slurry

Source: B. Łochowski
Fig. 52. The sample after bending test. Cover 17 mm. Environment – acidified slurry

Reinforcing bars in concrete samples, after a period of 6 months storage in acidified slurry, do not show significant corrosion changes in the form of rusty deposits. The condition of the bars with the 7mm and 17mm cover is practically the same as at the time of forming the samples, while on the fragment of the steel rod with a 2 mm cover, there was a coating indicating the beginning of the corrosion phenomenon.

Bending tests after 12 months

Table 36. The results of bending test of concrete samples after 12 months stored in water
Source: Own elaboration

No	Sample description according to		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	107/C	W-5-12	16.7	2
2	120/C	W-10-12	16.5	7
3	136/C	W-20-12	18.3	17

Table 37. The results of bending test of concrete samples after 12 months stored in slurry
Source: Own elaboration

No	Sample description according to		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	99/C	G-5-12	16.2	2
2	109/C	G-10-12	17.7	7
3	125/C	G-20-12	17.2	17

Table 38. The results of bending test of concrete samples after 12 months stored in acidified slurry
Source: Own elaboration

No.	Sample description according to		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	101/C	Z-5-12	14.5	2
2	115/C	Z-10-12	15.0	7
3	130/C	Z-20-12	16.4	17

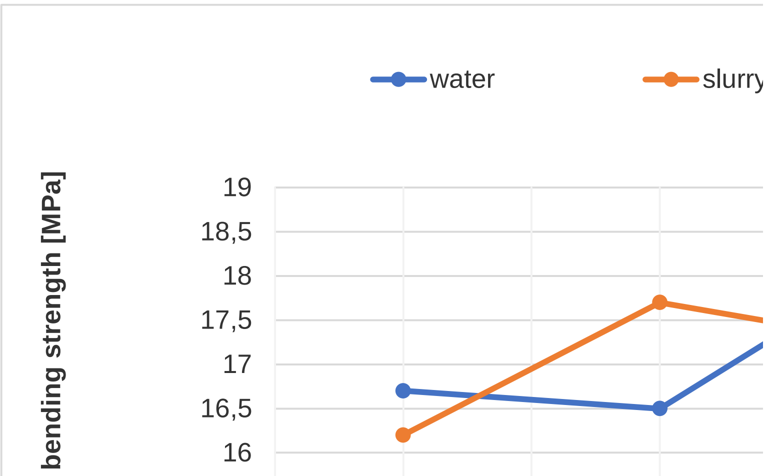


Fig. 53. The influence of the environment and the position of the steel rod on bending strength

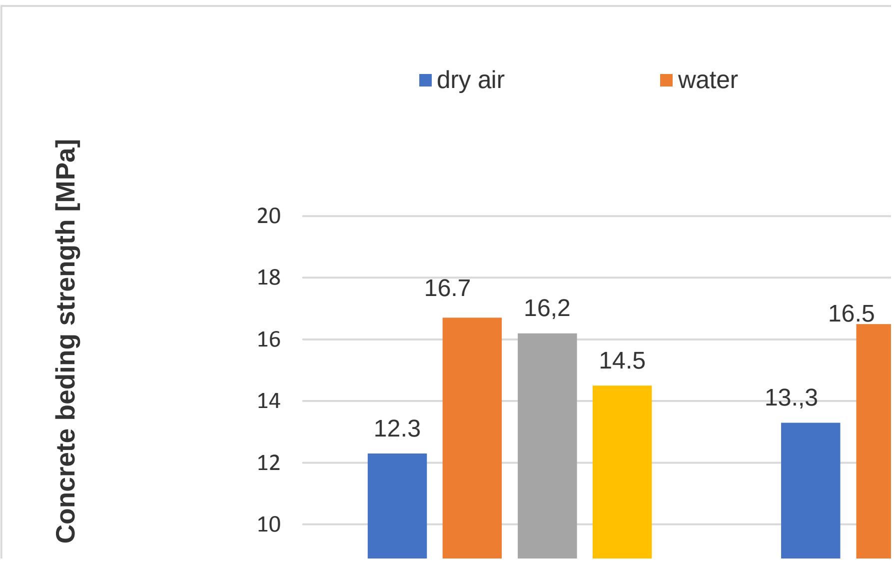


Fig.54. The influence of environment and thickness of reinforcement cover on strength of concrete on bending after 12 months

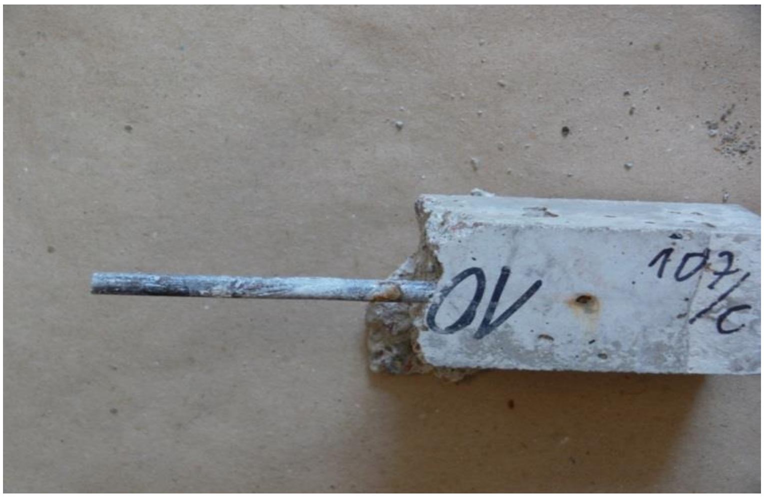
Summary after 12 months of storage

After a 12-month period of storage of concrete samples with steel bars, we can state as follows:
- for samples with a 2 mm coating, the bending strength of concrete stored in the water environment is higher than the bending strength of concrete stored in acidified slurry environment by 13%.
- for samples with a 7 mm coating, the bending strength of concrete stored in a water environment is higher than bending strength of concrete stored in acidified slurry environment by 9%.
- for samples with a 17 mm coating, the bending strength of concrete stored in a water environment is higher than bending strength of concrete stored in acidified slurry environment by 12%.
- for samples with 2 mm coating, the bending strengt of concrete stored in acidified slurry is 10.49 % lower than the bending strength of concrete stored in slurry environment.
- for samples with 7 mm coating, the bending strengt of concrete stored in acidified slurry is 15.2 % lower than the bending strength of concrete stored in slurry environment
- for samples with 17 mm coating, the bending strengt of concrete stored in acidified slurry is 4.65 % lower than the bending strength of concrete stored in slurry environment.

Macroscopic evaluation of concrete samples size 4cm x 4cm x 16cm reinforced with a steel rod after 12 months.

All samples stored for 12 months in the medium:-water, -slurry,- acidified slurry they did not show visible damage on the surface, cracking was not revealed, as also any scratches indicating a corrosive effect of the environment or a change in the volume of reinforcing steel were not observed.

Evaluation of reinforcing steel after 12 months, when samples were stored in a water environment



Source: B. Łochowski
Fig. 55. The sample after bending test. Cover 2 mm. Environment – water

Source: B. Łochowski
Fig. 56. The sample after bending test. Cover 7 mm. Environment – water

Source: B. Łochowski
Fig. 57. The sample after bending test. Cover 17 mm. Environment - water

Reinforcing bars in concrete samples, after 12 months of storage in the water environment, do not show any corrosion changes in the form of rusty deposits. The condition of bars with 2mm, 7mm and 17mm cover is practically the same as at the time of forming the samples.

Evaluation of reinforcing steel after 12 months, when samples were stored in slurry environment

Source: B. Łochowski
Fig. 58. The sample after bending test. Cover 2 mm. Environment – slurry

Source: B. Łochowski
Fig.59. The sample after bending test. Cover 7 mm. Environment – slurry

Source: B. Łochowski
Fig. 60. The sample after bending test. Cover 17 mm. Environment – slurry

Reinforcing bars in concrete samples, after a 12-month period of storage in a slurry environment, similarly to samples stored in water, do not show corrosion changes in the form of rusty deposits. The condition of bars with 2mm, 7mm and 17mm cover is practically the same as at the time when forming the samples.

Evaluation of reinforcing steel after 12 months, when samples were stored in acidified slurry environment

Source:B. Łochowski
Fig.61 The sample after bending test. Cover 2 mm. Environment – acidified slurry

Source:B. Łochowski
Fig. 62. The sample after bending test. Cover 7 mm. Environment – acidified slurry

Source: B. Łochowski
Fig. 63. The sample after bending test. Cover 17 mm. Environment – acidified slurry

Reinforcing bars in concrete samples, after a period of 12 months of storage in acidified slurry, do not show significant corrosion changes in the form of rusty deposits. The condition of the bars with the 7 mm and 17 mm cover is practically the same as at the time of forming the samples, whereas on the part of the steel rod with the 2 mm cover there is a rusty coating indicating the beginning of the corrosion phenomenon. Comparing Fig.50 showing the condition of the steel rod of the sample immersed in acidified slurry for a period of 6 months with Fig. 61 showing the state of a steel bar of a sample immersed in acidified slurry for a period of 12 months, it is stated that the increased time of exposure of acidified slurry affects the increase of the effect of corrosion.

Bending tests after 18 months

Water environment

Table 39. Results of bending test of concrete samples after 18 months stored in water
Source: Own elaboration

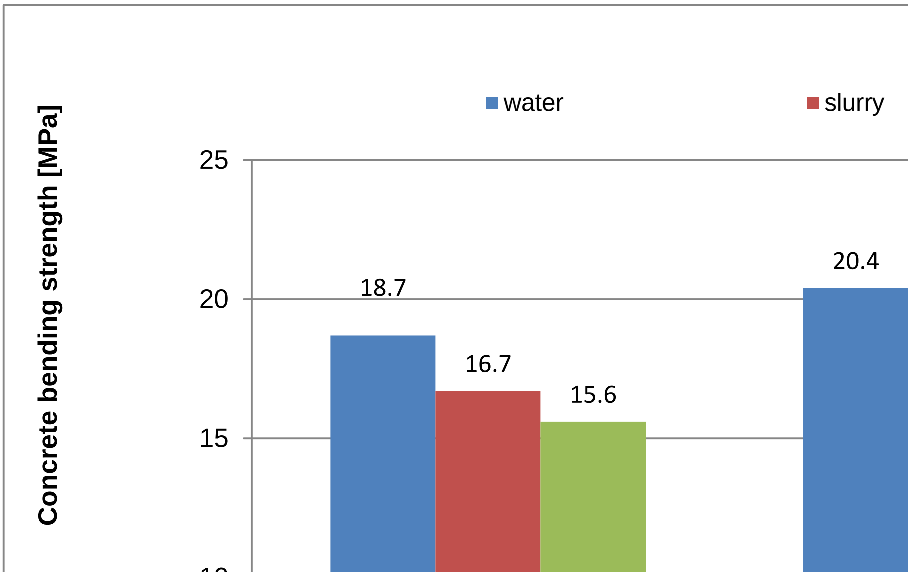
No.	Sample marking according to:		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	106/C	W-5-18	18,7	2
2	119/C	W-10-18	20,4	7
3	135/C	W-20-18	17,1	17

Table 40. Results of bending test of concrete samples after 18 months stored in slurry
Source: Own elaboration

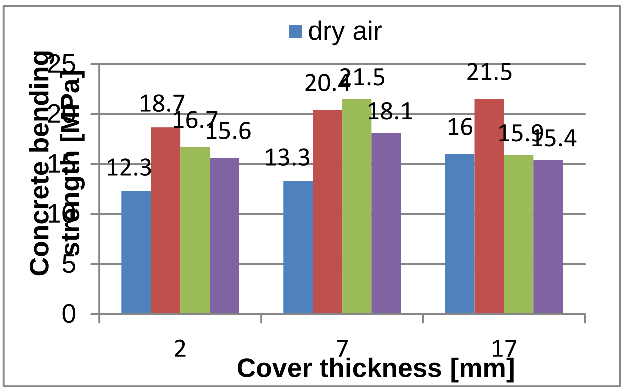
No	Sample marking according to:		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	100/C	G-5-18	16,7	2
2	113/C	G-10-18	21,5	7
3	126/C	G-20-18	15,9	17

Table 41. Results of bending test of concrete samples after 18 months stored in acidified slurry
Source: Own elaboration

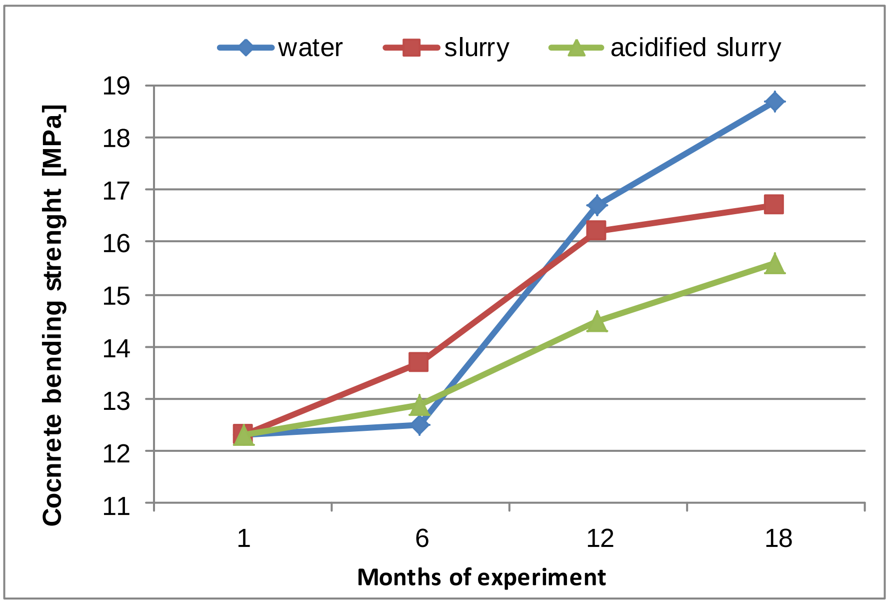
No.	Sample marking according to:		Bending strength R_f [MPa]	Thickness of concrete cover [mm]
	Hydrobudowa	ITP		
1	103/C	Z-5-18	15,6	2
2	117/C	Z-10-18	18,1	7
3.	131/C	Z-20-18	15,4	17



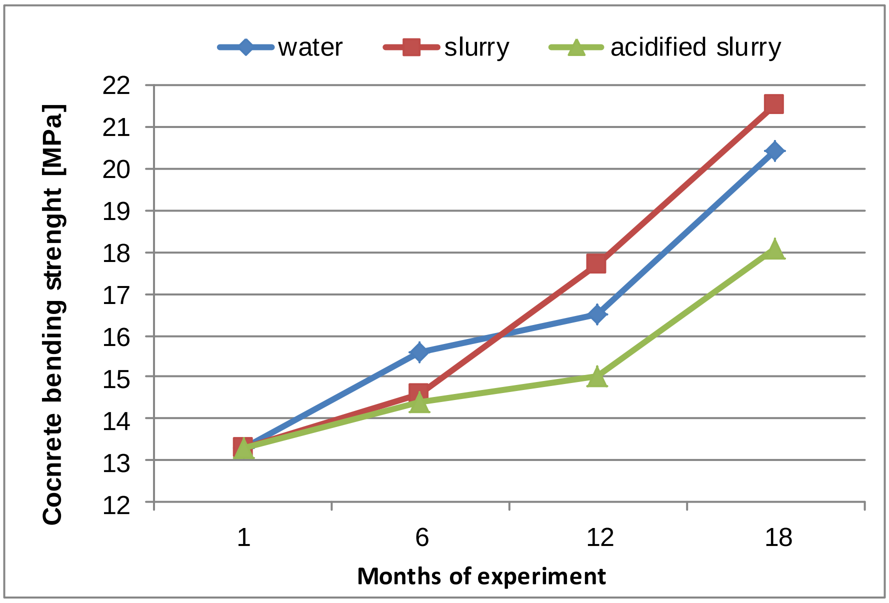
Source: Own elaboration
Fig. 64. The influence of the environment and the position of the steel rod on bending strength



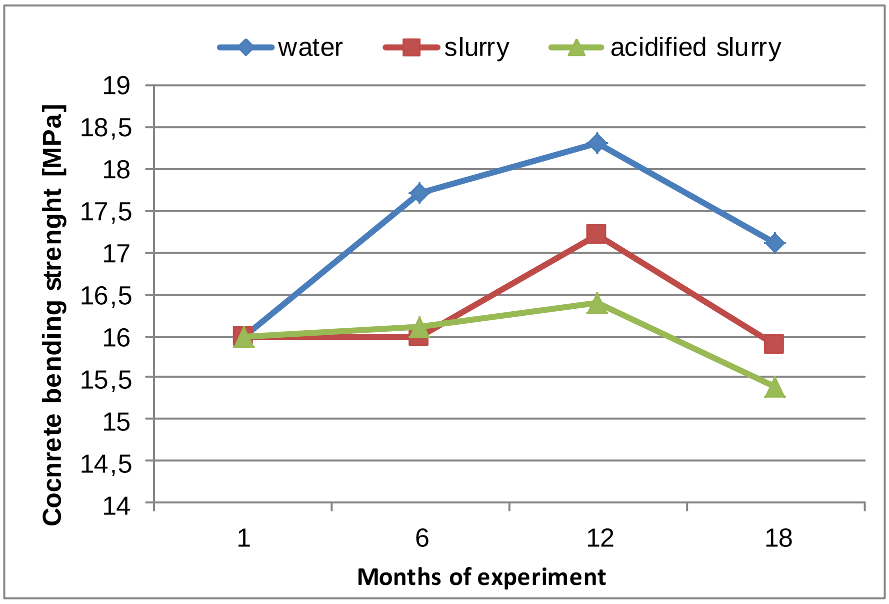
Source: Own elaboration
Fig. 65. The influence of environment and thickness of reinforcement cover on strength of concrete on bending



Source: Own elaboration
Fig. 66. The influence of time of storage concrete samples stored in water, slurry and acidified slurry on strength of concrete on bending / thickness of reinforcement cover 2mm/



Source: Own elaboration
Fig. 67. The influence of time of storage concrete samples stored in water, slurry and acidified slurry on strength of concrete on bending / thickness of reinforcement cover 7mm/



Source: Own elaboration
Fig.68. The influence of time of storage concrete samples stored in water, slurry and acidified slurry on strength of concrete on bending / thickness of reinforcement cover 17mm/

Summary

After period of 18 months of storage of reinforcing bars in concrete samples it could be stated:

- for samples with thickness of reinforcement cover 2 mm the strength of concrete on bending in acidified slurry is lower than water (17%) and lower than non-acidified slurry 6.58 %.

- for samples with thickness of reinforcement cover 7 mm the strength of concrete on bending in acidified slurry is lower than water (11%) and lower than non-acidified slurry 15.8%.

- for samples with thickness of reinforcement cover 17 mm the strength of concrete on bending in acidified slurry is lower than water (10%) and lower than non-acidified slurry 3.14%.

Destruction process in concrete reinforcement caused by acidified slurry is larger in by-surface layers compared with non-acidified slurry and water. Bending strength increases with with cover thickness in all environments and for all cases of cover thickness.

Macroscopic evaluation of concrete samples size 4cm x 4cm x 16cm reinforced with a steel rod after 18 months

All samples stored for 18 months in the mediums: -water, -slurry, - acidified slurry they did not show visible damage on the surface, cracking was not revealed, as also any scratches indicating a corrosive effect of the environment or a change in the volume of reinforcing steel were not observed.

Evaluation of reinforcing steel after 18 months, when samples were stored in a water environment

Source:B. Łochowski
Fig.69. Concrete sample after bending strength test. Side view of the sample

Source: B. Łochowski
Fig.70. The sample after bending test. Cover 2 mm. Environment – water

Source: B. Łochowski
Fig.71. The sample after bending test. Cover 7 mm. Environment – water

Source: B. Łochowski
Fig.72. The sample after bending test. Cover 17 mm. Environment – water

Reinforcing bars in concrete samples, after 18 months of storage in the water environment, do not show any corrosion changes in the form of rusty deposits. The condition of bars with 2 mm, 7 mm and 17 mm cover is practically the same as at the time of forming the samples and they are characterized by a gloss which can be seen in the above photographs.

Evaluation of reinforcing steel after 18 months, samples stored in slurry environment

Source: B. Łochowski
Fig.73. The sample after bending test. Environment – slurry

Source: B. Łochowski
Fig.74. The sample after bending test. Cover 2 mm. Environment – slurry

Source: B. Łochowski
Fig.75. The sample after bending test. Cover 7 mm. Environment – slurry

Source: B. Łochowski
Fig.76. The sample after bending test. Cover 17 mm. Environment – slurry

Evaluation of reinforcing steel after 18 months, samples stored in acidified slurry environment

Source:B. Łochowski
Fig.77. Concrete sample after bending strength test. Environment – acidified slurry

Source: B. Łochowski
Fig.78. The sample after bending test. Cover 2 mm. Environment – acidified slurry

Source: B. Łochowski
Fig.79. The sample after bending test. Cover 7 mm. Environment – acidified slurry

Source: B. Łochowski
Fig.80. The sample after bending test. Lagging 17 mm. Environment – acidified slurry

Reinforcing bars in concrete samples, after 18 months of storage in acidified slurry do not show any corrosion changes in the form of rusty deposits.

The condition of bars with a 7mm and 17mm casing is practically the same as at the moment of forming the samples. They are characterized by a gloss which can be seen in the above photographs. However, on the fragment of the steel rod with a 2 mm lagging there is a rusty coating that indicates the beginning of the corrosion phenomenon.

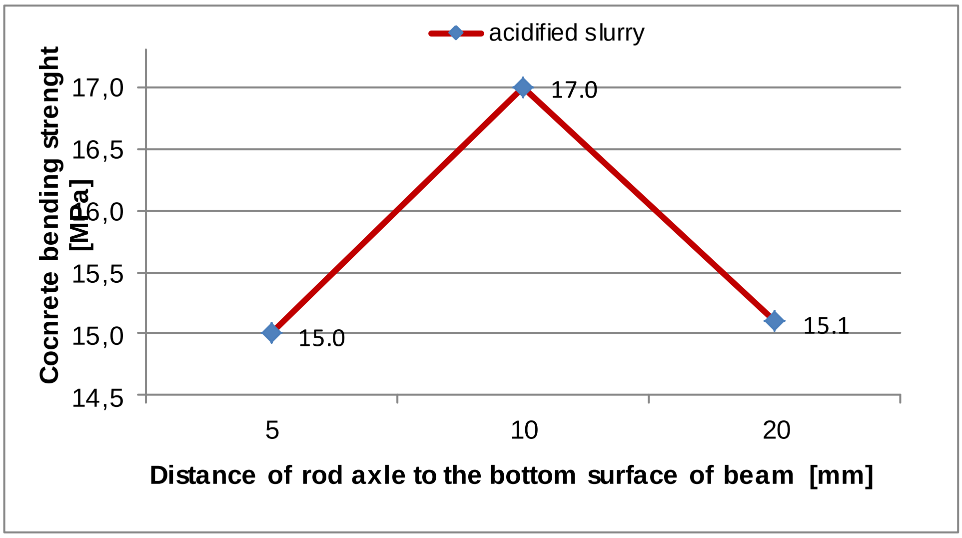
Comparing figure 50 showing the condition of the steel rod of the sample immersed in acidified slurry for a period of 6 months with fig.78. showing the condition of the steel rod of the sample immersed in acidified slurry over a period of 18 months, it is stated that the increased time of exposure of acidified slurry affects the increase of corrosion effect in a minimal way, not essential for technical solutions of facilities used for storing acidified slurry

The study after 21 months

According to the research methodology, after 21 months, the tests were carried out on concrete samples stored only in an acidified slurry.

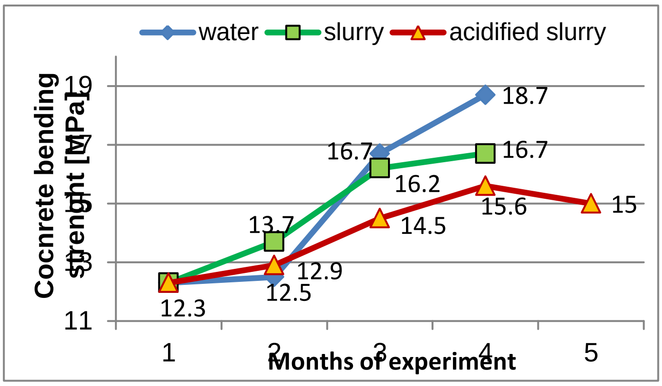
Table 42. Results of bending test of concrete samples after 21 months stored in acidified slurry. Source: Own elaboration

No.	Sample marking		Bending strength R_f [MPa]	Thickness of concrete lagging [mm]
	Hydrobudowa	ITP		
1	105/C	Z-5-21	15,0	2
2	118/C	Z-10-21	17,1	7
3	132/C	Z-20-21	15,1	17



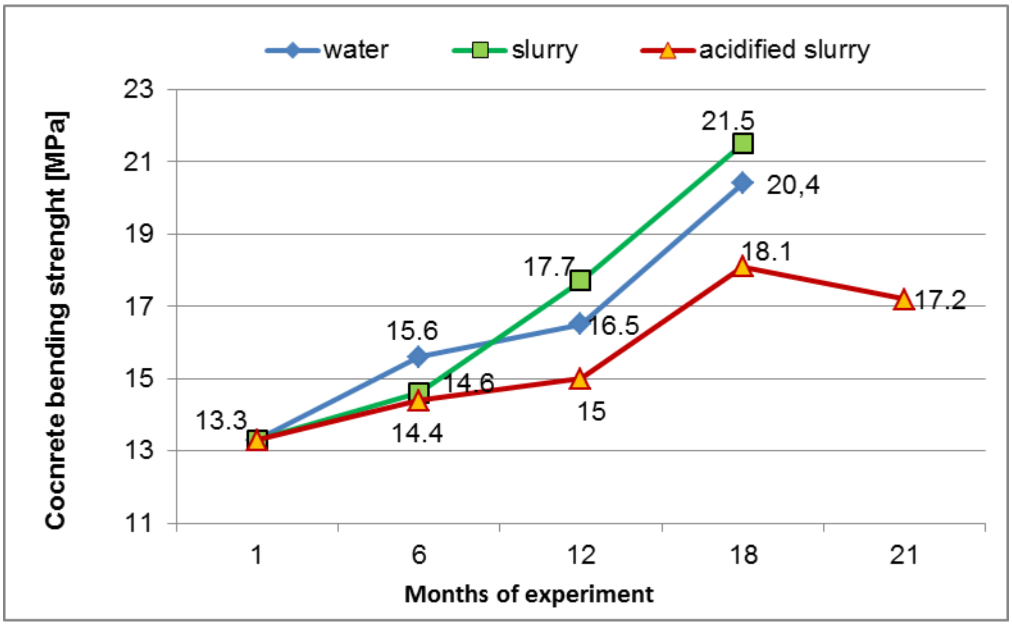
Source: Own elaboration

Fig.81. The influence of the environment and position of the steel rod on bending strength of concrete

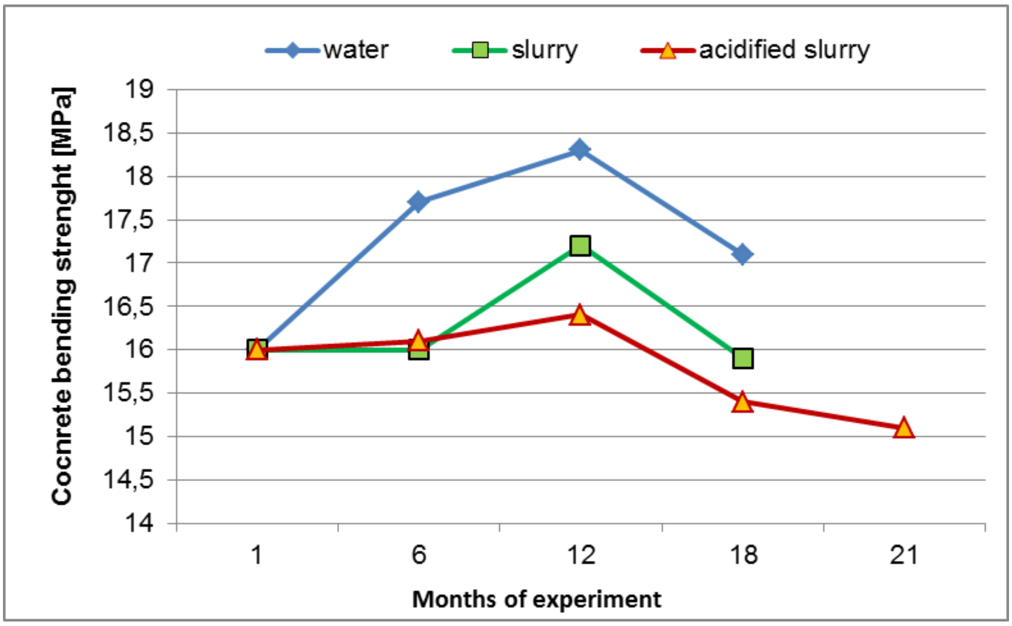


Source: Own elaboration

Fig. 82. Influence of the storage time of concrete samples in the water environment, in the slurry environment and the acidified slurry environment on strength of concrete for bending / reinforcement thickness - 2mm /



Source: Own elaboration
Fig.83. Influence of storage time of concrete samples in water environment, slurry environment and acidified slurry environment on bending strength of concrete / reinforcement thickness 7mm



Source: Own elaboration
Fig.84. Influence of storage time of concrete samples in water environment, slurry environment and acidified slurry environment on bending strength of concrete / reinforcement thickness 17mm /

After the research period between 18 and 21 months and the storage of concrete samples with steel rods in the environment of acidified slurry, we can state:

- for samples with a 2mm coating, the bending strength of concrete in an acidified slurry environment decreases

- for samples with a 7mm coating, the bending strength of concrete in an acidified slurry environment decreases

- for samples with a covering of 17mm, the concrete strength for bending in acidified slurry slurry decreases

Macroscopic evaluation of concrete samples 4cm x 4cm x 16cm reinforced with a steel rod after 21 months

All samples stored for 21 months in the medium:- acidified slurrythey did not show visible damage on the surface, cracking was not revealed, scratches indicating corrosive effect of the environment or change in the volume of reinforcing steel were not observed.

Evaluation of reinforcing steel after 21 months - samples stored in the acidified slurry environment

Source: B. Łochowski
Fig.85. The sample after bending test. Environment - acidified slurry

Source: B. Łochowski
Fig.86. The sample after concrete strangth bending test. Cover 2 mm. Environment - acidified slurry

Source: B. Łochowski
Fig.87. The sample after concrete strangth bending test. Cover 7 mm. Environment - acidified slurry

Source: B.Łochowski
Fig.88. The sample after concrete strangth bending test. Cover 17 mm. Environment - acidified slurry

Reinforcing bars in concrete samples, after a period of 21 months of storage in the environment of acidified slurry, do not show significant corrosion changes in the form of rusty deposits. The condition of the bars with the 7mm and 17mm cover is practically the same as at the time of forming the samples, while on the part of the steel rod with the 2 mm cover there is a minimal rusty coating indicating the beginning of the corrosion phenomenon.

Comparing Fig. 50 showing the condition of the steel rod with cover 2 mm, of the sample immersed in acidified slurry for a period of 6 months with Fig. 86 presenting the condition of the steel rod of the sample immersed in acidified slurry over a period of 21 months, it is stated that the increased time of acidification of slurry affects the increase of corrosion effects on rods in a minimal and even insignificant way for technical solutions of objects used to store acidified slurry.

Summary and conclusions from the tests of bending strength of concrete and the state of reinforcing steel

Concrete samples reinforced with a steel bar placed at different heights from the lower (stretched) base were stored in a water and slurry environment over a period of 18 months, whereas tests in the acidified liquid manure according to the methodology were extended to 21 months. The air-dry ripening and water ripening environment is a reference comparable reference point.

The obtained bending strengths of concrete allow to state:

- the general shape of the curves is similar and characteristic for particular environments,
- for each thickness; 2mm, 7mm, 17mm concrete reinforcement cover in the acidified slurry environment obtained the lowest numerical value of bending concrete strength in comparison with the results obtained in the environment of water and slurry,

- for 18 months, the bending strength of concrete for samples with a 2mm cover (Fig. 50) and 7mm (Fig. 51) increases and for samples with a cover of 17mm (fig. 57) after 12 months it decreases. The above phenomenon applies to all environments, i.e. water, slurry and acidified slurry, this is due to the fact that with a 17 mm cover, only concrete is virtually stretched / steel does not take part because it is placed in the neutral axis.

-the bending strength increases as the thickness of the steel bars coating increases to 7mm and then decreases, reaching a value close to the initial value at the maximum thickness. The above statement applies to all environments, water, slurry and acidified slurry, this results from the following fact: the maximum destructive force occurs when the axis of reinforcement bar Ø 6mm is spaced from the stretched beam zone in the 7mm cover.

The increase in this force can be explained by the retaining action on the steel reinforcing bar of vertical stresses caused by support force. These stresses have a maximum at the lower stretched edge of the vertical section and decrease rapidly as they move away in the vertical direction and move away in the horizontal direction.

The maximum value of strength of C 35/45 concrete for bending was obtained for a 7mm thick cover (fig. 73), which means that this layer provides sufficient protection against corrosion of the concrete-steel contact zone and ensures good adhesion of concrete to steel. The above statement applies to all environments, water, slurry and acidified slurry,

The reinforcing rods in the concrete cover stored in the acidified slurry environment in the period of 21 months show significant corrosion changes. On the steel rod with a concrete cover thickness of 2 mm shows slight corrosion in the form of a rusty coating. Sufficient thickness of the concrete reinforcement cover layer is 7mm in a 21 month perspective. Relevant standards included in Eurocode 2 specify the thickness of concrete reinforcement cover thickness at least 30mm.

5.3. Structural research under the electron microscope

5.3.1. The goal and scope of research

Structural investigations were conducted to determine the phase composition of concrete samples subjected to an acidified slurry environment after different periods of time.

5.3.2. Methodology of research

The concrete structure was determined using a scanning electron microscope type SEM. The test material were samples of concrete class:

- C 25/30

- C 30/37

stored in the environment of:

- air-dry 28 days after forming,
- acidified slurry for a period of 6 months,
- acidified slurry for a period of 12 months,
- acidified slurry for a period of 18 months,
- acidified slurry for a period of 21 months.

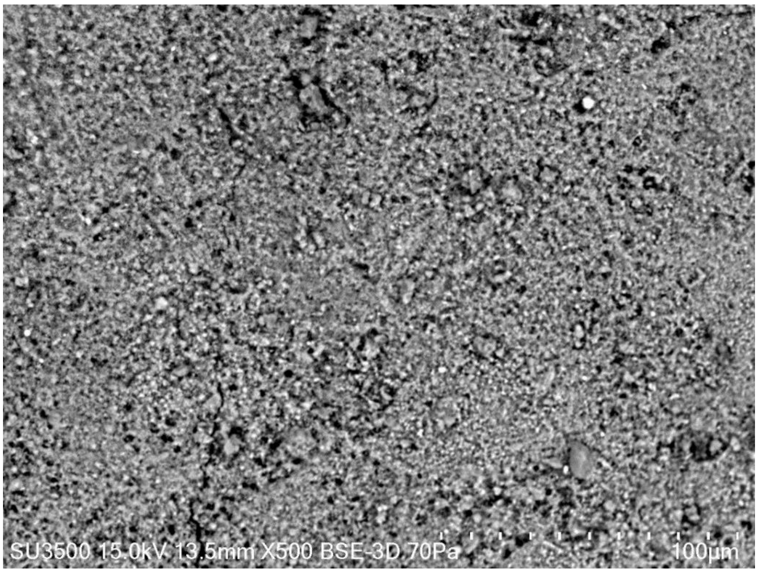
Samples were taken from concrete cubes 15cm x 15cm x 15cm subjected to compressive strength testing.

The test, 28 days after being molded, is the reference point for tests carried out in the following months. 9 elemental composition analyzes SEM-EDS will be made for the sample under test.

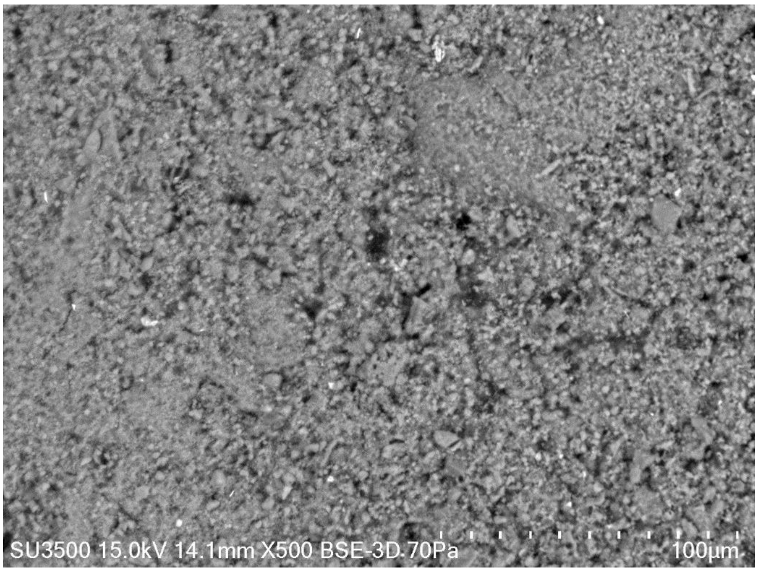
5.3.3. Test results

Test results after 28 days (22.03.2017)

Samples 28 days after being formed stored in air-dry conditions. The microstructure of samples C 25/30 and C30 / 37 is characterized by numerous pores and a network of small cracks. These surfaces are heterogeneous. The estimated pore size is from 1µm to 20µm. The main mass of the samples next to the aggregate is hydrated calcium silicate - C-S-H phase in fine crystalline form, which can be seen in fig. 89 and fig. 90.

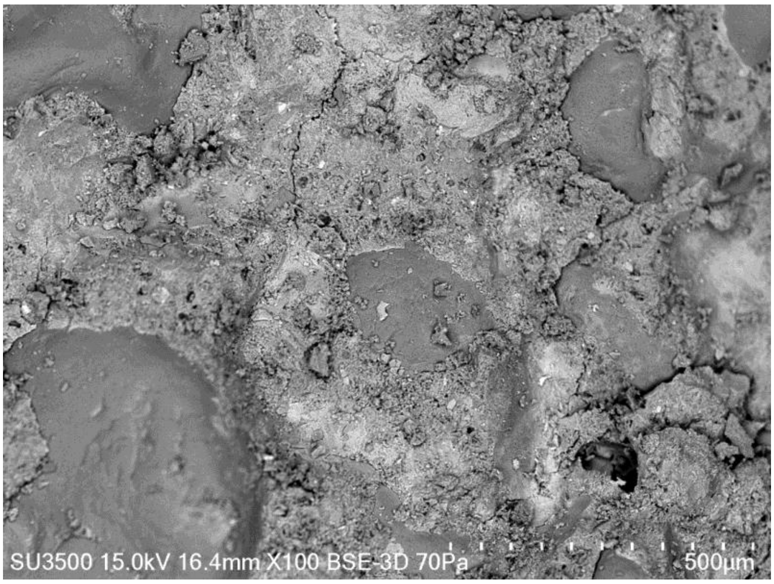


Source: Foundation of A. Mickiewicz University in Poznan WK/S/13/03/2017
Fig.89. A fine crystalline form of a hydrated calcium silicate phase C-S-H (hydrated calcium silicate) a sample of concrete C 25/30.



Source: Foundation of A. Mickiewicz University in Poznan WK/S/13/03/2017
Fig.90. A fine crystalline form of a hydrated calcium silicate phase C-S-H a sample of concrete C 30/37

It is possible to observe grains of aggregates with a diameter up to several hundred µm, they are clearly visible on fig. 91 and fig.92.



Source: Foundation of A. Mickiewicz University in Poznan WK/S/13/03/2017
Fig.91. Grains of aggregate in a concrete sample of a class C 25/30

Source: Foundation of A. Mickiewicz University in Poznan WK/S/13/03/2017
Fig.92. Grains of aggregate in a concrete sample of a class C 30/37

The composition of the samples was determined on the basis of the X-ray spectrum. For class C 25/30 concrete the composition is as follows;

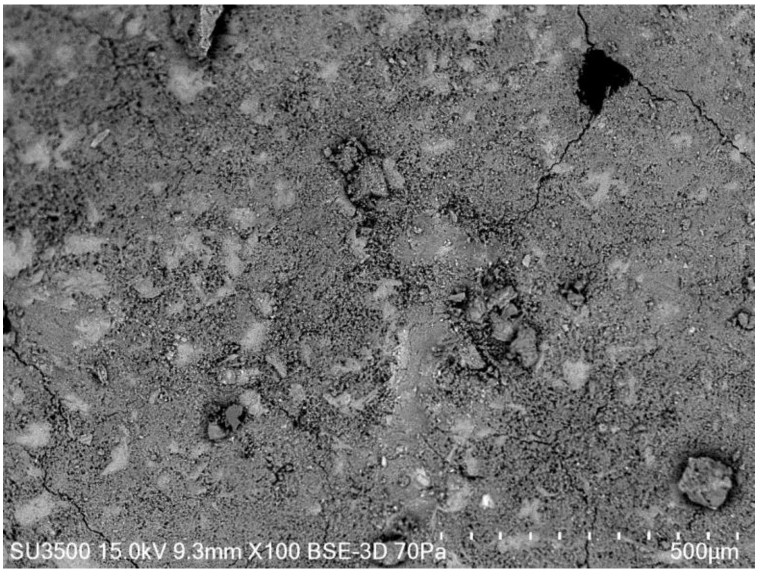
-oxygen 35-56%

-calcium 6-44%

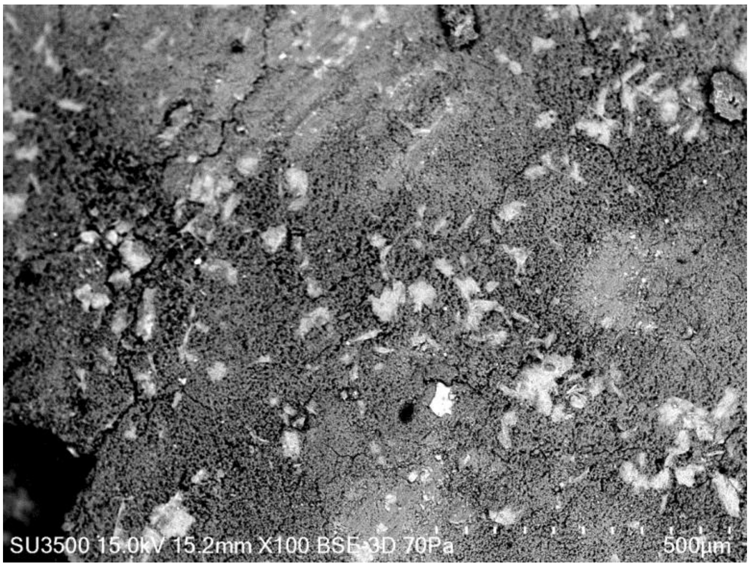
-silicon 3-38%

-mixtures of carbon, aluminum, iron, sulfur, magnesium, potassium, sodium.

In Fig. 93 and Fig. 94 bright areas with a diameter of up to 50 μm can be observed, on the basis of the chemical composition, we recognize the clear areas as calcium hydroxide crystals (Ca and O domination) and cement residues (Ca, Si, O).



Source: Foundation of A. Mickiewicz University in Poznan WK/S/13/03/2017
Fig. 93. The bright areas are calcium hydroxide crystals in concrete grade C 25/30



Source: Foundation of A. Mickiewicz University in Poznan WK/S/13/03/2017
Fig. 94. The bright areas are calcium hydroxide crystals in concrete grade C 25/30

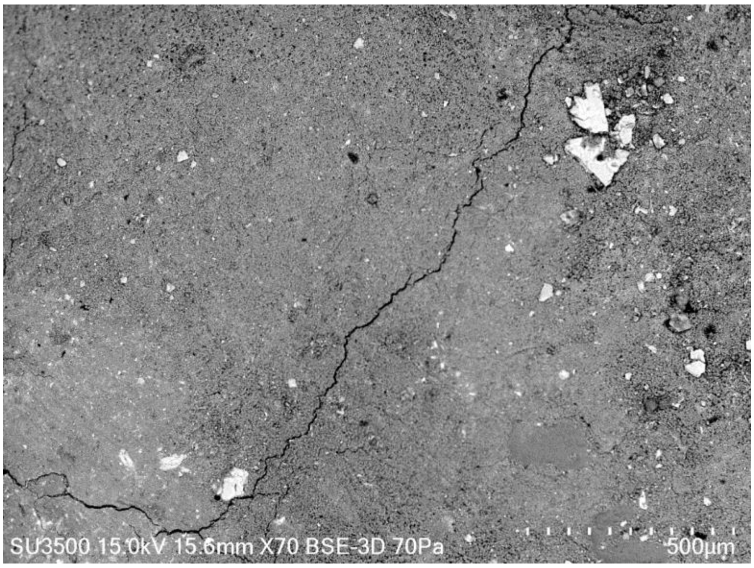
In tested samples concrete C 25/30, there are occasional clusters of metals such as iron and titanium with traces of manganese, which can be seen in the form of bright areas in fig.95.

Source: Foundation of A. Mickiewicz University in Poznan WK/S/13/03/2017
Fig. 95. The bright area - the clusters of iron, titanium with traces of manganese in the concrete of the class C 25/30

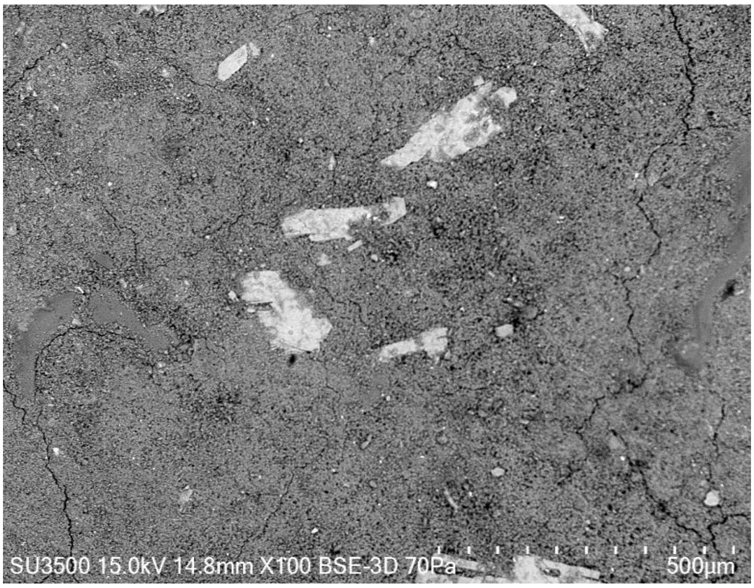
In the samples, no clear crystalline structures have been observed, i.e. etryngite probably due to the young age of concrete and the lack of open spaces and pores that allow the growth of this type of structures.

The composition of the samples was determined on the basis of the X-ray spectrum. For C 30/37 concrete, the composition is as follows;
-oxygen 35-55%
-calcium 5-40%
-silicon 1.5-40%
-mixtures of carbon, aluminum, iron, sulfur, magnesium, potassium, sodium.

In Fig. 96 and Fig. 97 could be observed bright areas of diameter up to 50 μm , based on chemical componds content bright ares are recognised as hydroxide crystals (Ca and O domination) and cement residues (Ca, Si, O).



Source: Foundation of A. Mickiewicz University in Poznan WK/S/13/03/2017
Fig. 96. Calcium hydroxide and cement residues in concrete class C 30/37 (The bright areas)

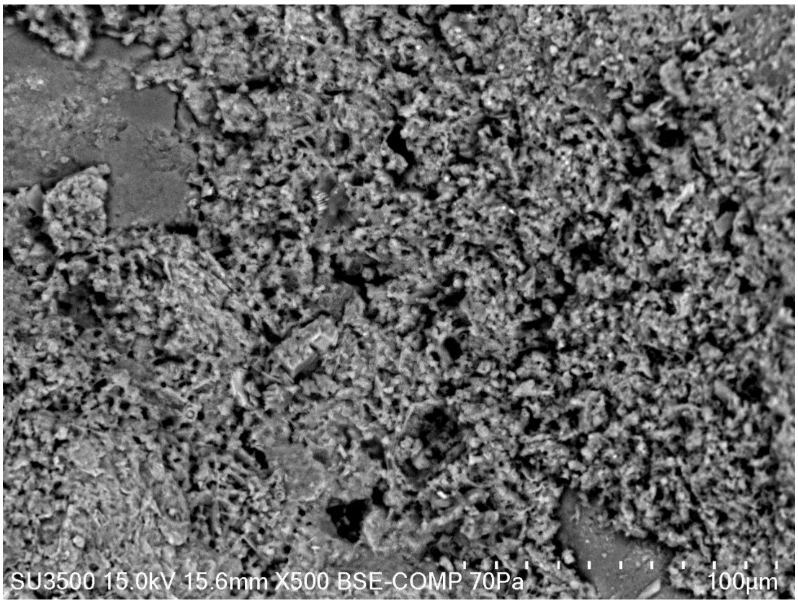


Source: Foundation of A. Mickiewicz University in Poznan WK/S/13/03/2017
Fig 97. The bright areas are calcium hydroxide and cement residues in the concrete class C 30/37

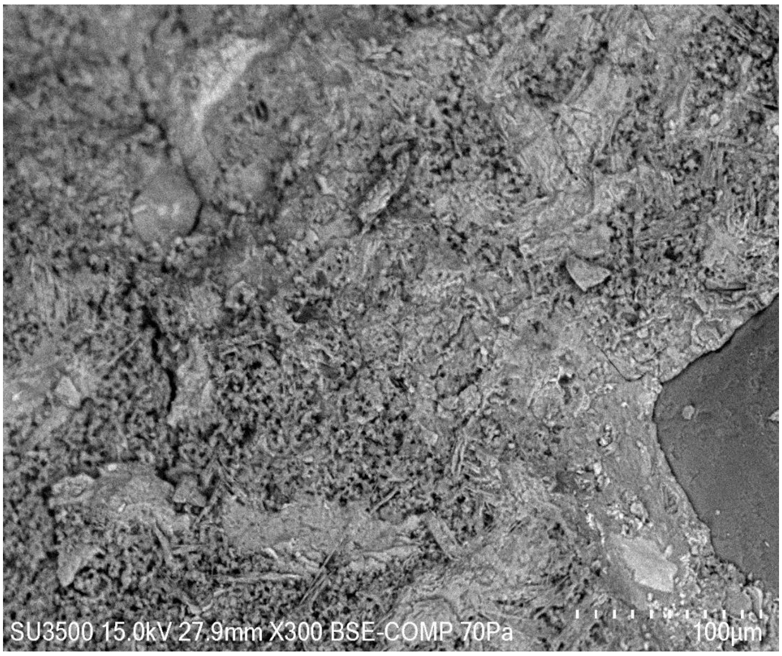
In concrete class C 30/37 no clear crystalline structures were observed, eg etryngite probably due to the young age of concrete and the lack of large voids and pores allowing the growth of this type of structures.

Samples after 180 days of storage exposed in acidified slurry (October 2017)

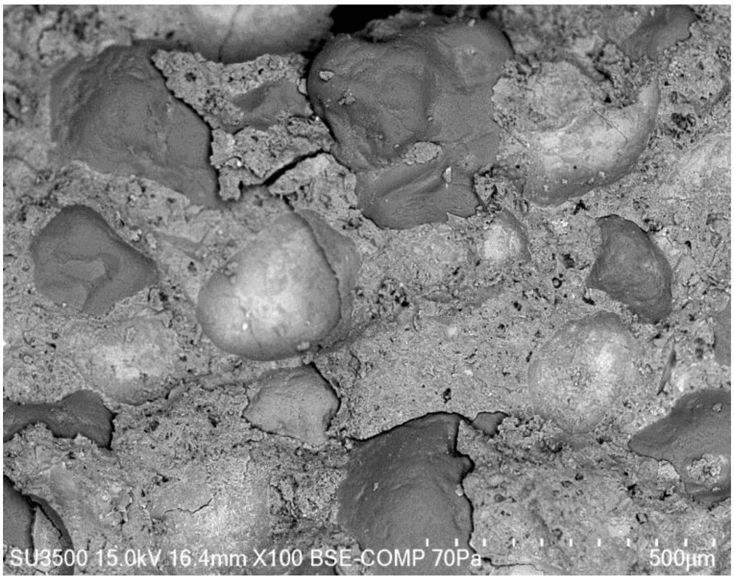
The microstructure of samples C 25/30 and C30 / 37 is characterized by numerous pores and a network of small cracks. These surfaces are heterogeneous. The estimated pore size is from 1μm to 20μm. The main mass of the samples next to the aggregate is hydrated calcium silicate - C-S-H phase in a fine crystalline form as can be seen in Fig. 98 and Fig. 99. In both samples it is possible to identify aggregate grains with a diameter up to several hundred μm visible in Fig. 100 and Fig. 101.



Source: Foundation of A. Mickiewicz University in Poznan WK/S/07/10/2017
Fig. 98.A fine crystalline form of a hydrated calcium silicate phase C-S-H sample of concrete class C 25/30



Source: Foundation of A. Mickiewicz University in Poznan WK/S/07/10/2017
Fig. 99. A fine crystalline form of a hydrated calcium silicate phase C-S-H,sample of concrete class C 30/37

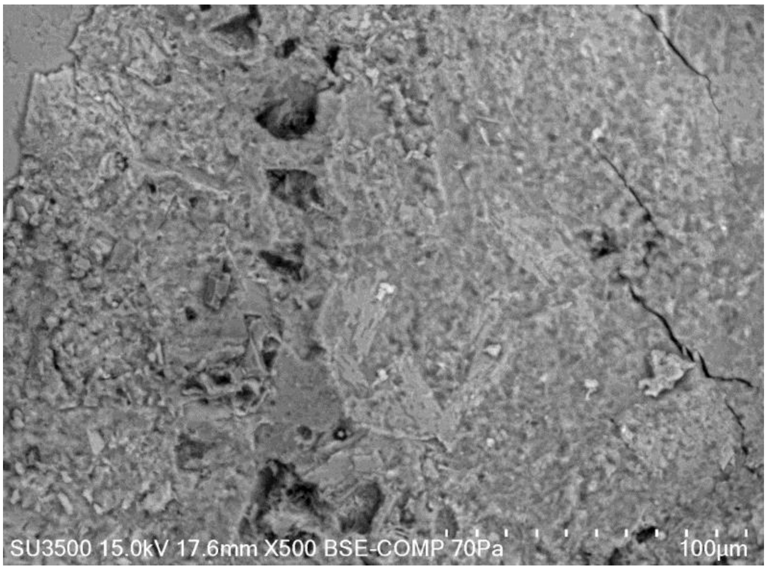


Source: Foundation of A. Mickiewicz University in Poznan WK/S/07/10/2017
Fig. 100. Grains of aggregate in a concrete sample of a class C 25/30

Source: Foundation of A. Mickiewicz University in Poznan WK/S/07/10/2017
Fig. 101. Grains of aggregate in a concrete sample of a class C 30/37

Concrete C25/30

Concrete sample contained mainly oxygen from 50 to 56%, calcium from 5 to 43% and silicon from 5 to 41% with admixtures of carbon, aluminum, iron, sulfur, magnesium, potassium and sodium. The sample does not contain light residues of cement or calcium hydroxide. Clusters of other metals, mainly of iron, appear sporadically.
In the few open spaces an increase in the crystalline structure in the shape of needles is observed, this is ettringite, visible in Fig. 102. in the middle part.



Source: Foundation of A. Mickiewicz University in Poznan WK/S/07/10/2017
Fig. 102. The bright areas are the forming etryngite crystals in the concrete of the class C 25/30

Concrete C30/37

The concrete sample contains mainly oxygen from 47 to 57%, calcium from 6 to 38% and silicon from 8 to 34%. The sample also contains carbon, aluminum, iron, sulfur, magnesium, potassium and sodium. There was no residue of cement or calcium hydroxide.

The amount of free space is small, however, an increase in clear crystalline structures in the form of plaques and needles / etryngite has been observed (Fig. 103. and Fig. 104).

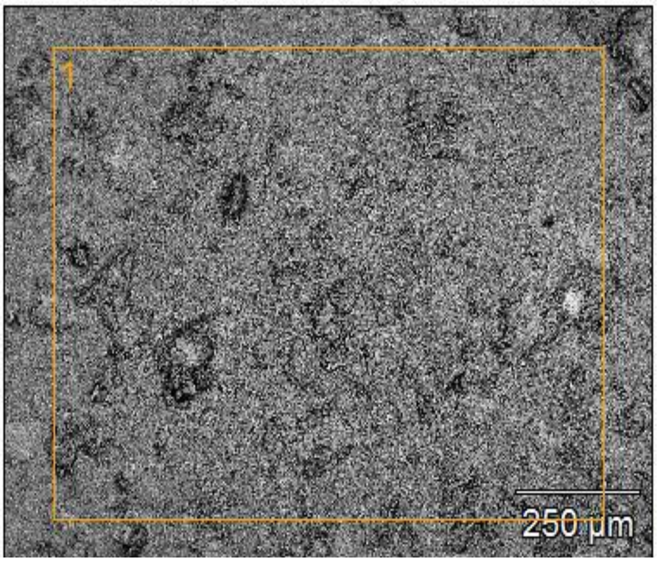
Source: Foundation of A. Mickiewicz University in Poznan WK/S/07/10/2017
Fig. 103. The bright areas are the forming of etryngite crystals in C 30/37 concrete in a hollow after the removal of the aggregate / top and bottom of the photo / grain.

Source: Foundation of A. Mickiewicz University in Poznan WK/S/07/10/2017
Fig. 104. The bright areas are the forming etryngite crystals in C 30/37 concrete in a hollow after removal of the aggregate / middle and lower part of the photo /.

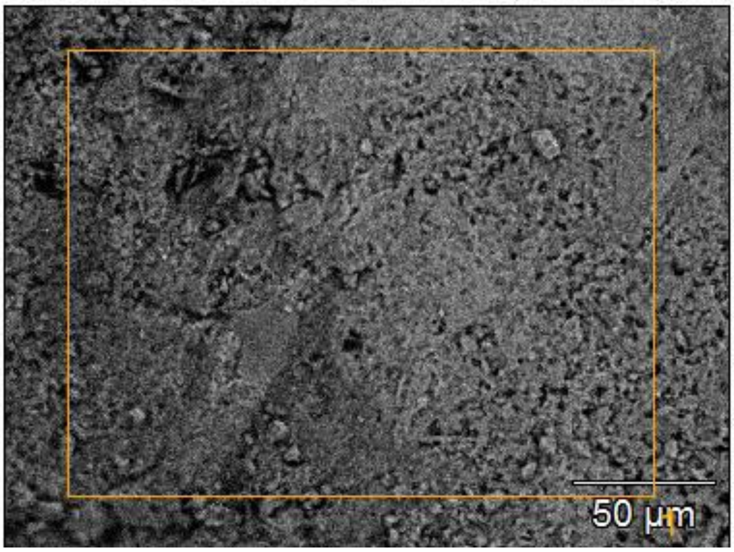
Samples after 12 months / 360 days / storage under acidified slurry

Research from 18/04/2018

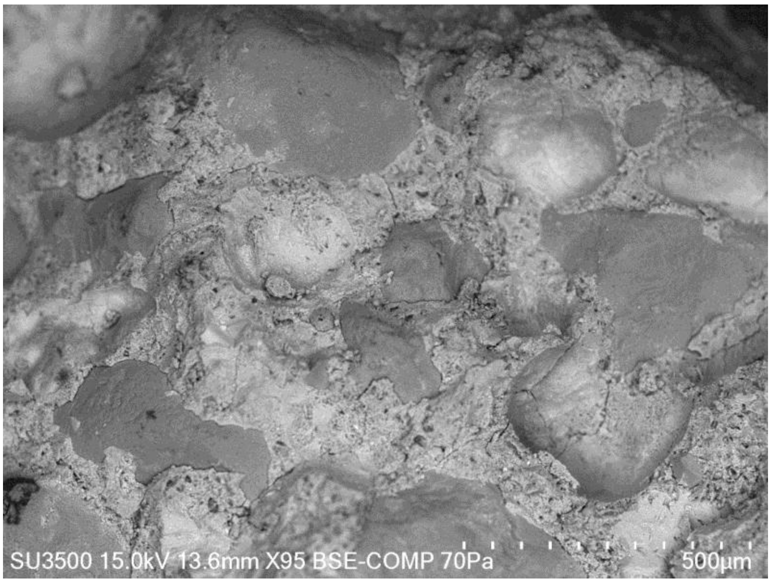
The microstructure of samples C 25/30 and C30/37 is characterized by numerous pores and a network of small cracks. These surfaces are heterogeneous. Pore size can be estimated at 1µm to 20µm. The main mass of the samples next to the aggregate is the hydrated calcium silicate - phase C-S-H in a fine crystalline form as can be seen in Fig. 105., Fig.106
In both samples, aggregate grains with a diameter up to several hundred µm can be identified, as shown in Fig. 107 and Fig. 108.



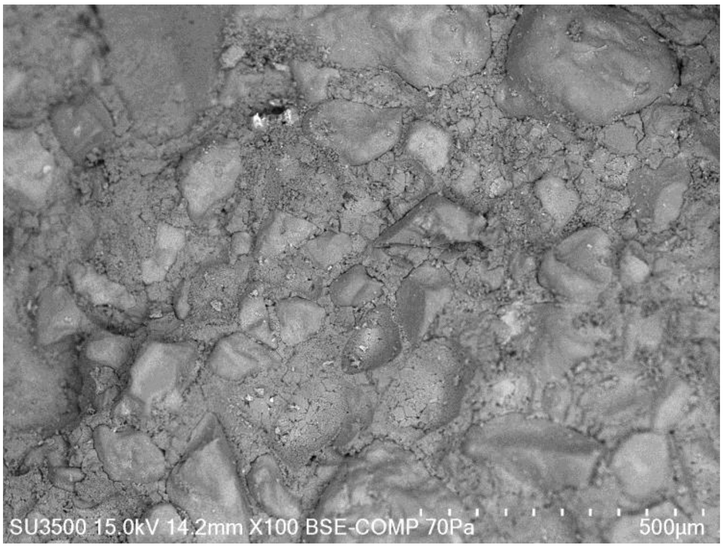
Source: Fundation of A.Mickiewicz University in Poznań ZUB/S/13/04/2018
Fig. 105. A fine crystalline form of a hydrated calcium silicate phase C-S-H a concrete sample class C 25/30



Source: Fundation of A.Mickiewicz University in Poznań ZUB/S/13/04/2018
Fig.106. A fine crystalline form of a hydrated calcium silicate phase C-S-H a sample concrete class C 30/37



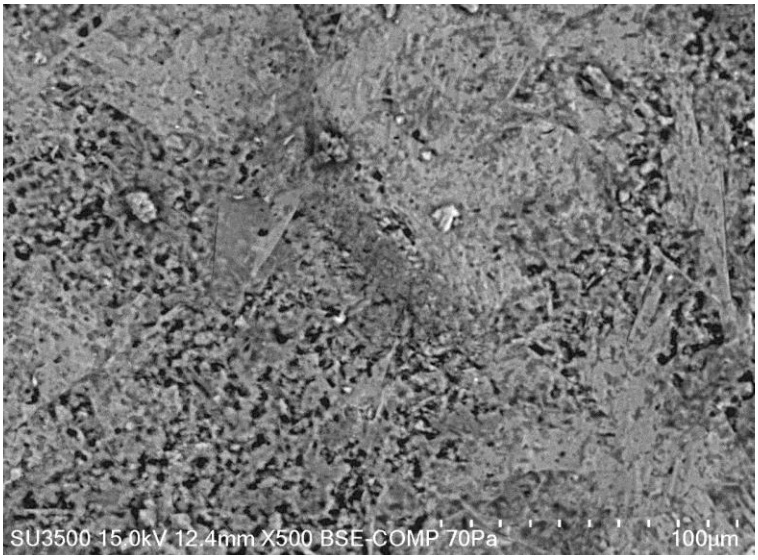
Source: Fundation of A.Mickiewicz University in Poznań ZUB/S/13/04/2018
Fig. 107. Grain aggregate in a concrete sample class C 25/30



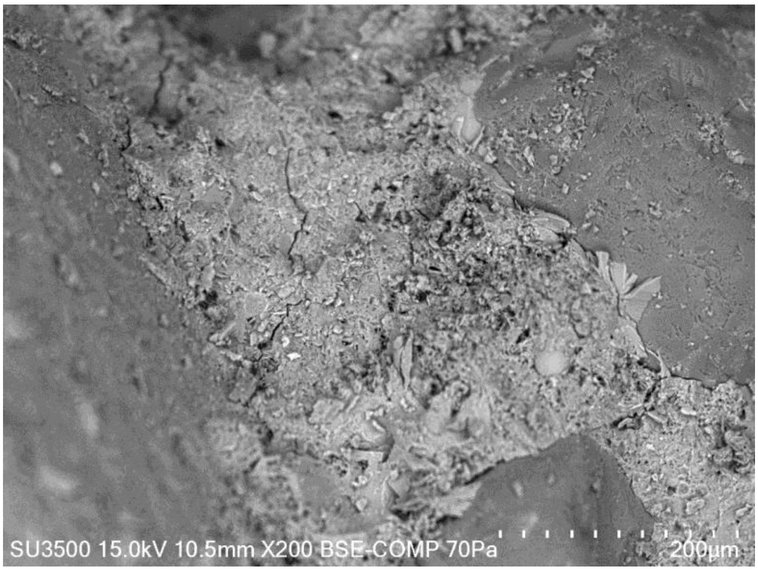
Source: Fundation of A.Mickiewicz University in Poznań ZUB/S/13/04/2018
Fig. 108. Grain aggregate in a concrete sample class C 30/37

Concrete class C25 / 30

Concrete sample contains mainly oxygen from 46 to 55%, calcium from 9 to 35% and silicon from 4 to 34% with admixtures of carbon, aluminum, iron, sulfur, magnesium, potassium and sodium.
The sample does not contain light residues of cement or calcium hydroxide. Clusters of other metals, mainly of iron, appear sporadically. In the few open spaces an increase in the crystalline structures in the shape of needles has been observed, this is etryngite visible on Fig. 109. in the middle part and in the form of lamellar structures of the C-S-H phase (Fig.110).



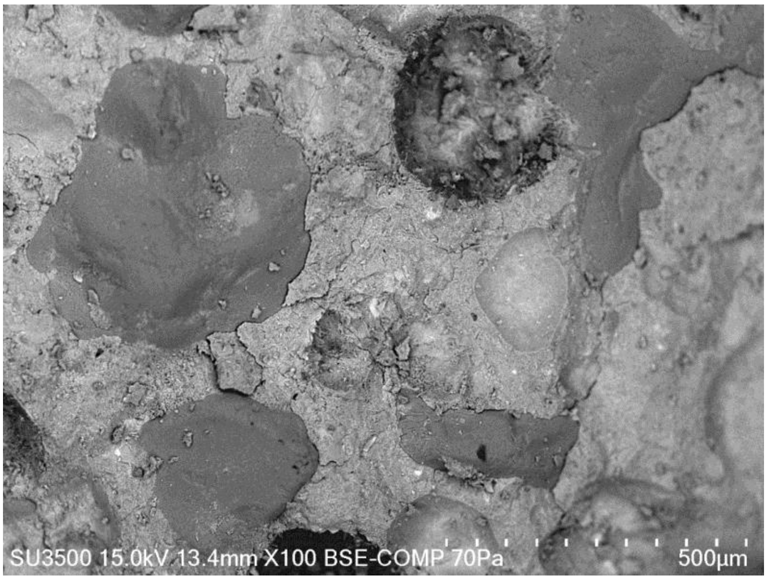
Source: Fundation of A.Mickiewicz University in Poznań ZUB/S/13/04/2018
Fig. 109. Crystalline structures in the shape of needles /etringite/ in concrete class C 25/30



Source: Fundation of A.Mickiewicz University in Poznań ZUB/S/13/04/2018
Fig. 110. Lamellar structures phase C-S-H in concrete C 25/30

Concrete class C30 /37

The concrete sample contains mainly oxygen from 40 to 54%, calcium from 8 to 45% and silicon from 6 to 37%. The sample also contains carbon, aluminum, iron, sulfur, magnesium, potassium and sodium. Clear residues of cement and calcium hydroxide were found. In a few places there are traces of metals, for example zirconium. The amount of free space is small, however, the growth of very fine, clear crystalline structures in the form of needles / etryngite/ has been observed (Fig. 111).



Source: Fundation of A.Mickiewicz University in Poznań ZUB/S/13/04/2018
Fig. 111.The bright areas are the forming of etryngite crystals in concrete class C 30/37 in the recess after removal of the grain aggregate and on the periphery of the crater /middle and upper part of the photograph/.

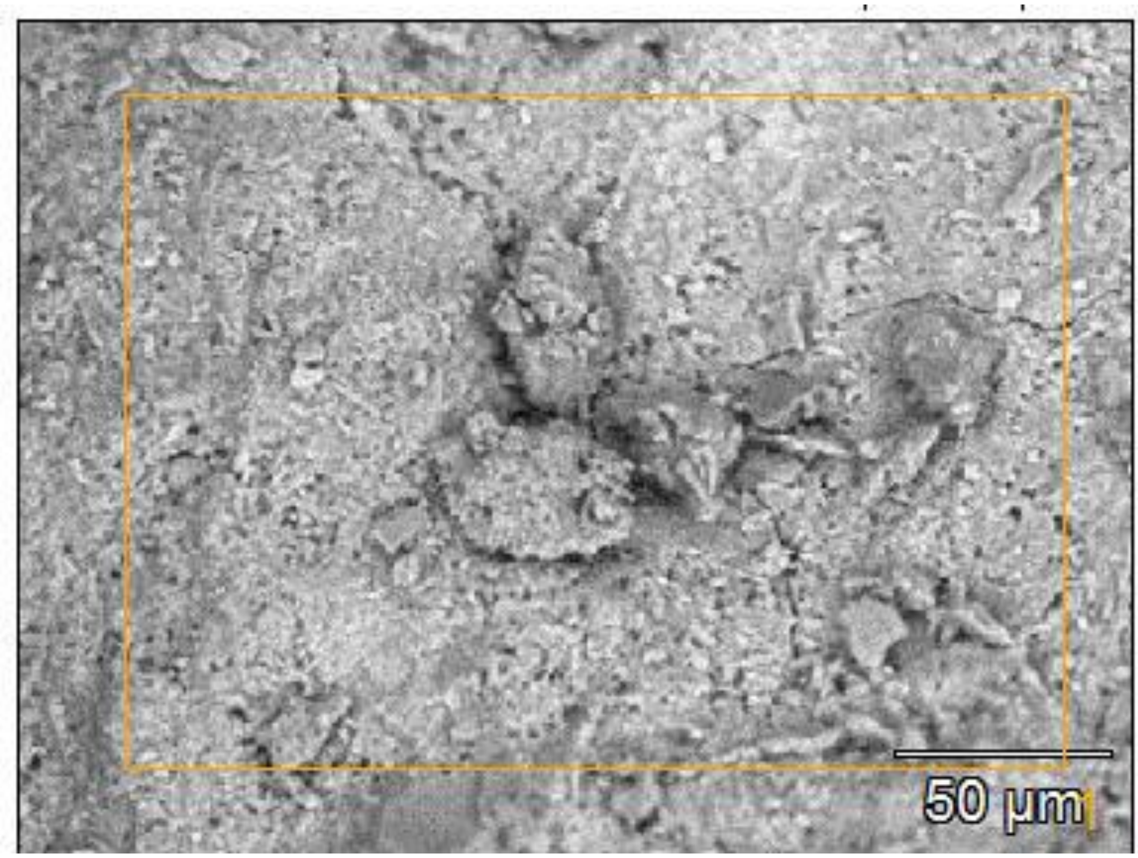
Summary

The morphology and chemical composition of the tested samples in comparison with the reference samples differ mainly due to the lack of crystals of calcium hydroxide and residual cement and a clear start to the formation of etryngite crystals. There was no significant increase in the porosity of the tested samples compared to the reference samples stored in air and phenomena supporting extensive degradation of the structure. The structure of the tests is close without numerous free spaces enabling the crystallization of concrete components.

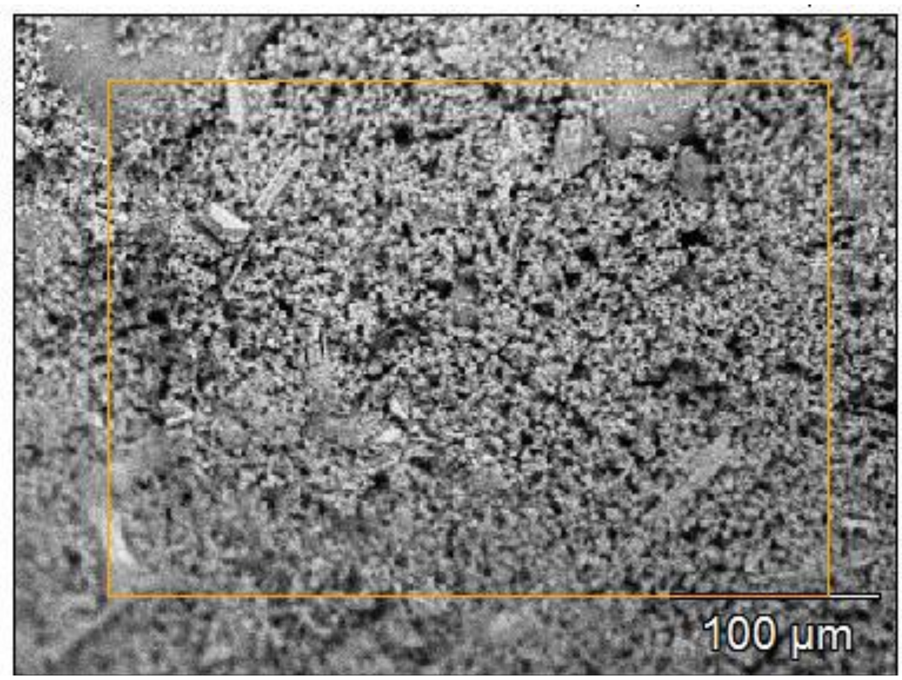
Samples after 18 months / 540 days / storage under acidified slurry conditions. Survey of 09/10/2018

The microstructure of samples C 25/30 and C30 / 37 is characterized by numerous pores and a network of small cracks. These surfaces are heterogeneous. Pore size can be estimated from 1μm to 20μm. The main mass of the samples next to the aggregate is the hydrated calcium silicate - phase C-S-H in fine crystalline form as can be seen in Fig. 112, and Fig. 113.

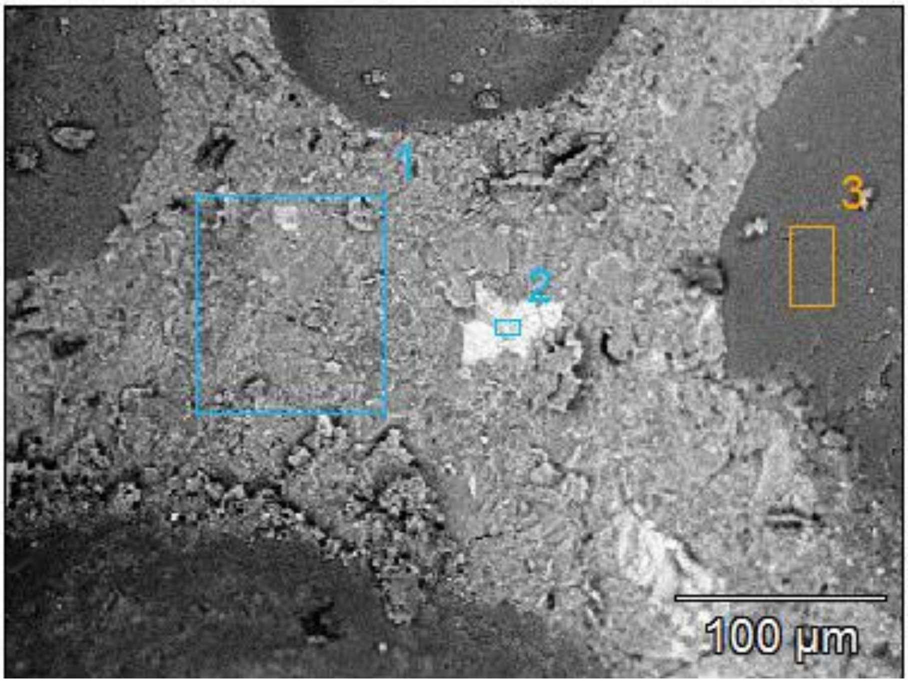
In both samples it is possible to identify aggregate grains with a diameter up to several hundred μm visible in Fig. 114 and Fig.115.



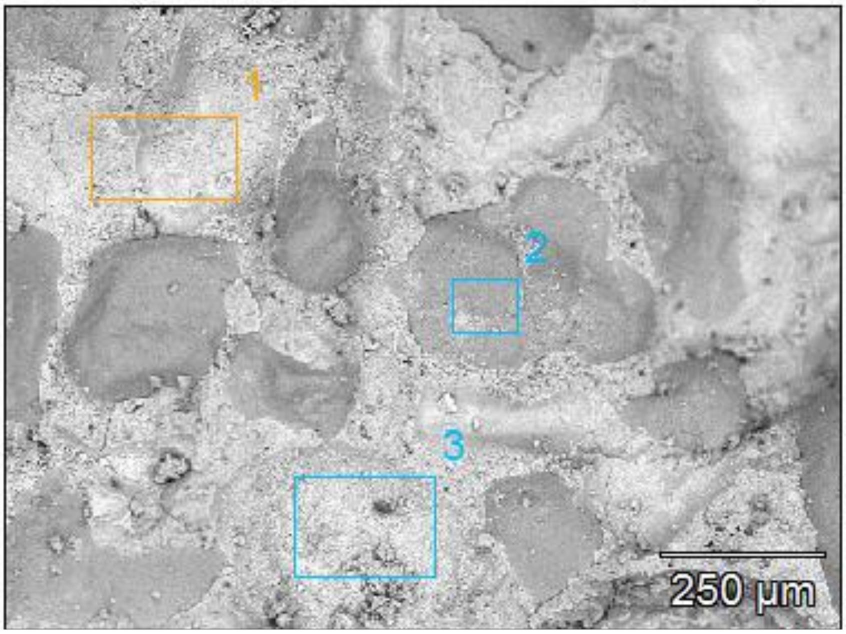
Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/03/10/2018
Fig. 112. A fine crystalline form of hydrated calcium silicate, C-S-H phase, a sample of concrete C 25/30



Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/03/10/2018
Fig. 113. A fine crystalline form of hydrated calcium silicate, C-S-H phase, a sample of concrete C 30/37



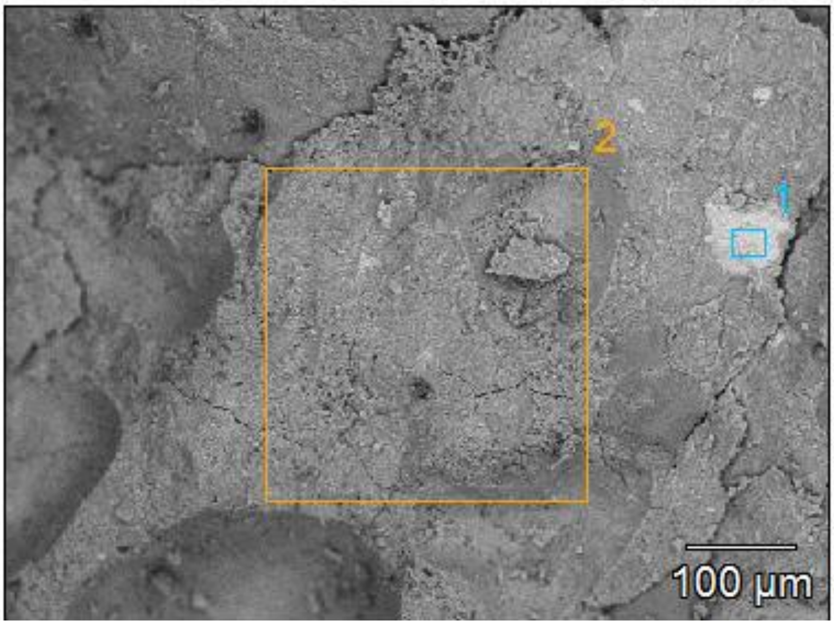
Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/03/10/2018
Fig. 114. Aggregate grains in a C-Class concrete sample 25/30 / dark areas at the edges of the image. 1, 2, 3- particular areas for analysis of elements



Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/03/10/2018
Fig. 115. Aggregate grains in a C-Class concrete sample 30/37. 1, 2, 3- particular areas for analysis of elements

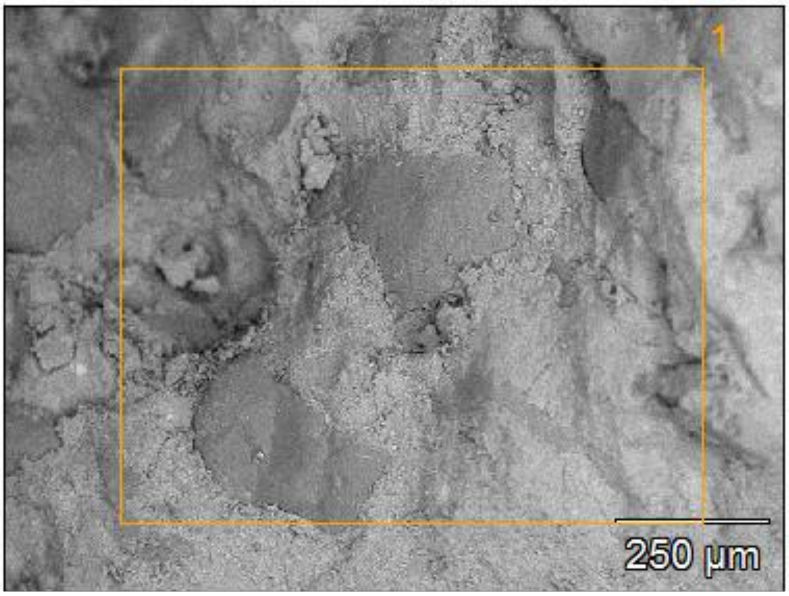
Concrete C25/30

The concrete sample contains mainly oxygen from 42 to 56%, calcium from 3.9 to 38.5% and silicon from 6.5 to 35.3% with added mixtures of carbon, aluminum, iron, sulfur, magnesium, potassium and sodium. The sample contains a few light residues of cement or calcium hydroxide visible in Fig. 116.

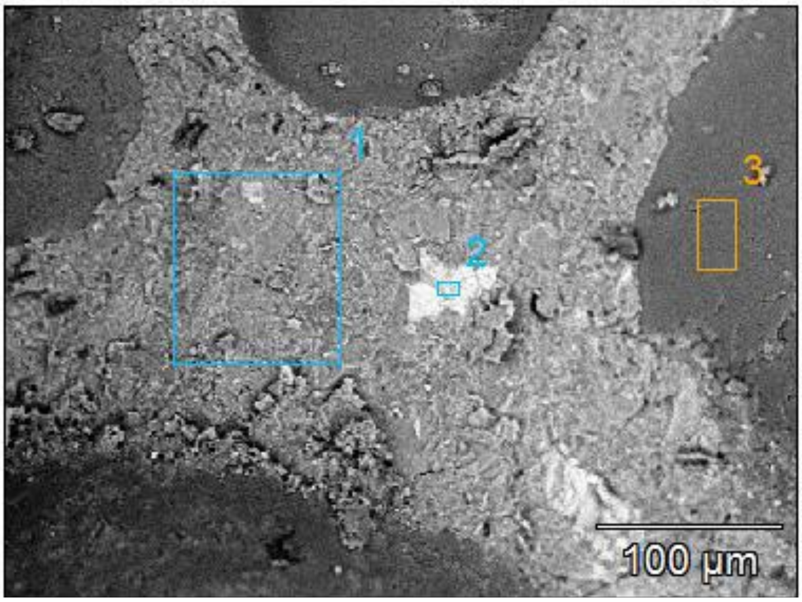


Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/03/10/2018
Fig. 116. The bright areas are calcium hydroxide and cement residues in concrete C 25/30 . 1, 2, particular areas for analysis of elements

The growth of crystalline structures in the shape of needles was observed in the open spaces, this is etryngite visible in Fig. 117. in the upper left part and in the form of lamellar structures of the C-S-H phase (Fig. 118).



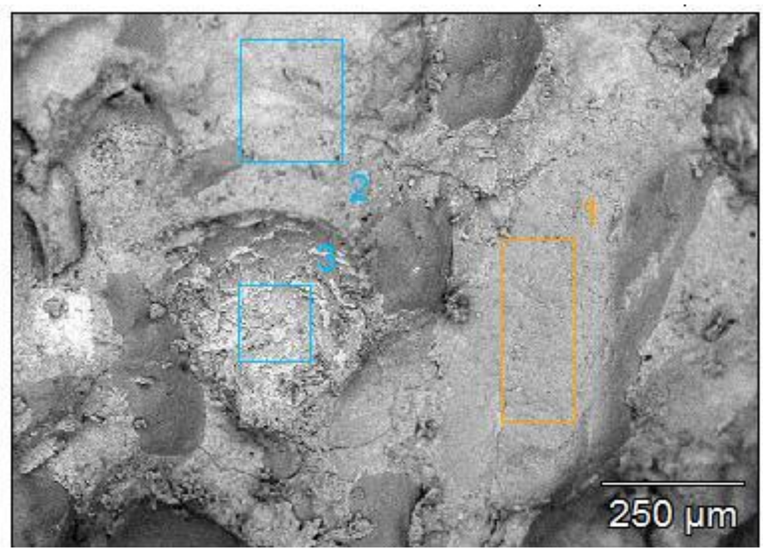
Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/03/10/2018
Fig. 117. The bright areas are the forming etryngite crystals in concrete C-Class 25/30 (left upper part of the photograph)



Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/03/10/2018
Fig. 118. Lamellar C-S-H phase structures in concrete C 25/30 1, 2, 3- particular areas for analysis of elements

Concrete C30/37

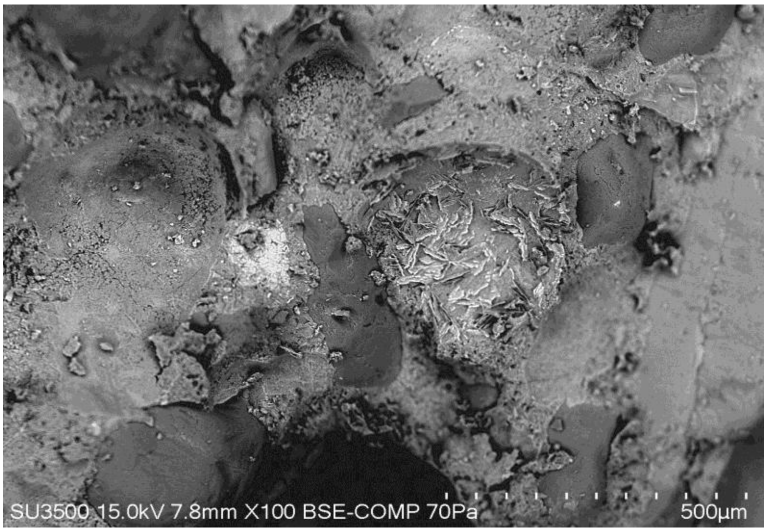
The concrete sample contains mainly oxygen from 34.8 to 55.2%, calcium from 3.3 to 38.9% and silicon from 5.6 to 39.2%. The sample also contains carbon, aluminum, iron, sulfur, magnesium, potassium and sodium. Clear residues of cement and calcium hydroxide were found visible in Fig. 119.



Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/03/10/2018
Fig. 119. The bright areas are calcium hydroxide and cement residues in concrete C 30/37
1, 2, 3- particular areas for analysis of elements

There are metal traces in a few places, eg zirconium.

The amount of free space is small, however, a marked increase in very fine crystalline structures in the form of needles / etryngite / in pores or openings remaining after removing the aggregate grains was observed (Fig. 120).



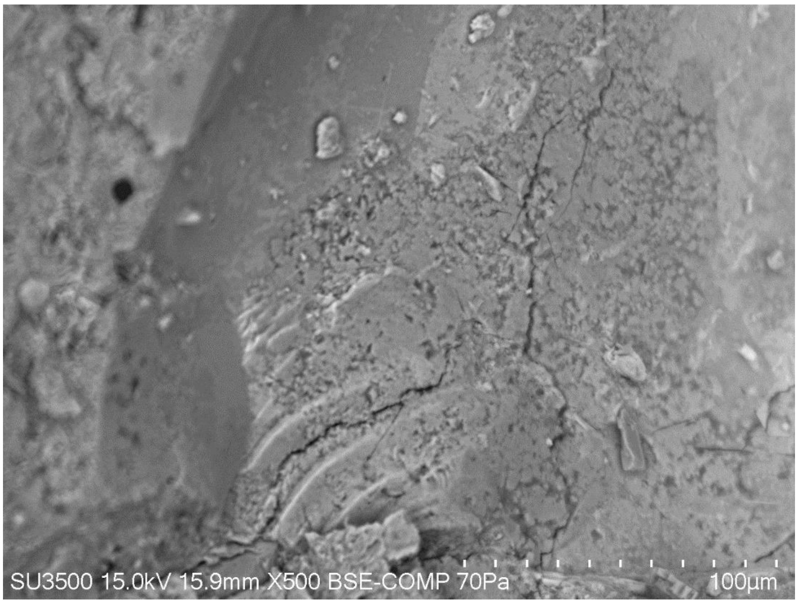
Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/03/10/2018
Fig. 120. The bright areas are the forming etryngite crystals in concrete C 30/37 in a hollow after removing the grains of the aggregate / middle part of the photograph/.

Summary

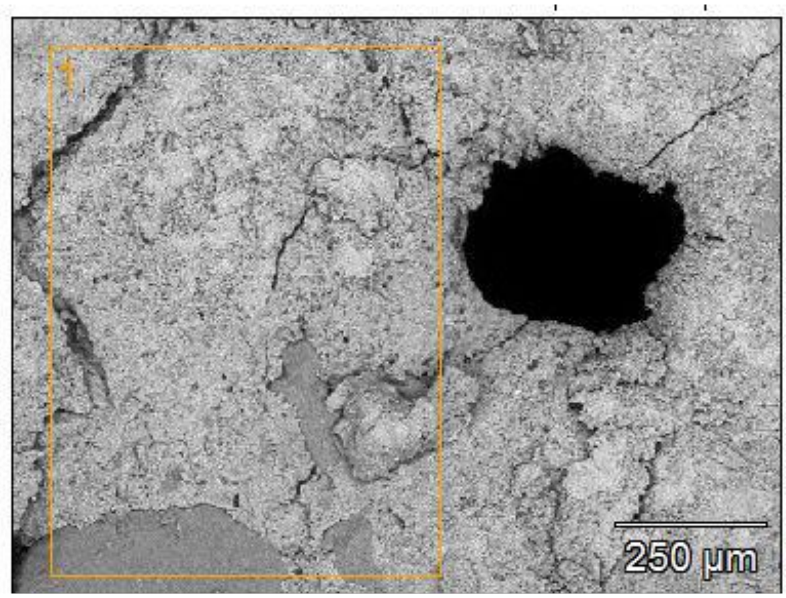
The morphology and chemical composition of the tested samples in comparison to the reference samples stored in air do not show significant differences. The presence of etryngite crystals was observed in the samples. There was no significant increase in the porosity of the tested samples compared to the reference samples and phenomena supporting the extensive degradation of the structure. The structure of the trials is quite tight. The free spaces between the binder and the aggregate grains are largely covered with products of crystallization of the components that may affect the weakening of the mechanical resistance of concrete.

Samples after 21 months storage under acidified slurry conditions (the study from 02.01.2019).

The microstructure of C 25/30 and C30 /37 samples is characterized by numerous pores and a clear network of cracks (Fig. 121). Larger pores were potentially formed due to the falling of aggregate grains. Fig. 122. Densely scattered fine pores are located in the fine-crystalline phase C-S-H. (Fig. 123). Sample surface is heterogeneous. Pore size can be estimated from 1µm to 20µm.In addition, losses occurring on the surface can be observed. The main mass of the samples next to the aggregate is the hydrated calcium silicate phase C-S-H in fine crystalline form as can be seen in Fig. 124 and Fig. 125. In both samples it is possible to identify aggregate grains with a diameter up to several hundred µm visible in Fig. 126 and fig. 127.

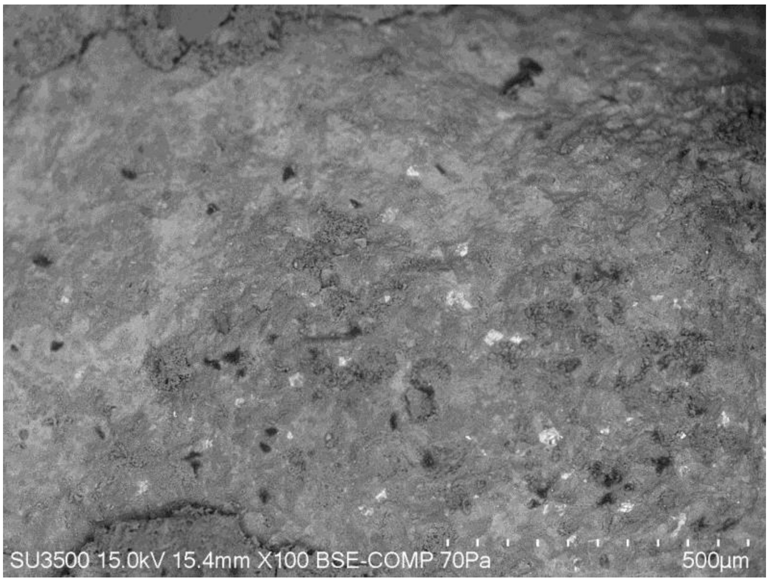


Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 121. Cracks network sample concrete C 25/30

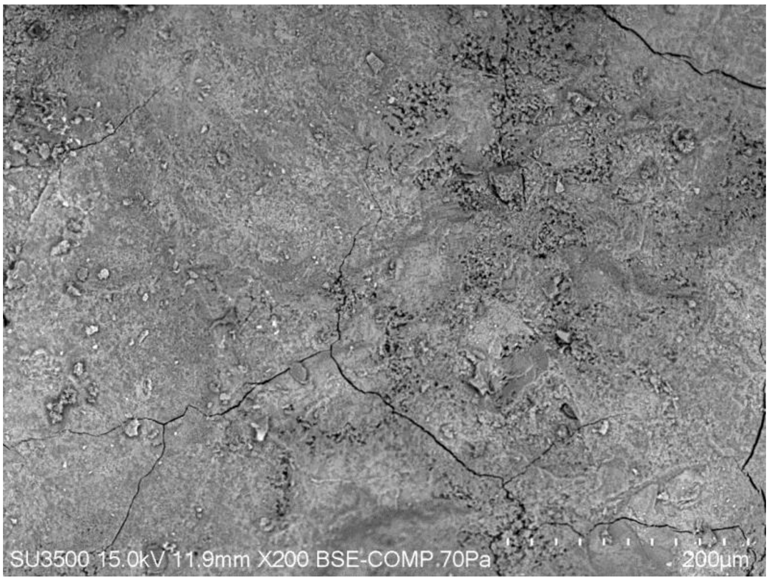


Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 122. Larger pores caused by falling grains of the aggregate sample of concrete C 25/30

Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 123. Small pores in a concrete sample C 25/30 / dark points /

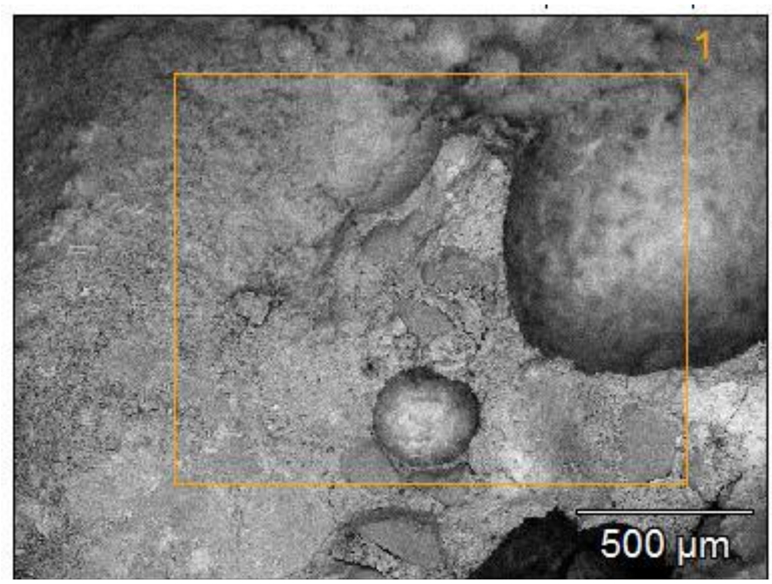


Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 124. Hydrated calcium silicate in fine crystalline form in a sample of concrete C 25/30



Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 125. Hydrated calcium silicate in fine crystalline form in a sample of concrete C 30/37

Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 126. Aggregate in a sample of concrete C 25/30



Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 127. Aggregate in a sample of concrete C 30/37

Concrete C25/30

Concrete sample contains mainly oxygen from 48.8 to 53.8%, calcium from 16.7 to 31.1% and silicon from 7.9 to 18.6% with added mixtures of carbon, aluminum, iron, sulfur, magnesium, potassium, sodium and places of titanium and chlorine. The sample contains a few bright residues of cement or calcium hydroxide visible in Fig. 128.

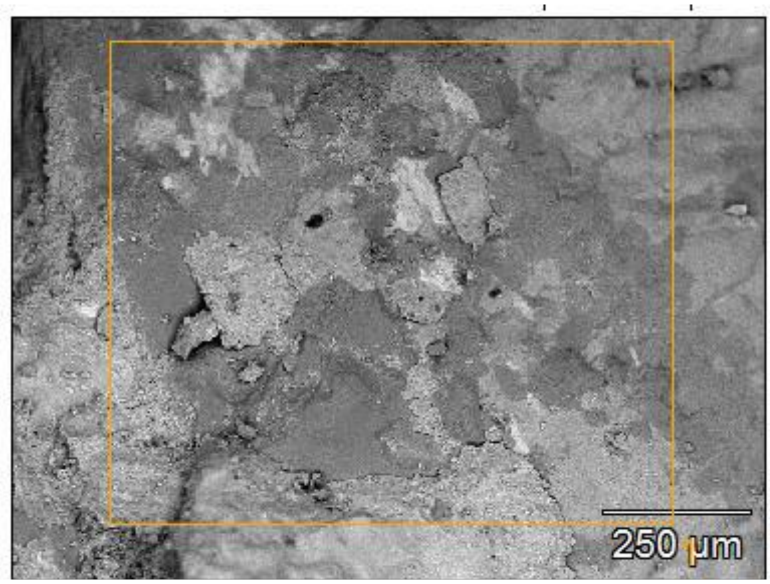
Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 128.The bright areas are calcium hydroxide and cement residues in concrete C 25/30

In free spaces, an increase in crystalline structures in the shape of needles and plaques was observed, this is etryngite visible in Fig. 129.

Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 129. The bright areas are the forming of ettringite crystals concrete in C 25/30.

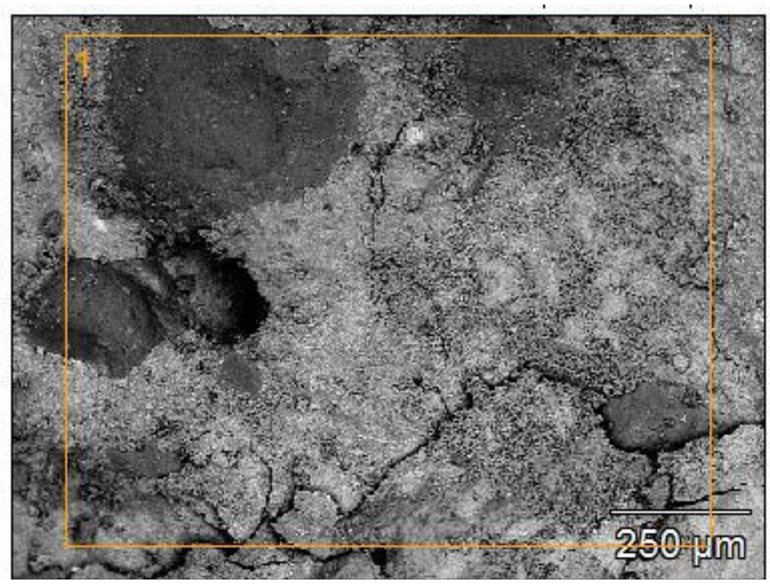
Concrete C30/37

The concrete sample contains mainly oxygen from 47.4 to 53.3%, calcium from 10.2 to 35.9% and silicon from 5.4 to 32.6%. The sample also contains carbon, aluminum, iron, sulfur, magnesium, potassium, sodium and titanium in some places. Clear residues of cement and calcium hydroxide were found visible in Fig. 130.



Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig.130. The bright areas are calcium hydroxide and cement residues in concrete C 30/37

The amount of free space is small, however, there was a clear increase in very fine crystalline structures in the form of needles / etryngite / in the pores or holes remaining after removing the aggregate grains (Fig. 131).



Source: University of A.Mickiewicz Fundation in Poznan ZUB/S/16/12/2018
Fig. 131. Areas of forming etryngite crystals in concrete C 30/37 in a cavity after removing grains / left part of the Figure /.

Summary

Samples for microscopic examination were taken after strength tests. A significant number of cracks and open spaces between the binder and the aggregate grains is the result of mechanical degradation during compression testing of concrete. The morphology and chemical composition of the tested samples in comparison to the reference samples stored in air do not show significant differences. The presence of etryngite crystals was observed in the samples of both classes C20/25 and C30/35 stored in acidified slurry. The samples in concrete class C 25/30 differ in the microstructure of the surface comparing to samples of class C30/37 after research period by scale of porosity. For example, the expanded porosity on the surface of the C-S-H phase (hydrated calcium silicates type C-S-H, in concrete C 25/30 samples may indicate a weakening of strength due to chemical degradation. An increase in the porosity of the tested samples was observed compared to the reference samples and phenomena supporting extensive degradation of the structure. The structure of the samples is quite tight. The free spaces between the binder and the aggregate grains are largely covered with products of crystallization of the components that may affect the weakening of the mechanical resistance of the concrete.

6. Basic conclusions from materials and tests results comparing acidified slurry with non- acidified slurry

1) Acidified slurry couses changes in concrete structure and strenght, what is especially known from:

a) SEM microscopic analyses;

b) compressive strength and bending tests of concrete.

2) Testing of compressive strength of concretes in the acidified slurry environment showed an increase in strength during the first 12 months and in the following months a slight decrease in strength and stability of strength.

The increase in the strength of concrete samples stored in a wet environment can be attributed to the reaction inducing swelling and filling the open spaces with growing etryngite crystals, the occurrence of which are confirmed by the results of microscopic examination. Breaking forces, in case of resistance increase are lower than tensile strength of concrete.

3) The tests have shown that the compressive strength of concrete is increased to 12 months of experiment, in the following months stabilization of the compressive strength of concrete occurs. This phenomenon applies to concrete samples stored in the environment of water and slurry. The batch samples in the acidified slurry environment show a slight decrease in strength after 18 months. During the research period, the deviations of concrete compressive strength results practically do not change the concrete class comparing to air-conditions at the beginning of tests. After a 21-month test period, samples of concrete class C25 / 30 placed in acidified slurry environment were still classified as C25 / 30, while samples of concrete class C30 / 37 were even classified as higher class C45 / 55.

5) For samples with thickness of reinforcement cover 7 mm the strength of concrete on bending in acidified slurry is lower than water (11%) and lower than non-acidified slurry by 15.8%.

6) On the basis of the maximum value of strength of C 35/45 concrete for bending obtained for a 7 mm thick casing, it can be stated, that this layer provides sufficient protection against corrosion of the concrete-steel contact zone. The condition of reinforcing bars in a 7mm thick concrete casing stored in the acidified slurry environment in the period of 21 months does not show any corrosive changes.

7) The environment of acidified slurry potentially destroys the concrete. In the concrete stored in this environment new products are created in the form of crystals (etryngite). In Class C 25/30, the phenomenon is more pronounced than in Class C 30/37. These results confirm the negative effect of the acidified slurry environment on the properties of concrete.

7. Evaluation of risks and knowledge gaps

Basing on collected material from producers and concrete 2-year laboratory tests following statements about risks of corrosion when implementing SATs could be given:

Assessment of risks- “in-house” SAT technique

Areas for risks for farmers using this technique are livestock building (slurry channels), slurry tanks, slurry tankers and spreading elements. Higher risk of corrosion of concrete will be present, because of longer time of influence. Therefore concrete of higher classes is recommended with special additives.

Assessment of risks- “in-storage” SAT technique

In case of this SAT, the risk could be assessed at the same level like for “in-house” technique. For temporary use of acid and shorter time of contact with slurry of lower pH ettringite crystals was formed in small amounts. This cristal is highly expansive, and when it fills the concrete slits it will male microcracks in the concrete structure. However, the effect of longer use of SAT, could mean larger damages. Concrete storages for slurry have usually a lifetime of 20 or more years.

Assessment of risks- “in-field” SAT technique

In this type of SAT only elements of slurry spreaders that are in contact with acidified slurry like hoses and pipes, are under consideration, but they are resistant to corrosion. The risk could be asummed as low or extremely low.

Recommendations and guidelines

1) When using “in-house” SAT, stronger classes of concrete should be used, especially concrete with additives like ashes (popular in Sweden, Estonia and Latvia) because of permanent conctact with acidified slurry, as in our tests.

2) There is a need of conducting further tests, with longer exposure time, to have better knowledge about influence of acidified slurry on concrete. Despite the difficulties in the form of length of research over time, research to refine the diagnosis should be continued as follows:

- the influence of aggressive environment on concretes with various admixtures,
- influence on acidified slurry on concrete with different chemical composition of this material and different content of dry matter.

3) The tests should lead to the unambiguous determination of the conditions that should be met by concretes not subjected to degradation in the construction of the agricultural facility throughout its entire lifetime.

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Interreg
Baltic Sea Region

EUROPEAN REGIONAL DEVELOPMENT FUND

EUROPEAN UNION

Baltic Slurry Acidification

www.balticslurry.eu

Summary of the project

Baltic Slurry Acidification is an agro-environmental project funded by the Interreg Baltic Sea Region program in the priority area Natural Resources focusing on Clear Waters. The aim of the project is to reduce nitrogen loss from animal production by testing, demonstrating and promoting the use of slurry acidification techniques in countries around the Baltic Sea.

Summary of the report

This report has two aims: 1) analysis of quality of equipment used in the slurry management chain in BSR countries, with special attention on elements heaving contact with acidified slurryand assessment the risk 2) research of the effect of slurry acidification on concrete and reinforcing comparing to non-acidified slurry.

Contributing partners

- **Institute of Technology and Life Sciences, ITP, Poland**
- **Research Institutes of Sweden, RISE, Sweden**
- **Estonian Crop Research Institute, ECRI, Estonia**
- **Latvian Rural Advisory and Training Centre, Ltd LLKC, Latvia**