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CO_2 as a cement based mortar additive

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Abstract

The global increase in CO_2 concentration is mainly due to the use of fossil fuels and changes in the use of soils. From the early 1800s to the present, but above all in the last half century, the concentration of carbon dioxide in the atmosphere is increasing. There is an increasing need to find a solution, particularly in the recycling of carbon dioxide produced.

This thesis aims to analyse the sustainability of concrete structures and to find a solution in the field of Civil engineering to increase the reuse of CO_2. Starting from the hypothesis that the use of carbon dioxide in the concrete mixture can increase the compressive strength of the mortar, the research was focused on testing the concrete combined with carbon dioxide, verifying the performances in mechanical and chemical terms, to produce a more sustainable cement mix.

1. Introduction

"We cannot only focus on renewable technologies, but we must also focus on capturing carbon dioxide emitted from fossil fuels"

Rodney Allam

Nowadays, concrete is the most important material in the construction. Thanks to its ease of production and retrieval of constituent materials, it is used in a wide variety of products such as houses, roads, bridges, dams, etc. Furthermore, at the end of the life cycle of these products, all the concrete used is often recycled and crushed as a secondary constituent for other structures, for example in the streets for base course or as filling material. The good mechanical characteristics that it presents, makes it the most used construction material in the world.

The binder and fundamental constituent of concrete is cement. Cement is a hydraulic binder, which is a finely ground inorganic material which, when mixed with water, forms a paste that sets and hardens following reaction and hydration processes and which, once hardened, maintains its resistance and its stability even under water [UNI EN 197 - 1]. The cement is obtained by grinding the cooking product of a mixture of clay, limestone and sand (*clinker*) with small additions of gypsum and other materials such as: natural pozzolana, micro-silica, fly ash and blast furnace slag. The cement production process consists of the production of clinker and its grinding after the addition of plaster.

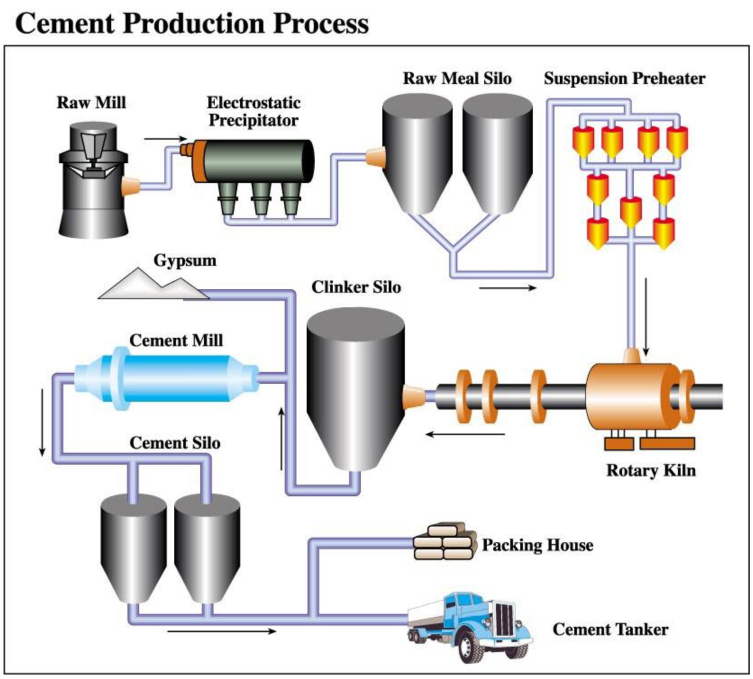


Figure 1: Cement Production process - https://www.climatetechwiki.org/technology/energy-saving-cement

The production of clinker requires high temperatures and therefore a large amounts of energy. Nowadays the contribution of this energy is still mainly given by fossil fuel derivatives such as oil and coal. All this makes cement and, consequently, concrete responsible for 5.6% of carbon dioxide emissions and the largest global industrial emitter (Le Quere 2016). In addition to the energy expended for production, an energy supply must be added for packaging and transporting of the material and its use on site.

Thus the need arose to find a solution to reduce carbon dioxide emissions and make this material more eco-friendly. The cement and concrete industry worked with the International Energy Agency to draw up a 50% reduction program for energy emissions between 2006 and 2050 called the "*Blue Map Scenario*". The aim is to improve low-carbon technology, develop energy security and bring benefits to people in economic and health terms.

It was concluded that it was necessary to arrive at a CO_2 reduction projection of 0.79 Gt by the 2050 emissions, thanks to the implementation of:

- The reduction of carbon dioxide emissions due to Portland cement production through the use of alternative energy sources (potentially 24% of the required reduction)
- The development of performance of the furnaces used for cement (10%)
- The use of alternative materials with low carbon content to gradually replace clinker (10%)
- The capture and sequestration of carbon dioxide emissions (56%)

As can be seen from the above, the capture and sequestration of emissions is the most significant method for reducing emissions. The method pursued in this thesis was to introduce carbon dioxide, in the form of dry ice, into the concrete mixture and to verify, not only the mechanical performance but also the effective capture of CO_2 by the mortar.

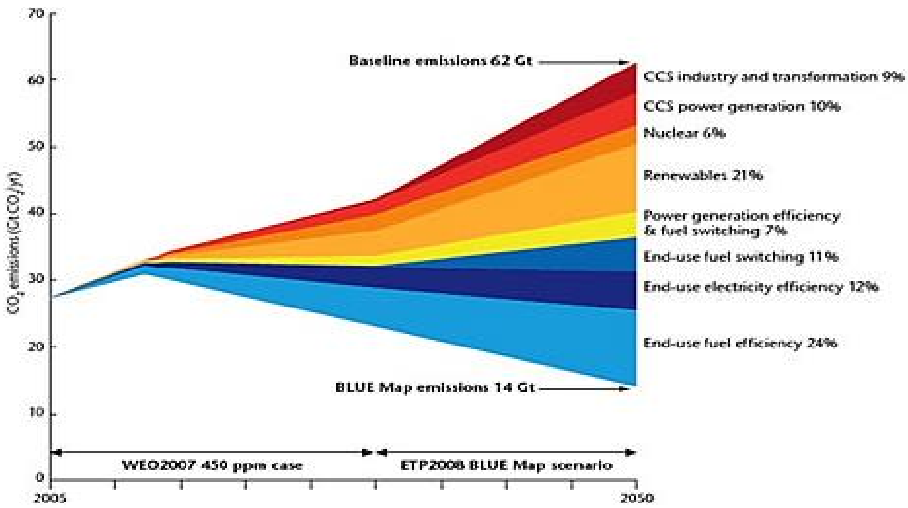


*Figure 2: Blue Map - http://www.ccstlm.com/content_31_*

The scenario presented highlights the importance, not only to develop more sustainable concretes, but also to identify an analysis method that allows designers to evaluate and control (already in the design phase) the environmental impacts related to the use of the materials themselves, through a holistic approach that takes bearing capacity, durability and sustainability into consideration. Knowledge and awareness during the design phase certainly allow for significant energy savings and a reduction in CO_2 emissions, while guaranteeing the quality of the building, safety and comfort of its occupants.

2. Sustainability of concrete constructions

"We do not inherit the Earth from our ancestors; we borrow it from our children."

Native American Proverb

2.1 General Concept

Sustainability is the ability to exist constantly. In the 21st century, refers generally to the ability to exist of the biosphere and human civilisation. Defined also as the process of people maintaining change in a balanced environment, in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.[1]

The 2005 *World Summit on Social Development* identified sustainable development goals, "such as economic development, social development and environmental protection"[2]. This concept can be represented by three overlapping ellipses that indicate that the three pillars of sustainability. Even if the three pillars are independent, in reality things cannot be considered completely separate. In recent years, these three pillars have been the basis for the definition of standards and certifications. Examples of standards are Rainforest Alliance, Fairtrade and UTZ Certified. Recently, a fourth fundamental pillar has been added: future generations. It indicates and emphasizes the need for long-term thinking and actions.

[1] *What is sustainability". www.globalfootprints.org. Retrieved 2 May 2018.*
[2] *https://en.wikipedia.org/wiki/Sustainability*

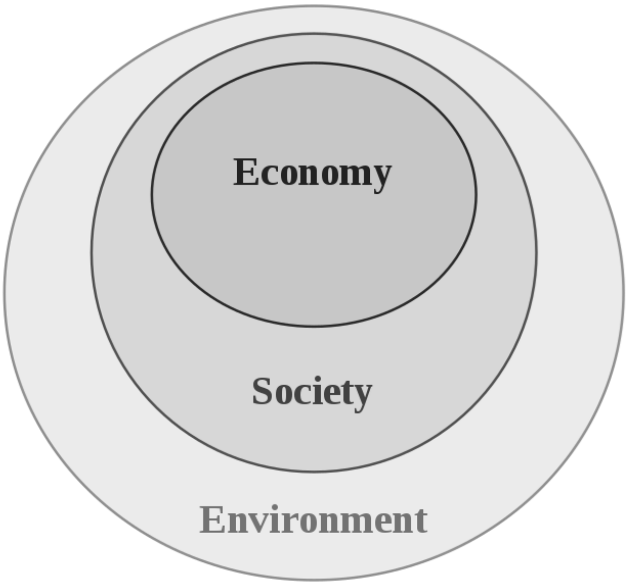


Figure 3: the three main pillars of sustainability

The main question is therefore to find a relationship between the needs of man and the environment. Developing in a sustainable way means finding the balance between local and global efforts without destroying the environment that hosts us. Environmental justice is as important as sustainable development. A timber industry would be useless without forests, a textile industry would be useless without animals. Seeing the way from this point of view, the economy is a subsystem of human society, which is itself a subsystem of the biosphere, and a gain in one area is a loss from another.

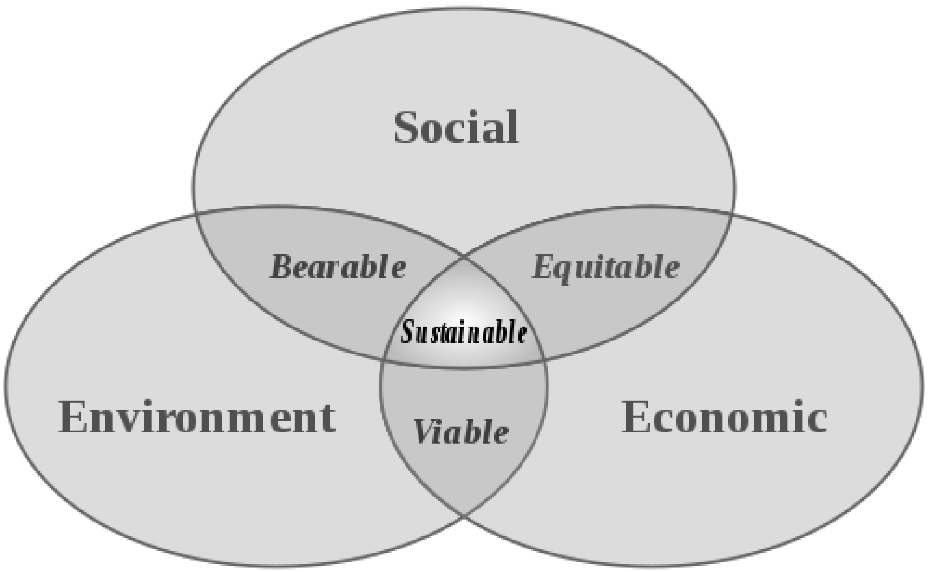


Figure 4: the pillars mixed togher

Sustainability is a profound concept, but aimed at practical action and defined by common goals. It implies a responsible and proactive decision-making and innovative process that minimizes the negative impact and maintains the balance between ecological resilience, economic prosperity, political justice and cultural vitality to guarantee a desirable planet for all species now and in the future.

2.2 Sustainability in the Construction field

Environmental sustainability has entered the building sector in a strong and integral manner for two fundamental reasons: on the one hand the construction sector is the main architect of environmental impact, and on the other hand the man who lives in the buildings claims to find a healthy, comfortable and eco-friendly place. For this reason, in construction, sustainability focuses on two main factors: the *building-environment relationship* and the *building-inhabitant relationship*.

In fact, building generates a significant impact on the environment: in addition to the mere building phase, the whole process must be taken into account from the procurement of raw materials, production and transport to the disposal of the construction and disposal of demolition materials. It should also be taken into account that the use of the built environment itself generates environmental impact in order to guarantee the comfort and well-being of the users. The exploitation of raw materials, the use of the land, the energy consumption create a strong environmental pollution.

Figure 5: scheme of the cycle

The concept of sustainability was first enunciated in 1987 in the *Brundtland report*, entitled "*Our Common Future*". The document was drafted by the Word Commission on Environmental and Development (WCED), where "Sustainable Development" was defined as the one capable of "*responding to the needs of the present without compromising the ability of future generations to satisfy their own*". After that, the concept was further refined in the following years specifying that in order to have a more balanced view, in addition to taking into account the environmental aspects, the analysis cannot ignore to take in consideration and also assess the economic and social aspects.

The interest in this field was born with the general observation of the climatic changes taking place in the last decades and of all those problems in the atmosphere, soil, water, flora and fauna derived from the ever stronger and uncontrolled expansion of human activities.

The report highlights the "*collective challenges*": the exhaustion of energy sources, the industrial impact, population and urban growth, food supply and the protection of species diversity. The answer to these problems has been found in "*sustainable development*": the management of the development of society and the well-being of people, paying attention to the limit that the environment can bear. It is not a matter of condemning what has been done, but of improving it and making it compatible with our environment.

The key approach of the Bruntland Report is based on its two foundations: *globalization* and *sustainability*. The first term means the fact that the problem must be tackled in an intersectoral, international and intergenerational way. The problems related to the environment have no boundaries and do not remain contained in the context of those who caused them. The second term, sustainability, refers to the "*carryng capacity*" of the environment, ie the possibility of being able to provide resources and absorb generated waste. Nowadays our environment is no longer able to withstand the rhythms of use and consumption. We must therefore promote eco-efficiency, use renewable energy sources, eliminate pollutants, enhance waste and stop desertification.

The theme of sustainability is therefore addressed on different scales: that of the territory, the urban, that of the building and finally that of the building component. Precisely because of this diversity, the issue of sustainability requires different judging criteria that often make a single assessment for the different scales difficult.

Back to the construction sector, it is therefore important to know and make known not only the sustainability of a product and its production process but also and above all what happens during the product application process: the use phase and the end of life cycle. But a balanced sustainable development can only be achieved through an awareness and a targeted intervention especially by those who manage that of "governance", the only component able to provide strategic guidelines, intervention policies and regulations with which it is possible to establish the objectives to be pursued and the degree of acceleration desired to achieve them. If we analyze only the environmental aspects of building materials it is clear that the impact is generally unsustainable. It is also necessary to consider the economic and social aspects, because only a complete 360 ° vision is able to guarantee the right balance between quality and quantity of material to be used, and thus assess the real capacity to respect the environment.

Figure 6: eco-friendly construction vs. non sustainable construction

3. Use of CO_2 to increase sustainability

"That of" climate "is an elusive concept, which does not lend itself to being easily harnessed into fixed rules."

Luca Mercalli

Global climate warming or climate change is the name given to long-term temperature changes around the earth's surface, which translate into long-term weather changes. Climate change is not limited to individual regions, but afflicts the whole Earth. Extreme weather events such as droughts and heat waves become more severe in certain areas, while typhoons and hurricanes are becoming more common in some regions of the world. The warmer ocean surface temperatures affect the corals and change the fauna and flora of coral reefs causing coral bleaching events and altering the chemistry of the ocean.

Since 1958, CO2 has been measured at the Mauna Loa observatory in Hawaii. In 1958, the concentration of CO2 in the atmosphere was measured at 316 ppm, while in May 2016 it was 407 ppm. Before the beginning of the industrial revolution (1880), the concentration of CO2 in the atmosphere was measured at 280 ppm and therefore in just 130 years CO2 concentrations increased by 45%.

By comparison, CO2 emissions in the last 800,000 years before the industrial revolution had fluctuated between 180 ppm (when the Earth was in an ice age) to a maximum of 280 ppm (in a warmer interglacial period). Never in the recent geological history and during the time when humans have been on Earth, the concentration of CO2 in the atmosphere has been as high as it is today.[3]

With the Paris Agreement, the European Union has set itself the goal of reducing greenhouse gas emissions by at least 40% by 1990 levels and reaching a climate-neutral economy by 2050.

[3] https://www.carbonfootprint.com/warming.html

Figure 7: effects of the climate change - carbonfootprint.com

3.1 Carbon Footprint

Figure 8: carbon footprint symbol

In order to measure the amount of CO_2 emissions, and to give it an objective value, a parameter has been defined: it is called the *Carbon Footprint*.

The Carbon Footprint is used to estimate the greenhouse gas emissions generated by a product, an individual, a service or an organization. It is generally expressed in tons of CO_2 equivalent (tCO_2) which relates the effect produced by greenhouse gases with the effect produced by CO_2, considered equal 1.

According to the indications of the Kyoto Protocol, the greenhouse gases that must be taken into consideration are:

- carbon dioxide (CO_2, hence the name "carbon footprint")
- methane (CH_4),
- nitrous oxide (N_2O),
- hydrofluorocarbons (HFC),
- perfluorocarbons (PFC)
- sulfur hexaffloride (SF_6)

All these gases can be emitted through the production and consumption of food, fuels, manufactured goods, wood, buildings, transport roads and many other services. Measuring the Carbon Footprint of a product or process requires identifying the consumption of raw materials and energy in the life cycle of the same. Often the Carbon Footprint is intended as an index of quality and sustainability of companies.

The companies, in addition to conducting the analysis and accounting of CO_2 emissions, are committed to defining a carbon management system aimed at identifying and implementing cost-effective emissions reduction interventions that use low-carbon technologies. The reduction measures can be supplemented by measures to neutralize emissions (carbon neutrality), achievable through activities that aim to compensate for emissions with equivalent measures aimed at reducing them with actions that are economically more efficient or more expendable in terms of image.

The main advantages of the Carbon Footprint are the ability to synthesize, the simplicity and clarity of the unit of measurement, the incisiveness and objectivity of the data obtained. Thanks to the Carbon Footprint it is possible to define immediately how a product affects the greenhouse effect. The data provided is easily understandable even for those who do not have technical and scientific knowledge.

3.2 Environmental Product declaration

Environmental Product Declaration (EPD) have as their main objective to provide relevant, verified and comparable information relating to the environmental impact of a product or service. This is because the global market requires more and more information on the environmental performance of products and services that must be based on scientific data. EDPs provide this information and also give the possibility to compare products and services through environmental indicators. To achieve this objective it is essential to define the calculation rules that must be followed by all those who are involved in the preparation of an EPD.

Figure 9: Environmental Product Declaration symbol

The rules, called Product Category Rules (PCR) allow preparing the preparation of Life Cycle Analysis studies and the related environmental declarations in a coherent and comparable way. Environmental Product Declarations are the basis for verification by recognized and certified third parties to evaluate Life Cycle Analysis studies and related declarations.

3.3 Life Cycle Analysis

To calculate the Carbon Footprint and the Environmental Product Declaration of cements and concrete and mortar families, the methodological approach of Life Cycle Analysis (LCA) is often used according to the UNI EN15804: 2014 standard, which evaluates the relative energy and environmental loads to the products. The Life Cycle Analysis considers the entire life cycle of the product: from the extraction of the raw materials to the final disposal, passing through the production, distribution and utilization processes, for the calculation of the Carbon Footprint of the cements and of the families of concrete and mortars. In this way the certifications obtained allowing to assess the environmental impact of the entire life cycle of a given infrastructure, also adding the calculation of the impacts related to the other materials and to the other phases of the life cycle of the infrastructure up to the final disposal of the material coming from its demolition.

Figure 10: https://www.carbonfootprint.com/productlifecycle.html

The adoption of a Life Cycle Analysis allows to understand the most critical phases from the environmental point of view of a production cycle, allowing the subsequent intervention to try to reduce and compensate the environmental impacts of the companies. So we try to reduce waste and increase efficiency.

3.4 Carbon Footprint, Environmental Product Declaration and sustainability

The Carbon Footprint and the Environmental Product Declaration are tools that help monitoring sustainability for organizations, companies and individuals, giving evidence of this through the use of an objective and certified third-party spirit.

The Carbon Footprint, like the EPDs, has the ability to promote continuous improvement through:

- the design of alternative products or the improvement of existing ones;
- observation of production and manufacturing methods;
- the appropriate choice of raw materials and suppliers; based on a life cycle assessment, using climate change as a motivation for improvement.

The Carbon Footprint and the EPDs also make it possible to monitor and track progress in reducing greenhouse gas emissions, encouraging changes in consumer behaviour.

3.5 European Union Emissions Trading Scheme

To fulfill the commitments made by the Kyoto Protocol, the Directive 2003/87 / EC on the Emission Trading Scheme (ETS) establishes at the EU level the exchange of CO_2 emission allowances called EUA - European Allowances. Established in 2005, this quota exchange system is one of the milestones on which EU policy to combat climate change is based and is an essential and economically efficient tool to try to reduce gas emissions.

The EU ETS operates on the principle of restricting emissions trading. A maximum limit is set for the quantity of greenhouse gases that can be emitted from the systems that fall within the system. Over time we try to reduce this limit ceiling in order to globally reduce emissions.

Within the set ceiling, companies receive or buy emission quotas which, if necessary, can be exchanged. It is also possible to buy international credits for emission reduction projects from all over the world. In order not to suffer burdensome fines, companies at the end of the year must return a sufficient number of quotas to cover their emissions. If a company reduces its emissions, it can hold excess quotas and reuse them in the future if necessary or sell them to others. This exchange creates flexibility and ensures that the emission reduction is done when it is convenient.

The first period of application, called phase one, coincides with the period of application of the Kyoto Protocol (2005-2007), while the second phase covered the next five years (2008-2012). The system is currently in its third implementation phase (2013-2020), which differs from the first two phases for:

- Single European, no longer national, ceiling for emissions
- auctioning is the common method of allocating allowances (instead of being allocated free of charge), while harmonized rules apply to the quotas still allocated free of charge
- covers a greater number of sectors and gases
- thanks to the NER 300 program, 300 million quotas have been set aside in the reserve for new entrants to finance the dissemination of innovative renewable energy technologies and the capture and storage of CO_2.

The fourth phase (2021-2030) aims to further reduce emissions, in line with the political framework issued with the Paris Agreement in 2015. The objectives are:

- Strengthen investments and the pace of annual reductions by 2.2% since 2021. Making the market more stable
- continue with the free allocation of quotas to guarantee international competitiveness
- help industry and the energy sector to meet the challenges of innovation for a low-carbon economy

Electricity producers and plants involved in the capture, transport and storage of CO_2 (CCS) must procure on the market the quotas needed to cover their emissions requirements. As far as manufacturing and aviation are concerned, they receive part of the allowances free of charge and resort to auctions for the remaining part. Financial entities such as banks, investment companies and financial intermediaries participate in auctions, helping to increase the liquidity of the primary and secondary markets.

The price of quotas is defined by the market, based on the interaction between demand and supply, and the change in price is caused by a series of macroeconomic, political, economic and environmental factors. Clearly the limitation of the total issue number guarantees the value of the units. Within the European Union, the exchange of CO_2 allowances (EU-ETS) and the use of emission credits deriving from projects for the reduction of the same to the annual return of allowances is permitted.

Emissions trading platforms are private initiatives that help users search and negotiate quota sales transactions. Currently the platforms are not connected to the national registers; the transactions that take place on these platforms, however, must be confirmed through the Registry, which examines and guarantees that they take place within the respective emission rights. The first Italian platform for the exchange of Greenhouse Gas Emission Units was prepared by the Electricity Market Operator (GME).

4. Investigations and tests

4.1 Scope

The purpose is to create cement specimens, according to codes, with the addition of CO_2. The second phase of the work is focused on testing the specimens in order to determine the compressive and the flexural strength of cement mortar.

Finally it is operated as to obtain the results deriving from the chemical tests, in particular analysing the pH of the mortar.

The method is used for assessing whether the compressive strength of cement is in conformity with its specification and for validation testing of a CEN Standard sand, EN 196-1, or alternative compaction equipment.

4.2 Principle

The dimension of the prismatic specimens is 40 mm x 40 mm x 160 mm in size. In the reference procedure the mortar is prepared by mechanical mixing and is pressed down in a mould using a jolting apparatus. Another compaction equipment and procedures may be used provided that they have been shown to give cement strength results which do not differ significantly from those obtained using the reference jolting apparatus and procedure.

The specimens are stored in the mould in a moist atmosphere for 24 h and, after demoulding, specimens are stored under water until strength testing.

After 28 days, the specimens are taken from their wet storage, broken in flexure, determining the flexural strength where required, or broken using other suitable means which do not subject the prism halves to harmful stresses, and each half tested for strength in compression.

4.3 Laboratory

In the preparation phase, and in all subsequent phases, we tried to comply with the standards set by the EN 196-1: 2005 (E) standard.

As regards the laboratory, where the preparation of the samples was made, a temperature of (20 ± 2) ° C and relative humidity of not less than 50% was maintained.

The humid chamber used for storing the samples in the mold was placed at a temperature of (20.0 ± 1.0) ° C and a relative humidity of not less than 90%.

The containers for storing the samples in water (also kept at (20.0 ± 1.0) ° C.) and the grids with which they are mounted are made of material that does not react with the concrete.

4.4 Equipment

4.4.1 Mixer

The mixer is composed of about 5 liters of the shape and dimensions shown in the standard. It is hooked to the frame in the mixer in such a way as to be firmly fixed. The height between blade and bowl can be adjusted and fixed precisely. The blade rotates around its own axis and can vary the speed thanks to an electric motor. The Figure 11 shows the vessel and the blade:

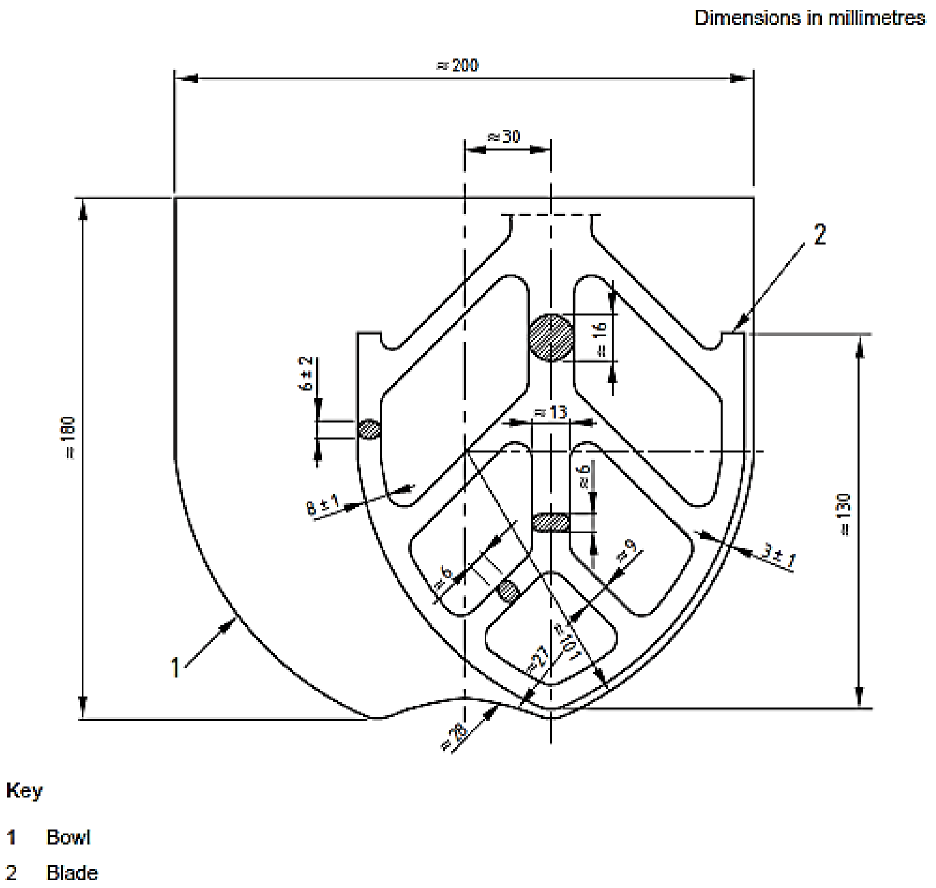


Figure 11: Typical bowl and blade

The mixer must operate at the speeds indicated in Table 1 when the mortar is mixed.

Table 1: Speeds of miexr blade

	Rotation min^{-1}	**Planetary movement** min^{-1}
Low speed	140 ± 5	62 ± 5
High speed	285 ± 10	125 ± 10

Figure 12: mixer and blade in lab

Figure 13: bowl

4.4.2 Moulds

The mould that was used is composed of three horizontal compartments so as to be able to simultaneously prepare three prismatic specimens of 40 mm × 40 mm section and 160 mm in length. The mould material is steel and the walls are about 10 mm thick. The mould design allows easy and safe removal of samples. Once assembled, the mould was then locked and fixed to the plate. The base plate must have adequate contact with the compaction apparatus table and be sufficiently rigid so as not to cause secondary vibrations.

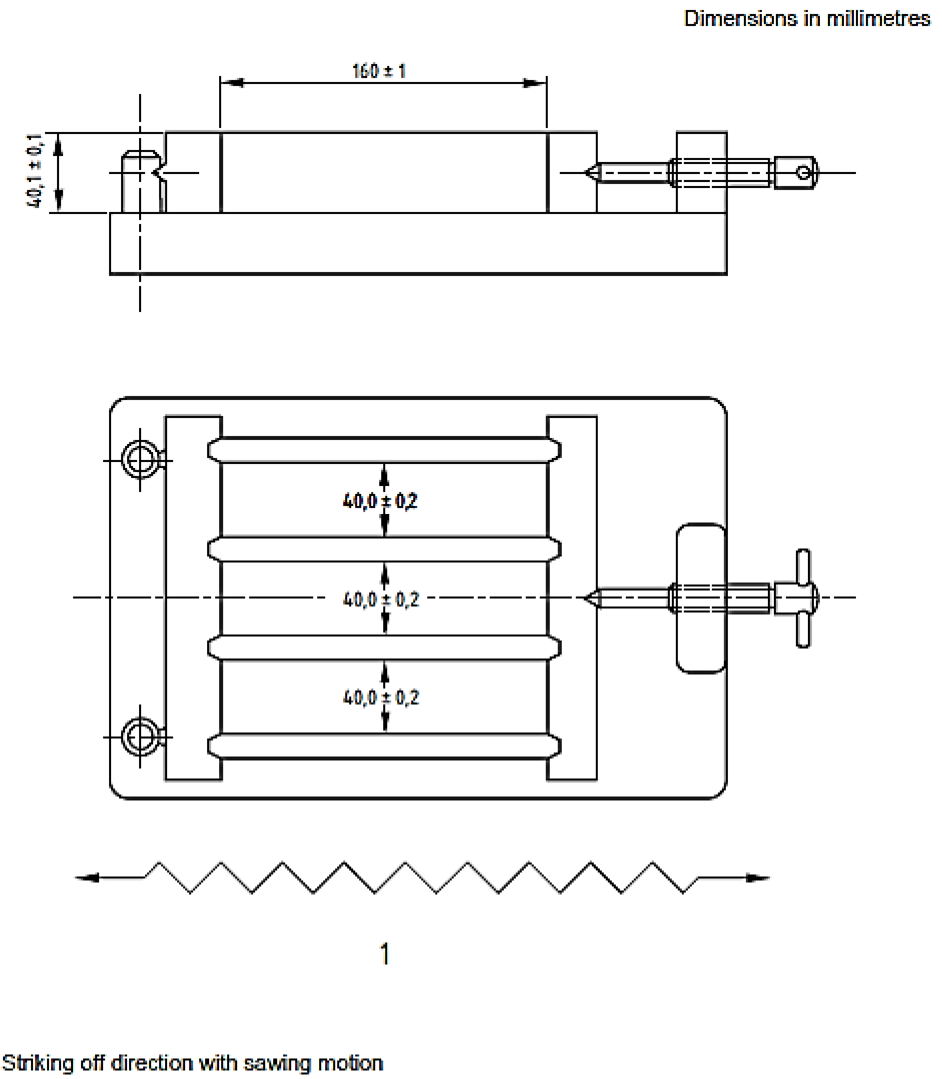
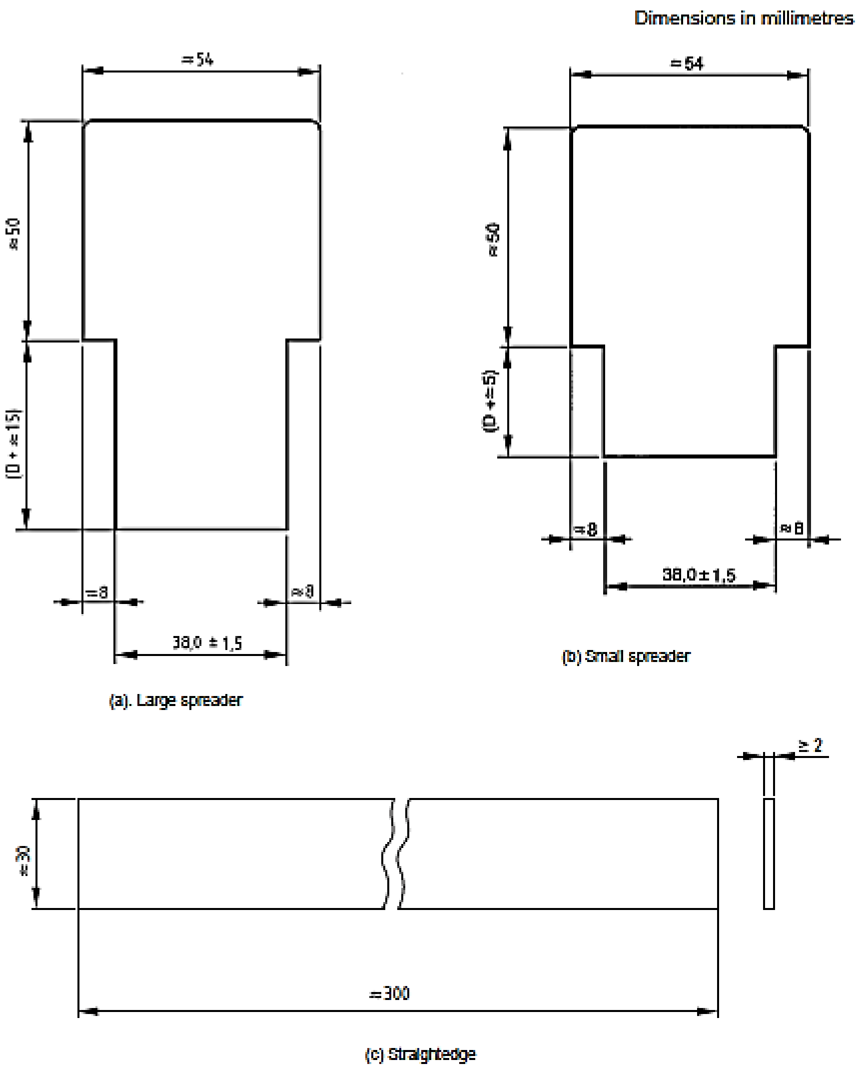


Figure 14: typical mould

The dimensions and internal tolerances of each compartment of the mould must be the following:

- length: (160 ± 1) mm;
- width: (40.0 ± 0.2) mm;
- depth: (40.1 ± 0.1) mm.

To facilitate filling of the mould it is necessary to provide a well-fitting metal hopper with vertical walls from 20 mm to 40 mm in height. When viewed on a flat surface, the hopper walls overlap the internal walls of the mould by no more than 1 mm. The outer walls of the hopper have been equipped with a positioning means to ensure correct positioning on the mould. For spreading and removing the mortar, two spreaders and a metal crosspiece of the type shown in Figure 3 must be provided.



Key

D = Height of hopper

Figure 15: typical spreaders and metal straightedge

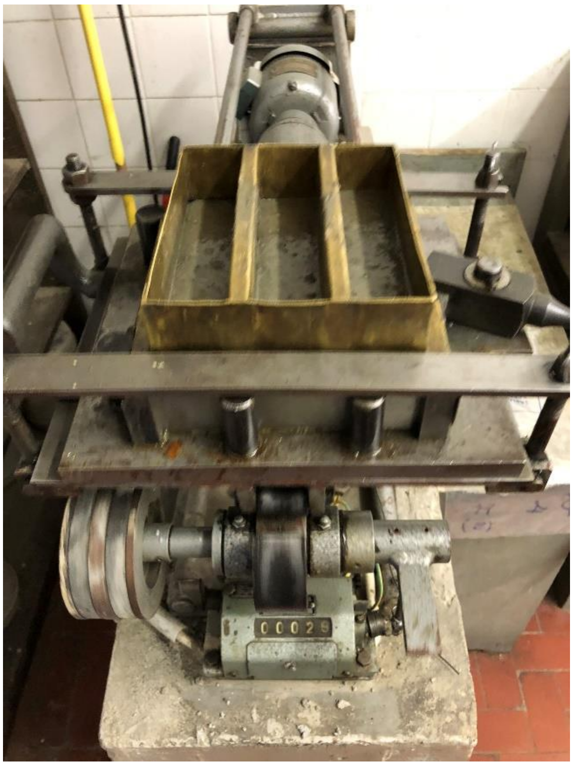


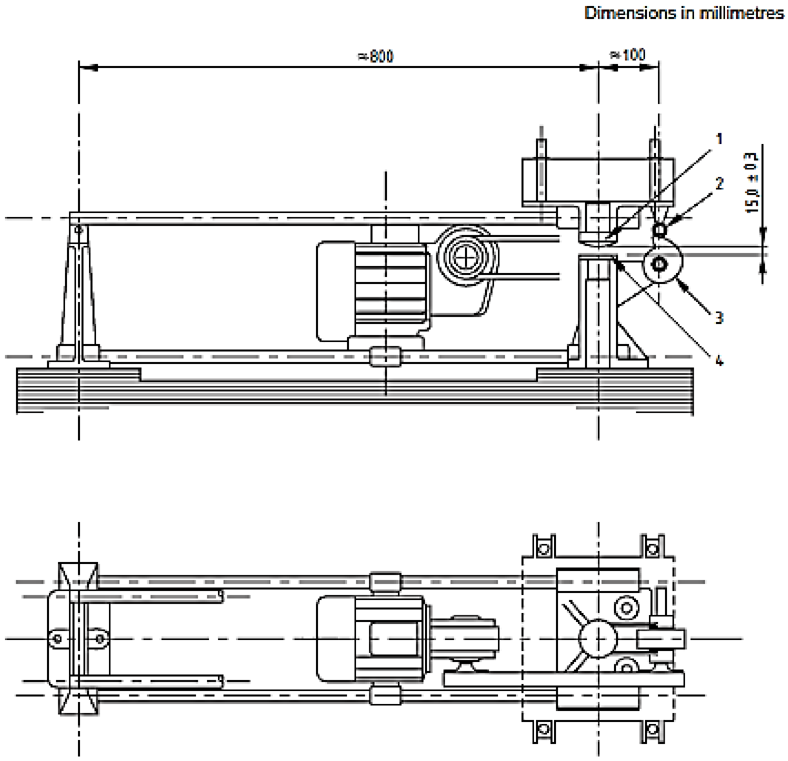
Figure 16: mould used

4.4.3 Jolting apparatus

The joltin apparatus consists of a rectangular table rigidly connected by two light arms to a pin 800 mm nominally from the center of the table. The table includes a protruding handle in its lower face. Under the protruding loop there is a small stop with the top surface of the plane and the stop must be vertical. When the ledge rests on the stop, the top face of the table must be horizontal. The table has dimensions comparable with the mold base plate. The rotating bearings used are of the ball type.

The operation consists of lifting the table from a steel cam and letting it fall freely from a height of (15.0 ± 0.3) mm before the fin hits the stop. The electric motor supplies energy for about 250W with a revolution speed of one per second. To count the beats there is a control mechanism and a counter that ensures that a jolt period of (60 ± 3) s contains exactly 60 shots.

The whole apparatus is mounted on a concrete block of about 600 kg.



Key

1 Lug
2 Cam follower
3 Cam
4 Stop

Figure 17: Typical jolting apparatus

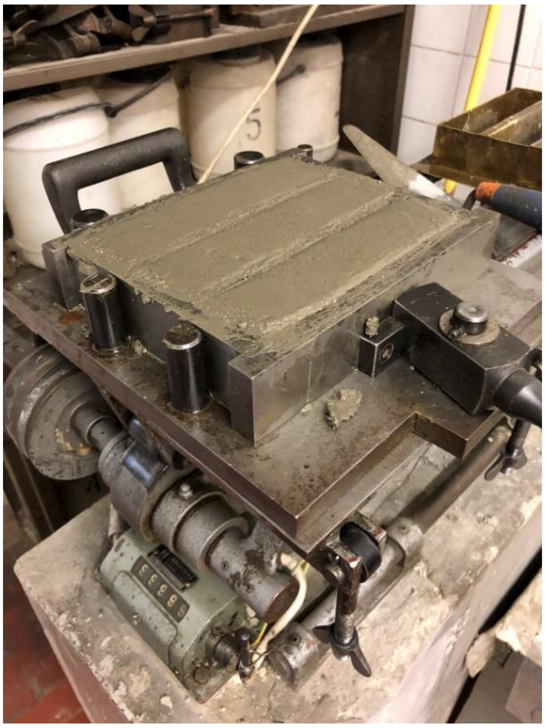


Figure 18: jolting apparatus

4.5 Mortar constituents

4.5.1 Sand

The CEN standard sands, produced in various countries, are required to determine the strength of the cement, and meet the requirements of the standards.

The CEN reference sand is a natural silica sand created from rounded particles and has a silica content of at least 98%. The quantity used was 1350 g per bag.

Its particle size distribution is within the limits indicated in Table 3

Table 2: Particle size distribution of CEN: Reference sand

Square mesh size (mm)	2,00	1,60	1,00	0,50	0,16	0,08
Cumulative sieve residue (%)	0	7 ± 5	33 ± 5	67 ± 5	87 ± 5	99 ± 1

Figure 19: sand used

4.5.4 Cement

The cement tested was of two different types: CEM I 42.5 and CEM I 52.5. All the cement have been provided by BuzziUnicem.

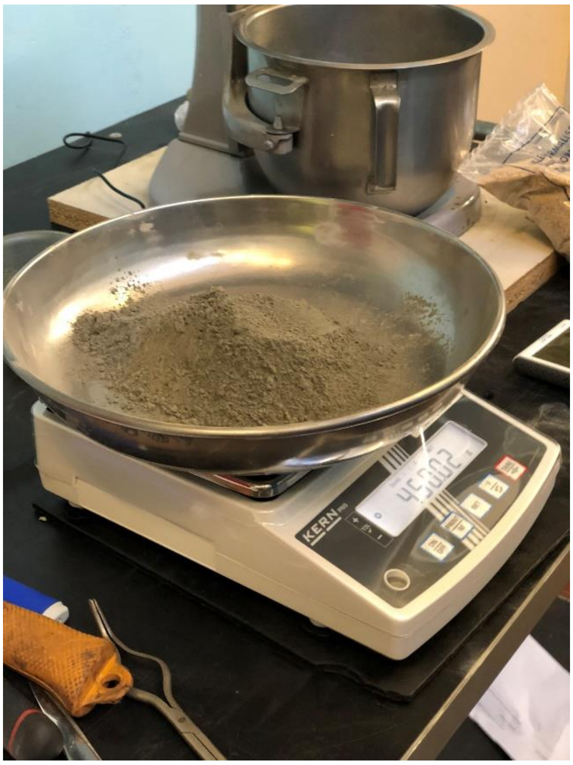


Figure 20: cement while being weighed

Table 3: cement compostion [BuzziUnicem]

%	CEM I 42.5 R	CEM I 52.5 R
SiO_2	20.2	19.9
Al_2O_3	4.5	5.1
Fe_2O_3	3.56	1.8
TiO_2	0.2	0.2
MnO	0.07	0.06
P_2O_5	0.06	0.04
CaO	63	62.9
SrO	0.03	0.04
MgO	1.44	1.6
K_2O	1.13	0.8
SO_3	2.54	3.2
ppc	3.6	4.1
Trattenuto a 24µm	38.7	21.1
Blaine (cm^2/g)	3600	4600

4.5.5 Water

Distilled water was used for packaging the samples.

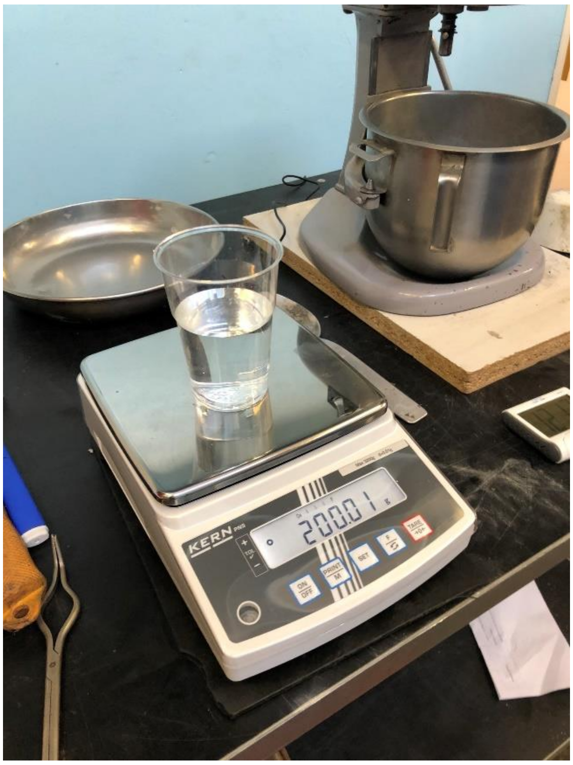


Figure 21: measurement of water

4.5.6 Carbon dioxide CO_2

The carbon dioxide was supplied by SIAD in the form of dry ice.

Figure 22: CO_2 in the packaging

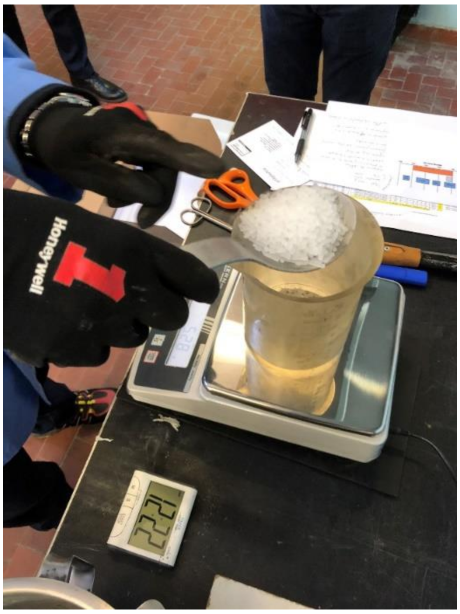


Figure 23: measurement of CO_2

4.6 Preparation of mortar

4.6.1 Composition of the mortar

To have the right ratio of components, the legislation requires having: a portion in bulk of cement, three portions of standard CEN sand and one half in mass of water (water / cement ratio 0.50).

Each batch for three samples must consist of (450 ± 2) g of cement, (1 350 ± 5) g of sand and (225 ± 1) g of water.

All the specimens created have the same mass ratios. The only parameter that differs is the amount of CO2 introduced into the mortar for the different specimens.

The following table shows the constituents of the mortar:

Table 4: constituents of the mortar - 29_01

Sample	Type of cement	Cement (g)	water (g)	sand (g)	CO_2 (g)	% CO_2/cem
29_01_00	N	450	225	1350	0	0
29_01_04	N	450	225	1350	1.8	0.4
29_01_08	N	450	225	1350	3.6	0.8
29_01_12	N	450	225	1350	5.4	1.2
29_01_16	N	450	225	1350	7.2	1.6
29_01_32	N	450	225	1350	14.4	3.2

Table 5: constituents of the mortar - 31_05

Sample	Type of cement	Cement (g)	water (g)	sand (g)	CO_2 (g)	% CO_2/cem
31_05_00	N	450	225	1350	0	0
31_05_08	N	450	225	1350	3.6	0.8
31_05_16	N	450	225	1350	7.2	1.6
31_05_24	N	450	225	1350	10.8	2.4
31_05_32	N	450	225	1350	14.4	3.2
31_05_40	N	450	225	1350	18	4

4.6.2 Mixing of mortar

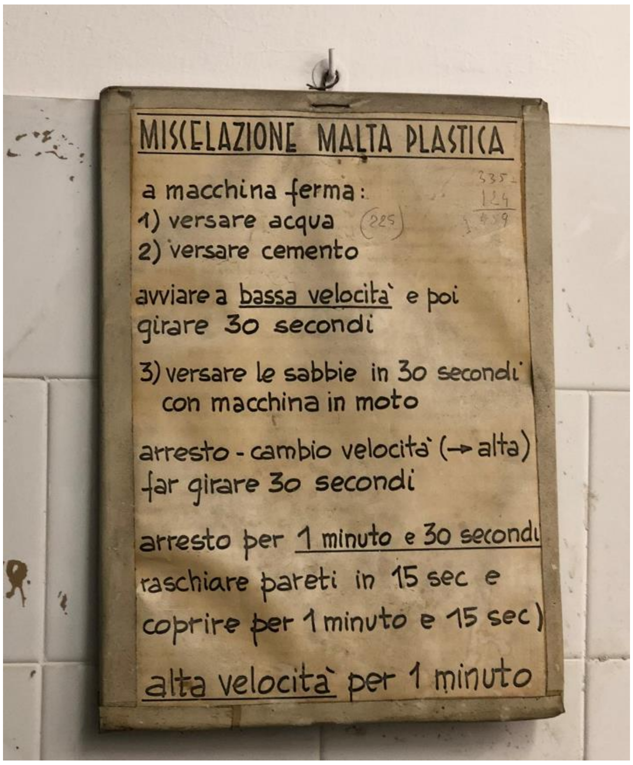


Figure 24: rules for the mixing in PoliTo Lab

After weighing all the components with the scale and verifying the correct weight measurement, the mixing procedure was performed according to the regulations. It includes various phases:

1. Water and cement are placed in the bowl, taking care to avoid leaks.
2. The CO2 is added meanwhile

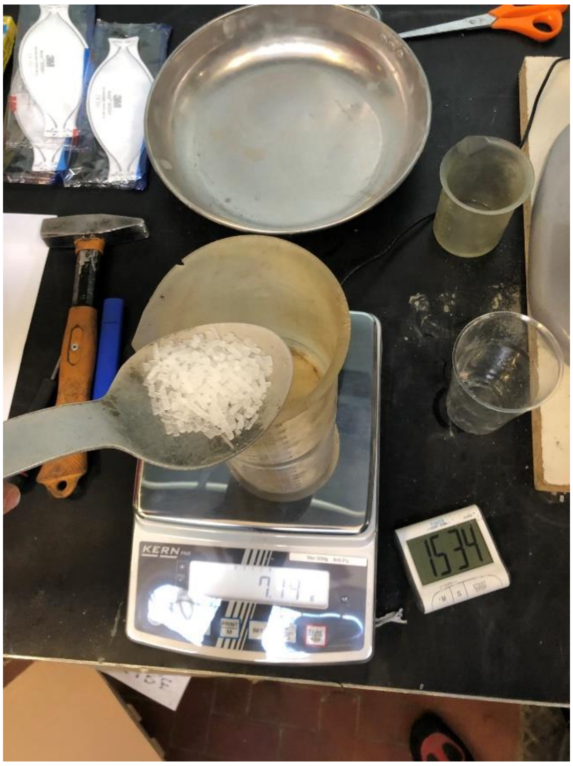


Figure 25: weighing carbon dioxide

3. The mixer is then started at low speed and run for 30 seconds.
4. In the following 30 seconds the sand is added.
5. It stops the system, after which the speed is changed, passing to the high one, and it runs for 30 seconds.
6. Stop the system for 90 seconds. During the first 30 seconds, the mortar sticking to the wall and the lower part of the bowl is removed with a rubber or plastic spatula and positioned in the center of the bowl; in the remaining minute the bowl is covered.
7. Continue mixing for 60 seconds again, before stopping the process.

Figure 26: the mixing

4.7 Preparation of test specimen

Once the mortar is created, it is introduced into the moulds directly from the mixing bowl. The test specimens shall be 40 mm × 40 mm × 160 mm prisms.

The jolting apparatus shakes the samples in such a way as to create a compact layer of mortar. The data pulses are 60. The mortar layers are given in two different phases alternated by 60 pulses each. In the last phase we make sure that we have a little surplus mortar.

Figure 27: preparation of the samples

The mould is then removed and the samples and carry out for demoluting. The hardening was done in water at a temperature of (20.0 ± 1.0) ° C. The samples were placed on grids and separated from each other so that the water had free access to all six the faces of the samples.

Figure 28: the samples before being put into the water

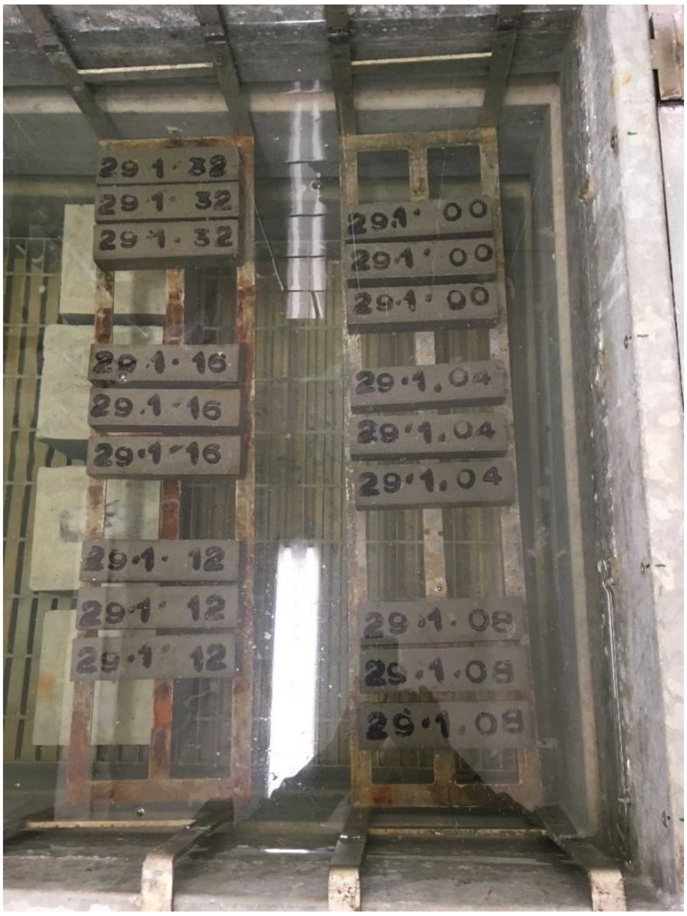


Figure 29: the samples in water

After 28 days the specimens were removed from the water and prepared for mechanical tests.

Figure 30: samples after the maturation

Figure 31: the samples are named

4.8 Testing Procedure

4.8.1 Flexural strength

Flexural strength apparatus

Flexural strength can be measured using a bending strength testing machine that must meet certain requirements. It must be able to apply loads up to 10 kN with an accuracy of ± 1.0% of the load recorded in the upper four fifths of the range used, in loading speeds of (50 ± 10) N / s. It must also be equipped with a bending device that incorporates two steel support rollers with a diameter (10.0 ± 0.5) mm spaced (100.0 ± 0.5) mm and a third steel loading roller of the same diameter placed centrally between the other two. The length of these rollers must be between 45 mm and 50 mm. The loading arrangement is shown in Figure 32.

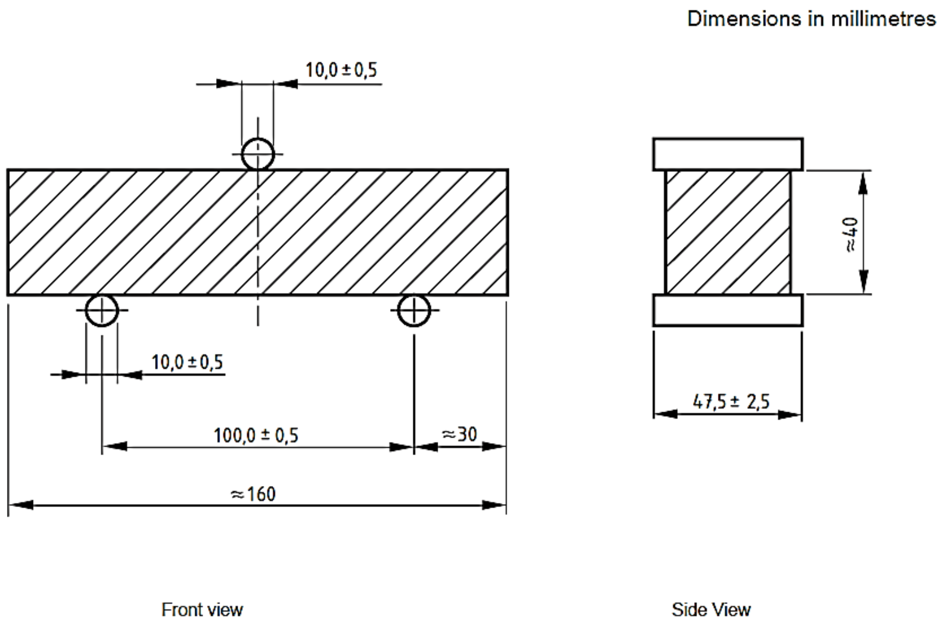


Figure 32: Arrangement of loading for determination of flexural strength

The three vertical planes through the axes of the three rollers must be parallel and remain parallel, equidistant and normal with respect to the direction of the test specimen under examination. One of the support rollers and the loading roller must be tilted slightly to allow a uniform distribution of the load over the width of the sample without subjecting it to torsional stresses.

Figure 33: Flexural strength apparatus

Procedure

The specimen is positioned in the apparatus with a lateral face on the support rollers and with its longitudinal axis normal to the supports. The load is vertically applied vertically through the loading roller on the opposite side face of the prism and gradually increased to the speed of (50 ± 10) N / s until the fracture.

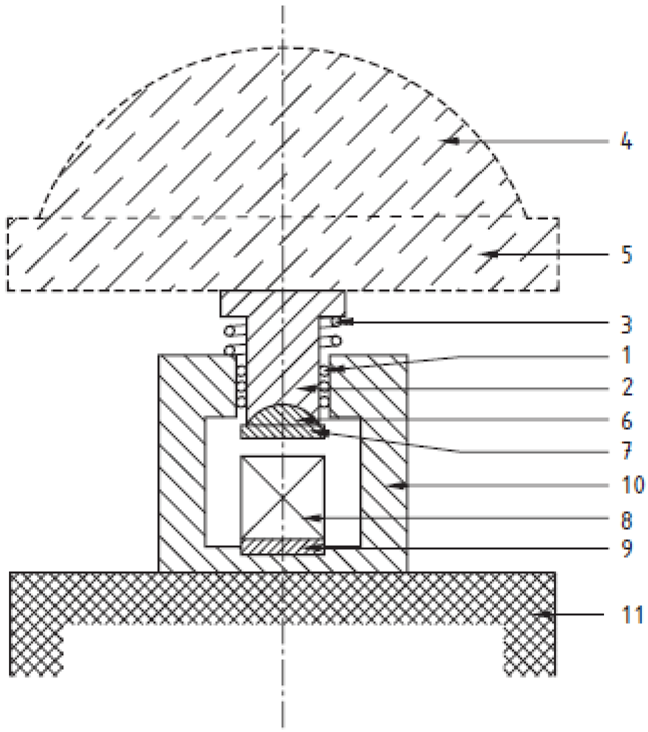
Figure 34: sample in the strength machine

Figure 35: sample in the strength machine

4.8.2 Compressive Strength

Compressive strength testing machinery

The test machine for the determination of the resistance is shown in the Figure 36 and provides a load increase speed of (2 400 ± 200) N / s. The vertical axis of the piston will coincide with the vertical axis of the machine and during loading the direction of movement of the piston will be along the vertical axis of the machine. Furthermore, the resultant force will pass through the centre of the sample.



Key

1 Ball bearings
2 Sliding assemble
3 Return spring
4 Spherical seating of machine
5 Upper platen of machine
6 Spherical seating of the jig
7 Upper platen of the jig
8 Specimen
9 Lower platen of the jig
10 Jig
11 Lower platen of the machine

Figure 36: Typical jig for compressive strength testing

Figure 37: compressive strength machine in lab.

Figure 38: sample in the compressive strength machine

Procedure

The test is carried out by taking the two halves of the broken sample in the bending test. The load is placed on each half of the prism. The middle of the prism is centered laterally to the plates of the machine within ± 0.5 mm and longitudinally so that the front surface of the prism protrudes about 10 mm on the plates or on the auxiliary plates.

The load is uniformly increased at the speed of (2 400 ± 200) N / s over the entire load application up to the break.

Figure 39: sample fractured

Figure 40: sample in the compressive machine

4.8.3 Carbonatation test

The test was conducted in the DIAST department of the Turin Polytechnic. The aim is to obtain the quantity of calcium carbonado ($CaCO_3$) present in a mixture of calcium carbonate and silica, measuring the volume of gas developed from the following reaction:

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_{2\ (g)}$$

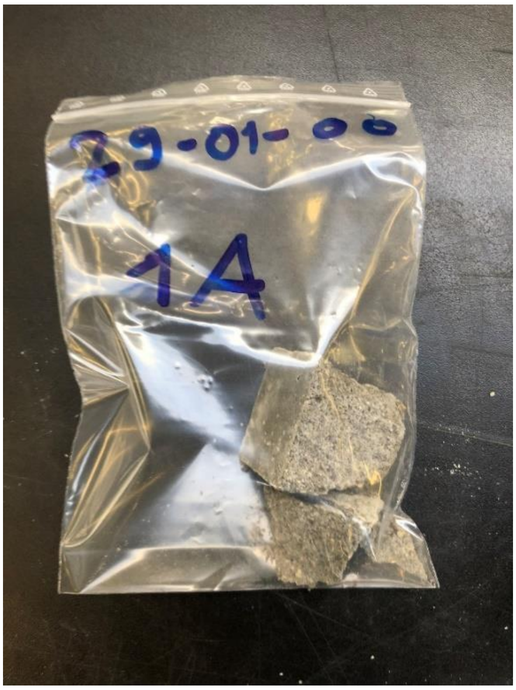


Figure 41: sample after the machanical tests

Figure 42: all the sample before the chemical tests

Calcimiter

The test was done using the Calcimeter. This instrument is composed of a graduated glass cylinder, a glass level tube per cylinder, two bent glass tubes. It uses the principle of communicating vessels and the ability of a gas to move volumes of water, allowing direct reading of calcium carbonate expressed in percentages.

Figure 43: calcimeter

Procedure

The procedure is as follows:

1. The calcimeter is zeroed by moving the smaller, unscaled cylinder so that the liquid level is equal to the zero of the graduated cylinder. This is possible thanks to the opening of the valve which allows to have the same pressure as the two cylinders.

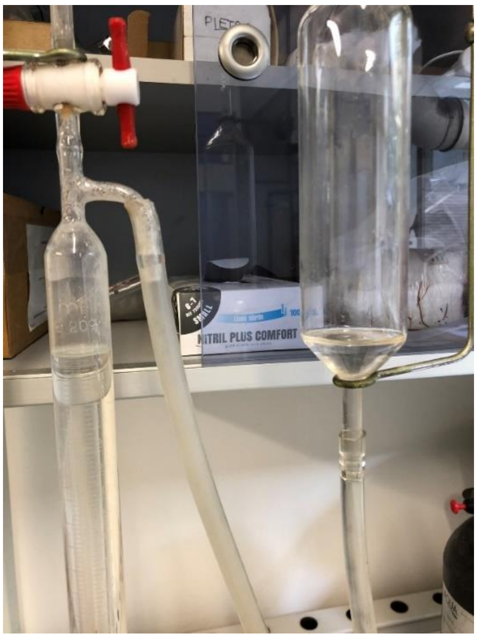


Figure 44: liquid level in the calcimeter

2. 0.5 g of the $CaCO_3 + SiO_2$ mixture is introduced and then placed in the glass jar
3. 5 ml of HCl are measured and placed in the plastic container

Figure 45: mesurement of HCl

4. The plastic container is placed in the glass jar being careful not to spill it
5. The glass jar is then closed with the rubber stopper, without causing the container of HCl to spill inside it
6. The valve closes at the top of the graduated cylinder
7. The mixture is then shaken by dropping the HCl on the mixture. The volume of CO_2 developed is measured from the graduated cylinder, moving the mobile cylinder so that the two levels coincide.
8. Thanks to the gas law we go back to the amount of calcium carbonate present:

$$PV=nRT$$

Where:

- P is the pressure of the gas,
- V is the volume of the gas,

- n is the amount of substance of gas (also known as number of moles),
- R is the ideal, or universal, gas constant, equal to the product of the Boltzmann constant and the Avogadro constant,
- T is the absolute temperature of the gas.

From the moles it is possible to go back to the grams and therefore to the percentage of $CaCO_3$.

Table 6: %CaCO3 in sample 29_01

Sample	% CO_2	% $CaCO_3$
29_01_00	0	5.90
	0	4.7
	0	3.5
29_01_04	0.4	5.4
	0.4	5.5
	0.4	6
29_01_08	0.8	6.1
	0.8	4.6
	0.8	5.3
29_01_12	1.2	7
	1.2	6.2
	1.2	7
29_01_16	1.6	7.4
	1.6	8.1
	1.6	6.8
29_01_32	3.2	6.6
	3.2	6.7
	3.2	7.3

Table 7: % CaCO3 in sample 31_05

Sample	% CO_2	% $CaCO_3$
31_05_00	0	6.1
	0	5.31
	0	5.6
31_05_08	0.8	5.69
	0.8	5.54
	0.8	6.23
31_05_16	1.6	7.2
	1.6	6.57
	1.6	5.78
31_05_24	2.4	5.85
	2.4	5.76
	2.4	6.7
31_05_32	3.2	6.73
	3.2	6
	3.2	4.76
31_05_40	4	5.85
	4	6.53
	4	7.225

4.9 pH test

The pH measurement of the samples 29_01 was done using an automatic digital water meter:

Figure 46: samples ready for the test

Figure 47: distilled water

Figure 48: instrument for the pH test

The pH tests were done in three different days. Also the temperature of the laboratory was recorded.

Table 8: results of pH test

Sample		%CO2	13-mag	15-mag	20-mag	
29_01_00	1A	0	12.15	12.29	12.38	12.27
	2A	0	12.15	12.31	12.37	12.28
	3A	0	12.15	12.29	12.31	12.25
29_01_04	1A	0.4	12.19	12.32	12.29	12.27
	2A	0.4	12.16	12.28	12.28	12.24
	3A	0.4	12.13	12.3	12.26	12.23
29_01_08	1A	0.8	12.18	12.31	12.28	12.26
	2A	0.8	12.16	12.32	12.31	12.26
	3A	0.8	12.16	12.31	12.31	12.26
29_01_12	1A	1.2	12.15	12.3	12.26	12.24
	2A	1.2	12.16	12.29	12.23	12.23
	3A	1.2	12.18	12.31	12.29	12.26
29_01_16	1A	1.6	12.19	12.3	12.27	12.25
	2A	1.6	12.16	12.31	12.25	12.24
	3A	1.6	12.18	12.29	12.24	12.24
29_01_32	1A	3.2	12.05	12.29	12.24	12.19
	2A	3.2	12.1	12.29	12.25	12.21
	3A	3.2	12.18	12.3	12.26	12.25
Temperature			21.5 °C	21.8°C	21.7°C	

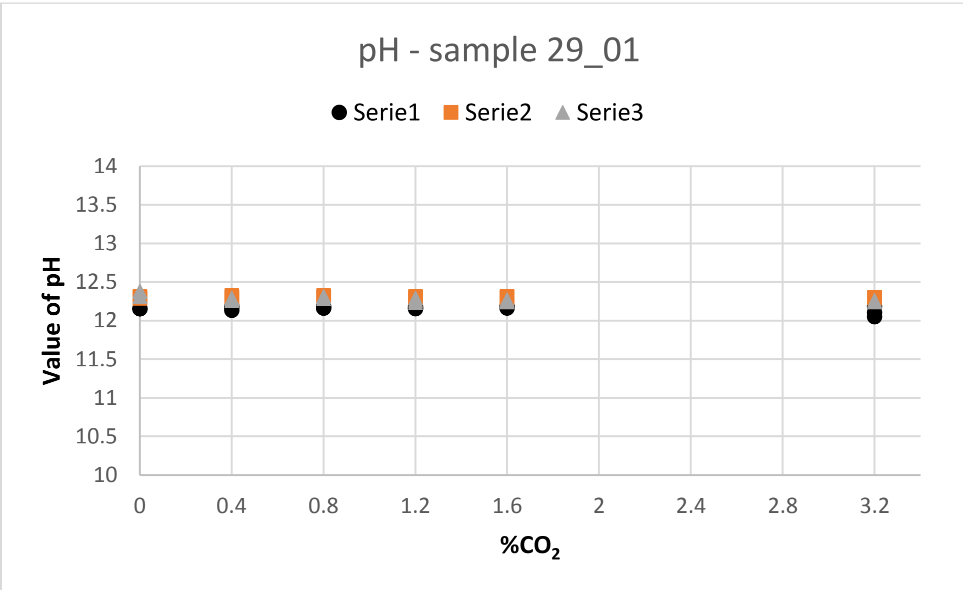


Figure 49: pH in sample 29_01 in 3 different days

5 Test results and interpretation

5.1 Flexural strength

The results of the flexural strength are shown in the following table and graph. All the results for each single sample are in the Appendix 9.

Table 9: results of flexural strength 29_01

Flexural strength		
Sample	% CO_2/cem	σ_{flex} [MPa]
29_01_00	0	7.51
		6.94
		6.27
29_01_04	0.4	0.00
		6.84
		6.51
29_01_08	0.8	6.04
		6.02
		7.05
29_01_12	1.2	6.53
		6.88
		6.61
29_01_16	1.6	6.22
		6.72
		6.86
29_01_32	3.2	6.61
		6.70
		6.42

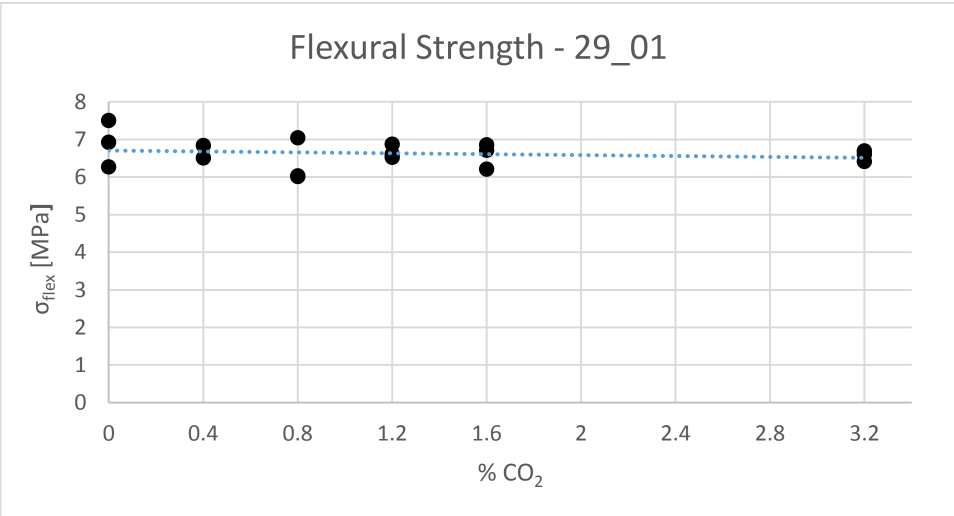


Figure 50: Flexural strength 29_01

Table 10: Flexural strength 31_05

Flexural strength		
Sample	% CO_2/cem	σ_{flex} [MPa]
31_05_00	0	7.10
		7.92
		7.47
31_05_08	0.8	7.54
		7.66
		7.94
31_05_16	1.6	7.42
		7.29
		-
31_05_24	2.4	6.64
		7.47
		6.81
31_05_32	3.2	7.08
		7.08
		6.69
31_05_40	4	7.28
		6.45
		6.54

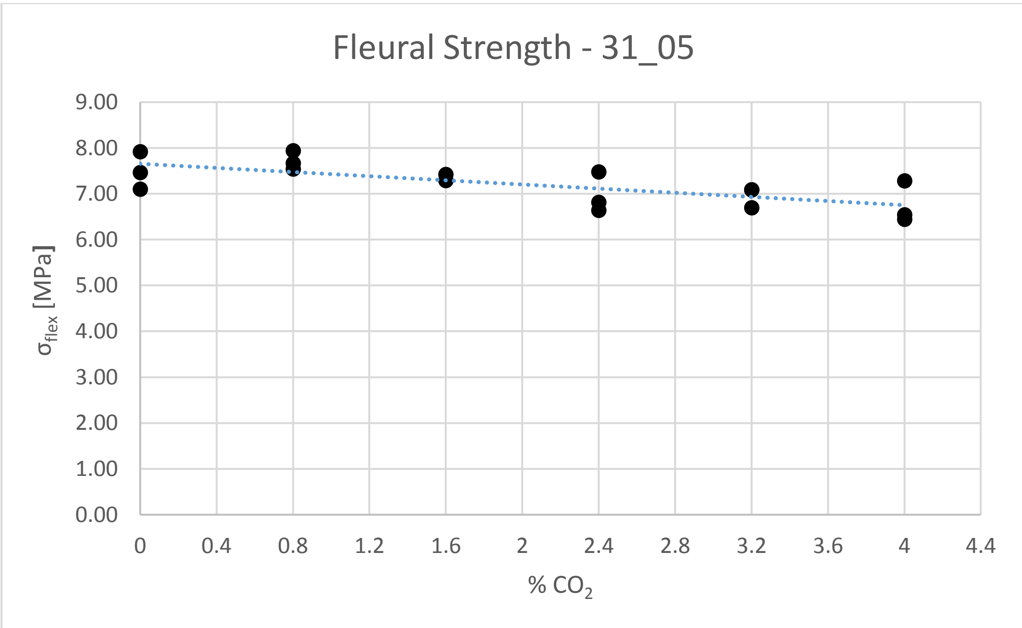


Figure 51: Flexural Strength 31_05

5.2 Compressive strength

The results of the compressive strength are shown in the following table and graph. All the results for each single sample are in the Appendix 9.

Table 11: Compression test - 29_01

Compressive strength			
Sample	% CO_2/cem	**σ₁ [Mpa]**	**σ₂ [Mpa]**
29_01_00	0	54.64	46.58
		44.77	42.11
		43.15	41.71
29_01_04	0.4	34.48	41.55
		44.38	45.33
		43.51	46.72
29_01_08	0.8	38.84	44.46
		41.26	40.48
		41.10	44.19
29_01_12	1.2	42.82	41.47
		43.35	45.39
		44.45	42.93
29_01_16	1.6	43.41	44.63
		42.74	44.72
		41.68	42.63
29_01_32	3.2	41.75	41.44
		44.02	42.47
		40.60	41.35

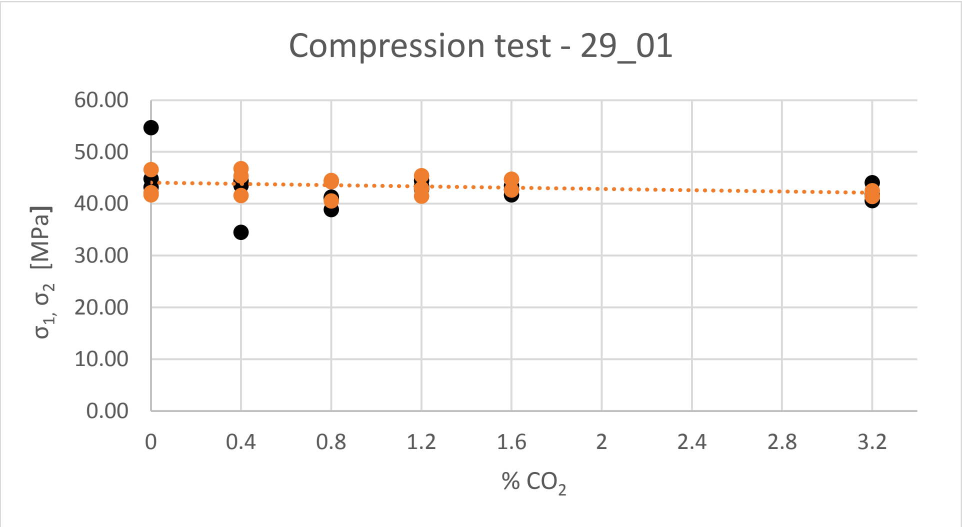


Figure 52: Compression test - 29_01

Table 12: Compression test - 31_05

Compressive strength			
Sample	% CO_2/cem	**σ_1 [Mpa]**	**σ_2 [Mpa]**
31_05_00	0	58.90	59.32
		59.18	62.19
		60.31	58.55
31_05_08	0.8	57.97	58.57
		59.40	58.90
		60.72	61.53
31_05_16	1.6	56.57	57.30
		56.71	58.30
		57.23	57.35
31_05_24	2.4	59.12	57.70
		61.12	59.65
		62.10	58.79
31_05_32	3.2	58.33	59.99
		58.96	56.45
		58.36	55.79
31_05_40	4	56.58	54.43
		59.51	59.59
		58.92	60.05

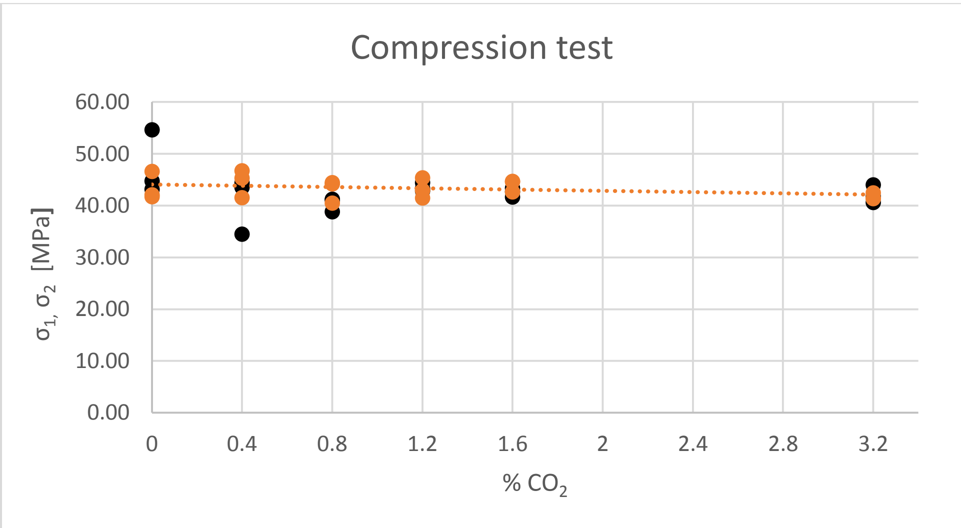
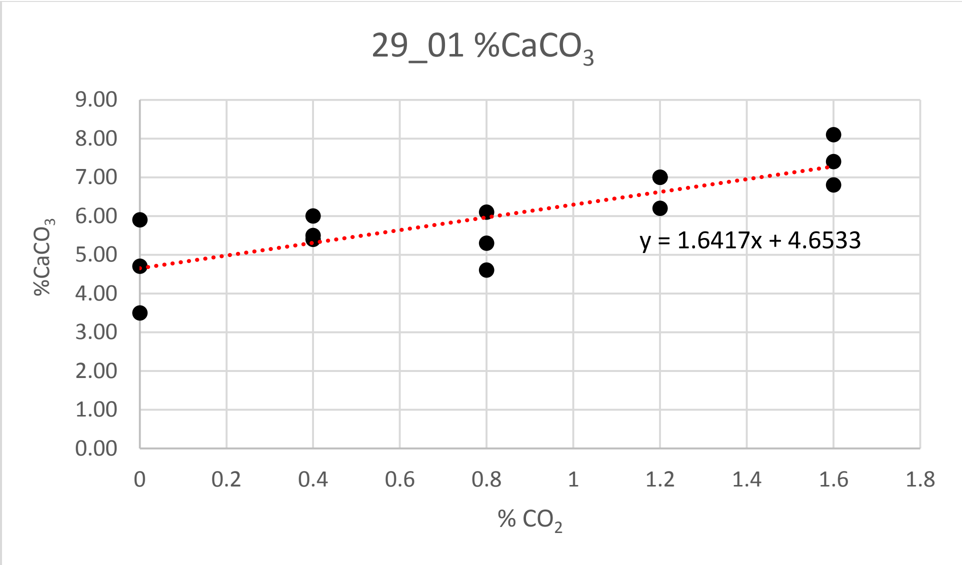


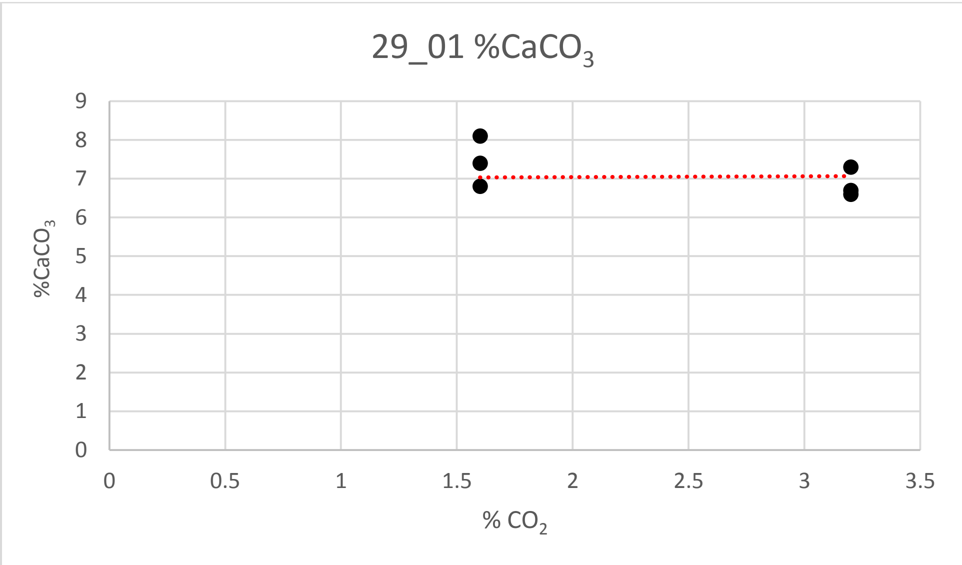
Figure 53: Compression test - 31_05

5.3 Calcimetry results

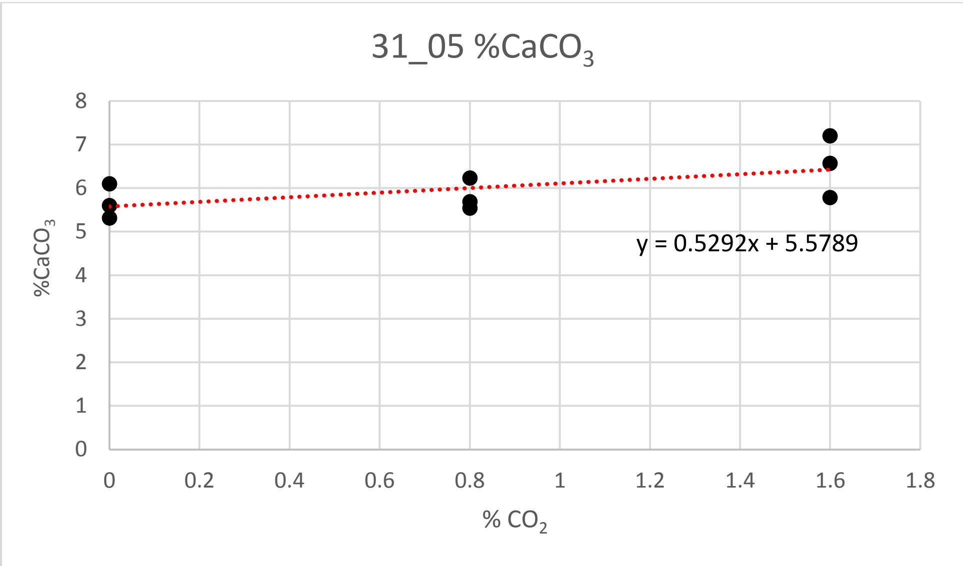
The results of the calcimetry tests are shown in the figure below:

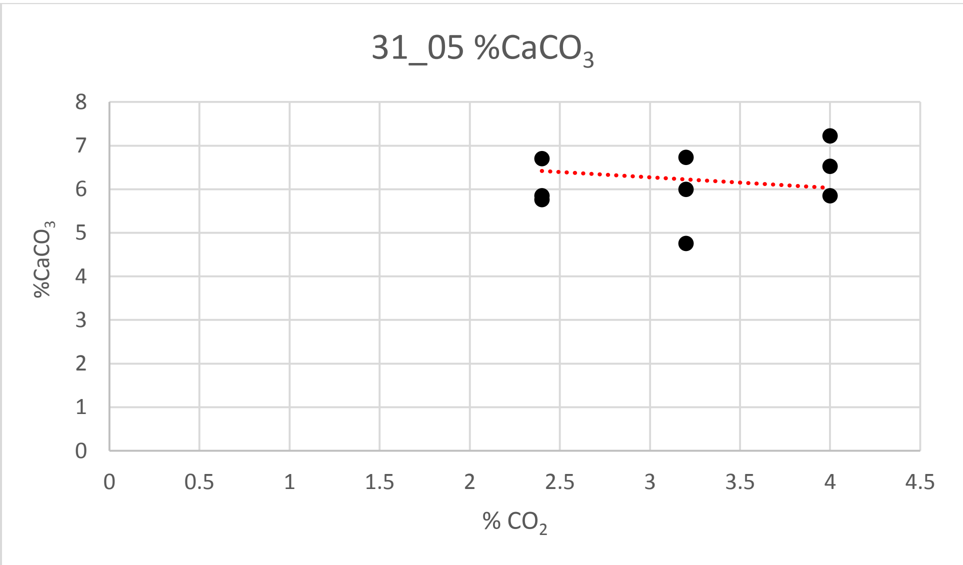
- Samples 29_01





- Samples 31_05





5.4 The quantity of carbon oxide absorbed

The quantity of carbon oxide absorbed, or efficiency, for the sample 29_01 and 31_05 are shown in the following tables:

Table 13: computation of efficiency 29_01

Sample	%CO2	%CaCO3	Averege-%CaCO3	CaCO3 [g]	CO2 absor [g]	ΔCO2 absor[g]	CO2 given[g]	Efficiency
29_01_00	0	5.90	4.70	26.55	11.68	0.0	0	-
		4.7		21.15	9.31	0.0	0	-
		3.5		15.75	6.93	0.0	0	-
29_01_04	0.4	5.4	5.63	24.3	10.69	1.4	1.8	0.8
		5.5		24.75	10.89	1.6	1.8	0.9
		6		27	11.88	2.6	1.8	1.4
29_01_08	0.8	6.1	5.33	27.45	12.08	2.8	3.6	0.8
		4.6		20.7	9.11	-0.2	3.6	-0.1
		5.3		23.85	10.49	1.2	3.6	0.3
29_01_12	1.2	7	6.73	31.5	13.86	4.6	5.4	0.8
		6.2		27.9	12.28	3.0	5.4	0.6
		7		31.5	13.86	4.6	5.4	0.8
29_01_16	1.6	7.4	7.43	33.3	14.65	5.3	7.2	0.7
		8.1		36.45	16.04	6.7	7.2	0.9
		6.8		30.6	13.46	4.2	7.2	0.6
29_01_32	3.2	6.6	6.87	29.7	13.07	3.8	14.4	0.3
		6.7		30.15	13.27	4.0	14.4	0.3
		7.3		32.85	14.45	5.1	14.4	0.4

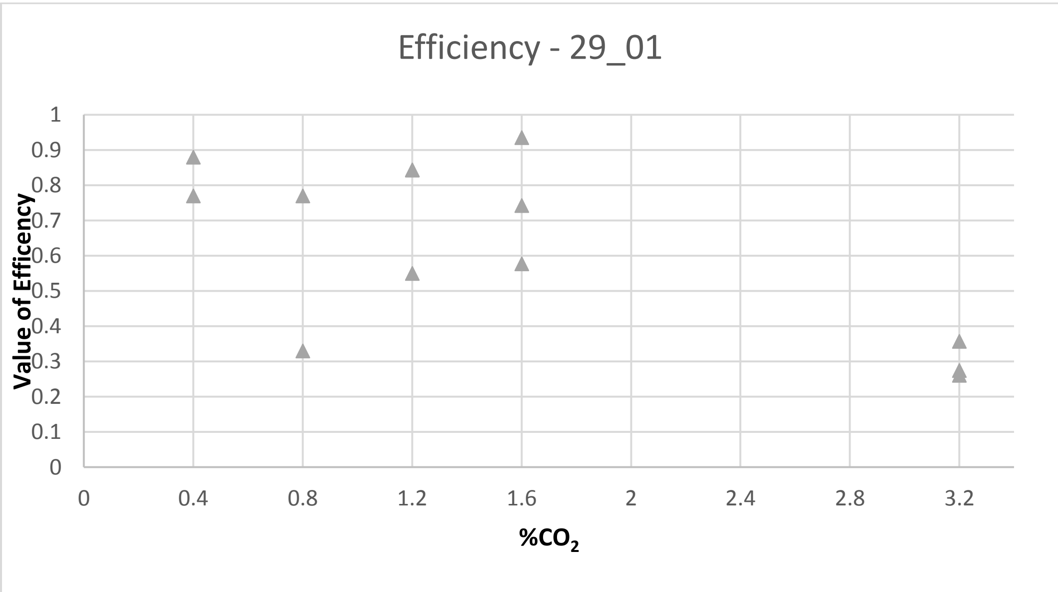
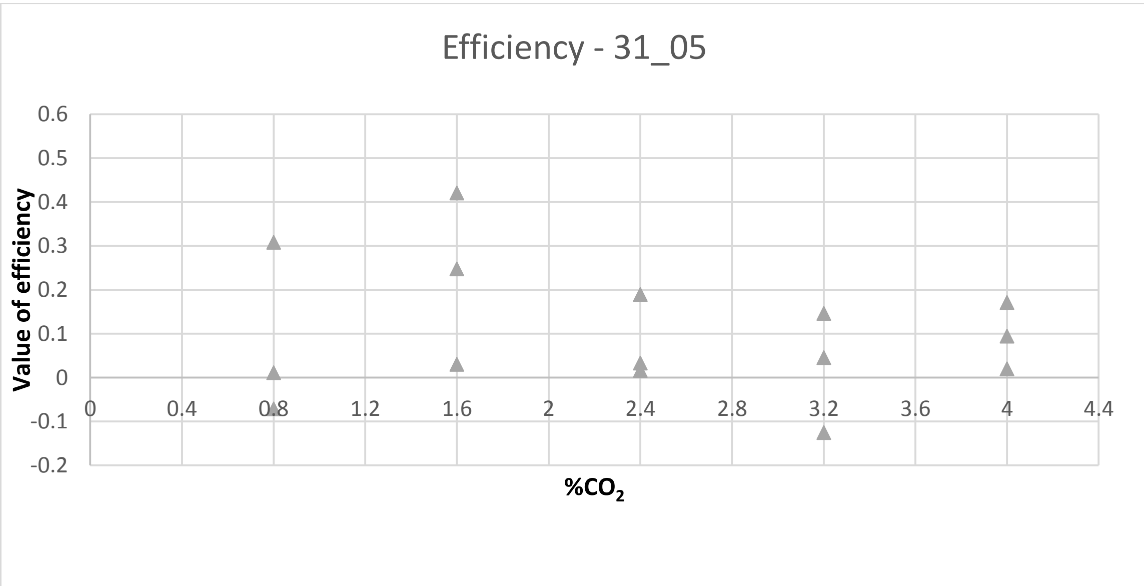


Table 14: computation of efficiency 31_05

Sample	%CO2	%CaCO3	Averege-%CaCO3	CaCO3 [g]	CO2 absor [g]	ΔCO2 absor[g]	CO2 given[g]	Efficiency
31_05_00	0	6.1	5.67	27.45	12.08	0.00	0.0	-
	0	5.31		23.90	10.51	0.00	0.0	-
	0	5.6		25.20	11.09	0.00	0.0	-
31_05_08	0.8	5.69	5.82	25.61	11.27	0.04	3.6	0.01
	0.8	5.54		24.93	10.97	-0.26	3.6	-0.07
	0.8	6.23		28.04	12.34	1.11	3.6	0.31
31_05_16	1.6	7.2	6.52	32.40	14.26	3.03	7.2	0.42
	1.6	6.57		29.57	13.01	1.78	7.2	0.25
	1.6	5.78		26.01	11.44	0.22	7.2	0.03
31_05_24	2.4	5.85	6.10	26.33	11.58	0.36	10.8	0.03
	2.4	5.76		25.92	11.40	0.18	10.8	0.02
	2.4	6.7		30.15	13.27	2.04	10.8	0.19
31_05_32	3.2	6.73	5.83	30.29	13.33	2.10	14.4	0.15
	3.2	6		27.00	11.88	0.65	14.4	0.05
	3.2	4.76		21.42	9.42	-1.80	14.4	-0.13
31_05_40	4	5.85	6.54	26.33	11.58	0.36	18.0	0.02
	4	6.53		29.39	12.93	1.70	18.0	0.09
	4	7.225		32.51	14.31	3.08	18.0	0.17



5.5 The model for research

The main idea was to be able to absorb more carbon dioxide into the concrete. Imagine taking the crystal of $Ca(OH)_2$ and approximating it to a sphere, its diameter is about twice the diameter of CaO.

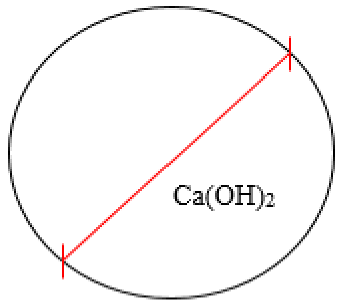


Figure 54: crystal of $Ca(OH)_2$

The chemical reaction is:

$$CaO + H_2O \rightarrow Ca(OH)_2$$

CaO is present in the cement and depends on how the cement was made. The diameter value is about 10µm.

When CaO is inserted, a $CaCO_3$ road is formed, which acts as a barrier, prevents its reaction and can vary from a few µm up to about 10 µm. The reaction therefore takes place very slowly over time.

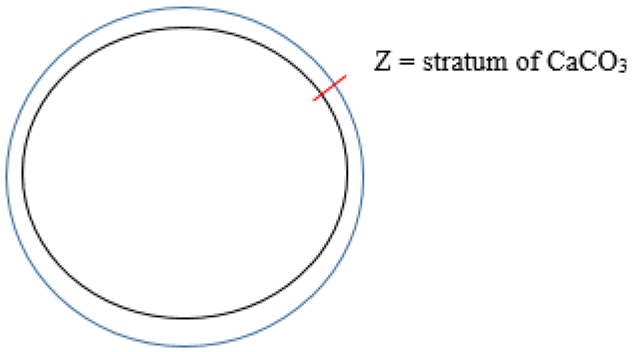


Figure 55: stratum of CaCO3 formed

Approaching by hypothesis a spherical shape of the crystal of $Ca(OH)_2$, the surface and volume of the sphere can be easily calculated:

$$S = 4\pi \left(\frac{d}{2}\right)^2$$

$$V = \frac{4}{3}\pi \left(\frac{d}{2}\right)^3$$

In cement and water paste, with measures from legislation (450g and 250g) there is about 20-25% of $Ca(OH)_2$, which means that:

- weight $Ca(OH)_2 = \frac{22}{100}\,(225 + 450) = 148.5g$
- volume $Ca(OH)_2 = \frac{148.5\ g}{2.93\ \frac{g}{cm^3}} = 435.105\ cm^3$
- number of particle di $Ca(OH)_2 \rightarrow \frac{Vol_{tot}}{Vol_{particicle}}$

External total surface = total volume * n of particle

Total surface = z * total volume of $CaCO_3$

$$\rightarrow \frac{weight\ CaCO_3}{450 + 225} * 100 \rightarrow particle\ di\ CaCO_3$$

By changing the pressure P or the temperature T it would be possible to increase the% of CaCO3. This method is certainly feasible but expensive and not compatible in the vision of finding an easily usable method in situ. The hypothesis is therefore to change the fineness of the cement is therefore to halve the diameter of Ca (OH) 2, reduce the volume of the single particle, increase the available surface. For this reason, further experiments were carried out from CEM I 42.5 to CEM I 52.5. The parameters and characteristics of the cements are the same, only the fineness varies.

In the table below there are the results of the model created:

Table 15

			Geometry $Ca(OH)_2$		
Diamiter of $Ca(OH)_2$	0.022	mm	surface	0.00151976	mm2
			volume	5.57245E-06	mm3
			weight	1.24266E-08	g
Cement	450	g			
Water	225	g	Quantity of $Ca(OH)_2$		
specific weight - $Ca(OH)_2$	0.00223	g/mm3	weight	151.875	g
specific weight - $CaCO_3$	0.00271	g/mm3	n° part	12221794799	
			external surface	18574194.86	mm2
			$CaCO_3$		
Stratum $CaCO_3$	0.001	mm	volume	18574.19486	mm3
(variable from 1 to 10 micron)			peso	50.33606808	g
max $CaCO_3$ from tests %			max theoretical $CaCO_3$ %		
7.4			7.457195271		

			Geometry $Ca(OH)_2$		
Diamiter of $Ca(OH)_2$	0.012	mm	surface	0.00045216	mm2
			volume	9.0432E-07	mm3
			weight	2.01663E-09	g
Cement	450	g			
Water	225	g	Quantity of $Ca(OH)_2$		
specific weight - $Ca(OH)_2$	0.00223	g/mm3	weight	151.875	g
specific weight - $CaCO_3$	0.00271	g/mm3	n° part	75311152209	
			external surface	34052690.58	mm2
			$CaCO_3$		
Stratum $CaCO_3$	0.001	mm	volume	34052.69058	mm3
(variable from 1 to 10 micron)			peso	92.28279148	g
max $CaCO_3$ from tests %			max theoretical $CaCO_3$ %		
-			13.67152466		

However, the laboratory results have shown that in reality the size of the portlandite remains fundamentally constant. What varies is the thickness of the calcium carbonate that forms. It decreases according to the diameter of the inert material, so the tests show that to absorb a greater quantity of carbon dioxide I have to use a less fine cement. The efficiency varies with the fineness of the cement used.

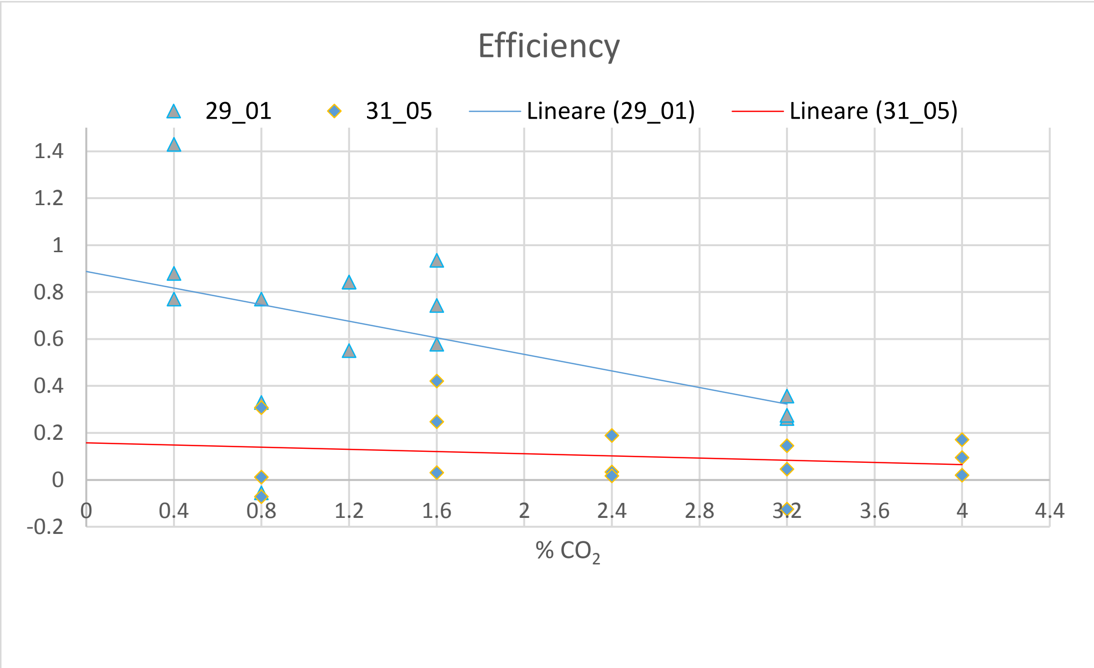
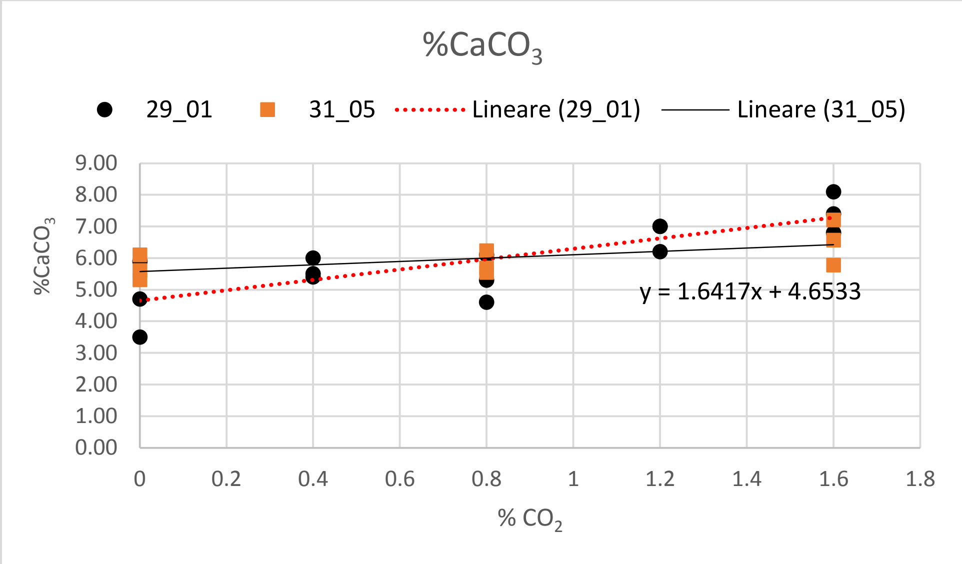


Figure 56. Efficiency of the sample compared

For sure the most interesting figure is that relating to the maximum absorption of carbon dioxide. In fact, there is a peak at 1.6% by weight. Beyond this threshold the absorption does not change or in some cases decreases. This data was also found in the literature.[4]

[4] Carbon dioxside as an admixture for better performance of OPC-based concrede – Xin Qian, Jialai Wang, Yi Fang, LiangWang



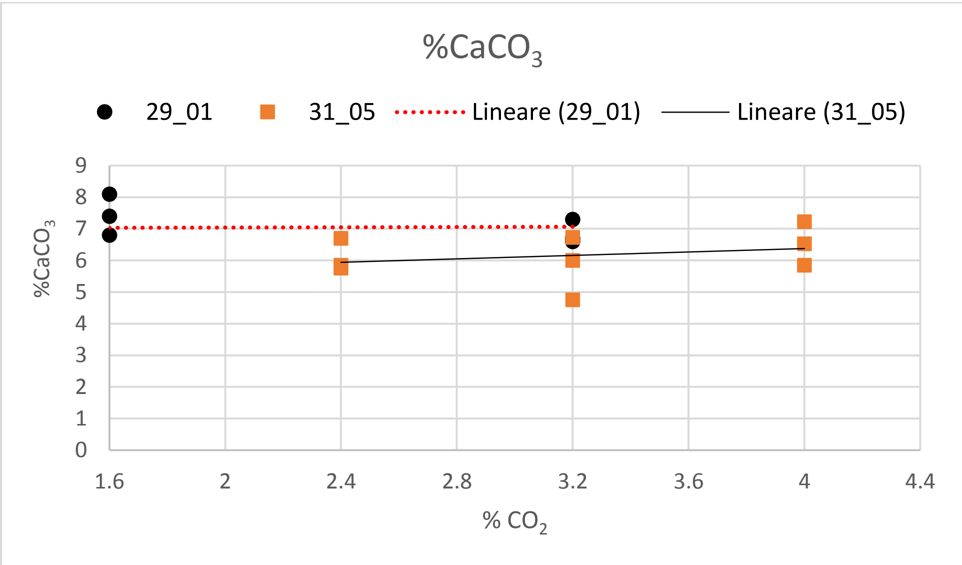


Figure 57: the % of CaCO3 of the two samples compared

6 Practical Application

It is analyse the executive project of the "Restructuring of the Magazzini Generali quay" situated in Ravenna,which is necessary for compliance with the provisions of P.R.P. (backdrop at -14.5 m s.l.m.m.m and distributed overload of 40kPa), for a stretch of about 202 m in length. The following data were taken by the projects from BESIX, the company take made this project.

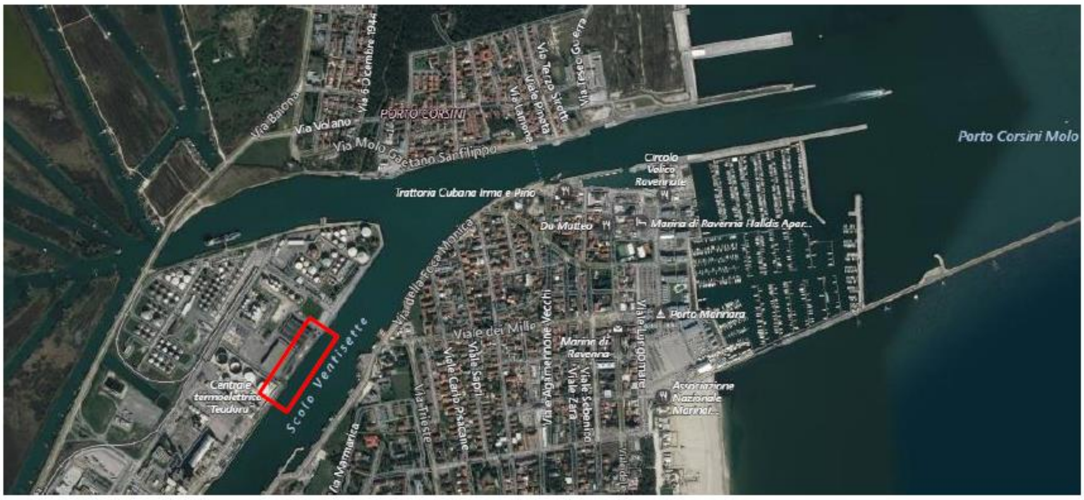


Figure 58: satellite view with red box of the current dock "Magazzini Generali",

Figure 59: aerial view of the current dock "Magazzini Generali", bing-maps 2018

The project of the current quay c.d. "Magazzini Generali", dating back to the 1960s and subject to subsequent modifications and additions in the 1980s, is suitable for a calculation background at -9.40 m s.l.m.m.

Below are some extracts from the graphic tables of the quay subject to the intervention.

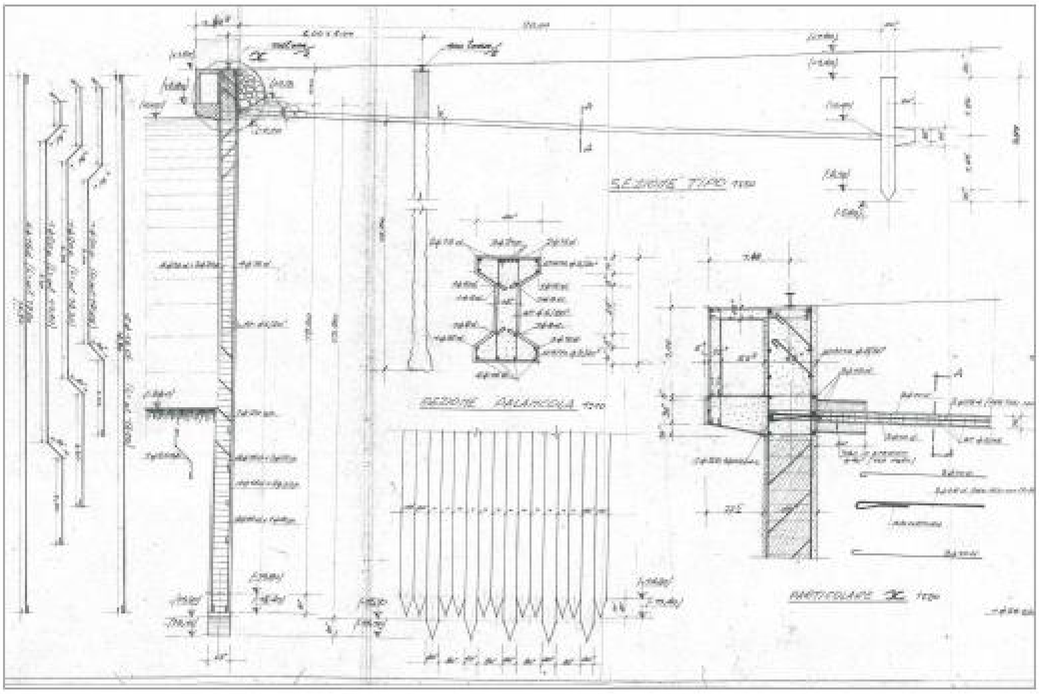


Figure 60: Magazzini Generali quay (1981) - section

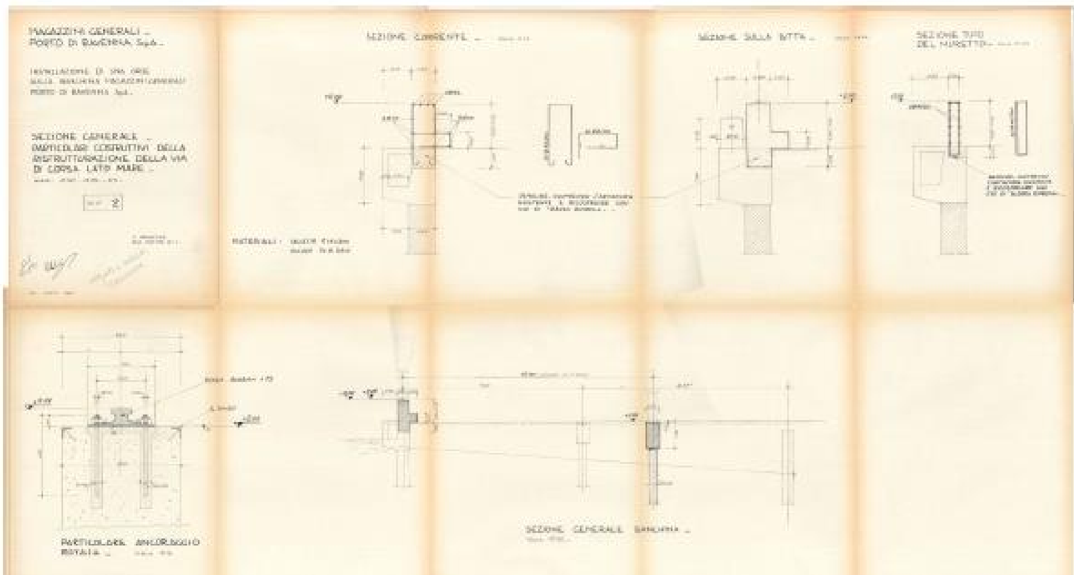


Figure 61: Magazzini Generali quay (1981) - anchorage.

It is a sheet piling in c.a. 65cm thick with a height of -15.50 m s.l.m. /16.10m s.l.m., anchored to a sheet piling in c.a. of contrast by means of beams in c.a. with pretended armor, 20m long.

The final project involves the construction of a new metal sheet piling in the section in front of the existing quay, where, as an external wire, the joining line was assumed between the extreme edges of the adjacent northern quays (P.I.R. quay) and in the South

(Enel quay).

The supporting structure of the quay is made with a metal sheet piling, the main elements are metal profiles type HZ 975 D - solution 24, in S430 GP steel, coupled with secondary metal profiles AZ 18 in S390 GP steel; the connection between the various profiles is performed by metal gargoyles.

The entry height of the main metal profiles is set at –29 m s.l.m.m with height at the top at +1.5 m s.l.m.m.m, while the secondary elements at height - 18 m s.l.m.m. with elevation at +0.5 m s.l.m.m.; the secondary elements have the function of containing the ground behind while the main elements are entrusted with the totality of the incident load.

The crowning curb consists of a beam in c.a. with L-shaped section whose dimensions are detailed in the graphic drawings attached to this project. The summit at the top is set at +2.50 m s.l.m.m. To increase the corrosion protection of the concrete, the external facing of the curb is made by a prefabricated panel in c.a. full-height, 15 cm thick, suitably stiffened with steel trusses. The panel, which has a constant height of 4500 mm starting from the height of the top of the quay, as well as acting as a disposable formwork, being made in the factory by vibrocompaction and controlled maturation, allows greater protection of the reinforcement, also thanks to the addition to the mix design of the concrete with appropriate additives to improve waterproofing and chemical protection against corrosion.

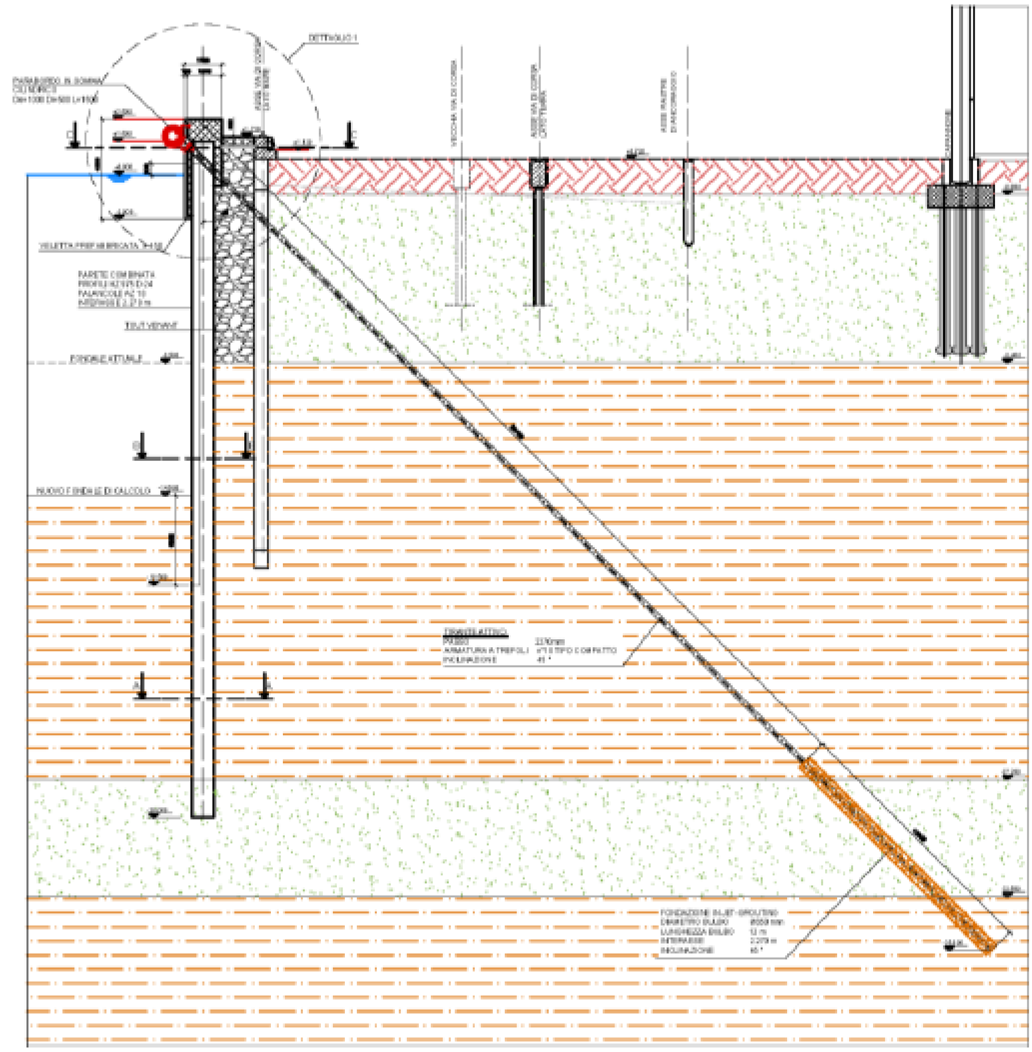


Figure 62: Final design section

6.1 The control of the emissions

The control of emissions into the atmosphere was carried out by means of an operational solution.

The first concerns the desire to build a "zero emission" carbon dioxide construction site. This solution is obtained through the compensation of the emissions of all the operating machines that will be used on site during the works (and which will in any case be of the EEV category, Enhanced Environmental Vehicle, according to the most recent European standards - Euro VI - or according to the type American ACERT) through the implementation of a certified reforestation project such as to absorb the equivalent amount of CO_2 emitted by the work vehicles, and thus canceling the so-called "carbon footprint" of the yard.

The following table shows the list of the main mechanical means used on site during the approximately 9 months of construction of the works.

Attrezzature	Sett.1	Sett.2	Sett.3	Sett.4	Sett.5	Sett.6	Sett.7	Sett.8	Sett.9	Sett.10	Sett.11	Sett.12	Sett.13	Sett.14	Sett.15	Sett.16	Sett.17	Sett.18	Sett.19	Totale settimane
Escavatore con martellone - 20T CAT320	1	1	1																	3
Fresatrice			1																	1
Gru gommata 45T	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1					16
Sollevatore telescopico 4T		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			16
Bulldozer cingolato - CAT D5			1																	1
Gru cingolata - 160T - LT1160					1	1	1	1	1	1	1	1								8
Escavatore - CAT 320			1	1																2
Vibroinfissore idraulico IHC S70						1	1	1	1	1	1	1								7
Escavatore di lunga portata - CAT 320					1															1
Betoniera										2	2	2	2	2	2	2	2			16
Autocarro 16mc	2	2	3	3	3	3								1	1	1	1	1	1	22
Autoarticolato 20T	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			17
Miniescavatore														1	1					2
Rullo vibrante														1	1					2
Finitrice																	1	1	1	3
Rullo gommato																	1	1	1	3
Perforatrice ICE 815C					1	1	1	1	1	1	1	1								8
Pala gommata CAT950	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1					21

Figure 63: use of work machines

The definition of an accurate project schedule allowed us to foresee, for each of the mechanical means, the actual time of use.

For each mechanical vehicle, in the table, the period of use is therefore identified, in weeks. Given the scale of the work, we work on a single 8-hour shift for 5 days a week. Each machine will therefore be used approximately for 40 hours a week. This calculation exercise is, of course, approximate and theoretical.

For each of the vehicles the maximum power has been identified, in kW. It was therefore assumed, as a precaution, that the vehicles operate on site at about half the maximum power for the entire period of use, with some exceptions, for example for the milling machine whose use can be considered above average for the small period in which you will be present on the site.

With a level of approximation and caution adjusted to the present forecast, multiplying the number of hours of use by the average power supplied by the engines gives an estimate of the total energy expended by the means of work which, in the case in question, considering also an even more precautionary increase of around 10% of the total forecast is approximately 500,000 kWh

Attrezzature	Totale settimane	Approccio (Mare/Terra)	Turni giornalieri	Ore di utilizzo	Potenza motore (kW)	Potenza media esercizio (kW)	Energia utilizzata (kWh)
Escavatore con martellone - 20T CAT320	3	T	1	120	120	60	7200
Fresatrice	1	T	1	40	100	80	3200
Gru gommata 45T	16	T	1	640	130	65	41600
Sollevatore telescopico 4T	16	T	1	640	75	35	22400
Bulldozer cingolato - CAT D5	1	T	1	40	75	35	1400
Gru cingolata - 160T - LT1160	8	T	1	320	55	30	9600
Escavatore - CAT 320	2	T	1	80	120	60	4800
Vibroinfissore idraulico IHC S70	7	T	1	280	400	200	56000
Escavatore di lunga portata - CAT 320	1	T	1	40	120	60	2400
Betoniera	16	T	1	640	120	100	64000
Autocarro 16mc	22	T	1	880	160	80	70400
Autoarticolato 20T	17	T	1	680	160	80	54400
Miniescavatore	2	T	1	80	110	55	4400
Rullo vibrante	2	T	1	80	100	50	4000
Finitrice	3	T	1	120	100	50	6000
Rullo gommato	3	T	1	120	100	50	6000
Perforatrice ICE 815C	8	T	1	320	80	40	12800
Pala gommata CAT950	21	T	1	840	150	100	84000
							454600

Figure 64: total energy used

As electrical means are not yet available in the construction equipment market, it is considered that all the power supplies are diesel. As defined in the European regulations in force diesel fuel is characterized by a toe (ton of oil equivalent) equal to 1.08 and, consequently, it has a lower conventional calorific value equal to 11.8604 kWh per Kg of fuel: they will therefore be necessary for the supply of all the operating machines to the yard about 42,200 kg of fuel which, considering a volume weight of 0.8 kg / l, correspond to approximately 53,000 liters of diesel. It is a datum that, from a quantitative point of view, goes well with the analysis of the elementary costs used in the price list items, and which well refers to the extent and duration of the construction site.

Based on the application of combustion formulas in diesel engines the emission of CO2 for every liter of diesel is 2.6 kg of CO_2. In conclusion, therefore, we obtain that the total emission of carbon dioxide determined by the use of operating machines during the nine months of the construction site is, by excess, *140 tonnes of* CO_2.

This is an absolutely non-negligible quantity which, wishing to make a reference, perhaps more usual, to an evaluation of road traffic, considering the limits of 95 g of

CO_2 emissions which according to European directives must be reached by 2020, correspond to about 150,000 km, which is, for example, covered by 15 large trucks in a year.

Forestry intervention

To give a quantitative example, in order to have an order of magnitude, based on simple biomass conversion calculations of the chlorophyll photosynthesis process, it results that the average amount of CO_2 absorbed during the biological life by a tall tree is about 1.3 tons of CO_2. Other evaluation criteria, depending on the type and planted essences, are based on the extension in hectares of the vegetation management plan. To return to the quantifiable example, we will therefore deal, approximately, with the planting of 110 tall trees. This is an intervention that, even from an economic point of view, is absolutely compatible with the management economies of the project intervention in question.

If you consider that the cost of a tree plus the subsequent installation costs about 50 euros, the total cost of forestation will be 5500 euros.

For the purposes of managing emissions, as sanctioned by the Kyoto Protocol, of which, of course, "the atmosphere is one" could be implemented in any developing country. The environmental certification will be the guarantee of the intervention. By adopting this total compensation it is legitimate to promise that the construction site will be "zero emission of carbon dioxide".

6.2 Intervention with CO_2 in cement mortar

From the data of the “computo metric” it was possible to trace the amount of cement used, about 1750 m3. This value multiplied by the specific weight of the cement (assumed 2.5 g7cm3) from a weight of 4375 tons of cement used for the work.

Num.Ord. TARIFFA	DESIGNAZIONE DEI LAVORI	DIMENSIONI				Quantità	IMPORTI	
		par.ug.	lung.	larg.	H/peso		unitario	TOTALE
	RIPORTO							5´618´828,68
	cmq.							
	riempimento entro tubi Ø1626 *(lung.=3,14/4*1,626*1,626)	66,00	2,08		0,200	27,46		
	lato interno per getto cordolo *(par.ug.=3,15/3,09)	1,02	202,39		0,200	41,29		
	scalette	8,00	7,70	1,000	0,100	6,16		
	SOMMANO m³					74,91	99,60	7´461,04
51 / 50 03.01.10.h 11/09/2018	Conglomerato cementizio di classe di esposizione XC1, XC2, XC3, XC4, XD1 e XA1 per strutture di fondazione quali travi rovesce, solettoni, plinti, cordoli, platee, travi di grandi dimensioni (sez. > 0,50 mq) e altre strutture assimilabili in c.a., confezionato a norma di legge con cemento e inerti calcarei o di fiume di idonea granulometria, dato in opera compreso costipamento meccanico o a mano, il disarmante, i controlli previsti dalle norme vigenti, ogni altro onere e magistero per dare il lavoro finito a regola d'arte, esclusa l'armatura metallica e casseformi: conglomerato cementizio con Rck non inf. a 45 N/mmq o 450 kg/cmq. n) sovrapprezzo per classi di esposizione XS2, XS3, XF2, XF3, XF4, XA3 10% su 158.80€/m³ TRAVE DI CORONAMENTO BANCHINA							
	trave di coronamento lato canale fino a quota ±0.00 m s.l.m. *(par.ug.=2,52/3,09)	0,82	202,39		1,700	282,13		
	trave di coronamento da quota ±0.00 m s.l.m. a quota +1.00 m s.l.m. *(par.ug.=5,38/3,09)	1,74	202,39		1,000	352,16		
	trave di coronamento da quota +1.00 m s.l.m. a quota +2.50 m s.l.m.							
	trave di coronamento da quota +1.00 m s.l.m. a quota +2.50 m s.l.m.	3,39	202,39		1,500	1´029,15		
	SOMMANO m³					1´663,44	174,68	290´569,70

Figure 65: quantity of cencrete used

Multiplying the tons of cement used by 1.6% of CO_2, it is possible to enter a quantity of about 70 tons of CO_2 into the mortar. Clearly, the efficiency, as shown in the previous chapters, varies with the type of cement.

Having previously calculated that the amount of CO_2 emitted is 140 tons, this gives the possibility of recycling around 50% of carbon dioxide.

Therefore this method, easily usable on site, allows already during the work phase to reuse a considerable part of the CO_2 produced. The remaining amount of CO_2 can be compensated by buying carbon dioxide stocks or simply planting trees.

CO_2 to be recycled [ton]	CO_2 already uses in the construction phase [ton]	CO_2 remaining [ton]
141	70	71

7 Conclusion

"Our biggest challenge in this new century is to adopt an idea that seems abstract - sustainable development."

Kofi Annan

The great dependence on fossil fuels and the consequent emissions of greenhouse gases have pushed the governs to try to find new policies aimed at achieving economic, financial and institutional goals, thus giving birth to the concept of sustainability: satisfying current needs without affecting the possibility of satisfying the needs of future generations. The construction industry plays a leading role in this context and cannot stand back in this challenge.

The research carried out with this thesis has shown that the integration on an industrial scale of an injection of carbon dioxide into the ready-mix concrete does not affect the mechanical performance of the concrete and makes the concrete more sustainable. The idea was to find a simple method that can be used on site by any operator to recycle the CO_2 produced. The efficiency of the method is strongly dependent on the type of cement used, but may be a viable option for increasing the sustainability of the construction sector. Cement producers and construction companies would therefore be able to use their waste products in an advantageous way so as to consistently use the resources following the principles of the circular economy.

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9 Sitography

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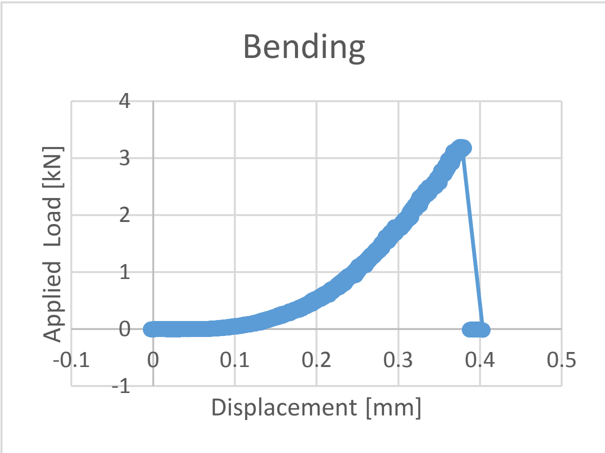
10. Annex

10.1 Sample 29_01 CEM I 42,5

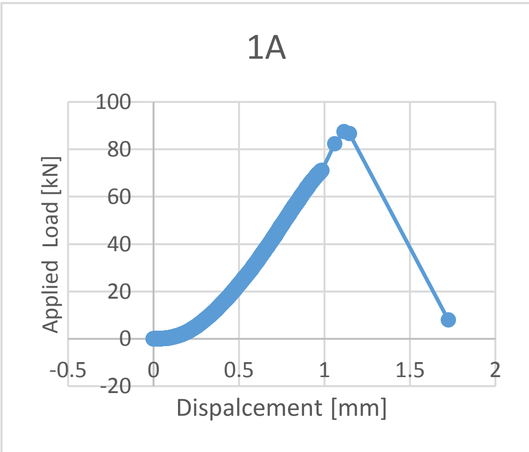
29_01_00_1 (0% of CO2)

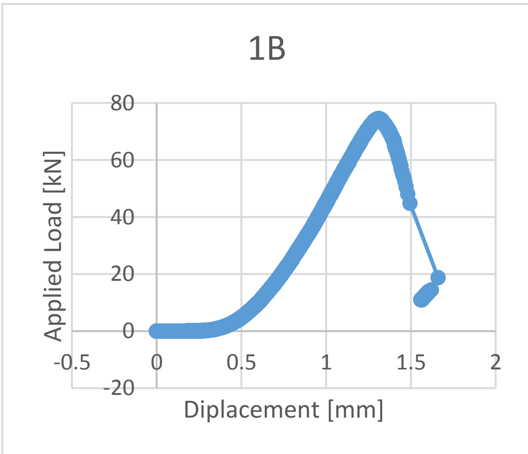
Bending test



Size speciment [mm]			Weight [g]
160	40.28	41.42	594.9

Compression test

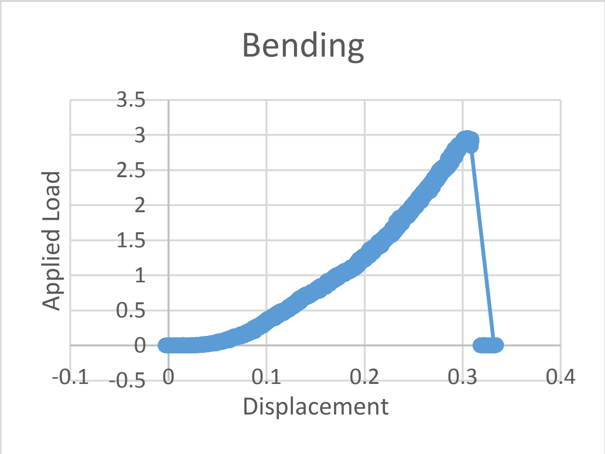




P_{max} [kN]	$\sigma_{flex}\ [MPa]$	F_1 [kN]	F_2 [kN]	$\sigma_1\ [MPa]$	$\sigma_2\ [MPa]$	% $CaCO_3$	pH
3.20	7.51	87.42	74.53	54.64	46.58	5.9	12.27

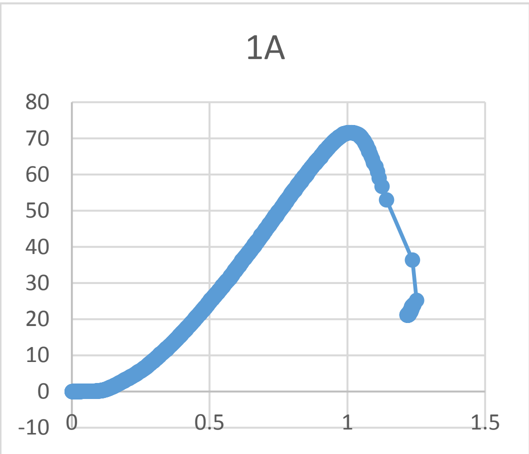
29_01_00_2 (0% of CO2)

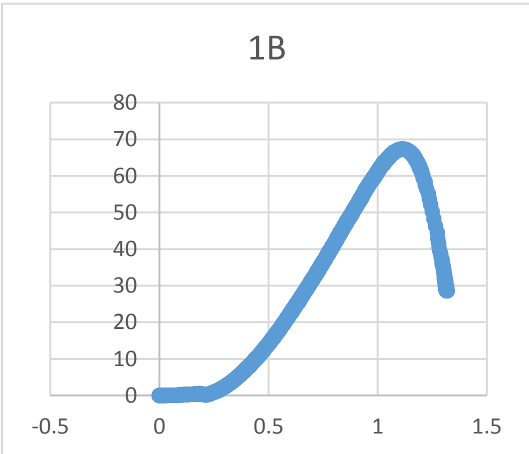
Bending test



Size speciment [mm]			Weight [g]
160	41.03	40.92	606.2

Compression test

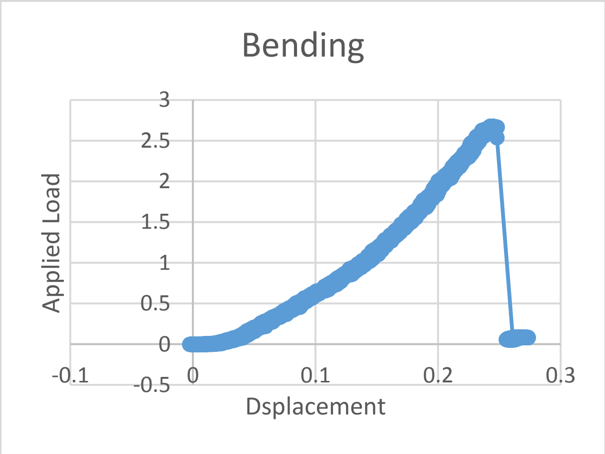




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.96	6.94	71.63	67.38	44.77	42.11	4.7	12.28

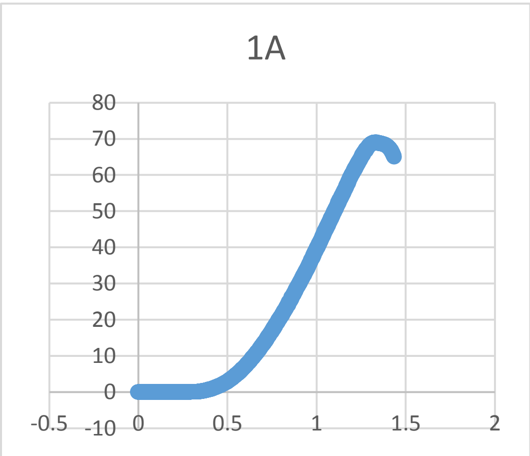
29_01_00_3 (0% of CO2)

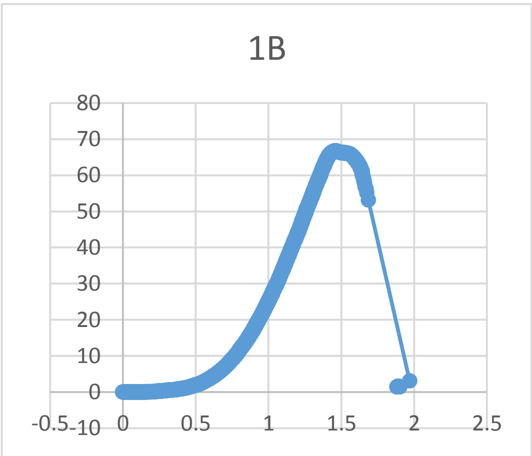
Bending test



Size speciment [mm]			Weight [g]
160	41.25	40.43	583.6

Compression test



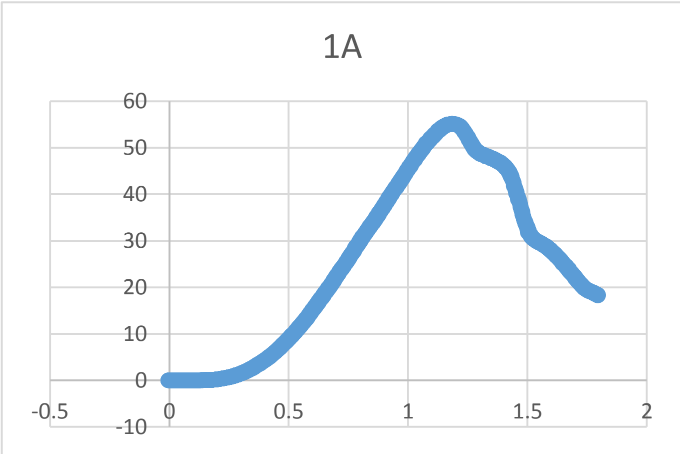


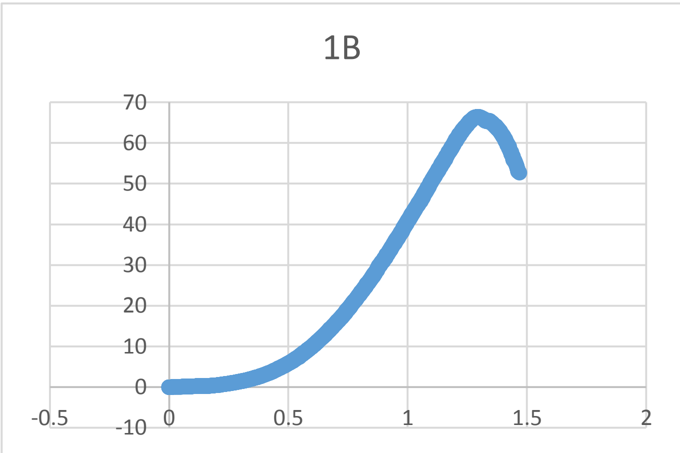
P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.68	6.27	69.04	66.73	43.15	41.71	3.5	12.25

29_01_04_1 (0.4% of CO2)

Size speciment [mm]			Weight [g]
160	40.02	40.74	588.2

Compression test

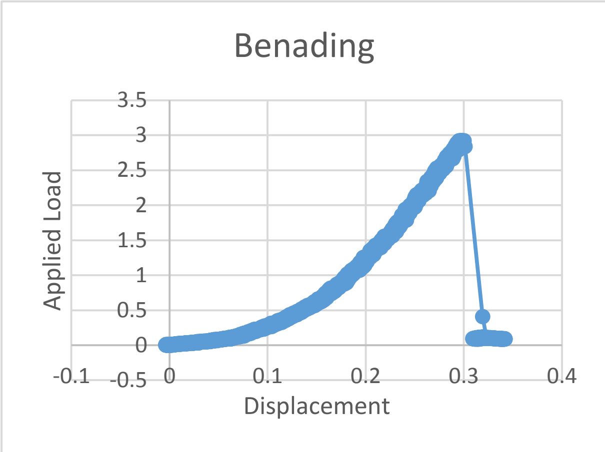




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
-	-	55.16	66.47	34.48	41.55	5.4	12.27

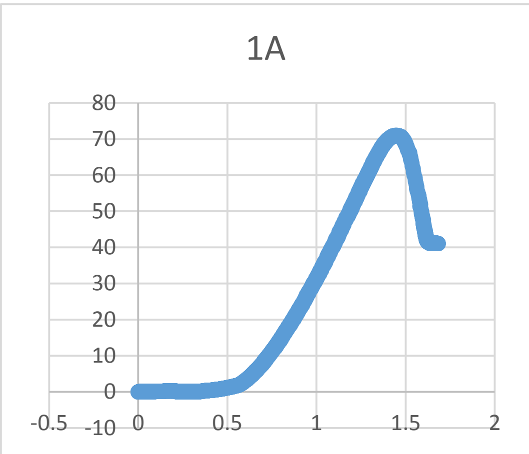
29_01_04_2 (0.4% of CO2)

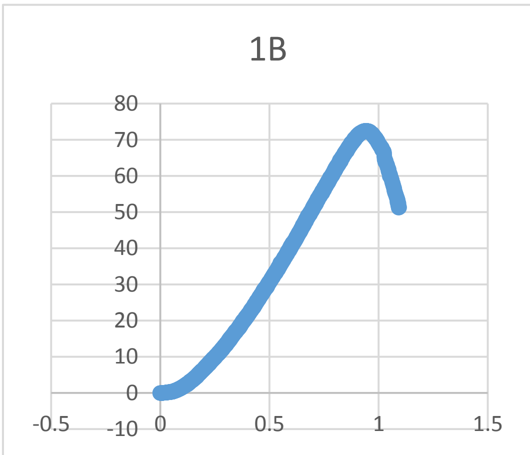
Bending test



Size speciment [mm]			Weight [g]
160	40.35	41.87	601.6

Compression test

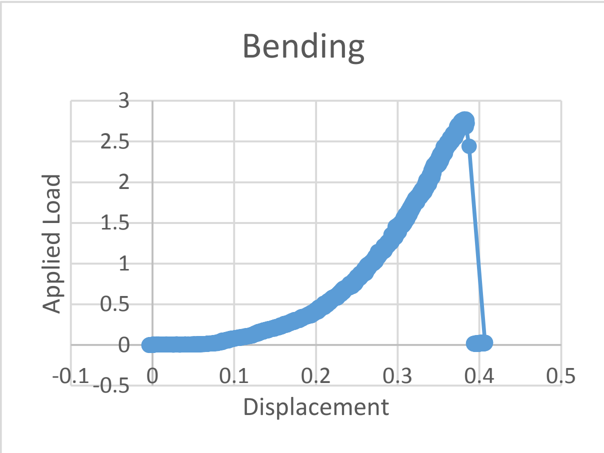




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.92	6.84	71.01	72.53	44.38	45.33	5.5	12.24

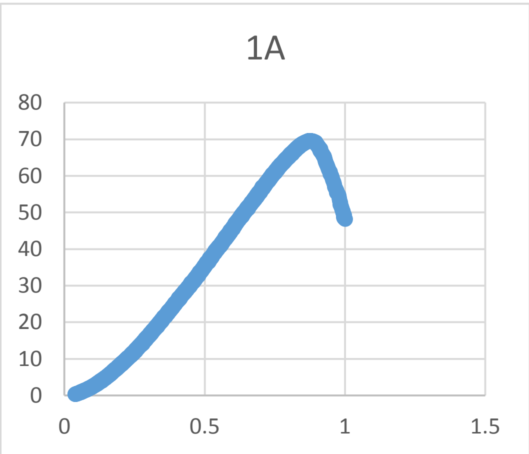
29_01_04_3 (0.4% of CO2)

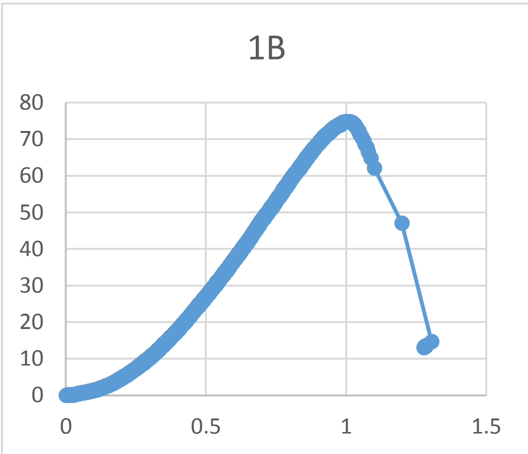
Bending test



Size speciment [mm]			Weight [g]
160	40.04	40.68	587.2

Compression test

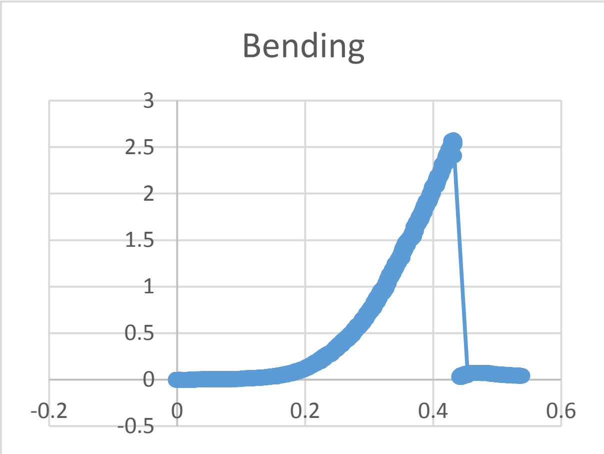




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.78	6.51	69.62	74.76	43.51	46.72	6	12.23

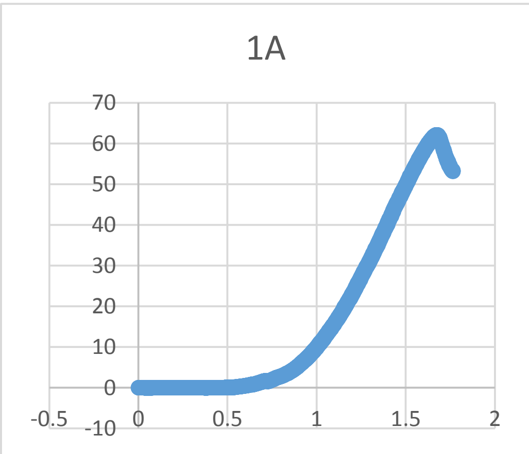
29_01_08_1 (0.8% of CO2)

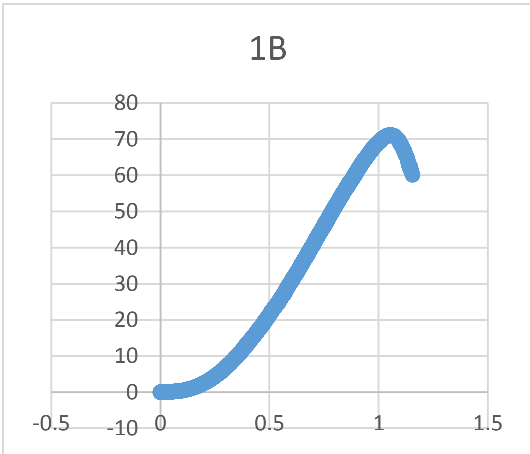
Bending test



Size speciment [mm]			Weight [g]
160	39.96	40.41	584.7

Compression test

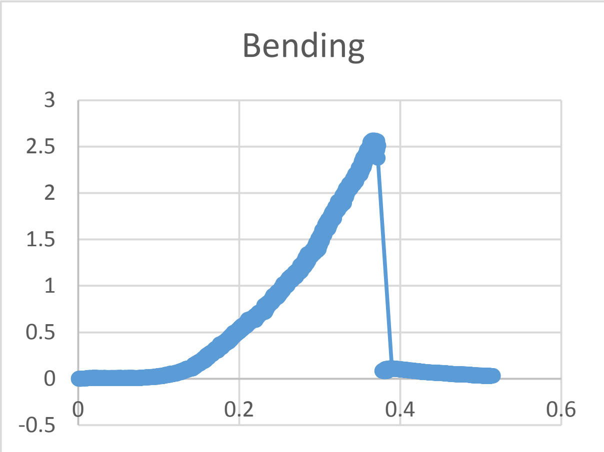




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.58	6.04	62.15	71.14	38.84	44.46	6.1	12.26

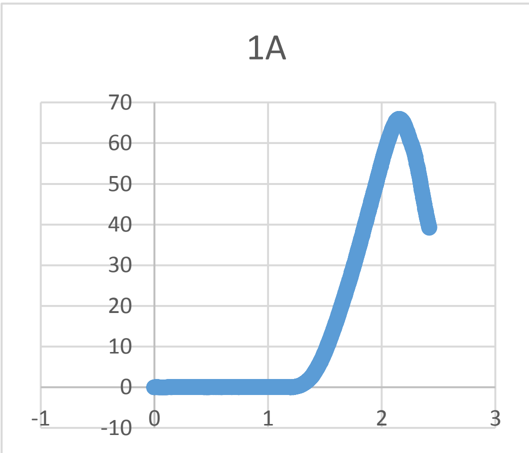
29_01_08_2 (0.8% of CO2)

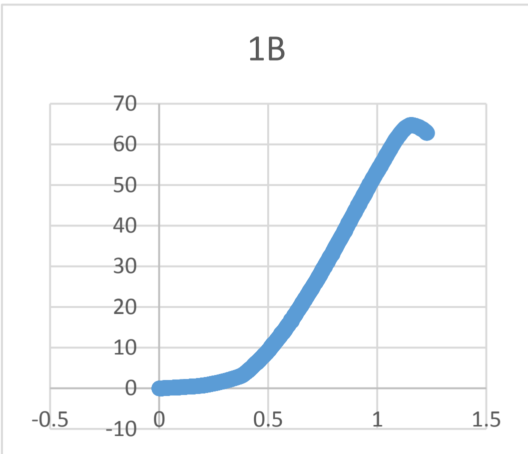
Bending test



Size speciment [mm]			Weight [g]
160	40.06	40.85	582.2

Compression test

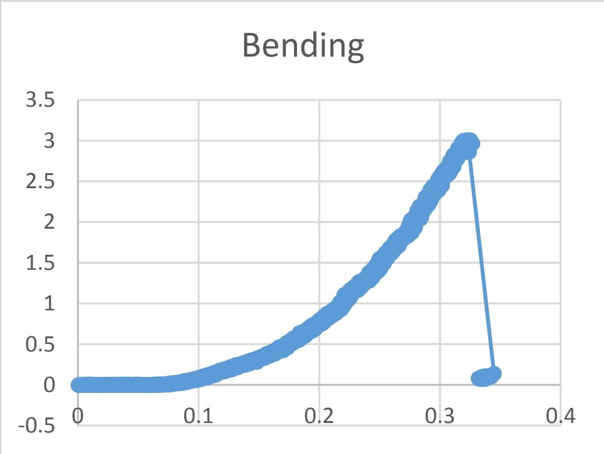




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.57	6.02	66.01	64.77	41.26	40.48	4.6	12.26

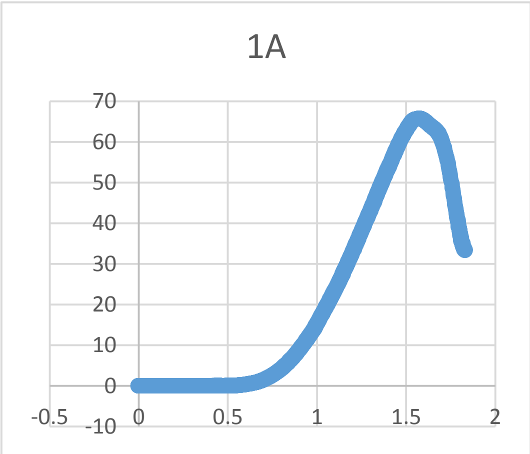
29_01_08_3 (0.8% of CO2)

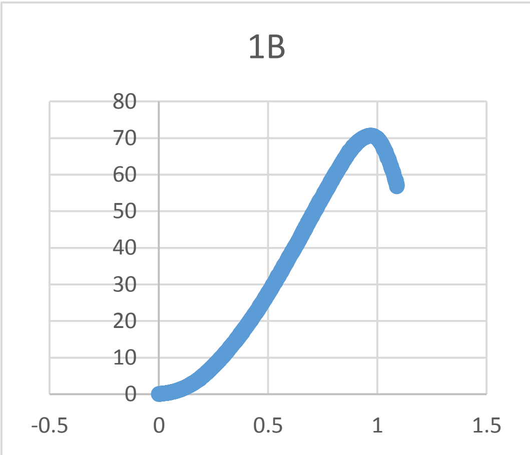
Bending test



Size speciment [mm]			Weight [g]
160	40.26	41.36	594.4

Compression test

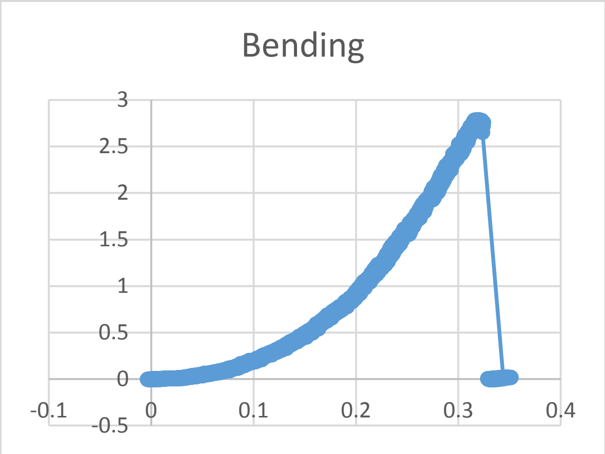




P_{max} [kN]	$\sigma_{flex}\ [MPa]$	F_1 [kN]	F_2 [kN]	$\sigma_1\ [MPa]$	$\sigma_2\ [MPa]$	% $CaCO_3$	pH
3.01	7.05	65.75	70.70	41.10	44.19	5.3	12.26

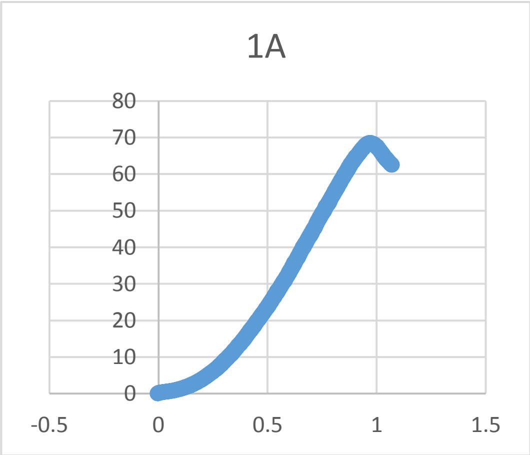
29_01_12_1 (1.2% of CO2)

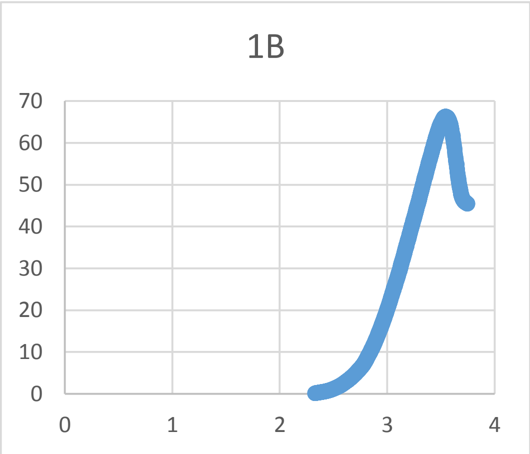
Bending test



Size speciment [mm]			Weight [g]
160	39.98	41.55	591.4

Compression test

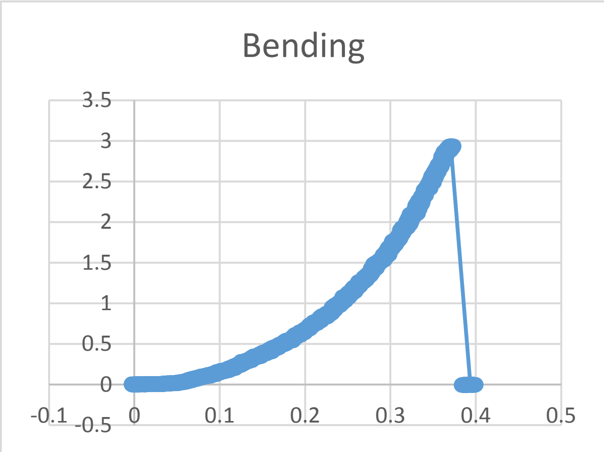




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.79	6.53	68.51	66.35	42.82	41.47	7	12.24

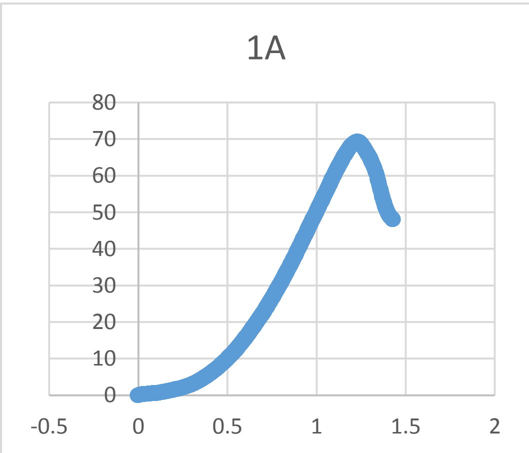
29_01_12_2 (1.2% of CO2)

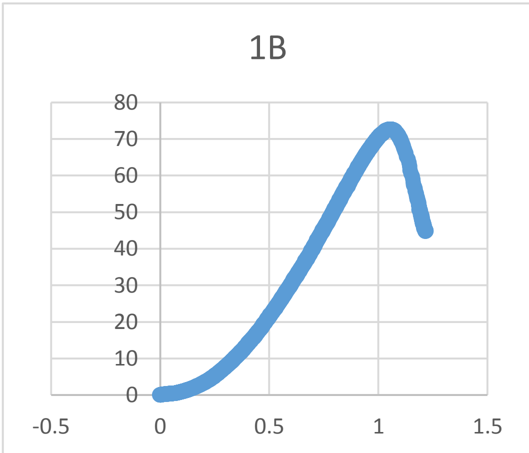
Bending test



Size speciment [mm]			Weight [g]
160	40.04	41.88	597.1

Compression test

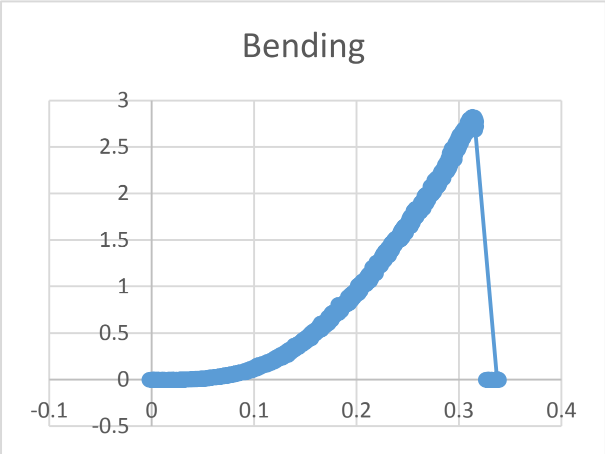




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.93	6.88	69.36	72.62	43.35	45.39	6.2	12.23

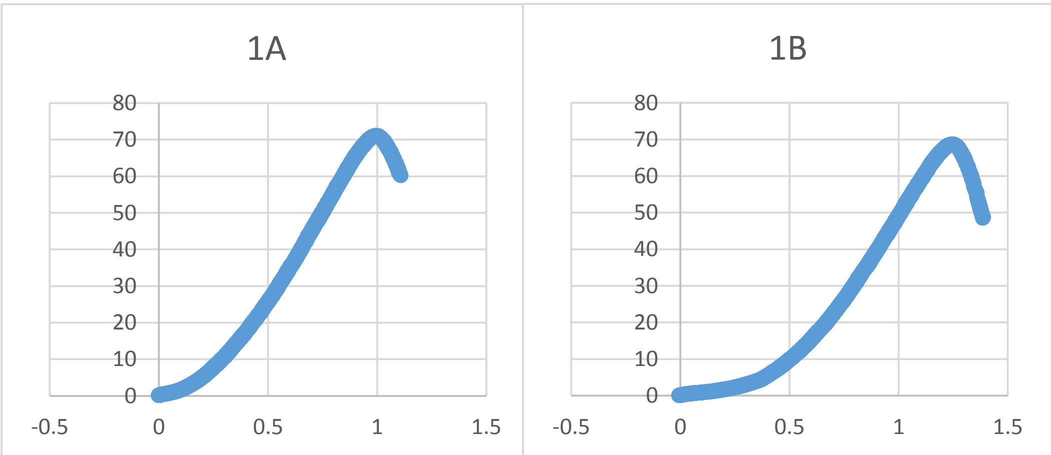
29_01_12_3 (1.2% of CO2)

Bending test



Size speciment [mm]			Weight [g]
160	40.17	41.01	590.1

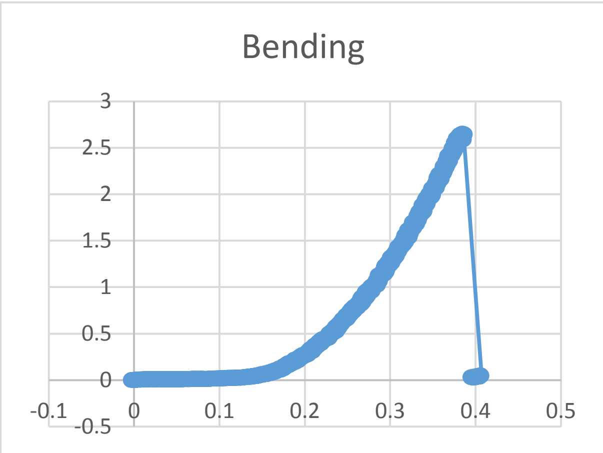
Compression test



P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.82	6.61	71.12	68.69	44.45	42.93	7	12.26

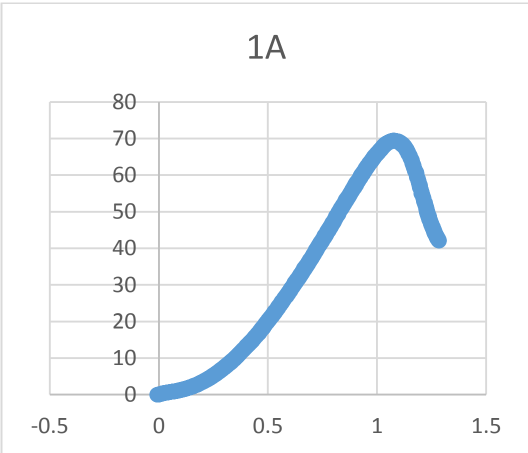
29_01_16_1 (1.6% of CO2)

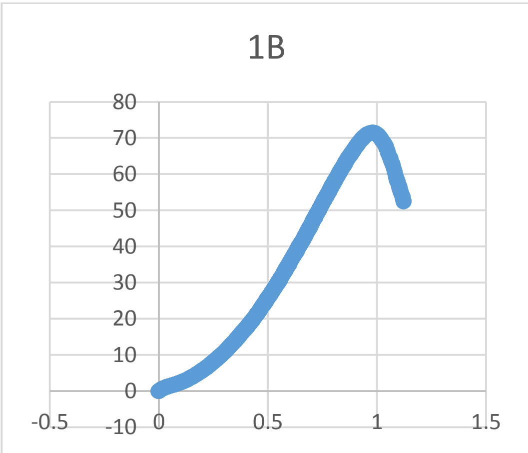
Bending test



Size speciment [mm]			Weight [g]
160	40.32	41.18	594.6

Compression test

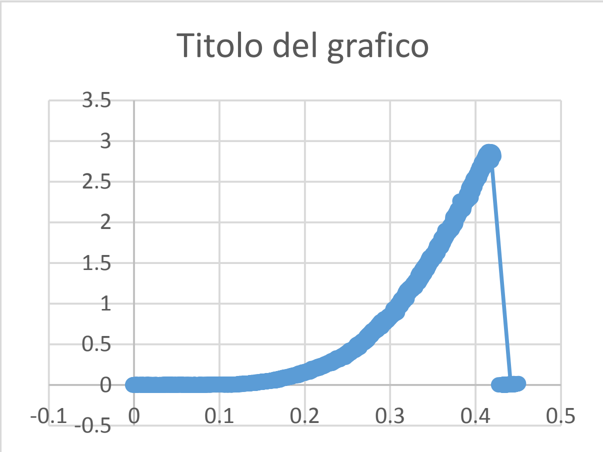




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.65	6.22	69.45	71.41	43.41	44.63	7.4	12.25

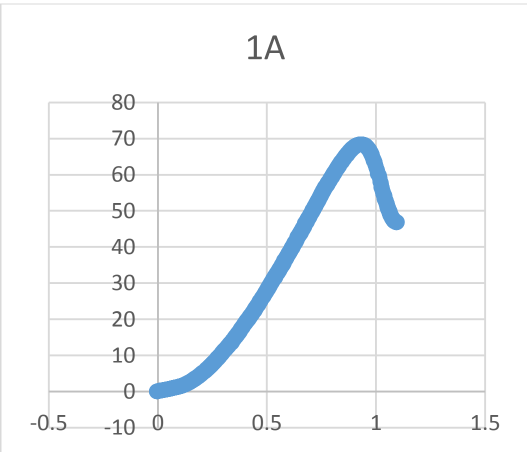
29_01_16_2 (1.6% of CO2)

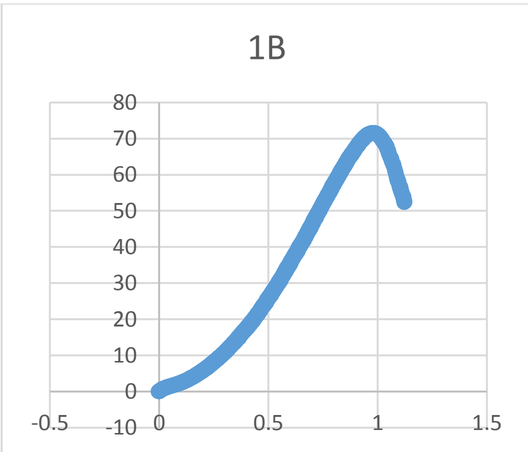
Bending test



Size speciment [mm]			Weight [g]
160	39.96	40.57	587.3

Compression test

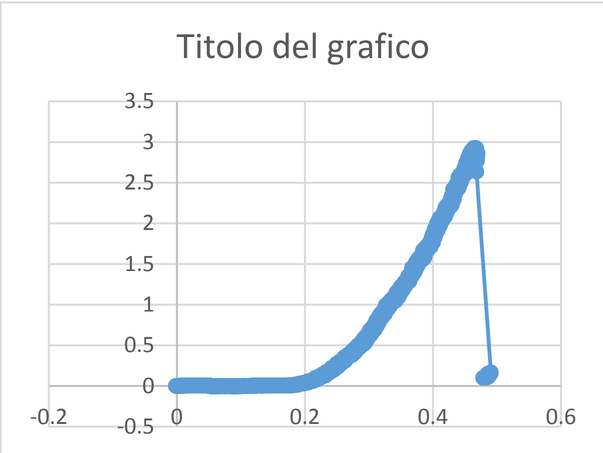




P_{max} [kN]	$\sigma_{flex}\ [MPa]$	F_1 [kN]	F_2 [kN]	$\sigma_1\ [MPa]$	$\sigma_2\ [MPa]$	% $CaCO_3$	pH
2.87	6.72	68.38	71.56	42.74	44.72	8.1	12.24

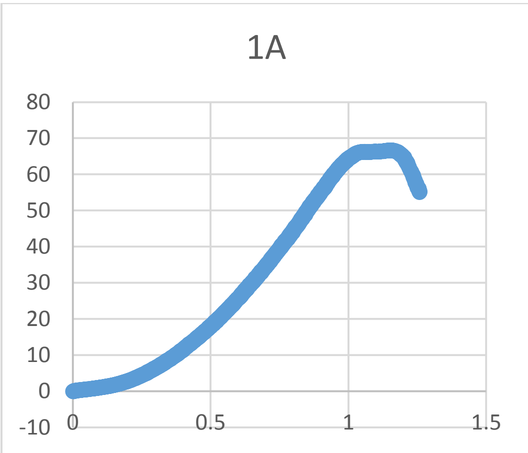
29_01_16_3 (1.6% of CO2)

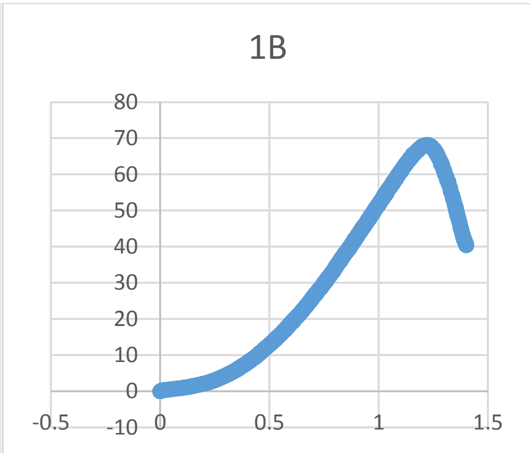
Bending test



Size speciment [mm]			Weight [g]
160	40.12	40.83	596.3

Compression test

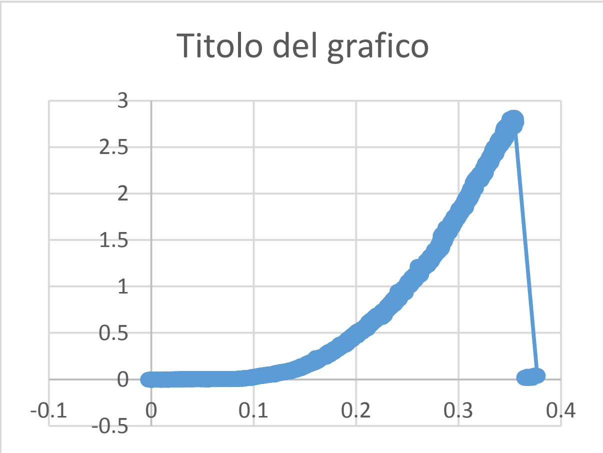




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.93	6.86	66.68	68.21	41.68	42.63	6.8	12.24

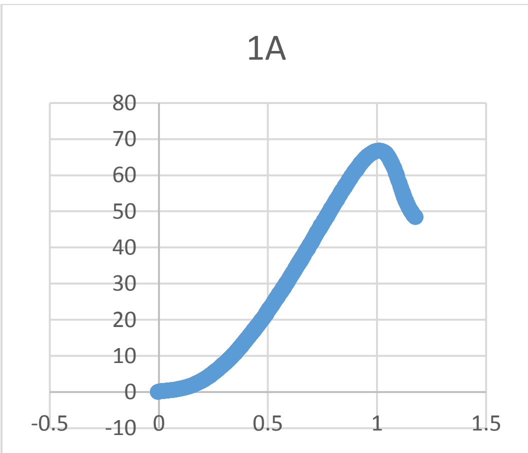
29_01_3.2_1 (3.2% of CO2)

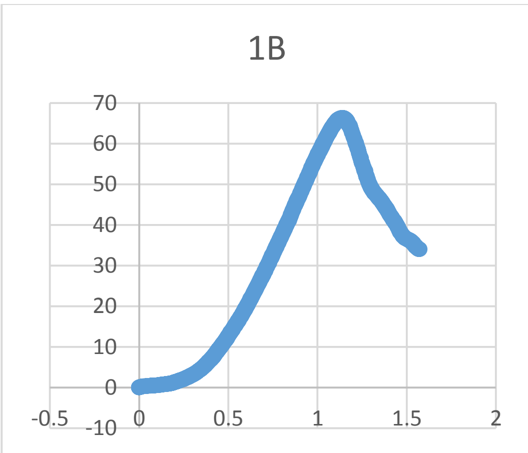
Bending test



Size speciment [mm]			Weight [g]
160	40.28	41.52	588.2

Compression test

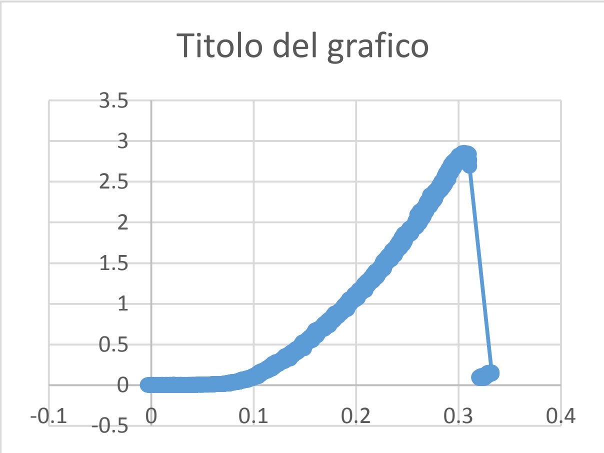




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.82	6.61	66.80	66.30	41.75	41.44	6.6	12.19

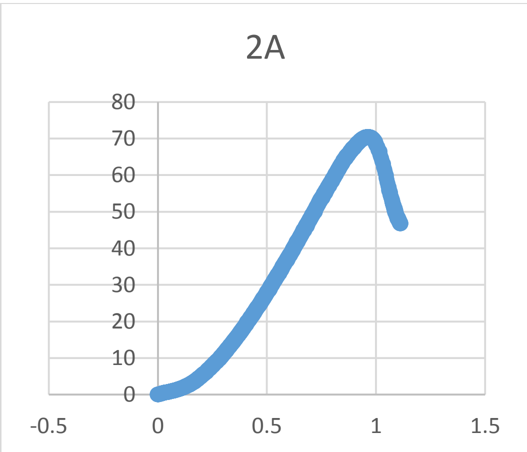
29_01_3.2_2 (3.2% of CO2)

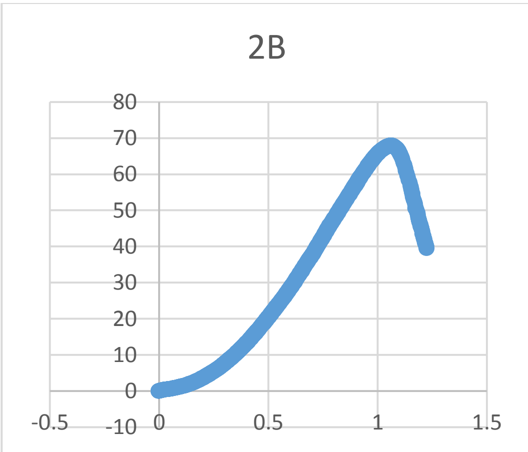
Bending test



Size speciment [mm]			Weight [g]
160	40.05	41.57	589.9

Compression test

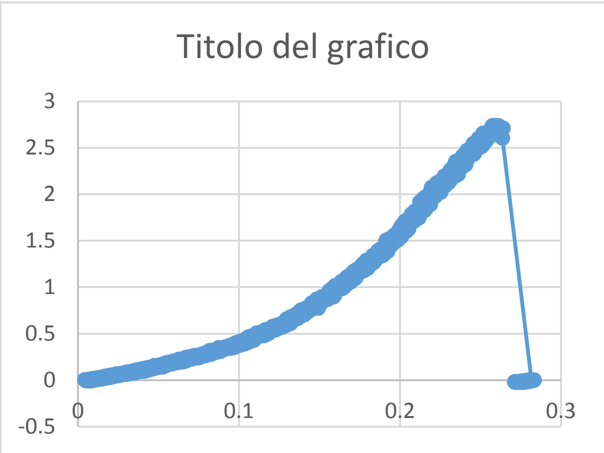




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.86	6.70	70.44	67.95	44.02	42.47	6.7	12.21

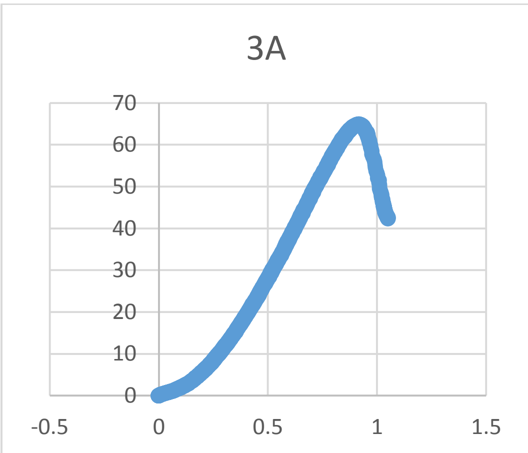
29_01_3.2_3 (3.2% of CO2)

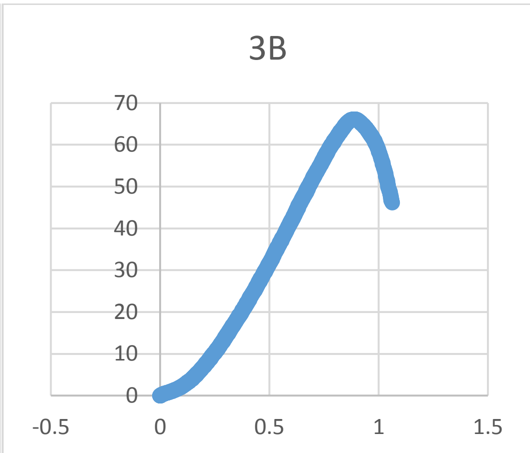
Bending test



Size speciment [mm]			Weight [g]
160	40.10	41.50	588.4

Compression test



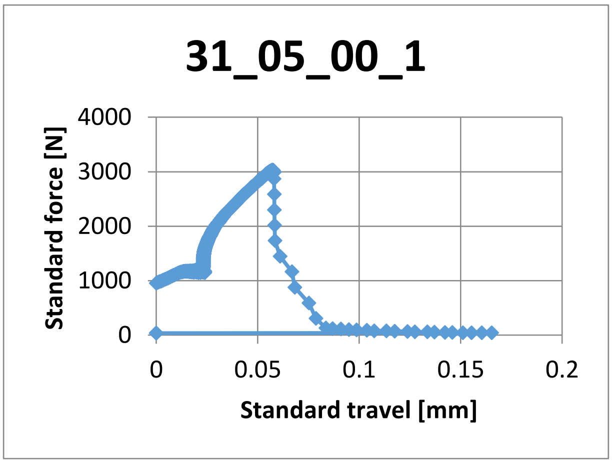


P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.74	6.42	64.96	66.16	40.60	41.35	7.3	12.25

10.2 Sample 31_05 CEM I 52,5

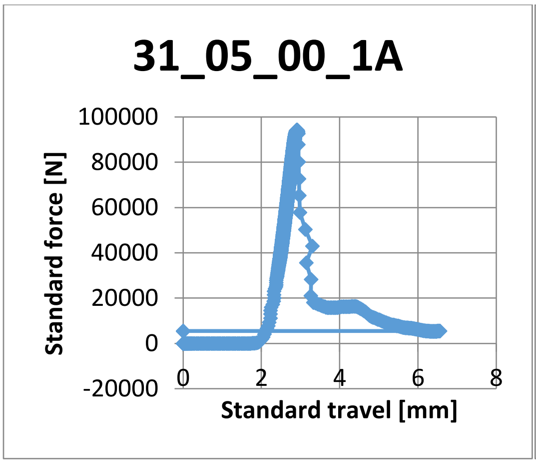
31_05_00_1 (0% of CO2)

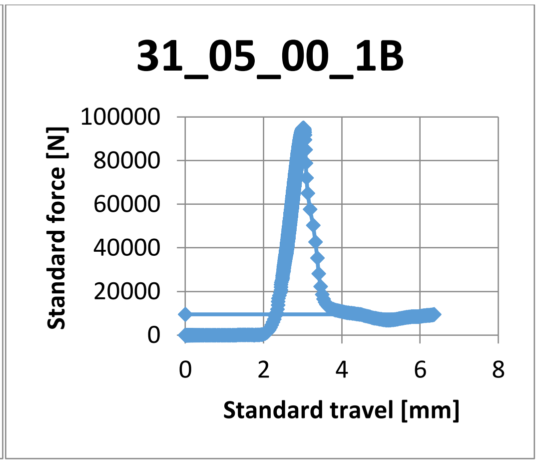
Bending test



Size speciment [mm]			Weight [g]
160	40.28	41.69	592

Compression test

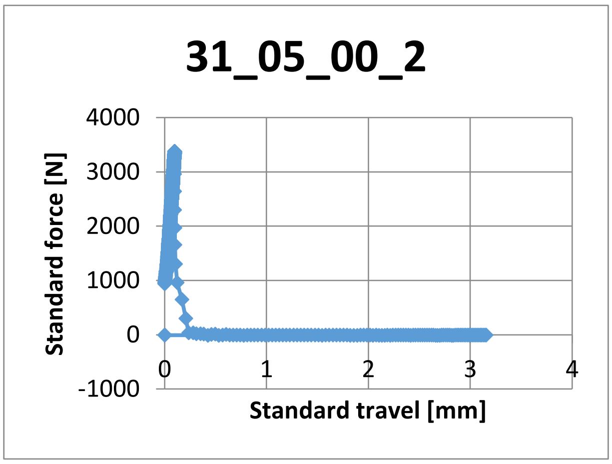




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
3.03	7.10	94.2452	94.9173	58.90	59.32	6.1	-

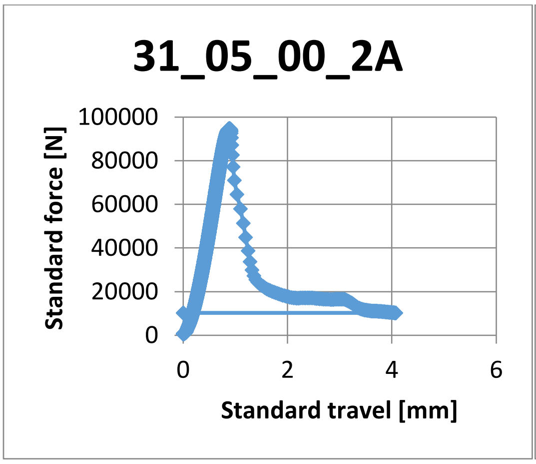
31_05_00_2 (0% of CO2)

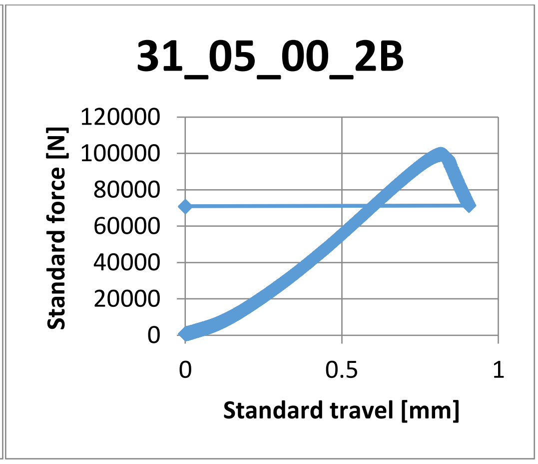
Bending test



Size speciment [mm]			Weight [g]
160	41.03	40.85	588

Compression test

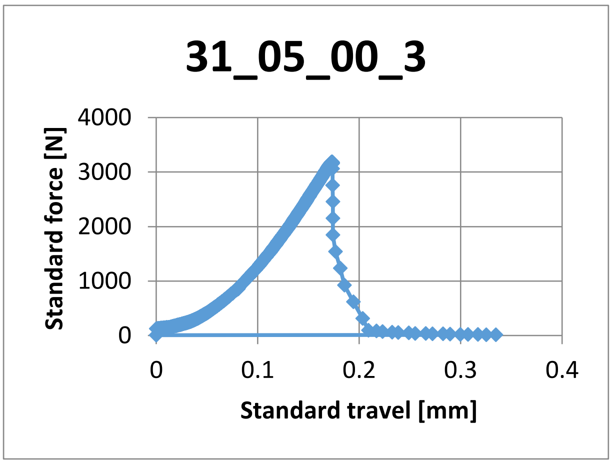




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
3.38	7.92	94.69	99.49	59.18	62.19	5.31	-

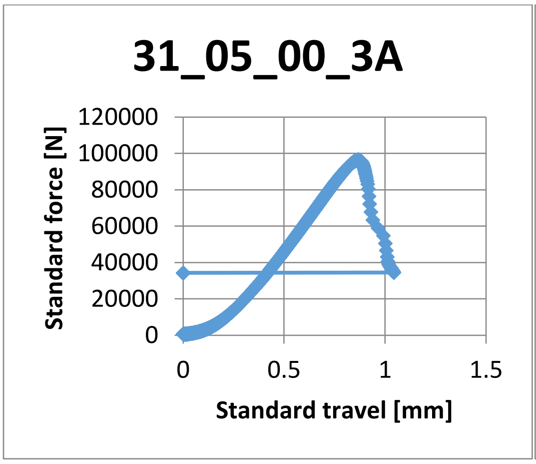
31_05_00_3 (0% of CO2)

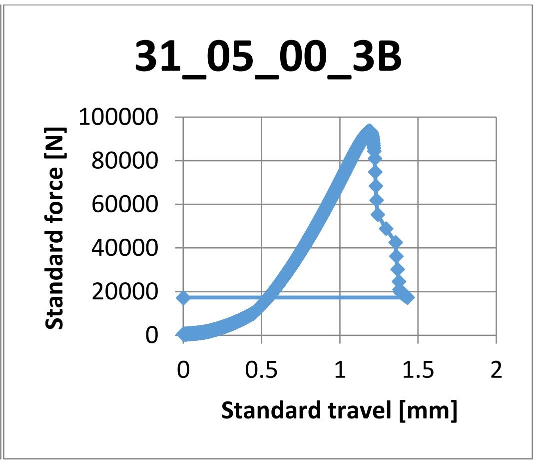
Bending test



Size speciment [mm]			Weight [g]
160	41.25	40.96	586

Compression test

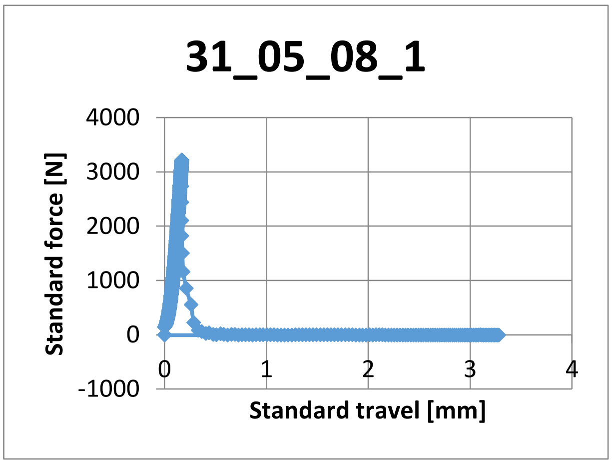




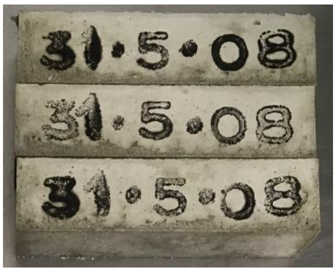
P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
3.19	7.47	96.49	93.68	60.31	58.55	5.6	-

31_05_08_1 (0.8% of CO2)

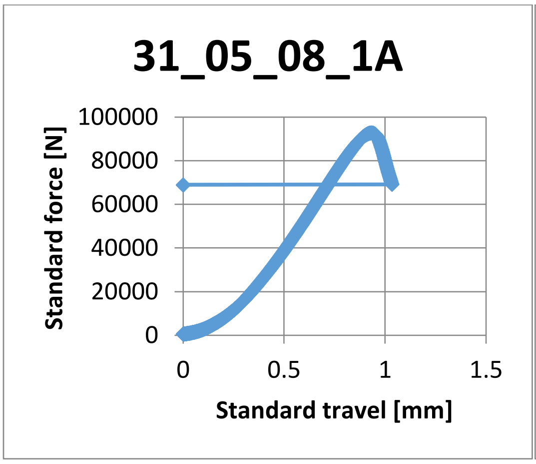
Bending test

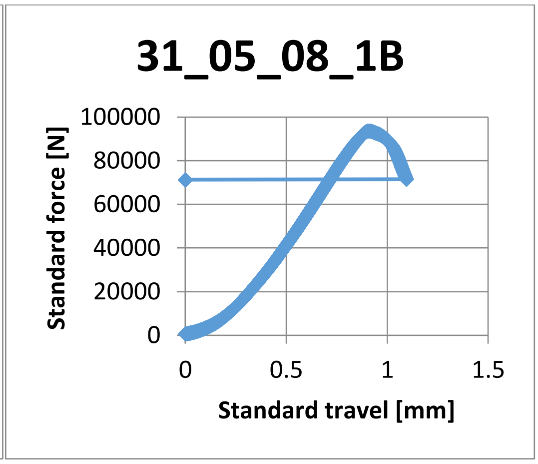


Size speciment [mm]			Weight [g]
160	40.02	40.77	584



Compression test

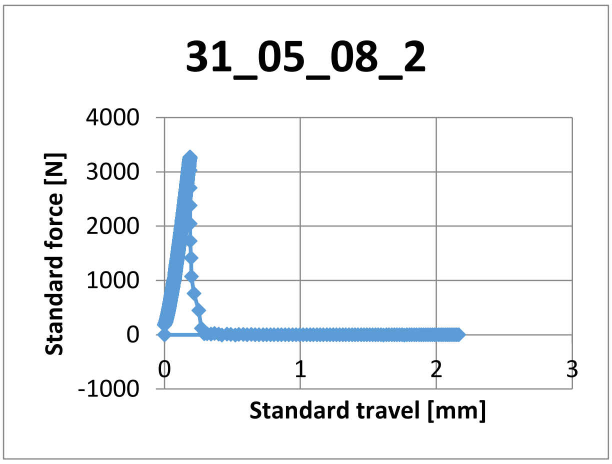




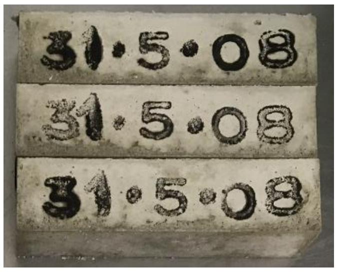
P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
3.22	7.54	92.75	93.71	57.97	58.57	5.59	-

31_05_08_2 (0.8% of CO2)

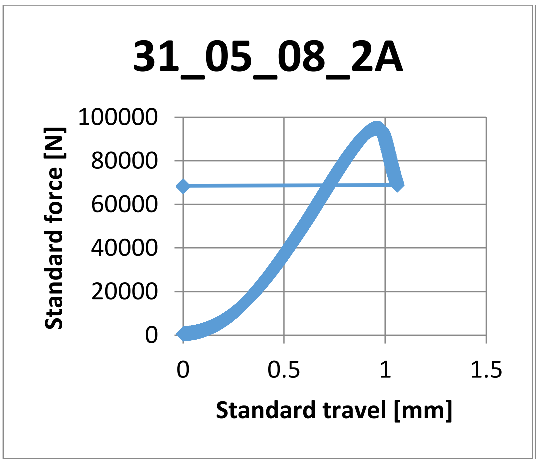
Bending test

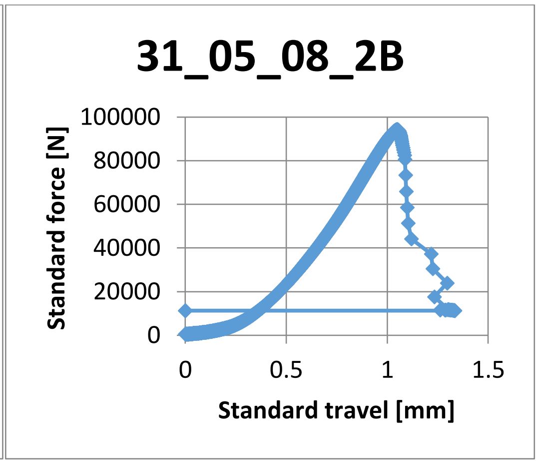


Size speciment [mm]			Weight [g]
160	40.35	40.78	585



Compression test

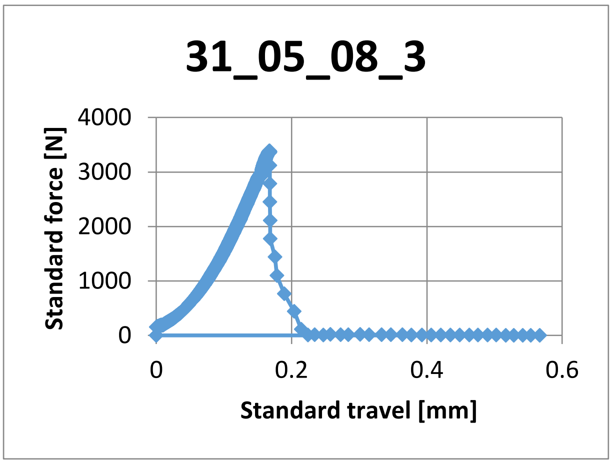




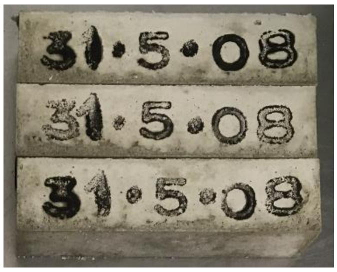
P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
3.27	7.66	95.03	94.24	59.40	58.90	5.54	-

31_05_08_3 (0.8% of CO2)

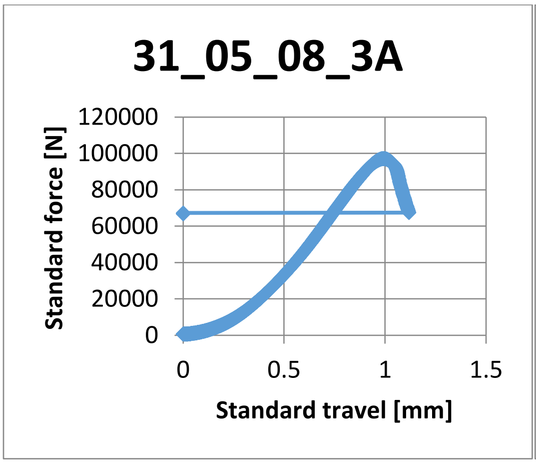
Bending test

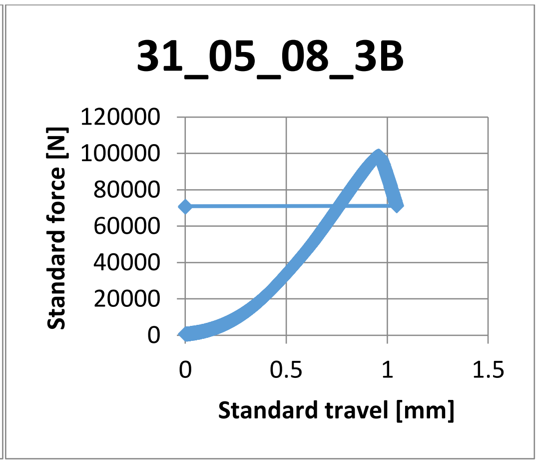


Size speciment [mm]			Weight [g]
160	40.04	41.34	591



Compression test

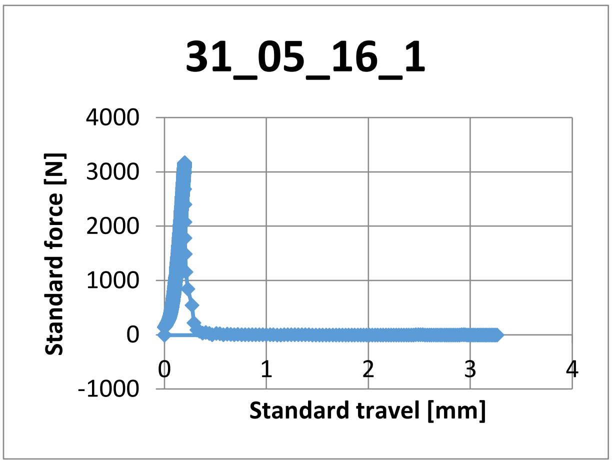




P_{max} [kN]	$\sigma_{flex}\ [MPa]$	F_1 [kN]	F_2 [kN]	$\sigma_1\ [MPa]$	$\sigma_2\ [MPa]$	% $CaCO_3$	pH
3.39	7.94	97.14	98.45	60.72	61.53	6.23	-

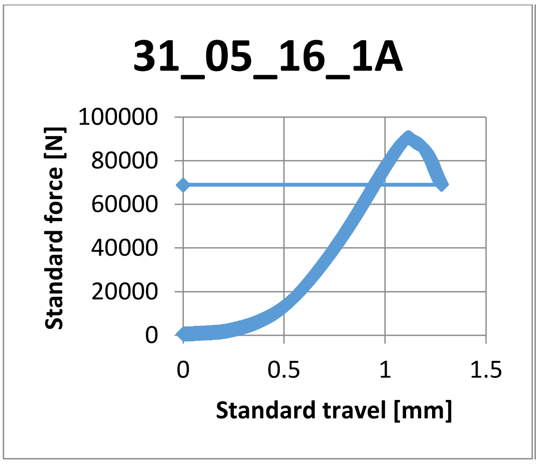
31_05_16_1 (1.6% of CO2)

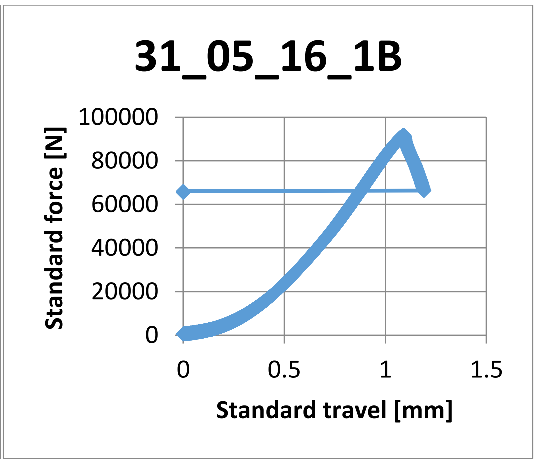
Bending test



Size speciment [mm]			Weight [g]
160	39.96	41.69	595

Compression test

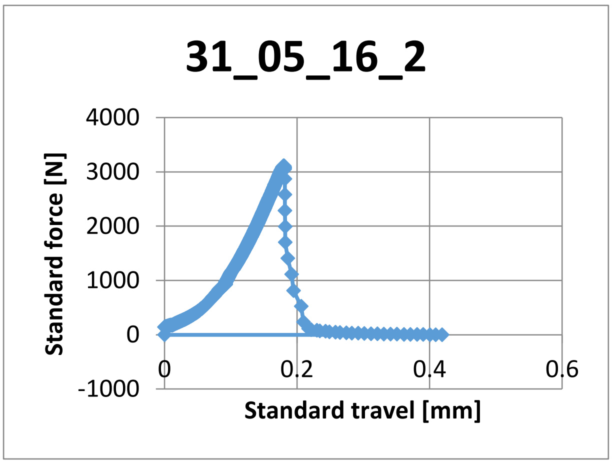




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
3.17	7.42	90.51	91.67	56.57	57.30	7.2	-

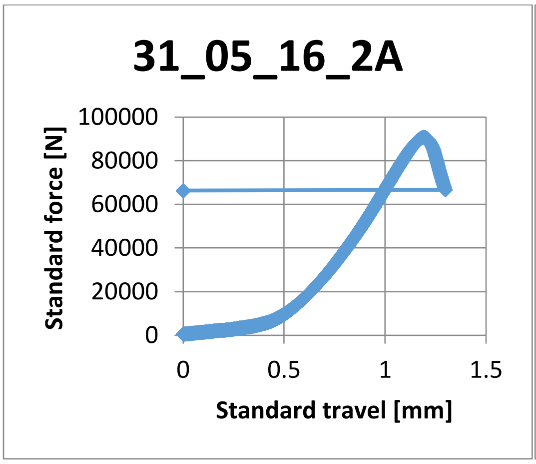
31_05_16_2 (1.6% of CO2)

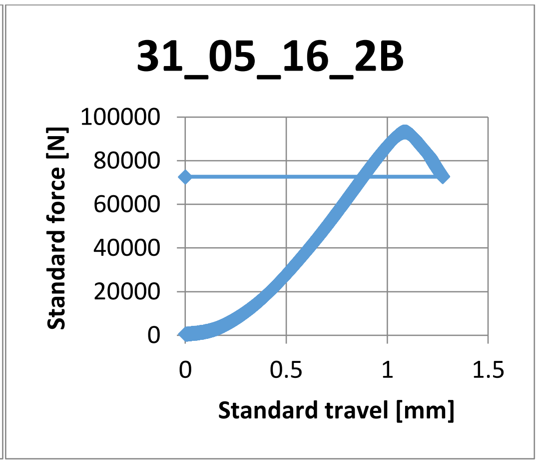
Bending test



Size speciment [mm]			Weight [g]
160	40.06	41.49	594

Compression test

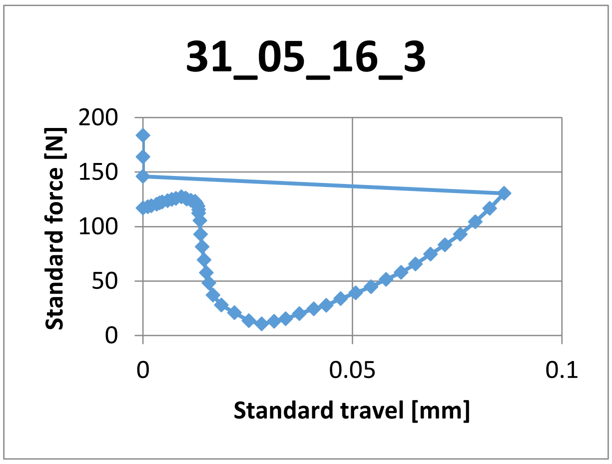




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
3.11	7.29	90.72	93.28	56.71	58.30	6.57	-

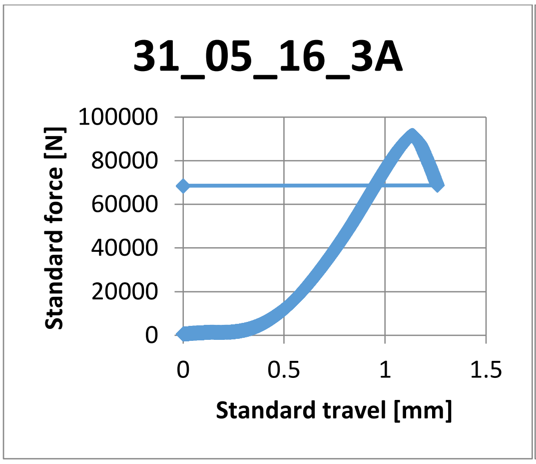
31_05_16_3 (1.6% of CO2)

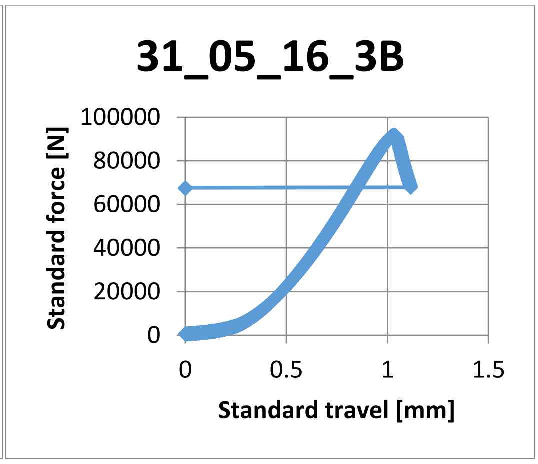
Bending test



Size speciment [mm]			Weight [g]
160	40.26	41.32	588

Compression test

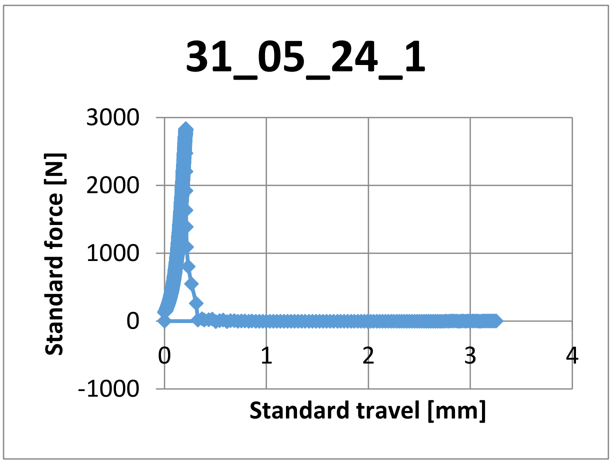




P_{max} [kN]	$\sigma_{flex}\ [MPa]$	F_1 [kN]	F_2 [kN]	$\sigma_1\ [MPa]$	$\sigma_2\ [MPa]$	% $CaCO_3$	pH
-	-	91.56	91.76	57.23	57.35	5.78	-

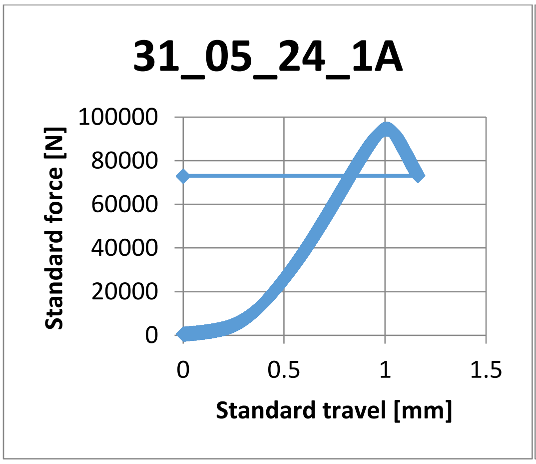
31_05_24_1 (2.4% of CO2)

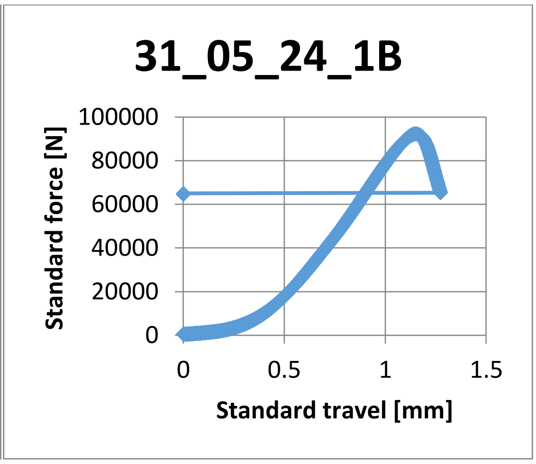
Bending test



Size speciment [mm]			Weight [g]
160	39.98	40.81	585

Compression test

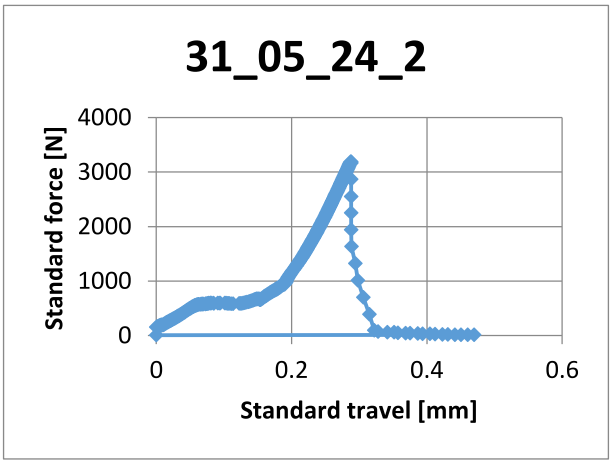




P_{max} [kN]	$\sigma_{flex}\ [MPa]$	F_1 [kN]	F_2 [kN]	$\sigma_1\ [MPa]$	$\sigma_2\ [MPa]$	% $CaCO_3$	pH
2.83	6.64	94.58	92.31	59.12	57.70	5.85	-

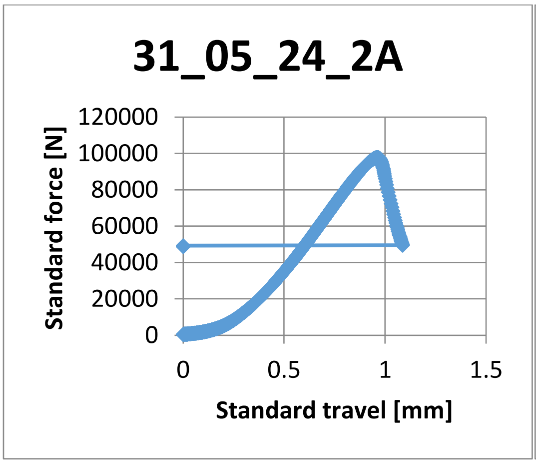
31_05_24_2 (2.4% of CO2)

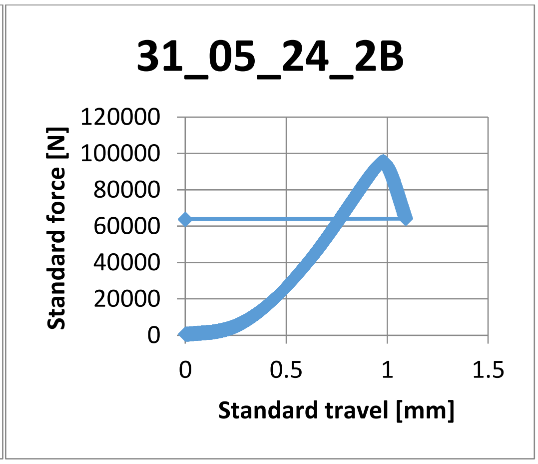
Bending test



Size speciment [mm]			Weight [g]
160	40.04	41.35	600

Compression test

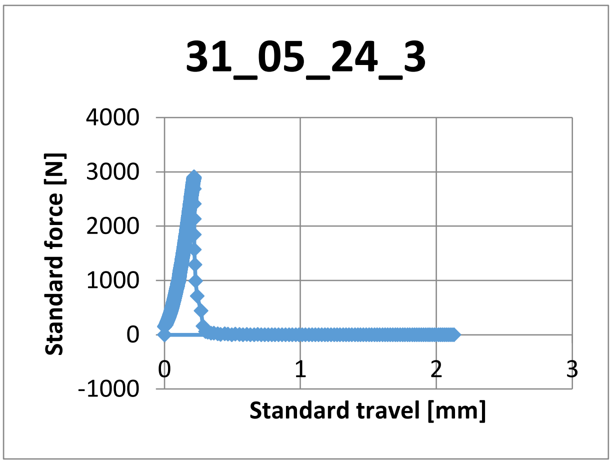




P_{max} [kN]	$\sigma_{flex}\ [MPa]$	F_1 [kN]	F_2 [kN]	$\sigma_1\ [MPa]$	$\sigma_2\ [MPa]$	% $CaCO_3$	pH
3.19	7.47	97.78	95.43	61.12	59.65	5.76	-

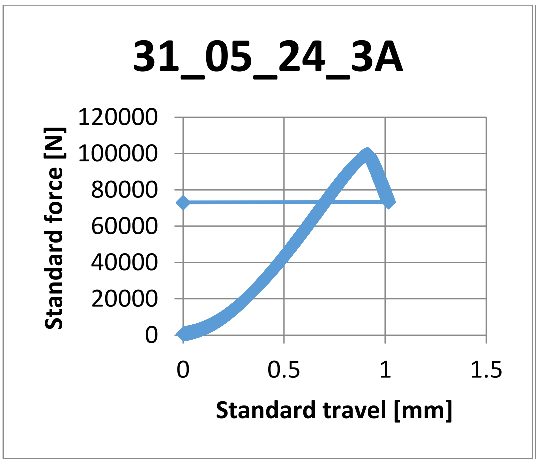
31_05_24_3 (2.4% of CO2)

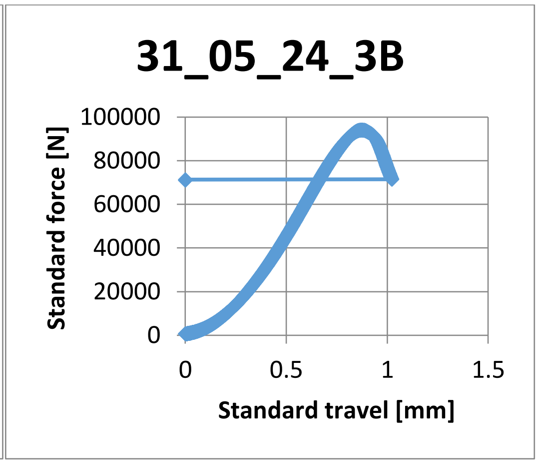
Bending test



Size speciment [mm]			Weight [g]
160	40.17	41.16	593

Compression test

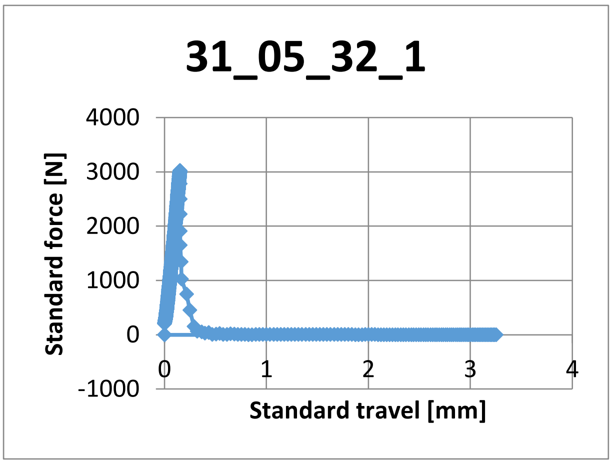




P_{max} [kN]	$\sigma_{flex}\ [MPa]$	F_1 [kN]	F_2 [kN]	$\sigma_1\ [MPa]$	$\sigma_2\ [MPa]$	% $CaCO_3$	pH
2.91	6.81	99.36	94.06	62.10	58.79	6.7	-

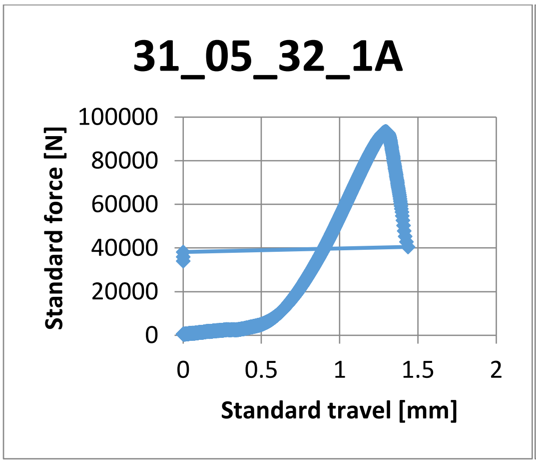
31_05_32_1 (3.2% of CO2)

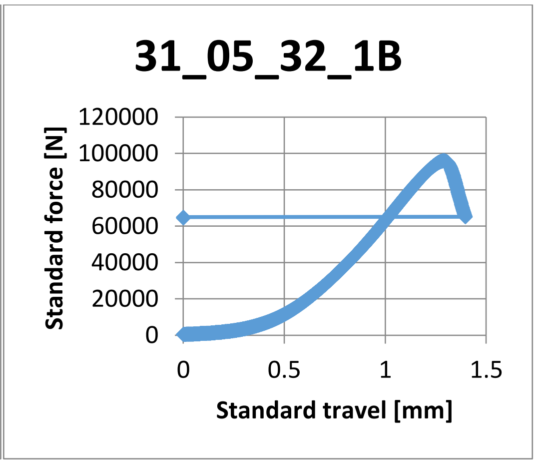
Bending test



Size speciment [mm]			Weight [g]
160	40.32	42.54	600

Compression test

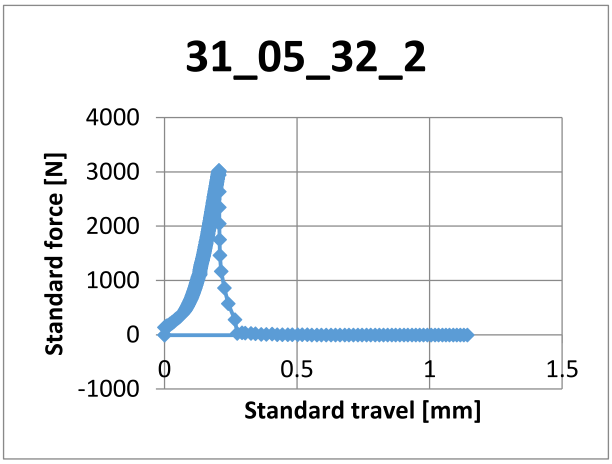




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
3.02	7.08	93.33	95.98	58.33	59.99	6.73	-

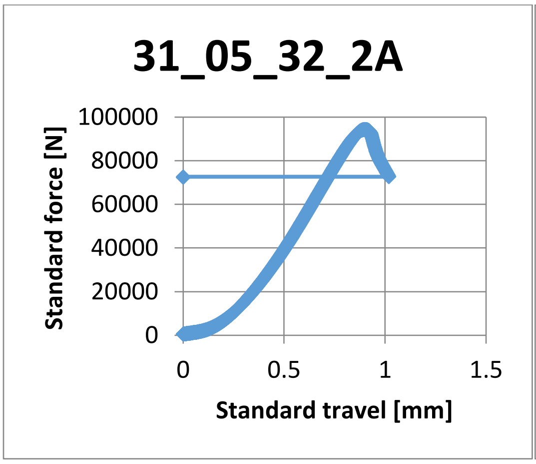
31_05_32_2 (3.2% of CO2)

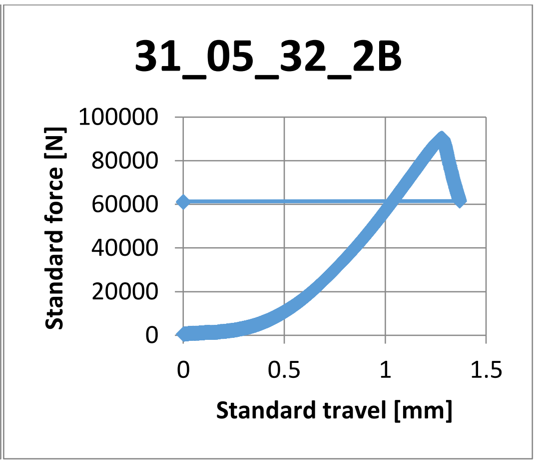
Bending test



Size speciment [mm]			Weight [g]
160	39.96	41.20	589

Compression test

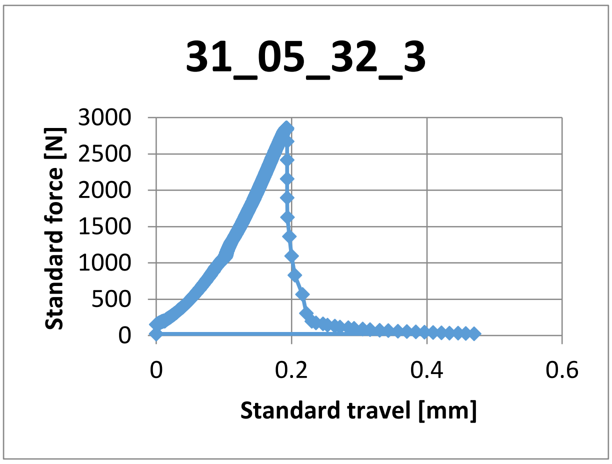




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
3.02	7.08	94.33	90.32	58.96	56.45	6	-

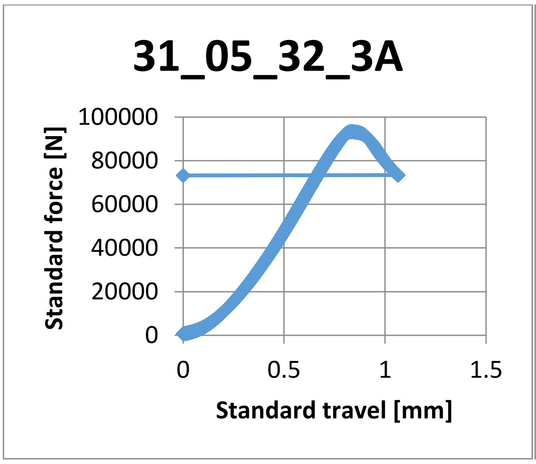
31_05_32_3 (3.2% of CO2)

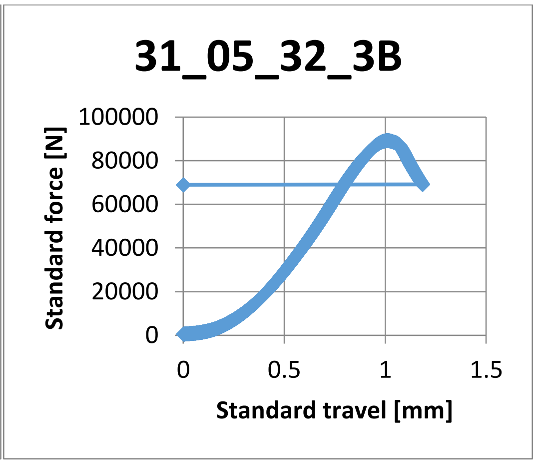
Bending test



Size speciment [mm]			Weight [g]
160	40.12	40.80	586

Compression test

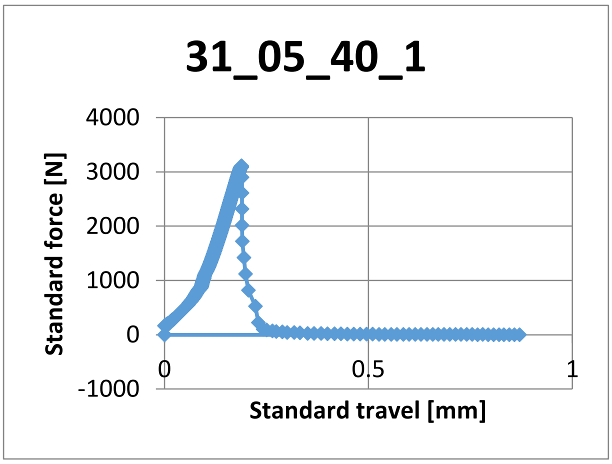




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.86	6.69	93.37	89.26	58.36	55.79	4.76	-

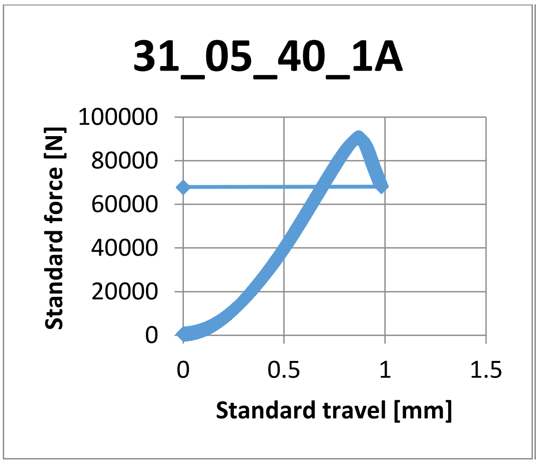
31_05_40_1 (4.0% of CO2)

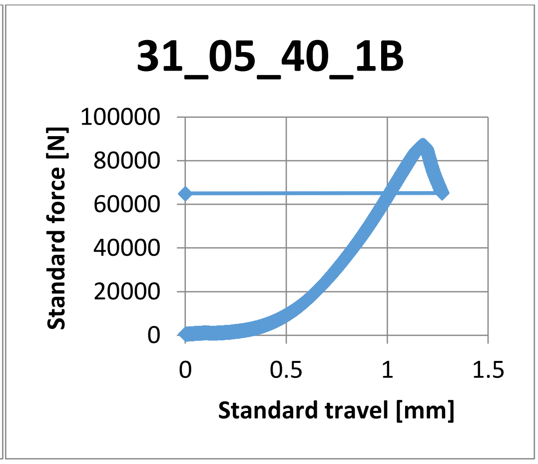
Bending test



Size speciment [mm]			Weight [g]
160	40.28	41.17	594

Compression test

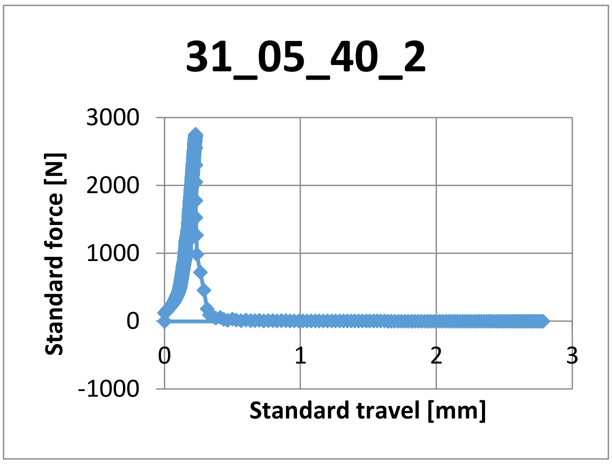




P_{max} [kN]	$\sigma_{flex}\ [MPa]$	F_1 [kN]	F_2 [kN]	$\sigma_1\ [MPa]$	$\sigma_2\ [MPa]$	% $CaCO_3$	pH
3.11	7.28	90.53	87.09	56.58	54.43	5.85	-

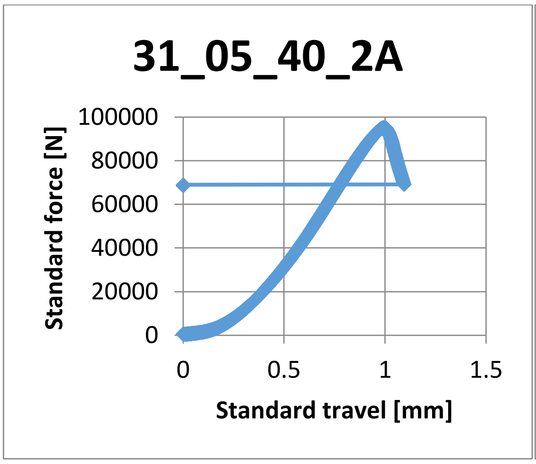
31_05_40_2 (4.0% of CO2)

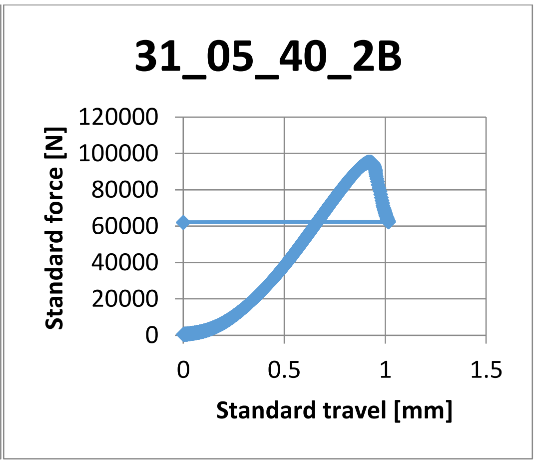
Bending test



Size speciment [mm]			Weight [g]
160	40.05	40.68	584

Compression test

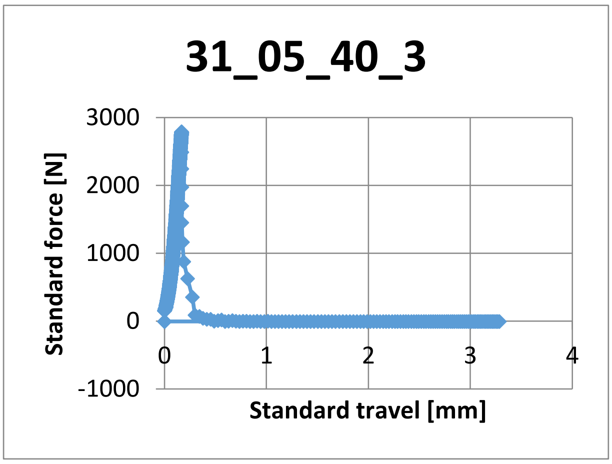




P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.75	6.45	95.22	95.33	59.51	59.59	6.53	-

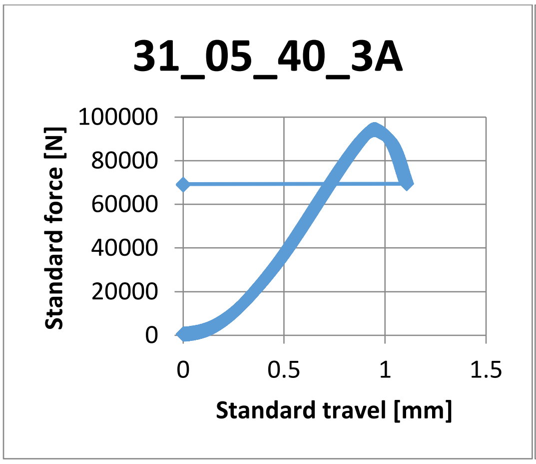
31_05_40_3 (4.0% of CO2)

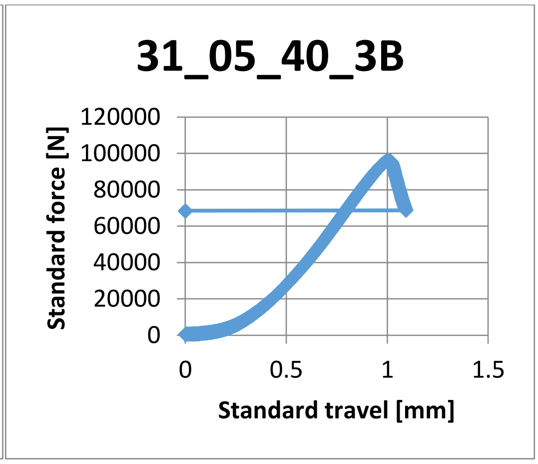
Bending test



Size speciment [mm]			Weight [g]
160	40.10	40.95	587

Compression test





P_{max} [kN]	σ_{flex} $[MPa]$	F_1 [kN]	F_2 [kN]	σ_1 $[MPa]$	σ_2 $[MPa]$	% $CaCO_3$	pH
2.79	6.54	94.27	96.07	58.92	60.05	7.25	-