MSc in European Construction Engineering, 2013-2014

EXPERIMENTAL STUDY ON THE EFFECT OF AGGREGATES IN CONCRETE PROPERTIES:

Influence of Washing Aggregates When the Content in Fly Ash Varies.

Author:
Lidia Corral Crespo

Supervisor:
Gitte Normann Munch-Petersen

Moderator:
Daniel Castro Fresno

Collaborator:
Aalborg Portland

ABSTRACT

It is widely known that aggregates have a great influence on fresh and hardened concrete properties. It is very important to wash the aggregates before their use in order to remove the layer of fine powder covering them that may affect the bond between the cement and the aggregates. The present research was focused in determining how important is to wash the aggregates before using them to make concrete when the amount of fly ash used in the mix is changed.

A serie of tests have been carried out and from the experimental data it has been concluded that the concrete made with unwashed aggregates has better hardened properties (compressive and tensile strength, and static and dynamic modulus of elasticity) than the concrete made with washed aggregates.

ACKNOWLEDGEMENTS

Firstly, I would like to show my gratitude to my supervisor Gitte Normann Munch-Petersen for her help and disposability along this dissertation and for all the materials se has provided me that have been very helpful.

Secondly, I would like to thank to Aalborg Portland for providing all the materials. Without them it would have been impossible to develop this research.

I also would like to thank to Víctor Marcos Mesón for his interest in this dissertation as well as for his great help and support along these months.

Thank you to my lab mate, Nicolás Toro Martínez, for the hours spent with me working in the lab. It would have been much harder without him.

I would like to dedicate this dissertation to my family (Manu, Lolo and Puri) for trust in me. Everything would have been impossible without them.

And last, but not least, thank you to all my colleagues from the Master, especially to those who were part of VIA University College during the summer. Your company has made me easier to overcome all these months of hard working.

Thank you to all.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Background

The topic of the present research was proposed by Aalborg Portland to VIA University College, and chosen by the author as the topic for the final dissertation of the Master in European Construction Engineering.

It was interesting for Aalborg Portland to be in touch with VIA University College so students could make some research with their products. In the same way, it was a good opportunity for VIA since students could put into practice their knowledge in a real case.

Aalborg Portland was interested in a better understanding on the effect of washing or not aggregates since a lot of money is spent in their pre-treatment. Furthermore, the effect of adding fly ash when the aggregates are either washed or not was also of their concern.

In this case, the dissertation will be focused on the aforementioned aspects and will pay special attention on their effect in concrete strength and elasticity, as they are important properties that characterise the behaviour of the hardened concrete.

The facilities in VIA's concrete lab will be used to test concrete specimens designed and casted for this specific research with all the components provided by Aalborg Portland.

The results of the present research will be of great importance to Aalborg Portland inasmuch as they will provide a general idea in the behaviour of the concrete under the aforesaid aspects and will lead to a deeper research in that area.

1.2. Aims and objectives

It is widely known that aggregates have a great influence on fresh and hardened concrete properties. It is very important to wash the aggregates before their use in order to remove the layer of fine powder covering them that may affect the bond between the cement and the aggregates.

The main objective of the present research is, therefore, to determine how important is to wash the aggregates before using them to make concrete.

To achieve this, series of tests are going to be carried out in order to understand which is the effect of washing or not the aggregates when the amount of fly ash used in the mix is changed. Three different amounts of fly ash are going to be considered that are 0%, 15% and 25%.

The properties of the concrete that are going to be determined are the following ones:

- Compression strength
- Tensile strength
- Modulus of elasticity
- Poisson's ratio

Thus, specific objectives are to understand how the bond between the aggregate and the cement due to the cleanliness of the first, affect the compression and tensile strength, the elastic modulus and the Poisson's ratio of the hardened and fresh concrete, and also the way it breaks, that means if they break because of the debonding of the aggregates from the cement paste or due to the break of the aggregates.

A secondary objective will be to find out which is the most suitable amount of fly ash for the washed and unwashed aggregates regarding the different properties of the concrete pointed out previously.

Finally, the ultimate objective is to determine which are the relationships between concrete elasticity and compressive and tensile strengths, which can be of great importance for a better understanding of the final concrete.

1.3. Research methodology

The research consists of four main points that are described next and that match with the structure of the present report. So further information about the stages of this research can be found in the corresponding chapters:

- **Theoretical research**. Through this stage, it has been possible to know how this topic has been studied until now, in which point were the researches and which were the tendencies.

  To find all this information several sources were used such as bibliographies, monographs, articles, other researches, official documents...

  The results of this first stage can be found in the State of the art, in Chapter 2.

- **Preliminary works**. Once the theoretical research has been done and it is clear what is the research going to be about, it is important to carry out preliminary works.

  In this stage European Standards have been studied to understand how the next stage, experimental study, is going to be carried out.

  Furthermore, some experiments have been performed to check which is the reliability of the methods that are going to be used. More detailed information about this stage can be found in Chapter 3.

- **Experimental study**. It is the most important stage of the present research along with the analysis of results and conclusions. It is summarized in the next points:

  - Characterization of the main properties of the materials provided by Aalborg Portland to develop the research.
  - Mixing, casting and curing following the European Standard EN 12390-1 and 2.
  - Characterization of the density, slump and air content in fresh conditions following the European Standard EN 12350.

   - Characterization of the mechanical properties of the hardened concrete based on the procedures set on EN 12390.

- **Analysis of the results and conclusions**. Analyse the data obtained from the tests performed during the experimental study and obtain conclusions and recommendations for future researches.

1.4. Scope and limitations

Regarding the scope of this research, the following aspects can be remarked:

- The research has been developed as a final dissertation for the Master in European Construction engineering, thus its scope is academic.
- It also has a professional scope since there is a company, Aalborg Portland, interested in this research that may take a profit of it.

However, there have been some limitations that have conditioned the work and are stated below:

Academic limitations:

- The time provided to execute the research was four months. Such a short period of time has constrained the scope of the research and thus, it has limited the results and conclusions obtained.
- Information regarding the use of the equipment available in the concrete lab in VIA have been provided. However, since most of the work has been performed without supervision, some limitations during the performance of the tests have occurred.
- Lack of experience in the field of the concrete.
- Even if most of the bibliography has been available, there have been some documents that could not have been found.
- Linguistic limitations when leading with Danish documents.

Technical limitations:

- Since all the materials needed for this research were supposed to be provided by Aalborg Portland, it was impossible to start with the mixing and testing until July when they delivered all the materials.
- Several series of concrete had to be made. Due to limitations imposed by the facilities it was needed to wait one day between casting days. Furthermore, it was needed to test samples the 28th day, thus the time available for the analysis of data was pretty short.
- Some technical problems resulted in a loss of electricity in the laboratory during one week of testing.
- The method used for testing concrete elasticity was not the most appropriate one and this resulted in some problems regarding the results.

1.5. Report outline

This research has been developed as a final dissertation for the Master in European Construction engineering. It has been carried out in the concrete lab of VIA University College in Horsens, Denmark.

The research has been divided in four main parts that are stated and briefly described below:

- **State of the art**. Through this stage, it has been possible to know how this topic has been studied until now, in which point were the researches and which were the tendencies.
- **Preliminary works**. Once the theoretical research has been done and it is clear what is the research going to be about, it is important to carry out preliminary works.

  In this stage European Standards have been studied to understand how the next stage, experimental study, is going to be carried out.

  Furthermore, some experiments have been performed to check which is the reliability of the methods that are going to be used.
- **Experimental study**. It is summarized in the next points:
  - Materials. Before starting mixing it is necessary to determine aggregates properties such as the density, absorption and moisture content.
  - Mixing. It is important to establish the same way of mixing for all the series in the research. The fewer variables during the mixing process the better to obtain comparable values.
  - Fresh concrete properties. Characterization of the density, slump and air content in fresh conditions following the European Standard EN 12350.
  - Casting and curing following the European Standard EN 12390-1 and EN 12390-2.
  - Hardened concrete properties. This last stage is the most important one. Characterization of the mechanical properties of the hardened concrete based on the procedures set on EN 12390.
- **Analysis of the results, conclusions and recommendations**. Analyse the data obtained from the tests performed during the experimental study and obtain conclusions. Further researches proposal
- **Appendix**. A final part with different appendix that underwrite the results and conclusions of the research.

2. STATE OF THE ART

2.1. Introduction

Concrete is considered the ultimate modern material, despite it was originated in ancient Rome, and it is used everywhere in construction today (Forty 2012), being the most widely used man-made material.

Concrete is so widely used due to the several advantages that are attributed to it. It can bear high compressive strengths, it is relatively easy to work with and it is cheap. Furthermore, it can be shaped into pretty much many shapes and it has great construction qualities.

However, concrete presents some disadvantages as well. It is a heterogeneous material and it is impossible to make concrete with exactly the properties desired. The most important disadvantage is the low tensile strength that can bear.

There are two criteria by which it can be said that a concrete is good (Neville & Brooks 2010): it has to be satisfactory in its fresh state while it is being transported from the mixer to the formwork, as well as in its hardened state.

The requirements for the concrete in the fresh state are that the consistency of the mix should be such that the concrete can be compacted by the means that are available on the job. Another requirement is that the mix should be cohesive enough so it can be transported and placed without segregation by the means available on the job.

As far as the hardened concrete concerns, the main requirement is a satisfactory compressive strength since it is its principal characteristic. Furthermore, many properties of concrete are in relation with its compressive strength. Some of these properties are impermeability, density, resistance to abrasion, durability, resistance to impact and tensile strength. These properties are not only a function of compressive strength, however, in a very general way, it can be affirmed that higher strength concrete has more desirable properties than lower strength concrete.

2.2. Composition

Concrete is composed of water, sand, coarse aggregate and cement. Additives and admixtures can also be added to the mix in order to improve, or just change, concrete properties.

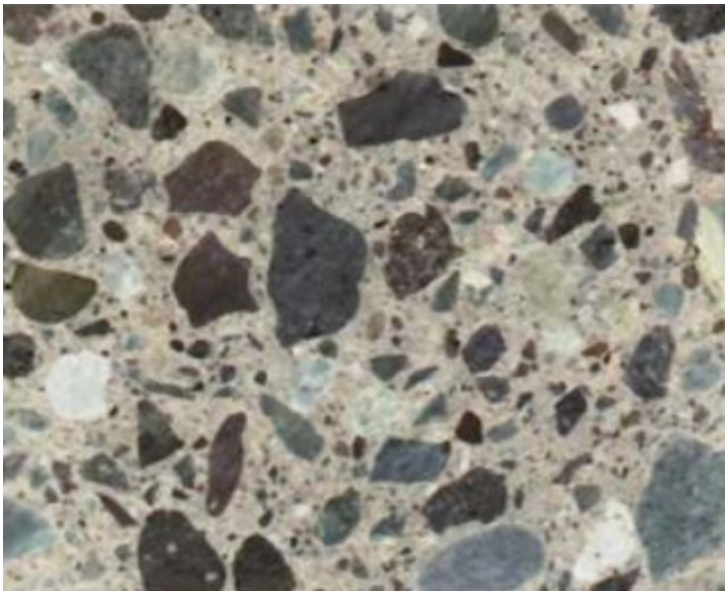


Figure 1. Concrete macrostructure (Blanco 2013).

Water is the most inexpensive component of concrete. It should be clean and free of impurities in order to avoid staining of the surface as well as interferences that may adversely affect the strength of the concrete and the setting of the cement. (Neville 1963). The amount of water in relation to the amount of cement, called water to cement ratio, affects the fresh concrete flowability and also its final strength.

Cement mixed with water produces a paste that acts as a glue and keeps aggregates together once the concrete has hardened. Cement also fills aggregate voids and provides workability to the fresh concrete mix. However, at the same time, paste produces heat generation in concrete, shrinkage and durability problems. The most used cement to make concrete is Portland cement.

Aggregates make up the majority of a concrete mixture. At least three quarters of the volume of concrete is occupied by aggregate (Neville 1963; Polat et al. 2013), thus, its characteristics have a significant effect on the performance of fresh and hardened concrete and an impact on the cost effectiveness of concrete (Quiroga & Fowler 2004; Hudson n.d.). Although, in terms of money, the component that affects the most the final price of the concrete is the cement, which is responsible for around 60 per cent of the total cost of the materials conforming concrete (Quiroga & Fowler 2004).

Concrete additives are inorganic materials with pozzolanic and hydraulic characteristics. The finely ground powder is added to the concrete mix with the goal of improving its properties or to provide it with special characteristics.

Admixtures for concrete can be both organic and inorganic materials which objective is to modify the physic properties of fresh concrete. They can be used as a liquid or powder.

The main functions of each of the above constituents of the concrete are (Blanco 2013):

- Cement (10-15 % of the mix):
  - To fill voids in the aggregates by linking them. When it is fresh it provides the mixture with cohesion. Whereas, when it is hardened it gives impermeability to the final product by filling the voids.
  - Confers resistance to the hardened concrete
- Aggregates (60-80 % of the mix):
  - Confers rigidity to resist loads and the weather. It makes concrete durable.
  - It improves concrete stability as it reduces possible changes in the paste.
  - It makes concrete more economic.
- Water (15-20 % of the mix):
  - Confers plasticity to fresh concrete
  - It hydrated the cement
  - It cures concrete
- Air entrainment (1-2 % of the mix)

2.3. Aggregates in concrete

Aggregates were originally viewed as inexpensive and inert materials dispersed throughout the cement paste in order to produce a large volume of concrete with the less possible amount of money. Actually, aggregates are not completely inert because its thermal, chemical and physical properties have influence in the performance of concrete (Neville & Brooks 2010). Since aggregates are not the most expensive component of the concrete, from the economic point of view, it is better to use a mix with as much aggregates as possible and little cement. However, the cost benefit has to be balanced with the desired properties of fresh and hardened concrete.

Aggregate characteristics of shape, texture, and grading influence workability, finishability, bleeding, pumpability, and segregation of fresh concrete and affect strength, stiffness, shrinkage, creep, density, permeability, and durability of hardened concrete (Quiroga & Fowler 2004).

Next, this state of the art is going to focus on the effect of aggregates in fresh and hardened concrete properties and, according to Quiroga & Fowler (2004), the main aggregate characteristics that affect the performance of concrete are:

- Type of coarse aggregates
- Aggregate grading
- Maximum aggregate size
- Aggregate shape
- Aggregate texture
- Aggregate coatings
- Porosity and absorption of aggregates

2.3.1. Type of coarse aggregate

When varying the mineralogical composition of aggregates, concretes of diverse characteristics can be made (Özturan & Çeçen 1997; Quiroga & Fowler 2004). The type of aggregate has an impact on the stiffness, long-term deformations and the strength of hardened concrete (Alexander 1996). On the one hand, some aggregates can respond beneficially with cement paste with a result of an increment in strength; or, on the other hand, they may react negatively with the cement paste, decreasing strength. As a result of this fact, depending on the aggregate type, the modulus of elasticity, creep or shrinkage can vary a lot.

In normal concrete, strength is controlled by the transition zone between the cement paste and aggregate or by the cement paste itself. However, in high strength concrete, the strength depends not only on the transition zone and cement paste but also on the type of coarse aggregate. Since bond strength between cement paste and aggregate is the limiting factor in the development of high strength concrete, the type of coarse aggregates should be such as to promote chemical bonding (Russell et al. 1997). Thus, it can be said that the influence that the type of coarse aggregate has on the strength of concrete is more important when the quality of mortar is improved.

Normal strength concrete is usually made with water to cement ratios above 0.4. In these cases, what mostly limits the strength of the concrete are the strength of the cement paste and the bond between mortar and aggregates. What happens in this case is that cracking through the mortar will lead to failure of the concrete, regardless of the strength of the coarse aggregate.

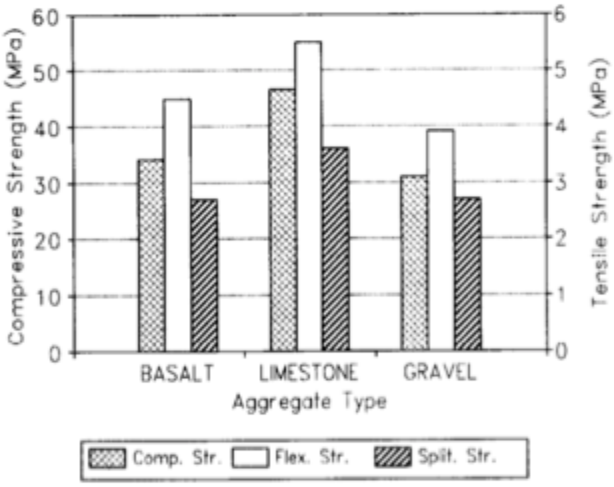


Figure 2. Effect of coarse aggregate type on the strength of concrete with target strength of 30 MPa (Özturan & Çeçen 1997).

Özturan & Çeçen (1997) probed that for concretes with target strength of 30 MPa, the compressive strengths of the concretes made with basalt and gravel are similar, while the compressive strength of the concrete made with limestone is bigger. These results are illustrated in the figure above. They stated that this result might be due to some chemical reactions between the limestone aggregate and the cement paste, which results in an improvement of the bond strength.

Other researches underwrite this conclusion and found that normal strength concretes containing basalt have slightly lower compressive strengths than concretes made with limestone (Kozul & Darwin 1997).

On the contrary, high strength concrete is usually made with water to cement ratios below 0.4. In this case, the strength of the cement paste and the bond between mortar and aggregates may be as important as the strength of the aggregates, according to Özturan & Çeçen (1997). Thus, it may be possible to use the full potential of the coarse aggregates and, consequently, the strength of the concrete may be improve by using a coarse aggregate of higher strength.

Özturan & Çeçen (1997) probed that for a concrete with target strength of 90 MPa (high strength concrete), aggregates of basalt and limestone (crushed aggregates) produce higher compressive strengths than gravel (rounded aggregate). Results are shown in the next figure. In the same way, Kozul & Darwin (1997) probed that high strength concrete containing basalt produces slightly higher compressive strengths than high strength concrete containing limestone.

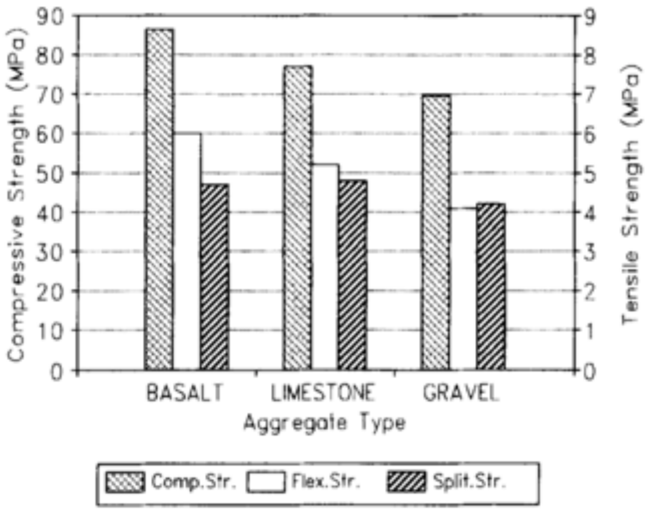


Figure 3. Effect of coarse aggregate type on the strength of concrete with target strength of 90 MPa (Özturan & Çeçen 1997).

They attributed this fact to the lower strength of the gravel, and also to the surface characteristics of the aggregates, as is going to be mentioned in following chapters.

As a conclusion, several researchers (Ezeldin & Aitcin 1991; Kozul & Darwin 1997; Özturan & Çeçen 1997) probed that the compressive strength is greatly influenced by the type of coarse aggregate when the concrete is made with a high target strength, while in normal strength concrete, coarse aggregate strength has little effect on compressive strength.

The tensile strength is mainly determined by the mortar strength and as the target strength of the concrete is reduced, the differences in tensile strength of concretes with different types of coarse aggregates are getting less (Özturan & Çeçen 1997).

Most researchers conclude that the type of coarse aggregate has little effect on flexural strength (Giaccio et al. 1992); however, other researchers argue that higher strength coarse aggregates yield higher flexural strengths than lower strength coarse aggregates (Kozul & Darwin 1997).

2.3.2. Aggregates grading

Apart from the type of aggregates, another way to classify aggregates is according to their size. The range of aggregate sizes is very wide, and all the specifications related to their size are collected in the European standard EN 12620.

When using to make concrete, aggregates with a whole range of sizes can be added, all varying from the smallest to the largest, referred to as all-in aggregates; or they can be separated into 2 different groups that are coarse aggregates, minimum size of 4 mm, and fine aggregates, maximum size of 4 mm, according to the standard EN 12620. The first way of making concrete results in a poorer quality concrete, while when separating the aggregates in two size groups good quality concrete is achieved. (Neville 1963).

It is important to classify the aggregates before using them to make concrete. In order to divide a sample of aggregate into fractions, the sieve analysis is used. In the European standard EN 933-1 it is specified how to obtain the granulometry of the particles through the sieve analysis. The test consists in dividing the particles in several fractions of the same size through a series of sieves whose properties are described in the standard EN 933-2.

Once the granulometry of the particles has been obtained, the results of the sieve analysis can be represented graphically by grading charts. These charts give the chance to see at a glance if the grading of a given sample corresponds to that specified.

Five different kinds of size distributions are represented in the figure below. These size distributions are: dense graded, gap-graded, uniformly graded, well graded and open graded. The most desirable gradations for making concrete, according to (Li 2012), are dense and well-graded aggregates, as they produce a well-packed structure by filling with small particles the space between larger particles. However, as it is going to be explained next, there is not a consensus about which is the ideal grading.

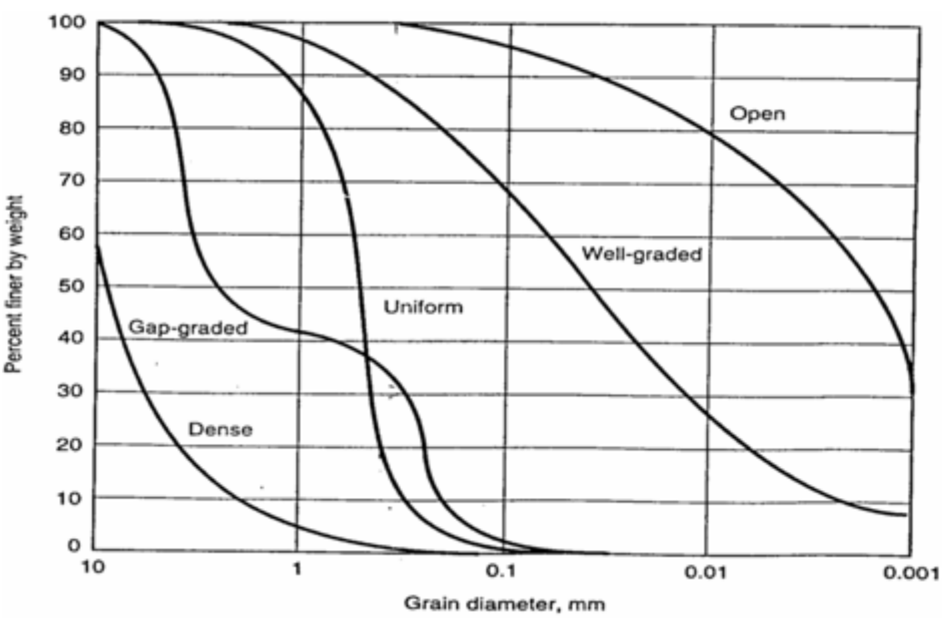


Figure 4. Five types of gradation (Li 2012)

As it has been said, grading is very important in concrete. Particles interact between them in such a way that bigger particles roll on smaller particles, thus it has an important effect on concrete properties. Many authors have addressed various aspects of this issue.

Quiroga & Fowler (2004) found out that grading is the aggregate property that affects the most the workability of fresh concrete. According to them, several authors stated that uniformly distributed mixtures result in better workability than gap-graded mixtures.

One of the most important characteristics that affects durability of hardened concrete is permeability. It is related with the void content of aggregates in the mixture as follows: the permeability is reduced with lower void content. Quiroga & Fowler (2004) stated that “In reducing permeability, it is desirable to have the highest aggregate content possible. Consequently, well-graded mixtures produce concrete that is more durable”.

Grading also affects slump, placeability and finishability (Russell et al. 1997) as well as it can influence the concrete compressive strength (Horta 2011). Shilstone (1999) concluded that pumpability is greatly affected by aggregate grading and that a uniform combined aggregate grading can result in a reduction in erosion due to cavitation from flowing water. Furthermore, the heat of hydration, that can affect the duration of concrete, can be reduced by using a proper grading of aggregates due to the less amount of cement needed (Shilstone 1999).

Concrete needs particles from different sizes to fill in the spaces, and the remaining spaces are filled with cement paste. When aggregate voids are minimized, for a given level of workability and strength, the quantity of paste needed for filling these voids is minimized as well. By reducing the amount of paste maintaining the water to cement ratio, more durable concrete is achieved (Shilstone 1994). Apart from an obvious economic benefit, a minimum amount of cement in a concrete results in less shrinkage and creep and a more dense and therefore probably a more durable and strong concrete (Glavind et al. 1993). Lower cement factor mixes avoid problems due to high heat of hydration that leads to thermal cracking and micro cracking, which can lead to brittleness and premature deterioration of higher strength concretes (Shilstone 1999). However, the less amount of cement, the less workable the concrete becomes, so it has to be found an optimum grading of aggregates which allows to reduce the amount of cement without compromising the workability. By adding water, a more workable mixture with less cement is achieved, but this fact increases the water to cement ratio and, as a consequence, decreases strength.

In conclusion, good quality concrete with a minimum quantity of cement can be produced through an optimal mixture proportioning. Minimizing the voids between aggregates should be an important objective when optimizing concrete mixtures. However, care must be taken when optimizing for maximum packing density or for maximum slump since these mixtures are very coarse, which makes them susceptible to segregation due to the absence of fines (Quiroga & Fowler 2004). Coarse mixtures present poor workability as well.

On the opposite, higher amount of fines results in higher water demand to wet the aggregate, due to the higher surface area; consequently, yield stress and plastic viscosity values increase (Quiroga & Fowler 2004). According to Horta (2011), the optimum grading in concrete is that with the minimum amount of fines required for a concrete with good cohesion. Thus, the most appropriate grading will be that which keeps concrete cohesive and homogeneous, with the least possible amount of fines. Quiroga & Fowler (2004) stated that maintaining a high packing density with a uniform grading is the most desirable mixture.

This high packing density theory has led to the advocacy of parabolic grading curves, or parabolic in part and then straight. In the figure below, an 'ideal' grading curve is represented. Despite of this 'ideal' curve, several researchers recommend somewhat varying shapes of it (Neville 1963).

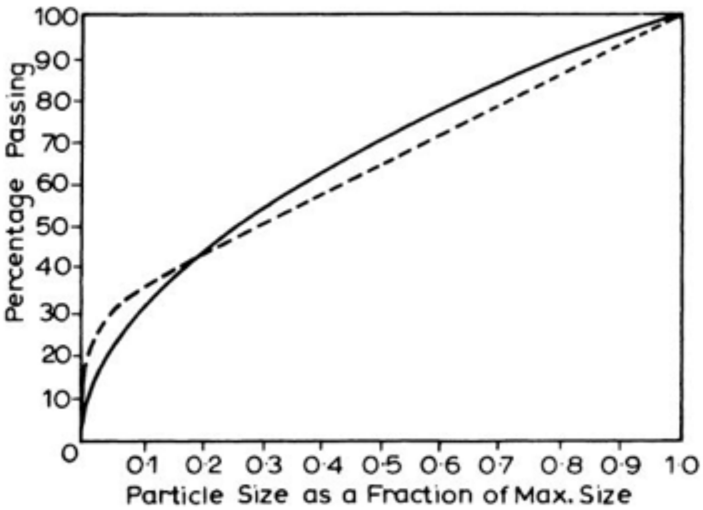


Figure 5. Fuller's grading curves (Neville 1963)

Cramer et al. (1995) carried out an investigation in Wisconsin in which the effect of optimizing aggregates gradation on the properties of concrete was examined. It was probed that an increase in compressive strength of 10 – 20 % was achieved when using optimized total aggregate gradations instead of gap-graded gradation in pavement. Water demand was reduced by up to 15 % and segregation following extended vibration was reduced. Even if not all efforts at gradation optimization in the investigation produced measurable improvements in the performance of concrete, a reasonable effort can result in significant mix benefits.

2.3.3. Maximum aggregate size

The importance of maximum size is illustrated in the table below that shows the relationship between the aggregate size and the amount of water and cement needed.

Maximum Size Aggregate	4.75 (sand)	9.5 mm	12.5 mm	19 mm	25 mm	37.5 mm	50 mm	76 mm	150 mm
				NON-AIR-ENTRAINED CONCRETE					
Water, kg/m[3a]	276	228	216	202	192	177	168	160	139
Cement, kg/m[3b]	520	430	406	382	360	334	316	302	262
Fine aggregate, %[c]	100	62	54	49	44	40	37	34	28
Entrapped air, %[d]	6	3	2.5	2	1.5	1	0.5	0.3	0.2
				AIR-ENTRAINED CONCRETE					
Water, kg/m[3a]	245	201	192	177	169	157	148	139	118
Cement, kg/m[3b]	462	380	362	334	318	296	279	262	222
Fine aggregate, %[c]	100	58	50	45	40	37	34	31	25
Total air, %[d]	13	8	7	6	5	4.5	4	3.5	3

[a] Approximate amount of mixing in kilograms per cubic metric required for 75-mm slump with well-shaped angular coarse aggregate. Quantities listed can be reduced significantly through the addition of water-reducing admixture.
[b] Cement required in kilograms per cubic metre for 0.53 water/cement ratio by weight.
[c] Approximate percentage of fine aggregate of total aggregate by absolute volume.
[d] Recommended average total percentage of entrained air required for frost resistance from Table 5.3.3 of ACI Recommended Practice for Selecting Proportions for Normal and Heavy Weight Concrete (ACI 211.1).

Table 1. Mortar requirements for workable concrete with different maximum aggregate sizes (Galloway 1994)

It is known that when the aggregate particle size increases, the surface area to be wetted per unit mas decreases. Thus, a larger maximum aggregate size lowers the water requirement of the mix, which results on an increment in the strength due to the lower water/cement ratio required for a specified cement content and workability (Neville 1963). This behaviour is assumed to extent to all maximum sizes of aggregates. However, it has been concluded by experimental results that for maximum sizes above 38.1 mm, the gain in strength due to the lower water requirement is offset by the harmful effects of discontinuities, owing to the big particles, and of the lower bond area. This fact exists throughout the range of sizes but for maximum aggregate sizes below 38.1 mm in lesser extent, being the effect of size on the decrease in the water requirement dominant.

The best maximum size of coarse aggregate regarding the strength is a function of the richness of the mix, as it has been confirmed by Nichols (1982).

Numerous studies have been carried out in order to determine the influence that the maximum coarse aggregate size has in concrete properties.

In terms of fracture energy, Hillerborg (1985) pointed out, after analysing 700 notched beams in 14 laboratories, that the fracture energy in concrete increases when the maximum aggregate size increases from 8 to 20 mm; however, this tendency was uncertain due to a large scatter.

Elices & Rocco (2008) found that the specific fracture energy increases with the aggregate size when aggregates are well bounded to a strong matrix, which means that all aggregates break during testing. When aggregates do not break, as a result of the matrix being soft and the crack path finding its way through the matrix instead of cracking the aggregates, it was also found that the specific fracture energy increases as the aggregate size increases. Finally, when aggregates debond from the matrix, no clear trend was found regarding the behaviour of the specific fracture energy as a function of aggregate size. However, (Sim et al. 2014) carried out some tests in light weight concrete and found that when the maximum aggregate size is larger than 8 mm, the effect on fracture energy is insignificant.

Many other researchers have reported the trend of increasing the fracture energy with aggregate size. For specimens of maximum aggregate size between 10 mm and 20 mm, El-sayed et al. (1998) proved that the fracture energy varies between 100 N/m and 141 N/m, for a w/c ratio of 0.48, while Yan et al. (2001) stated that, for the same range of aggregate size, the fracture energy increases from 172 N/m to 205 N/m for a w/c ratio of 0.26 and from 160 N/m to 212 N/m for a w/c ratio of 0.44.

Next table summarizes some results about how the maximum aggregate size has an influence on the fracture energy of concrete.

Reference	Maximum aggregate size	w/c ratio	Fracture energy
(Chen & Liu 2004)	10 to 20 mm	0.37	172 to 237 N/m
(Rao & Prasad 2002)	6.3 to 20 mm	0.32	137 to 165 N/m
		0.36	97.8 to 142 N/m
(Petersson 1980)	8 to 16 mm	0.5	101 to 111 N/m
(El-Sayed et al. 1998)	10 to 20 mm	0.48	100 to 141 N/m
(Issa et al. 2000)	9.5 to 19 mm	0.5	113.83 to 129.6 N/m
(Yan et al. 2001)	10 to 20 mm	0.26	172 to 205 N/m
		0.44	160 to 212 N/m

Table 2. Influence of maximum aggregate size in fracture energy

Beygi et al. (2014) evaluated the effect of maximum aggregate size on fracture behaviour of self compacting concrete and the results obtained are as follows:

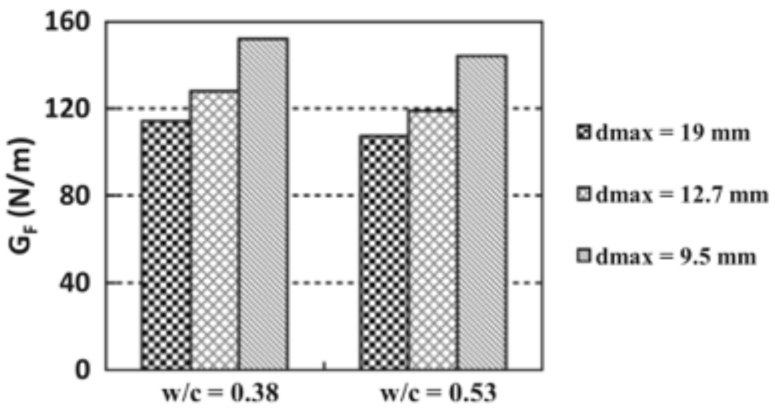


Figure 6. Variation of the total fracture energy with maximum size of coarse aggregate for mixes prepared with different w/c ratios (Beygi et al. 2014)

The reason of this trend of increasing the fracture energy with the maximum aggregate size is due to the fact that aggregates increase tortuosity of the fracture path in cement paste matrix. When the concrete is loaded, cracks can appear and they prefer to pass through weak zones such as paste pores and the bond between the surface aggregates and the matrix. With an increment of the aggregate size, a higher energy is required to overpass the strength of the aggregate-paste bond and also the fracture path becomes more tortuous, resulting in an increment of the fracture energy (Beygi et al. 2014).

Apart from the fracture energy, the maximum aggregate size also affects other concrete properties such as the compressive, tensile and flexural strength as well as the modulus of elasticity.

Regarding the compressive strength, Yaqub & Bukhari (2006) tested five different sizes of coarse aggregates (37.5 mm, 25 mm, 20 mm, 10 mm and 5 mm) and found that the higher compressive strength was achieved with the minimum size of aggregates (5 and 10 mm). Thus, they reached the conclusion that for the same w/c ratio the compressive strength increases with the decrease in the size of coarse aggregate. In contrast, there are studies that probed that the compressive strength of lightweight concrete is negligibly affected by the maximum aggregate size (Sim et al. 2014), and the compressive strength of both high strength and normal strength concrete is also little affected by aggregate size (Kozul & Darwin 1997). Zhang et al. (2005) tested different series of concrete and they found that the compressive strength is almost constant regardless the coarse aggregate size. The reason they gave is that the mixes had similar workability, which depends on the water to cement ratio, and thus, similar compressive strengths were obtained.

Several researches have been carried out in order to determine the influence that the aggregate size has in the tensile and flexural strength. It has been tested that tensile and flexural strength in normal and high strength concretes are greatly influenced by the aggregates size and, more precisely, the smaller the coarse aggregate size, the higher the aforementioned strengths (Zhang et al. 2005). Elices & Rocco (2008) found that the tensile strength seems to decrease with an increase in the aggregate size. However, there are studies with different conclusions: the flexural strength of normal and high strength concrete is not affected by aggregate size (Kozul & Darwin 1997), and the tensile strength on lightweight concrete increases a little when the maximum aggregate size increases (Sim et al. 2014).

To finish with the influence of the aggregate size on the concrete properties, the modulus of elasticity is going to be mentioned. It has been found that when aggregates are loosely bounded to the matrix no clear tendency with aggregate size was observed, while when they are well bounded the elasticity modulus decreases when the aggregate size increases (Elices & Rocco 2008). When comes to lightweight concrete, i.e., when lightweight aggregates are used, the modulus of elasticity is independent of the maximum aggregate size (Sim et al. 2014).

2.3.4. Aggregates shape

Aggregate's shape is related to several parameters, some of them are as follows (Quiroga & Fowler 2004): sphericity, form, elongation factor, flatness factor, roundness and angularity. Sphericity measures how similar are the three principal dimensions of a particle. Form is measured by the relation based on the ratios of these three principal dimensions that are the long, medium and short axes of the particle. Elongation and flatness factor are specific parameters of form, which relate the intermediate with the long dimension and the short with the intermediate dimension respectively. Roundness describes the outline of a particle, while angularity is related to the sharpness of the corners and edges of the particle.

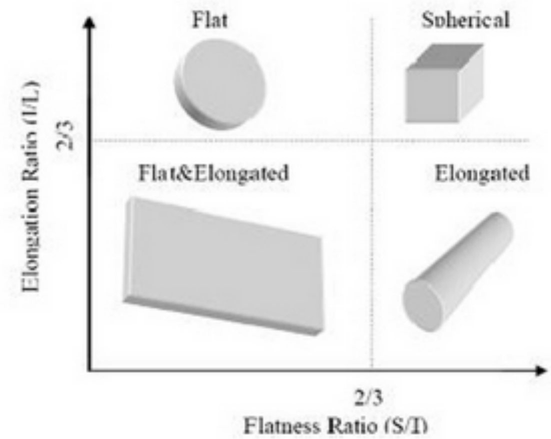


Figure 7. Four different particles shapes (Polat et al. 2013)

Particle shape can be assessed visually. Next, two charts for the visual assessment based on morphological observations and on measurements of sphericity and roundness are provided:

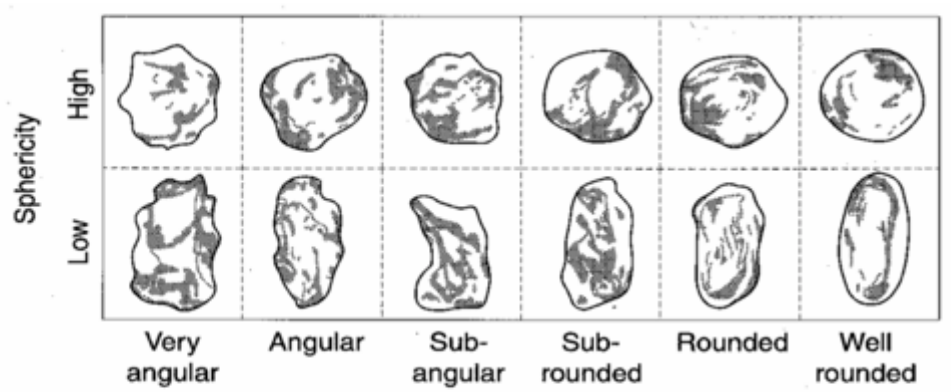


Figure 8. Visual assessment of particle shape based on morphological observations (Quiroga & Fowler 2004)

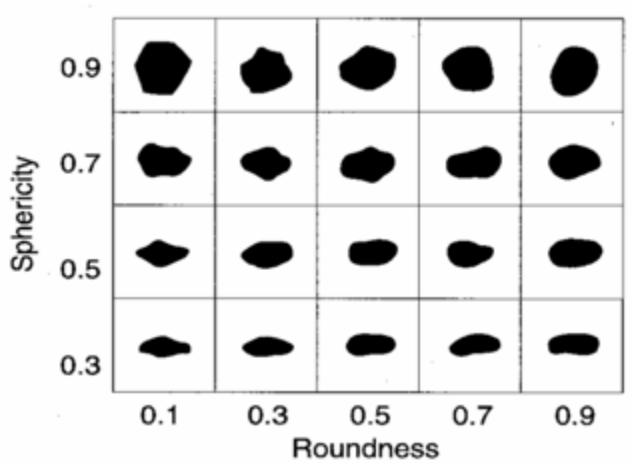


Figure 9 Visual assessment based on sphericity and roundness measurements (Powers 1966)

In relation to the shape of the aggregates, aggregates are broadly classified as crushed and rounded. Rounded aggregates or gravel are those natural aggregates with a rounded shape due to the friction they suffer in the rivers where they are obtained, while crushed rocks are obtained through the breakdown of a bigger parent rock so that they present sharper surfaces. However, it is not so simple; the shape of the aggregate can vary from greatly angular to fully rounded. This depends on different parameters such as the type of parent rock, the crushing equipment used and the forces to which they are subjected during their formation (Jamkar & Rao 2004).

Classification	*Description*	*Examples*
Rounded	Fully water-worn or completely shaped by attrition	River or seashore gravel; desert, seashore and wind-blown sand
Irregular	Naturally irregular, or partly shaped by attrition and having rounded edges	Other gravels; land or dug flint
Flaky	Material of which the thickness is small relative to the other two dimensions	Laminated rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types; talus; crushed slag
Elongated	Material, usually angular, in which the length is considerably larger than the other two dimensions	—
Flaky and elongated	Material having the length considerably larger than the width, and the width considerably larger than the thickness	—

Table 3. Particle shape classification according to BS 812-1: 1975, which has been replaced by BS EN 933-3: 1997 (Neville 1963)

Coarse aggregate shape has influence on certain properties of fresh and hardened concrete (Jamkar & Rao 2004; Quiroga & Fowler 2004; Neville 1963), although it is not as important as the influence that fine aggregates have (Polat et al. 2013).

Elongated particles compared to cubic particles have a tendency to break along their long axis. Thus, particle form affects the strength of the aggregates and life expectancy of the concrete. Many studies have shown that rounded gravel produces lower strengths than crushed stone (Russell et al. 1997). The reason for this fact is the highest mechanical bond of the crushed stone because of its angular particles. Nevertheless, great angularity is to be avoided due to the high water requirement and lower workability. According to Russell et al. (1997), the ideal aggregate has to be angular, cubical, 100% crushed aggregate, and with a minimum of elongated and flat particles that may generate hard mixtures and affect finishability. The presence of more than 10 to 15 % of elongated particles by weight of total aggregates is generally considered undesirable (Neville 2010).

Aggregate mixtures with rounded, well shaped and smooth particles need less cement paste for a given slump than those with elongated, flat, rough and angular particles. Consequently, they are cheaper and they will have fewer problems produced by the cement paste such as porosity, heat generation and drying shrinkage (Quiroga & Fowler 2004). Also, elongated, flat, rough and angular particles have a large amount of voids and need more sand to fill them and to produce workable concrete, thus increasing the water required (Polat et al. 2013).

As mentioned above, the importance that the shape of aggregates has on the performance of fresh concrete is well recognized. However, a little of studies have focused on the impact of aggregate shape to the hardened concrete properties.

The influence that the shape of coarse aggregates has on the strength of concrete depends on the water to cement ratio and it is bigger at lower values. When crushed aggregates instead of rounded aggregates are used, strengths up to 38% higher are achieved for water to cement ratios below 0.4. When this ratio increases, the influence that the aggregate shape has on the strength of concrete falls of, and it has been tested that above a water to cement ratio of 0.65 the strength of concretes made with gravel and crushed rock is the same (Rocco & Elices 2009; Neville 2010).

Angular aggregates produce tensile strength values higher than rounded aggregates (Rocco & Elices 2009; Guinea et al. 2002) although the influence of aggregate shape is almost negligible. Wakchaure et al. (2012) concluded that cubical and angular particles increase flexural strength of concrete due to the improvement of frictional properties. Spherical aggregate mixture is better than flat aggregate mixture when talking about compressive strength (Polat et al. 2013). Similarly, Neville (2010) indicated that flat particles produce lower compressive strength.

The shape of aggregates may also affect the fracture energy of concrete (Rocco & Elices 2009). It is because coarse aggregates act as crack arresters and when the load increases more cracks are likely to open, thus increasing the fracture energy. The tests they carried out suggest that those concretes composed of crushed aggregates have higher fracture energy values than those made with rounded aggregates.

When it comes to modulus of elasticity, concretes produced with crushed aggregates provide E values somewhat higher than concretes produced with spherical aggregates (Rocco & Elices 2009).

2.3.5. Texture

Surface textures can be different in particles with similar shapes. In the figure below an example is shown.

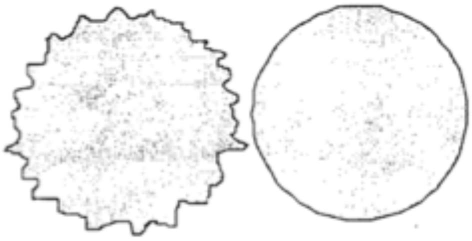


Figure 10. Particles with similar shapes and volumes, but different surface textures (Hudson n.d.).

According to Hudson, the particles can have similar volumes or even the same but, due to the fact that one particle has a rougher surface texture, it will not pack so efficiently as the other. A visual example is shown in the next figure.

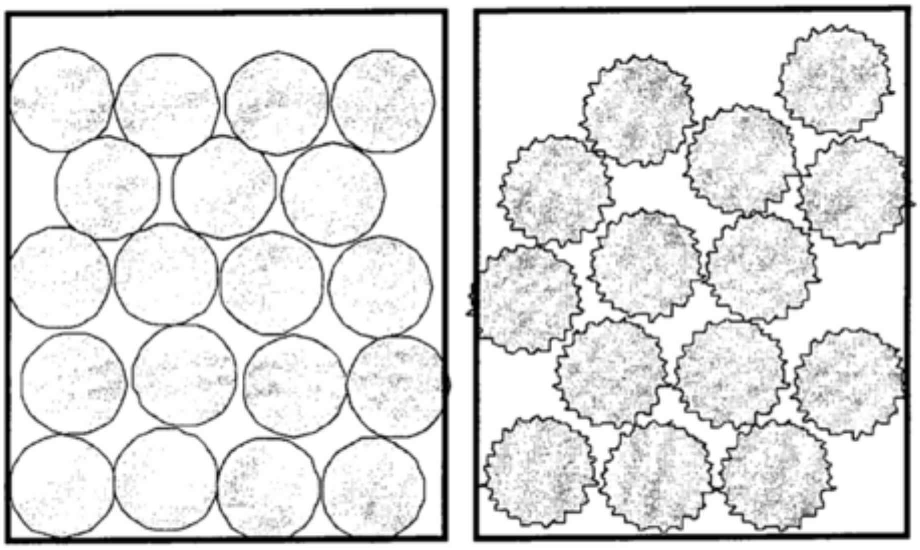


Figure 11. Difference between the packing efficiency of particles with smooth surface texture (left picture) and rough surface texture (right picture), (Hudson n.d.).

It can be seen that those particles with a rougher surface texture will have a higher voids content, thus less material in the container.

As aggregate's shape does, aggregate's texture also influences certain properties of fresh and hardened concrete, although it affects the properties of fresh concrete more than the properties of hardened concrete (Li 2012).

Surface texture, which is also called surface roughness, is a property that depends on the structure, the degree of weathering and the texture of the parent rock (Quiroga & Fowler 2004; Neville & Brooks 2010).

Visual estimation of aggregates roughness is quite reliable, nonetheless, in order to reduce misunderstanding the classification of aggregates texture can be that proposed by Neville and Brooks (2010), and it is as follows:

Group	Surface Texture	Characteristics	Examples
1	Glassy	Conchoidal fracture	Black flint, vitreous slag
2	Smooth	Water-worn, or smooth due to fracture of laminated or fine-grained rock	Gravels, chert, slate, marble, some rhyolites
3	Granular	Fracture showing more or less uniform rounded grains	Sandstone, oolite
4	Rough	Rough fracture of fine- or medium-grained rock containing no easily visible crystalline constituents	Basalt, felsite, porphyry, limestone
5	Crystalline	Containing easily visible crystalline constituents	Granite, gabbro, gneiss
6	Honeycombed	With visible pores and cavities	Brick, pumice, foamed slag, clinker, expanded clay

Figure 12. Surface texture classification of aggregates with examples (Neville & Brooks 2010).

As it happens when talking about aggregate's shape, texture of coarse aggregates is not as significant as texture of fine aggregates, but even so, it plays a significant role on the behaviour of fresh concrete, specially in flowability and slump (Quiroga & Fowler 2004), and also on hardened concrete. Russell et al. (1997) said that texture of fine aggregates can have an effect on mixing water requirements as great as that of coarse aggregates.

Rough particles have higher voids than smooth particles, affecting particle-packing efficiency, and they require more sand to provide workable concrete and to fill voids. This increment of required sand also increases the demand for water for a given workability, resulting in a reduction of strength and an increment of bleeding. However, satisfying concrete has been produced with aggregate surface textures varying from very smooth to very rough.

Talking about packing density, Quiroga & Fowler (2004) indicated that packing density is a function of the conjunct effect of grading, texture and shape of the particles. However, as mentioned by Quiroga & Fowler (2004), Kwan (2001) found that grading and shape are the main characteristics that affect packing density, and also that texture does not have a significant effect on packing while, on the opposite, Hudson (1999) said that surface texture has an important effect on packing density.

Aggregate's texture also has an influence on the strength and shrinkage as it affects bond between paste and particles. Smooth particles tend to provide weaker bond than rough particles and, as a result, smooth particles tend to produce lower strength, particularly flexural strength (Galloway 1994), and to decrease shrinkage as well. The effect that the mechanical bond between the particles and paste has on the strength of concrete, is more significant in case of high strength concrete than in normal strength concrete, and it is specially important when the water to cement ratio is less than 0.40 (Jamkar & Rao 2004).

Although rugosity increases the bond between mortar and particles, Ahn (2000) said that there are aspects of surface properties that are more important, such as the absorption, porosity and permeability of the area that is just subjacent to the surface. Ahn (2000) added that penetration of the cement paste in the aggregates results in a good bond, however, when this penetration is very high it may result in low tensile and shearing strength in the aggregates and thus, in the concrete.

As it has been said, the impact that the texture of fine aggregates has on concrete performance is more significant than the texture of coarse aggregates; Hudson (1999) stated that the effect of surface texture on concrete behaviour is more significant as particles get smaller because their specific surface increases proportionally.

With the increment of the specific surface, the water requirement increases as well. It has been probed (Toplicic-Curcic et al. 2010) that if fine aggregate characteristics are represented as a function of the void percentage in looseness condition, the influence on the amount of water needed will be as follows.

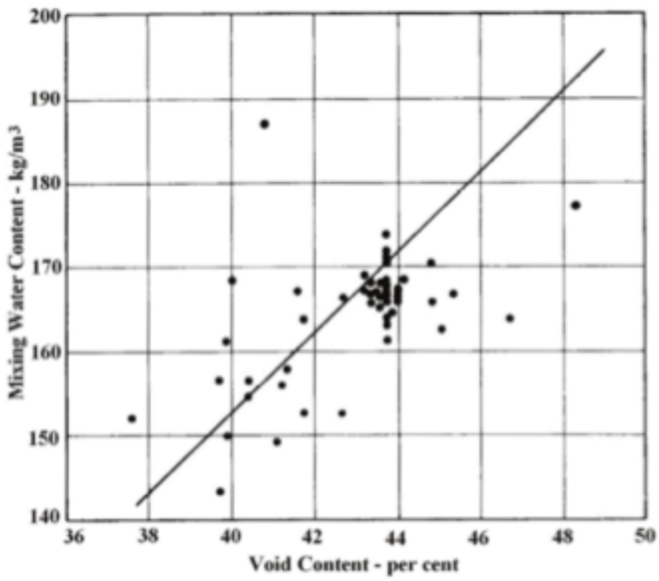


Figure 13. Ratio between fine aggregate voids in loose conditions and water requirement for concrete made with that fine aggregate (Toplicic-Curcic et al. 2010).

Fine aggregates have an important role on strength and durability of hardened concrete, and on workability of fresh concrete even if this effect on workability due to the texture is not as relevant as shape and grading (Galloway 1994); workable concrete can be produced with rough and angular particles if they are well graded and cubical.

Natural sands usually demand a lower amount of water than manufactured sands for given workability since they are often smoother and rounder, and due to this fact they are preferable in high strength concrete (Russell et al. 1997). However, angular and rough particles can be used to make workable concrete if they are well graded and have a cubical shape. Hudson (1999) stated that manufactured sands should be avoided if they are very rough and do not have cubical shape as it may negatively affect workability and water demand.

As it has been mentioned above, durability is also influenced by aggregate's texture since it is related with low water content. Rough aggregates increase the amount of water needed and this fact adversely affects durability.

2.3.6. Aggregates coatings

Coating is any material that is adhered to the aggregate surface. Coarse aggregates generally have small particles that are weakly or strongly bounded to the aggregate surface. These small particles can completely or partially cover the aggregate surface. These coatings can be made of foreign particles or they can be fine material with the same mineralogy as the parent rock (Galloway 1994).

Coatings can be a result of crushing or processing procedures, or they can be due to a natural weathering of the parent rock. One of the more common types of coatings are those containing dust from passing traffic or due to the wind when the aggregates are stored in wet conditions.

Coatings can be conformed by clays, calcium carbonates, and dust or silt. These coatings are to be avoided because they have a harmful effect on the behaviour of the concrete. Coatings may increase the amount of water needed and they interfere with the bond between the particles and the cement paste. Furthermore, this outer layer is sometimes formed by materials that can negatively affect concrete by interacting chemically with the cement paste (Quiroga & Fowler 2004).

Fortunately, washing the aggregates usually removes coatings. However, the profit of eliminating coatings can be reduced by the cost of washing and accumulating the fines that are removed. As a consequence, a better comprehension of aggregate cleaning could have an important impact on processing of aggregates from an economic point of view (Muñoz et al. 2007).

Most of the aggregate’s coatings are composed of clay minerals. Clay coatings are originated by precipitating water-soluble materials from gravel or sand deposits. These coatings are distinct from the rest since they are strongly adhered to the aggregate surface. It has been widely probed that the clay in contact with the cement paste decreases the compressive strength and also enhance shrinkage in concrete. This is due to the fact that an important amount of clay in cement paste decreases the quantity of water available for the hydration reactions and thus, reduces the workability of the concrete and also changes the progress of the different reactions (Muñoz et al. 2005).

A studied carried out by Muñoz et al. (2007), in which they investigated the effect that three different types of coatings had on the performance of concrete, probed that coatings with clays were more harmful than coatings with carbonates or dust. On the one hand they probed that coatings containing clays or dust significantly increase the amount of shrinkage suffered by the concrete and reduce slump. On the other hand, coatings containing carbonates did not considerably affect concrete workability. In addition, they demonstrated that the type of coatings used in their studies did not affect the compressive strength. However, aggregates with coatings containing carbonate fines were found to increase their tensile strength.

In order to have a better understanding on the effect that an outer layer of dirtiness has on the performance of concrete, Rocco & Elices (2009) carried out a research with crushed and rounded aggregates. They treated the surface of these two types of aggregates in order to simulate a coating of dirtiness that may affect the bond between the aggregates and the cement paste.

The dirtiness of the outer layer of the aggregates when they are not washed is supposed to result in a lower strength of the concrete and in a way of failure like that represented in the next figure:

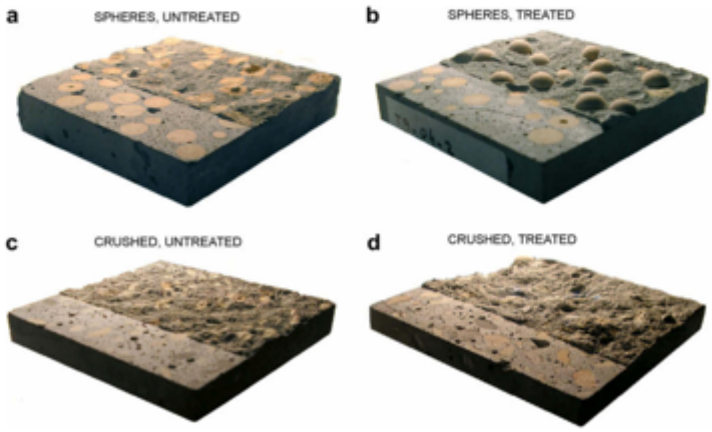


Figure 14. Different ways of failure depending on the type of coarse aggregate and if they are washed or not (Elices & Rocco 2008).

It can be seen that with crushed aggregates, the way of failure is very similar when they are either washed or not. This fact suggests that the stronger bond between the particles and the cement paste due to the rough surface is more important than if the surface is washed or not. On the opposite, with rounded aggregates the way of failure is different if they are washed of if they are not washed. When they are washed, the bond between particles and cement is strong and thus, the aggregates are broken. However, when the aggregates are not washed, the bond is not strong enough and some particles are debonded from the matrix.

2.3.7. Porosity and absorption of aggregates

The porosity, along with permeability and absorption of aggregates affects the bond between them and the cement paste, the resistance of concrete to abrasion, as well as the resistance to freezing and thawing.

The size of the pores in aggregates varies over a wide range, but even the smallest pores are larger than the gel pores in the cement paste. These pores can be entirely within the solid or open onto the aggregate surface. These open pores can be filled with water and the amount of it depends on the pores size, continuity and total volume.

The range of porosity of the aggregates can vary from 0 to 50 per cent. As it has been said, aggregates make up at least three quarter of the total volume of concrete, so it is clear that the porosity of the aggregates used contributes to the final porosity of concrete.

Aggregate is said to be saturated and surface dry when all the pores that are in the aggregate are full of water. When the water is evaporated to the air from the open pores, the aggregate is said to be air dry. The aggregate is completely dry when all the moisture has been removed. These stages are shown diagrammatically in the figure below:

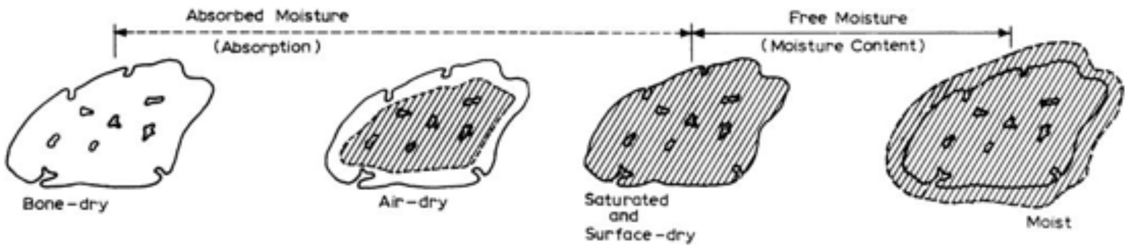


Figure 15. Diagrammatical representation of moisture in aggregates (Neville 1963)

Absorption represents the water contained in the aggregate in a saturated and surface dry condition. The amount of water absorbed by aggregates depends on the way of mixing the different materials that compose the concrete and on the coating of coarse aggregates with the cement paste. Also, this amount of water absorbed depends on the stage of the aggregate, if it is in an air dry condition it will absorb less water than in a bone dry condition.

They way the absorption has influence on the concrete properties is as follows: the water absorption of the aggregate has to be deducted from the total water required for the mix to obtain an effective water to cement ratio, which controls the strength of concrete as well as the workability (Neville & Brooks 2010).

Fine aggregates which have very low absorption commonly produce worse bonds and result in less durable concretes than aggregates with higher absorption (Quiroga & Fowler 2004). According to Washa (1998) and Day (2006) aggregates with low absorption reduce creep and shrinkage. If absorption increases, the strength of bond increases and the durability of concrete tends to decrease. However, care should be taken with aggregates with high water absorption. There are some aggregates able to absorb 20 per cent or more of their own weight. These aggregates must be used in a saturated state in order to avoid difficulty, otherwise, water will be absorbed during mixing, transporting and placing with a consequent loss in workability (Day 2006). Ahn (2000) stated that penetrable voids of very small size are the least recommendable when talking about durability and bond.

As an example of the importance that coarse aggregate absorption has on concrete properties, the experience of Day (2006) with two different basalts can be used. One of the basalts was superior to the other on every tested feature and it was denser and had less moisture movement. However, the other basalt was better to produce concrete with a strength over 60 MPa. It was assumed that this was due to the fact that the first bassalt, that with better properties, was so dense and impermeable that cement paste had difficulty in bonding to it.

2.4. Additives in concrete

There are several types of additives for concrete such as fly ash, blast furnace slag and silica fume. Next, this section is going to focus on fly ash influence in concrete.

2.4.1. Fly ash

Fly ash is a product that can be used in concrete as an admixture and contributes to improve concrete properties such as the strength. It is produced when coal is burned in electric power generating plants.

Fly ash is used as a replacement for some of the Portland cement content of concrete due to its pozzolanic properties (Scott & Thomas 2007). When Portland cement reacts with water it produces lime, which fills the voids, and hydrated calcium silicate, which develops strength. If fly ash is added to the mixture, it reacts with the lime and forms hydrated calcium silicate. This reaction of lime with fly ash results in an improvement of the concrete strength (Anon 2009; Rosenberg 2010).

Frequently, a percentage of fly ash between 15 and 35 by weight of cement is added in structural concrete. Whereas, up to 70 per cent is added for concrete used in parking areas, dams, and roller-compacted concrete (RCC). Care should be taken when selecting the percentage of fly ash to assure an improvement in concrete properties.

Fly ash is a perfect ingredient for concrete because of its characteristics: it has great durability and strength and, the most important thing, it is cheap. Furthermore, it is a recycled material, it contributes to prevent concrete companies from unnecessarily mining for other materials to make concrete. Since when using fly ash the amount of cement needed is reduced, it contributes to reduce energy and CO2 emissions associated with cement production.

The advantages of using fly ash to make concrete surpass by far the disadvantages. Using fly ash has advantages in both fresh and hardened concrete.

It can be obtained a decrease in the water required for mixing and placing concrete, since fly ash particles are spheric and with a similar size as Portland cement (Shilstone 1994). Fly ash provides fresh concrete with better workability. It also gives concrete better pumpability, finish, durability and cohesiveness, and reduces bleeding and segregation. Furthermore, properly cured concrete made with fly ash has smaller pores so the final product is denser, which increases strength and reduces permeability that is the major reason of early failure.

The most important factor that affects concrete strength is the water to cement ratio. Good quality fly ash allows to have better workability, or the same, with less amount of water. This decrease in the water needed leads to improve strength. Besides, some fly ash have bigger particles than Portland cement, so the hydration can continue for six months or even longer, resulting in higher ultimate strength than concrete made without fly ash (Rosenberg 2010).

Care should be taken when choosing the type of fly ash. Fly ash with poor quality can have adverse effects on concrete, such as increase permeability.

2.5. Admixtures in concrete

There are two main groups of admixtures in concrete. The first group are rheology modifiers; they change fresh concrete behaviour such as consistency, workability… Whereas, the second group are curing modifiers; they advance or delay the curing conditions or the curing itself.

According to their main function, admixtures are classified as follows by ASTM C 494-10 (Neville 1963):

- Water reducing
- Retarding
- Accelerating
- Water reducing and retarding
- Water reducing and accelerating
- High-range water-reducing or superplasticising
- High-range water reducing and retarding, or superplasticising and retarding

This paper is going to explain how the air entraining and superplasticising admixture work.

2.5.1. Air entraining admixture

Air entrainment consists in create tiny air bubbles in concrete. These bubbles are introduced into the concrete by an air entraining admixture. The bubbles are created during the mixing of the concrete, and they remain distributed uniformly inside the concrete once it has hardened. The use of air entraining admixtures in concrete provides them with better workability and durability.

The most important applications are for:

- Semidry concrete
- Low fine content concrete
- Freeze-thaw resistant concrete

2.5.2. Superplasticizers

Concrete superplasticizers are admixtures able to improve properties of concrete. They are used to confer concrete with better workability and pumpability as well as to improve its final strength and durability.

Generally, superplasticizers are used in concretes with liquid consistencies or even with self-compacting concrete. They provide a high reduction in the amount of water needed for the mix and it improves consistency so the fresh concrete is more workable.

By using superplasticizers concretes with the following properties are achieved:

- Low water to cement ratio

- High resistance
- High consistency
- Perfect workability

The dosage is, in general, between 0,6 and 2 per cent of the cement weight and it depends on features such as the desired strength and consistency, weather conditions, working conditions and materials (BASF 2014).

2.6. Conclusions and further research

As a summary it can be said that it has been widely probed that aggregates characteristics affect both fresh and hardened concrete properties. However, not all the aggregates properties affect in the same manner and extent. Aggregate characteristics that affect the most concrete properties are the type of coarse aggregate, grading, maximum aggregate size, shape, texture, coatings, porosity and absorption.

In order to get a better understanding in concrete properties it is indispensable to comprehend the role played by the aggregates.

As it has been previously mentioned, several researches have been carried out in order to determine how aggregate characteristics affect concrete properties. Most of the researches got the same conclusions and have contributed with their results to get a better understanding about aggregates and to improve concrete properties. However, there are some disagreements between different authors and further researches are needed.

In order to avoid problems due to aggregates coatings, they are washed before using them. It is widely known that washing the aggregates usually removes coatings. However, the profit of eliminating coatings can be reduced by the cost of washing and accumulating the fines that are removed. As a consequence, a better comprehension of aggregate cleaning could have an important impact on processing of aggregates from an economic point of view. And this research is going to focus on this aspect.

Since most of the aggregates are washed, researches about how fly ash affects concrete properties have been carried out with washed aggregates. Thus, it is interesting to study how the amount of fly ash in concrete affects fresh and hardened concrete properties when aggregates are either washed or not.

3. PRELIMINARY WORKS

In this section, the different tests and procedures carried out throughout the research to make concrete and to measure its characteristics in fresh and hardened state are explained. The structure followed is as summarized below:

- Materials. Before starting mixing it is necessary to determine aggregates properties such as the density, absorption and moisture content. Furthermore, in those series with washed aggregates it is necessary to wash them by hand, since they have been provided in unwashed conditions.
- Mix design. Stage pre mixing, when the procedure to design the mix is carried out.
- Mixing. It is important to establish the same way of mixing for all the series in the research. The fewer variables during the mixing process the better to obtain comparable values.
- Fresh concrete properties. Important stage in which concrete properties such as slump and air content are measured.
- Casting and curing. Once the fresh concrete properties have been measured, concrete is poured into the moulds and left curing during 24 hours at a room temperature. Then, they are placed in 20 ºC tanks and they continue curing until the test time.
- Hardened concrete properties. This last stage is the most important one. Concrete properties of splitting tensile strength, compressive strength, modulus of elasticity and Poisson’s ratio are measured.

3.1. Materials

The materials used in this research are as follows (see Chapter 4.1 for further information about their main properties) and all of them have been provided by Aalborg Portland:

- Crushed granite divided in 4 size ranges: 2/8, 8/11, 11/16 and 16/22
- Sand 00/02
- Low alkali cement
- Fly ash
- Superplasticizer: Glenium ACE 410
- Air entrainment: Amex SB 22

In order to prepare the mix design, first of all, it is needed to calculate some physical properties of the aggregates such as the density, moisture content and absorption capacity since they affect the amount of mixing water required.

Figure 16. Aggregates and sand in their buckets

3.1.1. Density, absorption and moisture content

The density and absorption are intrinsic properties of the aggregates and they have been measured and provided directly by Aalborg Portland. These properties are specified in Chapter 4.1.1.

However, the value of the moisture content depends on the day that is measured. Thus, it is needed to measure this value every day before mixing. The procedure to measure the moisture content is according to the European Standard EN 1097-5:2008 and the main aspects of this method are as follows:

- The aggregate is in a bulk sample and it has to be taken and prepared according to the European Standard EN 932-1:1997: Tests for general properties of aggregates Part 1: Methods for sampling.
- The sample is placed in a container and it is weighted. The value is recorded on the test sheet (Mwet).
- The sample is removed from the container and it is heated until its surface is dry, with special care in not loosing material.
- Once it is dry, it is placed again in the container and weighted. The value is recorded on the test sheet (Mssd).
- Then, the moisture content is calculated as follows:

$$u = \frac{m_{wet} - m_{ssd}}{m_{ssd}} \cdot 100\%$$

When the aggregate is wet, the value used to design the mix is the moisture content. However, if the aggregate is dry, the value of the absorption capacity is used instead of the moisture content.

3.1.2. Aggregates surface

As it has been mentioned, the research is going to be carried out with three different amounts of fly ash (0, 15 and 25 %) and with different surface conditions (washed and not washed). This section is about washing the aggregates.

The aggregates have been provided without washing. When series with unwashed aggregates are casted there is no need of treating the aggregates. However, when series with washed aggregates are casted, they have to be washed before mixing them with the rest of the components. The way of washing the aggregates has been as follows:

- A little more of the amount of aggregates needed for the mixing, divided into the different size ranges, is spread on the floor and washed with water so the biggest dirtiness is removed.
- Then, smaller fractions of aggregates are placed in a sieve and are immersed in water, so the smaller particles of dirtiness are unstuck from the surface.
- Finally, the aggregates are spread on a clean surface until they are dry.

This procedure has to be done the day before mixing with washed aggregates. As it has been mentioned in the previous section (Chapter 3.1.1) it is necessary to measure the moisture content before the mixing.

3.2. Mix design

The mix has been designed taking into account a serie of prerequisites that are:

- Water to cement ratio is equal to 0.4
- The volume of cement paste, cement + fly ash + water, is kept constant

An excel sheet has been designed with these two prerequisites (see Appendix B.2 for further details) so by entering the value of either the moisture content or the absorption, it is possible to determine the proportions of the mix. Other values that are required for the mix design are the amount of admixtures (superplasticizer and air entrainment) used to make fresh concrete with specific slump and air content.

The amount of admixtures used varies depending on the content of fly ash that the mix has. These values are not pre-established so it was necessary to carry out preliminary tests to calculate them (see values on Appendix B.1). These preliminary tests consisted in trying different proportions and measuring the slump and air content, as is going to be explained in Chapter 3.4, of a little amount of fresh concrete (12 litres) until the desired values were obtained. However, it was probed that the admixtures proportion were not the same when the amount of concrete was 12 litres as when it was around 40 litres, thus it was impossible to obtained the slumps and air contents desired.

3.3. Mixing

The mixer used is the one in the next figure.

Figure 17. Machine used for mixing concrete

The procedure of mixing is as stated below:

- The concrete mixer has to be started before adding anything into it.
- Aggregates, fly ash and cement are mixed 5 minutes before adding water and admixtures.
- Once water and admixtures are added, the concrete is mixed for 5 minutes more.

Then, concrete is ready for measuring its properties in fresh condition.

3.4. Fresh concrete properties

3.4.1. Density

The density of fresh concrete is measured according to the European Standard EN 12350-6: 2009. The following statements explain the main points of this test:

- The empty bucket is weighted and the value is recorded in a sheet (m1).
- The fresh concrete is poured into the 10 litres (V) bucket and then it is make up to the volume.

Figure 18. 10 litres bucket for measuring fresh concrete density

- The bucket filled with concrete is vibrated in a vibrating table for 20 seconds, so the air voids are eliminated.

Figure 19. Vibrating table

- The bucket with concrete is weighted and the value is written down in a sheet (m2).
- The density is calculated by the following formula:

$$D = \frac{m_2 - m_1}{V}$$

3.4.2. Slump

The slump of fresh concrete is measured according to the European Standard EN 12350-2: 2009. The main aspects of this test are as follows:

- The mould (cone) is placed over the base tray on a horizontal surface. Both the mould and the base tray are previously moistened.
- The cone is firmly held in place throughout the test with the foot pieces.
- The cone is filled in three times, each of them is 1/3 of the total height.
- Each layer is compacted with a rod 10 times. The rod has hemispherical steel tip.
- Once the last layer has been compacted, the excess concrete from the top of the cone is removed using the rod.
- The cone is removed by lifting it vertically and slowly.
- The cone is inverted and placed next to the slumped concrete without touching it.
- The slump is measured with a ruler as it is represented in the figure below, from the bottom of the cone to the top of the slumped concrete.

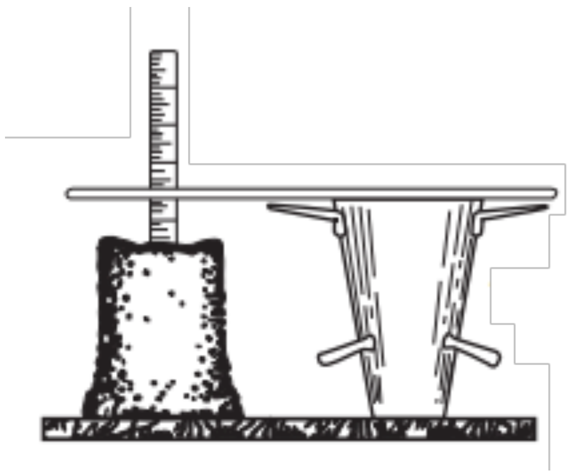


Figure 20. Slump test

- Finally, the value of the slump is recorded in mm in a sheet.

3.4.3. Air content

The air content in the fresh concrete is measured following the European Standard EN 12350-7: 2010. The procedure is as it is expressed in the statements below:

- Fresh concrete is poured into the container.
- It is filled to the top and then, it is vibrated in a vibration table during 15 seconds.
- The container with the fresh concrete inside is carefully placed over a horizontal surface and all the exceed concrete is cleaned from the container.
- The top part of the device, which consists of the manometer and air pumping, is placed on the container and tightly closed.

Figure 21. Device to measure the air content in fresh concrete

- The value of the air content is writing down on a sheet.

3.5. Casting and curing

The moulds used to make the samples are 200 mm height and have 100 mm of inner diameter. Both the moulds and the cylinders are as detailed in the European Standard EN 12390-1:2012: Shape, dimensions and other requirements for specimens and moulds. They are shown in the next figure:

Figure 22. Moulds used to make concrete

Casting and curing are carried out as it is specified in the European Standard EN 2390-2:2009: Making and curing specimens for strength tests. Next, the main points of the procedure are highlighted:

- Before pouring concrete, moulds are impregnated with a non-reactive release agent in order to avoid adherence of the concrete in the mould when demoling.
- The concrete is poured. The moulds have a ring in the upper part so an excess of concrete can be poured.

Figure 23. Rings for the moulds

- The moulds are vibrated in a vibrating table during 15 seconds.
- The ring is removed and the excess of concrete is removed as well with a trowel. Then, the surface should be carefully levelled.

- The cover of the mould is placed and firmly closed.

Once the samples are casted, they are left 24 hours before demolding them at room temperature.

Figure 24. Samples curing 24 hours at room temperature

24 hours after the casting, they are demolded. Chalk is used to write a code in each sample in order to distinguish the different series. Further information about the code and the composition of each serie can be found in Chapter 1.2.

Once they have been marked, they are placed in a water tank for curing. The temperature inside the water tank is 20ºC.

Figure 25. Tank filled with water for concrete curing at 20ºC

3.6. Hardened concrete tests

The samples are taken from the tank right before the performance of the test. Before testing any sample, measurements of the height, width and weight of the samples have to be taken. To measure height and width an electronic gauge is used as the one shown in the figure below:

Figure 26. Gauge for measuring cylinders height and width

Once the physical properties of the samples have been recorded, the tests can be carried out. The hardened concrete properties that are going to be measured are the compressive strength, tensile strength, modulus of elasticity and Poisson coefficient. To do so, a testing machine which properties are specified next, is used.

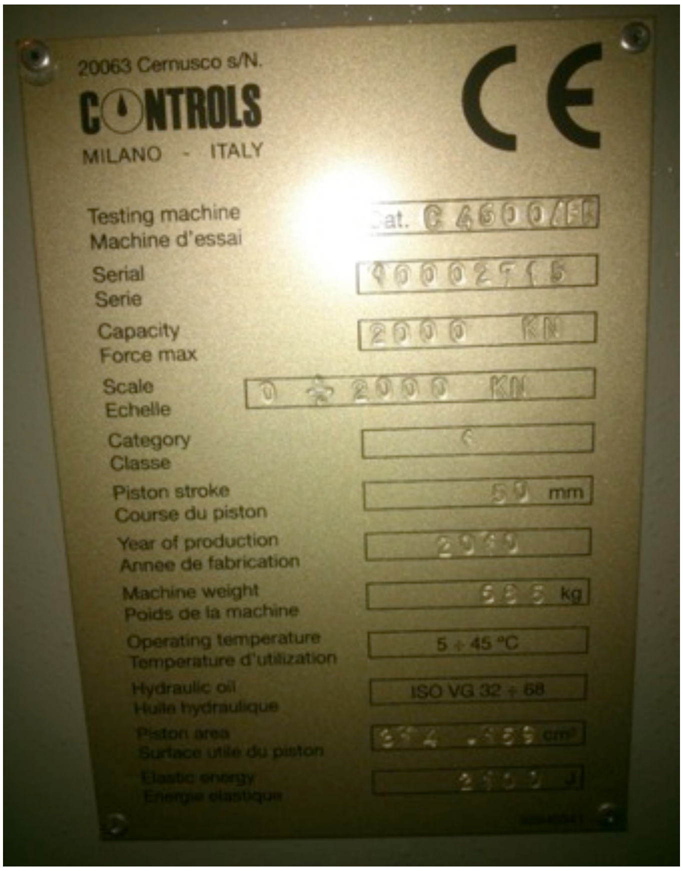


Figure 27. Testing machine properties

3.6.1. Compressive strength

The compressive strength test is performed as stated in the European Standard EN 12390-3: 2009 and the main points of the aforementioned procedure are those explained below:

- The characteristics of the machine used for the compressive test are those indicated in the European Standard EN 12390-4: 2001.
- It has to me assured that the disks of the machine are not dirty. Any kind of dirtiness has to be removed before placing the cylinder and starting the machine.
- The excess of humidity has to be removed from the surface of the cylinders before placing them in the machine.
- The cylinders have to be placed in the centre of the disk and in such a way that the load is applied perpendicularly to their axis.

Figure 28. Compressive strength test

- The load is applied as specified in the Standard.
- Once the cylinder is broken, the way of breaking is analysed and determined whether it is or not satisfactory according to the patterns shown in the Standard.
- The compressive strength is calculated with the following formula:

$$f_c = \frac{F}{A_c}$$

f_c: compressive strength

F: Breaking load

A_c: Transversal area of the cylinder

- The data obtained form the test is recorded.

3.6.2. Splitting tensile strength

The machine used in the splitting tensile strength test is the same as the one used in the compressive strength test. However, instead of using the three disks as in the compressive strength test, one of them is removed as shown in the figure below:

Figure 29. Machine ready for the splitting tensile strength test

The steps for the performance of the splitting tensile strength test are specified in the European Standard EN 12390-6: 2010, and they are summarized as follows:

- It has to me assured that the disks of the machine and the press are not dirty. Any kind of dirtiness has to be removed before placing the press.
- The press is placed inside the machine and centred on the disk.

Figure 30. Splitting tensile strength test

- The excess of humidity has to be removed from the surface of the cylinders before placing them in the press.
- Special care must be taken in order to assure that the cylinder is correctly placed in the press, so the load is uniformly applied.

Figure 31. Placement of the cylinder for the splitting tensile strength test

- The load is applied as specified in the Standard.
- The tensile strength is calculated with the following formula:

$$f_{ct} = \frac{2 \times F}{\pi \times L \times d}$$

f_{ct}: tensile strength

F: breaking load

L: length of the cylinder

d: diameter of the cylinder

- The data obtained form the test is recorded.

3.6.3. Modulus of elasticity and Poisson coefficient

In order to calculate the modulus of elasticity and the Poisson coefficient two Standard are followed, ASTM C 469-02: Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, and the European Standard EN 12390-13: 2013: Determination of secant modulus of elasticity in compression.

The result is summarized in the following statements:

- Firstly, the compressive strength has to be calculated according to the European Standard EN 12390-3.
- Two gauges are placed facing each other in the lateral part of the cylinder as represented in the figure below and as specified in the European Standard EN 12390-13. They are in charge of measuring the longitudinal strain of the cylinders in order to calculate the modulus of elasticity.

Figure 32. Gauges for measuring longitudinal strains

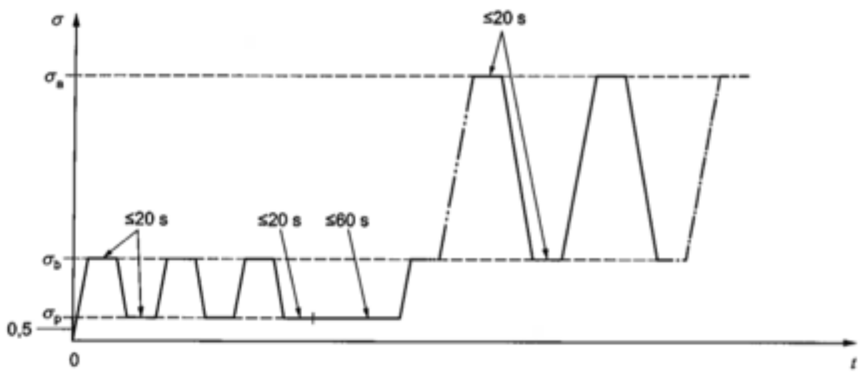
- An extensometer is mounted circumferentially at diametrically opposite points of the cylinder and at its midheight. It is in charge of measuring the circumferential strain in order to calculate the Poisson coefficient.

Figure 33. Circumferential extensometer for measuring transversal strain

- Place the cylinder with all the measuring equipment attached in the machine. It has to be placed in the centre of the disk, as represented in the next figure.

Figure 34. Extensometers for measuring longitudinal and transversal strains

- Start with the pre-loading cycles as specified in the European Standard EN 12390-13 and check the measurements as specified in the aforementioned Standard. If the checks are not correct, then the machine has to be restarted. An excel sheet used to check the measurements is shown in Appendix E.5.2 as an example.
- Start with the loading cycles as specified in EN 12390-13.
- The final plot must be similar to the following:



- Finally, data is analysed as explained in both Standards; EN 12390-13 for the modulus of elasticity and ASTM C 469-02 for the Poisson coefficient (an example is shown in Appendix E.5.3).

Further information about the elasticity and Poisson test is collected in Appendix E.5.

In order to determine which is the accuracy of the method used to calculate the modulus of elasticity and the Poisson coefficient, a preliminary test is implemented. The preliminary test consisted in testing Elasticity and Poisson in three different faces of a cylinder, and each face has been tested, without moving the equipment, three times. The results obtained can be found in Appendix E.5.1.

4. EXPERIMENTAL WORK

In the following section, the results of the different tests implemented will be presented. The procedure of the tests carried out have been stated in the previous section and next, a summary of the main results and conclusions are exposed.

4.1. Materials

In this section, a summary with the main properties of the components of the concrete mix is provided. For further information see Appendix A.1. All the materials used in this research to make concrete have been provided by Aalborg Portland.

The following statements summarize the main properties of the different components:

- The coarse aggregate used is crushed granite, thus it has an angular shape. The size range varies from 2 mm to 22 mm. They are divided in 4 size ranges that are 2/8, 8/11, 11/16 and 16/22.

Figure 35. Four size ranges of aggregates

- The sand is a common sand suitable for the desired mix.
- Low alkali cement is the one used in this research. It is specially designed for concrete used in civil works or other structures that are exposed to alkali-silica reactions, such as bridges or structures in touch with sulphated groundwater.
- Fly ash is added to the mix as it is suitable for the low alkali cement used.
- Glenium ACE 410 is a high performance superplasticizer. It may be used as a highly effective water reducer. It provides concrete with desirable properties for this research.
- The air entrainment chosen for this research is Amex SB 22. See Appendix A.2 for further information about its properties.

4.1.1. Density, absorption and moisture content

The following tables show the densities of the components mentioned above. They have been measured and provided by Aalborg Portland.

Component		Density (kg/m^3)
Cement paste		
Cement	Lavalkali	3210
Fly ash		2200
Water	Horsens water	1000
Air entrainment	Amex SB 22	1010
Super plasticizer	Glenium ACE 410	1050

Table 4. Cement paste component's densities

Component		Density (kg/m^3)
Aggregates		
Sand	00 / 02 mm	2634
Granite	2 / 8 mm	2750
Granite	8 / 11 mm	2779
Granite	11 / 16 mm	2759
Granite	16 / 22 mm	2751

Table 5. Aggregates' densities

The absorption of the aggregates are represented in the next table:

	Sand 00/02	Granite 16/22 mm	Granite 11/16 mm	Granite 8/11 mm	Granite 2/8 mm
Absorption (%)	0.17	0.31	0.30	0.30	0.51

Table 6. Moisture content

An important data before mixing concrete, as it has been said, is the moisture content of the aggregates (see Chapter 3.1.1) and their values per serie are summarized in the next table (see Appendix A.3 for further information about the moisture content):

	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Serie 1	0,74	0,26	0,22	0,19	0,00
Serie 2	1,46	0,96	1,16	0,70	0,11
Serie 3	1,14	1,16	0,00	0,00	0,00
Serie 4	0,92	1,28	0,66	0,40	0,14
Serie 5	1,47	0,50	0,82	0,41	0,11
Serie 6	1,40	5,13	1,72	1,04	0,25

Table 7. Moisture content of the aggregates per serie

4.2. Mix design

In this chapter, a summary with the different mix designs carried out is going to be exposed. The prerequisites for mix design have been explained in previous chapters (see Chapter 3.2) and more detailed data regarding compositions and proportions can be found in Appendix B.2.

The following list includes the different types of concrete divided in 6 different series:

- Serie 1: 0 per cent of fly ash and unwashed surface conditions.
- Serie 2: 15 per cent of fly ash and unwashed surface conditions.
- Serie 3: 25 per cent of fly ash and unwashed surface conditions.
- Serie 4: 0 per cent of fly ash and washed surface conditions.
- Serie 5: 15 per cent of fly ash and washed surface conditions.
- Serie 6: 25 per cent of fly ash and washed surface conditions.

SERIES	CODE	TEMPERATURE	SURFACE	% FA
Serie I	AUI	20ºC	UNWASHED	0
Serie II	AUII	20ºC	UNWASHED	15
Serie III	AUIII	20ºC	UNWASHED	25
Serie IV	AWI	20ºC	WASHED	0
Serie V	AWII	20ºC	WASHED	15
Serie VI	AWIII	20ºC	WASHED	25

Table 5. Composition of the different series

4.3. Mixing

As it has been said, 6 series of concrete have been made with different amounts of fly ash and with different surface conditions (washed or not). For each serie different amounts of concrete, depending on the number of cylinders required, have been used and they are as follows:

	Serie 1	Serie 2	Serie 3	Serie 4	Serie 5	Serie 6
Number of cylinders	30	30	24	23	23	23
Produced Volume (m3)	0,055	0,055	0,045	0,045	0,045	0,045
Produced Mass (kg)	128,81	123,53	100,13	105,19	100,73	102,38

Table 6. Amount of produced concrete

The dosage of each serie is represented in the tables below, divided into cement paste components and aggregates. For more details see Appendix C.

	Cement	Fly ash	Water	Air entrainment	Super plasticizer
Serie 1	19.830	0	7.637	22	43
Serie 2	17.430	2.610	6.446	33	88
Serie 3	13.190	3.300	5.421	23	81
Serie 4	16.230	0	5.809	18	36
Serie 5	14.260	2.140	5.411	27	72
Serie 6	13.190	3.300	4.133	23	81

Table 8. Dosage of the cement paste components per serie (in grams)

	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Serie 1	35.900	25.590	8.690	8.620	23.350
Serie 2	36.140	25.760	8.770	8.660	23.490
Serie 3	29.480	21.120	7.070	7.020	1.910
Serie 4	29.420	21.150	7.140	7.070	19.230
Serie 5	29.580	20.980	7.150	7.070	19.220
Serie 6	29.550	21.950	7.210	7.110	19.240

Table 9. Dosage of aggregates per serie (in grams)

4.4. Fresh concrete properties

According to the dosages represented in previous tables, the following properties of fresh concrete have been measured and are further detailed in Appendix D:

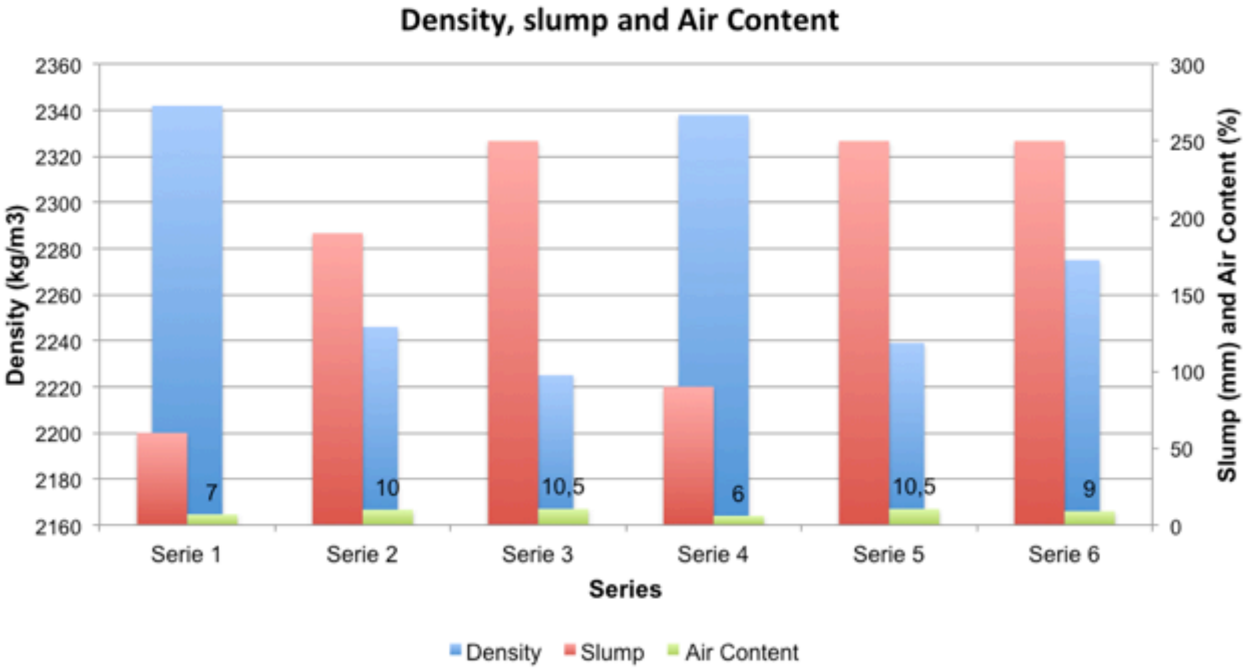


Figure 36. Density, slump and air content in fresh concrete

For higher air contents, lower densities and higher slumps have been achieved. The opposite has occurred with lower air contents.

Serie 1 and 4 (without fly ash) have almost the same values for the density, slump and air content.

4.5. Hardened concrete properties

The hardened concrete properties measured were, as it has been said, the compressive strength, tensile strength, modulus of elasticity and Poisson Coefficient. All the data obtained have been recorded in a sheet of paper as the one shown in Appendix E.1.

Curve fitting was made on strength and elastic development curves from the experimental data. The exponential equation used was proposed by Freiesleben Hansen & Pedersen (1985) for concrete under isothermal curing and it is as follows:

Strength curve fitting:

$$f_c = f_\infty \cdot \exp\left[-\left(\frac{\tau}{M}\right)^\alpha\right]$$

f_∞, total strength developed for M tending to infinity (MPa)

f_c, strength at the maturity day M (MPa)

M, concrete maturity day (days)

τ, time constant (days)

α, shape parameter

Elasticity curve fitting:

$$E_c = E_\infty \cdot \exp\left[-\left(\frac{\tau}{M}\right)^\alpha\right]$$

E_∞, total elasticity developed for M tending to infinity (MPa)

E_c, elasticity at the maturity day M (MPa)

M, concrete maturity day (days)

τ, time constant (days)

α, shape parameter

4.5.1. Compressive strength

A summary table with all the data obtained from the compressive strength test can be found in Appendix E.2.

A curve fitting, which represents the compressive strength against time, has been calculated and further information about these calculations is presented in Appendix E.3.

In the next graphic the compressive strength of the six series along time is shown:

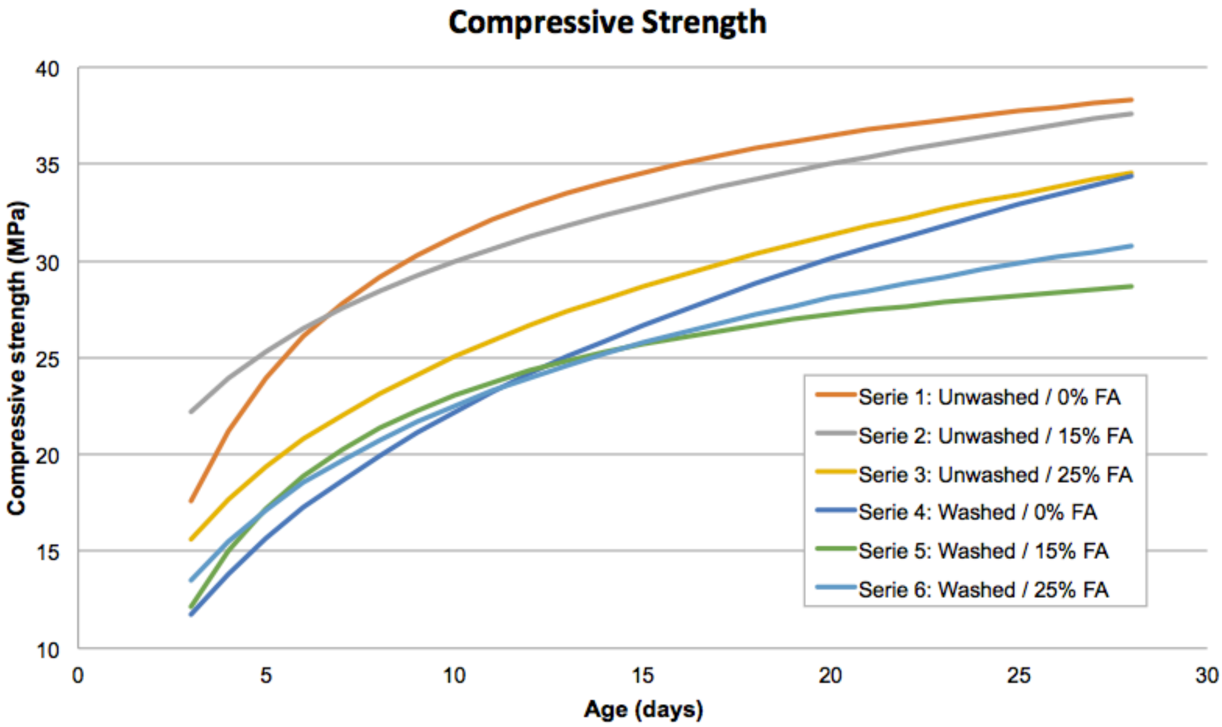


Figure 37. Compressive strength along time

The higher compressive strength (38,3 MPa) has been developed by that concrete made with unwashed aggregates and 0% of fly ash. Whereas, the lower compressive strength (11,7 MPa) is for that concrete made with washed aggregates and 0% of fly ash.

The compressive strength of the concrete made with unwashed aggregates is always higher than those concretes made with washed aggregates, regardless the percentage of fly ash in the mixture.

Those series with a fly ash composition of 0% get higher compressive strengths at the age of 28 days, while at the early ages the higher compressive strength is developed by the 15% fly ash mixture with unwashed aggregates, and by the 25% fly ash mixture with washed aggregates.

Due to the way the mix has been designed, the amount of cement paste is lower for a higher percentage of fly ash. Since the strength of the fly ash particle is lower than the cement particle, the strength of the concrete with a lower percentage of fly ash is supposed to be higher, as it has been probed in the present research for the compressive strength at 28 days.

It can be observed that the Serie 3 made with unwashed aggregates and 15% of fly ash achieved the 28th day the same compressive strength that the Serie 4 made with washed aggregates and 0% of fly ash. However, at early ages the compressive strength is higher for the Serie 3 than for the Serie 4.

From the graphic above it can be concluded that the hardening of concrete regarding the compressive strength is very similar for all the series. The fastest hardening at early ages is for the Serie with unwashed aggregates and 0% of fly ash and, as it has been remarked previously, that concrete has achieved the highest compressive strength.

4.5.2. Tensile strength

A summary table with all the data obtained from the splitting tensile strength test is shown in Appendix E.2.

A curve fitting, which represents the tensile strength along time, has been calculated and further information about these calculations is presented in Appendix E.4.

In the next graphic the tensile strength of the six series along time is shown:

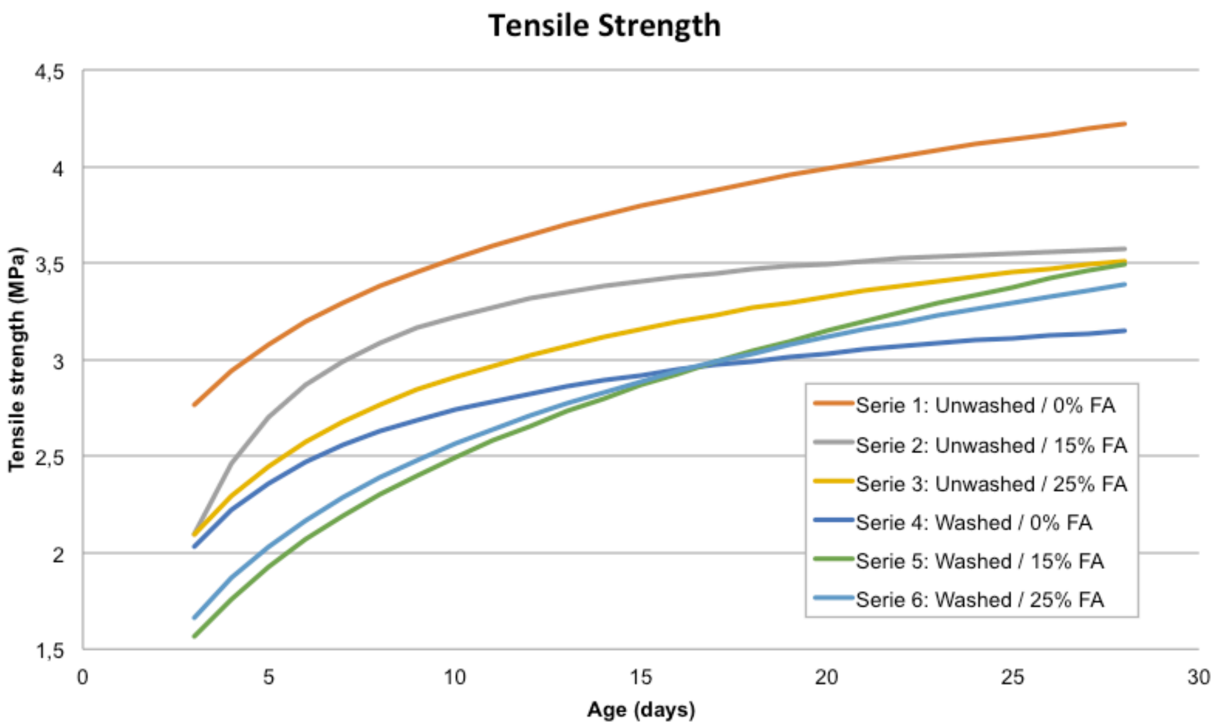


Figure 38. Tensile strength along time

The lower tensile strength (1,56 MPa) has been developed by that concrete made with washed aggregates and 15% of fly ash. Whereas, the higher tensile strength (4,22) is for that concrete made with unwashed aggregates and 0% of fly ash.

As it happened with the compressive strength, the tensile strength developed by the concrete made with unwashed aggregates is always higher than the tensile strength for concretes made with washed aggregates, regardless the percentage of fly ash in the mixture. This trend is observed for early ages as well as for ages of 28 days.

In the case of the tensile strength, it is clear that from the experimental data it can be concluded that the best mix is that with unwashed aggregates and 0% of fly ash since it develops the highest tensile strength in both early ages and for 28 days.

Regarding the concrete with unwashed aggregates and fly ash, almost the same tensile strength is achieved the 3rd day and the 28th day, however, the hardening speed at early ages is higher for the serie with 15% of fly ash. The same tensile strength at the 28th day is developed by the serie with washed aggregates and 15% of fly ash even if at the early ages the tensile strength is much lower.

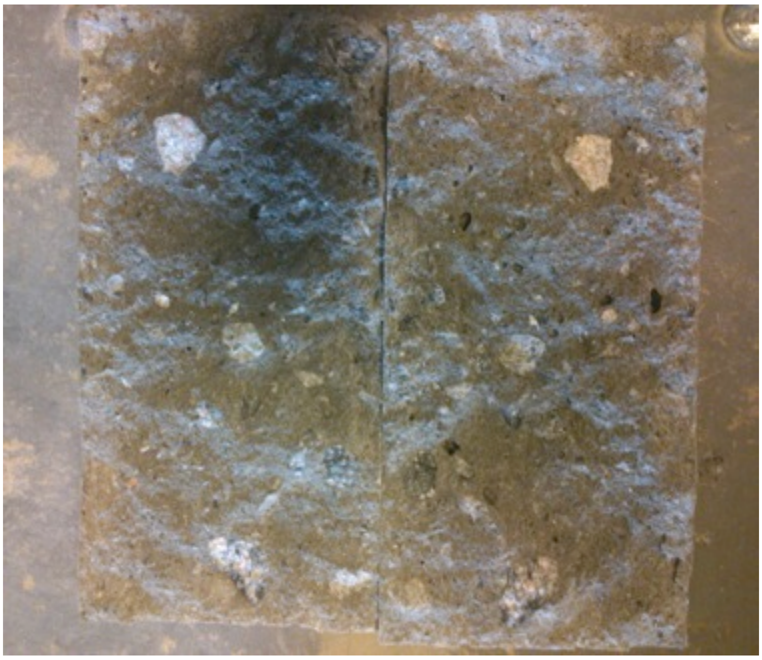
After the splitting tensile strength test, pictures have been taken to the section os the samples in order to observe which has been the mode of failure.

Next, a table with a picture from each serie is shown. It can be observed that all the specimens have broken through the aggregates instead of through the cement.

Serie 1: Unwashed / 0 % FA

Serie 2: Unwashed / 15 % FA


Serie 3: Unwashed / 25 % FA



Serie 4: Washed / 0 % FA

Serie 5: Washed / 15 % FA

Serie 6: Washed / 25 % FA

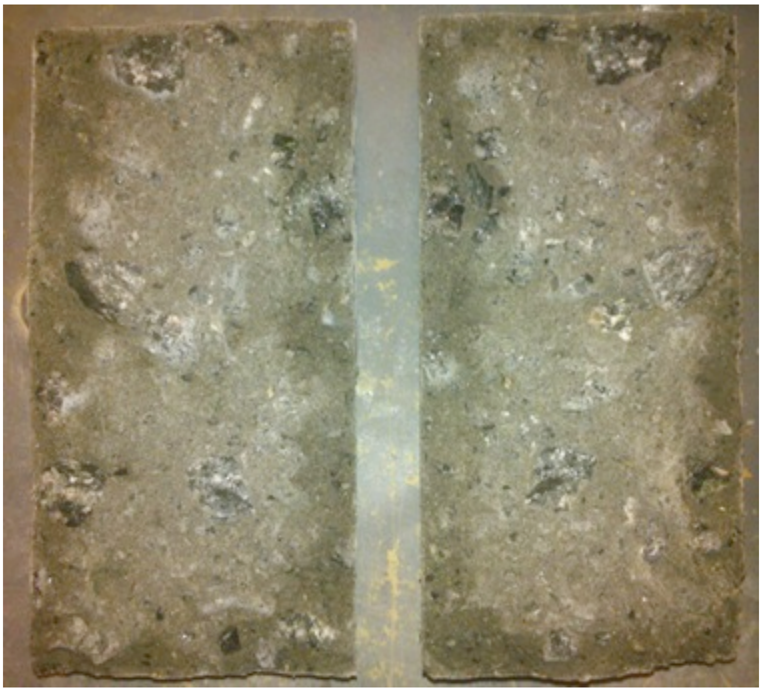


Table 10. Samples broken after the splitting tensile strength test

4.5.3. Modulus of elasticity

A summary table with all the data obtained from the elasticity test is shown in Appendix E.2.

A curve fitting, which represents the modulus of elasticity along time, has been calculated and further information about these calculations is presented in Appendix E.5.4 AND E.5.5.

In the next graphics the static and dynamic modulus of elasticity of the six series along time are shown:

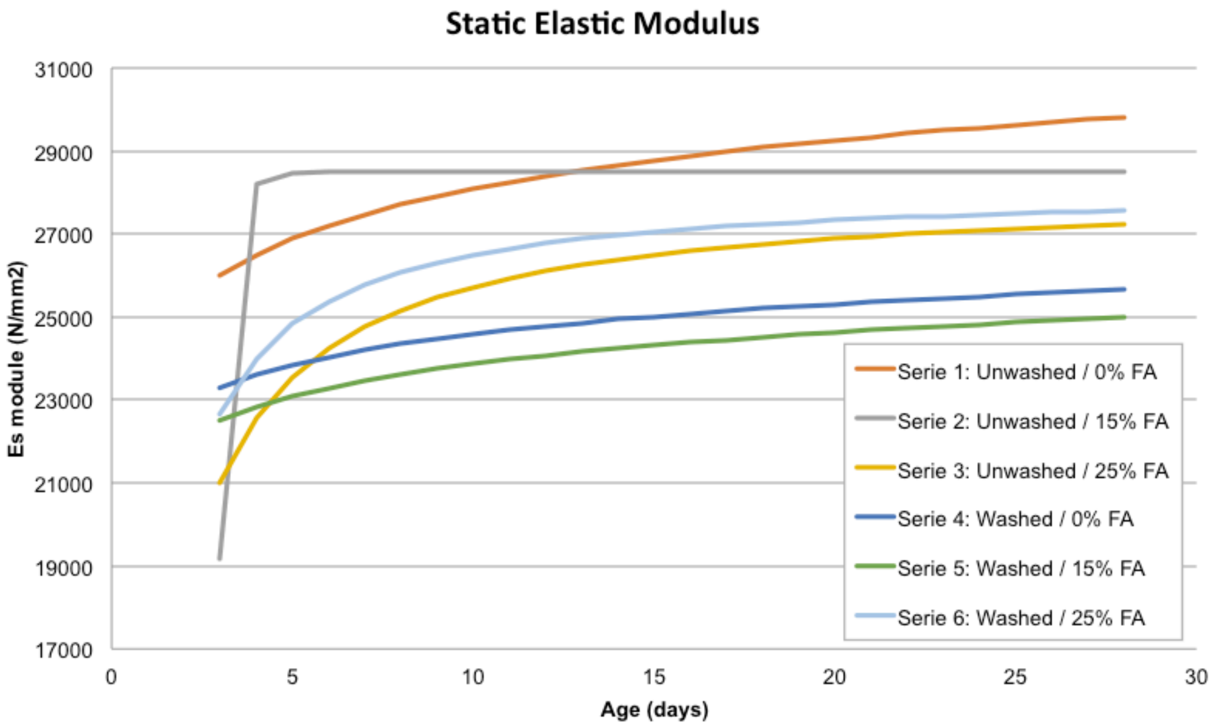


Figure 39. Static elastic modulus along time

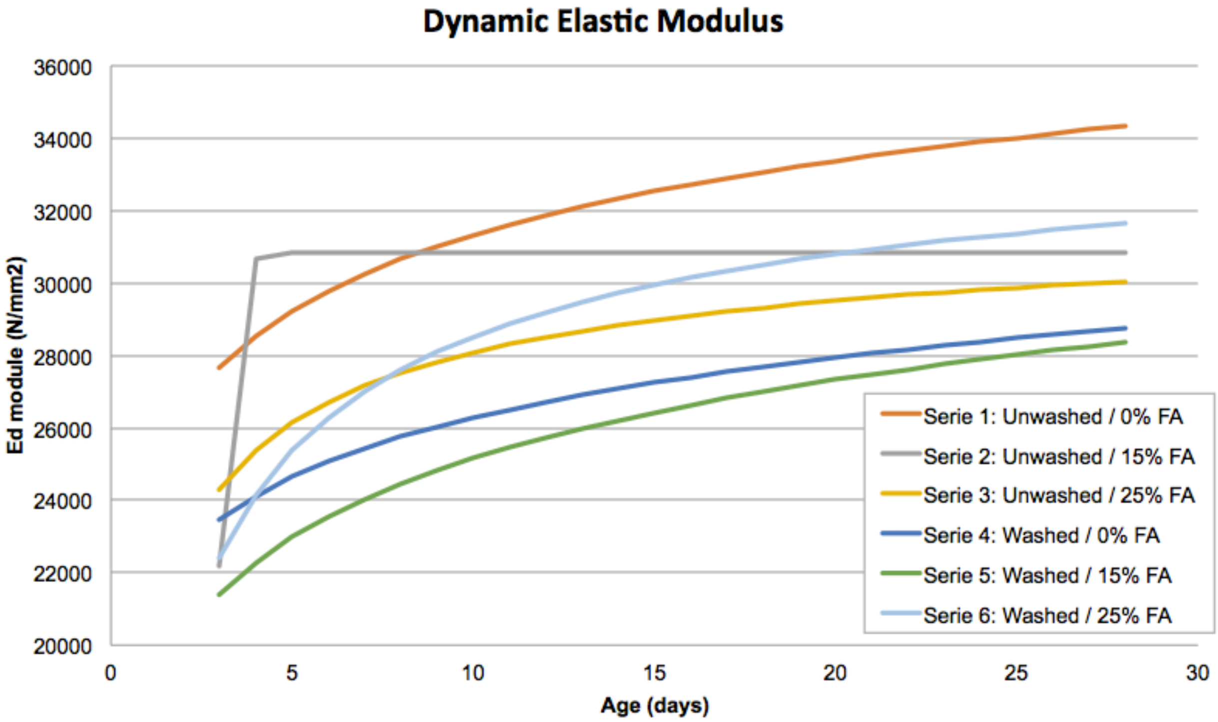


Figure 40. Dynamic elastic modulus along time

Both graphics, the static elastic modulus and the dynamic elastic modulus, are very similar. The shape of the fitting curves is quite similar for both elastic modulus, and the static elastic modulus is always around 2.000 MPA lower than the dynamic elastic modulus.

Regarding the modulus of elasticity, the trend of achieving higher values for mixes with unwashed aggregates is not as clear as in the case of the compressive and tensile strength. However, the highest value at 28 days is also developed by the serie with unwashed aggregates and 0% of fly ash.

On the one hand, the highest static and dynamic elastic modulus at 28th day were obtained by the unwashed and 0% of fly ash serie and the lowest by the washed and 15% of fly ash serie. On the other hand, at early ages, the highest static and dynamic elastic modulus were obtained by Serie 1, while the lowest static elastic modulus were obtained by Serie 2 and the lowest dynamic elastic modulus were obtained by Serie 5.

4.5.4. Poisson coefficient

A summary table with all the data obtained from the Poisson's test is shown in Appendix E.2.

The following graphic shows the experimental data obtained for the six series:

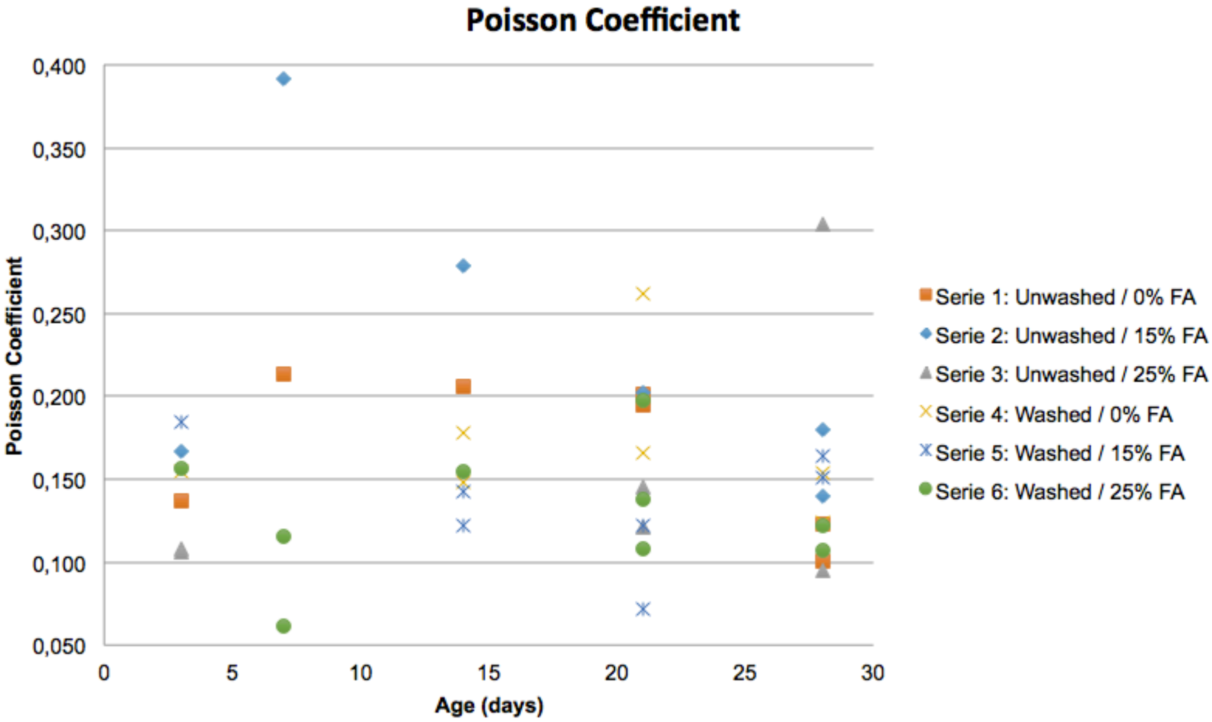


Figure 41. Poisson coefficient

Any clear conclusion can be obtained from the graphic above. The data obtained is not very reliable since the equipment needed for the test is very difficult to use and some problems occurred during the performance of the tests.

All the values obtained per serie are collected in Appendix E.5.6.

4.5.5. Relations between concrete properties

COMPRESSIVE AND TENSILE STRENGTH AGAINST FRESH CONCRETE PROPERTIES

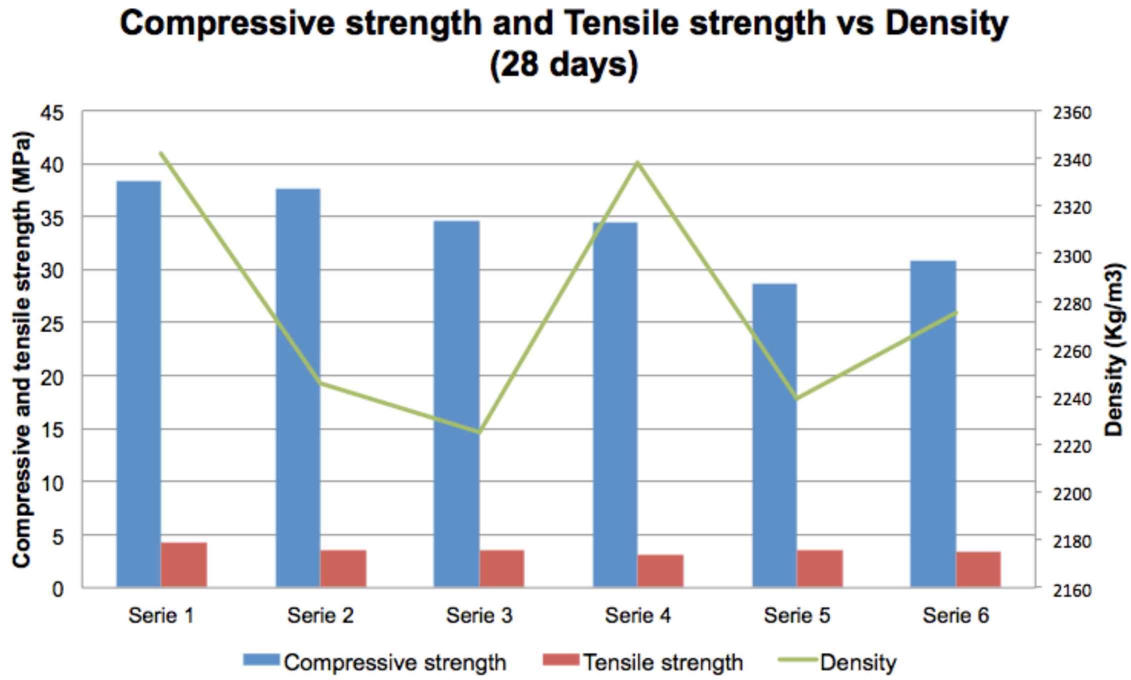


Figure 42. Compressive and tensile strength vs density

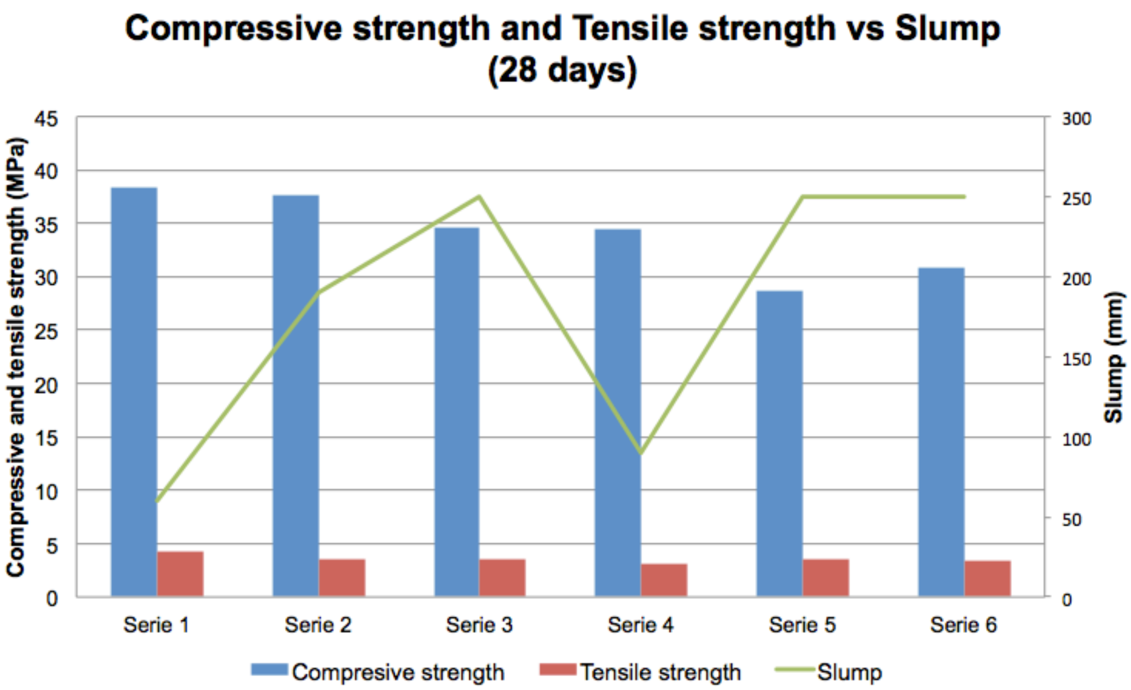


Figure 43. Compressive and tensile strength vs slump

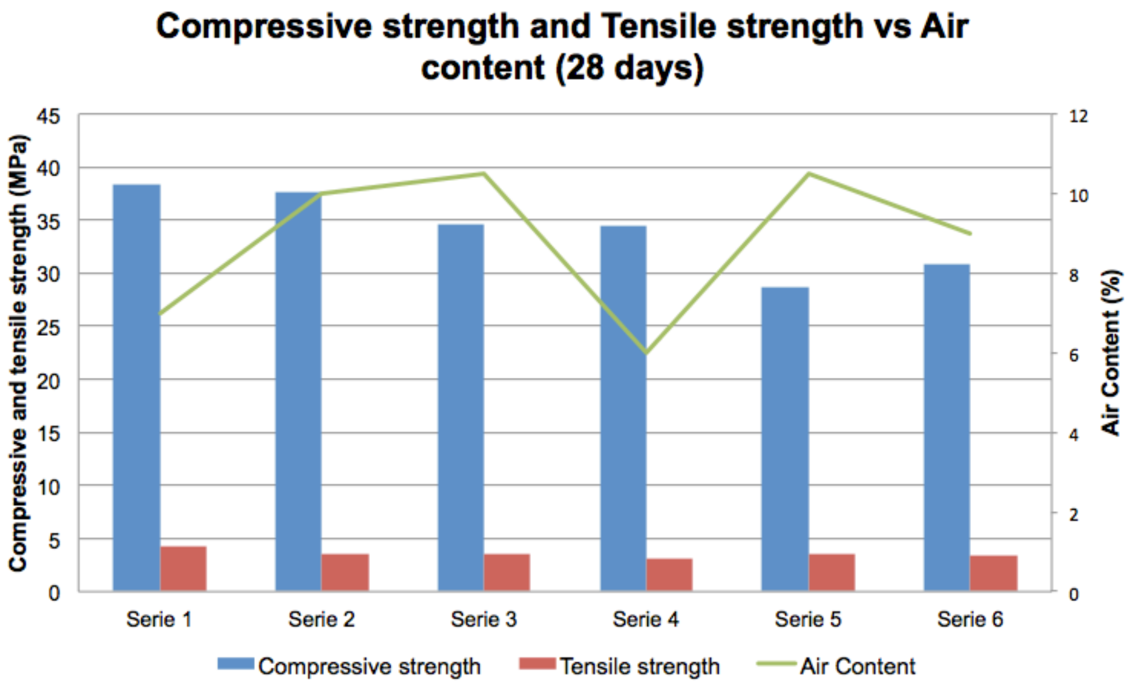


Figure 44. Compressive and tensile strength vs air content

The compressive strength and tensile strength follow a direct relationship, where and increment in the compressive strengths may result in greater tensile strengths.

Regarding the series with washed aggregates, the density is higher for higher compressive strengths. It happens the same with unwashed aggregates.

The serie with lower slump is the one with the highest compressive and tensile strength. On the contrary, there are three series with the same maximum slump and their compressive and tensile strengths are quite different.

In terms of air content, it seems to be no relation between series with washed aggregates and unwashed aggregates; however, it can be observed that the compressive strength decreases with an increment in the air content.

STATIC ELASTIC MODULUS AGAINST COMPRESSIVE AND TENSILE STRENGTH

In the next graphic it is represented the static elastic modulus against the compressive strength of all the series. The fitting curves have been used to plot the results.

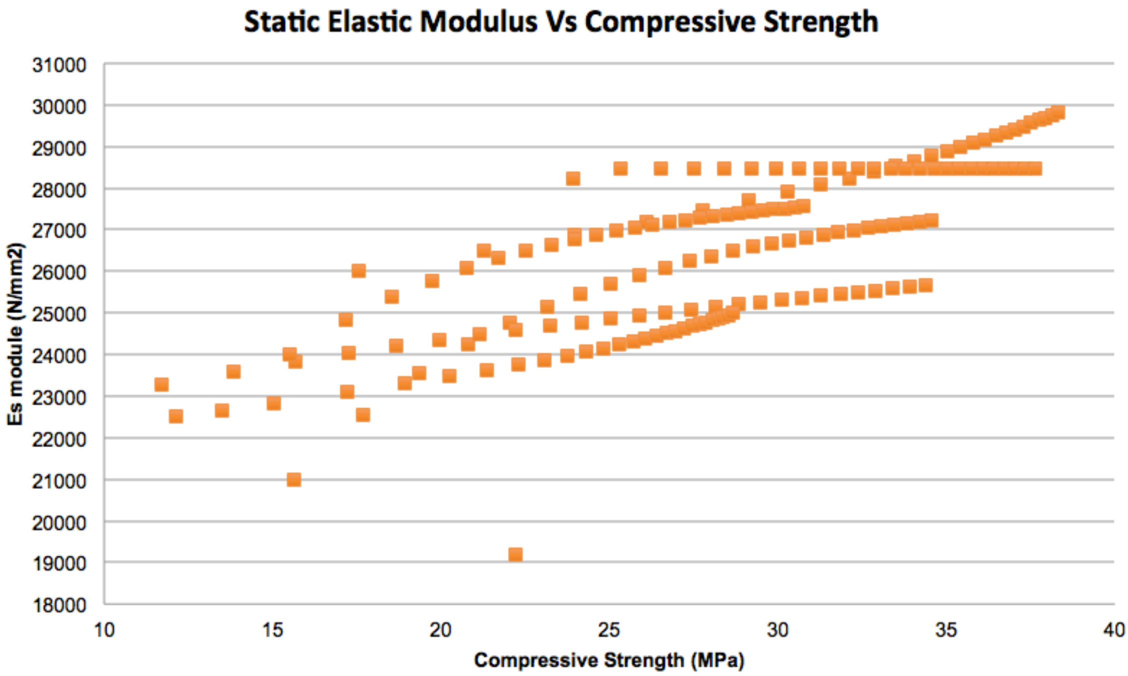


Figure 45. Static elastic modulus vs Compressive strength

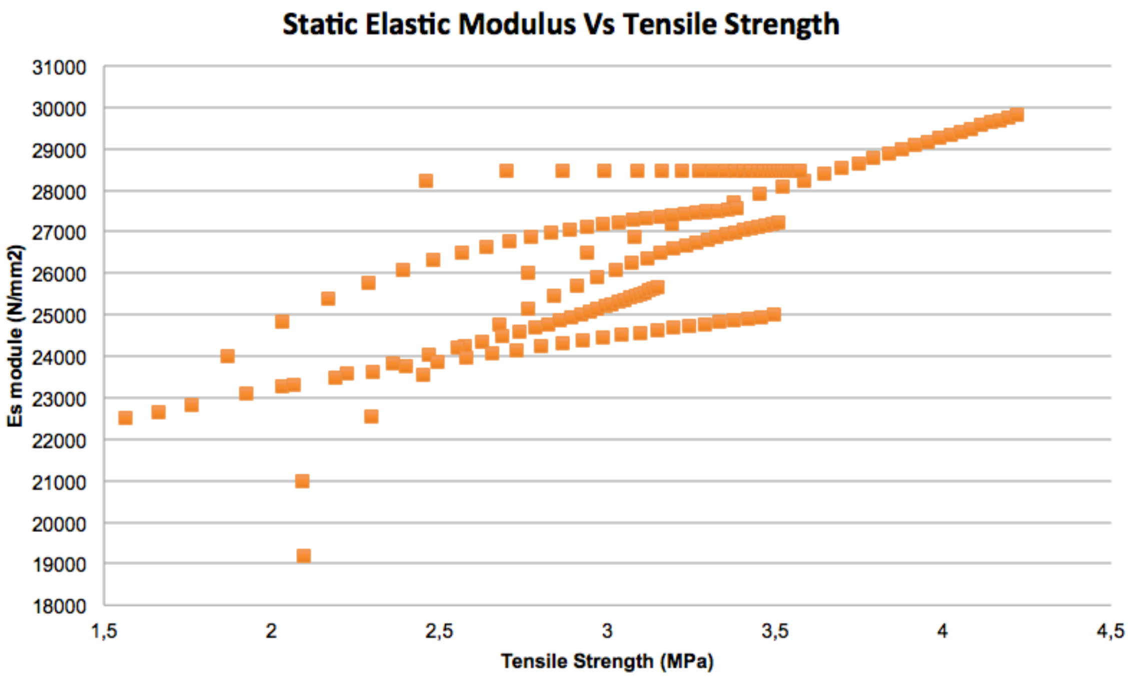


Figure 46. Static elastic modulus vs Tensile strength

It can be observed that the static elastic modulus increases with an increment in the compressive and tensile strength.

DYNAMIC ELASTIC MODULUS AGAINST COMPRESSIVE AND TENSILE STRENGTH

In the next graphic it is represented the dynamic elastic modulus against the compressive strength of all the series. The fitting curves have been used to plot the results.

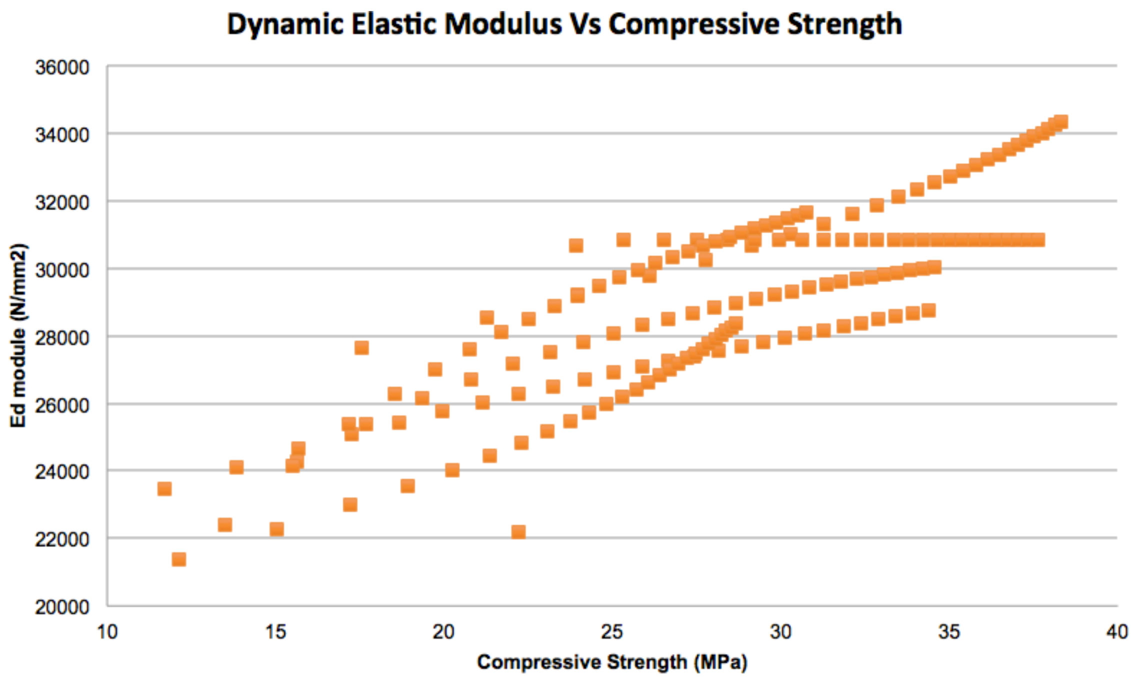


Figure 47. Dynamic elastic modulus vs Compressive strength

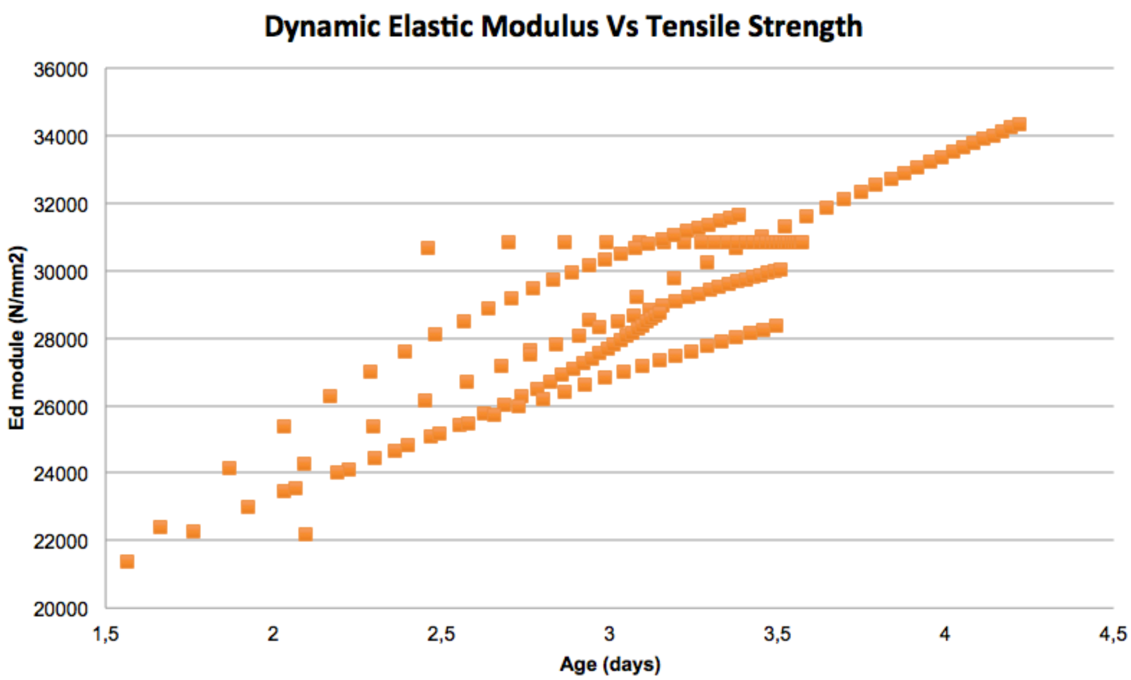


Figure 48. Dynamic elastic modulus vs Tensile strength

It can be observed that the dynamic elastic modulus increases with an increment in the compressive and tensile strength.

5. GENERAL CONCLUSIONS AND FUTURE RESEARCH PROPOSALS

Based on the research carried out whose procedures and experimental data have been explained and collected along this report, the main conclusions obtained have been summarized as follows:

- From the experimental data it can be easily concluded that the concrete made with unwashed aggregates has better hardened properties (compressive and tensile strength, and static and dynamic modulus of elasticity) than the concrete made with washed aggregates.
- When it comes to concrete with unwashed aggregates, the 0 per cent of fly ash mix has better hardened properties than the rest. This fact is not so clear in concrete made with washed aggregates when only the compressive strength is higher for 0% of fly ash.
- In general, it can be set a direct relationship between compressive and tensile strengths and the static and dynamic modulus of elasticity, where the elasticity is higher for higher strengths.
- The static modulus of elasticity is more susceptible to changes in aggregates characteristics and amount of fly ash than the dynamic modulus of elasticity.

Regarding the main conclusion exposed above and the limitations collected in Chapter 1.4, the following future researches are proposed:

- To carry out a similar research in which it can be possible to establish a relationship between compressive and tensile strength and static and dynamic elasticity modulus with the Poisson coefficient.
- It has been probed that hardened concrete properties for concretes with unwashed aggregates and 0% of fly ash are better than for concretes with washed aggregates. It would be interesting to carry out an economic study to determine if it is also the best solution from an economical point of view, since the money saved in not washing the aggregates can be overcome by the money spent in using only cement instead of mixing it with fly ash.

6. REFERENCES

Ahn, N., 2000. *An experimental study on the guidelines for using higher contents of aggregate microfines in Portland cement concrete*, Austin. Available at: http://www.robo.co.in/intro.pdf [Accessed July 28, 2014].

Alexander, M., 1996. Aggregates and the Deformation Properties of Concrete. *ACI Materials Journal*, 93(3), pp.569–577.

Anon, 2009. Building Green - Using Fly Ash in Concrete. Available at: http://www2.buildinggreen.com/article/using-fly-ash-concrete-0 [Accessed July 28, 2014].

BASF, 2014. Superplasticizer admixtures. Available at: http://www.hormigon-altas-prestaciones.com/aditivo-superplastificante [Accessed July 30, 2014].

Beygi, M.H. a. et al., 2014. Evaluation of the effect of maximum aggregate size on fracture behavior of self compacting concrete. *Construction and Building Materials*, 55, pp.202–211.

Blanco, F., 2013. Concrete. , p.361. Available at: http://www6.uniovi.es/usr/fblanco/Tema8.Materiales.Construccion.Hormigon.pdf [Accessed July 29, 2014].

Chen, B. & Liu, J., 2004. Effect of aggregate on the fracture behavior of high strength concrete. *Construction and Building Materials*, 18, pp.585–590.

Cramer, S.M., Hall, M. & Parry, J., 1995. Effect of optimized total aggregate gradation on Portland cement concrete for Wisconsin pavements. *Transportation research record*, 1478, pp.100–106. Available at: http://cat.inist.fr/?aModele=afficheN&cpsidt=2943164 [Accessed June 11, 2014].

Day, K.W., 2006. *Concrete Mix Design, Quality Control and Specification* 3rd ed., New York: Taylor & Francis.

El-Sayed, K.M. et al., 1998. Influence of aggregate shape on the fracture behaviour of concrete. *AEDIFICATIO Publishers, Fracture Mechanics of Concrete Structures*, 1, pp.171–180.

Elices, M. & Rocco, C.G., 2008. Effect of aggregate size on the fracture and mechanical properties of a simple concrete. *Engineering Fracture Mechanics*, 75, pp.3839–3851.

Ezeldin, A. & Aitcin, P.-C., 1991. Effect of Coarse Aggregate on the Behavior of Normal and High-Strength Concretes. *Cement, Concrete and Aggregates*, 13(2), pp.121–124.

Forty, A., 2012. Concrete and Culture. , p.336. Available at: http://www.reaktionbooks.co.uk/reaktion/display.asp?K=9781861898975&m=69&dc=631 [Accessed May 3, 2014].

Freiesleben Hansen, P. & Pedersen, J., 1985. Curing of Concrete Structures. *CEB Information Bulletin*, 166, p.42.

Galloway, J.E., 1994. Grading, Shape, and Surface Properties. Available at: http://books.google.es/books?hl=es&lr=&id=waJhxne7K1MC&oi=fnd&pg=PA401&dq=Galloway,+J.+E.+Jr.+Grading,+Shape,+and+Surface+Properties&ots=7OUZ-R8BRC&sig=D3LOt33nSf3znK4mQMOKdnEr82o#v=onepage&q&f=false [Accessed June 11, 2014].

Giaccio, G. et al., 1992. High- Strength Concretes Incorporating Different Coarse Aggregates. *ACI Materials Journal*, 89(3), pp.242–246.

Glavind, M., Olsen, G.S. & Munch-Petersen, C., 1993. Packing calculation and concrete mix design. *The Nordic Concrete Federation*, 2, pp.21–34.

Hillerborg, A., 1985. Results of three comparative test series for determining the fracture energy GF of concrete. *Materials and Structures*, 18(5), pp.407–413.

Horta, A., 2011. Impacts of Using Crushed Rocks in Concrete. , (June), p.58. Available at: http://www2.lwr.kth.se/Publikationer/PDF_Files/LWR_EX_11_14.pdf [Accessed May 29, 2014].

Hudson, B.P., Modification to the Fine Aggregate Angularity Test. , p.10. Available at: http://aftre.nssga.org/Symposium/1999-04.pdf [Accessed June 10, 2014].

Issa, M.A. et al., 2000. Size effects in concrete fracture : Part I, experimental setup and observations. *International Journal of Fracture*, 102, pp.1–24.

Jamkar, S.S. & Rao, C.B.K., 2004. Index of Aggregate Particle Shape and Texture of coarse aggregate as a parameter for concrete mix proportioning. *Cement and Concrete Research*, 34, pp.2021–2027.

Kozul, R. & Darwin, D., 1997. *Effects of Aggregate Type, Size and Content on Concrete Strength and Fracture Energy*, Lawrence, Kansas.

Li, Z., 2012. Chapter 3 Aggregates. In *Civil 111 Construction Materials*. Zhejiang, pp. 36–43.

Muñoz, J. et al., 2005. *Effects of coarse aggregate coatings on concrete performance*, Madison. Available at: http://ascelibrary.org/doi/abs/10.1061/(ASCE)0899-1561(2010)22:1(96) [Accessed July 27, 2014].

Muñoz, J.F. et al., 2007. Effects of Natural Coarse Aggregate Coatings on Concrete Perfomance and an Evaluation of the Monitoring Method Employed to Detect These Coatings. , pp.1–8.

Neville, A., 1963. *Properties of Concrete* 3rd ed., England: Longman Scientific & Technical. Available at: http://catalog.enu.kz:55555/guid/DBFC3F1E-34E9-4355-B7AD-8AC2ADE2D0D8.pdf [Accessed July 31, 2014].

Neville, A.M. & Brooks, J.J., 2010. *Concrete Technology* 2nd ed., England: Pearson.

Nichols, F.P., 1982. Manufactured Sand and Crushed Stone in Portland Cement Concrete. *Concrete International*, p.12.

Özturan, T. & Çeçen, C., 1997. Effect of Coarse Aggregate Type on Mechanical Properties of Concretes with Different Strengths. *Cement and Concrete Research*, 27(2), pp.165–170.

Petersson, P.E., 1980. Fracture energy of concrete: practical performance and experimental results. *Cement and Concrete Research*, 10(1), pp.91–101.

Polat, R. et al., 2013. The Corrleation between Aggregate Shape and Compressive Strength of Concrete: Digital Image Processing Approach. *International Journal of Structural and Civil Engineering Research*, 2(3), pp.61–81.

Powers, T.C., 1966. "The Nature of Concrete", Significance of Tests and Properties of Concrete and Concrete-making Materials. , (169), pp.61–72. Available at: http://books.google.es/books?hl=es&lr=&id=SdCWIb8sM5EC&oi=fnd&pg=PA58&dq=The+Nature+of+Concrete+Powers,+T.C.&ots=Zn1SkaMIQT&sig=ae9hxGZqRqgbTEGuy-XKLQCIG-8#v=onepage&q=The Nature of Concrete Powers%2C T.C.&f=false.

Quiroga, P.N. & Fowler, D.W., 2004. *The Effects of Aggregate Characteristics on the Performance of Portland Cement Concrete*, Austin.

Rao, G.A. & Prasad, B.K.R., 2002. Fracture energy and softening behavior of high-strength concrete. *Cement and Concrete Research*, 32, pp.247–252.

Rosenberg, A., 2010. What to look for when using fly ash in precast products. Available at: http://precast.org/2010/05/using-fly-ash-in-concrete/ [Accessed July 28, 2013].

Russell, H.G. et al., 1997. State-of-the-Art Report on High-Strength Concrete. , 92(Reapproved), p.55. Available at: http://www.bpesol.com/bachphuong/media/images/book/363r_92.pdf [Accessed May 8, 2014].

Scott, A.N. & Thomas, M.D.A., 2007. Evaluation of Fly Ash From Co-Combustion of Coal and Petroleum Coke for Use in Concrete. *Materials Journal*, 104(1), pp.62–69.

Shilstone, J.M., 1999. *The Aggregate: The Most Important Value-Adding Component in Concrete*, Dallas, Texas, Usa.

Shilstone, J.M.S., 1994. Changes in Concrete Aggregate Standards. *The Construction Specifier*, p.119.

Sim, J. et al., 2014. Effects of Aggregate and Specimen Sizes on Lightweight Concrete Fracture Energy. *Journal of Materials in Civil Engineering*, 26, pp.845–854.

Toplicic-Curcic, G. et al., 2010. Influence of crushed stone aggregate type on concrete consistency. *Facta universitatis - series: Architecture and Civil Engineering*, 8(1), pp.99–109. Available at: http://www.doiserbia.nb.rs/Article.aspx?ID=0354-46051001099T [Accessed June 11, 2014].

Washa, G.W., 1998. Permeability and Absorption. In Dobrowolski, ed. *Concrete Construction Handbook*. New York: J. McGraw-Hill.

Yan, A. et al., 2001. Effect of fracture path on the fracture energy of high-strength concrete. *Cement and Concrete Research*, 31, pp.1601–1606.

Yaqub, M. & Bukhari, I., 2006. Effect of Size of Coarse Aggregate on Compressive Strength of High Strength Concrets. In *31st Conference on Our World in Concrete and Structures*. Singapore, p. 4.

Zhang, J., Liu, Q. & Wang, L., 2005. Effect of Coarse Aggregate Size on Relationship between Stress and Crack Opening in Normal and High Strength Concretes. *J. Mater. Sci. Technol.*, 21(5), pp.691–700.

7. APPENDIX

Appendix A.1. Aggregates characteristics

	Sand	**Granite 16-25 mm**	**Granite 11-16 mm**	**Granite 8-11 mm**	**Granite 2-8 mm**
Density SSD [kg/m3]	2634	2759	2750	2779	2751
Density DRY [kg/m3]	-	2750	2742	2770	2737
Absorption [%]	0.17	0.31	0.30	0.30	0.51
<32 mm	-	100	100	-	-
<25 mm	-	97	-	-	-
<19 mm	-	50	-	-	-
<16 mm	-	10	79	100	100
<8 mm	-	0.2	3	20	100
<4 mm	100	0.2	3	5	53
<2 mm	100	0.2	3	3	8
<1 mm	98	0.2	3	2	3
<0.5 mm	79	0.2	3	2	2
<0.25 mm	22	0.2	3	2	2
<0.125 mm	1	0.2	3	1	2
<0.063 mm	0.2	0.2	2.5	1.3	1.6

Appendix A.2. Air Entrainment

BASF
The Chemical Company

DECLARATION OF PERFORMANCE

Nr. DK0225B/01

according to Annex III of the Regulation (EU) No 305/2011

Amex SB 22

1. Unique identification code of the product-type:

EN 934-2:T5

2. Type, batch or serial number or any other element allowing identification of the construction product as required pursuant to Article 11(4):

batch number: see packaging of the product

3. Intended use or uses of the construction product, in accordance with the applicable harmonized technical specification, as foreseen by the manufacturer:

Air Entraining Admixtures for Concrete

4. Name, registered trade name or registered trade mark and contact address of the manufacturer as required pursuant to Article 11(5):

BASF A/S
Hallandsvej 1
DK-6230 Rødekro

5. Where applicable, name and contact address of the authorized representative whose mandate covers the tasks specified in Article 12(2):

not relevant

6. System or systems of assessment and verification of constancy of performance of the construction product as set out in Annex V:

System 2+

7. In case of the declaration of performance concerning a construction product covered by a harmonized standard:

The notified testing laboratory Bureau Veritas Certification Denmark A/S, identification number 0615, has performed the initial inspection of the factory and of the factory production control and performs the continuous surveillance, assessment and approval of the factory production control according to Annex ZA of the standard EN 934-2:2009 + A1:2012. EC Certificate of factory production control 0615-CPR-9803.

The BASF A/S performed the initial type testing of the products and carries out factory production control according to Annex ZA of the standard EN 934-2:2009 + A1:2012.

8. In case of the declaration of performance concerning a construction product for which a European Technical Assessment has been issued:

not relevant

Appendix A.2. Air Entrainment

BASF

The Chemical Company

9. Declared performance (**Amex SB 22**)

Essential characteristics	Performance	Harmonized technical specification
Chloride ion content	≤0,25%	EN 934-2:2009+A1:2012
Alkali content	≤0,5%	
Corrosion behavior	Contains components only from EN 934-1:2008, Annex A.1.	
Compressive strength	At 28 days : test mix ≥ 75 % of control mix	
Air content (entrained air)	Test mix ≥ 2,5 % by volume above control mix Total air content 4 % to 6 % by Volume	
Air void characteristic	Spacing factor in test mix ≤ 0,200 mm	
Dangerous substances	None	

10. The performance of the product identified in points 1 and 2 is in conformity with the declared performance in point 9. This declaration of performance is issued under the sole responsibility of the manufacturer identified in point 4.

Signed for and on behalf of the manufacturer by:

Eva Christiansen, Quality Manager
Name/Function

Signature

Rødekro, 21.05.2013

Appendix A.3. Moisture content of the aggregates

SERIE: 1 **CODE: AUI**

AGGREGATES HUMIDITY	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**0,74**	**0,26**	**0,22**	**0,19**	**0**
M wet (g)	1349,2	1531	1268,6	955,8	1402,8
M dry (g)	1339,2	1527	1265,8	954	1402,2

SERIE: 2 **CODE: AUII**

AGGREGATES HUMIDITY	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**1,46**	**0,96**	**1,16**	**0,70**	**0,11**
M wet (g)	1025	498,2	1102,8	1430	1251,6
M dry (g)	1010	493,4	1090	1420	1250,2

SERIE: 3 **CODE: AUIII**

AGGREGATES HUMIDITY	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**1,14**	**1,16**	**0**	**0**	**0**
M wet (g)	1209,4	865	1284,2	1250	1242,8
M dry (g)	1195,6	855	1283	1250	1242,2

SERIE: 4 **CODE: AWI**

AGGREGATES HUMIDITY	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**0,92**	**1,28**	**0,66**	**0,40**	**0,14**
M wet (g)	1279,6	780	1282,2	1265	1460
M dry (g)	1267,8	770	1273,8	1260	1458

SERIE: 5 **CODE: AWII**

AGGREGATES HUMIDITY	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**1,47**	**0,50**	**0,82**	**0,41**	**0,11**
M wet (g)	928,2	995	1115,4	1220	1451,2
M dry (g)	914,6	990	1106,2	1215	1449,6

SERIE: 6 **CODE: AWIII**

AGGREGATES HUMIDITY	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**1,40**	**5,13**	**1,72**	**1,04**	**0,25**
M wet (g)	1232,2	1307	1418,6	1519,6	1417,6
M dry (g)	1215	1240	1394,2	1503,8	1414

Appendix B.1. Preliminary calculations

	Superplasticizer (GLENIUM)	Air entrainment (AMEX)	Slump (mm)	Air content (%)
0% FA				
1	1,9	0,6	180	11
2	1,8	0,5	240	11
3	1,7	0,4	240	15
4	1,8	0,2	240	11,5
5	0,6	0,4	50	7
6	0,8	0,4		

15% FA				
1	3	1,1	230	15
2	1,5	0,6	80	7
3	1,6	0,6		

25% FA				
1	1,9	0,6	180	7,9
2	1,5	0,4	0	3,8
3	1,7	0,5	30	5,5
4	1,8	0,5		

Appendix B.2. Mix design

Serie 1: Unwashed / 0% FA

Mix-design 100% Cement				
Component		*Density* kg/m³	*Mass per m³ (ssd)* kg	*Volume* m³
Cement	Lavalkali	3210	361	0,1123
Fly ash		2200	0	0,0000
Water	Horsens vandværk	1000	143	0,1433
Air entrainment	Amex SB 22	1010	0,4	0,0004
Super plasticizer	Glenium ACE 410	1050	0,7	0,0007
Air content 6%				0,0600
Cement paste + air				0,3167
Sand 00/02		2634	648	0,2460
Granite 2/8		2750	464	0,1688
Granite 8/11		2779	158	0,0567
Granite 11/16		2759	156	0,0567
Granite 16/22		2751	427	0,1551
Aggregates				0,6833
Concrete			2358	1,0000

Adjusted mix-design 100% Cement				
Moisture content (u) %	Absorption (wa) %	Mass per m³ (adjustet for moisture) kg	Volume to mix 55	Mixed
		361	**19,83**	
		0	**0,00**	
		139	**7,637**	
		0,4	**0,0220**	
		0,7	**0,0385**	
0,74		653	**35,90**	
0,26		465	**25,59**	
0,22		158	**8,69**	
0,19		157	**8,62**	
	0,51	425	**23,35**	
		2358		

	Dry substance	Mass	Density	Volumen	Dry substande	Water content	
		[kg/m³ concrete]	[kg/m³]	[m³/m³ concrete]	[m³/m³ concrete]	[m³/m³ concrete]	[kg/m³ concrete]
Amex	1,8%	0,40	1010	0,0004	7,12871E-06	0,0004	0,4
Glenium	22,5%	0,70	1050	0,0007	0,00015	0,0005	0,5
Water	0,0%	143,33	1000	0,1433	0	0,1433	143,3
Ekvivalent watercontent							**144,2**

w/c-ratio	0,4
Ekv. Water	144,2

Appendix B.2. Mix design

Serie 2: Unwashed / 15% FA

Mix-design 15% FA				
Component		*Density* kg/m³	*Mass per m³ (ssd)* kg	*Volume* m³
Cement	*Lavalkali*	*3210*	*317*	*0,0987*
Fly ash		*2200*	*48*	*0,0216*
Water	*Horsens vandværk*	*1000*	*134*	*0,1345*
Air entrainment	*Amex SB 22*	*1010*	*0,6*	*0,0006*
Super plasticizer	*Glenium ACE 410*	*1050*	*1,6*	*0,0015*
Air content 6%				*0,0600*
Cement paste + air				*0,3169*
Sand 00/02		*2634*	*648*	*0,2459*
Granite 2/8		*2750*	*464*	*0,1687*
Granite 8/11		*2779*	*158*	*0,0567*
Granite 11/16		*2759*	*156*	*0,0567*
Granite 16/22		*2751*	*427*	*0,1551*
Aggregates				*0,6831*
Concrete			2353	*1,0000*

Adjusted mix-design 100% Cement				
Moisture content (u) %	Absorption (wa) %	Mass per m³ *(adjustet for moisture)* kg	Volume to mix 55	Mixed
		317	***17,43***	
		48	***2,61***	
		117	***6,446***	
		0,6	***0,0330***	
		1,6	***0,0880***	
1,46		*657*	***36,14***	
0,96		*468*	***25,76***	
1,16		*159*	***8,77***	
0,69		*158*	***8,66***	
0,11		*427*	***23,49***	
		2353		

	Dry substance	Mass	Density	Volumen	Dry substande	Water content	
		[kg/m³ concrete]	[kg/m³]	[m³/m³ concrete]	[m³/m³ concrete]	[m³/m³ concrete]	[kg/m³ concrete]
Amex	1,8%	0,60	1010	0,0006	1,06931E-05	0,0006	0,6
Glenium	22,5%	1,60	1050	0,0015	0,000342857	0,0012	1,2
Water	0,0%	134,49	1000	0,1345	0	0,1345	134,5
Ekvivalent watercontent							**136,3**

w/c-ratio	0,4
Ekv. Water	136,3

Appendix B.2. Mix design

Serie 3: Unwashed / 25% FA

Mix-design 25 % FA					Adjusted mix-design 100% Cement				
Component		Density	Mass per m^3 (ssd)	Volume	Moisture content (u)	Absorption (wa)	Mass per m^3 (adjustet for moisture)	Volume to mix	Mixed
		kg/m^3	kg	m^3	%	%	kg	45	
Cement	Lavalkali	3210	293	0,0913			293	**13,19**	
Fly ash		2200	73	0,0333			73	**3,30**	
Water	Horsens vandværk	1000	130	0,1301			120	**5,421**	
Air entrainment	Amex SB 22	1010	0,5	0,0005			0,5	**0,0225**	
Super plasticizer	Glenium ACE 410	1050	1,8	0,0017			1,8	**0,0810**	
Air content 6%				0,0600					
Cement paste + air				0,3170					
Sand 00/02		2634	648	0,2459	1,14		655	**29,48**	
Granite 2/8		2750	464	0,1687	1,16		469	**21,12**	
Granite 8/11		2779	158	0,0567		0,30	157	**7,07**	
Granite 11/16		2759	156	0,0567		0,31	156	**7,02**	
Granite 16/22		2751	427	0,1550		0,51	424	**19,10**	
Aggregates				0,6830					
Concrete			2351	1,0000			2351		

	Dry substance	Mass	Density	Volumen	Dry substande	Water content	
		[kg/m^3 concrete]	[kg/m^3]	[m^3/m^3 concrete]	[m^3/m^3 concrete]	[m^3/m^3 concrete]	[kg/m^3 concrete]
Amex	1,8%	0,50	1010	0,0005	8,91089E-06	0,0005	0,5
Glenium	22,5%	1,80	1050	0,0017	0,000385714	0,0013	1,3
Water	0,0%	130,11	1000	0,1301	0	0,1301	130,1
Ekvivalent watercontent							**131,9**

w/c-ratio	0,4
Ekv. Water	131,9

Appendix B.2. Mix design

Serie 4: Washed / 0% FA

Mix-design 100% Cement				
Component		Density	Mass per m³ (ssd)	Volume
		kg/m³	kg	m³
Cement	Lavalkali	3210	361	0,1123
Fly ash		2200	0	0,0000
Water	Horsens vandværk	1000	143	0,1433
Air entrainment	Amex SB 22	1010	0,4	0,0004
Super plasticizer	Glenium ACE 410	1050	0,7	0,0007
Air content 6%				0,0600
Cement paste + air				0,3167
Sand 00/02		2634	648	0,2460
Granite 2/8		2750	464	0,1688
Granite 8/11		2779	158	0,0567
Granite 11/16		2759	156	0,0567
Granite 16/22		2751	427	0,1551
Aggregates				0,6833
Concrete			2358	1,0000

Adjusted mix-design 100% Cement				
Moisture content (u)	Absorption (wa)	Mass per m³ (adjustet for moisture)	Volume to mix	Mixed
%	%	kg	45	
		361	**16,23**	
		0	**0,00**	
		129	**5,813**	
		0,4	**0,0180**	
		0,7	**0,0315**	
0,92		654	**29,42**	
1,28		470	**21,15**	
0,66		159	**7,14**	
0,40		157	**7,07**	
0,14		427	**19,23**	
		2358		

	Dry substance	Mass	Density	Volumen	Dry substande	Water content	
		[kg/m³ concrete]	[kg/m³]	[m³/m³ concrete]	[m³/m³ concrete]	[m³/m³ concrete]	[kg/m³ concrete]
Amex	1,8%	0,40	1010	0,0004	7,12871E-06	0,0004	0,4
Glenium	22,5%	0,70	1050	0,0007	0,00015	0,0005	0,5
Water	0,0%	143,33	1000	0,1433	0	0,1433	143,3
Ekvivalent watercontent							**144,2**

w/c-ratio	0,4
Ekv. Water	144,2

Appendix B.2. Mix design

Serie 5: Washed / 15% FA

Mix-design 15% FA					Adjusted mix-design 100% Cement				
Component		Density	Mass per m³ (ssd)	Volume	Moisture content (u)	Absorption (wa)	Mass per m³ (adjustet for moisture)	Volume to mix	Mixed
		kg/m³	kg	m³	%	%	kg	45	
Cement	Lavalkali	3210	317	0,0987			317	**14,26**	
Fly ash		2200	48	0,0216			48	**2,14**	
Water	Horsens vandværk	1000	134	0,1345			120	**5,411**	
Air entrainment	Amex SB 22	1010	0,6	0,0006			0,6	**0,0270**	
Super plasticizer	Glenium ACE 410	1050	1,6	0,0015			1,6	**0,0720**	
Air content 6%				0,0600					
Cement paste + air				0,3169					
Sand 00/02		2634	648	0,2459	1,47		657	**29,58**	
Granite 2/8		2750	464	0,1687	0,50		466	**20,98**	
Granite 8/11		2779	158	0,0567	0,82		159	**7,15**	
Granite 11/16		2759	156	0,0567	0,41		157	**7,07**	
Granite 16/22		2751	427	0,1551	0,11		427	**19,22**	
Aggregates				0,6831					
Concrete			2353	1,0000			2353		

	Dry substance	Mass	Density	Volumen	Dry substande	Water content	
		[kg/m³ concrete]	[kg/m³]	[m³/m³ concrete]	[m³/m³ concrete]	[m³/m³ concrete]	[kg/m³ concrete]
Amex	1,8%	0,60	1010	0,0006	1,06931E-05	0,0006	0,6
Glenium	22,5%	1,60	1050	0,0015	0,000342857	0,0012	1,2
Water	0,0%	134,49	1000	0,1345	0	0,1345	134,5
Ekvivalent watercontent							**136,3**

w/c-ratio	0,4
Ekv. Water	136,3

Appendix B.2. Mix design

Serie 6: Washed / 25% FA

Mix-design 25 % FA				
Component		*Density*	*Mass per m³ (ssd)*	*Volume*
		kg/m³	*kg*	*m³*
Cement	*Lavalkali*	*3210*	*293*	*0,0913*
Fly ash		*2200*	*73*	*0,0333*
Water	*Horsens vandværk*	*1000*	*130*	*0,1301*
Air entrainment	*Amex SB 22*	*1010*	*0,5*	*0,0005*
Super plasticizer	*Glenium ACE 410*	*1050*	*1,8*	*0,0017*
Air content 6%				*0,0600*
Cement paste + air				*0,3170*
Sand 00/02		*2634*	*648*	*0,2459*
Granite 2/8		*2750*	*464*	*0,1687*
Granite 8/11		*2779*	*158*	*0,0567*
Granite 11/16		*2759*	*156*	*0,0567*
Granite 16/22		*2751*	*427*	*0,1550*
Aggregates				*0,6830*
Concrete			2351	*1,0000*

Adjusted mix-design 100% Cement				
Moisture content (u)	Absorption (wa)	Mass per m³ *(adjustet for moisture)*	Volume to mix	Mixed
%	%	kg	45	
		293	***13,19***	
		73	***3,30***	
		92	***4,133***	
		0,5	***0,0225***	
		1,8	***0,0810***	
1,40		*657*	***29,55***	
5,13		*488*	***21,95***	
1,72		*160*	***7,21***	
1,04		*158*	***7,11***	
0,25		*428*	***19,24***	
		2351		

	Dry substance	Mass	Density	Volumen	Dry substande	Water content	
		[kg/m³ concrete]	[kg/m³]	[m³/m³ concrete]	[m³/m³ concrete]	[m³/m³ concrete]	[kg/m³ concrete]
Amex	1,8%	0,50	1010	0,0005	8,91089E-06	0,0005	0,5
Glenium	22,5%	1,80	1050	0,0017	0,000385714	0,0013	1,3
Water	0,0%	130,11	1000	0,1301	0	0,1301	130,1
Ekvivalent watercontent							**131,9**

w/c-ratio	0,4
Ekv. Water	131,9

Appendix C. Concrete production

SERIE: 1 **CODE:** AUI

GENERAL DATA

SERIES CODE	AUI	SERIES COLOUR	Blue/Yellow
PRODUCED VOL (m3)	0,055	PRODUCED MASS (kg)	128,81
CASTING DATE	03/07/14	DEMOULDING DATE	04/07/14
HOUR	10:30	NUMBER OF SAMPLES	30

AGGREGATES HUMIDITY

	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**0,74**	**0,26**	**0,22**	**0,19**	**0**
M wet (g)	1349,2	1531	1268,6	955,8	1402,8
M dry (g)	1339,2	1527	1265,8	954	1402,2

DOSSIFICATION AND CORRECTIONS

	Mix (g)	Correction	Notes
Cement	19.830		
Fly ash	-		
Water	7.637		
Air entrainment	22		
Super plasticizer	44	39	+ 4 g during mixing
Air content 6% (4,5-8%)			
Sand 00/02	35.900		
Granite 2/8	25.590		
Granite 8/11	8.690		
Granite 11/16	8.620		
Granite 16/22	23.350		
TOTAL			

PRODUCTION TIMES

	Time (min)	Notes
Aggregates+cement+FA	5	
Water+admixtures	5	
TOTAL	**10**	

DENSITY — AIR CONTENT 6% (4,5 - 8 %) — SLUMP (120 ± 30 mm)

DENSITY (kg/m3)	**2342**	**AIR CONTENT (%)**			**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	7	Slump 1 (mm)		60,0
Full container (g)	29060	Measurement 2 (Air %)		Slump 2 (mm)		
Container vol (dm3)	10,0					

PRODUCTION TIMES

CODE	DATE	TIME	Temperature	DATE	TIME
NOTES					

Appendix C. Concrete production

SERIE: 2 **CODE:** AUII

GENERAL DATA

SERIES CODE	AUII	SERIES COLOUR	Red/Green
PRODUCED VOL (m3)	0,055	PRODUCED MASS (kg)	123,53
CASTING DATE	29/06/14	DEMOULDING DATE	30/06/14
HOUR	10:30	NUMBER OF SAMPLES	30

AGGREGATES HUMIDITY

	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**1,46**	**0,96**	**1,16**	**0,70**	**0,11**
M wet (g)	1025	498,2	1102,8	1430	1251,6
M dry (g)	1010	493,4	1090	1420	1250,2

DOSSIFICATION AND CORRECTIONS

	Mix (g)	Correction	Notes
Cement	17.430		
Fly ash	2.610		
Water	6.446		
Air entrainment	33		
Super plasticizer	88		
Air content 6% (4,5-8%)			
Sand 00/02	36.140		
Granite 2/8	25.760		
Granite 8/11	8.770		
Granite 11/16	8.660		
Granite 16/22	23.490		
TOTAL			

PRODUCTION TIMES

	Time (min)	Notes
Aggregates+cement+FA	5	
Water+admixtures	5	
TOTAL	**10**	

DENSITY — AIR CONTENT 6% (4,5 - 8 %) — SLUMP (120 ± 30 mm)

DENSITY (kg/m3)	**2246**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	10	Slump 1 (mm)	190,0
Full container (g)	28100	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

PRODUCTION TIMES

CODE	**DATE**	**TIME**	**Temperature**	**DATE**	**TIME**
AUII-3C1					

NOTES	

Appendix C. Concrete production

SERIE: 3 **CODE:** AUIII

GENERAL DATA

SERIES CODE	AUIII	SERIES COLOUR	Blue/Green
PRODUCED VOL (m3)	0,045	PRODUCED MASS (kg)	100,13
CASTING DATE	05/07/14	DEMOULDING DATE	06/07/14
HOUR	11:00	NUMBER OF SAMPLES	24

AGGREGATES HUMIDITY

	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**1,14**	**1,16**	**0**	**0**	**0**
M wet (g)	1209,4	865	1284,2	1250	1242,8
M dry (g)	1195,6	855	1283	1250	1242,2

DOSSIFICATION AND CORRECTIONS

	Mix (g)	Correction	Notes
Cement	13.190		
Fly ash	3.300		
Water	5.421		
Air entrainment	23		
Super plasticizer	81		
Air content 6% (4,5-8%)			
Sand 00/02	29.480		
Granite 2/8	21.120		
Granite 8/11	7.070		
Granite 11/16	7.020		
Granite 16/22	1.910		
TOTAL			

PRODUCTION TIMES

	Time (min)	Notes
Aggregates+cement+FA	5	
Water+admixtures	5	
TOTAL	**10**	

DENSITY AIR CONTENT 6% (4,5 - 8 %) SLUMP (120 ± 30 mm)

DENSITY (kg/m3)	**2225**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	10,5	Slump 1 (mm)	250,0
Full container (g)	27890	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

PRODUCTION TIMES

CODE	DATE	TIME	Temperature	DATE	TIME

NOTES	

Appendix C. Concrete production

SERIE: 4 **CODE:** AWI

GENERAL DATA

SERIES CODE	AWI	SERIES COLOUR	BLUE/BLACK
PRODUCED VOL (m3)	0,045	PRODUCED MASS (kg)	105,19
CASTING DATE	07/07/14	DEMOULDING DATE	08/07/14
HOUR		NUMBER OF SAMPLES	23

AGGREGATES HUMIDITY

	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**0,92**	**1,28**	**0,66**	**0,40**	**0,14**
M wet (g)	1279,6	780	1282,2	1265	1460
M dry (g)	1267,8	770	1273,8	1260	1458

DOSSIFICATION AND CORRECTIONS

	Mix (g)	Correction	Notes
Cement	16.230		
Fly ash	-		
Water	5.809	5.813	+4 gr during mixing
Air entrainment	18		
Super plasticizer	36	32	
Air content 6% (4,5-8%)			
Sand 00/02	29.420		
Granite 2/8	21.150		
Granite 8/11	7.140		
Granite 11/16	7.070		
Granite 16/22	19.230		
TOTAL			

PRODUCTION TIMES

	Time (min)	Notes
Aggregates+cement+FA	5	
Water+admixtures	5	
TOTAL	**10**	

DENSITY AIR CONTENT 6% (4,5 - 8 %) SLUMP (120 ± 30 mm)

DENSITY (kg/m3)	**2338**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	6	Slump 1 (mm)	90,0
Full container (g)	29015	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

PRODUCTION TIMES

CODE	**DATE**	**TIME**	**Temperature**	**DATE**	**TIME**

NOTES	

Appendix C. Concrete production

SERIE: 5 **CODE: AWII**

GENERAL DATA

SERIES CODE	AWII	SERIES COLOUR	BLACK/BLACK
PRODUCED VOL (m3)	0,045	PRODUCED MASS (kg)	100,73
CASTING DATE	10/07/14	DEMOULDING DATE	11/07/14
HOUR	11:00	NUMBER OF SAMPLES	23

AGGREGATES HUMIDITY

	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**1,47**	**0,50**	**0,82**	**0,41**	**0,11**
M wet (g)	928,2	995	1115,4	1220	1451,2
M dry (g)	914,6	990	1106,2	1215	1449,6

DOSSIFICATION AND CORRECTIONS

	Mix (g)	Correction	Notes
Cement	14.260		
Fly ash	2.140		
Water	5.411		
Air entrainment	27		
Super plasticizer	72		
Air content 6% (4,5-8%)			
Sand 00/02	29.580		
Granite 2/8	20.980		
Granite 8/11	7.150		
Granite 11/16	7.070		
Granite 16/22	19.220		
TOTAL			

PRODUCTION TIMES

	Time (min)	Notes
Aggregates+cement+FA	5	
Water+admixtures	5	
TOTAL	**10**	

DENSITY — AIR CONTENT 6% (4,5 - 8 %) — SLUMP (120 ± 30 mm)

DENSITY (kg/m3)	**2239**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	10,5	Slump 1 (mm)	250,0
Full container (g)	28025	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

PRODUCTION TIMES

CODE	DATE	TIME	Temperature	DATE	TIME

NOTES	

Appendix C. Concrete production

SERIE: 6 **CODE:** AWIII

GENERAL DATA

SERIES CODE	AWIII	SERIES COLOUR	GREEN/GREEN
PRODUCED VOL (m3)	0,045	PRODUCED MASS (kg)	102,38
CASTING DATE	11/07/14	DEMOULDING DATE	12/07/14
HOUR	15:30	NUMBER OF SAMPLES	23

AGGREGATES HUMIDITY

	Sand 00/02	Granite 2/8	Granite 8/11	Granite 11/16	Granite 16/22
Moisture content	**1,40**	**5,13**	**1,72**	**1,04**	**0,25**
M wet (g)	1232,2	1307	1418,6	1519,6	1417,6
M dry (g)	1215	1240	1394,2	1503,8	1414

DOSSIFICATION AND CORRECTIONS

	Mix (g)	Correction	Notes
Cement	13.190		
Fly ash	3.300		
Water	4.133		
Air entrainment	22,5		
Super plasticizer	81		
Air content 6% (4,5-8%)			
Sand 00/02	29.550		
Granite 2/8	21.950		
Granite 8/11	7.210		
Granite 11/16	7.110		
Granite 16/22	19.240		
TOTAL			

PRODUCTION TIMES

	Time (min)	Notes
Aggregates+cement+FA	5	
Water+admixtures	5	
TOTAL	**10**	

DENSITY — AIR CONTENT 6% (4,5 - 8 %) — SLUMP (120 ± 30 mm)

DENSITY (kg/m3)	**2275**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	9	Slump 1 (mm)	250,0
Full container (g)	28390	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

PRODUCTION TIMES

CODE	DATE	TIME	Temperature	DATE	TIME

NOTES	

Appendix D. Fresh concrete properties

SERIE: 1 **CODE: AUI**

DENSITY		AIR CONTENT		SLUMP	
DENSITY (kg/m3)	**2342**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	7	Slump 1 (mm)	60,0
Full container (g)	29060	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

SERIE: 2 **CODE: AUII**

DENSITY		AIR CONTENT		SLUMP	
DENSITY (kg/m3)	**2246**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	10	Slump 1 (mm)	190,0
Full container (g)	28100	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

SERIE: 3 **CODE: AUIII**

DENSITY		AIR CONTENT		SLUMP	
DENSITY (kg/m3)	**2225**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	10,5	Slump 1 (mm)	250,0
Full container (g)	27890	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

SERIE: 4 **CODE: AWI**

DENSITY		AIR CONTENT		SLUMP	
DENSITY (kg/m3)	**2338**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	6	Slump 1 (mm)	90,0
Full container (g)	29015	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

SERIE: 5 **CODE: AWII**

DENSITY		AIR CONTENT		SLUMP	
DENSITY (kg/m3)	**2239**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	10,5	Slump 1 (mm)	250,0
Full container (g)	28025	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

SERIE: 6 **CODE: AWIII**

DENSITY		AIR CONTENT		SLUMP	
DENSITY (kg/m3)	**2275**	**AIR CONTENT (%)**		**SLUMP (mm)**	
Empty container (g)	5640	Measurement 1 (Air %)	9	Slump 1 (mm)	250,0
Full container (g)	28390	Measurement 2 (Air %)		Slump 2 (mm)	
Container vol (dm3)	10,0				

Appendix E.1. Tests template

TESTING

DATE	
NAME	
TIME	
TEMPERATURE IN THE WESSEL	

SERIE	
CASTING DAY	
CODE	
AGE	
COLOR	

Diametre (mm)	
Weight (g)	
Height (mm)	
Density (g/mm3)	

ELASTICITY	
TIME	
MAX T	
MIN T	

COMPRESSIVE STRENGTH	
TIME	
FORCE (KN)	
STRESS (Mpa)	
DURATION (sec)	

TENSILE STRENGTH	
TIME	
FORCE (KN)	
DURATION (sec)	

NOTES

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting		Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength			
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIES 1 - AUI																
AUI-3C1	3	06/07/14	99,50	201,26	3718,90	2380,00	7	60	2342,00	158,90	20,40					
AUI-3C2 / 3E1	3	06/07/14	99,84	200,46	3661,70	2330,00	7	60	2342,00	139,10	17,80			25603	25201	
AUI-3T1 /3E2	3	06/07/14	99,87	199,44	3679,90	2360,00	7	60	2342,00			85,80	2,75	36014	30491	0,137
AUI-3T2	3	06/07/14	99,87	201,08	3712,90	2360,00	7	60	2342,00			89,60	2,85			
Mean						**2360,00**					**19,10**		**2,80**	**31000**	**28000**	**0,140**
Standard deviation						**20,62**					**1,84**		**0,07**			
Coefficient of variation						**0,87**					**9,63**		**2,53**			
AUI-7C1	7	10/07/14	99,80	199,99	3694,10	2360,00	7	60	2342,00	199,20	25,50					
AUI-7C2 / 7E1	7	10/07/14	99,69	200,37	3693,90	2360,00	7	60	2342,00	145,60	18,70					
AUI-7T1 / 7E2	7	10/07/14	99,68	200,04	3681,50	2360,00	7	60	2342,00			106,50	3,40	25050	29840	0,213
AUI-7T2	7	10/07/14	99,63	200,63	3714,20	2370,00	7	60	2342,00			102,20	3,25			
Mean						**2360,00**					**22,10**		**3,33**	**25000**	**30000**	**0,210**
Standard deviation						**5,00**					**4,81**		**0,11**			
Coefficient of variation						**0,21**					**21,76**		**3,19**			
AUI-14C1	14	18/07/14	99,57	200,68	3717,00	2380,00	7	60	2342,00	332,60	42,70					
AUI-14C2 / 14E1	14	18/07/14	99,64	201,36	3784,60	2410,00	7	60	2342,00	316,50	40,60			29176	32646	
AUI-14T1 / 14E2	14	18/07/14	99,63	200,78	3725,70	2380,00	7	60	2342,00			121,60	3,85	26995	30600	0,206
AUI-14T2	14	18/07/14	99,72	199,57	3700,50	2370,00	7	60	2342,00			95,50	3,05			
Mean						**2390,00**					**41,65**		**3,45**	**28000**	**31500**	**0,210**
Standard deviation						**17,32**					**1,48**		**0,57**	**1542**	**1447**	
Coefficient of variation						**0,72**					**3,57**		**16,40**	**5,51**	**4,59**	
AUI-21C1	21	24/07/14	99,76	200,52	3734,30	2380,00	7	60	2342,00	276,20	35,30					
AUI-21C2/21E1	21	24/07/14	99,75	200,26	3706,30	2370,00	7	60	2342,00	289,30	37,00			30957	35343	0,195
AUI-21T1/21E2	21	24/07/14	99,83	200,87	3762,60	2390,00	7	60	2342,00			138,00	4,40	29269	33450	0,201
AUI-21T2	21	24/07/14	99,63	200,70	3720,40	2380,00	7	60	2342,00			135,30	4,30			

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting				
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength	Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIES 1 - AUI																
Mean						**2380,00**					**36,15**		**4,35**	**30000**	**34500**	**0,200**
Standard deviation						**8,16**					**1,20**		**0,07**	**1194**	**1339**	**0,004**
Coefficient of variation						**0,34**					**3,33**		**1,63**	**3,98**	**3,88**	**2,12**
AUI-28C1	28	31/07/14	99,90	200,60	3695,40	2350,00	7	60	2342,00	291,80	37,20					
AUI-28C2	28	31/07/14	100,05	200,14	3693,20	2350,00	7	60	2342,00	266,50	33,90					
AUI-28T1 / E1	28	31/07/14	100,08	199,76	3748,20	2390,00	7	60	2342,00			143,00	4,55	30436	35842	0,123
AUI-28T2 / E2	28	31/07/14	100,19	200,02	3690,30	2340,00	7	60	2342,00			116,70	3,70	31131	34791	
AUI-28T2 / E3	28	31/07/14	100,19	200,02	3690,30	2340,00	7	60	2342,00					29056	31927	0,101
Mean						**2350,00**					**35,55**		**4,13**	**30000**	**34000**	**0,110**
Standard deviation						**22,17**					**2,33**		**0,60**	**1056**	**2026**	**0,016**
Coefficient of variation						**0,94**					**6,56**		**14,57**	**3,52**	**5,96**	**14,14**

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting		Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength			
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIE 2 - AUII																
AUII-3C1	3	02/07/14	99,52	200,80	3605,20	2310,00	10	190	2246,00	147,20	18,92					
AUII-3C2/E1	3	02/07/14	99,68	200,79	3525,80	2250,00	10	190	2246,00	123,60	29,30			17422	20496	
AUII-3T1/E2	3	02/07/14	99,76	201,53	3615,60	2300,00	10	190	2246,00			69,90	2,20	20916	23855	0,167
AUII-3T2	3	02/07/14	99,51	200,83	3502,80	2240,00	10	190	2246,00			62,80	2,00			
Mean						**2280,00**					**24,11**		**2,10**	**19000**	**22000**	**0,170**
Standard deviation						**35,12**					**7,34**		**0,14**	**2471**	**2375**	
Coefficient of variation						**1,54**					**30,44**		**6,73**	**13,00**	**10,80**	
AUII-7C1	7	06/07/14	100,28	200,85	3652,60	2300,00	10	190	2246,00	209,80	26,56					
AUII-7C2/E1	7	06/07/14	99,64	201,03	3645,50	2330,00	10	190	2246,00	192,00	24,62			34664	35476	0,392
AUII-7T1/E2	7	06/07/14	99,89	200,85	3616,30	2300,00	10	190	2246,00			95,90	3,05	31899	29182	
AUII-7T2	7	06/07/14	99,81	200,36	3531,80	2250,00	10	190	2246,00			90,50	2,90			
Mean						**2300,00**					**25,59**		**2,98**	**33500**	**32500**	**0,390**
Standard deviation						**33,17**					**1,37**		**0,11**	**1955**	**4451**	
Coefficient of variation						**1,44**					**5,36**		**3,57**	**5,84**	**13,69**	
AUII-14C1	14	13/07/14	99,67	202,15	3650,20	2310,00	10	190	2246,00	263,00	33,71					
AUII-14C2/E1	14	13/07/14	99,44	201,50	3552,80	2270,00	10	190	2246,00	220,20	28,36					
AUII-14T1/E2	14	13/07/14	99,84	201,90	3518,40	2230,00	10	190	2246,00			97,90	3,10	25696	31031	0,279
AUII-14T2	14	13/07/14	100,17	201,56	3680,90	2320,00	10	190	2246,00			116,80	3,70			
Mean						**2280,00**					**31,04**		**3,40**	**25500**	**31000**	**0,280**
Standard deviation						**41,13**					**3,78**		**0,42**			
Coefficient of variation						**1,80**					**12,19**		**12,48**			
AUII-21C1	21	20/07/14	99,65	201,02	3546,70	2260,00	10	190	2246,00	264,30	33,89					
AUII-21C2/E1	14	20/07/14	99,90	200,66	3656,00	2320,00	10	190	2246,00	286,30	36,52			26855	30554	
AUII-21T1/E2	14	20/07/14	99,74	199,72	3605,40	2310,00	10	190	2246,00			101,60	3,25	28770	31624	0,202
AUII-21T2	14	20/07/14	99,69	200,22	3642,80	2330,00	10	190	2246,00			119,20	3,80			

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting		Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength			
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIE 2 - AUII																
Mean						**2310,00**					**35,21**		**3,53**	**28000**	**31000**	**0,200**
Standard deviation						**31,09**					**1,86**		**0,39**	**1354**	**757**	
Coefficient of variation						**1,35**					**5,28**		**11,03**	**4,84**	**2,44**	

AUII-28C1	28	27/07/14	99,83	200,67	3637,60	2320,00	10	190	2246,00	305,50	38,90					
AUII-28C2	28	27/07/14	99,71	200,52	3645,80	2330,00	10	190	2246,00	307,50	39,39					
AUII-28T1/E1	28	27/07/14	99,85	200,66	3575,70	2280,00	10	190	2246,00			105,70	3,35	25661	28586	
AUII-28T2/E2	28	27/07/14	99,66	200,30	3575,80	2290,00	10	190	2246,00			117,50	3,75	26613	29084	0,180
AUII-28T1/E3	28	27/07/14	99,85	200,66	3575,70	2280,00	10	190	2246,00					27739	31311	0,140
Mean						**2300,00**					**39,15**		**3,55**	**26500**	**29500**	**0,160**
Standard deviation						**23,80**					**0,35**		**0,28**	**1040**	**1451**	**0,028**
Coefficient of variation						**1,03**					**0,89**		**7,97**	**3,93**	**4,92**	**17,68**

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting				
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength	Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIES 3 - AUIII																
AUIII-3C1	3	08/07/14	99,64	200,57	3522,00	2250,00	10,5	250	2225,00	115,30	14,80					
AUIII-3C2 / 3E1	3	08/07/14	99,77	199,78	3570,00	2290,00	10,5	250	2225,00	136,40	17,40			21732	24874	0,108
AUIII-3T1 /3E2	3	08/07/14	99,77	200,74	3504,40	2230,00	10,5	250	2225,00			62,30	2,00	20351	23952	0,106
AUIII-3T2	3	08/07/14	99,88	200,12	3586,70	2290,00	10,5	250	2225,00			68,50	2,20			
Mean						**2270,00**					**16,10**		**2,10**	**21000**	**24500**	**0,110**
Standard deviation						**30,00**					**1,84**		**0,14**	**977**	**652**	**0,001**
Coefficient of variation						**1,32**					**11,42**		**6,73**	**4,65**	**2,66**	**1,29**
AUIII-7C1	7	12/07/14	99,84	200,12	3610,20	2300,00	10,5	250	2225,00	178,50	22,80					
AUIII-7C2 / 7E1	7	12/07/14	99,77	200,35	3647,40	2330,00	10,5	250	2225,00	165,10	21,10			24158	25981	
AUIII-7T1 / 7E2	7	12/07/14	99,72	201,49	3795,10	2410,00	10,5	250	2225,00			88,90	2,80			
AUIII-7T2	7	12/07/14	99,66	201,37	3571,00	2270,00	10,5	250	2225,00			81,30	2,60			
Mean						**2330,00**					**21,95**		**2,70**	**24000**	**26000**	
Standard deviation						**60,21**					**1,20**		**0,14**			
Coefficient of variation						**2,58**					**5,48**		**5,24**			
AUIII-14C1	14	19/07/14	99,87	201,04	3759,10	2390,00	10,5	250	2225,00	191,60	24,50					
AUIII-14C2 / 14E1	14	19/07/14	99,65	200,77	3735,90	2390,00	10,5	250	2225,00	229,20	29,40			27709	31010	
AUIII-14T1 / 14E2	14	19/07/14	99,86	200,18	3563,70	2270,00	10,5	250	2225,00			93,70	3,00			
AUIII-14T2	14	19/07/14	99,66	200,59	3627,40	2320,00	10,5	250	2225,00			86,40	2,75			
Mean						**2340,00**					**26,95**		**2,88**	**27500**	**31000**	
Standard deviation						**58,52**					**3,46**		**0,18**			
Coefficient of variation						**2,50**					**12,86**		**6,15**			
AUIII-21C1	21	26/07/14	99,70	200,18	3662,30	2340,00	10,5	250	2225,00	224,40	28,70					
AUIII-21C2	21	26/07/14	99,86	200,91	3748,70	2380,00	10,5	250	2225,00	247,60	31,60					
AUIII-21C3	21	26/07/14	99,81	200,11	3616,20	2310,00	10,5	250	2225,00	266,50	34,10					
AUIII-21T1 / 21E1	21	26/07/14	99,42	200,85	3670,40	2350,00	10,5	250	2225,00			124,60	3,95	26296	29554	0,121

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting				
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength	Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIES 3 - AUIII																
AUIII-21T2 / 21E2	21	26/07/14	99,83	200,62	3679,90	2340,00	10,5	250	2225,00			113,10	3,60	26737	28323	0,145
Mean						**2340,00**					**31,47**		**3,78**	**26500**	**29000**	**0,130**
Standard deviation						**25,10**					**2,70**		**0,25**	**312**	**870**	**0,017**
Coefficient of variation						**1,07**					**8,59**		**6,56**	**1,18**	**3,00**	**13,05**
AUIII-28C1	28	02/08/14	99,81	200,11	3616,20	2310,00	10,5	250	2225,00	266,50	34,10					
AUIII-28C2	28	02/08/14	99,70	200,03	3612,30	2310,00	10,5	250	2225,00	290,10	37,20					
AUIII-28T1 / 28E1	28	02/08/14	100,01	200,33	3701,30	2350,00	10,5	250	2225,00			94,70	3,00	26266	28920	0,304
AUIII-28T2 / 28E2	28	02/08/14	99,76	200,06	3702,30	2370,00	10,5	250	2225,00			112,80	3,60	28221	31257	0,095
Mean						**2340,00**					**35,65**		**3,30**	**27000**	**30000**	**0,200**
Standard deviation						**30,00**					**2,19**		**0,42**	**1382**	**1653**	**0,148**
Coefficient of variation						**1,28**					**6,15**		**12,86**	**5,12**	**5,51**	**73,89**

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting		Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength			
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIES 4 - AWI																
AWI-3C1	3	10/07/14	99,68	200,19	3725,40	2380,00	6	90	2338,00	101,90	13,10					
AWI-3C2 / 3E1	3	10/07/14	99,55	200,73	3696,50	2370,00	6	90	2338,00	96,10	12,30			20650	20842	
AWI-3T1 /3E2	3	10/07/14	99,62	200,90	3733,00	2380,00	6	90	2338,00			64,40	2,05	26847	26878	0,155
AWI-3T2	3	10/07/14	99,40	200,97	3714,60	2380,00	6	90	2338,00			63,10	2,00			
Mean						**2380,00**					**12,70**		**2,03**	**23500**	**24000**	**0,160**
Standard deviation						**5,00**					**0,57**		**0,04**	**4382**	**4268**	
Coefficient of variation						**0,21**					**4,45**		**1,75**	**18,65**	**17,78**	
AWI-7C1	7	14/07/14	99,73	200,30	3735,20	2390,00	6	90	2338,00	136,20	17,40					
AWI-7C2 / 7E1	7	14/07/14	99,72	200,59	3736,40	2390,00	6	90	2338,00	139,60	17,90			24148	26174	
AWI-7T1 / 7E1	7	14/07/14	99,79	201,30	3727,60	2370,00	6	90	2338,00			86,30	2,75	23399	24019	
AWI-7T2	7	14/07/14	99,75	200,42	3728,40	2380,00	6	90	2338,00			78,40	2,50			
Mean						**2380,00**					**17,65**		**2,63**	**24000**	**25000**	
Standard deviation						**9,57**					**0,35**		**0,18**	**530**	**1524**	
Coefficient of variation						**0,40**					**2,00**		**6,73**	**2,21**	**6,10**	
AWI-14C1	14	21/07/14	99,76	200,73	3769,60	2400,00	6	90	2338,00	188,10	24,10					
AWI-14C2	14	21/07/14	99,84	200,51	3738,30	2380,00	6	90	2338,00	207,50	26,50					
AWI-14T1 / 14E1	14	21/07/14	99,77	200,41	3711,90	2370,00	6	90	2338,00			82,20	2,60	24686	27042	0,148
AWI-14T2 / 14E2	14	21/07/14	99,95	200,50	3721,50	2370,00	6	90	2338,00			80,00	2,55	23752	26049	0,178
Mean						**2380,00**					**25,30**		**2,58**	**24000**	**26500**	**0,160**
Standard deviation						**14,14**					**1,70**		**0,04**	**660**	**702**	**0,021**
Coefficient of variation						**0,59**					**6,71**		**1,37**	**2,75**	**2,65**	**13,26**
AWI-21C1	21	28/07/14	99,55	200,73	3787,90	2420,00	6	90	2338,00	238,80	30,70					
AWI-21C2	21	28/07/14	99,79	200,93	3753,40	2390,00	6	90	2338,00	246,50	31,50					
AWI-21T1 / 21E1	21	28/07/14	99,83	200,56	3761,70	2400,00	6	90	2338,00			110,00	3,50	25702	28594	0,262
AWI-21T2 / 21E2	21	28/07/14	99,61	200,30	3714,20	2380,00	6	90	2338,00			111,10	3,55	24704	27423	0,166

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting		Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength			
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIES 4 - AWI																
Mean						**2400,00**					**31,10**		**3,53**	**25000**	**28000**	**0,210**
Standard deviation						**17,08**					**0,57**		**0,04**	**706**	**828**	**0,068**
Coefficient of variation						**0,71**					**1,82**		**1,00**	**2,82**	**2,96**	**32,32**

AWI-28C1	28	04/08/14	100,11	200,85	3768,60	2380,00	6	90	2338,00	261,20	33,20					
AWI-28C2	28	04/08/14	99,82	200,15	3774,90	2410,00	6	90	2338,00	281,10	35,90					
AWI-28T1 / 28E1	28	04/08/14	99,89	200,57	3725,90	2370,00	6	90	2338,00			86,50	2,75	27438	30076	0,154
AWI-28T2 / 28E2	28	04/08/14	99,89	200,51	3729,20	2370,00	6	90	2338,00			97,10	3,10	25557	28520	0,124
Mean						**2380,00**					**34,55**		**2,93**	**26500**	**29500**	**0,140**
Standard deviation						**18,93**					**1,91**		**0,25**	**1330**	**1100**	**0,021**
Coefficient of variation						**0,80**					**5,53**		**8,46**	**5,02**	**3,73**	**15,15**

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting				
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength	Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIES 5 - AWII																
AWII-3C1	3	13/07/14	99,64	200,44	3515,50	2250,00	10,5	250	2239,00	91,50	11,70					
AWII-3C2 / 3E1	3	13/07/14	99,92	200,98	3591,60	2280,00	10,5	250	2239,00	106,70	13,60			22000	21544	0,185
AWII-3T1 /3E2	3	13/07/14	99,65	200,80	3597,90	2300,00	10,5	250	2239,00			56,40	1,80			
AWII-3T2	3	13/07/14	99,46	201,24	3568,10	2280,00	10,5	250	2239,00			48,70	1,55			
Mean						**2280,00**					**12,65**		**1,68**	**22000**	**21500**	**0,190**
Standard deviation						**20,62**					**1,34**		**0,18**			
Coefficient of variation						**0,90**					**10,62**		**10,55**			
AWII-7C1	7	17/07/14	99,72	200,32	3614,30	2310,00	10,5	250	2239,00	142,30	18,20					
AWII-7C2 / 7E1	7	17/07/14	99,84	200,37	3477,90	2220,00	10,5	250	2239,00	150,50	19,20			24423	23837	
AWII-7T1 / 7E1	7	17/07/14	99,50	200,82	3543,20	2270,00	10,5	250	2239,00			55,70	1,75	25805	24216	
AWII-7T2	7	17/07/14	99,91	200,95	3589,00	2280,00	10,5	250	2239,00			76,40	2,40			
Mean						**2270,00**					**18,70**		**2,08**	**25000**	**24000**	
Standard deviation						**37,42**					**0,71**		**0,46**	**977**	**268**	
Coefficient of variation						**1,65**					**3,78**		**22,15**	**3,91**	**1,12**	
AWII-14C1	14	24/07/14	99,95	200,83	3695,60	2350,00	10,5	250	2239,00	223,20	28,40					
AWII-14C2	14	24/07/14	99,82	200,36	3579,50	2280,00	10,5	250	2239,00	186,20	23,80					
AWII-14T1 / 14E1	14	24/07/14	99,77	200,60	3511,70	2240,00	10,5	250	2239,00			88,20	2,80	23015	28381	0,122
AWII-14T2 / 14E2	14	24/07/14	99,82	200,42	3498,50	2230,00	10,5	250	2239,00			87,10	2,75	20027	23240	0,143
Mean						**2280,00**					**26,10**		**2,78**	**21500**	**26000**	**0,130**
Standard deviation						**54,47**					**3,25**		**0,04**	**2113**	**3635**	**0,015**
Coefficient of variation						**2,39**					**12,46**		**1,27**	**9,83**	**13,98**	**11,42**
AWII-21C1	21	31/07/14	99,96	200,64	3738,20	2370,00	10,5	250	2239,00	228,30	29,10					
AWII-21C2	21	31/07/14	99,92	201,71	3729,80	2360,00	10,5	250	2239,00	245,20	31,30					
AWII-21T1 / 21E1	21	31/07/14	100,11	200,49	3606,40	2290,00	10,5	250	2239,00			99,60	3,15	24958	27666	0,122
AWII-21T2 / 21E2	21	31/07/14	99,63	200,46	3617,60	2310,00	10,5	250	2239,00			97,80	3,10	24979	28025	0,072

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting		Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength			
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m³	%	mm	kg/m³	kN	Mpa	kN	Mpa	N/mm²	N/mm²	-
SERIES 5 - AWII																
Mean						**2330,00**					**30,20**		**3,13**	**25000**	**28000**	**0,100**
Standard deviation						**38,62**					**1,56**		**0,04**	**15**	**254**	**0,035**
Coefficient of variation						**1,66**					**5,15**		**1,13**	**0,06**	**0,91**	**35,36**

AWII-28C1	28	07/08/14	99,79	200,77	3550,70	2260,00	10,5	250	2239,00	204,00	26,10					
AWII-28C2	28	07/08/14	99,94	200,45	3525,50	2240,00	10,5	250	2239,00	235,70	30,00					
AWII-28C3	28	07/08/14	99,97	200,45	3707,50	2360,00	10,5	250	2239,00	197,80	25,20					
AWII-28T1 / 28E1	28	07/08/14	99,70	200,58	3551,60	2270,00	10,5	250	2239,00			117,40	3,75	25803	27528	0,164
AWII-28T2 / 28E2	28	07/08/14	99,70	200,65	3664,50	2340,00	10,5	250	2239,00			108,80	3,45	26246	29141	0,151
Mean						**2290,00**					**27,10**		**3,60**	**26000**	**28500**	**0,160**
Standard deviation						**52,73**					**2,55**		**0,21**	**313**	**1141**	**0,009**
Coefficient of variation						**2,30**					**9,42**		**5,89**	**1,20**	**4,00**	**5,75**

Appendix E.2. Mechanical results

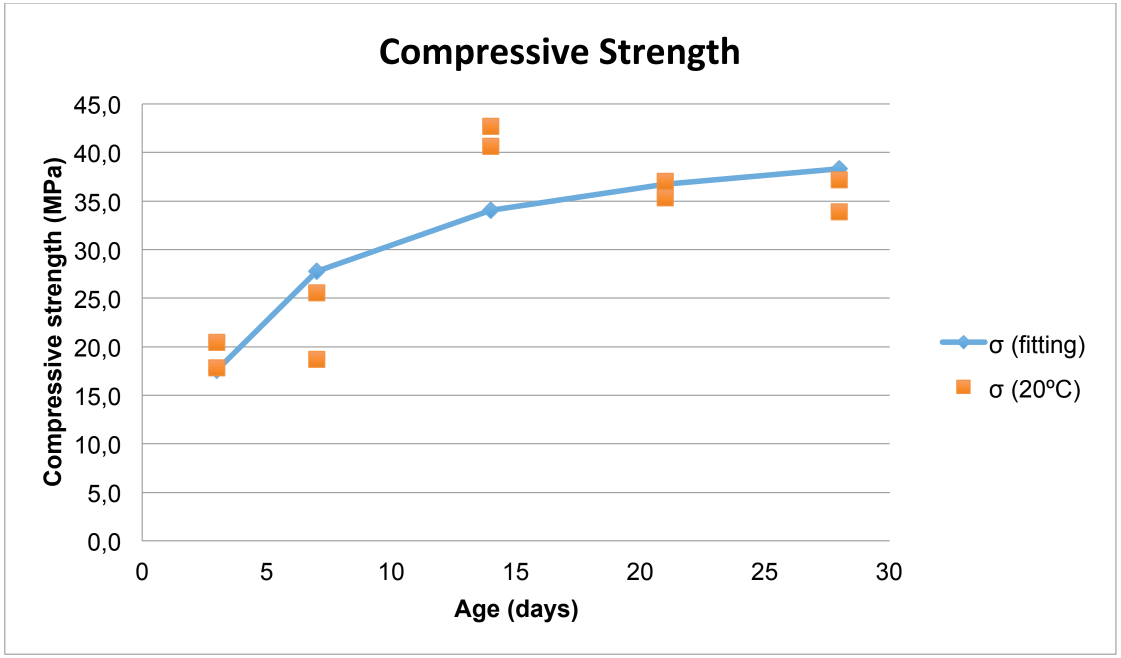
			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting		Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength			
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIES 6 - AWIII																
AWIII-3C1	3	14/07/14	99,44	200,89	3556,30	2280,00	9	250	2275,00	104,50	13,50					
AWIII-3C2 / 3E1	3	14/07/14	99,76	201,48	3574,80	2270,00	9	250	2275,00	99,30	12,70			19928	20845	0,157
AWIII-3T1 /3E2	3	14/07/14	99,88	200,91	3544,10	2250,00	9	250	2275,00			50,60	1,60	25408	24667	
AWIII-3T2	3	14/07/14	99,72	200,55	3572,90	2280,00	9	250	2275,00			60,00	1,90			
Mean						**2270,00**					**13,10**		**1,75**	**22500**	**23000**	**0,160**
Standard deviation						**14,14**					**0,57**		**0,21**	**3875**	**2703**	
Coefficient of variation						**0,62**					**4,32**		**12,12**	**17,22**	**11,75**	
AWIII-7C1	7	18/07/14	99,81	200,63	3594,40	2290,00	9	250	2275,00	146,60	18,70					
AWIII-7C2 / 7E1	7	18/07/14	99,68	200,39	3676,80	2350,00	9	250	2275,00	178,90	22,90			24663	25581	0,116
AWIII-7T1 / 7E2	7	18/07/14	99,70	200,36	3629,50	2320,00	9	250	2275,00			81,60	2,60	26919	26243	0,061
AWIII-7T2	7	18/07/14	99,82	200,26	3555,50	2270,00	9	250	2275,00			54,60	1,75			
Mean						**2310,00**					**20,80**		**2,18**	**26000**	**26000**	**0,090**
Standard deviation						**35,00**					**2,97**		**0,60**	**1595**	**468**	**0,039**
Coefficient of variation						**1,52**					**14,28**		**27,63**	**6,14**	**1,80**	**43,21**
AWIII-14C1	14	25/07/14	99,88	200,66	3698,00	2350,00	9	250	2275,00	157,50	20,10					
AWIII-14C2	14	25/07/14	99,63	200,58	3692,50	2360,00	9	250	2275,00	224,80	28,80					
AWIII-14T1 / 14E1	14	25/07/14	99,31	201,48	3717,90	2380,00	9	250	2275,00			91,20	2,90	25872	28582	0,155
AWIII-14T2 / 14E2	14	25/07/14	99,96	200,77	3563,60	2260,00	9	250	2275,00			73,70	2,35			
Mean						**2340,00**					**24,45**		**2,63**	**26000**	**28500**	**0,160**
Standard deviation						**53,15**					**6,15**		**0,39**			
Coefficient of variation						**2,27**					**25,16**		**14,82**			
AWIII-21C1	21	01/08/14	100,08	200,79	3621,30	2290,00	9	250	2275,00	226,20	28,80					
AWIII-21C2	21	01/08/14	99,89	200,74	3548,10	2260,00	9	250	2275,00	205,00	26,20					
AWIII-21T1 / 21E1	21	01/08/14	99,70	200,83	3716,70	2370,00	9	250	2275,00			117,10	3,70	28425	33744	0,108
AWIII-21T2 / 21E2	21	01/08/14	100,02	200,37	3656,10	2320,00	9	250	2275,00			108,60	3,45	25660	28544	0,198

Appendix E.2. Mechanical results

			Cylinder				Fresh Concrete			Compressive strength		Tensile splitting		Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	Age	Date	Diameter	Length	Weight	Density	Air Content	Slump	Density	Load	Compressive strength	Load	Tensile strength			
	M_{20}		d	L	m	ρ	A	S	ρ	F	f_c	F	f_{ct}	ε_{c0}	ε_{cs}	ν
	days		mm	mm	g	kg/m^3	%	mm	kg/m^3	kN	Mpa	kN	Mpa	N/mm^2	N/mm^2	-
SERIES 6 - AWIII																
AWIII-21E3	21	01/08/14	99,70	200,83	3716,70	2370,00	9	250	2275,00					30678	39211	0,138
Mean						**2310,00**					**27,50**		**3,58**	**28500**	**34000**	**0,150**
Standard deviation						**48,68**					**1,84**		**0,18**	**2513**	**5334**	**0,046**
Coefficient of variation						**2,11**					**6,69**		**4,94**	**8,82**	**15,69**	**30,55**
AWIII-28C1	28	08/08/14	99,72	200,68	3666,00	2340,00	9	250	2275,00	243,60	31,20					
AWIII-28C2	28	08/08/14	99,82	200,60	3614,20	2300,00	9	250	2275,00	252,10	32,20					
AWIII-28T1 / 28E1	28	08/08/14	99,83	200,57	3568,40	2270,00	9	250	2275,00			104,40	3,30	27048	30372	
AWIII-28T2 / 28E2	28	08/08/14	99,89	200,81	3684,20	2340,00	9	250	2275,00			96,90	3,10	27600	30390	0,122
AWIII-28E3	28	08/08/14	99,83	200,57	3568,40	2270,00	9	250	2275,00					26421	28100	0,107
Mean						**2300,00**					**31,70**		**3,20**	**27000**	**29500**	**0,110**
Standard deviation						**35,07**					**0,71**		**0,14**	**590**	**1317**	**0,011**
Coefficient of variation						**1,52**					**2,23**		**4,42**	**2,18**	**4,46**	**9,64**

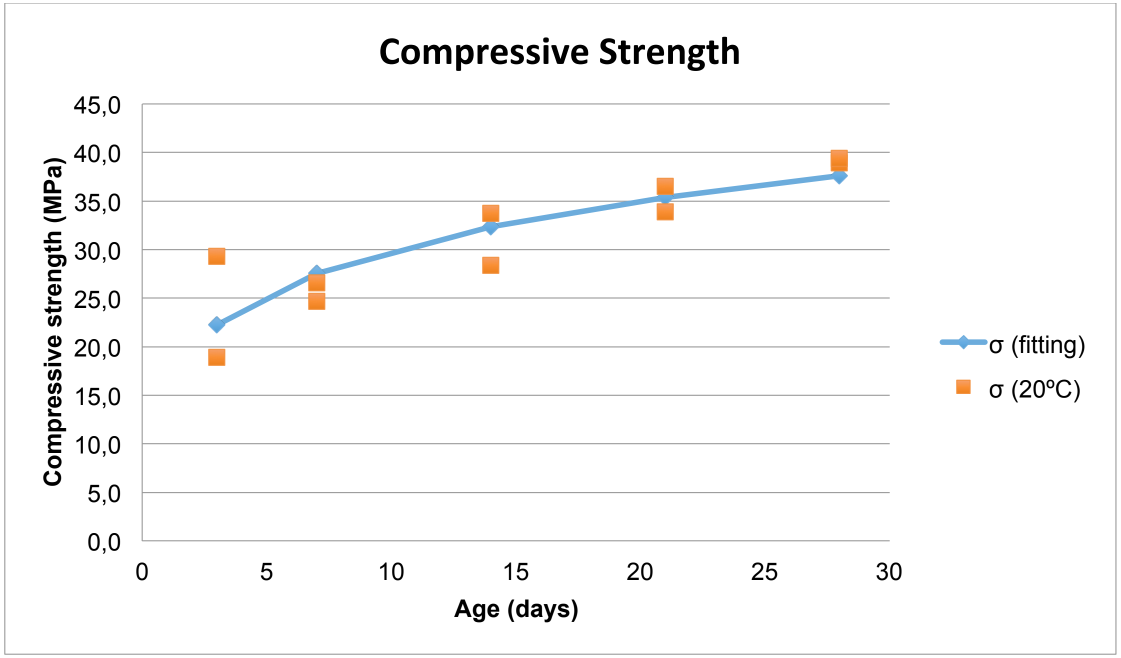
Appendix E.3. Compressive strength

Unwashed / 0% FA		f∞	τ	α
Age	Compressive strength	45	2,79	0,78
Days	Mpa	σ	$\Delta\sigma^2$	
3	20,4	17,6	8,0	
3	17,8	17,6	0,1	
7	25,5	27,8	5,2	
7	18,7	27,8	82,3	
14	42,7	34,0	75,0	
14	40,6	34,0	43,0	
21	35,3	36,8	2,1	
21	37,0	36,8	0,1	
28	37,2	38,3	1,2	
28	33,9	38,3	19,5	
		SUM:	236,4	



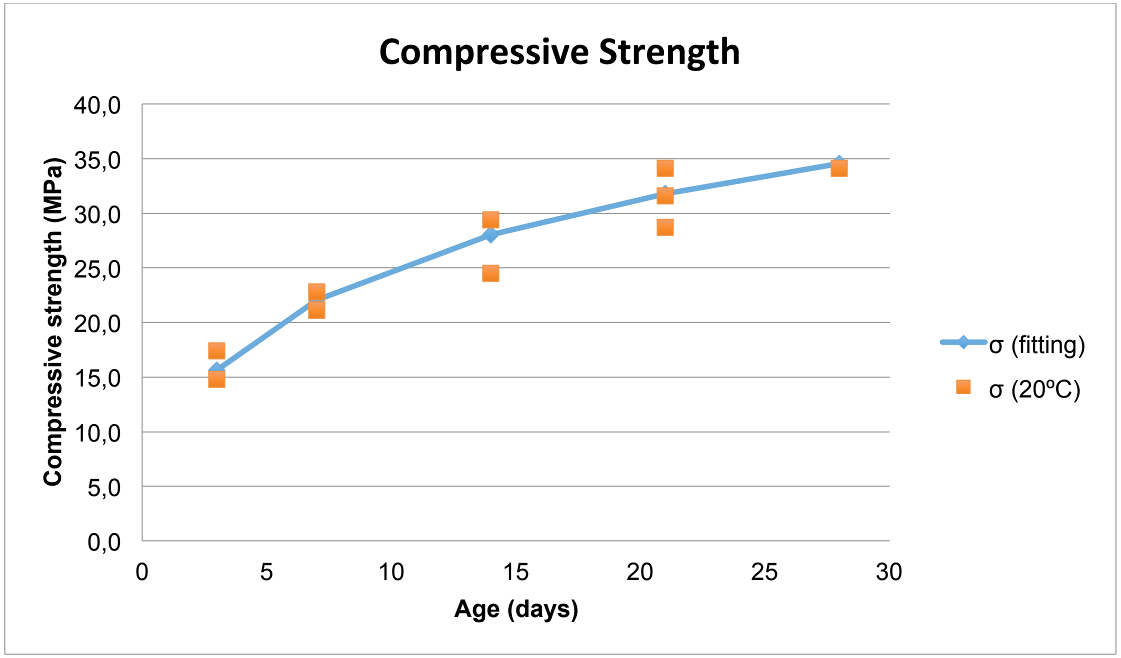
Appendix E.3. Compressive strength

Unwashed / 15% FA		f∞	τ	α
Age	Compressive strength	270	16753,38	0,11
Days	Mpa	σ	$\Delta\sigma^2$	
3	18,9	22,2	10,8	
3	29,3	22,2	50,3	
7	26,6	27,5	0,9	
7	24,6	27,5	8,5	
14	33,7	32,4	1,8	
14	28,4	32,4	16,0	
21	33,9	35,4	2,2	
21	36,5	35,4	1,3	
28	38,9	37,6	1,7	
28	39,4	37,6	3,2	
		SUM:	96,7	



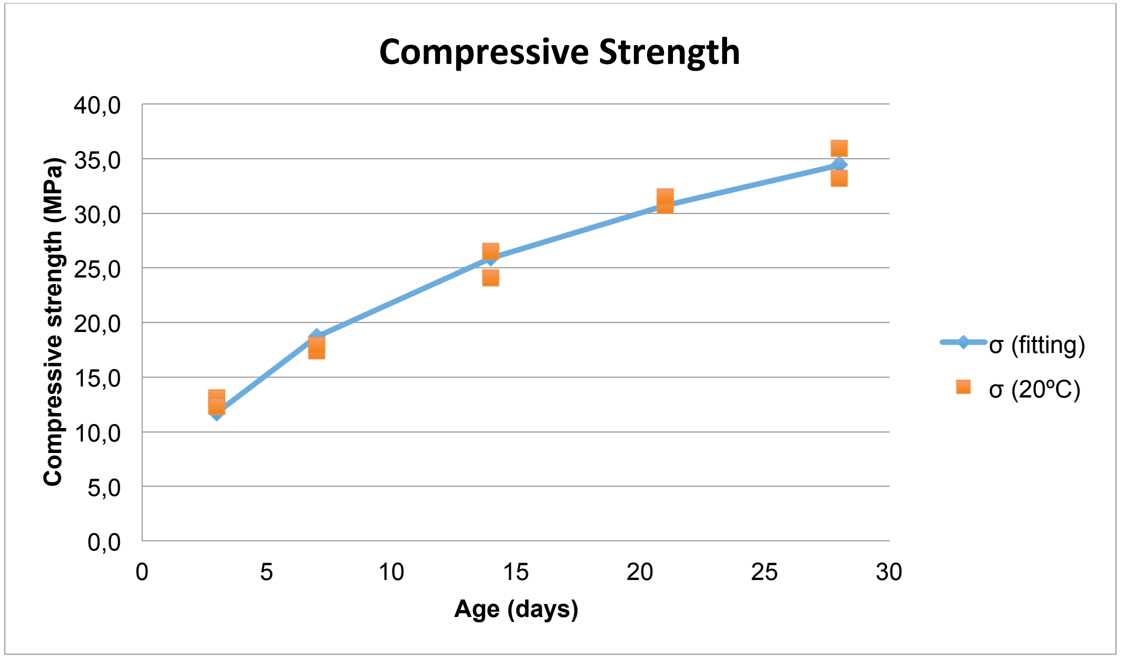
Appendix E.3. Compressive strength

Unwashed / 25% FA		f∞	τ	α
Age	Compressive strength	139	141,94	0,20
Days	Mpa	σ	$\Delta\sigma^2$	
3	14,8	15,6	0,7	
3	17,4	15,6	3,1	
7	22,8	22,0	0,6	
7	21,1	22,0	0,9	
14	24,5	28,0	12,5	
14	29,4	28,0	1,9	
21	28,7	31,8	9,6	
21	31,6	31,8	0,0	
21	34,1	31,8	5,3	
28	34,1	34,6	0,2	
28	37,2	34,6	7,0	
		SUM:	41,8	



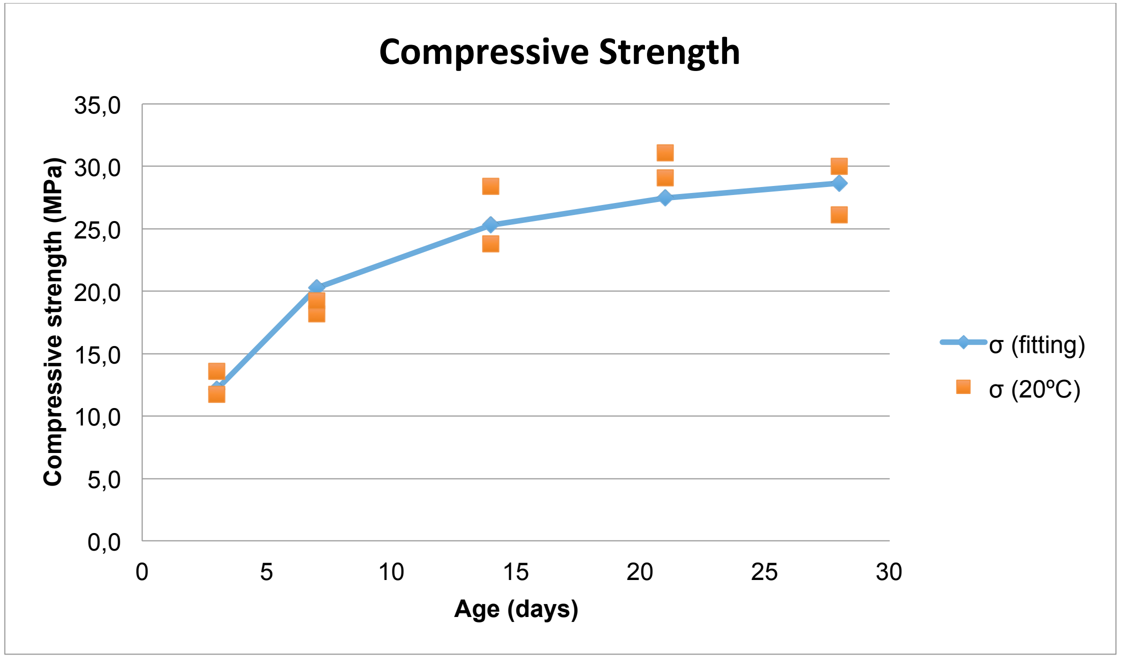
Appendix E.3. Compressive strength

Washed / 0% FA		f∞	τ	α
Age	Compressive strength	232	706,44	0,20
Days	Mpa	σ	$\Delta\sigma^2$	
3	13,1	11,7	1,9	
3	12,3	11,7	0,3	
7	17,4	18,7	1,6	
7	17,9	18,7	0,6	
14	24,1	25,9	3,2	
14	26,5	25,9	0,4	
21	30,7	30,7	0,0	
21	31,5	30,7	0,6	
28	33,2	34,4	1,4	
28	35,9	34,4	2,3	
		SUM:	12,3	



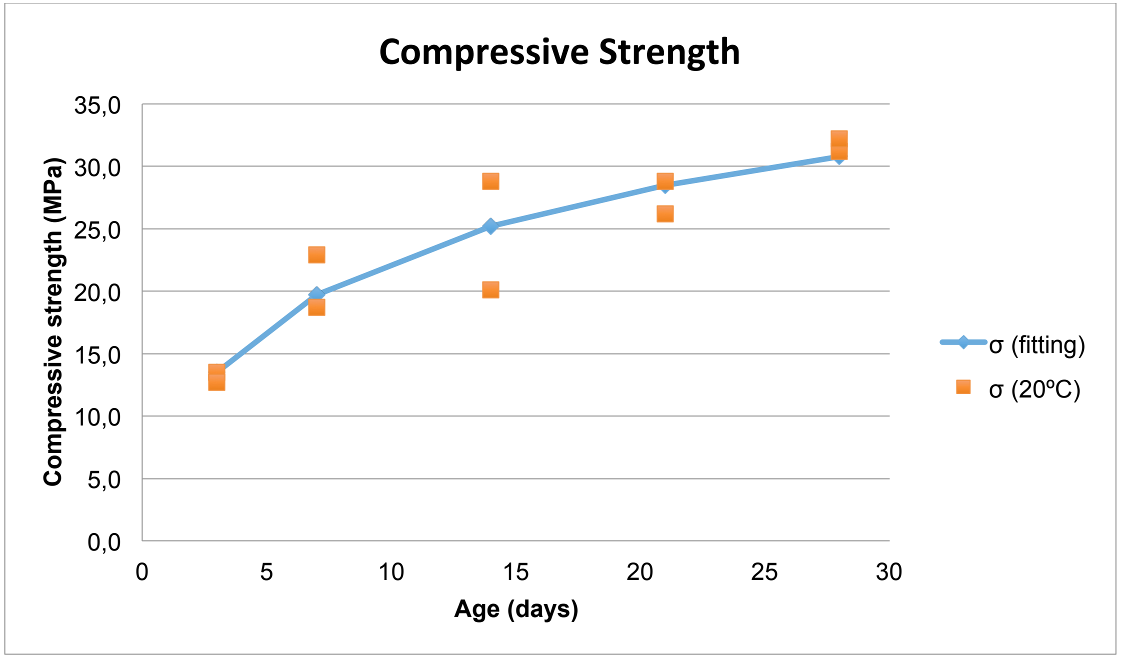
Appendix E.3. Compressive strength

Washed / 15% FA		f∞	τ	α
Age	Compressive strength	34	3,08	0,82
Days	Mpa	σ	$\Delta\sigma^2$	
3	11,7	12,1	0,2	
3	13,6	12,1	2,1	
7	18,2	20,3	4,3	
7	19,2	20,3	1,1	
14	28,4	25,3	9,7	
14	23,8	25,3	2,2	
21	29,1	27,4	2,7	
21	31,1	27,4	13,3	
28	26,1	28,7	6,6	
28	30,0	28,7	1,8	
28	25,2	28,7	12,1	
		SUM:	56,1	

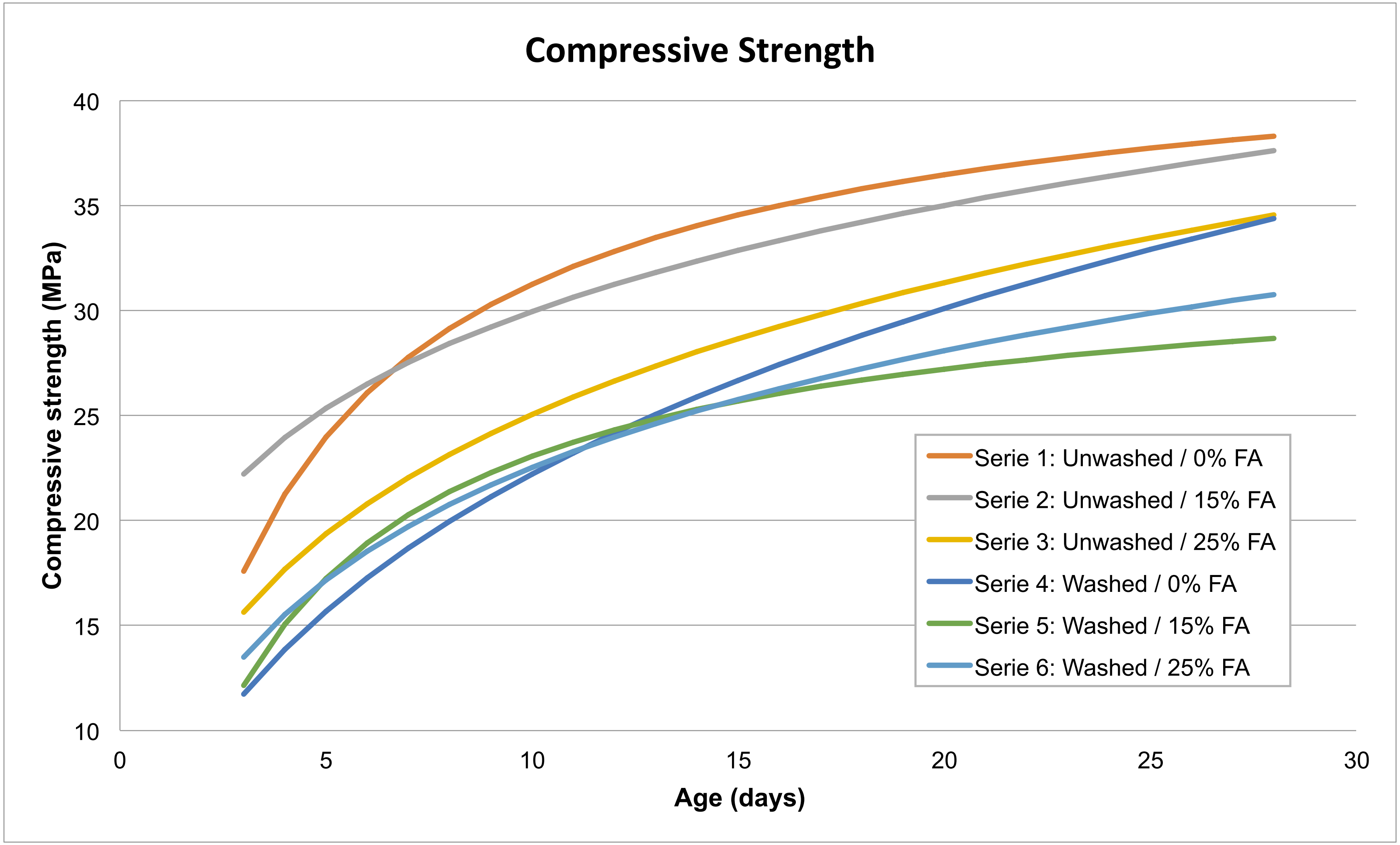


Appendix E.3. Compressive strength

Washed / 25 % FA		f∞	τ	α
Age	Compressive strength	72	16,33	0,30
Days	Mpa	σ	$\Delta\sigma^2$	
3	13,5	13,5	0,0	
3	12,7	13,5	0,6	
7	18,7	19,7	1,0	
7	22,9	19,7	10,1	
14	20,1	25,2	26,2	
14	28,8	25,2	12,8	
21	28,8	28,5	0,1	
21	26,2	28,5	5,2	
28	31,2	30,8	0,2	
28	32,2	30,8	2,0	
		SUM:	58,3	

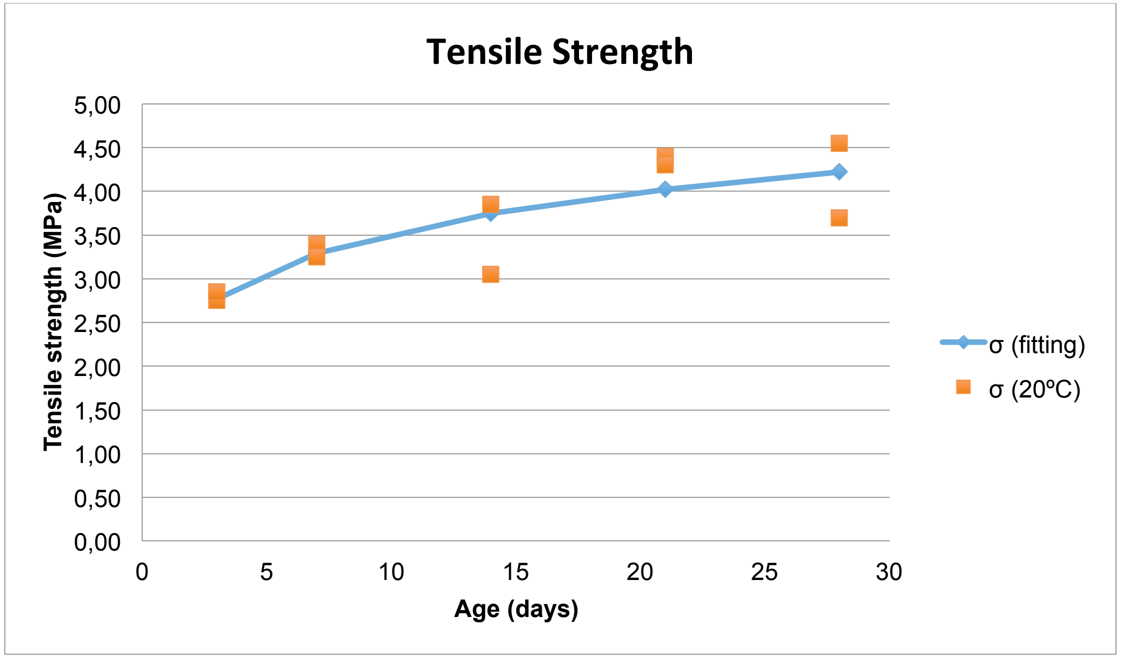


Appendix E.3. Compressive strength



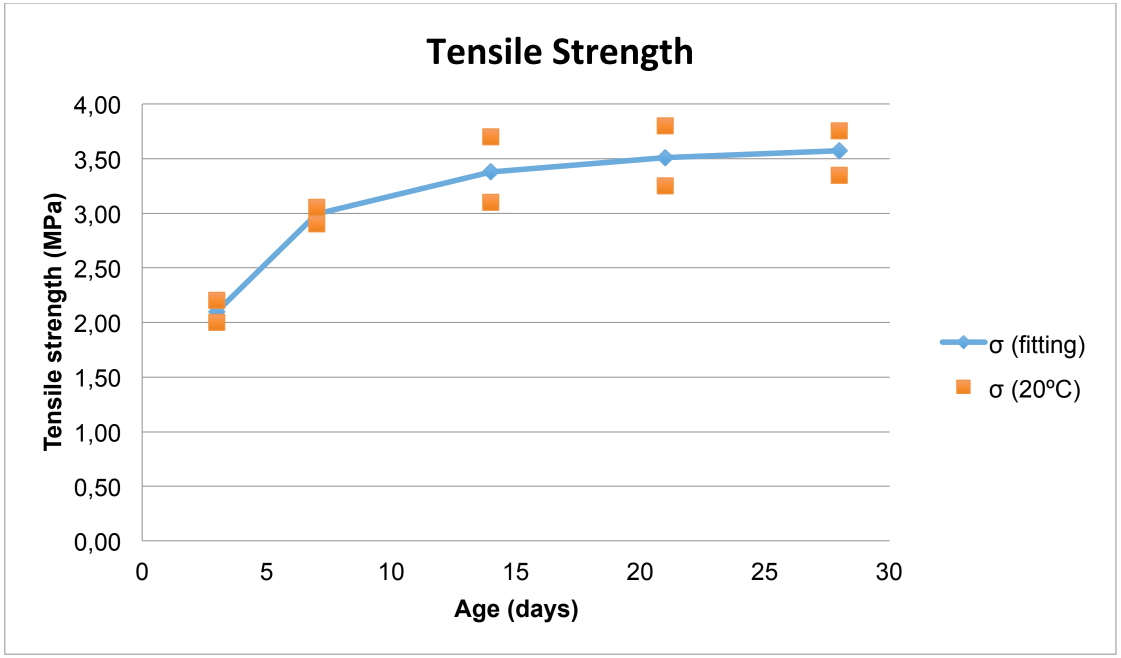
Appendix E.4. Tensile strength

Unwashed / 0% FA		f∞	τ	α
Age	Tensile strength	15,83	265,50	0,12
Days	Mpa	σ	$\Delta\sigma^2$	
3	2,75	2,77	0,00	
3	2,85	2,77	0,01	
7	3,40	3,29	0,01	
7	3,25	3,29	0,00	
14	3,85	3,75	0,01	
14	3,05	3,75	0,49	
21	4,40	4,02	0,14	
21	4,30	4,02	0,08	
28	4,55	4,22	0,11	
28	3,70	4,22	0,27	
		SUM:	1,12	



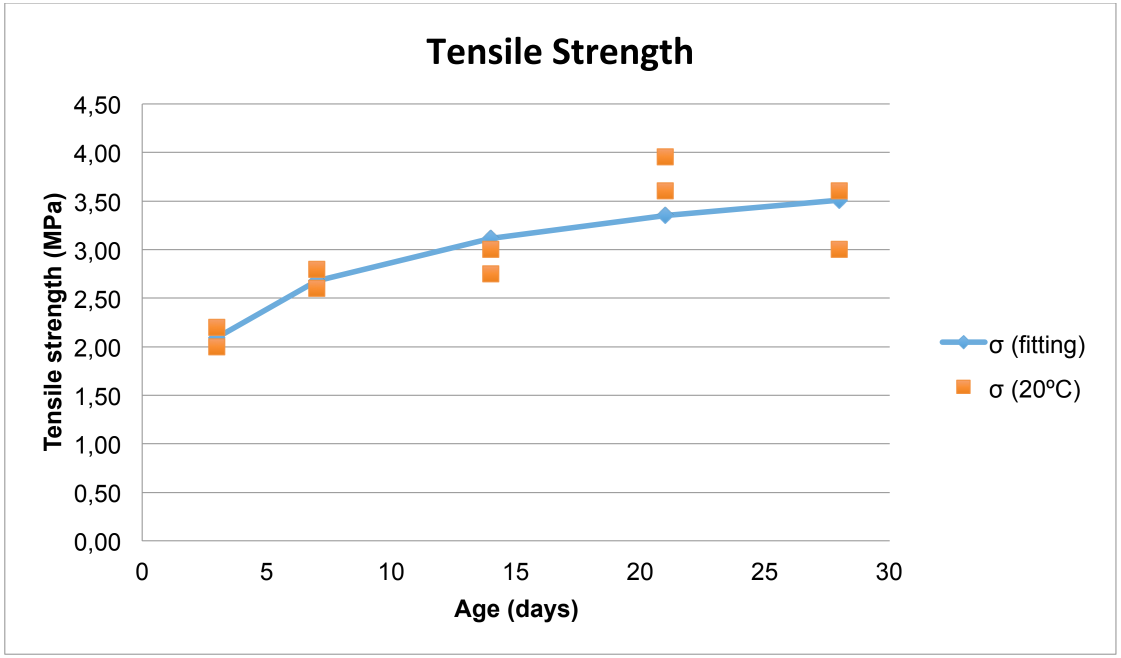
Appendix E.4. Tensile strength

Unwashed / 15% FA		f∞	τ	α
Age	Tensile strength	3,75	1,85	1,12
Days	Mpa	σ	$\Delta\sigma^2$	
3	2,20	2,10	0,01	
3	2,00	2,10	0,01	
7	3,05	2,99	0,00	
7	2,90	2,99	0,01	
14	3,10	3,38	0,08	
14	3,70	3,38	0,10	
21	3,25	3,51	0,07	
21	3,80	3,51	0,08	
28	3,35	3,57	0,05	
28	3,75	3,57	0,03	
		SUM:	0,45	



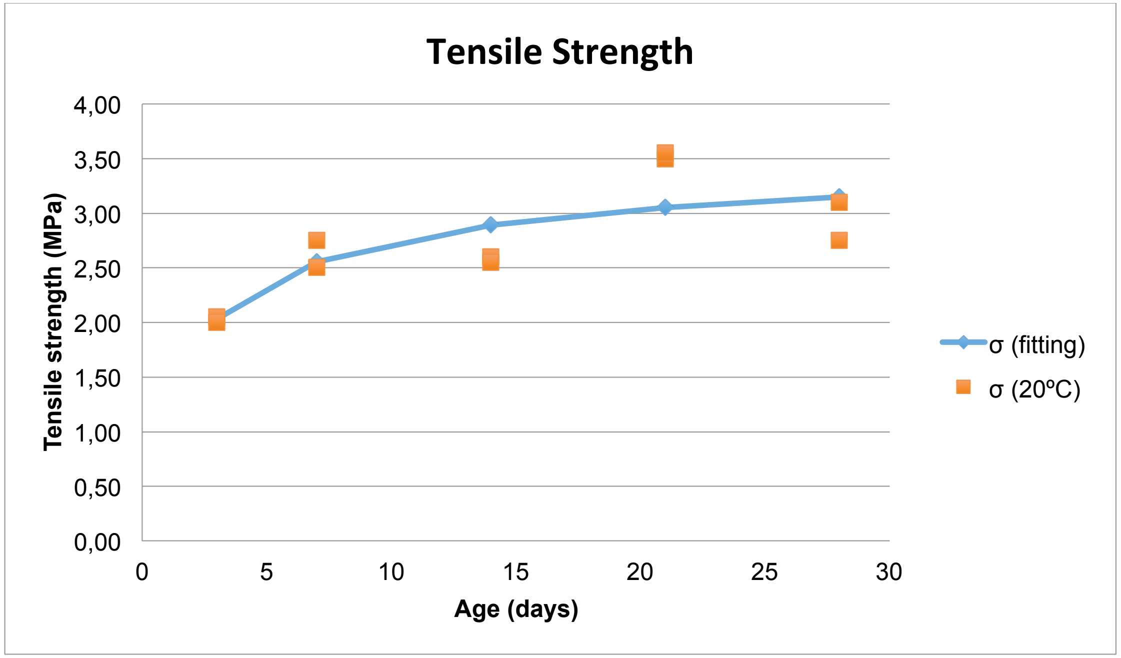
Appendix E.4. Tensile strength

Unwashed / 25% FA		f∞	τ	α
Age	**Tensile strength**	**5,33**	**2,49**	**0,36**
Days	**Mpa**	**σ**	**$\Delta\sigma^2$**	
3	2,00	2,09	0,01	
3	2,20	2,09	0,01	
7	2,80	2,68	0,02	
7	2,60	2,68	0,01	
14	3,00	3,12	0,01	
14	2,75	3,12	0,13	
21	3,95	3,35	0,36	
21	3,60	3,35	0,06	
28	3,00	3,51	0,26	
28	3,60	3,51	0,01	
		SUM:	**0,87**	



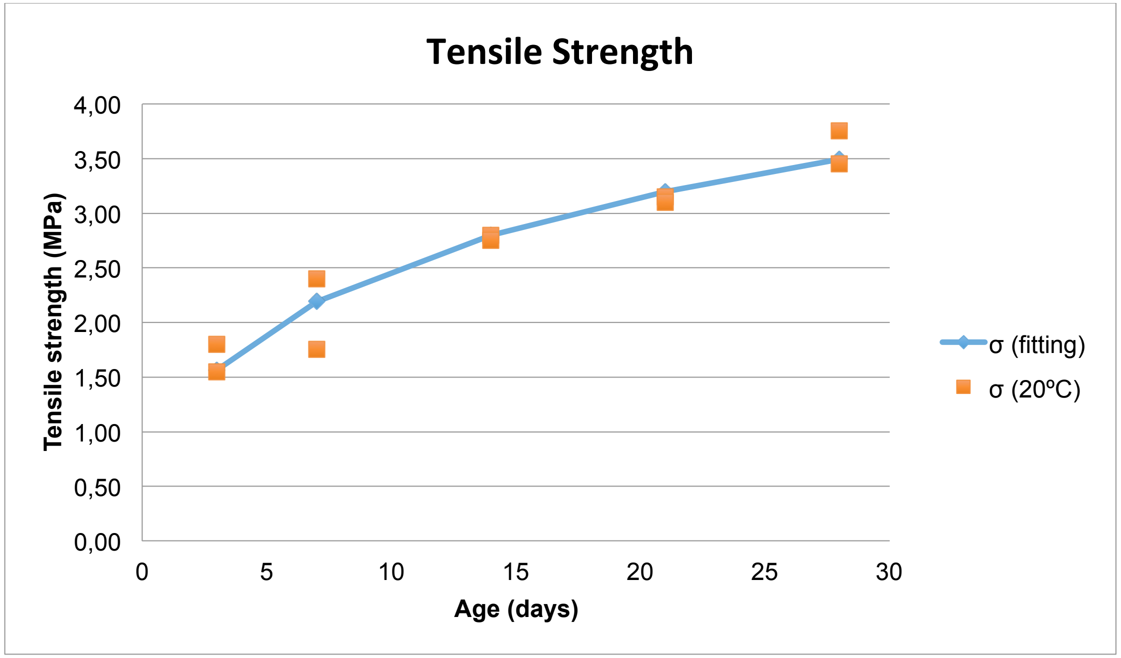
Appendix E.4. Tensile strength

Washed / 0% FA		f∞	τ	α
Age	Tensile strength	3,80	1,26	0,54
Days	Mpa	σ	$\Delta\sigma^2$	
3	2,05	2,03	0,00	
3	2,00	2,03	0,00	
7	2,75	2,55	0,04	
7	2,50	2,55	0,00	
14	2,60	2,89	0,08	
14	2,55	2,89	0,12	
21	3,50	3,05	0,20	
21	3,55	3,05	0,25	
28	2,75	3,15	0,16	
28	3,10	3,15	0,00	
		SUM:	0,86	



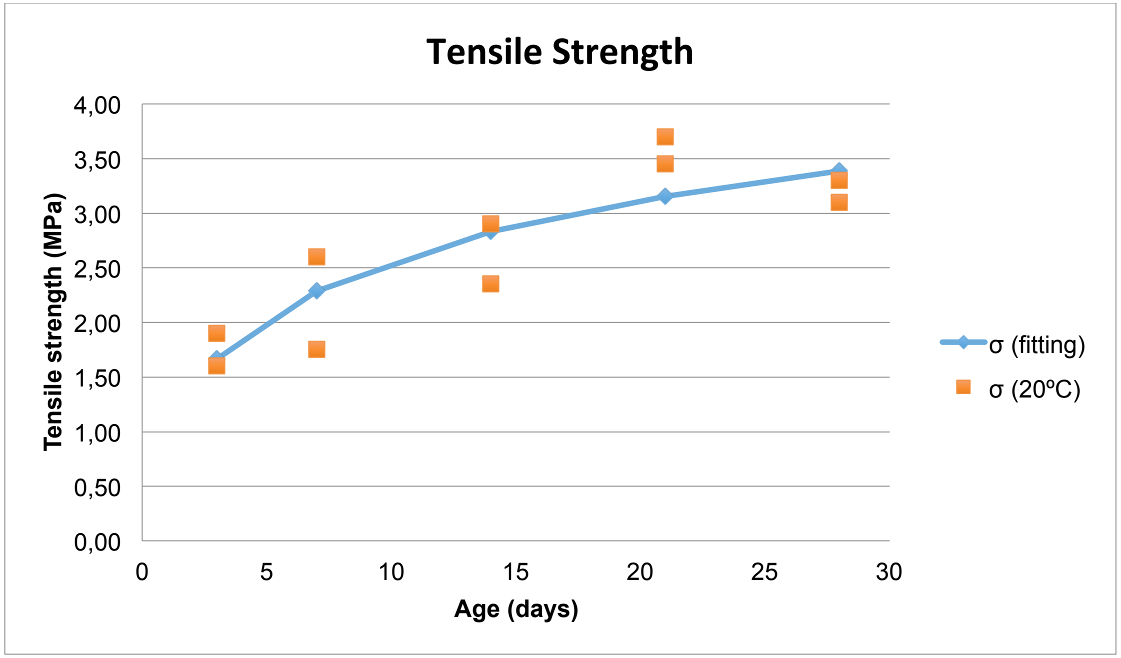
Appendix E.4. Tensile strength

Washed / 15% FA		f∞	τ	α
Age	Tensile strength	27,70	3944,66	0,15
Days	Mpa	σ	$\Delta\sigma^2$	
3	1,80	1,56	0,06	
3	1,55	1,56	0,00	
7	1,75	2,19	0,19	
7	2,40	2,19	0,04	
14	2,80	2,80	0,00	
14	2,75	2,80	0,00	
21	3,15	3,20	0,00	
21	3,10	3,20	0,01	
28	3,75	3,50	0,06	
28	3,45	3,50	0,00	
		SUM:	0,37	

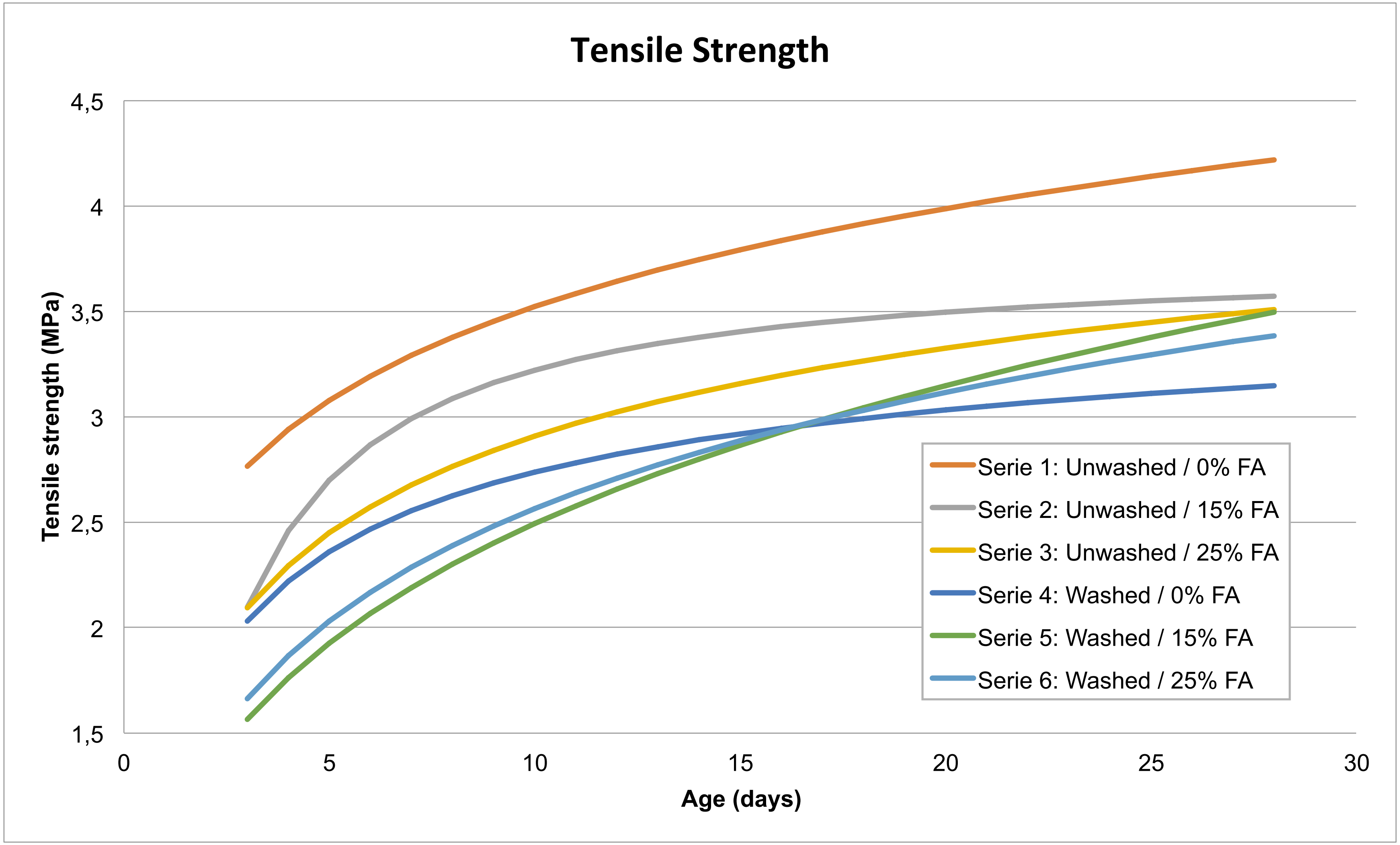


Appendix E.4. Tensile strength

Washed / 25 % FA		f∞	τ	α
Age	Tensile strength	8,50	20,28	0,26
Days	Mpa	σ	$\Delta\sigma^2$	
3	1,60	1,66	0,00	
3	1,90	1,66	0,06	
7	2,60	2,29	0,10	
7	1,75	2,29	0,29	
14	2,90	2,83	0,00	
14	2,35	2,83	0,23	
21	3,70	3,16	0,30	
21	3,45	3,16	0,09	
28	3,30	3,39	0,01	
28	3,10	3,39	0,08	
		SUM:	1,15	



Appendix E.4. Tensile strength



Appendix E.5.1. Elasticity and Poisson test reliability

	Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	ε_{c0}	ε_{cs}	v
	N/mm²	N/mm²	-
A	30794	33786	0,119
A	31622	32902	0,132
A	31131	33102	0,138
Mean	**31000**	**33500**	**0,130**
Sandard Deviation	**416**	**464**	**0,010**
Coefficient of variation	**1,34**	**1,38**	**7,47**
B	31085	32360	0,128
B	30971	32251	0,180
B	30717	32272	0,172
Mean	**31000**	**32500**	**0,160**
Sandard Deviation	**188**	**58**	**0,028**
Coefficient of variation	**0,61**	**0,18**	**17,50**
C	33504	35424	0,124
C	33514	35631	0,127
C	33590	36608	0,108
Mean	**33500**	**36000**	**0,120**
Sandard Deviation	**47**	**632**	**0,010**
Coefficient of variation	**0,14**	**1,76**	**8,51**

	Static Elastic Modulus	Dynamic Elastic Modulus	Poissons Ratio
	ε_{c0}	ε_{cs}	v
TOTAL	N/mm²	N/mm²	-
Mean	**32000**	**34000**	**0,140**
Sandard Deviation	**1267**	**1657**	**0,024**
Coefficient of variation	**3,96**	**4,87**	**17,15**

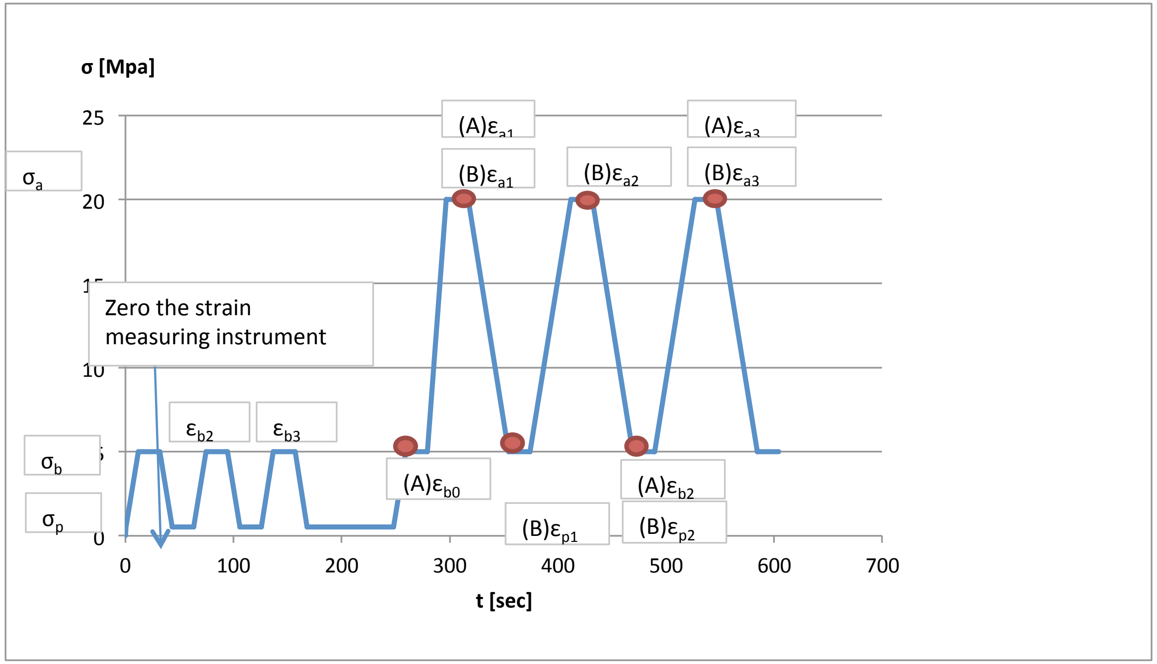
Appendix E.5.2. Check test

		Tid	Stress	Rate
		Sec	Mpa	MPa/s
		0	0	
	σ_p	0,6	0,5	0,8
1	σ_b	11,9	5,0	0,4
		31,9	5,0	
	σ_p	43,1	0,5	0,4
		63,1	0,5	
2	σ_b	74,4	5,0	0,4
		94,4	5,0	
	σ_p	105,6	0,5	0,4
		125,6	0,5	
3	σ_b	136,9	5,0	0,4
		156,9	5,0	
	σ_p	168,1	0,5	0,4
		248,1	0,5	
	σ_b	259,4	5,0	0,4
		279,4	5,0	
1	σ_a	296,9	20,0	0,4
		316,9	20,0	
	σ_b	354,4	5,0	0,4
		374,4	5,0	
2	σ_a	411,9	20,0	0,4
		431,9	20,0	
	σ_b	469,4	5,0	0,4
		489,4	5,0	
3	σ_a	526,9	20,0	0,4
		546,9	20,0	
	σ_b	584,4	5,0	0,4
		604,4	5,0	

f_c	50	MPa
σ_p	0,5	MPa
σ_b	5,0	MPa
σ_a	20,0	MPa
Break	20	sek

1. check			
ε_{b2}	90		
ε_{b3}	90	OK	

2. check		
ε_{b1}	85	OK
ε_{b2}	90	OK
ε_{b3}	90	OK
Average	88,3	



Appendix E.5.3. Template Elasticity and Poisson test

Load ch 1 (Kn)	Strain ch 5 (µe)	Strain ch 6 (µe)	Strain ch 7 (µe)	Strain ch 8 (µe)	Stress (N/mm²)	Time s	Strain "E-Module" (µe)	STANDARD DEVIATION	STRESS/STRAIN (N/mm2)	Ax "Poisson" (µm)
0	0	0	0	0	0	0	0	0,0%	0,000E+00	0
15,5	86	0	-1	-1	1,98	40,7	1	0,0%	1,980E+00	86
17	0	0	-3	-7	2,16	41,7	5	**40,0%**	4,320E-01	0
19,1	0	0	-12	-14	2,43	42,8	13	7,7%	1,869E-01	0
21,2	86	0	-20	-24	2,7	44	22	9,1%	1,227E-01	86
22,5	-172	0	-26	-30	2,87	45,1	28	7,1%	1,025E-01	172
23,1	-258	0	-28	-33	2,94	46,3	30,5	8,2%	9,639E-02	258
23,7	-258	0	-31	-35	3,02	47,5	33	6,1%	9,152E-02	258
24,2	-172	0	-33	-37	3,08	48,6	35	5,7%	8,800E-02	172
24,5	-344	0	-34	-41	3,13	49,7	37,5	9,3%	8,347E-02	344
24,9	-517	0	-35	-40	3,17	50,9	37,5	6,7%	8,453E-02	517
25,2	-517	0	-37	-41	3,21	52	39	5,1%	8,231E-02	517
25,5	-603	0	-37	-42	3,25	53,2	39,5	6,3%	8,228E-02	603
25,8	-517	0	-40	-44	3,29	54,4	42	4,8%	7,833E-02	517
26	-517	0	-41	-45	3,31	55,5	43	4,7%	7,698E-02	517
26,2	-689	0	-41	-46	3,33	56,6	43,5	5,7%	7,655E-02	689
26,3	-689	0	-41	-47	3,35	57,8	44	6,8%	7,614E-02	689
26,4	-603	0	-41	-48	3,37	58,9	44,5	7,9%	7,573E-02	603
26,6	-603	0	-42	-49	3,39	60	45,5	7,7%	7,451E-02	603
26,7	-517	0	-42	-50	3,4	61,1	46	8,7%	7,391E-02	517
26,8	-775	0	-43	-51	3,41	62,2	47	8,5%	7,255E-02	775
26,8	-517	0	-42	-52	3,42	63,4	47	10,6%	7,277E-02	517
27	-517	0	-42	-51	3,43	64,5	46,5	9,7%	7,376E-02	517
27	-430	0	-43	-52	3,44	65,7	47,5	9,5%	7,242E-02	430
27,1	-603	0	-44	-52	3,45	66,8	48	8,3%	7,188E-02	603
27,1	-603	0	-44	-54	3,45	67,9	49	10,2%	7,041E-02	603
27,1	-603	0	-44	-53	3,46	69	48,5	9,3%	7,134E-02	603
27,2	-603	0	-44	-53	3,47	70,1	48,5	9,3%	7,155E-02	603
27,2	-603	0	-45	-55	3,47	71,2	50	10,0%	6,940E-02	603
27,3	-689	0	-44	-54	3,47	72,3	49	10,2%	7,082E-02	689
27,3	-603	0	-45	-54	3,48	73,5	49,5	9,1%	7,030E-02	603
27,3	-689	0	-44	-54	3,48	74,6	49	10,2%	7,102E-02	689
27,3	-775	0	-44	-54	3,48	75,8	49	10,2%	7,102E-02	775
27,1	-775	0	-44	-54	3,45	76,8	49	10,2%	7,041E-02	775
25,3	-775	0	-40	-45	3,23	78	42,5	5,9%	7,600E-02	775
23,2	-689	0	-31	-37	2,95	79,2	34	8,8%	8,676E-02	689
21,1	-775	0	-24	-30	2,68	80,4	27	11,1%	9,926E-02	775
20,4	-775	0	-20	-27	2,6	81,3	23,5	14,9%	1,106E-01	775
19,9	-689	0	-18	-25	2,53	82,5	21,5	16,3%	1,177E-01	689
19,4	-603	0	-16	-23	2,47	83,6	19,5	17,9%	1,267E-01	603
18,9	-603	0	-15	-22	2,41	84,7	18,5	18,9%	1,303E-01	603
18,6	-775	0	-13	-19	2,37	85,9	16	18,8%	1,481E-01	775
18,2	-689	0	-12	-19	2,32	87	15,5	**22,6%**	1,497E-01	689
17,9	-689	0	-10	-16	2,28	88,2	13	**23,1%**	1,754E-01	689
17,7	-689	0	-9	-14	2,25	89,3	11,5	**21,7%**	1,957E-01	689
17,4	-603	0	-7	-14	2,22	90,5	10,5	**33,3%**	2,114E-01	603
17,2	-689	0	-7	-14	2,19	91,6	10,5	**33,3%**	2,086E-01	689
17,1	-689	0	-5	-14	2,17	92,7	9,5	**47,4%**	2,284E-01	689
16,9	-689	0	-5	-11	2,15	93,8	8	**37,5%**	2,688E-01	689
16,7	-603	0	-4	-10	2,13	94,9	7	**42,9%**	3,043E-01	603
16,6	-689	0	-3	-12	2,12	96	7,5	**60,0%**	2,827E-01	689
16,5	-775	0	-3	-10	2,1	97,2	6,5	**53,8%**	3,231E-01	775
16,4	-775	0	-3	-10	2,09	98,3	6,5	**53,8%**	3,215E-01	775
16,3	-689	0	-3	-9	2,08	99,4	6	**50,0%**	3,467E-01	689
16,2	-517	0	-2	-9	2,07	100,5	5,5	**63,6%**	3,764E-01	517
16,2	-775	0	-2	-9	2,06	101,6	5,5	**63,6%**	3,745E-01	775
16,1	-775	0	-3	-8	2,05	102,8	5,5	**45,5%**	3,727E-01	775
16	-603	0	-1	-9	2,04	103,9	5	**80,0%**	4,080E-01	603
16	-689	0	-2	-8	2,04	105,1	5	**60,0%**	4,080E-01	689
16	-775	0	-1	-8	2,03	106,1	4,5	**77,8%**	4,511E-01	775
15,9	-689	0	-3	-8	2,03	107,3	5,5	**45,5%**	3,691E-01	689
15,9	-861	0	-2	-8	2,03	108,4	5	**60,0%**	4,060E-01	861
15,8	-603	0	-2	-8	2,02	109,5	5	**60,0%**	4,040E-01	603
15,8	-603	0	-1	-8	2,02	110,6	4,5	**77,8%**	4,489E-01	603
15,8	-689	0	-1	-8	2,02	111,7	4,5	**77,8%**	4,489E-01	689
15,8	-689	0	-2	-8	2,02	112,8	5	**60,0%**	4,040E-01	689
15,8	-689	0	-1	-8	2,02	113,8	4,5	**77,8%**	4,489E-01	689
15,8	-689	0	-3	-7	2,01	115	5	**40,0%**	4,020E-01	689
15,8	-775	0	-1	-7	2,01	116	4	**75,0%**	5,025E-01	775
15,8	-775	0	-3	-8	2,02	117,4	5,5	**45,5%**	3,673E-01	775

Appendix E.5.3. Template Elasticity and Poisson test

Load ch 1 (Kn)	Strain ch 5 (µe)	Strain ch 6 (µe)	Strain ch 7 (µe)	Strain ch 8 (µe)	Stress (N/mm²)	Time s	Strain "E-Module" (µe)	STANDARD DEVIATION	STRESS/STRAIN (N/mm2)	Ax "Poisson" (µm)
17,3	-775	0	-5	-11	2,2	118,4	8	**37,5%**	2,750E-01	775
19	-689	0	-13	-18	2,43	119,5	15,5	16,1%	1,568E-01	689
21,2	-689	0	-20	-25	2,7	120,6	22,5	11,1%	1,200E-01	689
22,5	-775	0	-27	-32	2,87	121,8	29,5	8,5%	9,729E-02	775
23,1	-775	0	-27	-34	2,94	123	30,5	11,5%	9,639E-02	775
23,6	-775	0	-30	-36	3	124	33	9,1%	9,091E-02	775
24	-861	0	-33	-39	3,06	125,2	36	8,3%	8,500E-02	861
24,4	-689	0	-34	-40	3,11	126,2	37	8,1%	8,405E-02	689
24,8	-1033	0	-35	-40	3,16	127,4	37,5	6,7%	8,427E-02	1033
25,1	-861	0	-36	-42	3,2	128,5	39	7,7%	8,205E-02	861
25,5	-947	0	-38	-42	3,24	129,7	40	5,0%	8,100E-02	947
25,7	-1033	0	-38	-43	3,27	130,7	40,5	6,2%	8,074E-02	1033
25,9	-861	0	-39	-45	3,3	131,9	42	7,1%	7,857E-02	861
26,1	-1120	0	-40	-47	3,32	133,1	43,5	8,0%	7,632E-02	1120
26,2	-1120	0	-40	-47	3,34	134,2	43,5	8,0%	7,678E-02	1120
26,4	-947	0	-41	-48	3,36	135,4	44,5	7,9%	7,551E-02	947
26,5	-1033	0	-42	-49	3,38	136,5	45,5	7,7%	7,429E-02	1033
26,5	-1206	0	-41	-49	3,38	137,6	45	8,9%	7,511E-02	1206
26,7	-947	0	-41	-50	3,4	138,7	45,5	9,9%	7,473E-02	947
26,7	-1206	0	-41	-50	3,41	139,8	45,5	9,9%	7,495E-02	1206
26,8	-1033	0	-41	-51	3,41	140,9	46	10,9%	7,413E-02	1033
26,9	-947	0	-42	-50	3,43	142	46	8,7%	7,457E-02	947
27	-947	0	-42	-52	3,44	143,2	47	10,6%	7,319E-02	947
27	-1206	0	-42	-52	3,44	144,2	47	10,6%	7,319E-02	1206
27,1	-947	0	-42	-52	3,45	145,4	47	10,6%	7,340E-02	947
27,2	-1292	0	-44	-52	3,46	146,4	48	8,3%	7,208E-02	1292
27,2	-1206	0	-43	-53	3,46	147,5	48	10,4%	7,208E-02	1206
27,2	-1292	0	-44	-53	3,47	148,6	48,5	9,3%	7,155E-02	1292
27,2	-1206	0	-43	-52	3,47	149,7	47,5	9,5%	7,305E-02	1206
27,3	-1120	0	-43	-53	3,47	150,9	48	10,4%	7,229E-02	1120
27,3	-1292	0	-44	-53	3,48	151,9	48,5	9,3%	7,175E-02	1292
27,3	-1033	0	-44	-54	3,48	153,1	49	10,2%	7,102E-02	1033
26,6	-1206	0	-42	-51	3,39	154,2	46,5	9,7%	7,290E-02	1206
24,9	-1206	0	-36	-42	3,17	155,4	39	7,7%	8,128E-02	1206
23	-1206	0	-30	-37	2,93	156,4	33,5	10,4%	8,746E-02	1206
20,9	-1033	0	-21	-27	2,66	157,6	24	12,5%	1,108E-01	1033
20,3	-1120	0	-20	-26	2,58	158,7	23	13,0%	1,122E-01	1120
19,8	-1292	0	-17	-23	2,52	159,8	20	15,0%	1,260E-01	1292
19,2	-1033	0	-15	-22	2,45	161,1	18,5	18,9%	1,324E-01	1033
18,8	-1033	0	-13	-21	2,39	162,2	17	**23,5%**	1,406E-01	1033
18,4	-1292	0	-11	-18	2,35	163,4	14,5	**24,1%**	1,621E-01	1292
18,1	-1120	0	-10	-16	2,3	164,5	13	**23,1%**	1,769E-01	1120
17,8	-1206	0	-8	-15	2,27	165,6	11,5	**30,4%**	1,974E-01	1206
17,6	-1206	0	-8	-13	2,24	166,7	10,5	**23,8%**	2,133E-01	1206
17,3	-1120	0	-6	-13	2,21	167,9	9,5	**36,8%**	2,326E-01	1120
17,2	-1033	0	-6	-13	2,19	168,9	9,5	**36,8%**	2,305E-01	1033
17	-1206	0	-4	-12	2,16	170	8	**50,0%**	2,700E-01	1206
16,8	-1206	0	-3	-10	2,15	171,1	6,5	**53,8%**	3,308E-01	1206
16,7	-1206	0	-3	-10	2,13	172,3	6,5	**53,8%**	3,277E-01	1206
16,6	-1120	0	-3	-9	2,11	173,4	6	**50,0%**	3,517E-01	1120
16,5	-1292	0	-3	-9	2,1	174,6	6	**50,0%**	3,500E-01	1292
16,4	-1206	0	-3	-9	2,09	175,8	6	**50,0%**	3,483E-01	1206
16,3	-1033	0	-2	-8	2,08	176,9	5	**60,0%**	4,160E-01	1033
16,2	-1120	0	-2	-8	2,07	178,1	5	**60,0%**	4,140E-01	1120
16,2	-1120	0	-2	-8	2,06	179,2	5	**60,0%**	4,120E-01	1120
16,1	-947	0	-2	-8	2,05	180,2	5	**60,0%**	4,100E-01	947
16	-1120	0	-2	-8	2,04	181,4	5	**60,0%**	4,080E-01	1120
16	-1120	0	-2	-7	2,04	182,5	4,5	**55,6%**	4,533E-01	1120
16	-1292	0	-2	-7	2,03	183,6	4,5	**55,6%**	4,511E-01	1292
15,9	-1206	0	-1	-7	2,03	184,7	4	**75,0%**	5,075E-01	1206
15,9	-1120	0	-2	-8	2,03	185,7	5	**60,0%**	4,060E-01	1120
15,9	-1120	0	-3	-8	2,03	186,8	5,5	**45,5%**	3,691E-01	1120
15,8	-1206	0	-2	-7	2,02	188	4,5	**55,6%**	4,489E-01	1206
15,8	-1033	0	-2	-7	2,02	189	4,5	**55,6%**	4,489E-01	1033
15,8	-1206	0	-3	-8	2,02	190,2	5,5	**45,5%**	3,673E-01	1206
15,8	-1378	0	-2	-7	2,01	191,2	4,5	**55,6%**	4,467E-01	1378
15,8	-1120	0	-1	-7	2,01	192,4	4	**75,0%**	5,025E-01	1120
15,8	-1292	0	-1	-7	2,01	193,5	4	**75,0%**	5,025E-01	1292
15,8	-1120	0	-2	-7	2,01	194,6	4,5	**55,6%**	4,467E-01	1120
16,6	-1206	0	-2	-9	2,12	195,7	5,5	**63,6%**	3,855E-01	1206
18,5	-1206	0	-9	-14	2,35	196,8	11,5	**21,7%**	2,043E-01	1206

Appendix E.5.3. Template Elasticity and Poisson test

Load ch 1 (Kn)	Strain ch 5 (με)	Strain ch 6 (με)	Strain ch 7 (με)	Strain ch 8 (με)	Stress (N/mm²)	Time s	Strain "E-Module" (με)	STANDARD DEVIATION	STRESS/STRAIN (N/mm2)	Ax "Poisson" (μm)
20,4	-1206	0	-16	-22	2,6	197,9	19	15,8%	1,368E-01	1206
22,3	-1464	0	-23	-30	2,84	199	26,5	13,2%	1,072E-01	1464
22,8	-1378	0	-25	-33	2,91	200,1	29	13,8%	1,003E-01	1378
23,4	-1378	0	-28	-34	2,98	201,3	31	9,7%	9,613E-02	1378
23,9	-1378	0	-30	-36	3,04	202,3	33	9,1%	9,212E-02	1378
24,3	-1206	0	-33	-38	3,1	203,5	35,5	7,0%	8,732E-02	1206
24,7	-1464	0	-33	-40	3,14	204,5	36,5	9,6%	8,603E-02	1464
25	-1551	0	-34	-40	3,18	205,6	37	8,1%	8,595E-02	1551
25,3	-1464	0	-35	-41	3,22	206,7	38	7,9%	8,474E-02	1464
25,5	-1637	0	-37	-42	3,25	207,8	39,5	6,3%	8,228E-02	1637
25,8	-1637	0	-39	-42	3,29	209	40,5	3,7%	8,123E-02	1637
26	-1551	0	-38	-45	3,31	210	41,5	8,4%	7,976E-02	1551
26,1	-1464	0	-39	-45	3,33	211,1	42	7,1%	7,929E-02	1464
26,3	-1723	0	-41	-46	3,35	212,2	43,5	5,7%	7,701E-02	1723
26,4	-1809	0	-40	-47	3,37	213,4	43,5	8,0%	7,747E-02	1809
26,5	-1723	0	-42	-48	3,38	214,5	45	6,7%	7,511E-02	1723
26,7	-1637	0	-42	-48	3,4	215,6	45	6,7%	7,556E-02	1637
26,8	-1637	0	-40	-49	3,41	216,8	44,5	10,1%	7,663E-02	1637
26,8	-1637	0	-41	-50	3,41	217,8	45,5	9,9%	7,495E-02	1637
26,9	-1895	0	-42	-50	3,43	219	46	8,7%	7,457E-02	1895
27	-1637	0	-42	-50	3,44	220,1	46	8,7%	7,478E-02	1637
27	-1809	0	-42	-50	3,44	221,3	46	8,7%	7,478E-02	1809
27,1	-1895	0	-41	-52	3,45	222,4	46,5	11,8%	7,419E-02	1895
27,1	-1895	0	-42	-50	3,46	223,5	46	8,7%	7,522E-02	1895
27,2	-1895	0	-42	-51	3,46	224,6	46,5	9,7%	7,441E-02	1895
27,2	-1809	0	-42	-51	3,47	225,7	46,5	9,7%	7,462E-02	1809
27,2	-1895	0	-43	-50	3,47	226,8	46,5	7,5%	7,462E-02	1895
27,3	-1895	0	-43	-53	3,47	227,9	48	10,4%	7,229E-02	1895
27,3	-1637	0	-43	-51	3,47	229,1	47	8,5%	7,383E-02	1637
27,3	-1723	0	-44	-52	3,48	230,1	48	8,3%	7,250E-02	1723
27,3	-1809	0	-43	-52	3,47	231,5	47,5	9,5%	7,305E-02	1809
25,8	-1895	0	-38	-46	3,28	232,5	42	9,5%	7,810E-02	1895
23,7	-2067	0	-31	-37	3,01	233,8	34	8,8%	8,853E-02	2067
21,6	-1809	0	-24	-31	2,75	234,9	27,5	12,7%	1,000E-01	1809
20,5	-1981	0	-19	-26	2,61	236,1	22,5	15,6%	1,160E-01	1981
19,9	-1895	0	-18	-24	2,54	237,2	21	14,3%	1,210E-01	1895
19,4	-1809	0	-14	-22	2,47	238,4	18	22,2%	1,372E-01	1809
19	-1895	0	-13	-21	2,42	239,4	17	23,5%	1,424E-01	1895
18,6	-1809	0	-12	-18	2,37	240,6	15	20,0%	1,580E-01	1809
18,3	-2153	0	-9	-15	2,33	241,6	12	25,0%	1,942E-01	2153
17,9	-1809	0	-8	-14	2,29	242,8	11	27,3%	2,082E-01	1809
17,7	-1723	0	-8	-15	2,25	243,9	11,5	30,4%	1,957E-01	1723
17,5	-1809	0	-7	-14	2,22	245,1	10,5	33,3%	2,114E-01	1809
17,2	-1981	0	-4	-11	2,19	246,2	7,5	46,7%	2,920E-01	1981
17,1	-1723	0	-4	-11	2,17	247,4	7,5	46,7%	2,893E-01	1723
16,9	-1809	0	-4	-11	2,16	248,5	7,5	46,7%	2,880E-01	1809
16,7	-1895	0	-3	-10	2,13	249,6	6,5	53,8%	3,277E-01	1895
16,6	-1723	0	-3	-9	2,12	250,8	6	50,0%	3,533E-01	1723
16,5	-1723	0	-2	-8	2,11	251,9	5	60,0%	4,220E-01	1723
16,4	-1981	0	-2	-8	2,09	253,1	5	60,0%	4,180E-01	1981
16,3	-1981	0	-2	-8	2,08	254,2	5	60,0%	4,160E-01	1981
16,3	-1981	0	-2	-7	2,07	255,4	4,5	55,6%	4,600E-01	1981
16,2	-1981	0	-2	-7	2,06	256,3	4,5	55,6%	4,578E-01	1981
16,1	-1981	0	-2	-8	2,05	257,5	5	60,0%	4,100E-01	1981
16,1	-1981	0	-2	-6	2,05	258,7	4	50,0%	5,125E-01	1981
16	-1895	0	-2	-6	2,04	260	4	50,0%	5,100E-01	1895
16	-1723	0	-2	-7	2,04	260,9	4,5	55,6%	4,533E-01	1723
16	-1895	0	-3	-6	2,03	261,9	4,5	33,3%	4,511E-01	1895
15,9	-1895	0	-2	-6	2,03	263,2	4	50,0%	5,075E-01	1895
15,9	-1895	0	-1	-6	2,02	264,2	3,5	71,4%	5,771E-01	1895
15,8	-1637	0	-1	-5	2,02	265,4	3	66,7%	6,733E-01	1637
15,8	-1895	0	-1	-6	2,02	266,5	3,5	71,4%	5,771E-01	1895
15,8	-1809	0	-1	-6	2,02	267,6	3,5	71,4%	5,771E-01	1809
15,8	-1723	0	-2	-7	2,01	268,7	4,5	55,6%	4,467E-01	1723
15,8	-1723	0	-1	-6	2,01	269,7	3,5	71,4%	5,743E-01	1723
15,8	-1981	0	-2	-5	2,01	271	3,5	42,9%	5,743E-01	1981
15,7	-1895	0	-1	-6	2	272,1	3,5	71,4%	5,714E-01	1895
15,8	-1723	0	0	-5	2,01	273,2	2,5	100,0%	8,040E-01	1723
15,8	-1809	0	-1	-6	2,01	274,3	3,5	71,4%	5,743E-01	1809
15,8	-1809	0	0	-5	2,01	275,5	2,5	100,0%	8,040E-01	1809
15,7	-1723	0	-1	-5	2	276,6	3	66,7%	6,667E-01	1723

Appendix E.5.3. Template Elasticity and Poisson test

Load ch 1 (Kn)	Strain ch 5 (µe)	Strain ch 6 (µe)	Strain ch 7 (µe)	Strain ch 8 (µe)	Stress (N/mm²)	Time s	Strain "E-Module" (µe)	STANDARD DEVIATION	STRESS/STRAIN (N/mm2)	Ax "Poisson" (µm)	
15,7	-1637	0	1	-4	2	277,8	1,5	166,7%	1,333E+00	1637	
15,7	-1809	0	0	-5	2	278,9	2,5	100,0%	8,000E-01	1809	
15,7	-1809	0	-1	-5	2	280	3	66,7%	6,667E-01	1809	
15,7	-1809	0	0	-4	2	281,1	2	100,0%	1,000E+00	1809	
15,7	-2067	0	0	-3	2	282,4	1,5	100,0%	1,333E+00	2067	
15,7	-1895	0	1	-4	2	283,5	1,5	166,7%	1,333E+00	1895	
15,7	-1895	0	0	-4	2	284,5	2	100,0%	1,000E+00	1895	
15,7	-1723	0	0	-5	2	285,7	2,5	100,0%	8,000E-01	1723	
15,7	-1723	0	0	-6	2	286,9	3	100,0%	6,667E-01	1723	
15,7	-1809	0	1	-5	2	287,9	2	150,0%	1,000E+00	1809	
15,7	-1895	0	0	-5	2	289,1	2,5	100,0%	8,000E-01	1895	
15,7	-1895	0	-1	-5	2	290,3	3	66,7%	6,667E-01	1895	
15,7	-1895	0	0	-4	2	291,3	2	100,0%	1,000E+00	1895	
15,7	-1637	0	-1	-4	2	292,5	2,5	60,0%	8,000E-01	1637	
15,7	-1637	0	0	-5	2	293,8	2,5	100,0%	8,000E-01	1637	
15,7	-1723	0	0	-5	2	295	2,5	100,0%	8,000E-01	1723	
15,7	-1637	0	0	-5	2	296,1	2,5	100,0%	8,000E-01	1637	
15,7	-1895	0	1	-3	2	297,3	1	200,0%	2,000E+00	1895	
15,7	-1723	0	0	-5	2	298,3	2,5	100,0%	8,000E-01	1723	
15,7	-1895	0	-1	-4	2	299,5	2,5	60,0%	8,000E-01	1895	
15,7	-1895	0	0	-4	2	300,5	2	100,0%	1,000E+00	1895	
15,7	-1637	0	0	-5	2	301,7	2,5	100,0%	8,000E-01	1637	
15,7	-1809	0	1	-5	2	302,8	2	150,0%	1,000E+00	1809	
15,7	-1895	0	-1	-5	1,99	303,9	3	66,7%	6,633E-01	1895	
15,7	-1981	0	0	-4	2	305	2	100,0%	1,000E+00	1981	
15,7	-1895	0	1	-4	2	306,1	1,5	166,7%	1,333E+00	1895	
15,7	-1637	0	-1	-4	2	307,3	2,5	60,0%	8,000E-01	1637	
15,7	-1809	0	-1	-3	2	308,3	2	50,0%	1,000E+00	1809	
15,7	-1809	0	0	-3	1,99	309,6	1,5	100,0%	1,327E+00	1809	
15,7	-1723	0	1	-4	1,99	310,7	1,5	166,7%	1,327E+00	1723	
15,7	-1895	0	1	-5	2	311,9	2	150,0%	1,000E+00	1895	
15,9	-1895	0	0	-4	2,02	312,9	2	100,0%	1,010E+00	1895	
17,6	-1723	0	-4	-11	2,24	314,1	7,5	46,7%	2,987E-01	1723	
19,7	-2240	0	-13	-18	2,51	315,3	15,5	16,1%	1,619E-01	2240	
21,6	-2326	0	-20	-25	2,75	316,3	22,5	11,1%	1,222E-01	2326	
22,6	-2498	0	-24	-29	2,87	317,4	26,5	9,4%	1,083E-01	2498	
23,1	-2498	0	-26	-32	2,94	318,4	29	10,3%	1,014E-01	2498	
23,6	-2498	0	-28	-33	3,01	319,6	30,5	8,2%	9,869E-02	2498	
24,1	-2412	0	-29	-35	3,07	320,7	32	9,4%	9,594E-02	2412	
24,5	-2584	0	-32	-37	3,12	321,9	34,5	7,2%	9,043E-02	2584	
24,8	-2584	0	-33	-38	3,16	322,9	35,5	7,0%	8,901E-02	2584	
25,1	-2756	0	-33	-39	3,2	324,2	36	8,3%	8,889E-02	2756	
25,4	-2756	0	-35	-43	3,24	325,2	39	10,3%	8,308E-02	2756	
25,7	-2842	0	-35	-43	3,27	326,4	39	10,3%	8,385E-02	2842	
25,9	-2842	0	-36	-42	3,3	327,5	39	7,7%	8,462E-02	2842	
26,1	-2842	0	-37	-44	3,33	328,8	40,5	8,6%	8,222E-02	2842	
26,3	-2756	0	-39	-44	3,34	329,8	41,5	6,0%	8,048E-02	2756	
26,4	-2842	0	-40	-44	3,36	330,9	42	4,8%	8,000E-02	2842	
26,5	-2756	0	-39	-45	3,37	332,1	42	7,1%	8,024E-02	2756	
26,6	-2756	0	-40	-45	3,39	333,1	42,5	5,9%	7,976E-02	2756	
26,7	-2929	0	-40	-46	3,4	334,2	43	7,0%	7,907E-02	2929	
26,8	-2842	0	-41	-48	3,42	335,4	44,5	7,9%	7,685E-02	2842	
26,9	-2929	0	-41	-47	3,43	336,7	44	6,8%	7,795E-02	2929	
27	-2929	0	-40	-49	3,44	337,8	44,5	10,1%	7,730E-02	2929	
27	-2929	0	-41	-48	3,45	339	44,5	7,9%	7,753E-02	2929	
27,1	-2842	0	-41	-49	3,45	340,1	45	8,9%	7,667E-02	2842	
27,1	-2929	0	-42	-50	3,45	341,3	46	8,7%	7,500E-02	2929	
27,2	-2842	0	-42	-49	3,46	342,4	45,5	7,7%	7,604E-02	2842	
27,2	-2929	0	-42	-51	3,47	343,7	46,5	9,7%	7,462E-02	2929	
27,2	-2929	0	-42	-49	3,47	344,7	45,5	7,7%	7,626E-02	2929	
27,3	-3015	0	-42	-50	3,47	346	46	8,7%	7,543E-02	3015	
27,3	-2929	0	-41	-50	3,48	347,1	45,5	9,9%	7,648E-02	2929	
27,3	-3015	0	-42	-50	3,48	348,3	46	8,7%	7,565E-02	3015	Eb0
28	-2929	0	-44	-55	3,57	349,4	49,5	11,1%	7,212E-02	2929	
29,7	-3015	0	-49	-61	3,79	350,4	55	10,9%	6,891E-02	3015	
32	-3187	0	-58	-70	4,08	351,6	64	9,4%	6,375E-02	3187	
34,4	-3273	0	-69	-80	4,38	352,8	74,5	7,4%	5,879E-02	3273	
36,9	-3273	0	-78	-89	4,7	353,9	83,5	6,6%	5,629E-02	3273	
39,6	-3445	0	-88	-99	5,05	355,1	93,5	5,9%	5,401E-02	3445	
42,5	-3618	0	-98	-111	5,42	356,2	104,5	6,2%	5,187E-02	3618	
45,7	-3790	0	-112	-126	5,83	357,5	119	5,9%	4,899E-02	3790	

Appendix E.5.3. Template Elasticity and Poisson test

Load ch 1 (Kn)	Strain ch 5 (με)	Strain ch 6 (με)	Strain ch 7 (με)	Strain ch 8 (με)	Stress (N/mm²)	Time s	Strain "E-Module" (με)	STANDARD DEVIATION	STRESS/STRAIN (N/mm2)	Ax "Poisson" (μm)	
49	-3876	0	-125	-138	6,25	358,7	131,5	4,9%	4,753E-02	3876	
51,7	-3962	0	-136	-153	6,59	359,7	144,5	5,9%	4,561E-02	3962	
54,6	-4220	0	-145	-161	6,95	360,7	153	5,2%	4,542E-02	4220	
57,6	-4393	0	-159	-176	7,34	361,7	167,5	5,1%	4,382E-02	4393	
60,6	-4565	0	-169	-186	7,72	362,7	177,5	4,8%	4,349E-02	4565	
64	-4651	0	-183	-201	8,16	363,9	192	4,7%	4,250E-02	4651	
67,3	-4824	0	-195	-213	8,57	364,9	204	4,4%	4,201E-02	4824	
71	-5082	0	-209	-229	9,04	366,1	219	4,6%	4,128E-02	5082	
74,2	-5254	0	-221	-242	9,46	367,1	231,5	4,5%	4,086E-02	5254	
77,8	-5427	0	-235	-258	9,92	368,3	246,5	4,7%	4,024E-02	5427	
81,5	-5685	0	-249	-272	10,38	369,4	260,5	4,4%	3,985E-02	5685	
85,5	-5857	0	-265	-289	10,89	370,7	277	4,3%	3,931E-02	5857	
88,9	-6030	0	-278	-301	11,32	371,7	289,5	4,0%	3,910E-02	6030	
92,2	-6288	0	-291	-314	11,75	372,8	302,5	3,8%	3,884E-02	6288	
96	-6375	0	-306	-329	12,23	374	317,5	3,6%	3,852E-02	6375	
99,4	-6632	0	-320	-341	12,67	375	330,5	3,2%	3,834E-02	6632	
101,1	-6719	0	-330	-349	12,88	376,1	339,5	2,8%	3,794E-02	6719	
102,5	-6719	0	-334	-356	13,06	377,3	345	3,2%	3,786E-02	6719	
103,7	-6891	0	-340	-362	13,21	378,5	351	3,1%	3,764E-02	6891	
104,6	-6977	0	-344	-366	13,33	379,7	355	3,1%	3,755E-02	6977	
105,3	-6977	0	-347	-367	13,41	380,7	357	2,8%	3,756E-02	6977	
106	-6977	0	-352	-370	13,5	381,9	361	2,5%	3,740E-02	6977	
106,6	-7063	0	-353	-375	13,58	383,1	364	3,0%	3,731E-02	7063	
107,2	-7063	0	-355	-376	13,65	384,3	365,5	2,9%	3,735E-02	7063	
107,5	-7063	0	-357	-378	13,7	385,5	367,5	2,9%	3,728E-02	7063	
107,8	-7149	0	-359	-380	13,73	386,6	369,5	2,8%	3,716E-02	7149	
108,2	-7149	0	-360	-381	13,79	387,6	370,5	2,8%	3,722E-02	7149	
108,5	-7149	0	-362	-382	13,83	388,8	372	2,7%	3,718E-02	7149	
108,9	-7235	0	-363	-385	13,87	390	374	2,9%	3,709E-02	7235	
108,6	-7321	0	-364	-384	13,84	391,1	374	2,7%	3,701E-02	7321	
110	-7408	0	-369	-389	14,01	392,1	379	2,6%	3,697E-02	7408	εa1
110,2	-7580	0	-371	-392	14,04	393,2	381,5	2,8%	3,680E-02	7580	
111,6	-7838	0	-378	-396	14,21	394,2	387	2,3%	3,672E-02	7838	
111,4	-7752	0	-378	-396	14,19	395,2	387	2,3%	3,667E-02	7752	
108,2	-7580	0	-365	-385	13,78	396,2	375	2,7%	3,675E-02	7580	
110,8	-7838	0	-379	-397	14,12	397,4	388	2,3%	3,639E-02	7838	
110,9	-7666	0	-380	-397	14,13	398,5	388,5	2,2%	3,637E-02	7666	
112	-7752	0	-381	-399	14,27	399,8	390	2,3%	3,659E-02	7752	
108,1	-7838	0	-368	-387	13,78	401	377,5	2,5%	3,650E-02	7838	
104,7	-7752	0	-357	-375	13,34	402,1	366	2,5%	3,645E-02	7752	
101,1	-7408	0	-345	-364	12,89	403,2	354,5	2,7%	3,636E-02	7408	
98,6	-7408	0	-336	-355	12,57	404,3	345,5	2,7%	3,638E-02	7408	
98,7	-7408	0	-340	-358	12,57	405,4	349	2,6%	3,602E-02	7408	
95,8	-7235	0	-329	-348	12,21	406,5	338,5	2,8%	3,607E-02	7235	
94,3	-7149	0	-321	-341	12,01	407,6	331	3,0%	3,628E-02	7149	
86,7	-6977	0	-296	-315	11,05	408,9	305,5	3,1%	3,617E-02	6977	
84	-6977	0	-286	-307	10,7	409,9	296,5	3,5%	3,609E-02	6977	
83,2	-6977	0	-280	-299	10,6	410,9	289,5	3,3%	3,661E-02	6977	
78,7	-6805	0	-266	-284	10,02	412,1	275	3,3%	3,644E-02	6805	
77,6	-6632	0	-259	-279	9,88	413,2	269	3,7%	3,673E-02	6632	
74,1	-6460	0	-248	-268	9,43	414,4	258	3,9%	3,655E-02	6460	
68,7	-6460	0	-228	-247	8,75	415,6	237,5	4,0%	3,684E-02	6460	
65,8	-6116	0	-217	-236	8,38	416,8	226,5	4,2%	3,700E-02	6116	
62,6	-6202	0	-205	-226	7,98	417,8	215,5	4,9%	3,703E-02	6202	
59,7	-6116	0	-195	-214	7,6	419,1	204,5	4,6%	3,716E-02	6116	
56,2	-5943	0	-181	-200	7,16	420,2	190,5	5,0%	3,759E-02	5943	
53,1	-5771	0	-170	-187	6,76	421,3	178,5	4,8%	3,787E-02	5771	
50,2	-5685	0	-160	-178	6,4	422,2	169	5,3%	3,787E-02	5685	
47	-5599	0	-144	-164	5,98	423,4	154	6,5%	3,883E-02	5599	
43,8	-5427	0	-132	-153	5,58	424,5	142,5	7,4%	3,916E-02	5427	
40,7	-5427	0	-121	-136	5,19	425,5	128,5	5,8%	4,039E-02	5427	
38,2	-5082	0	-112	-126	4,87	426,7	119	5,9%	4,092E-02	5082	
36,8	-4996	0	-104	-119	4,69	427,8	111,5	6,7%	4,206E-02	4996	
35,5	-4910	0	-98	-113	4,52	429,1	105,5	7,1%	4,284E-02	4910	
34,5	-4910	0	-91	-107	4,39	430,2	99	8,1%	4,434E-02	4910	
33,5	-4651	0	-89	-103	4,27	431,5	96	7,3%	4,448E-02	4651	
32,8	-4824	0	-86	-101	4,18	432,4	93,5	8,0%	4,471E-02	4824	
32,2	-4651	0	-84	-98	4,1	433,5	91	7,7%	4,505E-02	4651	
31,5	-4824	0	-80	-92	4,02	434,7	86	7,0%	4,674E-02	4824	
31,1	-4651	0	-77	-92	3,96	435,8	84,5	8,9%	4,686E-02	4651	
30,6	-4565	0	-78	-90	3,89	437	84	7,1%	4,631E-02	4565	

Appendix E.5.3. Template Elasticity and Poisson test

Load ch 1 (Kn)	Strain ch 5 (µe)	Strain ch 6 (µe)	Strain ch 7 (µe)	Strain ch 8 (µe)	Stress (N/mm²)	Time s	Strain "E-Module" (µe)	STANDARD DEVIATION	STRESS/STRAIN (N/mm2)	Ax "Poisson" (µm)
30,2	-4651	0	-74	-88	3,85	438,2	81	8,6%	4,753E-02	4651
29,8	-4565	0	-73	-86	3,8	439,3	79,5	8,2%	4,780E-02	4565
29,6	-4479	0	-70	-85	3,77	440,3	77,5	9,7%	4,865E-02	4479
29,3	-4565	0	-71	-84	3,74	441,3	77,5	8,4%	4,826E-02	4565
29,1	-4651	0	-70	-82	3,71	442,5	76	7,9%	4,882E-02	4651
28,9	-4651	0	-68	-81	3,68	443,7	74,5	8,7%	4,940E-02	4651
28,7	-4479	0	-67	-81	3,66	444,8	74	9,5%	4,946E-02	4479
28,6	-4565	0	-68	-79	3,64	446	73,5	7,5%	4,952E-02	4565
28,4	-4479	0	-67	-79	3,62	447,1	73	8,2%	4,959E-02	4479
28,3	-4479	0	-66	-79	3,6	448,3	72,5	9,0%	4,966E-02	4479
28	-4479	0	-65	-76	3,56	449,3	70,5	7,8%	5,050E-02	4479
27,9	-4565	0	-65	-76	3,55	450,5	70,5	7,8%	5,035E-02	4565
27,8	-4565	0	-64	-76	3,54	451,6	70	8,6%	5,057E-02	4565
27,8	-4479	0	-63	-75	3,54	452,7	69	8,7%	5,130E-02	4479
27,8	-4479	0	-62	-76	3,54	453,9	69	10,1%	5,130E-02	4479
27,6	-4479	0	-60	-75	3,51	455	67,5	11,1%	5,200E-02	4479
27,6	-4479	0	-61	-74	3,51	456,1	67,5	9,6%	5,200E-02	4479
27,5	-4565	0	-61	-73	3,51	457,2	67	9,0%	5,239E-02	4565
27,5	-4479	0	-61	-73	3,51	458,4	67	9,0%	5,239E-02	4479
27,6	-4393	0	-61	-74	3,51	459,5	67,5	9,6%	5,200E-02	4393
27,6	-4479	0	-61	-75	3,52	460,7	68	10,3%	5,176E-02	4479
27,6	-4479	0	-60	-74	3,51	461,7	67	10,4%	5,239E-02	4479
27,6	-4393	0	-60	-73	3,51	463	66,5	9,8%	5,278E-02	4393
27,6	-4393	0	-60	-73	3,52	464,3	66,5	9,8%	5,293E-02	4393
29,3	-4479	0	-67	-79	3,73	465,5	73	8,2%	5,110E-02	4479
31,3	-4479	0	-74	-86	3,99	466,6	80	7,5%	4,988E-02	4479
33,2	-4479	0	-79	-92	4,24	467,6	85,5	7,6%	4,959E-02	4479
35,9	-4479	0	-88	-102	4,57	468,8	95	7,4%	4,811E-02	4479
38,2	-4393	0	-98	-109	4,87	469,9	103,5	5,3%	4,705E-02	4393
40,8	-4479	0	-108	-120	5,2	471	114	5,3%	4,561E-02	4479
43,5	-4479	0	-118	-129	5,54	472	123,5	4,5%	4,486E-02	4479
46,5	-4651	0	-128	-141	5,92	473,2	134,5	4,8%	4,401E-02	4651
49,6	-4651	0	-138	-156	6,32	474,3	147	6,1%	4,299E-02	4651
52,6	-4651	0	-152	-168	6,7	475,4	160	5,0%	4,188E-02	4651
55,9	-4824	0	-165	-180	7,12	476,5	172,5	4,3%	4,128E-02	4824
59,3	-4910	0	-178	-192	7,55	477,7	185	3,8%	4,081E-02	4910
62,7	-5168	0	-189	-207	7,98	478,8	198	4,5%	4,030E-02	5168
66	-5513	0	-202	-217	8,41	479,9	209,5	3,6%	4,014E-02	5513
69,5	-5513	0	-217	-233	8,86	481,1	225	3,6%	3,938E-02	5513
73,1	-5685	0	-229	-245	9,32	482,2	237	3,4%	3,932E-02	5685
76,7	-5857	0	-244	-260	9,77	483,4	252	3,2%	3,877E-02	5857
79,9	-5943	0	-255	-273	10,17	484,3	264	3,4%	3,852E-02	5943
83,8	-6288	0	-271	-287	10,67	485,6	279	2,9%	3,824E-02	6288
87,4	-6288	0	-284	-302	11,13	486,7	293	3,1%	3,799E-02	6288
90,8	-6546	0	-299	-314	11,57	487,8	306,5	2,4%	3,775E-02	6546
94,5	-6546	0	-311	-328	12,04	488,9	319,5	2,7%	3,768E-02	6546
97,9	-6891	0	-325	-341	12,47	490	333	2,4%	3,745E-02	6891
100,5	-7063	0	-336	-352	12,81	491,2	344	2,3%	3,724E-02	7063
101,5	-7149	0	-340	-357	12,93	492,2	348,5	2,4%	3,710E-02	7149
103,4	-7235	0	-347	-364	13,17	493,3	355,5	2,4%	3,705E-02	7235
102,9	-7408	0	-347	-364	13,11	494,4	355,5	2,4%	3,688E-02	7408
105,8	-7580	0	-356	-373	13,48	495,6	364,5	2,3%	3,698E-02	7580
106,5	-7580	0	-360	-378	13,57	496,7	369	2,4%	3,678E-02	7580
105,8	-7580	0	-357	-375	13,48	497,8	366	2,5%	3,683E-02	7580
106,9	-7752	0	-361	-378	13,62	499	369,5	2,3%	3,686E-02	7752
109,6	-7752	0	-373	-390	13,97	500,1	381,5	2,2%	3,662E-02	7752
107,1	-7838	0	-368	-385	13,65	501,3	376,5	2,3%	3,625E-02	7838
107,5	-7924	0	-370	-387	13,7	502,3	378,5	2,2%	3,620E-02	7924
105,8	-8011	0	-361	-379	13,47	503,5	370	2,4%	3,641E-02	8011
107,9	-7838	0	-366	-385	13,74	504,6	375,5	2,5%	3,659E-02	7838
107,4	-7838	0	-365	-383	13,68	505,7	374	2,4%	3,658E-02	7838
108,5	-7924	0	-373	-392	13,82	506,8	382,5	2,5%	3,613E-02	7924
110,4	-7838	0	-380	-396	14,06	507,9	388	2,1%	3,624E-02	7838
110	-7924	0	-380	-399	14,02	509	389,5	2,4%	3,599E-02	7924
107,6	-7752	0	-367	-386	13,71	510,2	376,5	2,5%	3,641E-02	7752
107,7	-7838	0	-368	-386	13,72	511,3	377	2,4%	3,639E-02	7838
111	-7838	0	-382	-401	14,14	512,4	391,5	2,4%	3,612E-02	7838
111	-7924	0	-384	-401	14,14	513,5	392,5	2,2%	3,603E-02	7924
110,4	-7924	0	-382	-400	14,06	514,6	391	2,3%	3,596E-02	7924
110,4	-7838	0	-382	-400	14,07	515,7	391	2,3%	3,598E-02	7838
109,7	-7924	0	-380	-399	13,97	516,8	389,5	2,4%	3,587E-02	7924

Appendix E.5.3. Template Elasticity and Poisson test

Load ch 1 (Kn)	Strain ch 5 (µe)	Strain ch 6 (µe)	Strain ch 7 (µe)	Strain ch 8 (µe)	Stress (N/mm²)	Time s	Strain "E-Module" (µe)	STANDARD DEVIATION	STRESS/STRAIN (N/mm2)	Ax "Poisson" (µm)	
104,9	-7838	0	-361	-379	13,37	517,9	370	2,4%	3,614E-02	7838	
102,7	-7752	0	-352	-372	13,08	519,1	362	2,8%	3,613E-02	7752	
100,9	-7838	0	-349	-368	12,85	520,1	358,5	2,6%	3,584E-02	7838	
101,3	-7666	0	-349	-368	12,9	521,3	358,5	2,6%	3,598E-02	7666	
98,4	-7666	0	-339	-360	12,54	522,4	349,5	3,0%	3,588E-02	7666	
93,1	-7580	0	-318	-338	11,87	523,5	328	3,0%	3,619E-02	7580	
90,6	-7321	0	-309	-328	11,54	524,6	318,5	3,0%	3,623E-02	7321	
85,7	-7321	0	-294	-314	10,92	525,7	304	3,3%	3,592E-02	7321	
84,3	-7149	0	-291	-310	10,75	526,9	300,5	3,2%	3,577E-02	7149	
82,3	-7149	0	-282	-303	10,49	528	292,5	3,6%	3,586E-02	7149	
77,4	-6891	0	-263	-284	9,86	529,2	273,5	3,8%	3,605E-02	6891	
74,3	-6805	0	-251	-271	9,47	530,2	261	3,8%	3,628E-02	6805	
71,7	-6719	0	-243	-263	9,14	531,5	253	4,0%	3,613E-02	6719	
69	-6632	0	-232	-251	8,79	532,6	241,5	3,9%	3,640E-02	6632	
65,7	-6546	0	-218	-238	8,37	533,7	228	4,4%	3,671E-02	6546	
61,8	-6375	0	-206	-225	7,87	534,8	215,5	4,4%	3,652E-02	6375	
58,1	-6288	0	-190	-209	7,4	536	199,5	4,8%	3,709E-02	6288	
54,6	-6202	0	-178	-198	6,96	537,1	188	5,3%	3,702E-02	6202	
51,4	-6202	0	-166	-186	6,55	538,3	176	5,7%	3,722E-02	6202	
48,1	-5943	0	-154	-171	6,12	539,4	162,5	5,2%	3,766E-02	5943	
45	-5771	0	-139	-159	5,74	540,5	149	6,7%	3,852E-02	5771	
41,6	-5599	0	-126	-143	5,31	541,7	134,5	6,3%	3,948E-02	5599	
38,8	-5427	0	-115	-131	4,94	542,7	123	6,5%	4,016E-02	5427	
37,3	-5341	0	-109	-123	4,75	543,9	116	6,0%	4,095E-02	5341	
36	-5254	0	-103	-117	4,59	545	110	6,4%	4,173E-02	5254	
34,9	-5254	0	-97	-113	4,45	546,1	105	7,6%	4,238E-02	5254	
34,1	-5168	0	-92	-108	4,34	547,2	100	8,0%	4,340E-02	5168	
33,3	-4996	0	-90	-104	4,24	548,3	97	7,2%	4,371E-02	4996	
32,5	-5168	0	-87	-101	4,14	549,5	94	7,4%	4,404E-02	5168	
31,9	-5082	0	-85	-99	4,07	550,5	92	7,6%	4,424E-02	5082	
31,4	-5082	0	-82	-94	4	551,7	88	6,8%	4,545E-02	5082	
30,9	-4996	0	-79	-92	3,94	552,7	85,5	7,6%	4,608E-02	4996	
30,4	-4910	0	-79	-90	3,88	553,9	84,5	6,5%	4,592E-02	4910	
30,1	-4996	0	-78	-89	3,84	554,9	83,5	6,6%	4,599E-02	4996	
29,8	-4824	0	-74	-88	3,8	556,1	81	8,6%	4,691E-02	4824	
29,5	-4824	0	-73	-86	3,75	557,2	79,5	8,2%	4,717E-02	4824	
29,2	-4824	0	-72	-84	3,72	558,4	78	7,7%	4,769E-02	4824	
29	-4824	0	-71	-84	3,7	559,5	77,5	8,4%	4,774E-02	4824	
28,7	-4824	0	-68	-82	3,66	560,6	75	9,3%	4,880E-02	4824	
28,6	-4737	0	-69	-81	3,64	561,8	75	**8,0%**	**4,853E-02**	4737	
28,4	-4910	0	-69	-81	3,62	562,9	75	8,0%	4,827E-02	4910	
28,3	-4737	0	-67	-81	3,6	564,1	74	9,5%	4,865E-02	4737	
28,2	-4737	0	-66	-80	3,6	565,1	73	9,6%	4,932E-02	4737	
28,1	-4737	0	-67	-80	3,58	566,3	73,5	8,8%	4,871E-02	4737	
28	-4824	0	-66	-79	3,57	567,4	72,5	9,0%	4,924E-02	4824	
28	-4737	0	-65	-79	3,56	568,5	72	9,7%	4,944E-02	4737	
27,9	-4824	0	-65	-78	3,55	569,6	71,5	9,1%	4,965E-02	4824	
27,8	-4651	0	-64	-77	3,54	570,7	70,5	9,2%	5,021E-02	4651	
27,8	-4651	0	-64	-77	3,54	571,9	70,5	9,2%	5,021E-02	4651	
27,7	-4824	0	-65	-77	3,53	572,9	71	8,5%	4,972E-02	4824	
27,7	-4737	0	-63	-77	3,53	574,1	70	10,0%	5,043E-02	4737	
27,6	-4824	0	-64	-77	3,52	575,2	70,5	9,2%	4,993E-02	4824	
27,6	-4910	0	-63	-77	3,52	576,3	70	10,0%	5,029E-02	4910	
27,6	-4737	0	-64	-76	3,51	577,4	70	8,6%	5,014E-02	4737	
27,6	-4910	0	-62	-76	3,51	578,4	69	10,1%	5,087E-02	4910	
27,6	-4737	0	-63	-75	3,51	579,6	69	8,7%	5,087E-02	4737	εb2
27,6	-4910	0	-62	-76	3,52	580,6	69	10,1%	5,101E-02	4910	
29,3	-4996	0	-69	-80	3,73	581,8	74,5	7,4%	5,007E-02	4996	
31,1	-4651	0	-76	-86	3,96	582,8	81	6,2%	4,889E-02	4651	
33,4	-4910	0	-81	-94	4,25	584	87,5	7,4%	4,857E-02	4910	
35,7	-4910	0	-90	-103	4,54	585,1	96,5	6,7%	4,705E-02	4910	
38,1	-4824	0	-98	-111	4,86	586,2	104,5	6,2%	4,651E-02	4824	
40,9	-4910	0	-110	-124	5,21	587,4	117	6,0%	4,453E-02	4910	
43,8	-4996	0	-120	-134	5,58	588,5	127	5,5%	4,394E-02	4996	
46,8	-4910	0	-131	-146	5,96	589,7	138,5	5,4%	4,303E-02	4910	
50	-5082	0	-142	-158	6,36	590,8	150	5,3%	4,240E-02	5082	
53,1	-5168	0	-156	-172	6,77	592	164	4,9%	4,128E-02	5168	
56,2	-5341	0	-168	-184	7,16	593	176	4,5%	4,068E-02	5341	
59,7	-5513	0	-181	-197	7,61	594,2	189	4,2%	4,026E-02	5513	
63,1	-5513	0	-192	-209	8,04	595,3	200,5	4,2%	4,010E-02	5513	
66,7	-5771	0	-206	-223	8,5	596,5	214,5	4,0%	3,963E-02	5771	

Appendix E.5.3. Template Elasticity and Poisson test

Load ch 1 (Kn)	Strain ch 5 (με)	Strain ch 6 (με)	Strain ch 7 (με)	Strain ch 8 (με)	Stress (N/mm²)	Time s	Strain "E-Module" (με)	STANDARD DEVIATION	STRESS/STRAIN (N/mm2)	Ax "Poisson" (μm)	
70	-5943	0	-219	-236	8,92	597,6	227,5	3,7%	3,921E-02	5943	
73,3	-5943	0	-230	-247	9,34	598,6	238,5	3,6%	3,916E-02	5943	
76,9	-6288	0	-246	-262	9,8	599,8	254	3,1%	3,858E-02	6288	
80,5	-6288	0	-261	-278	10,26	600,9	269,5	3,2%	3,807E-02	6288	
84,2	-6546	0	-274	-292	10,73	602,1	283	3,2%	3,792E-02	6546	
87,6	-6805	0	-287	-304	11,17	603,1	295,5	2,9%	3,780E-02	6805	
91,2	-6805	0	-301	-318	11,63	604,3	309,5	2,7%	3,758E-02	6805	
94,7	-7235	0	-314	-332	12,06	605,4	323	2,8%	3,734E-02	7235	
98,4	-7321	0	-328	-345	12,53	606,5	336,5	2,5%	3,724E-02	7321	
100,6	-7494	0	-338	-355	12,81	607,6	346,5	2,5%	3,697E-02	7494	
101,9	-7408	0	-343	-361	12,98	608,7	352	2,6%	3,688E-02	7408	
103	-7580	0	-347	-365	13,12	609,8	356	2,5%	3,685E-02	7580	
104,1	-7666	0	-352	-369	13,26	611	360,5	2,4%	3,678E-02	7666	
104,8	-7666	0	-354	-372	13,35	612,1	363	2,5%	3,678E-02	7666	
105,6	-7752	0	-358	-376	13,45	613,3	367	2,5%	3,665E-02	7752	
106,3	-7838	0	-360	-378	13,54	614,5	369	2,4%	3,669E-02	7838	
106,6	-7666	0	-362	-379	13,58	615,6	370,5	2,3%	3,665E-02	7666	
107,1	-7752	0	-366	-383	13,65	616,7	374,5	2,3%	3,645E-02	7752	
108,1	-7838	0	-368	-386	13,78	617,9	377	2,4%	3,655E-02	7838	
107,5	-8097	0	-367	-385	13,7	619	376	2,4%	3,644E-02	8097	
108,6	-8269	0	-369	-388	13,84	620,1	378,5	2,5%	3,657E-02	8269	
107,9	-8269	0	-371	-389	13,74	621,3	380	2,4%	3,616E-02	8269	
108,1	-8355	0	-370	-389	13,77	622,4	379,5	2,5%	3,628E-02	8355	
110,2	-8269	0	-378	-396	14,04	623,5	387	2,3%	3,628E-02	8269	
108,5	-8441	0	-374	-392	13,82	624,7	383	2,3%	3,608E-02	8441	
108,4	-8528	0	-373	-392	13,82	625,8	382,5	2,5%	3,613E-02	8528	
109,4	-8355	0	-376	-396	13,94	626,8	386	2,6%	3,611E-02	8355	Ea3
109,3	-8355	0	-376	-395	13,92	628	385,5	2,5%	3,611E-02	8355	
108,8	-8355	0	-375	-394	13,87	629	384,5	2,5%	3,607E-02	8355	
109,7	-8355	0	-377	-396	13,97	630,2	386,5	2,5%	3,614E-02	8355	
109,4	-8441	0	-377	-397	13,94	631,3	387	2,6%	3,602E-02	8441	
108,2	-8269	0	-373	-394	13,79	632,4	383,5	2,7%	3,596E-02	8269	
106,9	-8355	0	-369	-388	13,62	633,5	378,5	2,5%	3,598E-02	8355	
104,1	-8269	0	-361	-380	13,26	634,7	370,5	2,6%	3,579E-02	8269	
101,2	-8183	0	-351	-370	12,9	635,7	360,5	2,6%	3,578E-02	8183	
98,7	-8269	0	-342	-360	12,57	636,9	351	2,6%	3,581E-02	8269	
96,7	-8269	0	-335	-355	12,32	638	345	2,9%	3,571E-02	8269	
91,9	-8097	0	-317	-336	11,7	639,2	326,5	2,9%	3,583E-02	8097	
89,4	-7838	0	-307	-327	11,39	640,3	317	3,2%	3,593E-02	7838	
88,6	-7752	0	-304	-325	11,28	641,4	314,5	3,3%	3,587E-02	7752	
85,7	-7494	0	-295	-314	10,92	642,5	304,5	3,1%	3,586E-02	7494	
82,7	-7408	0	-284	-303	10,54	643,6	293,5	3,2%	3,591E-02	7408	
79,7	-7408	0	-272	-292	10,15	644,7	282	3,5%	3,599E-02	7408	
74,6	-7321	0	-252	-273	9,5	645,9	262,5	4,0%	3,619E-02	7321	
70,6	-7235	0	-239	-257	8,99	647	248	3,6%	3,625E-02	7235	
67,4	-7063	0	-226	-246	8,59	648,1	236	4,2%	3,640E-02	7063	
65,2	-6891	0	-219	-238	8,31	649,2	228,5	4,2%	3,637E-02	6891	
62,4	-6891	0	-207	-227	7,95	650,4	217	4,6%	3,664E-02	6891	
58,5	-6719	0	-193	-212	7,46	651,5	202,5	4,7%	3,684E-02	6719	
55,2	-6546	0	-181	-202	7,04	652,6	191,5	5,5%	3,676E-02	6546	
51,9	-6546	0	-168	-186	6,62	653,7	177	5,1%	3,740E-02	6546	
48,5	-6375	0	-156	-175	6,18	654,9	165,5	5,7%	3,734E-02	6375	
45,3	-6288	0	-140	-160	5,77	656	150	6,7%	3,847E-02	6288	
41,9	-6030	0	-128	-146	5,34	657,2	137	6,6%	3,898E-02	6030	
38,8	-5857	0	-116	-132	4,94	658,3	124	6,5%	3,984E-02	5857	
35,5	-5685	0	-102	-117	4,53	659,4	109,5	6,8%	4,137E-02	5685	
32,2	-5513	0	-89	-104	4,1	660,6	96,5	7,8%	4,249E-02	5513	
29,1	-5427	0	-76	-89	3,71	661,6	82,5	7,9%	4,497E-02	5427	
27	-5254	0	-66	-80	3,44	662,8	73	9,6%	4,712E-02	5254	
25,6	-5082	0	-58	-74	3,26	663,9	66	12,1%	4,939E-02	5082	
24,5	-5082	0	-54	-70	3,12	665	62	12,9%	5,032E-02	5082	
23,4	-5082	0	-50	-63	2,98	666,2	56,5	11,5%	5,274E-02	5082	
22,5	-4996	0	-46	-58	2,87	667,3	52	11,5%	5,519E-02	4996	
21,7	-4824	0	-41	-52	2,77	668,4	46,5	11,8%	5,957E-02	4824	
20,9	-4824	0	-39	-47	2,67	669,5	43	9,3%	6,209E-02	4824	
20,3	-4824	0	-35	-43	2,59	670,7	39	10,3%	6,641E-02	4824	
19,8	-4737	0	-33	-41	2,52	671,7	37	10,8%	6,811E-02	4737	
19,3	-4651	0	-31	-39	2,46	672,9	35	11,4%	7,029E-02	4651	
18,9	-4737	0	-28	-36	2,4	674	32	12,5%	7,500E-02	4737	
18,5	-4737	0	-27	-32	2,36	675,1	29,5	8,5%	8,000E-02	4737	
18,2	-4651	0	-25	-33	2,32	676,2	29	13,8%	8,000E-02	4651	

Appendix E.5.3. Template Elasticity and Poisson test

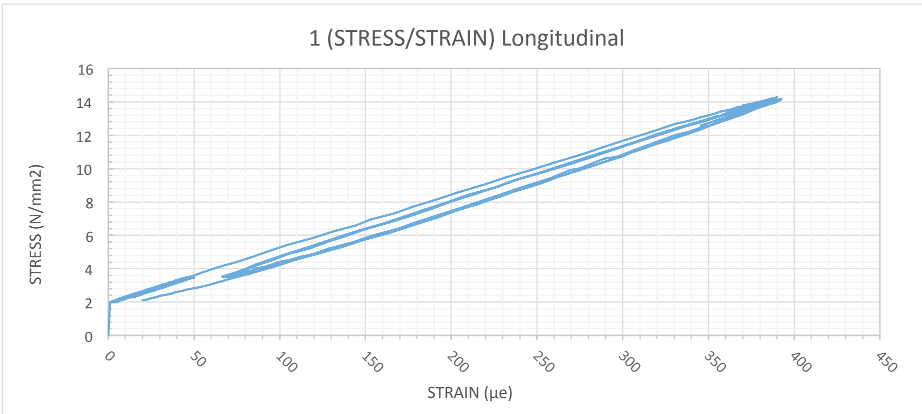
Load ch 1 (Kn)	Strain ch 5 (µe)	Strain ch 6 (µe)	Strain ch 7 (µe)	Strain ch 8 (µe)	Stress (N/mm²)	Time s	Strain "E-Module" (µe)	STANDARD DEVIATION	STRESS/STRAIN (N/mm2)	Ax "Poisson" (µm)
17,9	-4651	0	-23	-32	2,28	677,3	27,5	16,4%	8,291E-02	4651
17,6	-4737	0	-21	-29	2,24	678,5	25	16,0%	8,960E-02	4737
17,3	-4651	0	-20	-29	2,21	679,5	24,5	18,4%	9,020E-02	4651
17,2	-4651	0	-20	-27	2,19	680,7	23,5	14,9%	9,319E-02	4651
17	-4565	0	-19	-27	2,16	681,8	23	17,4%	9,391E-02	4565
16,8	-4565	0	-18	-25	2,14	683	21,5	16,3%	9,953E-02	4565
16,6	-4651	0	-17	-24	2,12	684,1	20,5	17,1%	1,034E-01	4651
16,5	-4565	0	-16	-24	2,11	685,2	20	20,0%	1,055E-01	4565

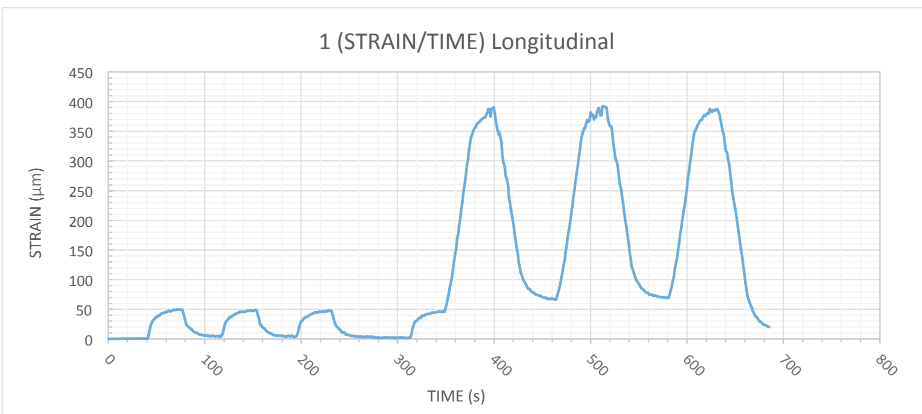
Appendix E.5.3. Template Elasticity and Poisson test

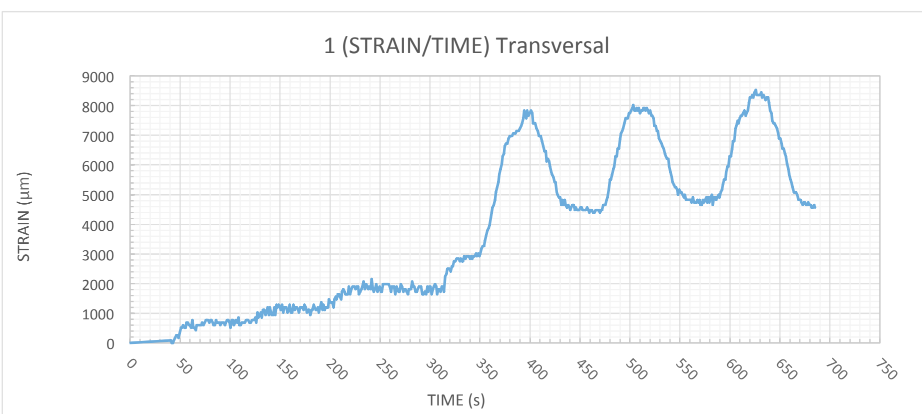
	STRESS (N/mm2)	STRAIN "E-MODULE" (µe)	Ax "POISSON" (µm)	TIME (s)
εb0	3,48	46	3015	348,3
εb2	3,51	69	4737	579,6
εa1	14,01	379	7408	392,1
εa3	13,94	386	8355	626,8

EC0	31622
Ecs	32902

µ	0,132

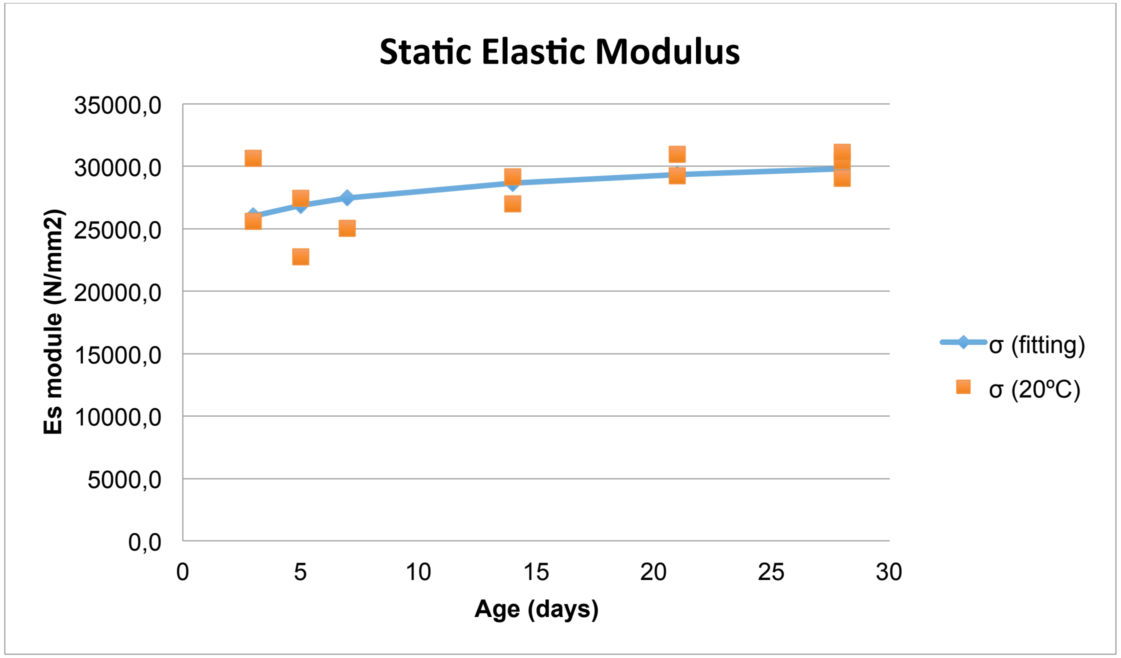






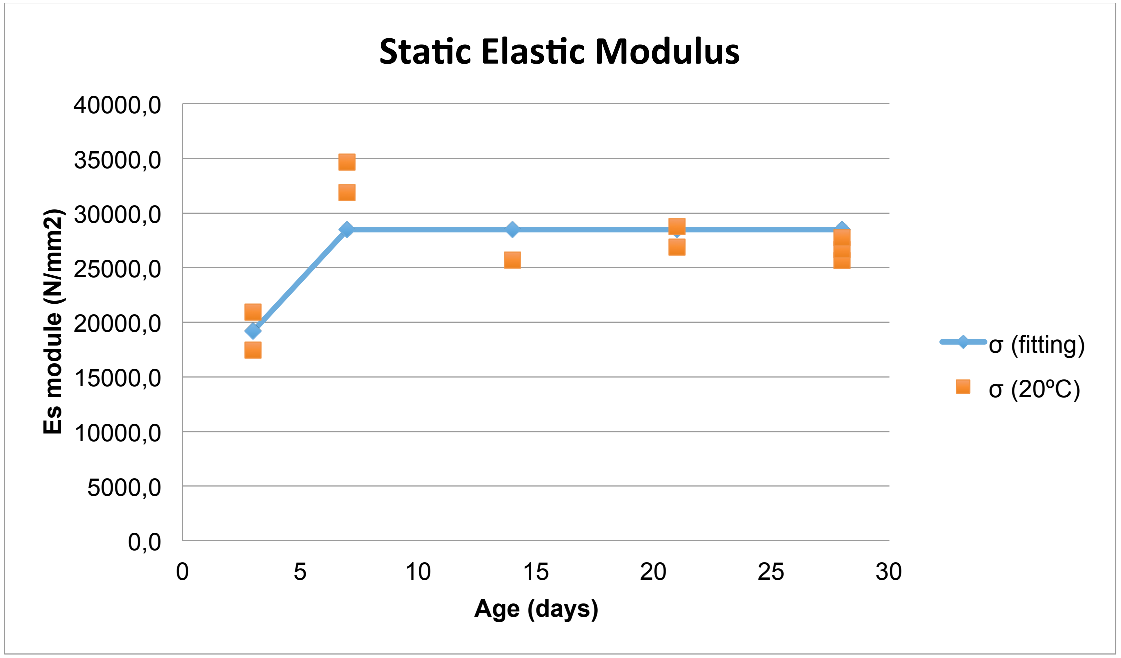
Appendix E.5.4. Static Elastic Modulus

Unwashed / 0% FA		f∞	τ	α
Age	Static Elastic Modulus	59642	0,30	0,08
Days	N/mm^2	E	ΔE^2	
3	25603	26001,9	159101,0	
3	30679	26001,9	21875501,4	
5	22745	26889,3	17175249,0	
5	27408	26889,3	269046,4	
7	25050	27469,9	5855716,2	
14	29176	28654,4	272117,7	
14	26995	28654,4	2753445,5	
21	30957	29339,2	2617116,9	
21	29269	29339,2	4935,0	
28	30436	29821,3	377873,3	
28	31131	29821,3	1715350,8	
28	29056	29821,3	585662,6	
		SUM:	53661115,9	



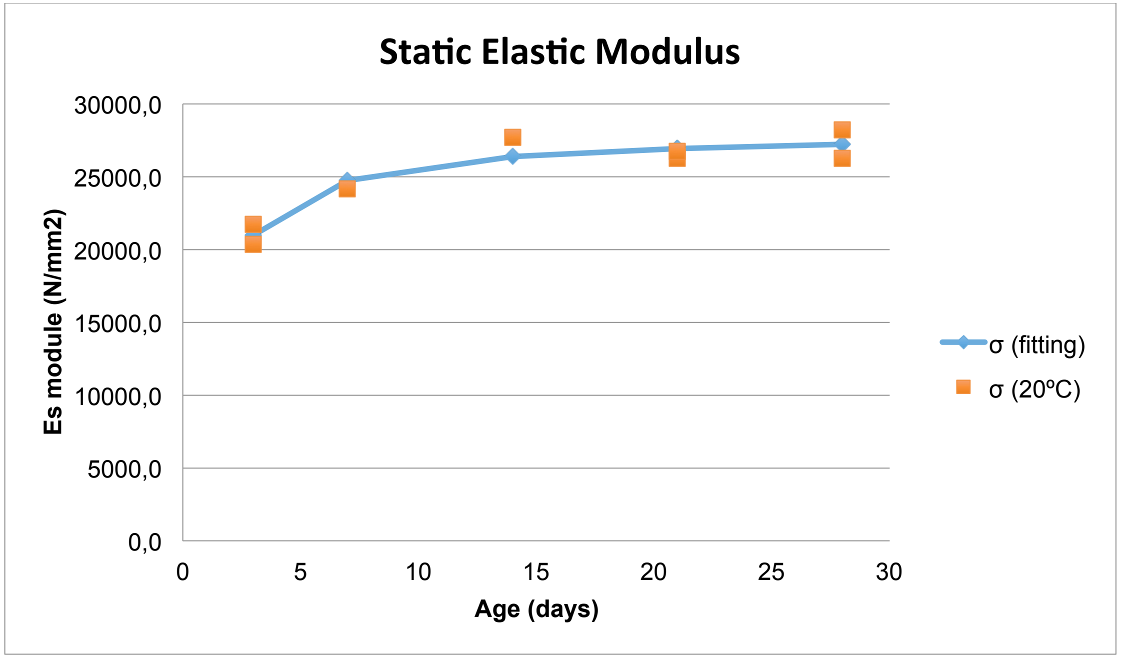
Appendix E.5.4. Static Elastic Modulus

Unwashed / 15% FA		f∞	τ	α
Age	Static Elastic Modulus	28484	2,79	13,04
Days	N/mm²	E	ΔE²	
3	17422	19170,9	3058521,6	
3	20916	19170,9	3045503,4	
7	34664	28484,0	38192251,7	
7	31899	28484,0	11662143,1	
14	25696	28484,2	7774014,0	
21	26855	28484,2	2654266,3	
21	28770	28484,2	81686,3	
28	25661	28484,2	7970412,6	
28	26613	28484,2	3501359,2	
28	27739	28484,2	555311,0	
		SUM:	78495469,1	



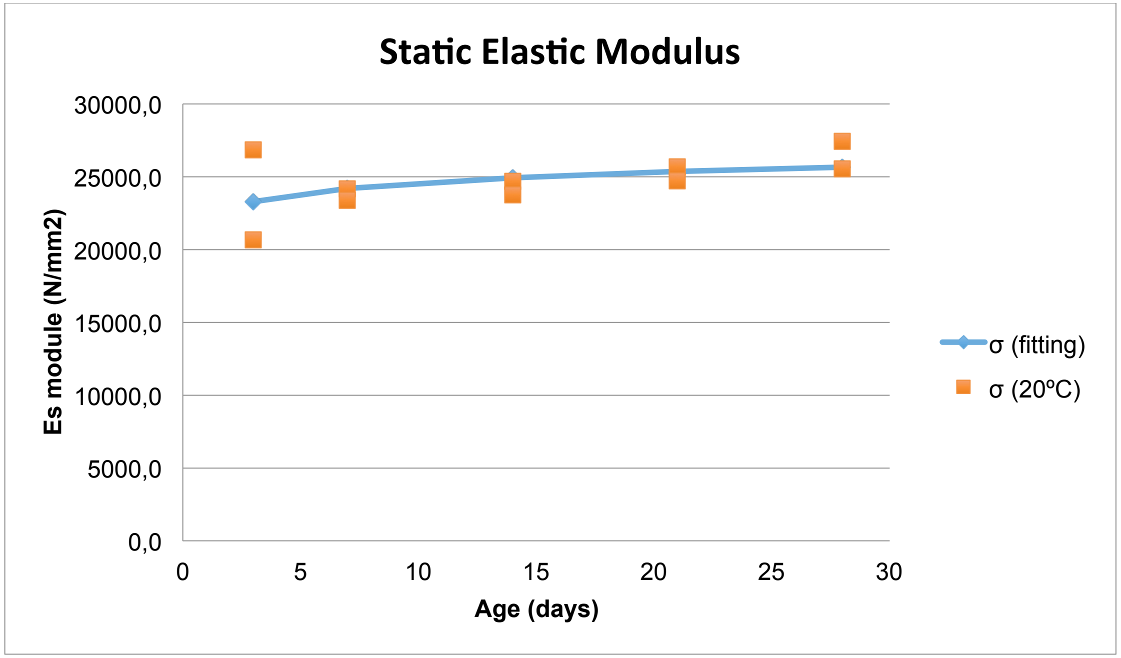
Appendix E.5.4. Static Elastic Modulus

Unwashed / 25% FA		f∞	τ	α
Age	Static Elastic Modulus	28152	0,85	0,98
Days	N/mm²	E	ΔE²	
3	21732	20992,4	546964,8	
3	20351	20992,4	411431,6	
7	24158	24760,6	363114,2	
14	27709	26373,4	1783960,2	
21	26296	26941,9	417154,5	
21	26737	26941,9	41973,8	
28	26266	27233,2	935485,1	
28	28221	27233,2	975739,4	
		SUM:	5475823,5	



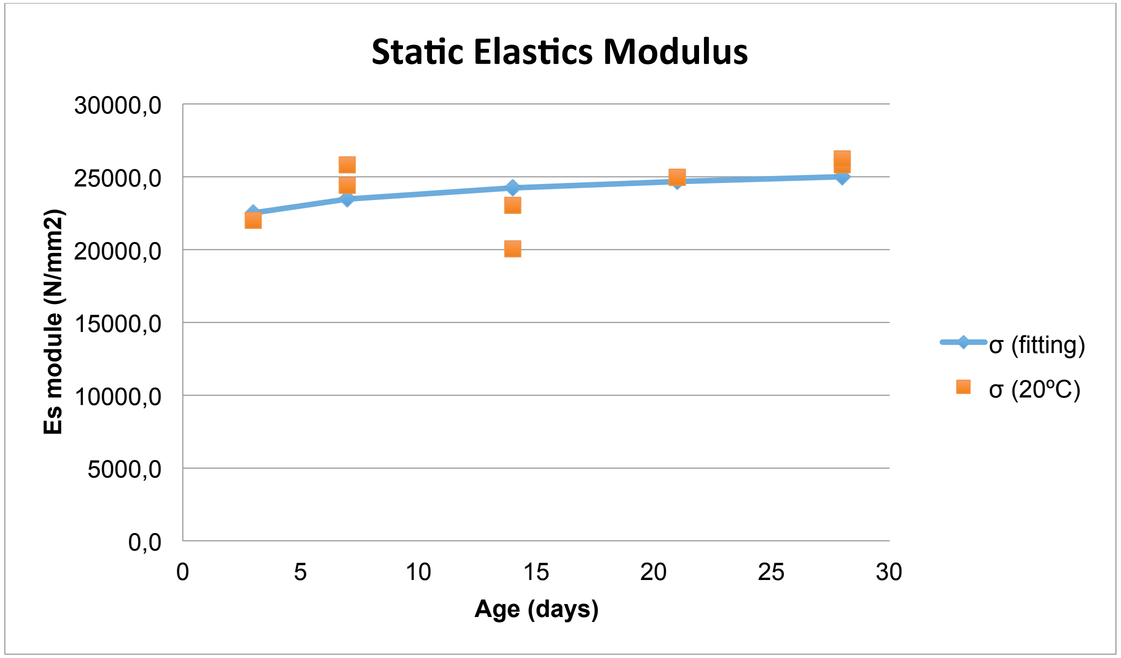
Appendix E.5.4. Static Elastic Modulus

Washed / 0% FA		f∞	τ	α
Age	Static Elastic Modulus	44897	0,01	0,07
Days	N/mm²	E	ΔE²	
3	20650	23291,2	6975956,4	
3	26847	23291,2	12643688,1	
7	24148	24205,3	3284,9	
7	23399	24205,3	650142,2	
14	24686	24937,7	63338,3	
14	23752	24937,7	1405815,8	
21	25702	25359,3	117460,8	
21	24704	25359,3	429384,7	
28	27438	25655,3	3178149,7	
28	25557	25655,3	9655,7	
		SUM:	25476876,6	



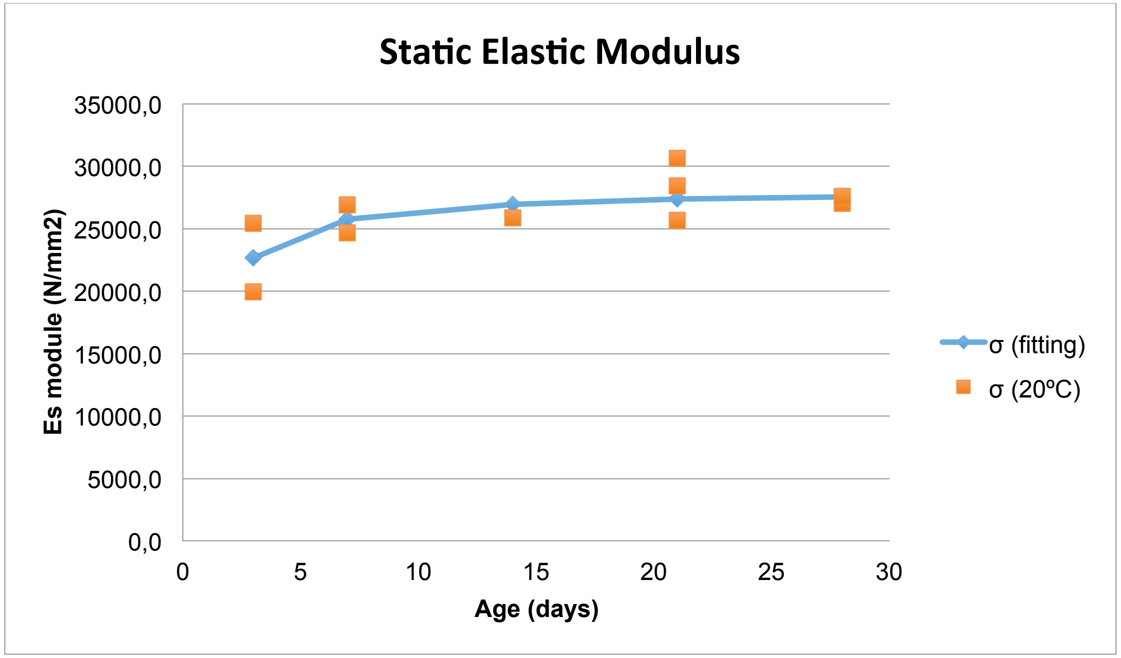
Appendix E.5.4. Static Elastic Modulus

Washed / 15% FA		f∞	τ	α
Age	Static Elastic Modulus	43246	0,01	0,08
Days	N/mm²	E	ΔE²	
3	22000	22506,8	256855,4	
7	24423	23469,5	909136,8	
7	25805	23469,5	5454497,9	
14	23015	24239,0	1498066,1	
14	20027	24239,0	17740565,7	
21	24958	24681,1	76696,7	
21	24979	24681,1	88769,2	
28	25803	24991,0	659284,0	
28	26246	24991,0	1574932,2	
		SUM:	**28258803,8**	

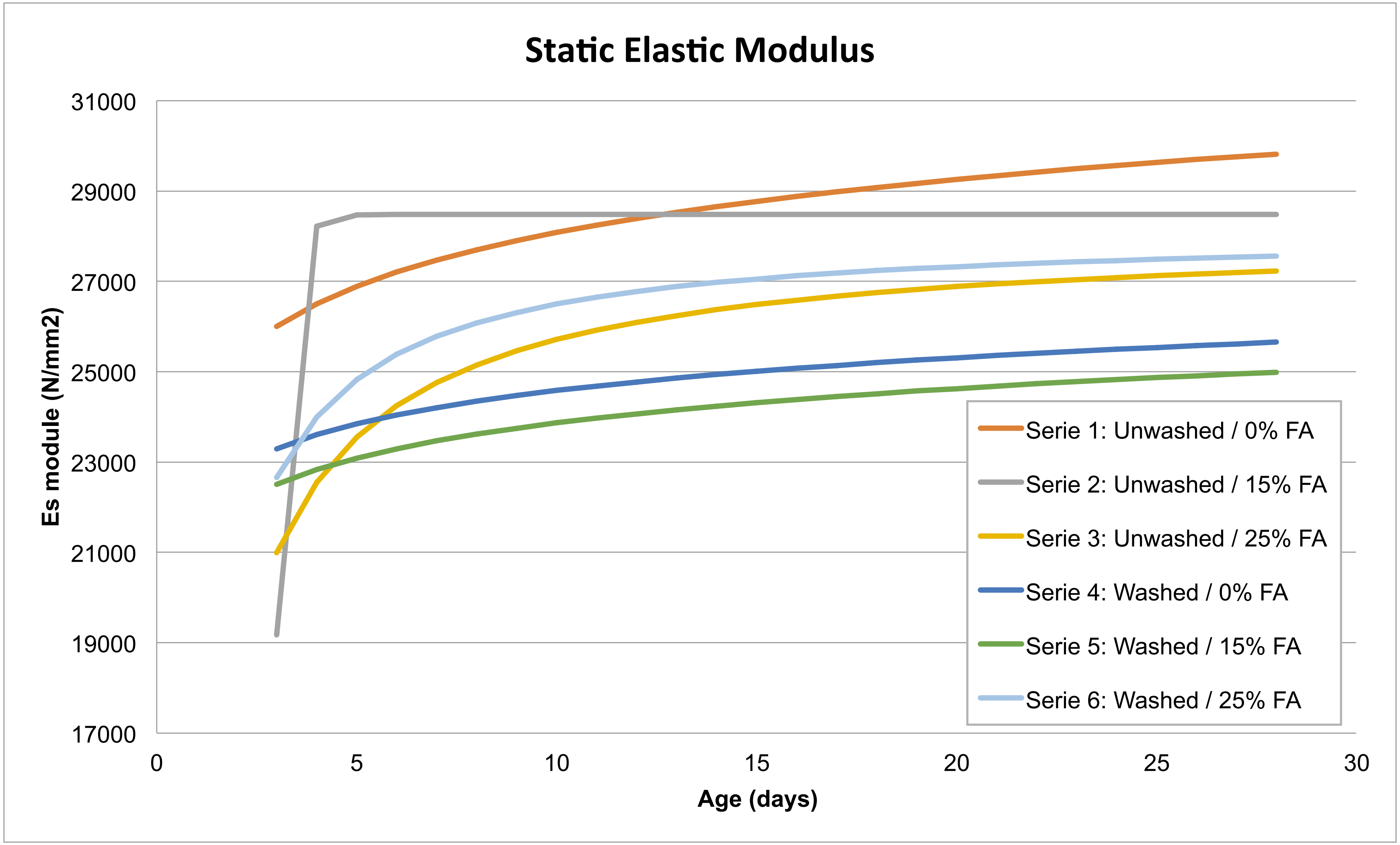


Appendix E.5.4. Static Elastic Modulus

Washed / 25 % FA		f∞	τ	α
Age	Static Elastic Modulus	28087	0,73	1,08
Days	N/mm^2	E	ΔE^2	
3	19928	22657,6	7450871,5	
3	25408	22657,6	7564543,7	
7	24663	25781,0	1249899,1	
7	26919	25781,0	1295069,3	
14	25872	26975,3	1217202,4	
21	28425	27365,8	1121932,7	
21	25660	27365,8	2909708,4	
21	30678	27365,8	10970756,7	
28	27048	27557,3	259386,0	
28	27600	27557,3	1823,3	
28	26421	27557,3	1291176,7	
		SUM:	35332369,9	

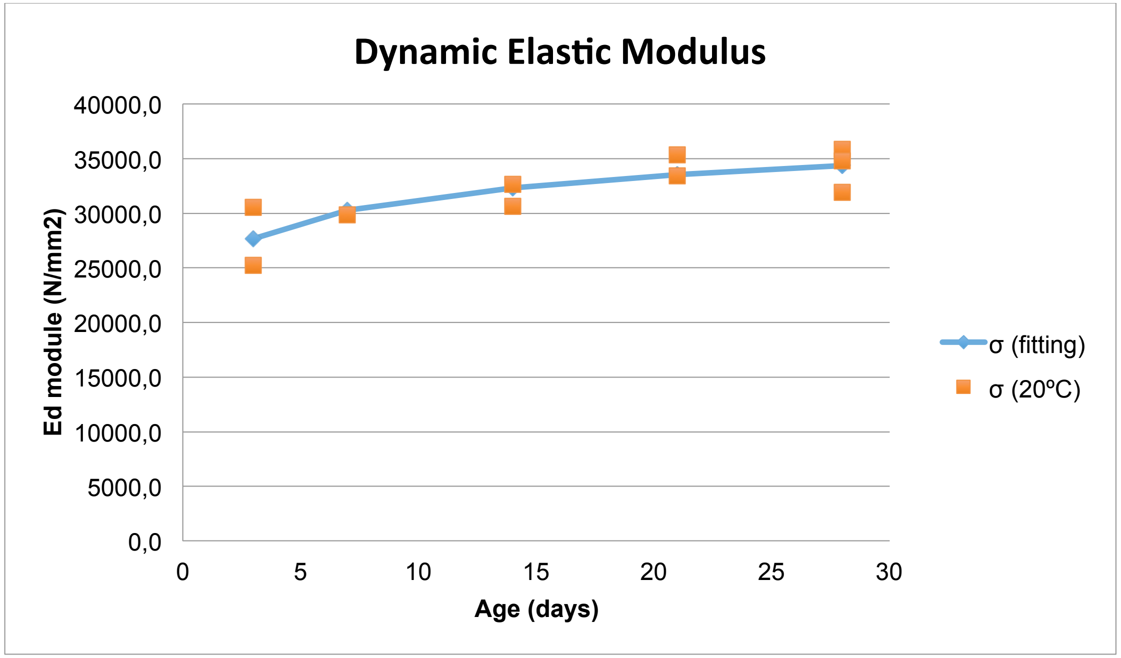


Appendix E.5.4. Static Elastic Modulus



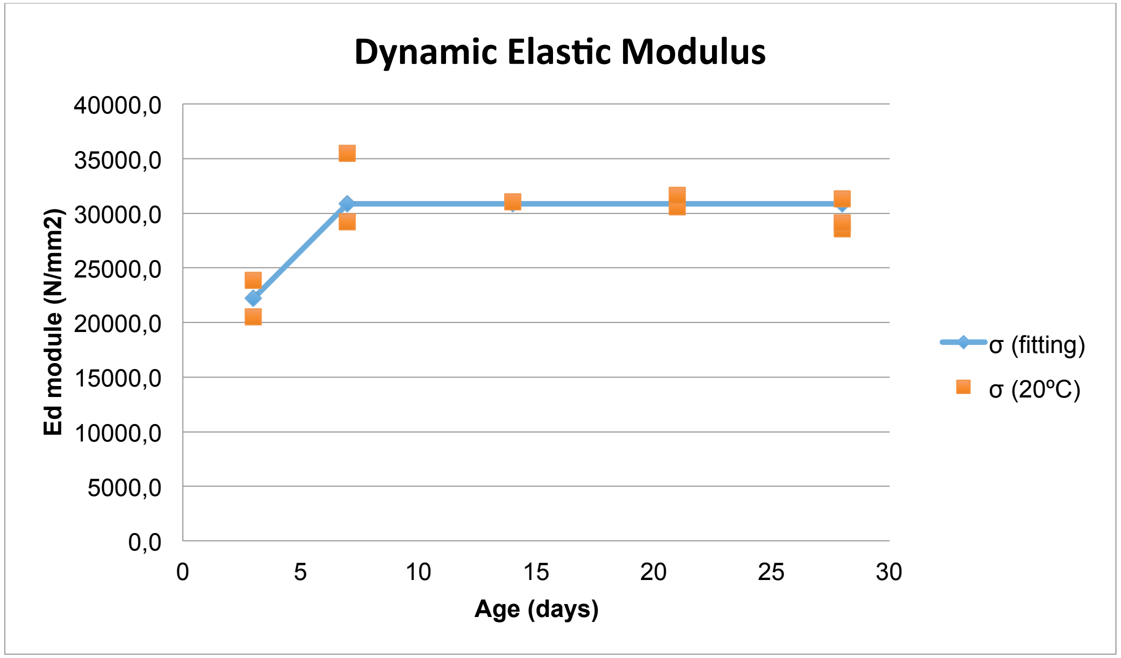
Appendix E.5.5. Dynamic Elastic Modulus

Unwashed / 0% FA		f∞	τ	α
Age	Dynamic Elastic Modulus	64771	0,88	0,13
Days	N/mm^2	E	ΔE^2	
3	25201	27662,7	6059737,3	
3	30491	27662,7	7999544,6	
7	29840	30255,0	172190,6	
14	32646	32326,3	102229,1	
14	30600	32326,3	2979998,4	
21	35343	33512,3	3351446,2	
21	33450	33512,3	3881,8	
28	35842	34341,0	2253059,3	
28	34791	34341,0	202517,5	
28	31927	34341,0	5827302,3	
		SUM:	28951907,1	



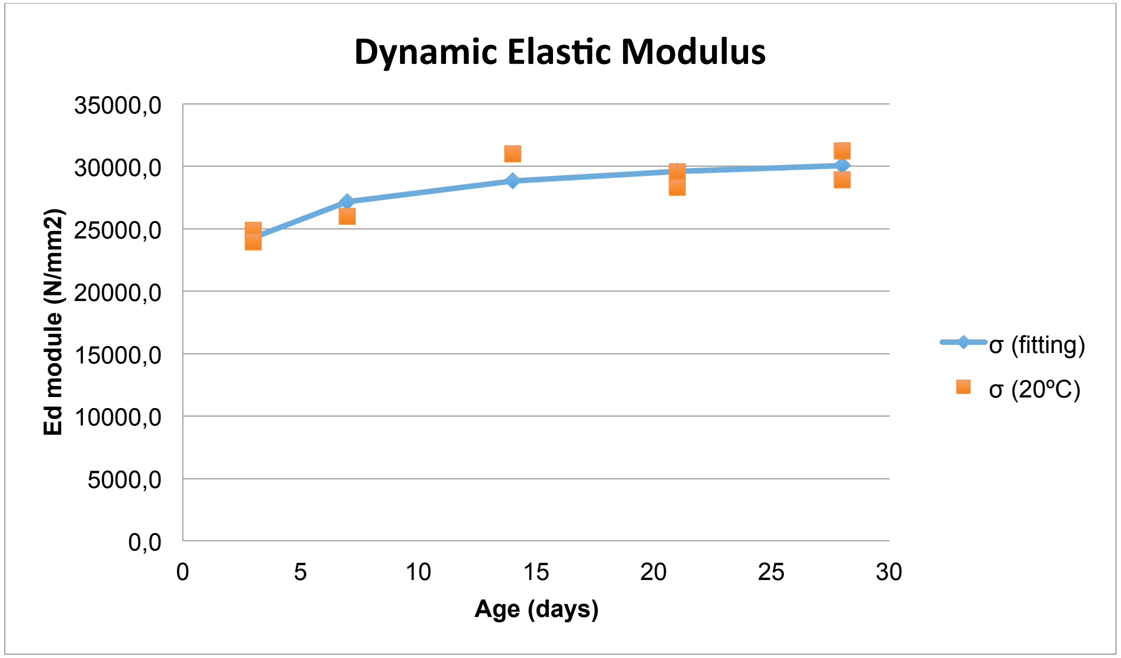
Appendix E.5.5. Dynamic Elastic Modulus

Unwashed / 15% FA		f∞	τ	α
Age	Dynamic Elastic Modulus	30858	2,77	13,58
Days	N/mm^2	E	ΔE^2	
3	20496	22172,7	2811488,7	
3	23855	22172,7	2829967,0	
7	35476	30857,5	21330560,8	
7	29182	30857,5	2807293,5	
14	31031	30857,6	30067,3	
21	30554	30857,6	92173,5	
21	31624	30857,6	587367,6	
28	28586	30857,6	5160170,5	
28	29084	30857,6	3145660,1	
28	31311	30857,6	205570,8	
		SUM:	39000319,7	



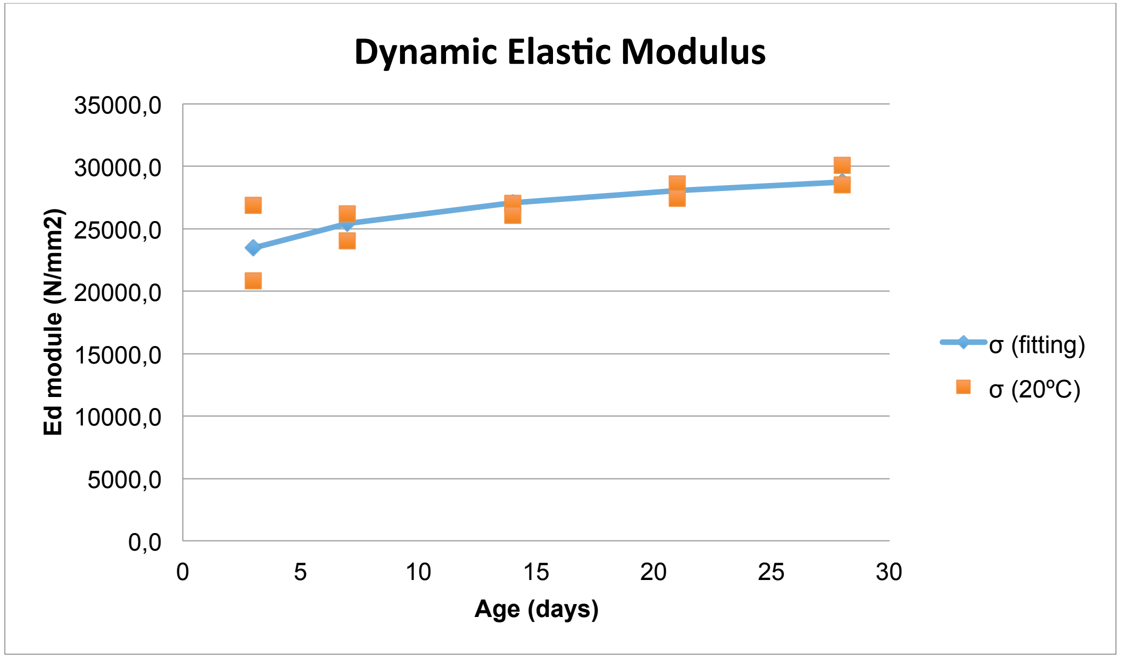
Appendix E.5.5. Dynamic Elastic Modulus

Unwashed / 25% FA		f∞	τ	α
Age	Dynamic Elastic Modulus	32923	0,33	0,54
Days	N/mm^2	E	ΔE^2	
3	24874	24293,5	337001,2	
3	23952	24293,5	116609,9	
7	25981	27155,7	1379884,0	
14	31010	28835,0	4730450,7	
21	29554	29594,9	1675,6	
21	28323	29594,9	1617816,9	
28	28920	30051,2	1279524,9	
28	31257	30051,2	1454048,0	
		SUM:	10917011,2	



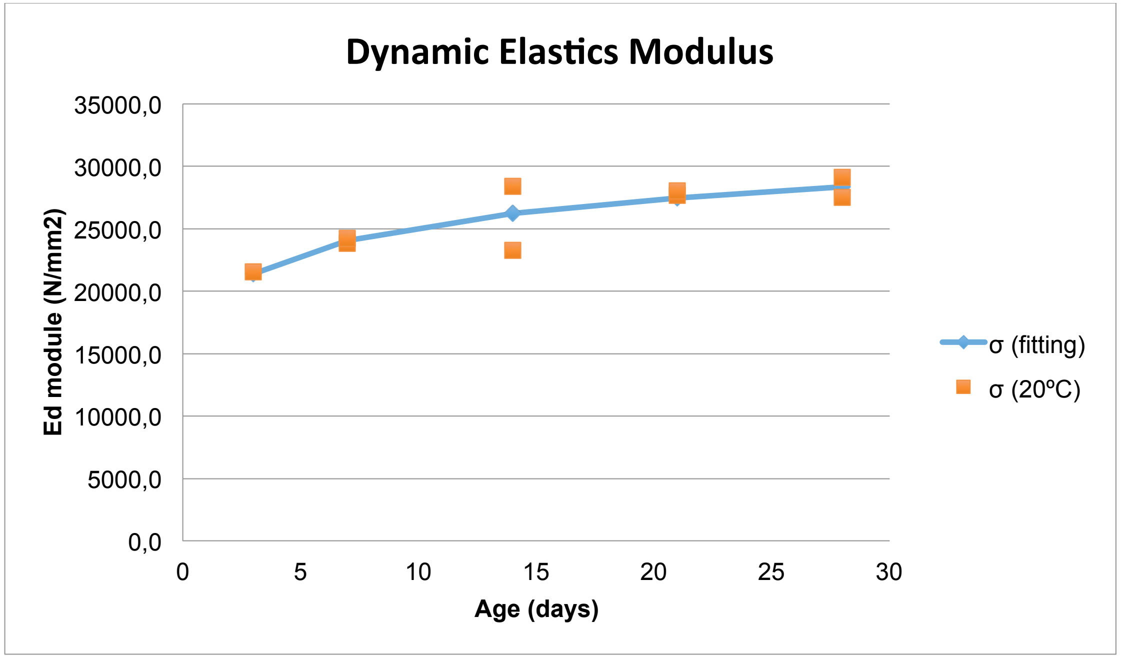
Appendix E.5.5. Dynamic Elastic Modulus

Washed / 0% FA		f∞	τ	α
Age	Dynamic Elastic Modulus	90908	193,22	0,07
Days	N/mm²	E	ΔE²	
3	20842	23454,4	6824827,0	
3	26878	23454,4	11720783,7	
7	26174	25437,1	543006,1	
7	24019	25437,1	2011037,4	
14	27042	27084,6	1818,4	
14	26049	27084,6	1072555,3	
21	28594	28056,9	288485,0	
21	27423	28056,9	401819,0	
28	30076	28749,8	1758698,0	
28	28520	28749,8	52826,8	
		SUM:	24675856,9	



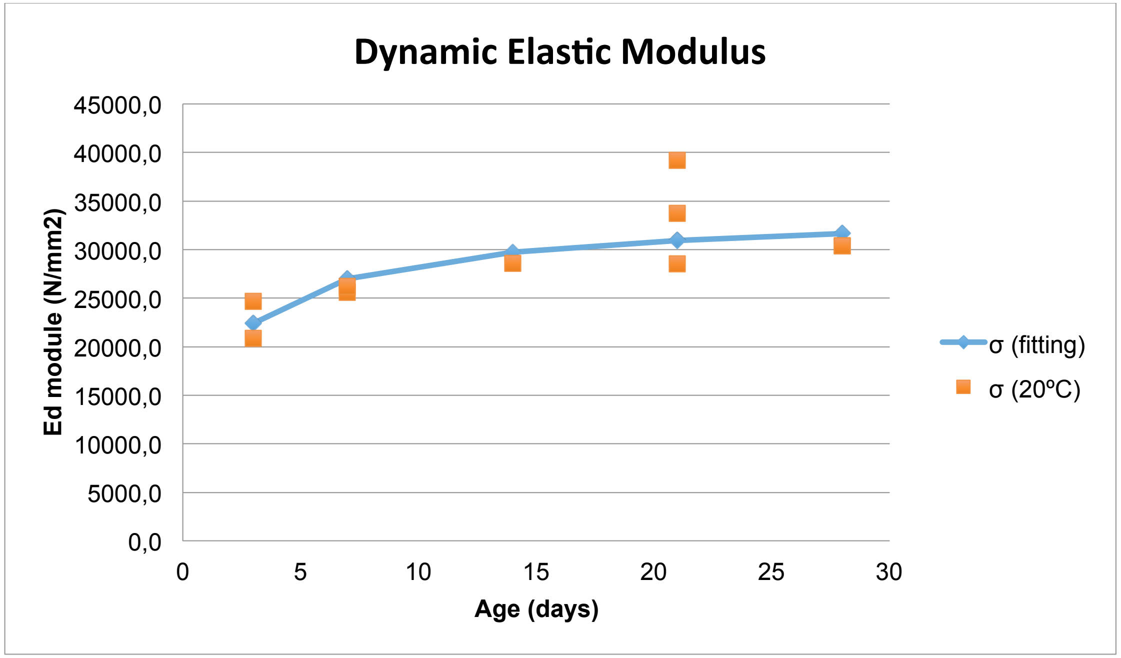
Appendix E.5.5. Dynamic Elastic Modulus

Washed / 15% FA		f∞	τ	α
Age	Dynamic Elastic Modulus	67077	8,58	0,13
Days	N/mm^2	E	ΔE^2	
3	21544	21392,9	22825,7	
7	23837	24038,8	40704,6	
7	24216	24038,8	31416,2	
14	28381	26210,4	4711618,7	
14	23240	26210,4	8823119,7	
21	27666	27476,4	35945,1	
21	28025	27476,4	300953,0	
28	27528	28370,6	710000,4	
28	29141	28370,6	593492,7	
		SUM:	15270076,1	

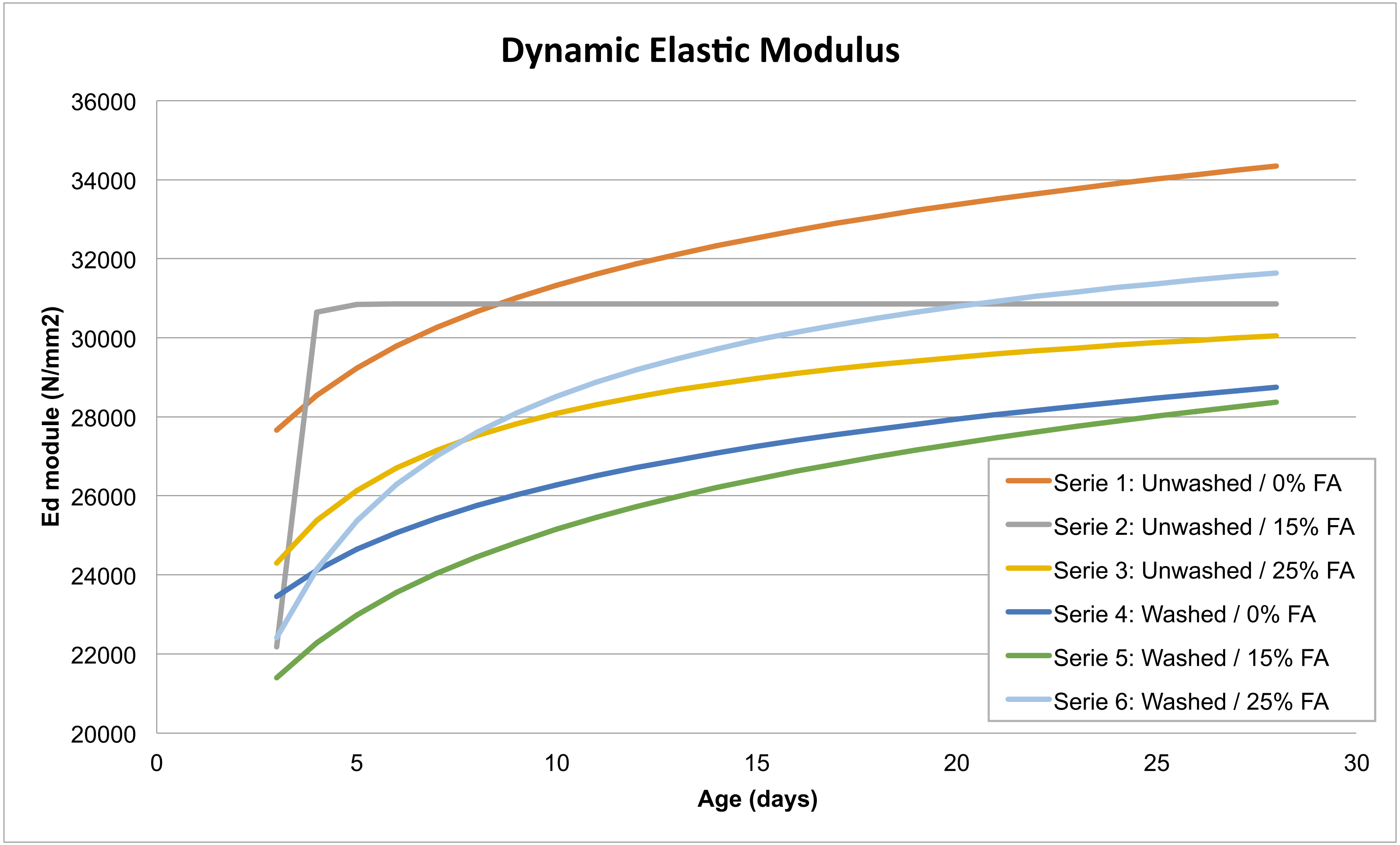


Appendix E.5.5. Dynamic Elastic Modulus

Washed / 25 % FA		f∞	τ	α
Age	Dynamic Elastic Modulus	35676	0,85	0,61
Days	N/mm^2	E	ΔE^2	
3	20845	22409,2	2446849,9	
3	24667	22409,2	5097475,7	
7	25581	27013,2	2051092,1	
7	26243	27013,2	593151,7	
14	28582	29719,1	1292976,3	
21	33744	30926,7	7937447,3	
21	28544	30926,7	5677032,6	
21	39211	30926,7	68630414,7	
28	30372	31642,2	1613414,6	
28	30390	31642,2	1568011,3	
28	28100	31642,2	12547199,0	
		SUM:	109455065,3	

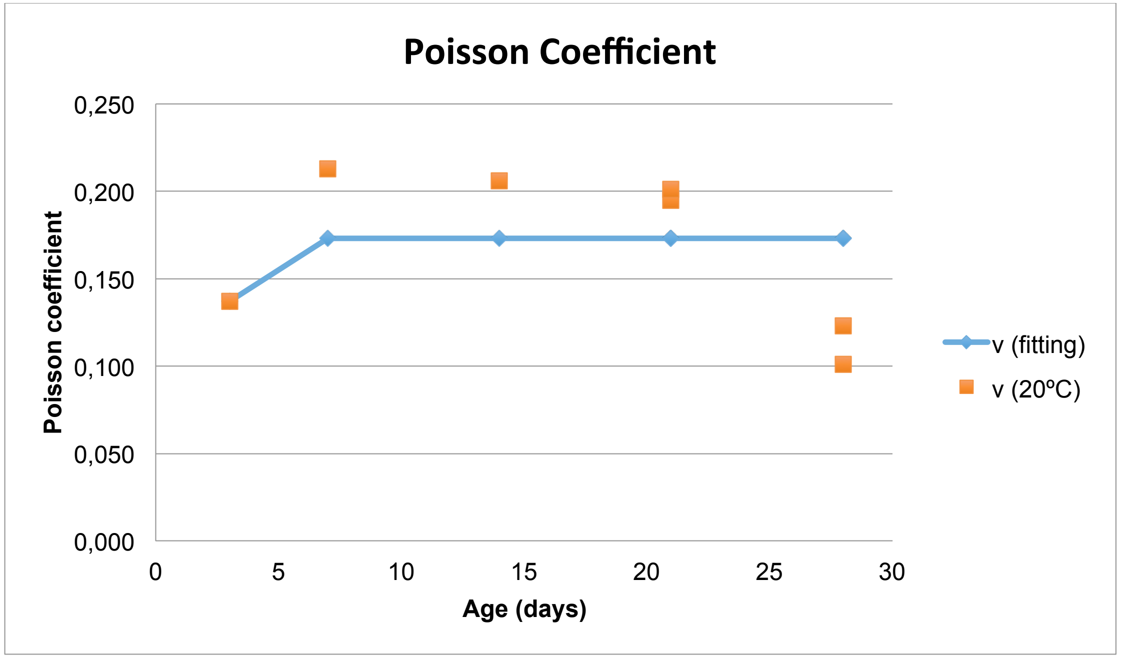


Appendix E.5.5. Dynamic Elastic Modulus



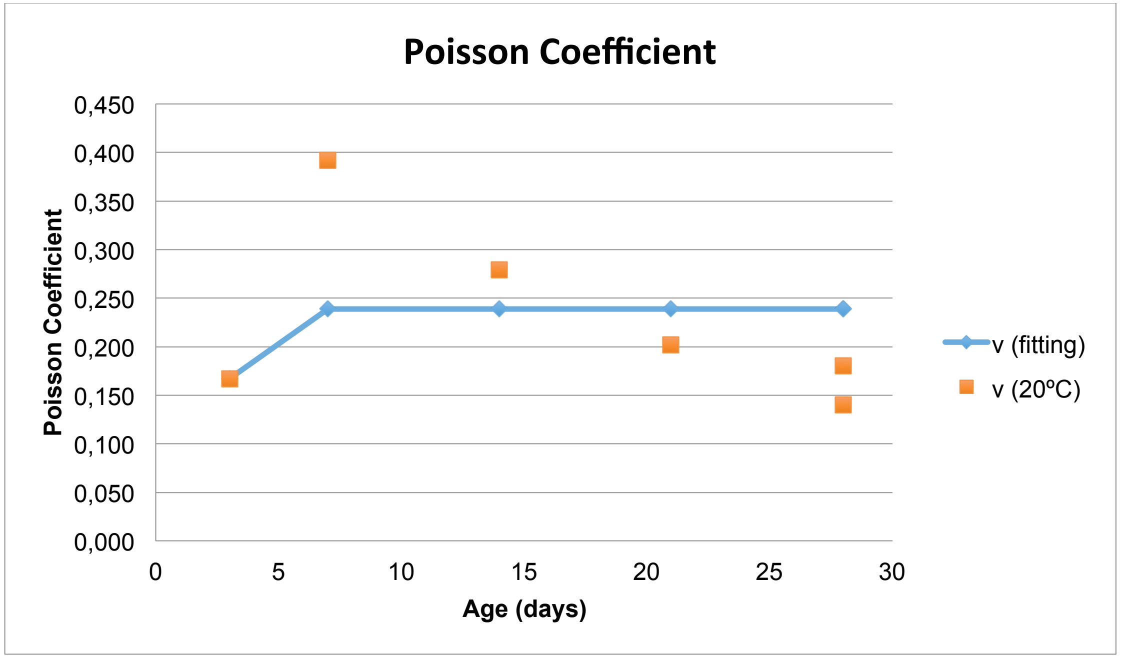
Appendix E.5.6. Poisson Coefficient

Unwashed / 0% FA		f∞	τ	α
Age	**Poisson Coefficient**	**0,173**	**2,747**	**16,492**
Days		**v**	**Δv²**	
3	0,137	0,137	0,000	
7	0,213	0,173	0,002	
14	0,206	0,173	0,001	
21	0,195	0,173	0,000	
21	0,201	0,173	0,001	
28	0,123	0,173	0,003	
28	0,101	0,173	0,005	
		SUM:	**0,012**	



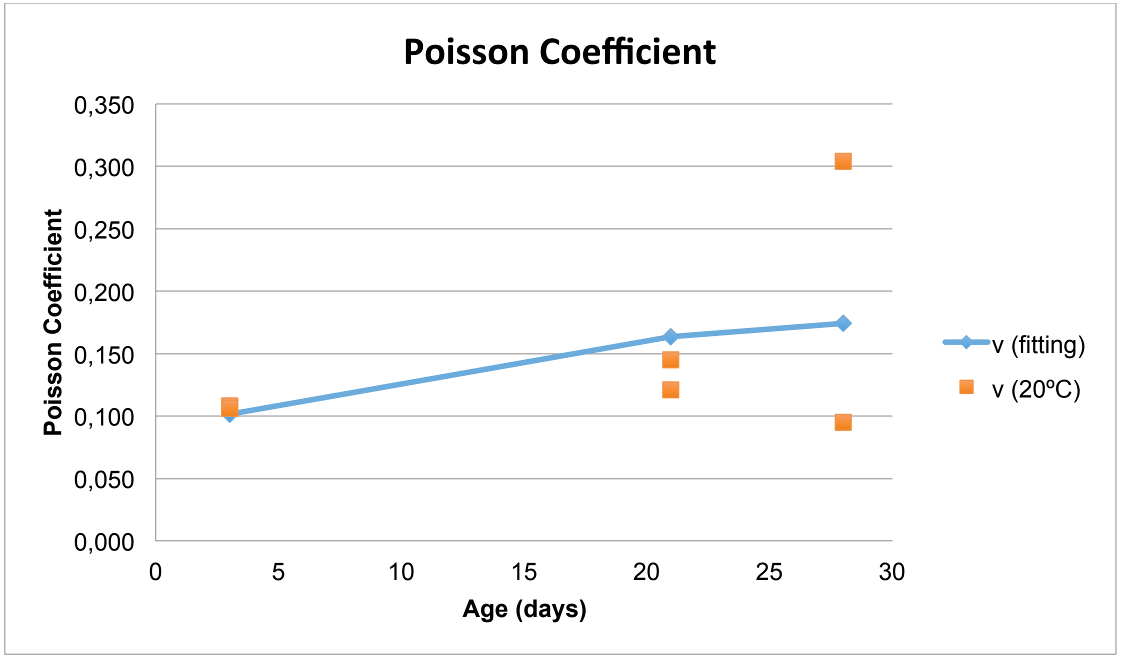
Appendix E.5.6. Poisson Coefficient

Unwashed / 15% FA		f∞	τ	α
Age	Poisson Coefficient	0,239	2,79	14,42
Days		v	Δv^2	
3	0,167	0,167	0,000	
7	0,392	0,239	0,024	
14	0,279	0,239	0,002	
21	0,202	0,239	0,001	
28	0,180	0,239	0,003	
28	0,140	0,239	0,010	
		SUM:	0,040	



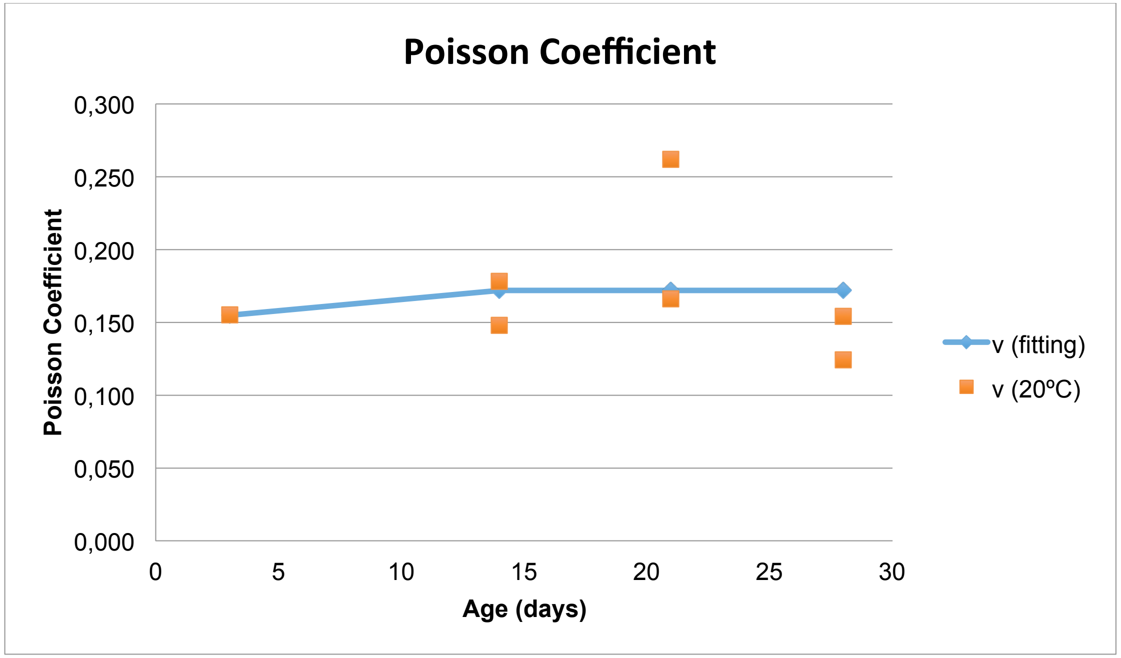
Appendix E.5.6. Poisson Coefficient

Unwashed / 25% FA		f∞	τ	α
Age	Poisson Coefficient	1,375	30003,55	0,10
Days		v	Δv^2	
3	0,108	0,101	0,000	
3	0,106	0,101	0,000	
21	0,121	0,164	0,002	
21	0,145	0,164	0,000	
28	0,304	0,174	0,017	
28	0,095	0,174	0,006	
		SUM:	0,025	



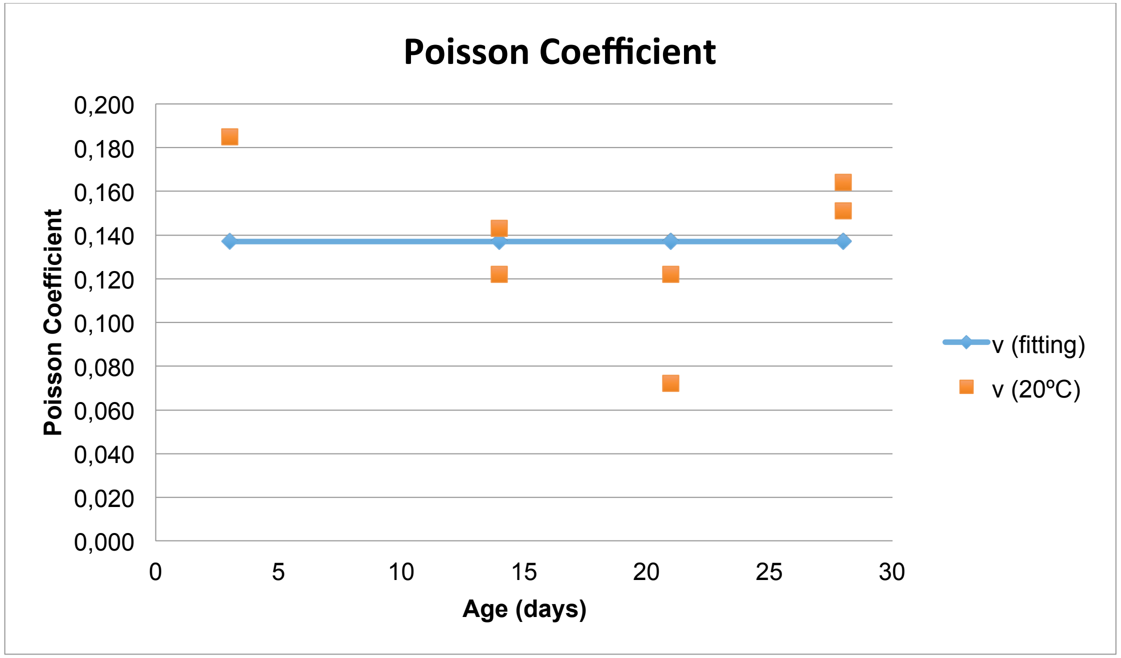
Appendix E.5.6. Poisson Coefficient

Washed / 0% FA		f∞	τ	α
Age	**Poisson Coefficient**	**0,172**	**1,47**	**3,18**
Days		**v**	**Δv^2**	
3	0,155	0,155	0,000	
14	0,148	0,172	0,001	
14	0,178	0,172	0,000	
21	0,262	0,172	0,008	
21	0,166	0,172	0,000	
28	0,154	0,172	0,000	
28	0,124	0,172	0,002	
		SUM:	**0,011**	



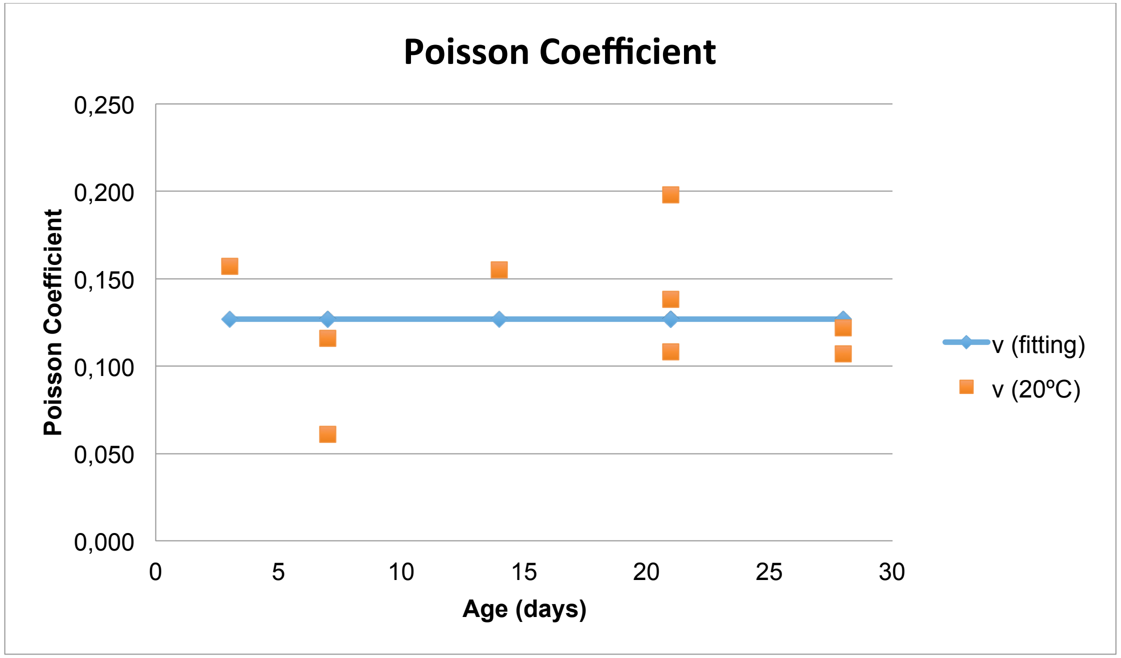
Appendix E.5.6. Poisson Coefficient

Washed / 15% FA		f∞	τ	α
Age	Poisson Coefficient	0,137	0,00	1,77
Days		v	Δv^2	
3	0,185	0,137	0,002	
14	0,122	0,137	0,000	
14	0,143	0,137	0,000	
21	0,122	0,137	0,000	
21	0,072	0,137	0,004	
28	0,164	0,137	0,001	
28	0,151	0,137	0,000	
		SUM:	0,008	



Appendix E.5.6. Poisson Coefficient

Washed / 25 % FA		f∞	τ	α
Age	Poisson Coefficient	0,127	0,00	1,48
Days		v	Δv^2	
3	0,157	0,127	0,001	
7	0,116	0,127	0,000	
7	0,061	0,127	0,004	
14	0,155	0,127	0,001	
21	0,108	0,127	0,000	
21	0,198	0,127	0,005	
21	0,138	0,127	0,000	
28	0,122	0,127	0,000	
28	0,107	0,127	0,000	
		SUM:	0,012	



Appendix E.5.6. Poisson Coefficient