Crushed Fine Aggregate

An age sensitive material.

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Forord

Denne masteren her er utarbeidet ved institutt for ingeniørvitenskap som en del av masterprogrammet for byggdesign ved Universitetet i Agder.

I starten av denne oppgaven var det mye opp og ned turer. Etter et forprosjekt som ga en liten pekepinne på hvor modnings effekten kunne komme fra, ble det satt opp nye eksperimenter som kunne vise mer presist hvor det kunne oppstå, og et nytt eksperiment forløp ble satt opp. Halvveis inn i eksperimentet skjedde det som alle fryktet, pandemien, dette gjorde at oppgaven måtte gå fra å være eksperimental til litterær. Under forprosjektet fant jo jeg ut at det ikke var noe artikler som tok fram modningsfenomenet i tilslag, derfor ble vi enige om å gå rundt temaet for å finne en løsning. Nå var det på tide å få en bedre forståelse på noe jeg ikke kunne: geologi!

For en masterstudent som ikke har hatt mer kjennskap til kjemi enn hvordan man regner ut mol så ble introduksjonen til geologi, spesifikt mineralogi og silikat strukturer et eventyr i seg selv. Med flere nedganger enn man ønsker og et høyere stressnivå en man trodde var mulig, måtte oppgaven bli ferdigstilt på en ny og annerledes måte. Heldigvis, med god støtte fra veiledere fikk dette eventyret en god slutt allikevel. Uten veilederne så ville nok denne oppgaven falt i avgrunnen veldig lett og på grunn av det så måtte jeg mest sannsynlig ha startet på nytt.

Denne oppgaven har gitt meg en mye bedre forståelse på tilslag og hvor viktig mineralogi er for betong industrien. Dette mener jeg fult og holdent er noe betong industrien trenger flere teknologer på, kjennskap til både betong teknologi og geologi. Om det kanskje ikke har stor betydning for trykkfastheten, vil det ha stor betydning på ferskegenskapene. For å tillat meg å ha en så spennende oppgave, vil jeg først og fremst takke mine veiledere:


Rein Terje Thorstensen


Ingrid Lande Larsen


Rolands Cepuritis


Knut O. Kjellsen

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Martin Skjerve Dyvesveen

Summary

Concrete has been the world's building block since 7000 BC. Due to our extensive use of concrete, a problem has arisen in the world, the lack of good quality natural aggregate for concrete production. The lack of sand has caused an extreme world where we have a black market for aggregate, mafias which illegally mine aggregate, and on top of that, people are dying for aggregate. Luckily, Norway, and several other countries, has not gotten there yet. Still, the lack of natural aggregate is starting to become a topic which Norway should address not only for the aforementioned extreme case but also for environmental reasons. The replacement material of natural aggregate is all around us, rocks, more precisely crushed rocks. The technology has slowly been implemented into Norway's concrete industry, but the crushed aggregate geometry and particle size distribution make it unfavorable to use. Therefore, more research needs to be done to completely implement the produced material. In recent years, there has been a rumor about crushed fine aggregate maturing overtime. There has been little to no research on the subject, and based on a small test in a research project called ManSand, there should be a phenomenon that during storage of crushed aggregate improves the slump and slump-flow overtime. Before this master thesis, there has also been a preliminary study, which also suggests that there should be an improvement overtime when the aggregate is stored for six weeks. The goal of this thesis is to further pinpoint the reason why the maturing phenomenon might exist by both experimental work and literature study. The original goal was to answer only by experimental work. Still, due to COVID-19, the thesis needed to do a 180-degree turn to be more literature-based since the experiment could not be continued after four weeks. The result shows that the maturing phenomenon might be caused by chemical weathering of the aggregate, and the weathering rate differs based on mineral composition and particle size distribution, but due to many complications in this thesis, it is highly suggested that this theory should be further researched.

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1. Introduction

In the last years, there has been increased attention on using crushed manufactured aggregate instead of natural aggregate in concrete. The attention originates from the predicted shortage of suitable natural gravel pits and the increased travel distances from the points of use to acquire such. The change from natural- to crushed aggregate has its challenges, mainly the change in workability. In Norway, the building industries want concrete that has high workability. Crushed aggregate might reduce the workability. Although there are manufacturing processes that are being used to change the geometry of the aggregate, there could also be other factors apart from the physical differences between the crushed and natural sands that contribute to the differences in concrete workability

As described in a memo from ManSand 2019, a “rumor” [appendix 1] on how the concretes slump changes due to the age of the crushed aggregate has been circulating in both Norway and Sweden. Due to long-time environmental exposure, some of the particle surface properties can get altered, thus improving the workability of the fresh concrete. There has been relatively little research on the subject of “maturing crushed aggregate,” and if this hypothesis is right, the research can be used to enhance the workability of fresh concrete with crushed aggregate.

A preliminary project was conducted at the University of Agder, autumn 2019. The project showed that the aging phenomenon is related to the storage method of the aggregate, and the effect of the storage method was amplified by the addition of chemical admixtures. The preliminary conclusion stated that the cause might come from a decreased content of fines over the storage period or due to electrostatic forces.

This thesis builds on the finding from the preliminary work and aims to further pinpoint where the possible maturing phenomenon comes from. Due to COVID-19, the experiments in this thesis were canceled halfway into the project, and the thesis needed to take another direction to be more theoretical. To fill the “gap” due to the pandemic, a literature study to find a cause by aggregate production or mineralogy.

The thesis is in cooperation with NTNU, Norcem, Norstone, Norsk Stein, Norbetong, Skanska Norge, and Feiring Bruk who all form academic and industrial partners in the MiKS project – Mikroproporsjonering med Knust Sand (Norwegian for Micro-proportioning with Crushed Sand), which is a KPN (Competence Project for the Industry) funded by the Research Council of Norway (RCN) contract No. 247619. The initial idea for the need for this research work has been proposed by the MiKS project participants.

2. Social perspective

The social perspective chapter will talk little about concrete history, a world orientation of aggregate usage and production, and how it is seen in Norway.

In our world, concrete is the backbone of our society. It was used as early as in 7000 BC at Yiftah'el in Galilee [1, 2], and even the Egyptians used it in 1950 BC [2]. In the golden age of Greece, 500 BC, they started to mix the world first pozzolan into concrete, volcanic tuff, making a huge leap in concrete technology. That technology was heavily "borrowed" by the Romans, making concrete the very building block for the mighty Roman empire. Even the word we use today for materials with a known effect on concrete, pozzolana, is derived from a Roman place called Pozzuoli [2]. Roman concrete structures can still be seen today, such as Pantheon (128 BC), which is still the world's largest unreinforced dome made of concrete [3], and the Basilica of Maxentius (312 BC) [4].

Concrete is made primarily of aggregate, cement, and water, but also other constituents such as pozzolanic materials and chemical admixtures to alter the concretes properties as well as reducing its environmental impact. Aggregate takes up to circa 70% of the concretes volume [5-7]. Therefore, the type of aggregate used will greatly change the properties of the concrete. Aggregate mining is also one of the most valuable parts of the mining industry [8]. The commonly used fine aggregate type for concrete production is natural sand, and it might seem like there is an unlimited supply of this finite resource. The demand for natural aggregate for concrete production has shown an increasing problem [5, 9]. 80% of all sand and gravel that have been excavated in Norway have happened in our generation [5]. The excavation of natural sand was taken for granted for too long and has caused a huge problem where the natural sand and gravel pits around populated areas have been depleted. The problem does not only apply for Norway but for the whole world as well [5, 7].
The depletion of natural aggregate resources is not only due to the excessive quarrying but is also caused by other area needs, local/national regulations, low sustainability due to geological or technical reasons, unsuitable location for the market, protection of groundwater, or low profitability. [10] It is estimated that Norway has circa 12 000 million cubic meters (m^3) of suitable natural aggregate for concrete production and with the today's rate of exploitation it should last for circa 450 years, but due to the aforementioned reasons, the volume available is significantly lower than estimated [5, 10, 11]. Therefore, the essential resource for concrete production might be depleted within 10 to 30 years [5, 9, 11].

In 1984, all aggregate in Hong Kong was produced locally from granite quarries and other rock processing sites, but a rapidly growing population and economy gave an intensive construction activity in the following years, making Hong Kong dependent on the processed stone from Chinese sources. In 1991, 46% of the total aggregate used in Hong Kong came from the Shenzhen region [12].

In Dubai, the United Arab Emirates, the land reclamation project where they make huge artificial archipelagos has exhausted all the marine sand resources in Dubai [5, 13]. As seen in figure 1, the land reclamation project has had a huge impact on the coastline of Dubai. The palm Jumeirah required 186,5 million cubic meters of sand to build, which also has been followed by a second palm project, The Palm Jebel Ali. And then, by the World Islands project, representing the map of the world with 300 artificial islands, requiring 450 million tons of sand [5], together, it required more than 750 million tons of sand to build [14]. Since the marine sand resources are exhausted, Dubai is importing sand from Australia [13]. Burj Khalifa, the highest building in the world at 828 meters, is an example of the importation of sand from Australia [5].

Figure 1: Left: Dubai February 2002 ASTER Image. Right: July 2012 ASTER image. [14]

Unknown to the public, illegal mining operations and criminal activity is the result of the lack of natural aggregate. In several countries, there are criminal gangs that are quarrying up a large amount of natural aggregate to sell it on the black market. Half of the aggregate used in Morocco comes from illegal coastal quarrying operations, which is their natural tourist attractions, to build hotels, roads, and other tourism-related infrastructure. In India, there has been an ongoing battle against the "sand mafia," killing hundreds of people, including police officers, government officials, and even regular people [15].

Due to the laws and regulations in Norway, the aggregate mining industries are moving away from the local areas, increasing the travel distance and directly increases the environmental impact. In 2012 the total transportation of aggregate by truck reached 879 million ton-kilometers and was responsible for over 100 000 tons CO_2-equivalent (CO_2-eqv) as well as 30 000 tons from marine transportation. If travel distance increases with three kilometers, the CO_2-eqv emissions will increase by 10% [5, 16]. The distance traveled will also increase the cost, and if the aggregate is transported more the 40-50 kilometers, the transport cost will be comparable to the aggregate cost itself [6].

The tendency when finding more natural aggregate is delocalization; there are aggregate businesses that produce concrete aggregate based on crushed hard rock. The process is usually based on crushing boulders with a diameter of 200 to 300 mm to crushed coarse aggregate, not fine aggregate. Although one cannot avoid producing fine fractions from the crushing process, and the produced bi-product can be as much as 30% of the original production [5, 7, 17]. The bi-product has the same particle size as natural aggregate, but the shape and size distribution differ, which affects the concretes properties. Therefore, it is disadvantageous to use in concrete production where the mix design is optimized based on the natural aggregates aptitudes, which renders the bi-product to a waste product [5] —seen in figure 2, the unusable crushed aggregate piles up to mountains of waste.

Figure 2: Piles and piles of the waste product from coarse crushed aggregate, crushed fine aggregate. Picture taken in Skien. [own]

Since the volumes of suitable natural aggregate for concrete is starting to decrease rapidly, it is crucial to find a reasonable solution to reduce the consumption as much as possible, and clearly, the waste product from the coarse crushed aggregate production can be a viable solution if the properties of the aggregate are improved due to extra, or different crushing steps, which will help the aggregate industry to produce their products at a reasonable distance from local concrete producers, which reduce both the cost and the emissions. However, current research and development of utilizing fine crushed aggregate in concrete lack throughout Europe [5, 7].

3. Theory

This chapter contains the previous knowledge about aggregate, mineralogy, and concrete rheology, which revolves around the subject of aggregate maturing.

3.1 Crushed Aggregate

Crushed aggregate compared to natural aggregate is quite different. Not only is it different in shape and particle size distribution, but also in the processing method. In Norway, Natural aggregate is quarried from gravel pits. The aggregate is deposited by glacial rivers during the smelting of the ice cap approximately 10 000 years ago and contains materials from the bedrock the glacial “slid over” [6]. Since the deposit’s location is governed by the glacial river, and the bedrocks minerals, the location of natural quarrying aggregate is heavily restricted. However, the location of the crushed aggregate can be hand-picked based on the bedrocks mineral composition and location since the fundamental criteria are that there are rocks there [6, 18].

There are three main factors influencing the aggregate “final quality” [6]:

- Geological origin
- Production and processing
- Handling and storage

3.1.1 Geological origin

The geological origin governs properties such as strength, stiffness, and durability (alkali-reactivity, frost resistance, and pyrite) of the aggregate. It will also govern how the fine filler material will behave in fresh concrete, especially due to interactions with chemical admixtures. The aggregate may also have been influenced by metamorphic processes [6].

3.1.2 production and processing

Production and processing are done in two different ways to produce aggregate for concrete. Developing a pit for naturals and gravel deposit or producing crushed sand in a hard rock quarry.
The production process for high quality crushed aggregate involves several steps, including crushing, transportation (mainly conveyor belts), size control, and classification equipment. A typical layout can be seen in figure 3. And Tabell 1 explains the different stages in figure 3.

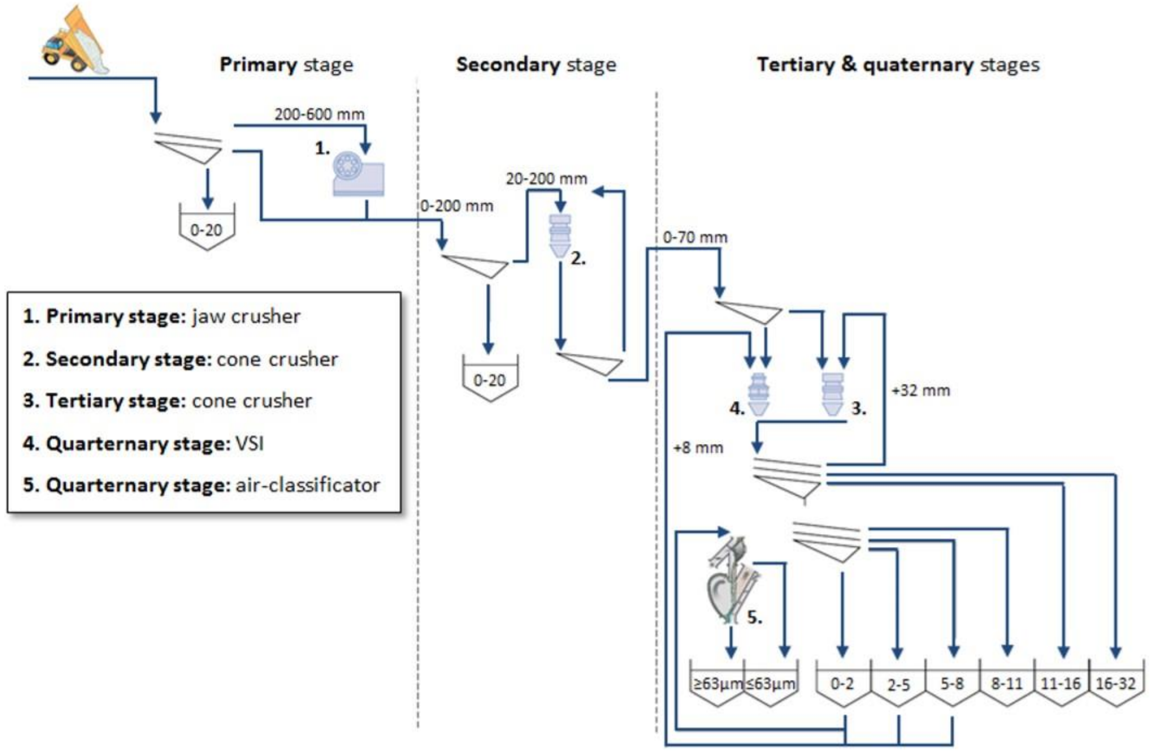

Figure 3: Typical layout for producing a higher quality crushed aggregate. [5]

Table 1: Description of the different stages from figure 4. [own]

Stage	*Description*
Primary Stage: Jaw crusher	The primary stage aims to reduce the blasted or excavated rocks into particles smaller than 200 mm. The process is done by first separating the particles, which is less than 20 mm in size, for the rest then to be crushed in a jaw crusher.
Secondary Stage: Cone crusher	The secondary stage is to further crush the particles from the primary stage to a particle size under 70 mm. The process is very similar to the primary stage, but after sieving out everything under 20 mm the rocks go to a cone crushed set to crust the rocks between 20-200 mm to 0-70 mm. after the cone-crusher, the aggregate is sieved, and the material which is larger than 70 mm is sent back into the cone-crusher.
Tertiary Stage: Cone crusher	The tertiary stage is another cone crusher, but it is set to crush the aggregate down to 0-32 mm. First, the aggregate is sieved to divide particles less than 8 mm from the mass, and then it goes through a cone crusher for then to be further separated by several sieves to divide the aggregate in different fractions used in concrete production. As in the secondary stage, everything over 32 mm will be sent back into the cone-crusher.

Quaternary Stage: VSI	The quaternary stage is split up into two different stages. The first stage with Vertical Shaft Impact (VSI) is to further process the fines aggregate between 0-8 mm to yield a better shape characteristic (flakiness).
Quaternary Stage: Air-classification	The second quaternary stage is to separate the finest particles from the 0-2 fraction. This is done by sending the fine aggregate through an air-classifier. The air-classifier removes particles smaller than 63 micrometers (µm) from the aggregate.

Vertical shaft impact (VSI)

VSI is a rock-on-rock crusher. It works by spinning at high speed and "throwing" rocks from the center of the machine at high speed against other rocks at the edge of the machine. The impact will break the rocks at the weakest spot, and it will also give the rocks a more equidimensional shape [19]. It is common to use the VSI as one of the last stages in crushing for the production of high-quality aggregate [19-21]. There are several variables in the VSI crushing process: tip speed, cascade flow, influence of a closed circuit, and feed rock size and characteristics [18].

Air Classifier

Air classification uses air to classify a product by size and shape. By accelerating the air inside a chamber, gravitational- and/or a centrifugal force acts against the airs drag force to create a "sieve," allowing only particles with a certain shape, weight, and density to pass the "sieve" while the coarser particles will fall down [18, 22]. Air classifiers are very suitable for crushed aggregate production since it has no moving parts as well as a ceramic layer lined inside its chambers which reduce wear costs [22]. There are several types of static air classifiers, Gravitational, Gravitational-Inertial, and Centrifugal, and the type used will influence the cut-size [22]. Figure 4 shows how the gravitational air classifier works. Cepuritis et al. [18] explain that the feed material is dropped continuously from the top (1). Low velocity of air enters at the inlet (2) and is forced through the stream of material (3), through the outlet dragging with smaller particles from the material stream (4). The larger particles will bounce off the vanes of the outlet and fall down (5) [18]. The other static air classifiers also operate in a similar way, as seen in figure 4, but the chamber and air stream are configured to allow finer cut-size [18, 22].

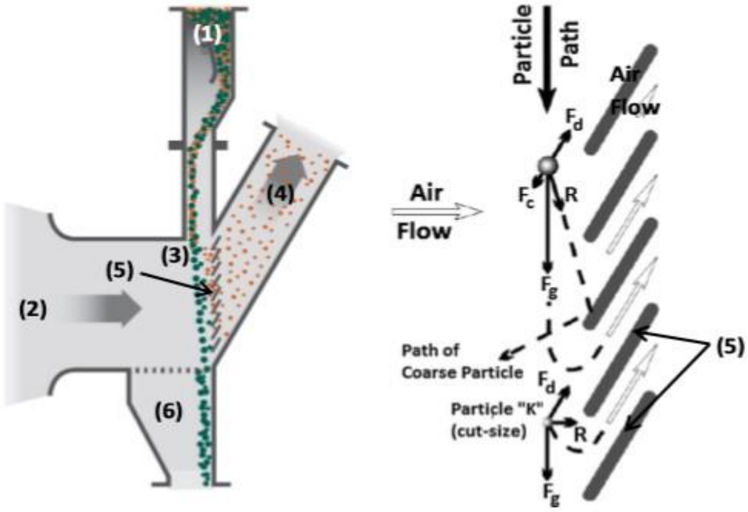

Figure 4: Operational principle of static gravitational air classifier [18].

3.1.3 Handling and storage

Both transportation and storage can affect the aggregate. Under transportation, especially for fine aggregate, there is a risk of separation. The separation can cause grading variations within the pile. It is also a risk of chloride contamination during transportation both in the winter on the road and while shipped by boat [6].

Storage at both the manufacturer and client is also vital for the result. To prevent segregation, one must not store sand fractions in large piles. The sand fraction should be distributed into layers [6]. If stored outside, it would also be a problem if the aggregate is containing ice, snow, or a high amount of water since it will directly influence the water content of the concrete if not compensated for [6].

In Norwegian concrete production, it is common that the aggregate is delivered either by truck (ca. 24 tons) or boat (ca. 5000-10000 tons) depending on location, logistics, and economy. To store the aggregate, it is used either a silo, which can store up to 40 tons, or dedicated outside storage where they can place a tent over if the aggregate is frequently exposed to snow or ice [23-27].

3.1.4 The aggregates effect on fresh concrete

Material grading, or Particle Size Distribution (PSD), influences the fresh concretes workability, water demand, and stability. It is determined by dry screening through different size meshes layered on top of each other. It is then plotted into a cumulative graph by mass % passing or retained on a particular sieve [6]. Natural sand deposits in Norway usually have an S-shaped cumulative curve due to an increased percentage of particles between 250 µm to 1000 µm. The crushed fine aggregate usually has a Fuller-type curve, which has fewer particles around 250 µm to 1000 µm. This is caused by the crushing processes making a more uniform material grading [6]. The particle size distribution of crushed aggregate also gives a more densely packed material, which can lead to less water demand if the PSD has a low percentage of fines. If the product is flaky (not equidimensional), the dense PSD will result in an increased water demand, therefore, requiring more cement to uphold the water-cement ratio [6, 9].

Particle shape/roundness influences workability and water demand in concrete. It affects the plastic viscosity of the concrete, the rougher and elongated it is, the plastic viscosity will increase compared to aggregate with rounder and smoother surfaces [28-30]. According to NS-EN 12620, "Aggregates for concrete" [31], aggregate size from 4 mm and above are regularly tested. While the sizes under 4 mm must be tested every 3rd year [6]. For crushed aggregate, the particles under 4 mm are essential due to the impact of concretes workability. To test the flakiness index, the aggregate is sieved through elongated screens, and the calculation described in NS-EN 933-3 "Tests for geometrical properties of aggregates – Part 3: Determination of particle shape – Flakiness index" gives a percentage of elongated particles which is in each particle size by mass [6, 32].

Fines in the aggregate are usually defined as material less than 125 µm in Norway when aggregate is considered for use in concrete, but EN 12620 defines fines as less than 63 µm [9, 31]. The more fines the aggregate has, the lower the void content is, and therefore less space the cement paste must fill. But the workability of the fresh concrete will decrease due to an increase in the percentage of fines in the aggregate due to increased specific surface of the aggregate, which will dominate over the decreased voids effect [5, 6].

Free mica in the finer fractions of the aggregate causes an increased water demand. It is determined by particle counting applying a stereo-microscope, and the content is given as % of the number of particles counted in the fraction 125 – 250 µm [6]. 10-15% is regarded as relatively high [6].

Water absorption in aggregate mainly influences the water demand in concrete, especially if the dry aggregate is used [6]. Water absorption must be considered when calculating the water-binder ratio of the mix design. It should also be stated that water in aggregates with high water absorption may later be used to further hydrate the concrete, resulting in a self-desiccation and autogenous shrinkage also called "internal curing" [6].

3.1.5 Rheology in mortars

Rheology is the study of flowability in the liquid state of different materials. In the case of concrete, the rheology expresses its ability to retain its shape under low pressure, yield stress, and its elasticity, plastic viscosity. Materials that have these characteristics are often called "soft solid." Simplified, soft solids are made of a network of linked chains that acts more like a rubber string with a given stiffness proportional to the molecule length and temperature. Therefore, the elastic modulus can be described as a function of the chain's characteristics. Under external forces, the load is distributed over the whole chain network instead of the area of the force [6, 33].

As mentioned, concrete is a soft solid and shows a two-fold characteristic, yield stress (τ_0 = Pa), and plastic viscosity (μ = Pa*s), meaning it can behave as a solid as well as a liquid based on the magnitude of the applied force. The force needed to transition the material from a solid state to a liquid is called yield stress, but concrete also has the ability to be deformed without remembering its stress history, called plastic viscosity, giving the liquid state a thixotropic ability [6, 33].

To test the rheological properties of concrete, “Two-point workability test” is used to determine the concrete’s yield stress and plastic viscosity. As seen in figure 5, a Bingham fluid, as concrete is, has a linear relation between forces needed to move the fluid and the flow of the fluid [6, 33, 34]. Therefore, the relation can be described as a linear function seen in equation 1:

$$\tau = \tau_0 + \mu\dot{\gamma} \tag{1}$$

τ	- Shear stress (Pa)
τ_0	-Yield stress (Pa)
μ	-Plastic viscosity (Pa*s)
$\dot{\gamma}$	-Rate of shear (1/s)

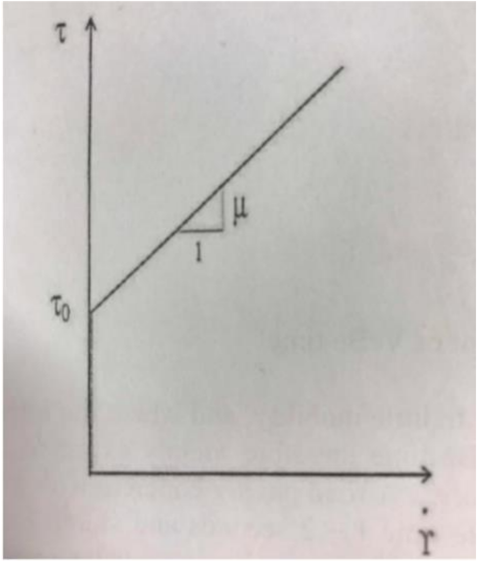

Figure 5: Bingham graph [6].

To measure the two-fold workability, it is normal to measure it indirectly with torque (T) and applied speed of rotation (N). As can be seen in figure 6, the rotor in which the torque is applied is placed in a cylindrical container filled with concrete. The two-point workability test gives the same graph as he Bingham model in figure 6 but altered for torque and rotor speed [6, 33]. The formula is therefore adjusted as follows:

$$T = g + hN \tag{2}$$

T	-Torque (Nm)
G	-Moment at an initial yield of fresh concrete (Nm)
H	-Proportionality of rate of change (Nms)
N	-Speed of rotation (1/s)

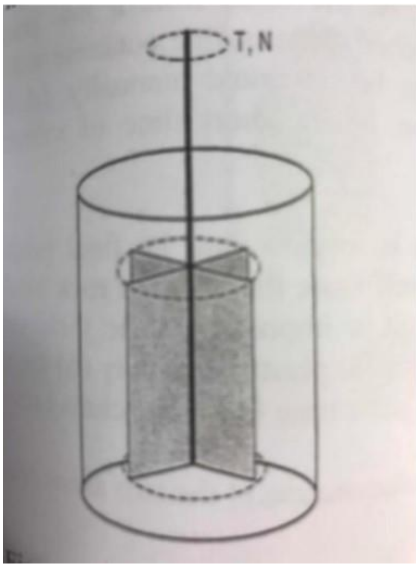

Figure 6: Basic principal on how a viscometer works [6].

3.2 Mineralogy

When talking about aggregate in general, one cannot get away from the fact that every aggregate has specific mineralogy. This mineralogy governs the aggregate specific density. The minerals were formed several hundreds of million years ago from magma. Either solidified on the surface, called extrusive rocks, or inside earth crust, intrusive rocks. Rocks go through three stages overtime. First, its igneous stage, where the magma hardens into rock, overtime the rock will slowly be weathered and become sedimentary rock, and then when the sedimentary rock layer gets high enough [appendix 3]. The bottom layer will be compressed with extreme forces to a morphic rock. The composition of the magma defines which minerals will be created under solidification, and under solidification, it can separate into different mineral layers due to different hardening temperature [35].

The most common elements in the earth's crust and mantle are silicon and oxygen [36]. In silicate minerals, these two elements are bound together in a specific way where the silicate element is bound to four oxygen, making a tetrahydric configuration named SiO_4-tetrahedron [36]. The SiO_4-tetrahedron can have several configurations between one another, which makes up all silicate minerals. Seen in figure 7, there are six different molecular structures the SiO_4-tetrahedron can make; these structures allow the silicate minerals to contain different types of trace elements [36].

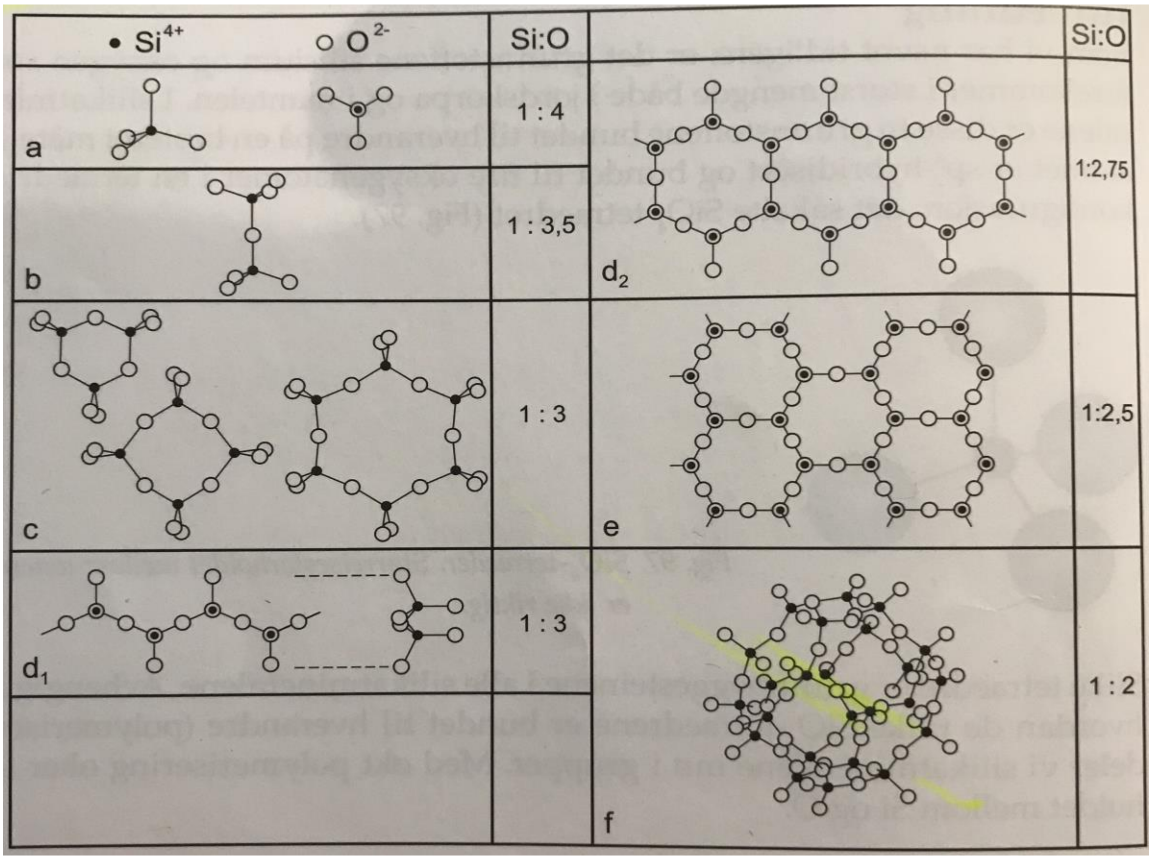

Figure 7: The different molecular structures SiO_4 can make. a) Nesosilicate, b) Sorosilicate, c) Cyclosilicate, d_1) single row inosilicate, d_2) double row inosilicate, e) Phyllosilicate, and f) tectosilicate [35].

Nesosilicate	The silicate minerals act separately and are bound to positive cations due to their four negative charges in the tetrahedron [36]. A typical mineral which is a nesosilicate is olivine.
Sorosilicate	When two SiO_4-tetrahedrons are bound together such that they share one oxygen, forming $(Si_2O_7)^{6-}$, is called a double tetrahedron. There are few minerals that belong to the sorosilicate group; one of them is epidote [36].
Cyclosilicate	Cyclosilicate is a group where SiO_4-tetrahedrons shares two oxygen atoms with each other, and the polymerization forms a circle of SiO_4-tetrahedrons. It is common that the polymer structure is formed by three to six SiO_4-tetrahedrons [36].
Inosilicate	Inosilicate can be divided into two different silicate polymers. The first one is a single-row of SiO_4-tetrahedrons that shares two oxygen atom to their neighbors, and the second one is a double-row SiO_4-tetrahedrons polymer where three oxygens are shared with their neighbors [36].

Phyllosilicate — Phyllosilicate's SiO_4-tetrahedrons shares three oxygen atoms with their neighbors as double-row Inosilicates does, but the polymer is making an "infinite" continues layer of SiO_4-tetrahedrons [36]. Mica is a common mineral with a phyllosilicate structure.

Tectosilicate — Tectosilicate shares all their oxygen atoms with their neighbors. This kind of structure is found in quartz and feldspar [36].

Two terms usually used with igneous rocks are felsic and mafic. These are used to describe the chemical composition of the silicate minerals that comprise them, and the magmas they originated from [37]. Felsic describes rocks that have a silicate content of higher than 66 % in weight and is usually enriched in sodium and potassium while being depleted in iron, magnesium, and calcium in comparison to mafic, which has a silicate content of 45-52% in weight [37]. Between 53%-65%, the minerals are described as intermediate, and less than 45% are called ultramafic minerals. A felsic mineral is also more acidic and has a lower crystallization temperature than mafic minerals and has a lower density [37]. Visually, mafic minerals also tend to be darker in color, as seen in figure 8.

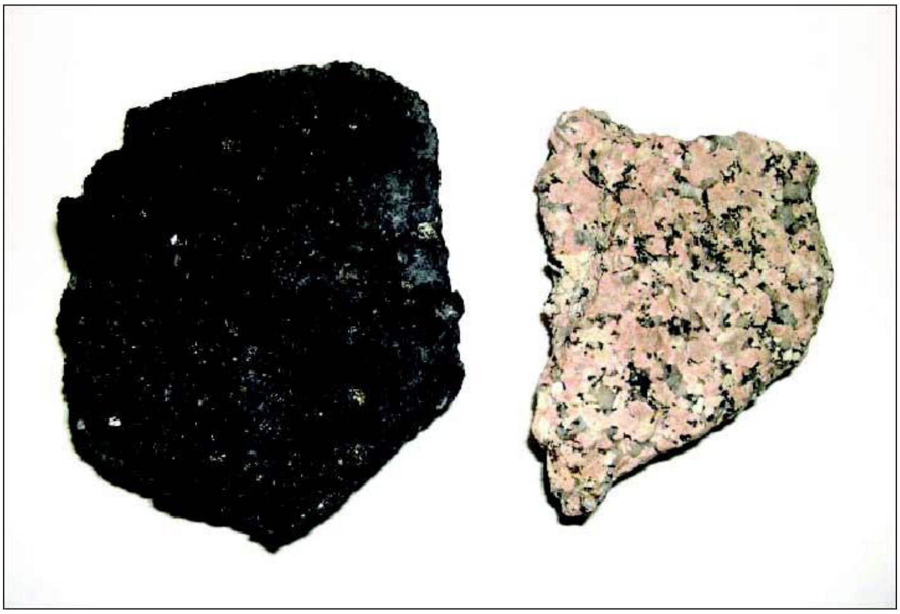

Figure 8: Example of felsic and mafic igneous rocks. Left: Basalt; right: granite [32].

As seen in figure 9 [38], tectosilicates, quartz, have a higher silicate content than nesosilicate, olivine. Feldspar, which is a tectosilicate [36], can vary significantly in silicate content as well as trace elements. The reason why the silicate content varies is due to the replacement of silica in the tetrahedron with aluminum (Al). In feldspar, aluminum can replace up to 25-50% of the silicate content, and since aluminum does prefer certain structures that give a less ordered structure from "low-temperature modification" [36].

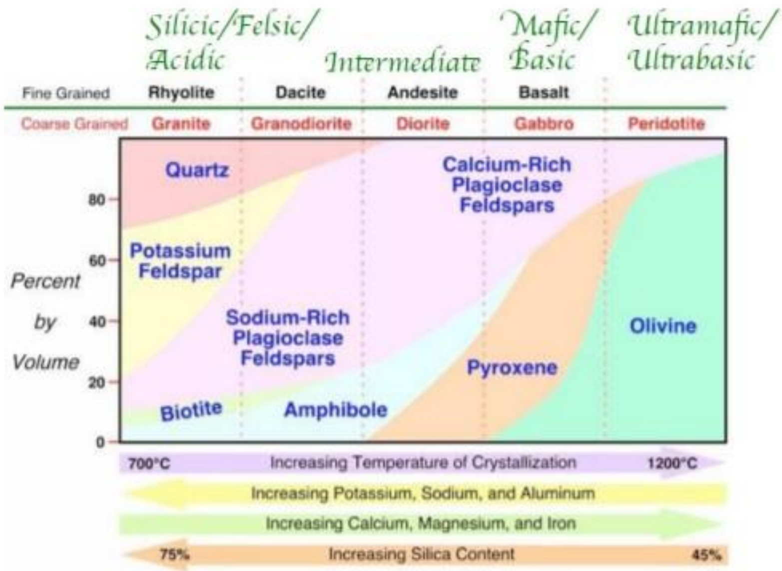

Figure 9: Igneous rock chart based on temperature of crystallization, trace element content, and silica content [37].

The less ordered structure makes it possible for the feldspar to contain potassium, sodium, and calcium. Based on these minerals, feldspar is split into two different main categories, alkali feldspar, and plagioclase. Seen in figure 10, alkali feldspar contains potassium and sodium, and plagioclase feldspar contains sodium and calcium. Both types of feldspar contain sodium, and with a high amount of sodium feldspar, it is common to find traces of both calcium and potassium [36].

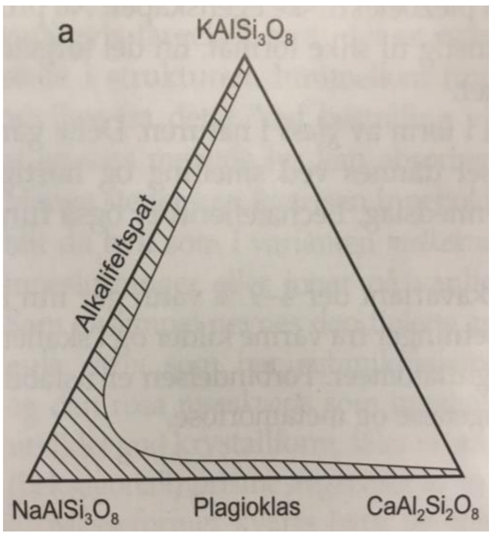

Figure 10: Highlighted area represent the feldspar compositions of potassium, sodium, and calcium in high teperatures (>700 degrees celcius) [35].

3.3 Potential causes for the maturing phenomenon

3.3.1 Technological reasons

The technological reasons for the maturing phenomenon can be closely related to the machines used to produce the crushed aggregate. A crusher plant with a VSI will, due to the method VSI works, make more fines than a production plant without. Depending on the rock type being crushed, VSI machines can give an extensive % volume of fines in the PSD, making a stiffer fresh concrete. The size of these fines is under 125 µm and can be suspended in water [9, 18]. Therefore, under storage, the fines can be seeped out of the aggregate if the pile is oversaturated, reducing % volume fines in the overall PSD. It is also believable that the VSI crushing can induce more friction between aggregate particles than other common crushing methods due to the impact method.

3.3.2 Mineralogical reasons

The maturing phenomenon may also happen due to mineralogical reasons, such as weathering making rounder particles or reducing its electrostatic charge.

Minerals can weather in two different ways, chemically, corrosion, and physically, erosion.
Chemical weathering happens due to spontaneous chemical reactions. Erosion is the physical weathering of minerals when material from the earth's surface degrades, and the loose material moves away due to running water, wind, or glacial. Fundamentally, chemically corrosion and physically erosion is the process that cycles elements globally.
It is estimated that the weathering processes combined (chemically + physically) are responsible for a denudation rate of 252 tons km^{-1} $year^{-1}$ on the continents, while chemically corrosion alone accounts for only 20% of that value [39]. Physical weathering can enhance the chemical weathering by exposing fresh mineral surfaces to be attacked by water, and chemical weathering also enhances the physical weathering by reducing bedrock coherence [39]. If chemical weathering is the cause, the rate of weathering will differ between rock types due to the mineral composition, silicate structure, and trace elements, the main difference will be the lack of increased volume of fines which physical weathering would make.

4. Research question

This master thesis continues the work from the preliminary project [appendix 20]. The thesis will be aimed at trying to quantify the phenomenon in an even more refined way as before, including as a function of rock type, i.e., acidic, intermediate, alkaline, and a rock type including a relatively high content of free mica. This thesis will also try to explore possibilities to accelerate the phenomenon. There will also be a structural literature study to find causes on either side of crushed aggregate production and mineralogy.

As such, the research question will be:

How will the ambient environment effect on aggregate maturing influence the rheology of fresh concrete?

The research question will be answered by the following sub-questions:

1. What influences the maturing phenomenon in crushed fine aggregate?

2. How does the water content in the sand effect the maturing process?

3. What is the repeatability in experimental based assumption on the influence of superplasticizer on aggregate maturing?

4. What is known about the maturing phenomenon from a mineralogical perspective?

5. Materials

This chapter revolves around the materials that were used in the experimental phase of this thesis.

The aggregates selected are based on their mineralogical composition based on figure 9. It is important to base the experiment on a variety from Granite to Gabbro. The four aggregates range from felsic to mafic. Årdal and Ledinge are granite, Tau is intermediate, and Ledinge is gabbro, as seen in figure 11.

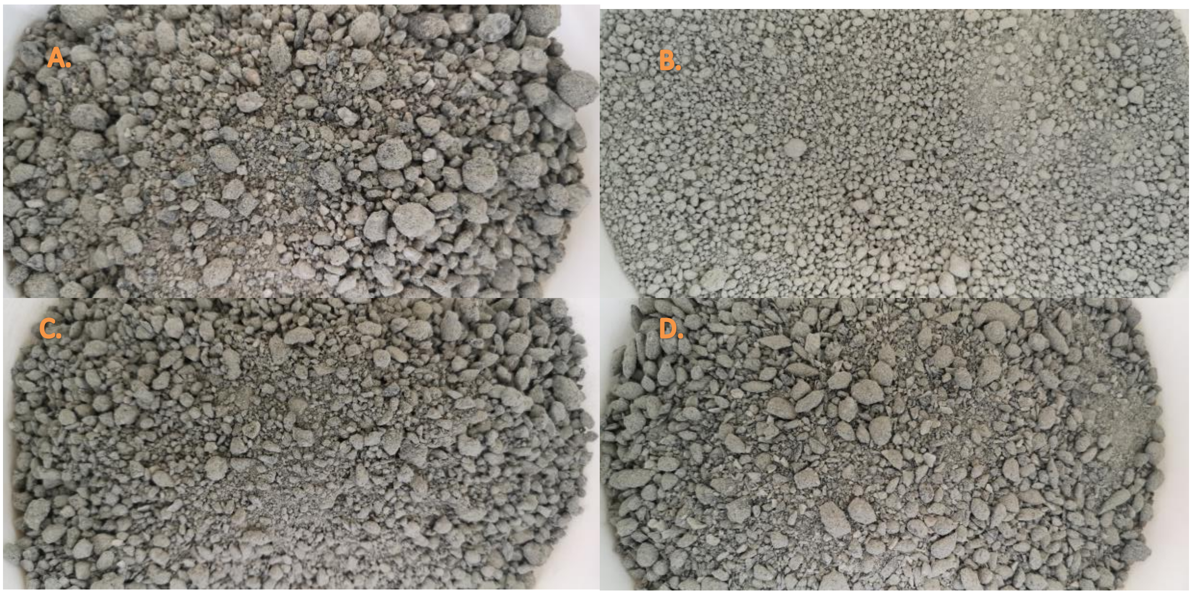

Figure 11: Picture of the four aggregates used in this thesis. A. Årdal, B. Tau, C. Ledinge, and D. Svingen [own].

The material grading also varies due to production, and all except Årdal are made commercially. Årdal has a material grading between 0 to 8 mm, Svingen and Ledinge have a material grading of 0 to 4 mm, and Tau has a material grading between 0 to 2 mm.

Table 2: The crushing processes of the different aggregate used in this thesis [own].

Aggregate	*Crushing stages*
Årdal (Granite) Unwashed	1. Jaw crushing 0/95 mm 2. Cone crushing 0/8 mm 3. VSI crushing
Tau (Granodiorite) Unwashed	Was not given
Svingen (Granite) Unwashed	1. Jaw crusher 2. and 3. Cone crushing 4. VSI
Ledinge (Gabbro) Unwashed	1. Jaw crusher mm 2.Spindle crusher 3. and 4. Cone crusher

The cement used where standard FA (STD FA) from Norcem, which is from one single batch of production. And the chemical admixture used is from Mapei and was Dynamon SX-23 and Mapetard R.

6. Method

This chapter goes through the methods used in this thesis; it contains a structured literature search and method of testing for the experimental phase.

In the experimental phase, to figure out what causes the maturing phenomenon, the base of the different ideas from the preliminary study was organized into a flow chart, with potential causes and how we should see the difference—seen in figure 16, to figure out any of the causes, there are two experiments that need to be carried out. Testing with and without SP, in the preliminary study, it was found that testing with SP while storing the fine aggregate outside gives a positive “yield” in slump and slump-flow overtime, but not while being stored inside [appendix 20]. Therefore, the experiment will show repeatability from the preliminary study, but to show if any fine particles are leached out from the aggregate under the period of the experiment, one must store, and sieve batches of the aggregate taken from different dates. If there are no changes in % fines over time, but a change in slump and slump-flow occur, that would give a strong indication for hypothesis one is true. If there is a decrease in % fines, and a change, that gives a strong indication for hypothesis two is true. The second test will be to see if water has an impact on the aggregate while being stored inside, sealed. The stored aggregates also have a different amount of water in them, one fully dry, one around 2%, and one around 4%. If the materials show a uniform change in slump or slump-flow, but not while stored fully dry, it might be that the water changes something in the aggregate. If the aggregates show different changes in slump and slump-flow, i.e., have different trends, it strongly suggests that the aggregate has been chemically corroded, and therefore, the aggregates mineralogy might cause the maturing phenomenon. It should also be stored and sieved on different dates to see if there has been any physical weathering, which in a sealed container would increase the fine content of the aggregate.

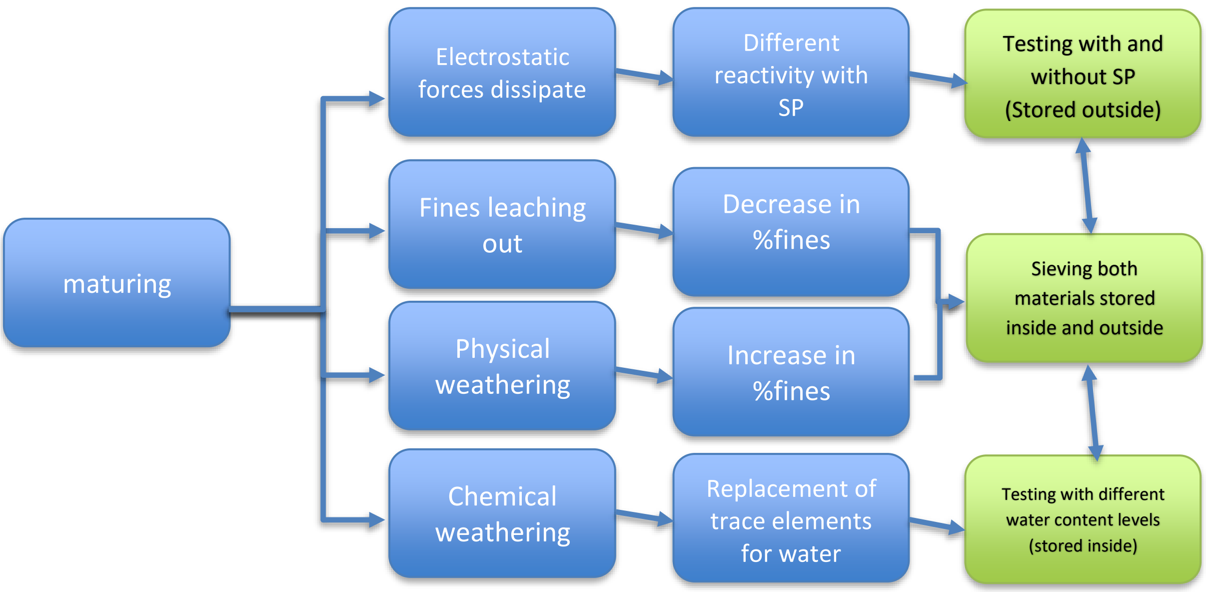

Figure 12: Flow chart over the possible causes and method of proving them [own].

6.1 Literature search

For this thesis, it is essential to have a structured literature search over two different but closely related disciplines, crushed aggregate production, and mineralogy, to ensure good enough theoretical background to answer the thesis research question. It is also used to find out if anything is known about the maturing phenomenon outside the aggregate production industry. The search is organized with all the search terms and their respected synonyms to establish a good ground point. As seen in Table 2, there were established "OR" words and "AND" words to represent the type of discipline and a specific field for the discipline, respectively.

Table 3: Example of an established table for literature study. [own]

Search word (OR words) [n.0]	*Additional words (AND words) [n.m]*
1. Crushed aggregate *Synonyms:* *Manufactured crushed sand* …	1.1 Water content Synonyms: Moisture content …
2. Mineralogy *Synonyms:* *Petrology* …	2.1 Igneous rocks Synonyms: Magmatic rocks …

The search is to gather scientific articles to help explain why a maturing phenomenon occurs when storing crushed aggregate; it was also to gather basic knowledge for the different disciplines. Some books were also considered, but mainly "*concrete technology*" from NTNU and "*Mineralogy – An introduction to crystallography and mineralogy*" from Tore Prestvik was used [6, 36].

The search is going through several search engines, Google Scholar, Science Direct, and Oria. When searching, each combination of search "And" words and "OR" words, as well as the result of each search engine, are recorded. Only the first 200 articles from the search should be considered due to time restrictions.
The method throughout the search can be described as follows:

1. Record both the search terms and results, as seen in table 3.
2. Read through the first 200 articles and select those who contain the search word and does not talk about another discipline.
3. Record the result after sifting through the first 200 articles from each search engine.
4. Download the articles with their respective name into one singular folder.
    4.1 If an article is already downloaded, but it appears yet again in a different search, the article should not be accounted for when recording the number of valid articles.
5. After the initial search, the articles which are left in the folder are counted, and then each article summary is red to see if it is interesting for this study.

6. after reading the summary and discarding those who do not fit, the number left is recorded and can then be further studied.

Table 4: Example of the table to record each search. [own]

Search Term	*Google Scholar*	*Science Direct*	*Oria*	*Cumulative*
1.1.a "Crushed Aggregate" AND "water content."	Results 2000 Worth: 6	Result: 307 Worth: 1	Result: 71 Worth: 0	7
1.1.b "Crushed Aggregate" AND "moisture content."	Result: 1990 New: 5	Result: 244 New: 1	Result: 142 New: 0	13

Wigum et al. [9] reported that there are various terms used for crushed aggregate; these search terms were considered when making the search "matrix" for the crushed aggregate. Secondly, the "AND" search-action was used to combine an additional search term, which would further specify the search [Appendix 4].

6.2 Experimental testing

Each of the procedures is performed every time a test is carried out. It is essential to do these tests not only in the same way for every single mixing test but also that they are tested in the same order. Therefore, the order of a mixing procedure is as follows:

1. Testing the aggregate for water content.
2. Storing the dried aggregate for sieving, marking both date and which aggregate it is from.
3. Compensating added water content in the mix composition based on the water content in the aggregate.
4. Weighing the different constituents.
5. Mixing mortar.
6. Start 30 min timer
7. Slump- and rheological test
8. Test Slump- and rheological test after 30 min past from mixing
9. Cleaning.

Step 6 and 8 are only preformed when testing if the water content of the aggregate has an impact on the maturing phenomenon. The stored aggregate is later sieved to map out its grading curve, and possible changes over time, although, it was intended to do so, COVID-19 limited the access to the laboratory. Thus, it was not carried out in this thesis.

Table 5 shows the different mix-design for this thesis. The mix-designs were made under the preliminary project and gave a good flow to the aggregates, although the aggregates from Svingen and Tau shows very stiff results, and the mix design needed to be readjusted for them with a water-cement ratio of 0.6.

Table 5: Mix-designs for the different experiments to prove the maturing process [own].

Material	Benevning	Grunn	MA 0%	MA 2,7%	MA 4,3%	NO SP A	SP A
Sement	[kg/m3]	596,8	596,8	596,8	596,8	596,8	596,8
Sand	[kg/m3]	1456,7	1456,7	1456,7	1456,7	1456,7	1456,7
Vann	[kg/m3]	296	291,8	291,8	291,8	294,1	291,8
Retarder	[kg/m3]	2,4	2,4	2,4	2,4	2,4	2,4
SP	[%]	0,00 %	0,50 %	0,50 %	0,50 %	0,00 %	0,50 %
	[kg/m3]	0	2,984	2,984	2,984	0	2,984
W/B-tall	-	0,50	0,50	0,50	0,50	0,50	0,50

Under the experimental testing, it is also important to test the experimental error of the test procedures being used; therefore, this is also being tested.

6.2.1 Preparing for water content aging test

To test the effect of water content in the crushed aggregate when aging, two aggregates were chosen based on the aggregate's acidity from figure 8 and then prepared with three different water content levels and left to be stored in three different sealed containers for each aggregate.

To prepare the containers with certain water content, a procedure was developed:

1. Tumbling the crushed aggregate.
2. Water content.
   2.1. Weigh up 1000 gram (±1g) of crushed aggregate.
   2.2. Dry the aggregate on a pan on a heater.
   2.3. Weigh the aggregate again after it is dried out to the nearest gram.
   2.4. Calculate the water content:

$$Water\ content\ (WC\%) = \left(1 - \frac{M_{Dry}}{M_{Wet}}\right) \times 100\% \tag{1}$$

Where: M_{Dry}: Mass of aggregate when dry.
M_{Wet}: Mass of aggregate when wet.

3. Calculate the compensation for adding or reducing water.

3.1. Adding water:

$$\Delta M = \left(M_{Wet,\beta} - \frac{(1 - WC_{\beta}) * M_{Wet,\beta}}{(1 - WC_{\alpha})} \right) = Water\ Needed \quad (2)$$

Where:
- ΔM: Difference in mass.
- $M_{Wet,\beta}$: Mass of wet aggregate desired.
- WC_{β}: Desired water content for aggregate.
- WC_{α}: The water content of the original wet aggregate.

3.1.1. After it is calculated how much water needed to increase the water content to the desired percentage. The needed water is then added to the aggregate for then to be tumbled for 10 minutes to equally distribute the water.

3.2. Reducing water:

$$M_{Dry,needed} = M_{needed} * \frac{(WC_{\beta} - WC_{\alpha})}{WC_{\beta}} \quad (3)$$

3.2.1. After calculating how much dry mass needed to reduce the water content to the desired percentage. The dry aggregate is then added and tumbled for 10 minutes to evenly distribute the dry material within the wet material. Then the finished material is left to let the dry aggregate absorb water for 24 hours before use.

6.2.2 Mixing mortar

The mixing procedure is taken from the Norcem's mixing procedure for mixing 30-40 liters batches in a different mixer. A Hobart with a flat beater was used under the experiments to make 7-liter batches.

1. Weigh up every dry constituent.
2. Place first the aggregate then the cement in the mixing bowl.
3. Weigh up every wet constituent.
4. Start the Hobart and let it mix for 1 minute at speed 1.
5. Pour the water into the Hobart and let it mix for 1 minute at speed 1.
6. Pour the admixtures into the Hobart and let it mix for 1 minute at speed 1.
7. Stop the Hobart for 2 minutes.
8. Start the Hobart and let it mix for 3 minutes at speed 2.

6.2.3 Slump test

Slump and slump-flow are measured due to its practical method, and it is the standard way to measure concrete and mortars' workability in the industry. The higher the slump is, the easier the mortar is to move; the higher the slump-flow is, the easier it is for the mortar to flow. The slump test was based on a small slump cone with a top diameter of 38 mm, a bottom diameter of 80 mm, and a height of 120 mm. The measurement is also measured with an electric caliper which can give a precision of 0,001 mm, but the tests will have an accuracy of 0,1 mm

1. Fill up the cone half full.
2. Stamp 25 times
3. Fill up the cone.
4. Stamp 25 times
5. Slowly lift the cone upwards using 2 to 3 seconds.
6. Place the cone next to the slump "cake."
7. Place a straight pin on top of the cone, pointing horizontally towards the slump "cake."
8. Measure how much the mortar has sunk to the nearest millimeter (±0,1mm)
9. Place the pin vertical next to the edge of the slump "cake."
10. Measure the diameter from the pin to the opposite side to the nearest millimeter (±0,1mm).
11. Repeat the diameter measurement 90 degrees to the original measurement.

6.2.4 Rheological test

As slump and slump-flow give an indication of the material yield value, while viscometer allows obtaining both yield stress and plastic viscosity parameters. These tests are more exact, but it is costly and takes time. Therefore, it is not normal to measure the concretes rheological properties at a concrete plant. The rheological test is based on the user manual for the program RheoMixer 400 and the rheometer-4SCC from ConTec. The rheological values are measured in pascal (Pa), yield stress (YS), and Pascal seconds (Pa*s), plastic viscosity (PV). The Rheometer-4SCC gives out the YS and PV as G-value (mA) and H-value (mAs), respectively [6]. These measurements can be converted over to YS and PV by calibrating the rheometer. This is not necessary when measuring to determine a relative change in flowability.

Preparations

1. Set up the Rheometer-4SCC and plug it into the computer.
2. Start the program RheoMixer 400 on the computer.
3. Set up the test sequence based on figure 17. There should be seven measuring points with different r.p.s. Where the first one is the highest at 0,47, and the last one is on 0,07. Each measuring point has a 5-second measurement interval, except the first one for 10 seconds. Each set is also going to take four measurements throughout the interval.
4. Turn on the rheometer and start the test sequence to measure the noise of the device.
5. Calibrate the program to cancel out the given noise.
6. Fill the container with 7 liters of mortar and place the rheometer on top of the container.
7. Clampdown the rheometer and start the program.
8. Read out the G-value, H-value, and R^2-value. As seen in figure 10, the G- and H-value is between the green windows, and the R^2-value is located on the right of the screen.
9. Let the mortar rest for 10 minutes and then start the test over.
10. Read out the G-value, H-value, and R^2-value.

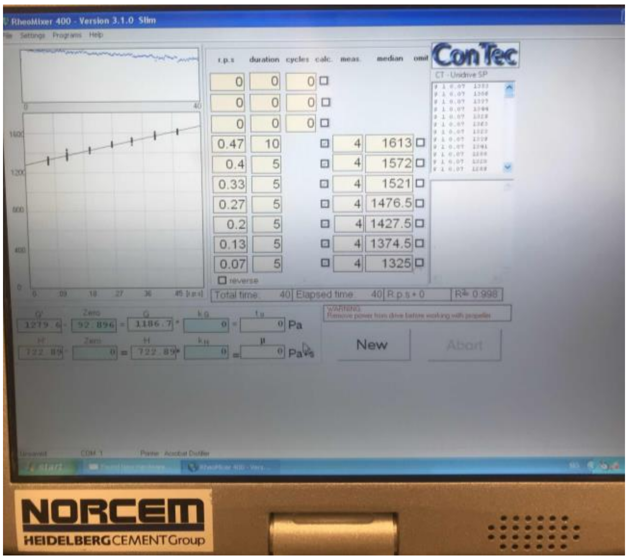

Figure 13: Picture of Rheomixer 400 and its settings. [own]

6.2.5 Material grading test

The aggregates material grading curve is tested accordingly to *Statens Vegvesen: Håndbok 014 laboratorieundersøkelser, 14.432 Kornfordeling ved sikting [40].*

When sieving, the aggregate was preheated and weight to 500 grams or 1000 grams depending on the sieve diameter being used. After being shaken for 10 minutes, each sieve in the sieve stack is weighted for then to calculate what the weight I sin percent weigh of aggregate used. Again, since COVID-19 limited the access to the laboratory equipment, this stage was not carried out but was intended.

7. Result

This chapter presents the result both from the literature study as well as the experimental study. The results from the experimental study are objectively discussed.

7.1 Literature study

After the first search over ScienceDirect, Google scholar, and Oria, there were a total of 144 articles that qualified to go through the summary reading. After that stage, there were a total of 62 articles, 28 articles from a geological standpoint, and 34 articles from an aggregate production standpoint. When further studying the remaining articles, there were many of them which did not contain any useful information. But the articles that were understood, and contained useful information, is written about in technological reasons and mineralogical reasons.

7.1.1 Technological reasons

Bengtsson et al. talks about in their paper "*Measuring characteristics of aggregate material from vertical shaft impact crusher*" the increased volume of fines in the aggregate production from the vertical shaft impact crusher (VSI) and to make sand with similar density to natural gravel; it is necessary to increase the rotor speed on the VSI – which increases the volume of fines [41].

7.1.2 Mineralogical reasons

Kerisit et al. [42] presents in "*Water and carbon dioxide absorption at olivine surfaces*" how olivine can form a water film on the surface by water molecules can bond with surface oxygen from the nesosilicate structure. When the water first makes a film on the surface, the olivine crystals can start to dissolve. Differences in solubility from corresponding carbonates could mean that a higher concentration of dissolved magnesium ions in the water film will further lead to water film growth and therefore increase the reactivity.

West et al. [43] presents in "*Tectonic and climatic controls on silicate weathering*" [43] a new assortment of chemical and physical erosion rates in small catchments to show that silicate weathering rates require considerations in multiple dimensions. His findings show that silicate weathering rates vary predictably depending on the total denudation rate, being only controlled by erosion rate at low erosion rate, but by temperature and runoff-related kinetics at high erosion rates.

Schott et al. [44] writes about in the paper "*Mechanism of pyroxene and amphibole weathering – I. Experimental studies of iron-free minerals*," from 1981, how pyroxene and amphibole minerals undergo dissolution during weathering, mainly enstatite, diopside, and tremolite. They found that all three minerals had a constant silica dissolution rate if the material were properly treated to remove ultrafine particles. The three rock types showed different preferential release from the outer surface to the solution, where diopside released calcium while tremolite and enstatite released magnesium preferentially. The incongruent release of cations from the surface of diopside and tremolite was followed by a harmonious dissolution. They also discovered that the dissolution rate is higher if the Ph-value is lower than neutral.

7.2 Experimental results

The experimental result chapter is based on the original experiment, which was canceled halfway in due to COVID-19. Originally the experiment should have lasted six weeks based on what was seen in the preliminary study. Note that the particle size distribution test and experimental error test was not carried out. The first test happened what the aggregates were one (1) week old since not all aggregate was crushed at the same time, and they got delivered to Norcem at different dates. The aggregate from Ledinge, Tau, and Årdal was crushed on the same date, but the aggregate from Svingen was crushed three days later due to complications at the crushing plant.

7.2.1 Maturing with superplasticizer outside.

As seen in figures 14-18, an apparent maturing phenomenon in the form of decreased workability is still present from one week to four. The slump represented in figure 14 shows a decrease in slump where Ledinge and Årdal had an 8,6 mm and 10,9 mm drop, respectively. The standard deviation for Ledinge is 2 mm at one week and four mm at four weeks, Årdal is 3,2 mm at one week and 3,2 mm at four weeks. Figure 15 shows the same type of decrease for Ledinge, but Årdal has a steeper graph and a higher standard deviation in one week. Figures 16-18 show the same increase in rheological properties, H and G value, supporting the decrease in both slump and diameter.

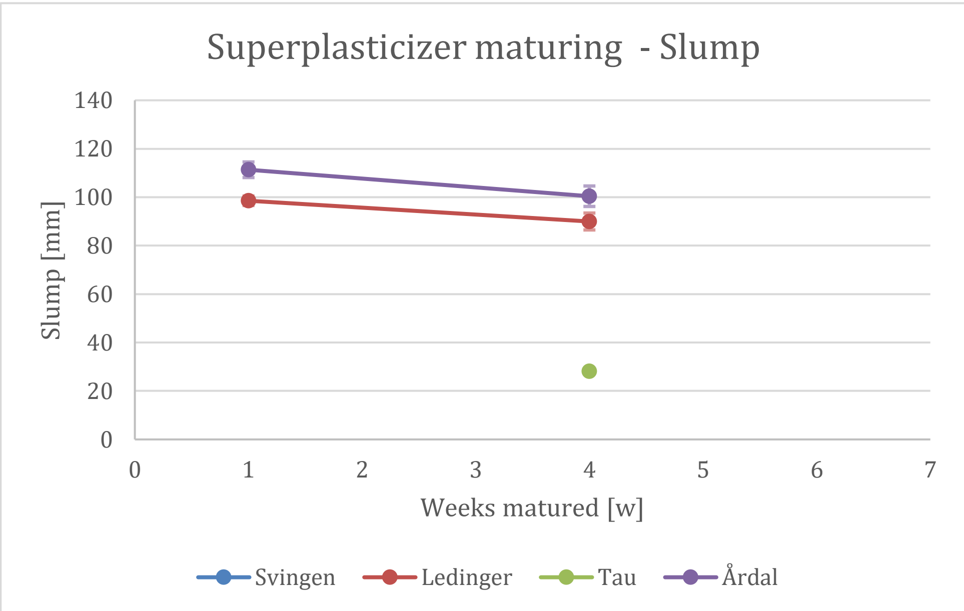

Figure 14: Slump development overtime on different aggregates with superplasticizer [own].

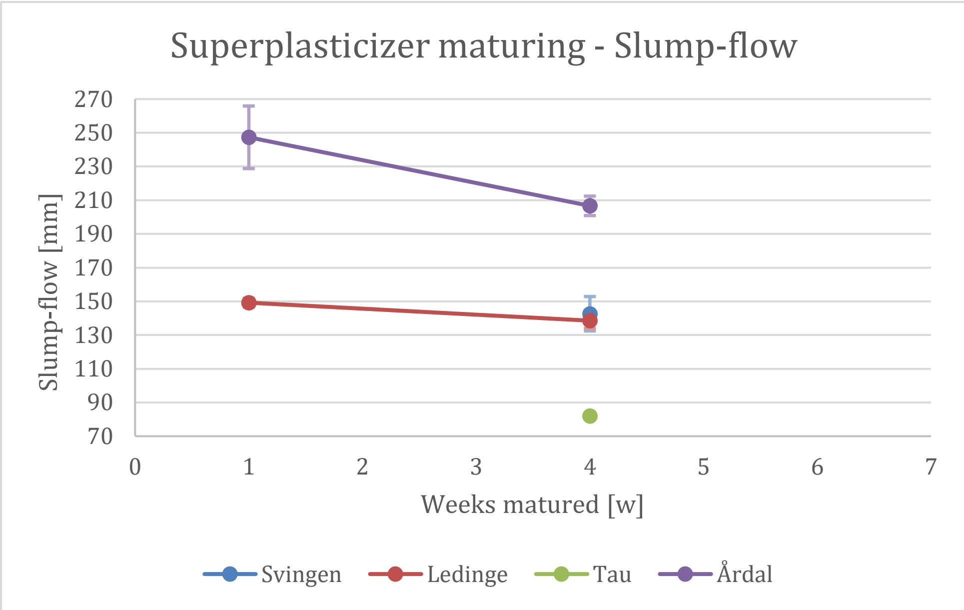

Figure 15: Slump-flow development overtime on different aggregates with superplasticizer [own].

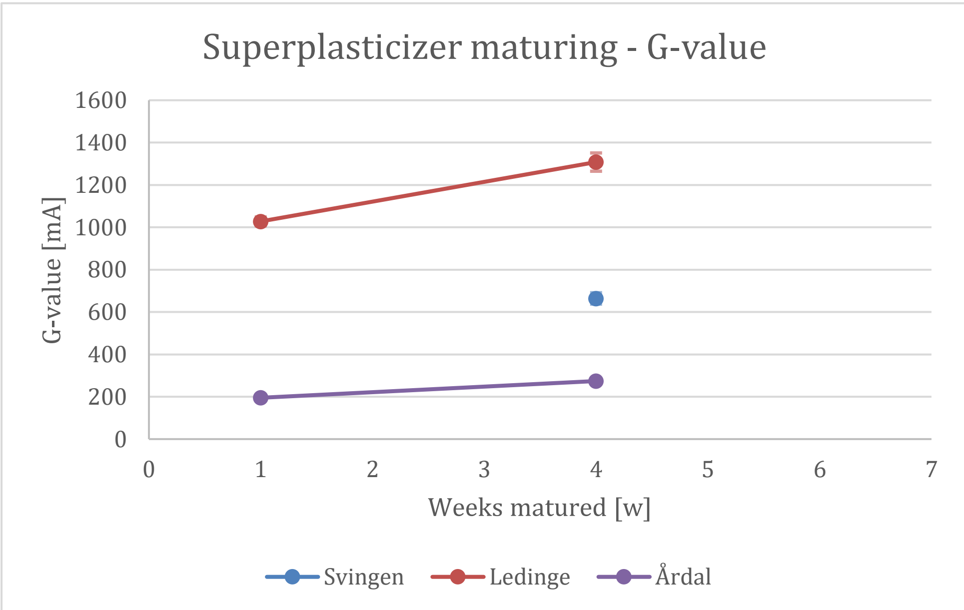

Figure 16: G-value development overtime on different aggregates with superplasticizer [own].

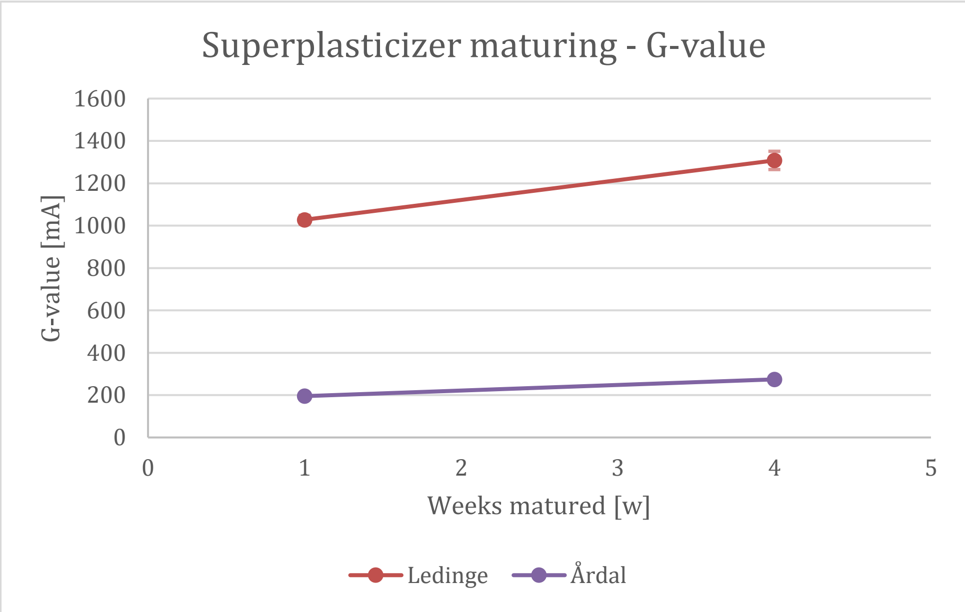

Figure 17: A more detailed look at the G-value development overtime on Lendinge and Årdal with superplasticizer [own].

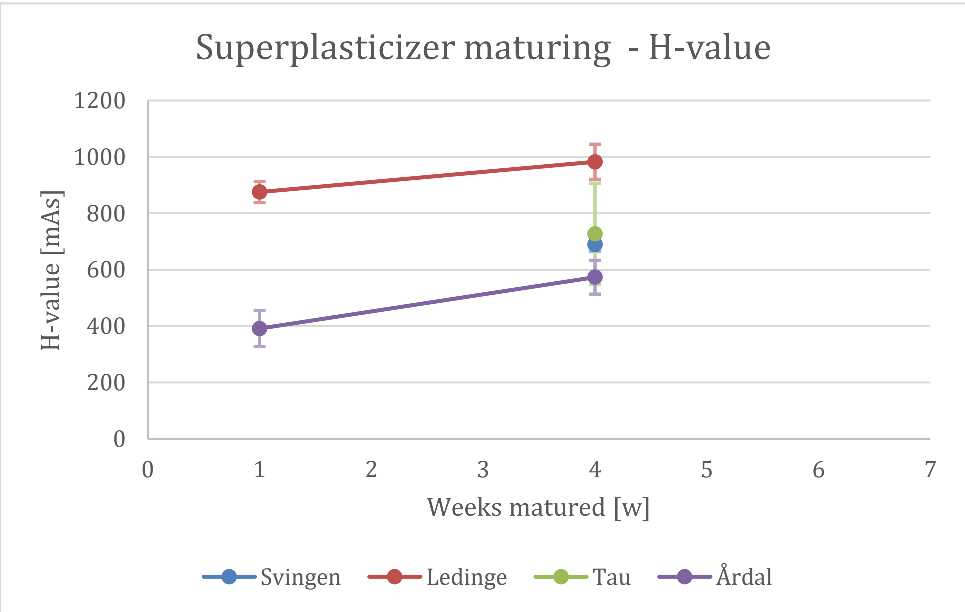

Figure 18: H-value development overtime on different aggregates with superplasticizer [own].

7.2.2 Maturing without superplasticizer outside.

Figure 19-22 shows the maturing phenomenon without superplasticizer. There is a significant difference in slump development, but both trends in figure 19 show improved workability. Figure 20 shows that the slump-flow has reduced for Årdal with 11,2 mm, while Ledinge has increased 2,6 mm. Figures 21 and 22 show the same trends as figure 20, but it is clear that the standard deviation for Ledinge is significantly higher.

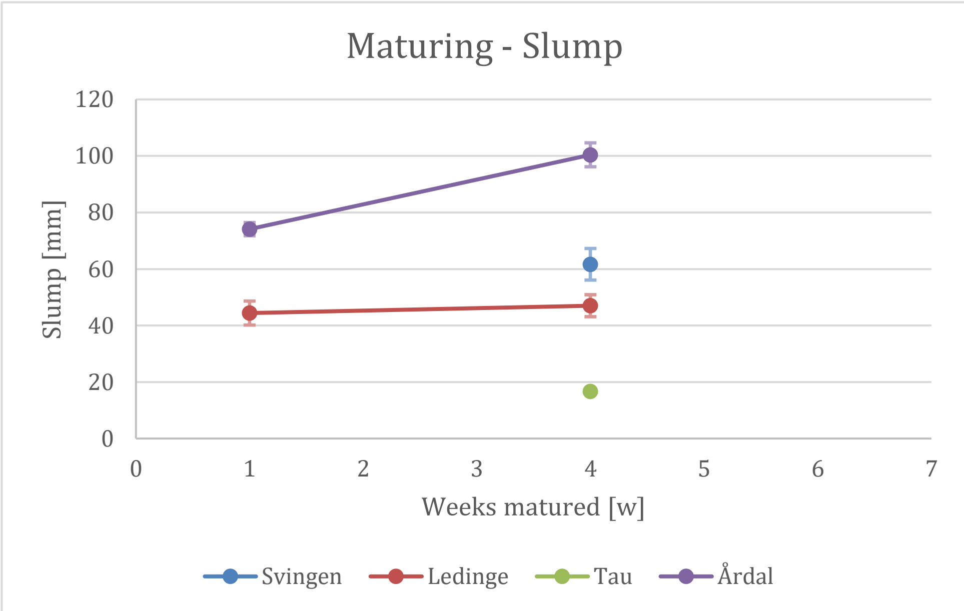

Figure 19: Slump development overtime on different aggregates [own].

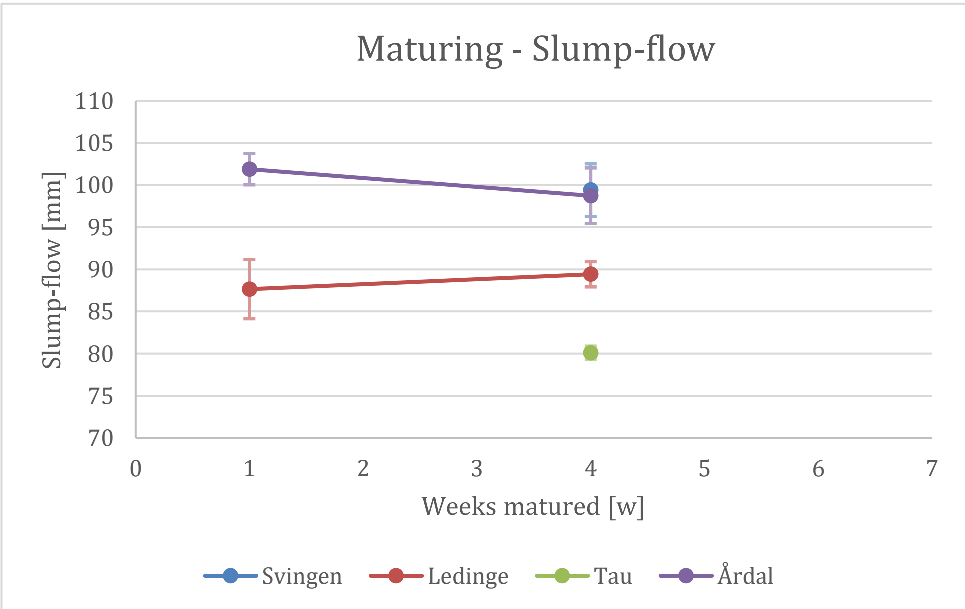

Figure 20: Slump-flow development overtime on different aggregates [own].

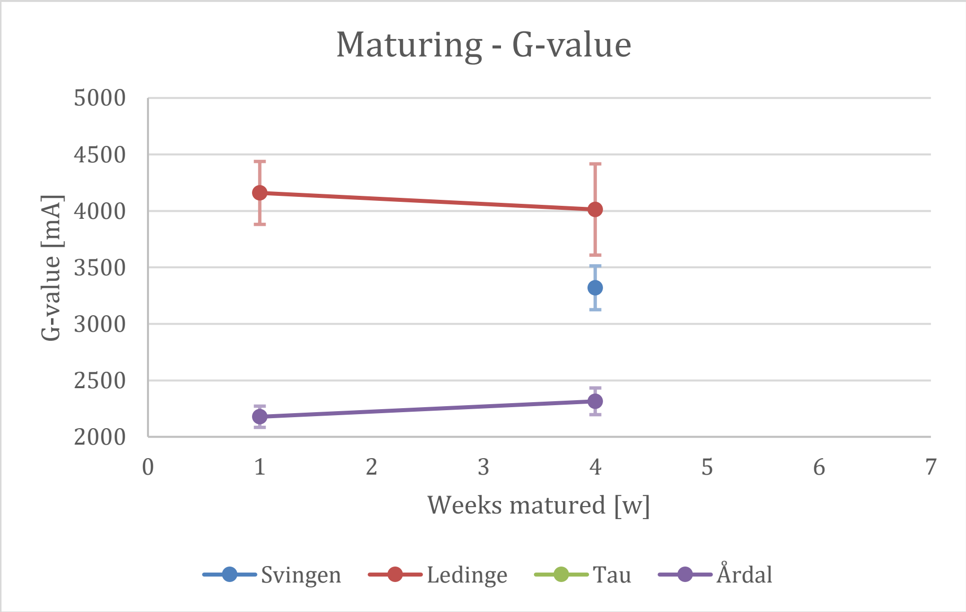

Figure 21: G-value development overtime on different aggregates [own].

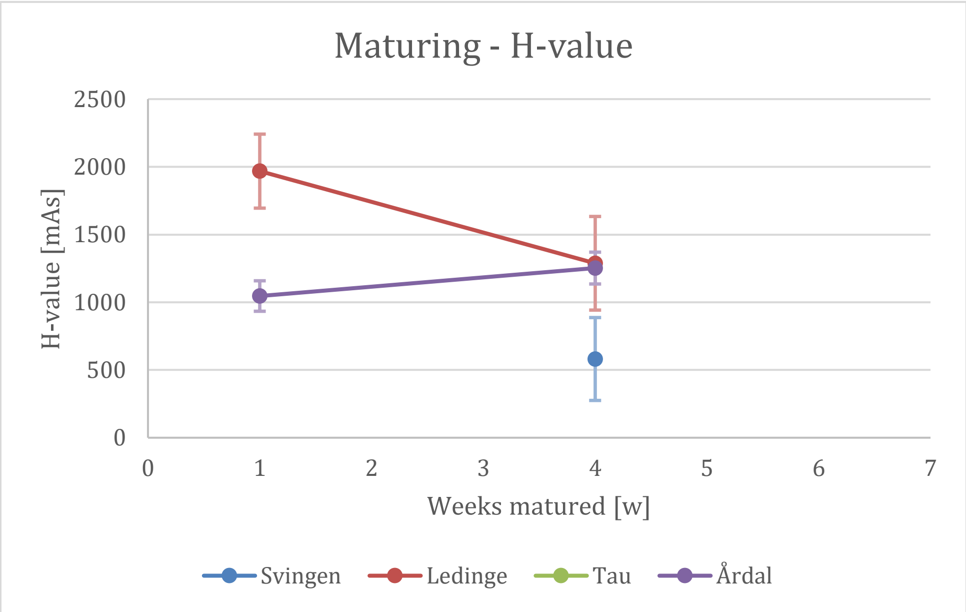

Figure 22: H-value development overtime on different aggregates [own].

7.2.3 Maturing with different levels of water content.

Figure 23-26 shows the maturing phenomenon based on aggregates, which were stored with 0% water content in a sealed container. Over three weeks, there was no indication of improvement on Årdal in figure 23, but the standard deviation is significantly higher than the other aggregates. Figure 24 shows the slump-flow is increasing. The increase in both slump and slump-flow can also be shown in Figures 25 and 26 by the decrease in G- and H-value, respectively.

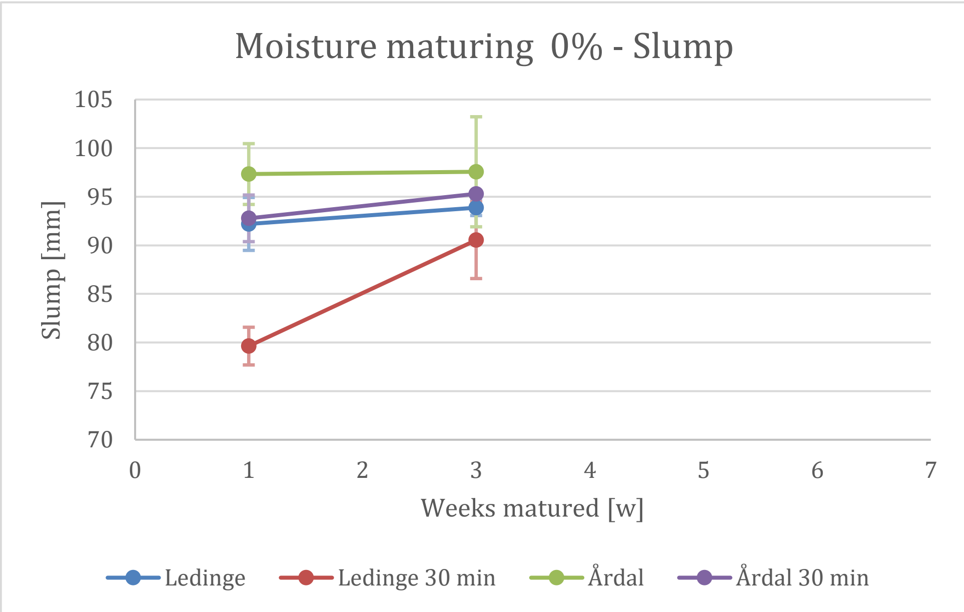

Figure 23: Slump development overtime on aggregates stored with 0% moisture content [own].

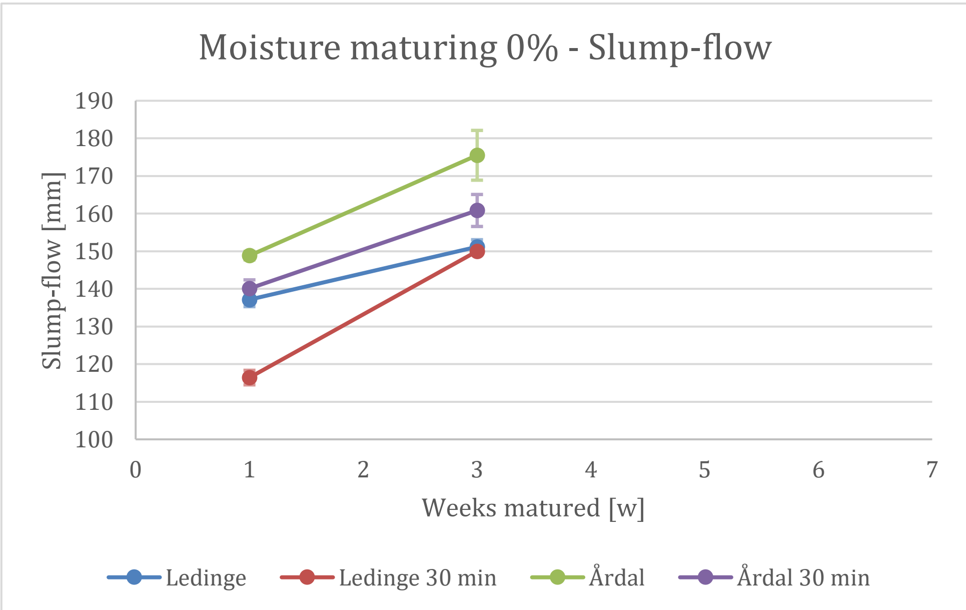

Figure 24: Slump-flow development overtime on aggregates stored with 0% moisture content [own].

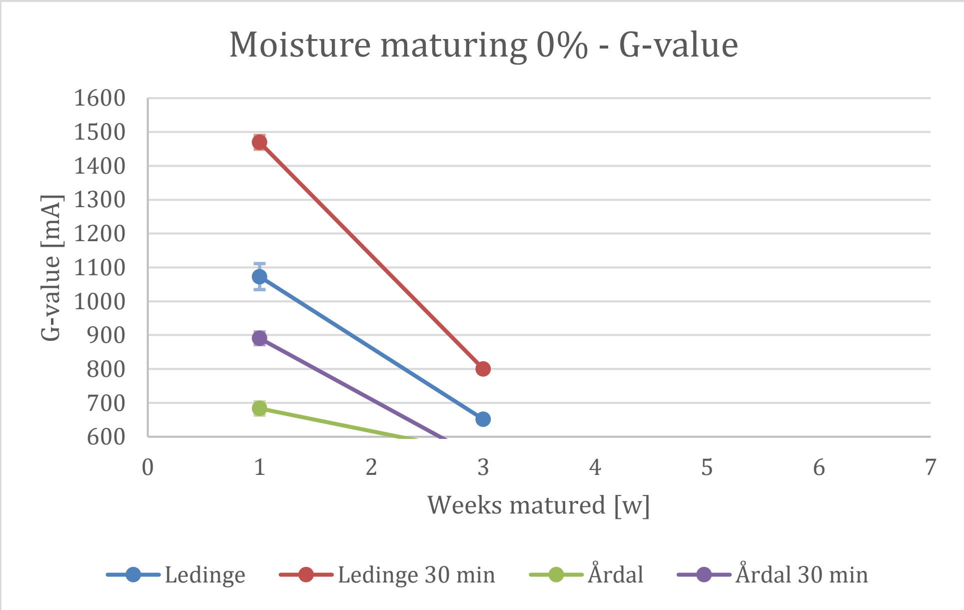

Figure 25: G-value development overtime on aggregates stored with 0% moisture content [own].

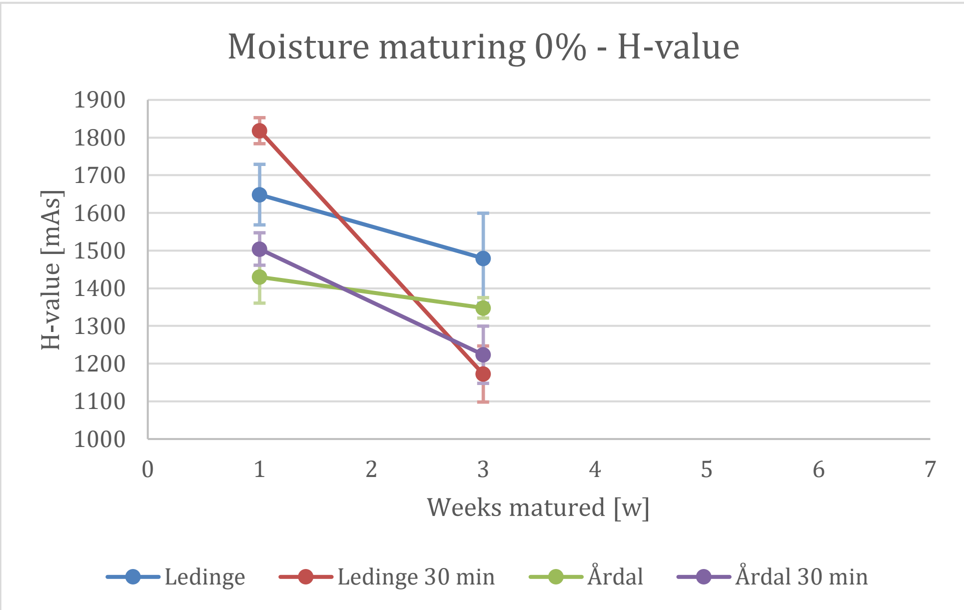

Figure 26: H-value development overtime on aggregates stored with 0% moisture content [own].

Figure 27-30 shows the development under the experiment of storing aggregate in a sealed container with a water content of 2,7 %. As previously seen in figure 23, there was no significant change in Årdal, but the standard deviation has significantly decreased. The slump diameter in figure 28 shows an increase in both aggregate types. The increase can also be seen in figures 29 and 30 due to their decrease in G- and H-value, respectively.

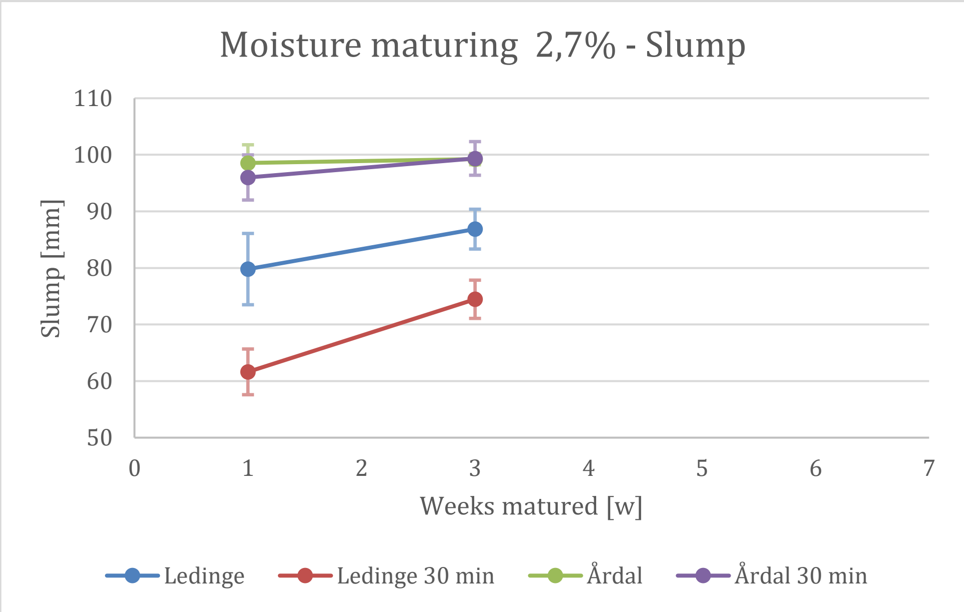

Figure 27: slump development overtime on aggregates stored with 2,7% moisture content [own].

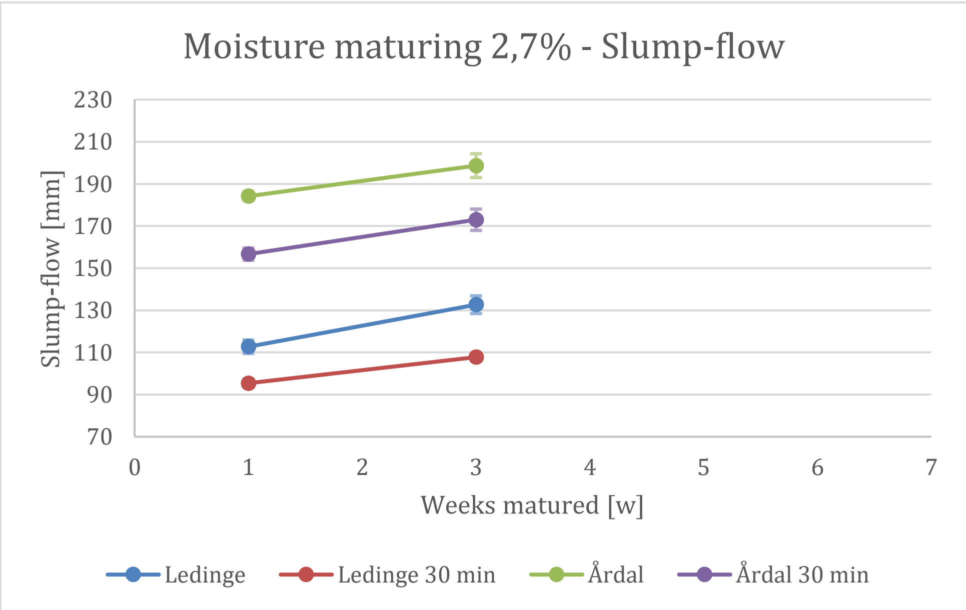

Figure 28: Slump-flow development overtime on aggregates stored with 2,7% moisture content [own].

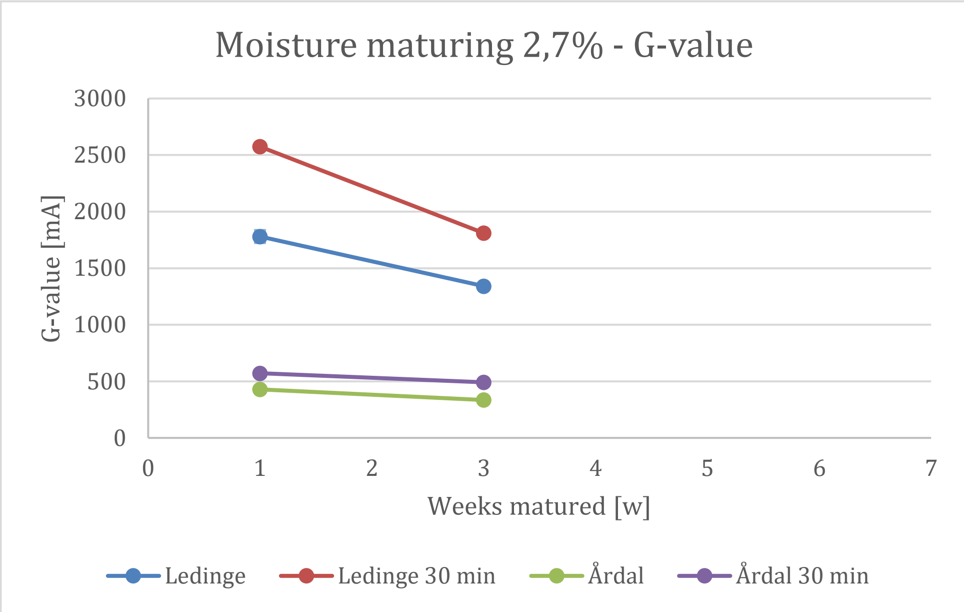

Figure 29: G-value development overtime on aggregates stored with 2,7% moisture content [own].

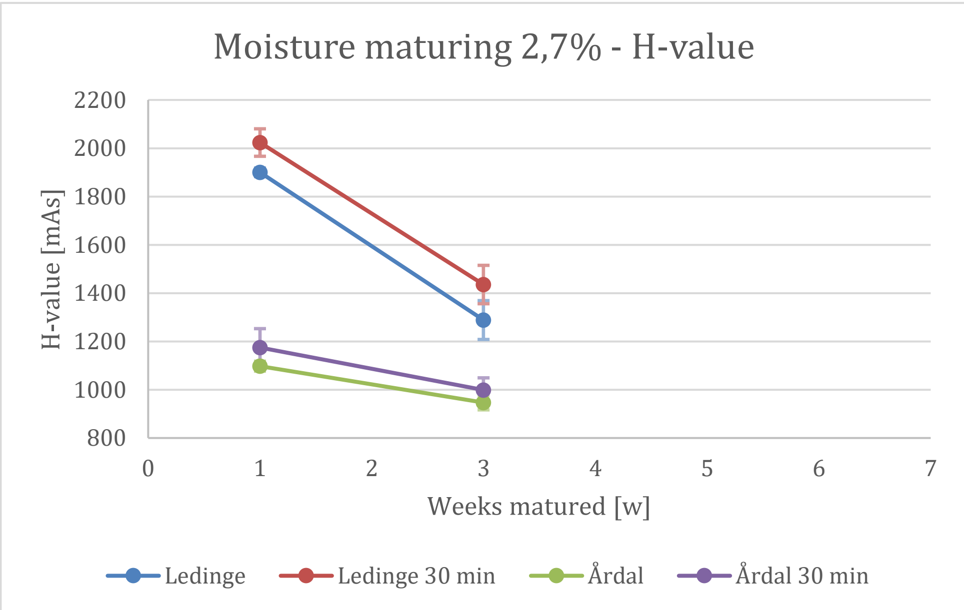

Figure 30: H-value development overtime on aggregates stored with 2,7% moisture content [own].

At 4,3% water content, the aggregates start to show different results where the slump development in figure 31 shows a decrease for both Årdal types and Ledinge after 30 min, but not Lendinge. The increase in slump diameter in figure 32 also shows a lesser increase then from water content tests. But figure 33 and 34 show that the G-value and H-value for Ledinge are decreasing while the parameters for Årdal is either decreasing slowly or show no relative sign of change.

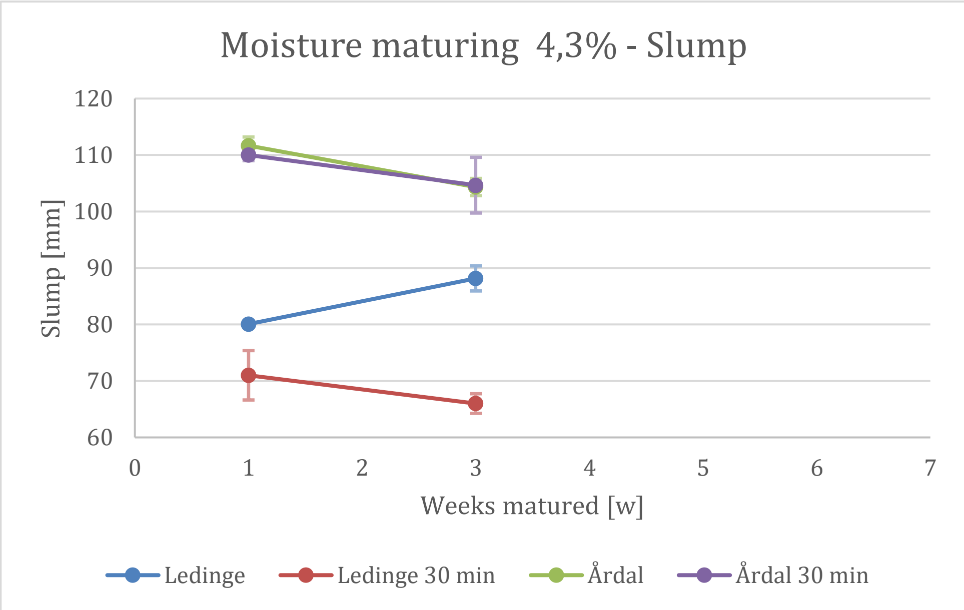

Figure 31: Slump development overtime on aggregates stored with 4,3% moisture content [own].

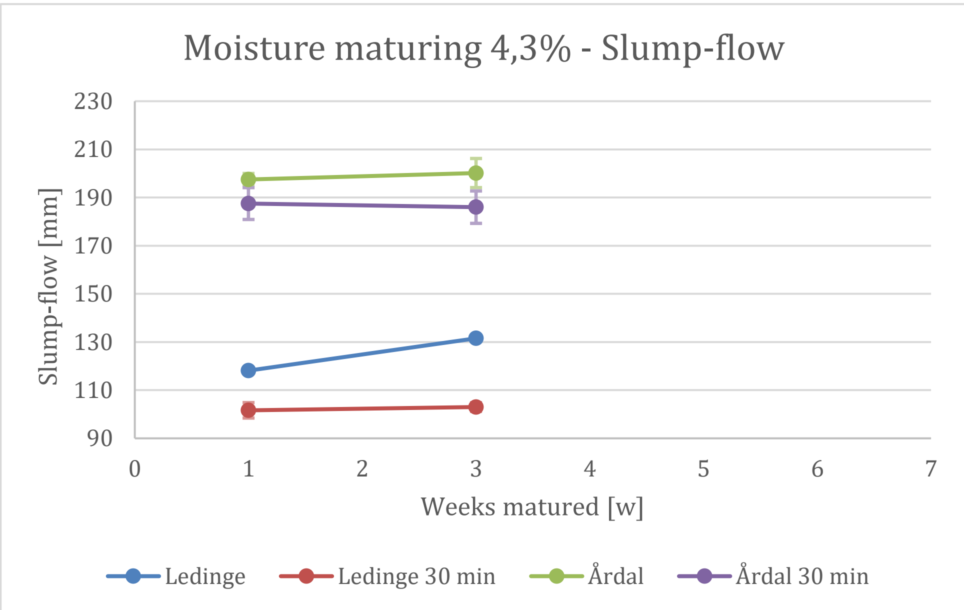

Figure 32: Slump-flow development overtime on aggregates stored with 4,3% moisture content [own].

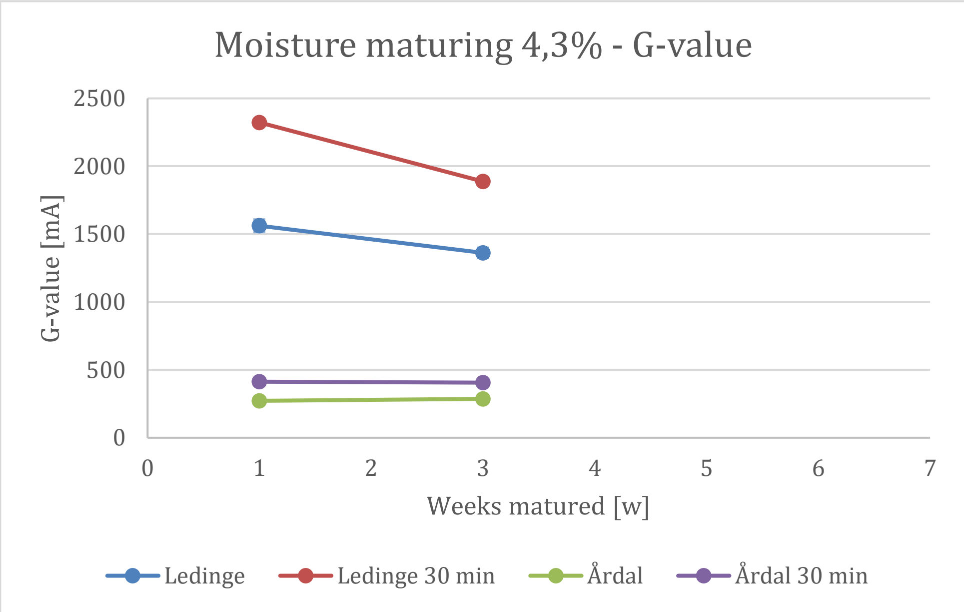

Figure 33: G-value development overtime on aggregates stored with 4,3% moisture content [own].

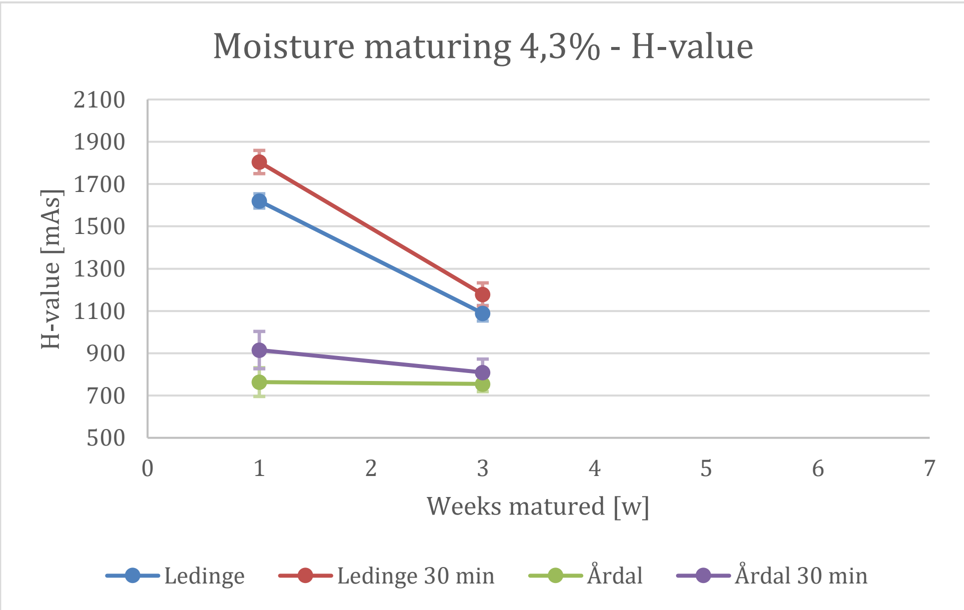

Figure 34: H-value development overtime on aggregates stored with 4,3% moisture content [own].

7.2.3 Water content's contribution to workability.

Figure 35-38 shows the water content's impact on the different parameters tested above, and figures 39 and 40 show the changes in the parameters after three weeks. In figure 35-38, both aggregates with their respective 30-minute test show the same development for each water content level. And as seen in figures 39 and 40, after three weeks, both aggregates have the same development. The one exception is Ledinge 30 min 3 weeks, where the result shows an increase from 2,7% to 4,3%.

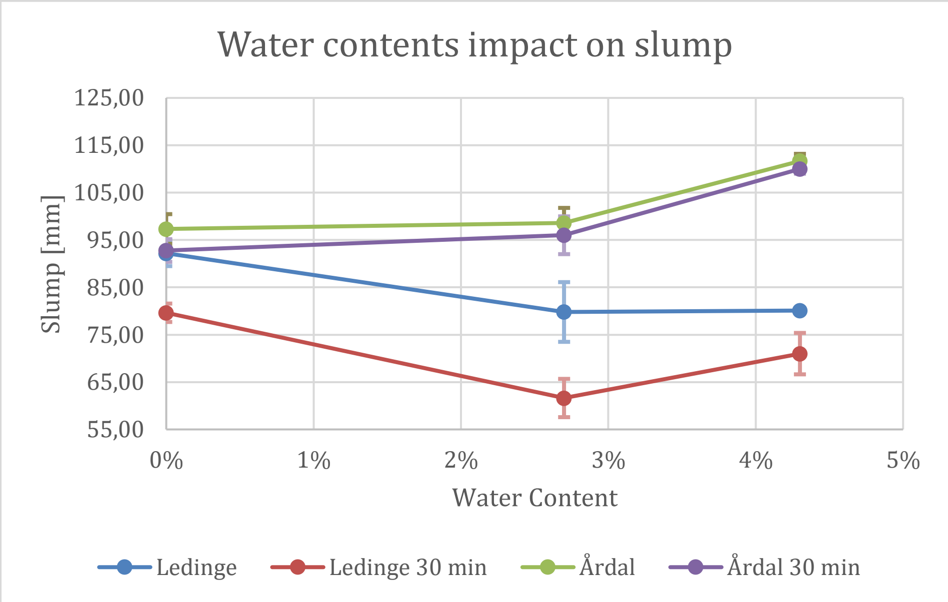

Figure 35: Slump at different water content as well as after 30 min of rest for Ledingen and Årdal [own].

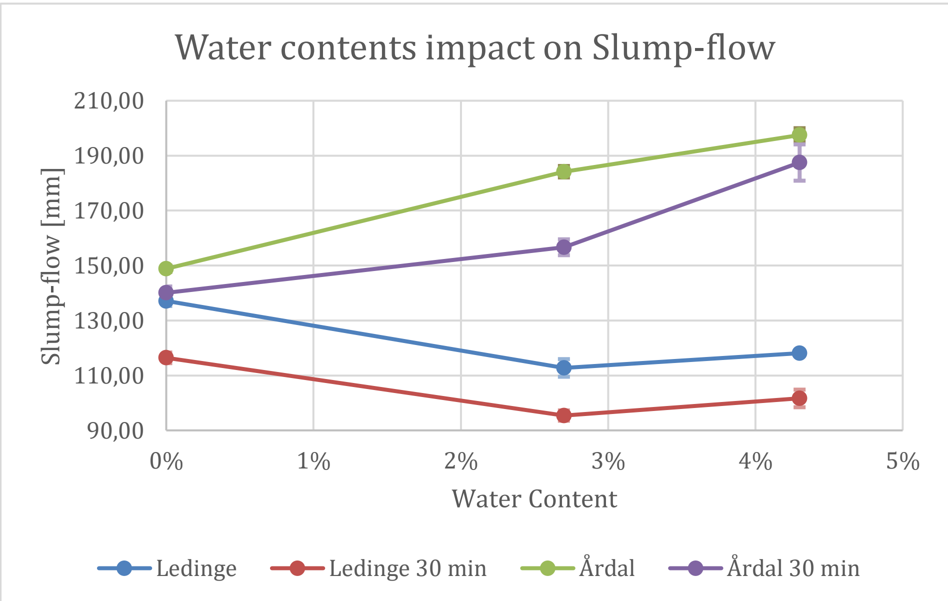

Figure 36: Slump-flow at different water content as well as after 30 min of rest for Ledinge and Årdal [own].

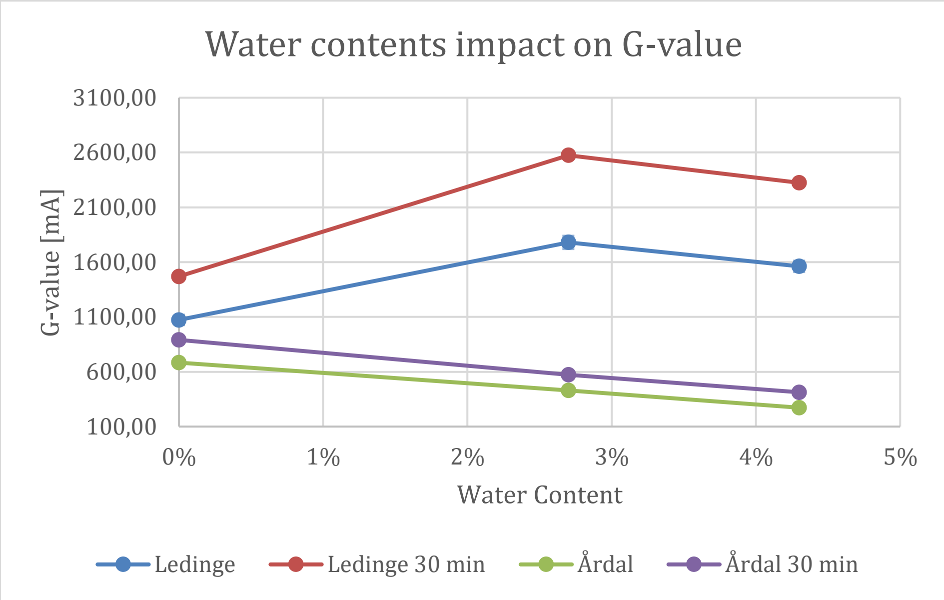

Figure 37: G-value at different water content as well as after 30 min of rest for Ledingen and Årdal [own].

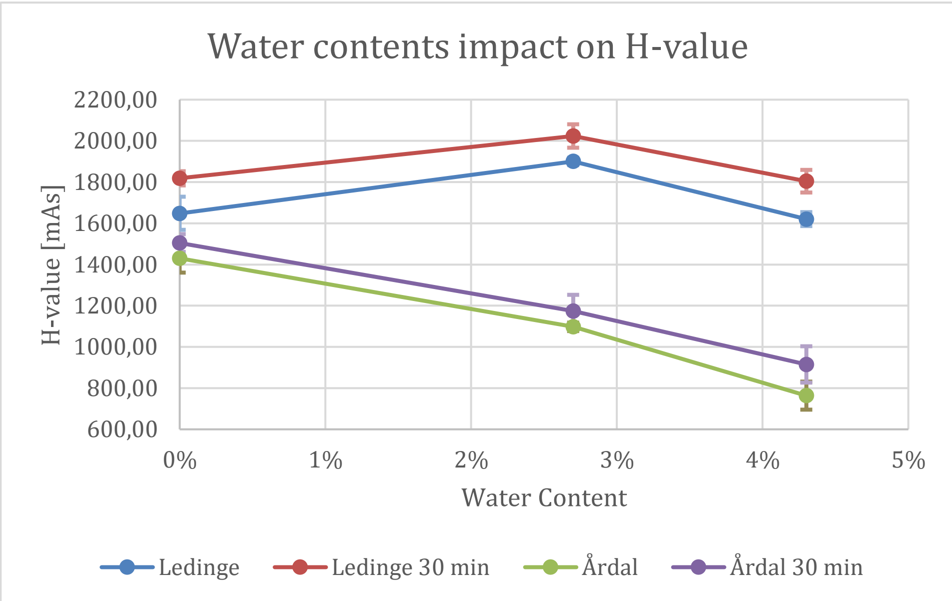

Figure 38: H-value at different water content as well as after 30 min of rest for Ledingen and Årdal [own].

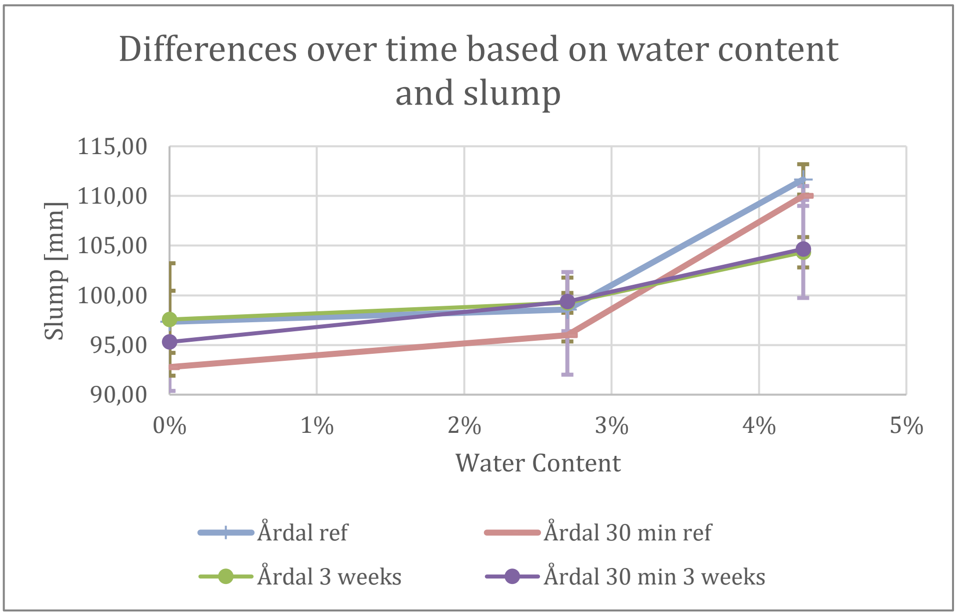

Figure 39: Differences overtime based on water content at ref (one week) and three weeks after for Årdal [own].

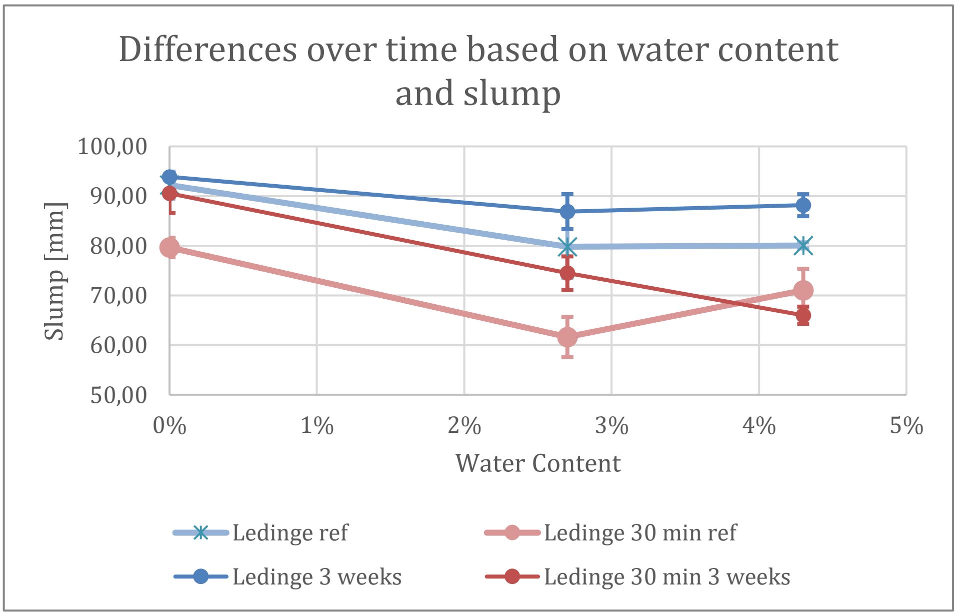

Figure 40: Differences overtime based on water content at ref (one week) and three weeks after for Ledinge [own].

8. Discussion

In this chapter, we will discuss how the experiments might correlate with the literature study and how it can prove the maturing phenomenon. In the end, we will critic the methods used in the thesis.

8.1 experiments and literature

As seen in the experimental work, there is not enough data to say anything certain, the poor data-collection is caused by sicknesses and due to COVID-19, the experimental work needed to stop halfway into the experiment.

What we can see for certain is that there has been a change in the aggregate from one week (reference day) to three weeks in moisture maturing. At 0% moisture in slump (figure 23), there is not so much of a change in the freshly finished mortar batches, but after 30 minutes, we can see a significant change in Ledinge. But as seen in slump-flow (figure 24), both aggregates, freshly mixed and 30 minutes after, have had a significant increase. When we start increasing the water content the aggregate is stored with, Ledinge shows an increase in slump as freshly mixed, but also after 30 minutes. Årdal has a slight improvement in the 30-minute test, but as seen on the standard deviation, it might not be correct. If we further look at maturing in 4,3% water content storage, the slump (figure 31) is decreasing. The trend is common in three of four cases, only freshly made mortar with Ledinge that did not decrease. Looking at the rheological properties of the 4,3% stored aggregate (figure 33 and 34), Ledinge should not have had an increase in slump. Both G-value and H-value show a decrease, meaning that the mortar's yield-stress and plastic viscosity would let the substance move more freely after lifting the slump-cone. The G-value and H-value for Årdal correlate with its slump and slump-flow, take the standard deviation into account. The difference we see in the experiment with 4,3% water content might be caused by the abnormal amount of water; it is well known that too much moisture in aggregate will cause local moisture variations [6].

If we look at the trend of slump and slump-flow, with the assumption that Ledinge at 4,3% is questionable and should not be included, water might affect the maturing, but it is based on the aggregates mineralogy. Ledinge's mineral composition is gabbro, which contains nesosilicate olivine, inosilicate pyroxene, and tectosilicate calcium-rich plagioclase feldspar, while Årdal's mineral composition is of granite that is composed of tectosilicates such as quartz, potassium-feldspar, and sodium-rich plagioclase feldspar (see figure 9) [37]—linking the trends to more specific towards how the minerals behave chemically with water. Pyroxene and olivine are some of the primary resources of magnesium, and the dissolution of magnesium ions can cause a greater water film, which again will increase the chemical weathering rate as Kerisit et al. found [42]. On the contrary, Schott et al. found out that under neutral pH, pyroxene minerals preferably released calcium from its outer surface, which also is in accord with magnesium having a stronger bond than calcium to the tetrahedral-silicate-molecule. Schott also points out that the weathering rate is higher at the start if there are ultrafine particles [44].

It is important to point out if maturing is caused by the minerals chemically weathers that I have not found any articles which describe the rate of weathering in time. Therefore, if it is chemical weathering, the time frame of the maturing process, as far as I know, could be between weeks to years.

Under the second part of the experiment, maturing with and without superplasticizer (SP), we were supposed to test out four different materials, only Ledinge and Årdal were successful. Tau and Svingen, which is the other two aggregate, made a too stiff mortar for proper testing, and a successful mix-design did not occur before four weeks after the initial test. Therefore, they will not be included under discussion on how SP and no SP impacted the maturing process.

The slump and slump-flow of the experiment for Ledinge shows a slight increase without SP (figures 19 and 20), and with SP (figures 14 and 15), both slump and slump-flow show a decrease. This is the opposite of what we saw in the preliminary study seen in figures 41 and 42. The difference brings up the question: what is the repeatability of the experiment?

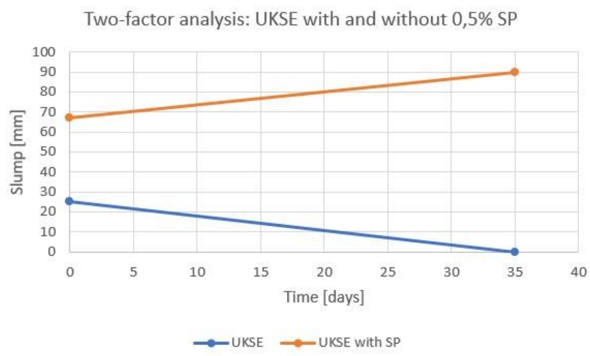

Figure 41: Two-factor analysis of Ledinge stored outside with and without SP for my preliminary study, the Y-axis shows the recorded slump in millimeter and the x-axis shows the recorded time. UKSE means outside stored crushed aggregate from Sweden [own][appendix 20].

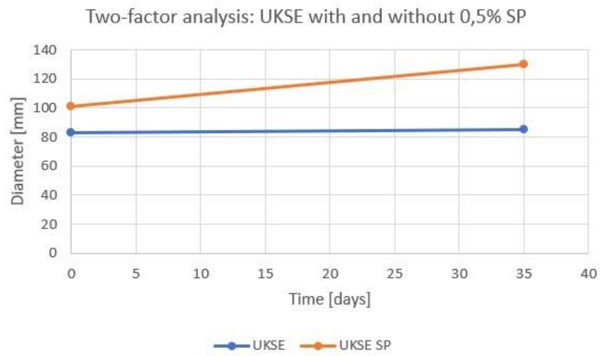

Figure 42: Two-factor analysis of Ledinge stored outside with and without SP for my preliminary study, the Y-axis shows the recorded slump-diameter in millimeter and the x-axis shows the recorded time. UKSE means outside stored crushed aggregate from Sweden [own][appendix 20].

It seems like Årdal and Ledinge show a continues result in slump with SP, and as seen in the standard deviation, the batches were stable, and the tests did not differ from each other. Looking at the slump-flow with SP, Årdal has a huge standard deviation at the first test. If the point were on the lower end of the standard deviation, it would have had the same pattern as Ledinge. It is important to point out that the mix-design used in this thesis is the same as the one produced in the preliminary study. Therefore, the mixing ratio and mixing method are the same. Based on the assumption that Årdal and Ledinge show the same pattern of "maturing" and the fact that the mixing and mix-design are the same as used in the preliminary work, I would say since it is the opposite result of previous tests, maybe the environment it has been stored in governs the impact. It is also important to point out that when storing outside, one cannot control the water content of the stored aggregate. And under the testing, we had different water content results before mixing. Of course, the water content of the mortar batch is compensated for the water content of the aggregate. But as seen in figures 35 to 36, the water content of the aggregate will impact the overall slump and slump-flow. Although, we only have recorded the impact of water content in the aggregate to a maximum of 4,3 % of the aggregate weight. We could make an educated guess that the impact of water content either increases or decreases the slump and slump-flow as the water content in aggregate increases. The recorded water content for Ledinge and Årdal at reference point was 6,5% and 7,6%, respectively, and the last recorded water content was 8,1% and 6,3%, respectively, four weeks. The water content from the preliminary study was 7,62% on the first test day and 7,05% and 35 days. Looking at specifically Ledinge, it might be that the slight decrease in slump and slump-flow is due to increased water content, and we see the opposite in the preliminary work due to the decrease. This is, of course, only speculations, and looking at the difference in the preliminary experiment, it seems less likely that a change of 0,57% should increase the slump and slump-flow with more than 20 mm and 30 mm, respectively. Another factor, which was not recorded, is the material grading. If both experiments had a recorded PSD, we could look deeper into the fractions lost and the fractions that were not present in both experiments. As Magnus Bengtson et al. and Cepuritis et al. describe, there is a high amount of % fines produced under vertical impact crushing and based on the idea that fines can leach out under heavy rain, it would most likely show a result of decreased fines [18, 41]. This is a problem for the whole thesis itself and would have been the next logical reason for why we see such a difference in the experiments. Although, since we see a type of "maturing" trend in the sealed experiment, this might not be the case after all.

Looking more closely into Årdal's aggregate, we can see based on the development of G- and H- value in figures 16 to 18 that the recorded slump and slump-flow do not comply with the rheological properties in the magnitude recorded.

On the SP tests, we see a slight decrease in slump as well as in slump-flow. There is also no significant standard deviation that could explain why these tests show the opposite of what the SP tests from the preliminary project showed. It is also important to look at the tests without SP, and one thing to point out here is that the G- and H-value of Ledinge should have to give us a significantly better slump, and Årdal should not. These are important to point out as there might be an error in the testing method.

When comparing the different studies on maturing, as seen in figure 43, the results differ. All preliminary trends show a decrease in slump over time, while the same experiment in the master, "master," and "master /w SP," shows the variable result. The results from the water content experiment show an increase in slump all over, and in a way, "correlate" with the experiment from ManSand. But, in ManSand, there was a huge difference in water content over time. The water content decreased overtime steadily, and from start to finish, it had a difference of as much as 2,5%. As seen in figure 35, how water content impacts slump on aggregate, Ledinge, based on that experiment, will have a better slump, the lower the water content is.

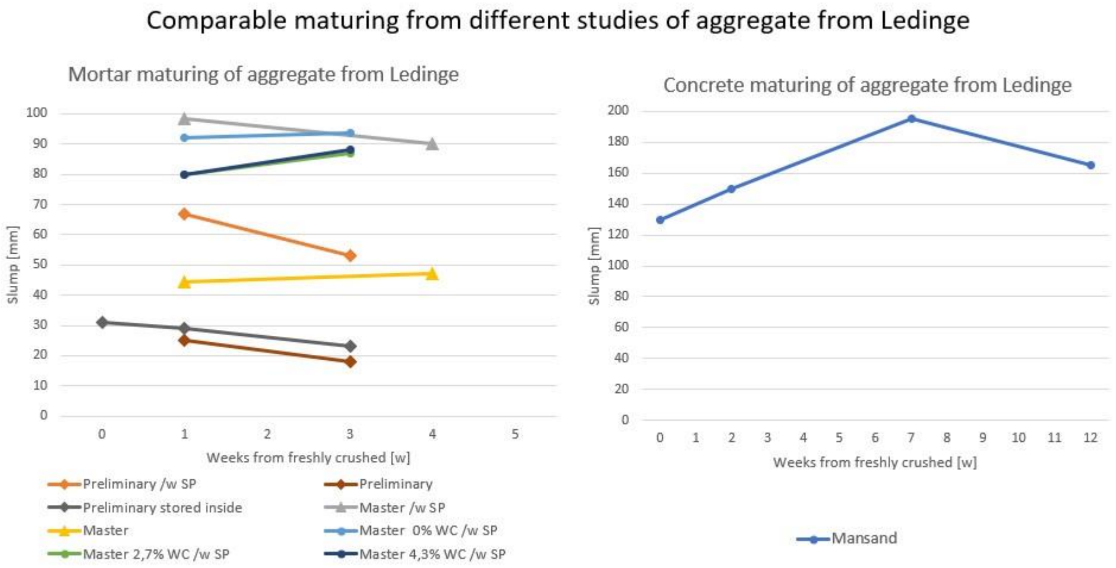

Figure 43: Comparing the different maturing studies that has been done on the aggregate from Ledinge. To the left is the work from the preliminary study and master on mortars. Right graph shows what has been done in the ManSand project on Concrete [own].

8.2 Critic of method

In this thesis, there have been many setbacks. The COVID-19 pandemic, which stopped the experimental study of the thesis and shifted towards a more literature study, has also stopped me from testing the standard deviation for both the rheometer and slump cone.
Therefore, the standard deviation on the graph is based on the differences when doing each test three times on the same mortar batch.

8.2.1 Experimental critic

Of course, one of the biggest sources of error when doing an experiment is the person doing them. To take accurate measurements of fresh mortar is not easy, and when using a ruler, there might be a chance that the person measuring is missing by a millimeter or two. In this experiment, there were used electronic calipers to measure both slump and slump-flow, but if the slump-flow were wider than 150 mm, the calipers could not reach the ends, and a ruler would be used instead. Therefore, the results with a high slump-flow are more likely to have a larger measurement error than the test with lower slump-flow.
The procedures are pretty straight forward when it comes to carrying out the slump cone filling, but it is important to note that in a slump cone, the way you fill and stamp the mortar, especially with stiff mortar, will impact the end result significantly. This also is important to note when filling the rheometer with mortar too.

The stiffness of the mortar also brought some problems to the tests, especially the mortars made of aggregate from Svingen and Tau, since the slump cone would not sink or not fill properly. And in the rheometer, the mortar prohibited the impeller from turning. Ending up with a lot of problems and the tests, in the end, could not be carried out. It was not before week four that the mix-design was tuned enough to yield measurements for those aggregates, which was the week we needed to stop the experiment due to COVID-19. After each test with the rheometer, it would give an R-value, which signifies the correlation of the measured torque and torque seconds with a linear regression line that again gives us the “yield stress” and “plastic viscosity.” In this experiment, most of the measurements yielded a high R-value, which is good, but the stiffer the mortar was, the lower the R-value became, which means that the linear regression line from the rheometer tests with low R-value might not be accurate.

Looking at the water content test, the transferal of sand from the measuring bowl to the heating pan and back can disperse the lighter particles in the air instead. This is very clear when dealing with hot and dry aggregate.

The fine particles dispersing into the air were also a huge problem when working with the mix-designs that had dry aggregate. The transferal from measuring bucket to mixing bowl led to a huge dust cloud in the air, and the use of protective masks was necessary for health reasons. The dispersed dust could also be a significant volume of the fines in the aggregate and could have altered the results of the mix-designs.

8.2.2 Literature study

Under the literature study, there were many faults to point to the lack of results in the end. The search was a necessary act to fill up the gap from halted experiments and had a short time frame to be executed.

To find synonyms for each word in the literature study was hard, and most likely, all synonyms were not found. One big miss in the literature search was to use the “OR” term in the search, meaning that the search ended up unnecessarily long, and most synonyms were not included. If used, the search could have been more specified to the desired result and significantly reduced search time. Since it was not used, the search terms yielded high amounts of academic papers, and due to the short time frame, only 200 articles from each search were selected for further analysis. It should also be noted that the search was too broad, there were too many search terms I wanted to go through, and it ended up as a barrier for me to be more thorough.

Another potential source of error under the literature study is the fact that the publishing journals the papers found were not validated. This leads to the question of whether or not the articles had poor academic stands due to the unknown academic publishing journals, at least for me, it is published through. There have been several publishing channels that have publisher “fake” science over the years. Scandinavia has tried to solve this problem by validating academic publishing journals and giving the researchers a website to search up the publishing journals [45].

In the end, the number of articles found is few. There was as said limited time, and, in the end, several articles were ruled out. There are several articles about the weathering of minerals in the geology world; this is not an uncommon occurrence. Therefore, if the study were more thorough, it would yield a significant number of articles concerning weathering.

9. Conclusion

To answer the research question, we will first answer the sub-questions

1. What influences the maturing phenomenon in crushed aggregate?

After the experiment and literature study, it seems like the aggregate could mature due to some kind of initial chemical corrosion. Therefore, the mineral composition of the aggregate contributes towards the corrosion. This also might be the reason why we see a difference in maturing rates from Årdal, which is granite, to Ledinge, which is a Gabbro even though the actual mechanism and timeframe remains unknown and seems not to be previously described in the literature.

2. How does the water content in the aggregate affect the maturing phenomenon?

Based on the first answer, the water is the “chemical” reactant for corrosion, but it seems like it does not significantly contribute. The experiments show that when the aggregate has a water content of 4,3 %, it should technically react negatively compared to the test for 2,7% and 0%. Still, as we have discussed, the too high water content can promote local moisture variation in the aggregate, therefore, tempering with the lab results and making it hard to distinguish between the hectic effect of high aggregate moisture on workability testing results and any actual contribution to the sand surface maturing. The experiments also show that the water content of the aggregate impacts the slump and slump-flow that can also alter any experiment results, which is stored outside or not properly being controlled. It is important to state that in this thesis, we looked at moisture content from 0% to 4,3%; beyond 4,3%, we do not know if the water content increases or decreases the slump and slump-flow.

3. What is the repeatability in experimental based assumption on the influence of superplasticizer on maturing?

The experiment on this master thesis was performed in the same manner as in the superplasticizer experiment in my preliminary work, but the results show a different maturing growth. There can be many reasons for this, as long as the execution of the experiment were the same, the ones talked about is the environmental effect from storing the aggregate outside, differences in material grading and how some fractions might decrease, and the difference in water content. Since COVID-19 haltered the experiment, the change in material grading was not recorded, and we do not have any data on the standard deviation of the instruments being used. It is, however, clear that very precise control of the water content is absolutely necessary to expect any repeatability in these kinds of experiments.

4. What is known about the maturing phenomenon from a mineralogical perspective?

The geological community has known that minerals do corrode and erode. It is vastly written about since it is also the reason why we have earth on the surface. But it seems like the aggregate/concrete industry, based on the literature study done in this thesis, has not researched how it can affect the aggregate's effect on fresh concrete. Although it is well known that the mineral composition of the aggregate is important to prevent increased water consumption and alkali-reactions. It is important to state that I did not find out what the rate of chemical weathering was. This is a crucial factor if the aggregates maturing effect is from chemical weathering.

How will the ambient environment influence the rheology of fresh concrete due to aggregate maturing?

Based on the sub-question, it seems like the ambient environment does have an effect if the maturing phenomenon we see is caused by chemical corrosion. It is then governed by the water content in the aggregate and the weather patterns under storage. The corrosion rate is also governed by the mineral composition of the aggregate and its material grading.

10. Recommendations

To further research the maturing subject, it is important to do a further literature study on the geology of aggregates, and it is also important to further experiment with different aggregates with different material grading, mineral composition, water content, and storage methods.

It is important to find out if physical erosion impacts the aggregate; this will increase the % fines in the material grading. It is also important to know if the fines will leach out of the aggregate if stored outside, i.e., reducing the % fines in the material grading.

The water content can still also be a huge factor if the chemical corrosion theory is true. Therefore, the experiment with different % of water content in aggregates should be revisited to see how the different mineral compositions react to the water and amount of water. This experiment is also useful to record how water content can impact the slump and slump-flow of the concrete, which itself is something that has not been looked at so much. Still, in the industry, concrete engineers have a lot of experience with it that has not been written about.

11. References

[1] J. Lindland, *Betongrehabilitering; Reperasjonsmetoder, utførelse og kontroll*. Norsk Forening for betong, 2016.

[2] P. Hewlett and M. Liska, *Lea's chemistry of cement and concrete*. Butterworth-Heinemann, 2019.

[3] D. Moore, *The Roman Pantheon: the triumph of concrete*. MARC/CCEOP, University of Guam Station., 1995.

[4] L. C. Lancaster, *Concrete vaulted construction in Imperial Rome: innovations in context*. Cambridge University Press, 2005.

[5] R. Cepuritis, "Development of crushed sand for concrete production with microproportioning," 2016.

[6] S. S. M. M. S. Jacobsen (Editor), *Concrete Technology* NTNU, 2016.

[7] S. W. Danielsen and E. Kuznetsova, "Resource management and a best available concept for aggregate sustainability," *Geological Society, London, Special Publications,* vol. 416, no. 1, pp. 59-70, 2016.

[8] R. Poulin and K. Sinding, "A North American perspective on land use and mineral aggregate production," *GeoJournal,* vol. 40, no. 3, pp. 273-281, 1996.

[9] S. W. Danielsen, B. J. Wigum, B. Petersen, and O. Hotvedt, "Production and Utilisation of Manufactured Sand. State-of-the-art-report. COIN P 2 Improved construction technology. SP 2.5 Production of manufactured sand," 2009.

[10] S. Danielsen, "Sand-/ Gravel resources in Årdal, Ryfylke - social importance as raw material in construction. Norstone internal memo (In Norwegian)," *NorStone, Sandnes,* 2003.

[11] B. M. Pedersen, "Alkali-reactive and inert fillers in concrete. Rheology of fresh mixtures and expansive reactions," 2004.

[12] T. Irfan, "Aggregate properties and resources of granitic rocks for use in concrete in Hong Kong," *Quarterly Journal of Engineering Geology and Hydrogeology,* vol. 27, no. 1, pp. 25-38, 1994.

[13] D. Delestrac, *Le sable: enquête sur une disparition*. Arte France [éd., 2013.

[14] P. Peduzzi, "Sand, rarer than one thinks," *Environmental Development,* vol. 11, pp. 208-218, 2014.

[15] V. Beiser. "The Deadly Global War for Sand." Wired. https://www.wired.com/2015/03/illegal-sand-mining/ (accessed 15. November, 2019).

[16] S. Danielsen. "Kortreist stein løser knipe." Dagens Næringsliv. https://www.dn.no/teknologi/co2/bygg-og-anlegg/debatt/kortreist-stein-loser-knipe/1-1-5228528 (accessed 15. November, 2019).

[17] M. Bengtsson, P. Svedensten, and C. M. Evertsson, "Improving yield and shape in a crushing plant," *Minerals Engineering,* vol. 22, no. 7-8, pp. 618-624, 2009.

[18] R. Cepuritis, S. Jacobsen, and T. Onnela, "Sand production with VSI crushing and air classification: Optimising fines grading for concrete production with micro-proportioning," *Minerals Engineering,* vol. 78, pp. 1-14, 2015.

[19] R. Cepuritis, E. J. Garboczi, and S. Jacobsen, "Three dimensional shape analysis of concrete aggregate fines produced by VSI crushing," *Powder Technology,* vol. 308, pp. 410-421, 2017.

[20] H. Pettingell, “An effective dry sand manufacturing process from Japan. Potential to replace natural sand entirely in concrete,” *Quarry Management Magazine,* vol. 1, pp. 1-6, 2008.
[21] T. Kaya, M. Hashimoto, and H. Pettingell, “The development of sand manufacture from crushed rock in Japan, using advanced VSI technology,” in *Proceedings of the International Center for Aggregates Research Symposium, Austin, TX, USA*, 2009, pp. 4-5.
[22] K. Aslaksen Aasly, S. Danielsen, B. Wigum, S. Norman, R. Cepuritis, and T. Onnela, “Review report on dry and wet classification of filler materials for concrete,” *State-of-the-art. COIN Project report,* pp. 52-2014, 2014.
[23] S. Skjæret, "Personlig kommunikasjon," 16.04.2020, 2020.
[24] R. Vigre, "Personlig kommunikasjon," 16.04.2020, 2020.
[25] Ø. Mortensvik, "Personlig kommunikasjon," 16.04.2020, 2020.
[26] B. G. Petersen, "Personlig kommunikasjon," 16.04.2020, 2020.
[27] O. Røe, "Personlig kummunikasjon," 16.04.2020, 2020.
[28] R. Cepuritis, “Effects of concrete aggregate crushing on rheological properties of concrete and matrix,” Norges teknisk-naturvitenskapelige universitet, Fakultet for ..., 2011.
[29] M. Alexander and S. Mindess, “Aggregates in concrete, vol. 13,” *Oxon: Taylor and Francis,* 2005.
[30] L. Murdock, “The workability of concrete,” *Magazine of Concrete research,* vol. 12, no. 36, pp. 135-144, 1960.
[31] *NS-EN 12620:2002+A1:2008+NA:2016 - Aggregates for concrete*, 2016.
[32] *NS-EN 933-3:2012 - Tests for geometrical properties of aggregates - Part 3: Determination of particle shape - Flakiness index*, 2012.
[33] N. Roussel, *Understanding the rheology of concrete*. Elsevier, 2011.
[34] M. Westerholm, B. Lagerblad, J. Silfwerbrand, and E. Forssberg, “Influence of fine aggregate characteristics on the rheological properties of mortars,” *Cement and Concrete Composites,* vol. 30, no. 4, pp. 274-282, 2008.
[35] B. J. Wigum, "Personlig kommunikasjon," 16.04.2020, 2020.
[36] T. Prestvik, *Mineralogi en innføring i krystallografi og mineralogi*. Vett & viten, 2005.
[37] J. Rakovan, "Word to the Wise: Felsic & Mafic," *Rocks & Minerals,* vol. 84, no. 6, pp. 559-560, 2009.
[38] “Classification of Igneous Rocks.” http://wray.eas.gatech.edu/epmaterials2013/LectureNotes/Lecture17.pdf (accessed 25.02.2020, 2020).
[39] A. White and H. Buss, “7.4-Natural weathering rates of silicate minerals,” *Treatise on Geochemistry, Second Edition. Elsevier, Oxford,* pp. 115-155, 2014.
[40] *Statens Vegvesen: Håndbok 014 laboratorieundersøkelser, 14.432 Kornfordeling ved sikting*, S. Vegvesen, 2005.
[41] M. Bengtsson and C. M. Evertsson, “Measuring characteristics of aggregate material from vertical shaft impact crushers,” *Minerals Engineering,* vol. 19, no. 15, pp. 1479-1486, 2006.
[42] S. Kerisit, E. J. Bylaska, and A. R. Felmy, “Water and carbon dioxide adsorption at olivine surfaces,” *Chemical Geology,* vol. 359, pp. 81-89, 2013.
[43] A. J. West, A. Galy, and M. Bickle, “Tectonic and climatic controls on silicate weathering,” *Earth and Planetary Science Letters,* vol. 235, no. 1-2, pp. 211-228, 2005.

[44] J. Schott, R. A. Berner, and E. L. Sjöberg, “Mechanism of pyroxene and amphibole weathering—I. Experimental studies of iron-free minerals,” *Geochimica et Cosmochimica Acta,* vol. 45, no. 11, pp. 2123-2135, 1981.
[45] "Register over vitenskapelige publiseringskanaler." NSD. https://dbh.nsd.uib.no/publiseringskanaler/Forside (accessed 19. November, 2019).

12. Appendix

1 ManSand Project 2019 MEMO
2 MiKS project - 2019-09-16 - WG5 meeting No.1
3 Referat - Møte med Wigum 16.03.2020
4 Report - A litterature study on aggregate production and mineralogy based on the disposision
5 Experiment Report – Change in workability due to mineralogy with and without superplasticizer
6 Experiment Report – Change in workability due to variability in water content
7 Aggregate experiment data
8 NorStone Svingen NS-EN 13043 0-4 mm art nr 76204
9 0 4 mm NorStone Svingen mars 2020
10 Ledinge 20200127 232 Ny Bergart Densitet & Vattenabsorption
11 STD FA Datablad
12 Dynamon SX-23
13 Mapetard R
14 Project description Master 2020 revised
15 Oppstartsmøte 21.01.2020
16 Veiledningsmøte 13.02.2020
17 Veiledningsmøte 06.03.2020
18 Veiledningsmøte 17.03.2020
19 Veiledningsmøte 08.05.2020
20 Crushed aggregate - An age sensitive material
21 A3 research poster - Crushed Fine Aggregate – An age sensitive material