CIV5017Z: MINOR DISSERTATION FOR THE DEGREE OF MASTER OF ENGINEERING

Use of grape pomace as a fine aggregate in concrete

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Abstract

The construction industry utilizes significant quantities of natural resources, which is most evident in the production of concrete. With the global shift towards sustainable construction materials and techniques, research has been conducted into the replacement of cement or aggregates with alternative materials. These alternatives range from recycled glass, plastic, rubber, hemp, and sawdust, to other organic materials. Minimal research has been conducted into the use of pomace in concrete.

Grape pomace is a waste by-product from the six-stage wine-making process comprising skins, stalks, and seeds. Stalks are removed during destemming at stage two while white grape pomace is removed after the pressing process, stage 3, and red grape pomace after the fermentation process, stage 4. The waste is generated annually during the harvest season and is currently either used as a conditioner in the vineyards or taken to landfill sites. The abundance of pomace in the Western Cape of South Africa necessitates the need for the valorisation of the material with the focus of this research being the partial replacement of fine aggregate in concrete with grape pomace. Grapes are the most abundant crop globally with the highest wastage factor of approximately 20% when used for winemaking. Red grape pomace from a single source in Stellenbosch, South Africa, was used as white grapes are expected to contain sugars that may retard the setting of the concrete. The stalks were omitted from the pomace and only the seeds and skins were oven dried and ground from a particle size of 3 to 5 mm down to 0.6 to 2.4 mm.

Fine aggregate in concrete aids the binding of cement, water, and coarse aggregate, increasing workability, limiting shrinkage, and reducing the cement content required to fill the voids between the coarse aggregate. Philippi dune sand was used as the fine aggregate in the concrete mix design and was replaced with the dried and ground pomace by volume at 5, 10, 15, 20, and 30%. Specimens were cast in the laboratory and cured in a temperature-controlled water bath and compression testing performed at 1, 7, 14, 28, and 56 days. Water absorption testing was performed on the pomace multiple times and the results were deemed unreliable, for this reason, the mix water quantity was kept constant in all the specimens and no adjustment was made for absorption. The slump testing displayed the effects of water absorption on the pomace with the slump decreasing with an increase in pomace content.

The compressive strength testing highlighted that an increase in pomace content resulted in a decrease in compressive strength. Two pomace specimens, 5 and 10% achieved the design strength of 25 MPa after 28 days while the control specimen achieved 1.5 times the design strength after the same 28-day period. The remaining pomace specimens all failed to reach the design strength after 28 days with the lowest strength recorded at 18.2 MPa after 28-days.

It is expected that the material properties of the grape pomace, having a lower specific gravity to the fine aggregate, were the cause of the reduction in the slump, lower density, and reduced compressive strength. The density reduction is attributed to the differing material densities between the pomace and fine aggregate, while the slump variation is because of the pomace's absorption of available mix water. The pomace particles aided the mechanical interlock while blocking the bleed water resulting in a weaker bond between the cement paste and aggregates causing the concrete specimens to experience a reduction in compressive strength. Furthermore, the low pH of the pomace could be causing an unstable environment restricting the microstructure development.

Concrete is designed for a specific compressive strength requiring a certain water-to-cement ratio. The experimental testing highlighted that pomace, even at low replacement percentages, significantly reduced the compressive strength of concrete. To achieve a 25 MPa pomace concrete, the water-to-cement ratio would have to be lowered resulting in an increased cement content. The pomace content would need to be a minimum of 30% and yield similar results to the control specimen to justify its use. Pomace is not deemed to be a suitable replacement for fine aggregate in concrete as it results in inferior concrete, is uneconomical, and increases the concrete’s carbon footprint.

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Symbols

A	Area (m^2)
CBD	Dry compacted bulk density (kg/m^3)
D	Relative density
FM	Fineness modulus of sand
K	Factor based on maximum stone size
M	Mass (kg/m^3)
M_a	Mass of stone (kg/m^3)
Ms	Mass of sand (kg/m^3)
$w:c$	Water-cement ratio

1. Introduction

1.1 Background

The depletion of natural resources results in damage to eco-systems and animal life. Annually, 29 billion tonnes of sand and gravel are mined globally with 13 billion tonnes being used in construction and this is expected to continue rising year on year (Weyler, 2018). Concrete is still one of the preferred building materials due to its ability to take on any shape, it's ease and speed of construction and durability amongst others. However, the increased use of concrete has seen a rapid depletion of fine and coarse aggregates with researchers seeking alternative aggregates and cements.

Fine and coarse aggregates are mined natural resources and continued mining will result in the depletion of these resources. Research and testing are on-going into sustainable alternatives for concrete aggregates. Owen (2019) notes that the compressive strength of coarse aggregate has shown no influence on the compressive strength of hardened concrete, and it is expected that many researchers believe alternative aggregates will yield similar results due to this.

With a shift towards sustainable construction materials and energy efficient buildings, construction materials need to be recyclable and renewable to prevent unnecessary extraction of natural resources. This combined with energy efficient buildings which reduce the heating and cooling required, generate renewable energy and treat wastewater for reuse, will reduce the construction industries impact on the environment. Efforts have been made to replace bricks and concrete with timber, utilise solar power to generate electricity and treat effluent water for irrigation of gardens. (Jackson, 2021)

Bricks and concrete utilise a significant quantity of natural resources. Bricks can be made from clay or fine aggregate and cement while concrete comprises cement with fine and coarse aggregate. The research into aggregate substitutes include by-products such as glass, rubber, hemp, saw dust, sugar cane, muscle shells, rice husk, plastic, fly ash, lime, wool or straw bales. Similarly, cement alternatives are being investigated to reduce the large carbon footprint of cement.

Testing of alternative aggregates in concrete is typically quantified by compressive strength followed by tensile strength and permeability. Compressive strength testing of alternative aggregates has mainly shown a significant decrease in the strength of hardened concrete while tensile strength reduced slightly often even increasing and, permeability predominantly decreasing. Compressive strength decreased in tests conducted using mussel shells, compost, or alum sludge as either cement or aggregate replacements. Tensile strength increased in the testing of Fathi & Fathi (2016) where 13% of the complete mix design was substituted with 6% sugar beet and 7% tragacanth gum.

The processing of fruit and vegetables generates waste in the form of skins, pips and stalk and also liquid waste from wash water. Solid waste is usually disposed of at landfill sites while liquid waste can pollute water sources and create imbalances in eco-systems. In South Africa, citrus crops have the highest yield followed by apples, grapes and olives. The Western Cape of South Africa has a large wine producing region resulting in large quantities of grape pomace being produced annually during harvest. (Warren, 2015)

Pomace is a by-product and derived from the crushing or mashing of fruit, vegetables, seeds, nuts or fish. Grapes are one of the most abundant crops globally yielding 63 million tonnes annually (García-Lomillo & González-SanJosé, 2017) with 75% being used for wine making and the remainder processed into spirits or sold as table grapes. The South African wine industry consumed 1.34 million tonnes of grapes in 2020 resulting in 1 042 million litres of wine worth R22.4 billion. Pomace constitutes 10 – 20% of the grape mass and it is estimated that South Africa generates 200 000 tonnes of pomace annually. The pomace either gets tilled into the vineyards as a soil conditioner, dumped in farm spoil pits or taken to landfill. The high cost of transportation sees most pomace remaining on the farms and mainly dumped in spoil pits. Farmers are cautious when using pomace as a soil conditioner as a high level of control is required to ensure that the pH of the soil is not altered significantly. (García-Lomillo & González-SanJosé, 2017)

Repurposing pomace as a sustainable building material can have many social, economic and environmental benefits. Not only will this result in less material being taken to landfill, but it will also create jobs for farm workers who are typically un-skilled and earn minimum wage. Farm workers are often employed on a contract basis during the harvest season and thereafter rely on government grants or part time employment to generate an income during the off-season. The Western Cape of South Africa is the main wine producing region in South Africa and the use of pomace concrete will create interest in local government or regulating authorities and potentially attract foreign investment.

To reduce the dependence on natural resources in concrete, grape pomace was tested as an alternative to fine aggregate to repurpose the waste pomace and reduce the requirement for mining of fine aggregates. This would further reduce the carbon footprint of mining and transportation required for dumping the pomace at landfill sites. The use of grape pomace concrete would primarily be limited to wine producing regions and could extend to other regions utilising other forms of pomace local to that region.

To evaluate the influence of pomace in concrete, compressive strength was investigated using a 25 MPa mix design for ease of reference against tests performed by other researchers. Philippi dune sand and Greywacke were selected as the fine and coarse aggregate respectively as it is commonly used in concrete and widely available in Cape Town. The Klipheuwel variety of sand was omitted due to the high organic content expected in the sand and it is used mainly in mortars or plastering. Slump tests were performed prior to casting the cube specimens and the effects of the dry pomace are clearly visible in the reduced slump recorded.

1.2 Problem statement

Wine farms would ideally like to repurpose grape pomace and prevent the current dumping of the material. There is a lack of guidelines on the reuse of pomace and without this, landfill sites will continue to increase, and pomace will continue to pollute soil or water systems. There is a growing need for sustainability to preserve natural resources, through the reuse of waste products, and it has become apparent that there is a need to understand the influence of pomace in concrete, particularly by substituting fine aggregates with pomace.

1.3 Research objective

The objectives of this research are:

1. Analyse literature on:
    a. How pomace is generated and the production volumes both locally and globally.
    b. The role of aggregates in concrete and the influence of alternative aggregates with a focus on organic aggregates.
    c. The factors that contribute to the performance of concrete and the relationship with the constituents’ characteristics.
2. Determine the influence of pomace in concrete.
3. Compare the testing results with similar tests performed using alternative aggregates by other researchers.
4. Determine the suitability of pomace in concrete as a fine aggregate replacement.

1.4 Scope and limitations

- Only red grape pomace was used as white grape pomace may contain traces of sugars which could retard the setting of the concrete.
- Grape pomace was only sourced from one supplier, Lievland Wine Estate in Stellenbosch.
- Grape pomace, in varying percentages, was substituted for fine aggregate only.
- Strength testing was restricted to compressive strength only.
- A single type of cement, fine aggregate, and coarse aggregate were used.

1.5 Dissertation outline

This report has been compiled in six chapters with a list of references and three appendices also included.

Chapter 1 provides a background to the research and motivates the need for the research while defining the aims and objectives. Chapter 2 is a literature review of the wine making process and by-products generated from this process, it goes on further to review South African National Standards and the use of other organic matter in bio-composite materials.

Chapter 3 details the methodology for the testing and provides more detailed material properties. Chapter 4 contains the results from the laboratory testing and discusses the findings of the results. Chapter 5 concludes the report with an analysis of the findings.

The reference list provides all the sources of literature cited in the report while the appendices provide the testing results used to generate the tables and graphs within this report.

2. Literature Review

2.1 The wine making process

Wine is believed to have originated in Georgia as early as 6000 BC, when wild yeast and wine grapes were combined, while other archaeological evidence of wine making has also been found in China, Iran, Greece, Armenia and Sicily. Wine making in South Africa only started in 1659 by the Cape Town governor Jan van Riebeeck (SAWIS, 2021). The wine making process takes place in six different phases (Robillard, 2018):

1. Harvesting
2. Destemming and crushing
3. Pressing
4. Fermentation
5. Clarification
6. Aging and bottling

Harvesting is the process of collecting the ripe fruit, grapes, from the vines and this is performed from February to May in South Africa as seen in Figure 2-1. Harvesting in the northern hemisphere takes place between September and November due to the difference in season. Grapes are harvested at different periods depending on their requirements, white grapes are generally harvested first followed by red grapes then the remaining white grapes for dessert wines. (Robillard, 2018)

Figure 2-1: Grapes are collected by workers in the vineyards during harvesting and taken to the wine cellar for processing (SAWIS, 2015)

Destemming involves the separation of the grapes from the stems before crushing, see Figure 2-2. Historically, crushing of the grapes was performed by foot but today majority of the crushing is performed by mechanical equipment. Often white grapes are left on the stem for crushing to aid the flow of juices while red grapes are always removed from the stems before crushing. The crushing process removes 80 – 90% of the juice from the grapes and the material remaining after the crushing process is known as pomace which contains the remaining juices. (Robillard, 2018)

Figure 2-2: Destemming red grapes with the berries sent for processing into wine and the stems taken to landfill sites (Machines, 2019)

Pressing follows crushing and involves the pomace being placed in a mechanical press to release the final 10 – 20% of the juices. These juices are known to be of a higher quality and are often used to create premium wines (Robillard, 2018). Figure 2-3 is a pneumatic press typically used in South African wineries.

Figure 2-3: Pneumatic grape press (Pellenc, 2021)

Fermentation is the process whereby the grapes are converted into wine through the addition of natural yeast, Figure 2-4 represent fermentation in oak barrels. During primary fermentation, the yeast consumes the grape sugars and releases carbon dioxide and alcohol. Once the alcohol level increases, the yeast becomes dormant, and fermentation stops. (Robillard, 2018)

Figure 2-4: Fermentation of grapes in oak barrel with occasional mixing (Robillard, 2018)

Clarification removes all the unwanted sediment from the wine as seen in Figure 2-5. Dead yeast cells and pomace accumulate at the bottom the fermentation tanks and need to be removed before bottling. This is either performed by allowing the solids to settle and then transferring the wine to stainless steel tanks or oak barrels or the wine is passed through a filtration system. (Robillard, 2018)

Figure 2-5: Wine prior to clarification is easily identified by the residue left on the glass(Robillard, 2018)

Aging and bottling are the final steps in the wine making process, aging of wines can be performed in the bottles, tanks or barrels and can take many years. The aging process is more common with red wines while white wines are generally bottled and distributed after clarification (Robillard, 2018). Figure 2-6 highlights a temperature-controlled barrel store, these stores are typically of concrete construction and are often built below ground level to assist with temperature control.

Figure 2-6: Wine barrel storage in temperature-controlled rooms (Wise, 2022)

The wine making process utilises between 0.5 – 14 litres of water per litre of wine for washings tanks, cellars, bottles and machinery. This wastewater often contains high quantities of solvents, detergents or chemicals which are not suitable for disposal in municipal wastewater systems. Wastewater will either be highly alkaline or acidic and have a high organic content resulting in a high biochemical oxygen and chemical demand. When wastewater is discharged into water sources it creates unpleasant odours and reduces the available oxygen causing the death of aquatic life. If discharged onto open fields, wastewater can breakdown the soil structure resulting in a lack of seed germination or low rates of infiltration into the soil (Zacharof, 2017). Easton (2016) noted that 95% of South African wineries dispose of wastewater through irrigation systems on their land while the Champagne region in France collects, treats and recycles 100% of their wastewater.

2.2 The South African wine making industry

One of the most abundant crops globally are grapes with 63 million tonnes produced annually, of which 75% are destined for the wine industry. South Africa produced 1.34 million tonnes of wine grapes in 2020 resulting in 1 042 million litres of wine being produced, yielding R22.4 billion in sales and the creation of 80 183 jobs for farm workers (SAWIS, 2021). The total global area of planted vines is 7 402 000 hectares of which 92 000 hectares (1.2%) are in South Africa, with 45% being white grapes and 55% red grapes. Spain has the largest planted area of 966 000 hectares followed by France and Italy at 794 000 and 708 000 hectares respectively. (SAWIS, 2015) Grape pomace, Figure 2-7, is the term used for all the by-products from the wine-making process and comprises of skins, seeds, stalks, and lees. Lees are composed mainly of yeast and formed after fermentation while skins, seeds, and stalks are extracted during the initial crushing process or after fermentation. (García-Lomillo & González-SanJosé, 2017; Portilla Rivera *et al.*, 2021)

Figure 2-7: Grape pomace directly after pressing the juice from the berries prior to transport to landfill sites (Vinpro, 2021)

2.2.1 Properties of winery by-products

Grape pomace contains a rich source of phenolic acids, citric acid, dietary fiber, flavonoids, lipids, cellulose, and oil (Arvanitoyannis *et al.*, 2006; Portilla Rivera *et al.*, 2021). Red grapes undergo fermentation while still in contact with the grape skins and seeds, while skins and seeds are removed before fermenting white wine. As a result, fermentable sugars remain in white and rosé grape waste unlike that of the red grape waste. The waste comprises 43 – 75% dietary fiber, 6 – 15% protein, and 14 – 17% lipids which means it can be repurposed or combined into food colourings, flavouring, soft drinks, medicines, cosmetics, and animal feed. (García-Lomillo & González-SanJosé, 2017)

Grape seed properties were investigated by Milani & Moetamedzadegan (2019) and found the seeds to be composed of 8-15% oil and 90% poly and monounsaturated fatty acids. They tested the seeds at moisture contents ranging from 12.3 to 24.6% and found the geometric mean diameter to be between 3.71 and 3.82 mm, the bulk density was 469.3 to 546.3 kg/m^3 and true density was 1058.7 to 1159.3 kg/m^3. Porosity decreased with the increase in moisture content from 55.7 to 52.9%. Sousa et al (2014) tested grape pomace from Northeast Brazil which included the skins and seeds by drying and grinding the pomace into flour with particle sizes between 0.42 and 0.60 mm. They found that 1 kg of raw material resulted in 321 grams of dried pomace flour with the flour having a pH of 3.8 in comparison to 3.7 of fresh grapes, the moisture content was 3.3%, glucose 7.9%, fructose 8.9%, and no sucrose was present. Palma & Nicolai (2020) tested eight grape pomace specimens that they oven-dried and milled in a domestic blade grinder, the specimens were from Portugal, and they found the pH to vary between 3.7 and 4.5 while the moisture content ranged between 3.4 and 9.6.

2.2.2 Utilisation of winery by-products

Grape waste is often reworked back into vineyards as a soil conditioner, composting of the waste is another common practice that requires the addition of organic matter and machinery on site to mechanically turn the composting piles. Composting, therefore, is a lesser preferred method of utilizing the waste due to the cost, time, and expertise involved in the process. Applications of fresh pomace are minimal due to its high-water content which limits chemical and microbiological stability. Fresh pomace is incorporated into cheese to assist with ripening. Methods to preserve pomace include blast freezing or drying using ovens or sunlight. Freeze drying ensures the bioactive compounds are retained however, this process can cost up to eight times that of drying. (García-Lomillo & González-SanJosé, 2017; Portilla Rivera *et al.*, 2021)

Brenn-o-Chem, a South African based company, purchase grape pomace from wineries and process it through their centrifuge system to recover wine, yeast and tartrates. Their wine extract is sold to local brandy and fortified wine producers, the yeast is used in animal feed and the tartrates exported to Spain or Italy to produce tartaric acid. The South African market is too small to justify a tartaric acid plant; however, 90% of the imported tartaric acid is used in the wine industry while the remaining 10% being used in pharmaceuticals. (Easton, 2016)

Grape seed oil is extracted from the seeds of the grapes during a pressing process and is perceived as a healthier alternative to other oils although its price is much higher than most oils. Skins and seeds are dried and ground into flour as a wheat flour alternative or incorporated into seasonings due to its antioxidant and antimicrobial properties which also allow the reduction of salt in food items. Other food items include; bread, biscuits, cereals, colouring, pasta, yoghurt, ice cream and sausages with pomace constituting up to 30%. (García-Lomillo & González-SanJosé, 2017)

2.3 Applications of pomace

Pomace is defined as any substance which remains after pressing, crushing or mashing and typically refers to fruit and vegetables but also includes nuts, seeds or fish amongst others (Webster, n.d.). Juice or oil is obtained during this process and the pomace is primarily seen as a waste product in the process.

Carrot, beetroot and apple pomace was trialled in pasta as a flour replacement ranging between 10 and 30%, through consumer participation the 10% carrot replacement was the preferred (Kultys & Moczkowska-wyrwisz, 2022). Apple pomace represents only 20 – 35% of the fresh weight with the main product being juice. The largest producers in Europe are Russia, Poland, Germany, France and Turkey with the pomace being used for animal feed or food production (Adrian *et al.*, 2021).

2.3.1 Applications of pomace in building materials

The olive oil industry globally produces 30 million tonnes of pomace annually. During the pressing process, 20 – 30% of the olive weight is extracted while 70 – 80% becomes pomace. Zhang, Zhao & Wang (2022) investigated the use of olive pomace as a binder replacement in asphalt. The pomace was broken down in a pestle and mortar and then finely ground in a coffee grinder from a particle size of 4.75mm to 1.18mm. The ground pomace was tested at 5, 15 and 25% binder replacement with a non-polymer modified binder. They found that 15% replacement yield lower cracking than the control specimen and similar rutting resistance.

The use of ground olive pomace aggregates (OPA) and olive pomace mill wastewater (OPMW) was investigated by M. Boukhari (2023) in cementitious materials as a substitute for natural sands. The testing included olive pomace aggregates substituted with sand by volume of 5, 10 and 15% and olive aggregates combined equally with olive pomace and substituted with sand by the same volumes. The dried and ground materials can be seen in Figure 2-8. OPA had a bulk density of 530 kg/m^3 and OPMW 550 kg/m^3.

Figure 2-8: Olive pomace aggregates, when dried, have a larger particle size when compared visually to natural sand (Boukhari, 2023)

The control specimens achieved a compressive strength of 40 MPa for both specimens while the pomace specimens all performed significantly lower as seen in Figure 2-9. The research concluded that workability decreased given the increase in olive pomace content and an increase in porosity was also observed. The control specimens exceeded the design strength of 30 MPa along with the 5% OPMW specimen, all other specimens failed to achieve the design strength.

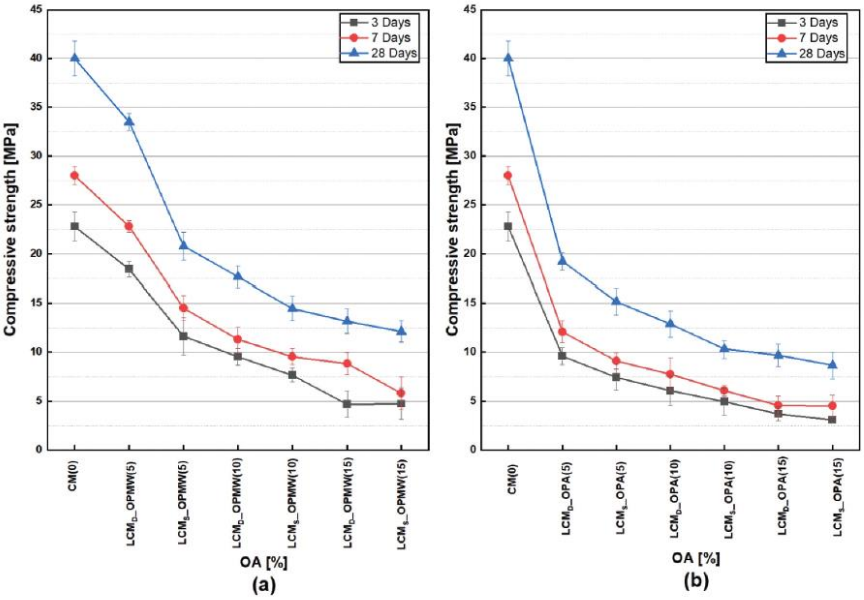


Figure 2-9: Compression strength of olive pomace at different percentages (Boukhari, 2023)

The replacement of clinker with olive pomace and kernels to determine the effect on mechanical strength and setting time of cement was investigated by Lila et al. (2020). The pomace was dried and ground, Figure 2-10, then shock-burned at a temperature of 900 ˚C for 1 hour, Figure 2-11. The pomace and kernel specimens performed similarly with specimens containing 10 and 30% replacement experienced a 25% decrease in compressive strength after

28-days however, when tested at 365-days a 2% decrease was seen in the 5% specimen and 5% decrease in the 30% specimen. The testing highlighted that shock-burned olive pomace and kernels are pozzolanic and mixed with Portland cement contribute to the consumption of calcium hydroxide leading to the formation of calcium silicate hydrate gel reinforcing the strength of the cement.

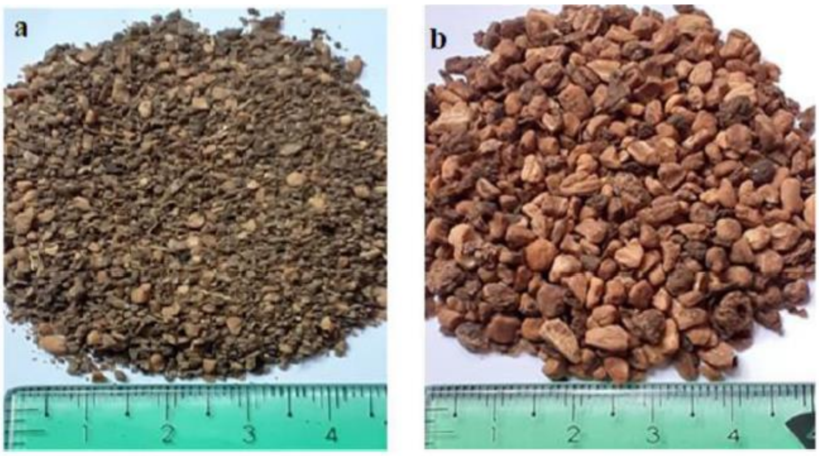


Figure 2-10: Ground olive pomace (a) and ground olive kernels (b) prior to shock-burning (Lila *et al.*, 2020)

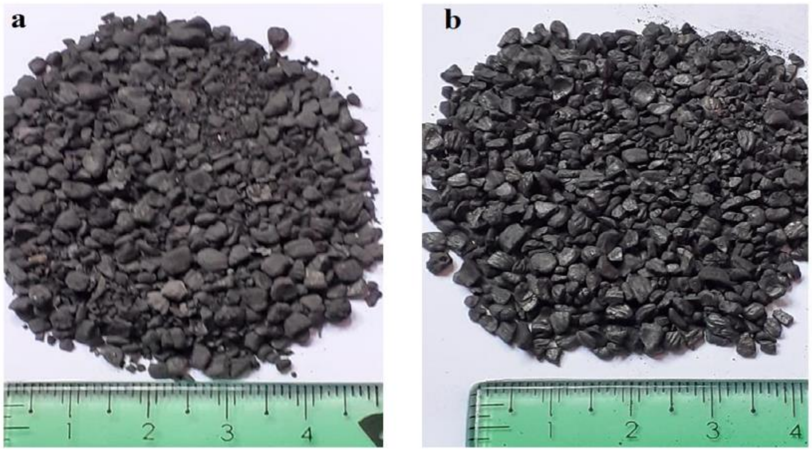


Figure 2-11: Ground olive pomace (a) and ground olive kernels (b) post shock-burning (Lila *et al.*, 2020)

Grape pomace was used as a foaming agent to produce lightweight clay bricks by Taurino et al., (2019). The pomace was oven dried and milled in a grinder before being passed through a 1mm sieve to achieve a uniform particle size. The bricks were extruded and contained 5 or 10% pomace by volume prior to being oven dried and fired. The oven drying although increasing the pomace energy requirements and CO^2 footprint, helped to reduce the moisture content while firing was performed at 980 ◦C for 30 minutes then allowed to cool for 12 hours. The results displayed an increase in water absorption, due to the dried pomace, a decrease in linear shrinkage and decrease in flexural strength. The 5% specimen achieved flexural strengths of 12.5 MPa compared to the control at 15.5 MPa with both achieving the 1.5 MPa required to meet European standards

2.4 The use of by-products as Biocomposites materials

Biocomposite materials comprise natural fibers combined in a matrix material, these matrix materials can be biodegradable, non-biodegradable or synthetic. Natural fibers are often waste products and are degradable, renewable and non-toxic. The largest yield globally of natural fibers is bagasse, the dry pulp of sugarcane after crushing with a production volume of 102 million tonnes annually. In comparison, cotton has an annual yield of 19 million tonnes globally and bamboo 10 million tonnes. With the global shift towards sustainability, more attempts are being made to replace synthetic fibers with natural fibers; however, their advantages and disadvantages need to be considered. The advantages to natural fiber composites are that they are light weight which reduces fuel consumption when used in vehicle parts and are also good sound absorbers. The disadvantages are their poor fire resistance, low thermal resistance, low mechanical properties and due to their hydrophilic nature tend to swell when exposed to water. Biocomposite material properties are highly dependent on the natural fibers and unlike synthetic fibers, the plant fiber properties differ according to regions, climate or plant type and these factors are often dealt with through chemical treatments. As a result of pre-treatment required and the rich source of raw materials, biomass is often used in animal feed instead of being converted into fuels, chemicals, bioplastics, detergents or oils. (Bharath & Basavarajappa, 2016; Zacharof, 2017; Robbins, 2020)

The textile industry uses natural fibers to manufacture ropes, sacks, bags and even clothes. In the construction industry, Biocomposite materials are used to produce window frames, doors, ceiling boards, floor coverings and roof tiles. Bharath & Basavarajappa (2016) note that natural fibers comprise six basic types:

1. Bast fibers – Jute, flax, hemp, ramie and kenaf
2. Leaf fibers – Abaca, sisal and pineapple
3. Seed fibers – Coir, cotton and kapok
4. Core fibers – Kenaf, hemp, jute
5. Grass and reed fibers – Wheat, corn and rice
6. Other fibers – Wood and roots

Natural fibers have been extensively used in the automotive industry with manufactures such as Audi, Ford, Mercedes-Benz and Volkswagen using composite materials for interior and exterior applications on vehicles. Mercedes-Benz fabricated some of their interior door panels using mats which contain 60% natural fiber and combine these with Baypreg polyurethane resins, as opposed to using synthetic fibers like glass, carbon, Kevlar or nylon.

The plastics sector is far behind on their shift to bioplastics, and this is likely due to their lower strength properties than that of synthetic plastics and higher cost of manufacturing. Synthetic plastic is made from oil while bioplastic is made from corn or sugarcane. In 2019, 368 million tonnes of plastic were produced globally with only 2.11 million tonnes of this being bioplastics and of that, 55.5% were biodegradable. This equates to 0.3% of all plastic produced being biodegradable. It is estimated that 11 million tonnes of plastic end up in the ocean annually. The highest demand for plastic is seen in packaging (42%) followed by the construction industry (19%) and textiles industry (17%). Coca-Cola has trialled a Plant Bottle made from 30% sugarcane and 70% traditional oil-based plastic. The Plant Bottle makes up 7% of their bottle volume and has seen little growth due to the high production costs. (Robbins, 2020; Manu *et al.*, 2022)

Biocomposite boards consist of biodegradable polymers and bio fibers which act as the matrix material and filler respectively. White and red grape waste was tested as a filler material when used with soy flour and polyvinyl alcohol as binders. The grape waste displayed differing results when comparing flexibility and biodegradability with the white grape outperforming the red grape in flexibility, but the opposite was observed for biodegradability. The research conducted by Jiang et al (2010) concluded that the Biocomposite red grape boards are suitable for the agricultural and food industry where packaging materials require high mechanical strength and stability in water while the white grape board is better suited for applications that have minimal exposure to water and are required to biodegrade at a faster rate.

Coir is the outer husk of the coconut and a waste product from coconut production. Each coconut tree produces between 50 and 100 coconuts annually and the estimated global yield is 50 billion coconuts or 1.25 million tonnes. The kernel or white flesh is used to manufacture oil, cream, milk or gets dried while the shell and coir are seen as waste products. Most of this waste is used for soil conditioning to improve porosity and increase water retention while other applications include manufacturing of brushes, rugs or geotextiles, floor finishes, insulation or building materials. Like most other natural fibers, it has limitations when used in Biocomposite materials and predominantly gets used in horticulture applications. (Both *et al.*, 2022)

2.5 The effect of substituting concrete constituents

The use of organic material in concrete has been researched with laboratory tests conducted by many researchers to establish the effect it has on plastic and hardened concrete. Organic matter is often found, in small traces, within the fine aggregates used in concrete. Most of the concrete produced in the Cape Peninsula makes use of sand from the Cape Flats or Klipheuwel mines. The sand mined in the Cape Flats is dune sand classified into shell-free and shell-bearing sand, the shell-bearing sands contain 25 to 30% shell contents when measured as carbonate. Klipheuwel sand is siliceous pit sand that often contains organic matter which could result in set retardation in concrete mixes. Retarders are added to concrete when increased setting time is required, an example of this is when concrete is used in sprayed or exposed aggregate surfaces applications. (Owen, 2009)

The effect on compressive strength of cement substituted with molasses was investigated by Jumadurdiyev et al (2005) while Fathi & Fathi (2016) proposed the use of sugar beet fiber and tragacanth gum. The replacement of cement with 0.2, 0.4, and 0.7% equivalent weight of three molasses variants resulted in lower 3-day compressive strengths but slightly increased strength after 7 days or longer when compared to control specimens. The setting time can be up to six times longer than the control specimen as seen in Table 2-1. The experiments conducted by Fathi & Fathi (2016) also replaced cement with organic materials but at a higher ratio of 1 – 7% resulting in higher slump flows but lower compressive strengths. The control specimen had a slump flow of 50 cm and compressive strength of 37 MPa while the 7% replacement specimen had a slump flow of 85 cm and compressive strength of 32.5 MPa. The setting time of the cement was noted as 135 minutes however, unlike Jumadurdiyev et al (2005), the actual set time of each specimen was not documented.

Table 2-1: Setting time of cement replaced with molasses (Jumadurdiyev *et al.*, 2005)

	0.2% Cement replacement		**0.4% Cement replacement**		**0.7% Cement replacement**	
	Start (min)	**End (min)**	**Start (min)**	**End (min)**	**Start (min)**	**End (min)**
Control	155	255	155	255	155	255
Carsamba molasses	450	560	720	1145	945	1470
Konya molasses	520	655	780	1070	1110	1400
Corum molasses	475	580	760	1000	930	1370

Mussel shells as a replacement for fine aggregate was investigated by *Martínez-García et al* (2017). The shells are ground to a fine powder and analysed for their physical and chemical properties; the organic content of the mussel shell is below 2.5% when measured with the potassium permanganate method. Their mix design saw fine aggregate being replaced with fine mussel shell sand having a fineness modulus of 4.64 while coarse aggregate was replaced with mussel shell gravel, fineness modulus of 5.38. Nine mix designs were created for structural concrete, intended for marine applications, while ten mix designs were created for non-structural concrete. Mussel shell replacement ranged from 0 – 67%. Testing of concrete cube specimens in the laboratory identified the optimum replacement of fine or coarse aggregate at 25% combined or 12.5% of each aggregate.

Green alternatives for aggregates in concrete are becoming more important with the depletion of current resources (Owen, 2009; Muthulakshmi *et al.*, 2021). Organic waste is often incinerated or stored in permanent landfill sites which Ablison (2019) claim leads to less recycling and affects human and animal life among others. The recycling of solid organic waste has upcycling potential to be used in concrete by replacing fine aggregates. The testing conducted by Muthulakshmi and Uma & Hemalatha (2021) involved replacing fine aggregate with 20, 25, and 30% dried compost in a 25 MPa mix design, the specific gravity of the compost was 2.59. The 7- and 28-day cube testing results have been provided in Table 2-2 and the report recommends a maximum fine aggregate replacement with compost of 25% based on compressive strength only. The favourable results have been contributed to the early strength development of concrete containing compost.

Table 2-2: 7 & 28 day cube results for compost replacement (Muthulakshmi *et al.*, 2021)

Replacement of sand with compost (%)	7-day cube strength (Mpa)	28-day cube strength (Mpa)
20	16.9	25.8
25	16.8	25.4
30	16	24.3

With the large volumes of sludge produced from wastewater treatment plants, that would typically be disposed of at landfills, Yee et al (2021) tested concrete specimens with alum sludge replacement of cement up to 8%. Their mix design was for 20 MPa concrete and the compressive strength, slump, water absorption, and porosity results can be seen in

Table **2-3**. While the compressive strength and workability decrease with the increase in alum sludge, the contrary is seen with water absorption and porosity. The authors recommend 4% cement replacement with alum sludge when considering compressive and flexural strength only.

Table 2-3: Compressive strength, water absorption, and porosity of cement replaced with alum sludge (Yee *et al.*, 2021)

Replacement of cement with alum sludge (%)	Compressive strength 28 days (Mpa)	Flexural strength 28 days (Mpa)	Slump (mm)	Water absorption 28 days (%)	Porosity 28 days (%)
0	40.5	3.0	85	4.0	8.5
2	25.1	2.7	45	1.9	6.7
4	30.8	3.0	30	1.4	5.7
6	23.8	2.2	25	1.2	3.8
8	21.9	2.0	20	1.0	3.3

Pesce et al. (2021) studied the influence of organic materials on calcium hydroxide crystallisation formation during lime slaking. The research investigation was carried out prior to slaking and 6 months afterwards and found that the calcium hydroxide crystals were modified by the organic molecules. The calcium hydroxide crystals overdeveloped unstable faces and the crystals were much smaller in size. These unstable faces increased the chance of carbonation and mechanical failure.

Reinforced mortar specimens containing 4% aerobic microorganisms were tested by Kawaai et al (2019) to determine their corrosion resistance. The research highlighted an increase in corrosion resistance when using half-cell potential along with microcell and macrocell corrosion current density. The aerobic process was believed to have reduced the dissolved oxygen in the pore solution resulting in an increased corrosion resistance. The resistance to salinity and low pH were also tested and the microorganisms remained stable under these conditions. Compressive strength displayed a reduction of 7% given the 4% addition.

The effects of water absorption in the concrete mix design has been ignored by most researchers although it has shown significant impact on slump readings. Sisman, Gezer & Kocaman (2011) investigated compressive strength and water absorption of rice husk replaced with coarse and fine aggregates at a volume ratio of 5, 10, 15, 20, 25 and 30% and a constant water to cement ratio of 0.6. Compressive strength reduced by a minimum of 9% and a maximum of 47%, while water absorption ranged from 3% for the 5% replacement specimen and 5.5% for the 30% specimen.

Absorption of wheat straw ash was investigated by Memon et al (2021) and found the ash to have a water absorption of 13.6% while the fine aggregated was only 2.4%. the ash had a relative density of 1.89 while the Lawrencepur river sand from Pakistan had a relative density of 2.62 a water to cement ratio of 0.5 and design strength of 21 MPa. The fine aggregate was replaced with the wheat straw ash by volume of 5, 10, 15 and 20% and the slump increase was almost linear with the control being 25mm followed by an increase of 148, 180, 212 and 240% for the specimens which was expected as a result of the absorptive properties of the ash. Compression strength saw increases of 19, 39, 16 and 12% at 28-days and this is believed to be as a result of the pozzolanic nature of the ash. Water absorption of the hardened concrete decreased with the increased ash content and this is suspected to be as a result of the clogging of voids due to the pozzolanic reaction and filler effects caused by the ash.

2.6 South African National Standards (SANS) on concrete aggregates

Aggregates can be classified as being formed through the disintegration of rock or by mechanical crushing or milling of rock and can often be blends of the two processes. Fine aggregates are classified according to sieve analysis and must be retained on a 75 µm sieve with 90% of its mass passing through the 4 750 µm sieve. Masonry cement is permitted, SANS 50413:2004, to contain 0.5% organic additives by mass of cement in addition to the usual constituents of Portland cement clinker and inorganic material while organic pigments are not permitted. (SANS 50413, 2004; SANS 1083, 2006)

2.6.1 Testing for organic matter in fine aggregate

Often remote construction sites have abundant resources for use in construction but when tested are deemed not fit for purpose according to the standard codes of reference and design manuals. Importing materials is usually not financially viable and engineers seek alternative ways to utilize the materials. SANS 1083:2006 allows the use of aggregates in concrete that fail to meet the acceptance criteria, on the basis that the use of the aggregate is unavoidable. The concrete characteristics when tested with the site-specific aggregates must also not be impaired or cause future long-term durability concerns. (SANS 1083, 2006)

The test methodology to establish the presence of organic matter in fine aggregates is documented in SANS 5832:2006 and involves the submersion of fine aggregates in a reference solution which is compared to a control specimen. The reference solution comprises tannic acid, ethanol, and sodium hydroxide. A 2.5 mL specimen of tannic acid (2% volume fraction solution) and ethanol (10% volume fraction) is combined with 97.5 mL of sodium hydroxide solution (3% solution in distilled or demineralized water) to make up the reference solution. When the solution is combined with the fine aggregate, agitated, and allowed to settle for 24 hours, aggregates containing organic matter will produce a darker solution when compared to washed specimens. (SANS 5832, 2006)

Table 2-4 is an extract from SANS 1083:2006 and notes that the colour of the liquid above the fine aggregate, when performing a test for organic content, shall not be darker than the reference specimen unless the fine aggregate complies with the requirements for deleterious impurities. The table also notes that concrete specimens containing soluble deleterious impurities shall achieve strengths of at least 85% of a control specimen. (SANS 1083, 2006)

Table 2-4: Extract from Table 1 of SANS 1083:2006 (SANS 1083, 2006)

1	2	3	4
	Class		
Property	**Fine aggregate is derived from the natural disintegration of rock and any mixture (blend) of this class and fine aggregate is derived from the mechanical crushing or milling of rock**	**Fine aggregate derived from the mechanical crushing or milling of rock**	**Test method subclause**
Organic impurities	The colour of the liquid above the fine aggregate shall not be darker than the colour of the reference solution, except that this requirement shall not be applicable if the fine aggregate complies with the requirement for soluble deleterious impurities.	-	6.8
Presence of sugar	Free from sugar unless the fine aggregate complies with the requirement for soluble deleterious impurities.	-	6.9
Soluble deleterious impurities	The strength of specimens made with the fine aggregate shall at least be 85% of that of the specimens made with the same fine aggregate after it has been washed, except that this	-	6.10

	requirement shall not be applicable if the fine aggregate complies with the requirements both for organic impurities and for the presence of sugar.		

2.7 The role of aggregates in concrete

2.7.1 Classification of aggregates

Aggregates are a vital component of concrete and make up 75-80% of the volume. Aggregates act as a structural filler in concrete reducing the cement content, the cement paste coats the aggregates and binds the mix. The aggregate shape, size and composition play an important role in the concrete workability, durability, strength and shrinkage.

Aggregates can be classified as natural, manufactured, by-products or recycled aggregates from inorganic or construction materials. Natural aggregates are formed through the weathering of rock through wind or water and are mined and used without processing. Manufactured aggregates are produced by crushing igneous, sedimentary or metamorphic rock and screening to achieve the desired grading. Synthetic aggregates are either by-products like slag, fly ash and blast-furnace slag or require processing into aggregates like expanded clay, shale or slate often used as light weight aggregates. Recycled aggregates are produced through processing of waste products such as concrete, glass, rubber, asphalt or bricks. Aggregates are further defined into fine and coarse aggregates. Fine aggregates comprise of material whereby 90% of its mass passes through the 4.75mm sieve while coarse aggregates are all the material retained on the 4.75mm sieve and higher. (Domone *et al.*, 2010; Suchorski, 2018; Alexander, 2021)

Fine aggregates passing the 150 and 300 µm has the greatest influence on workability, cohesiveness and bleeding of fresh concrete. Fine aggregates results in a well graded mix and aids pumpability as the round sand particles are easier to pump than the sharp angular shape of the coarse aggregate alone. Coarse aggregates have a minor influence on fresh concrete and are typically specified, in South Africa, as 20mm gap-graded for most concrete mixes. Gap-graded aggregates are single size and combine well with coarse crusher sands. Continuous grading results in aggregates of varying size resulting in less segregation of wetter mixes, increased pumpability and increased flexural strength. Examples of single sized or gap graded, poorly graded and well graded or continuous graded aggregates can be seen in Figure 2-12. (Suchorski, 2018; Baylinx, 2023)

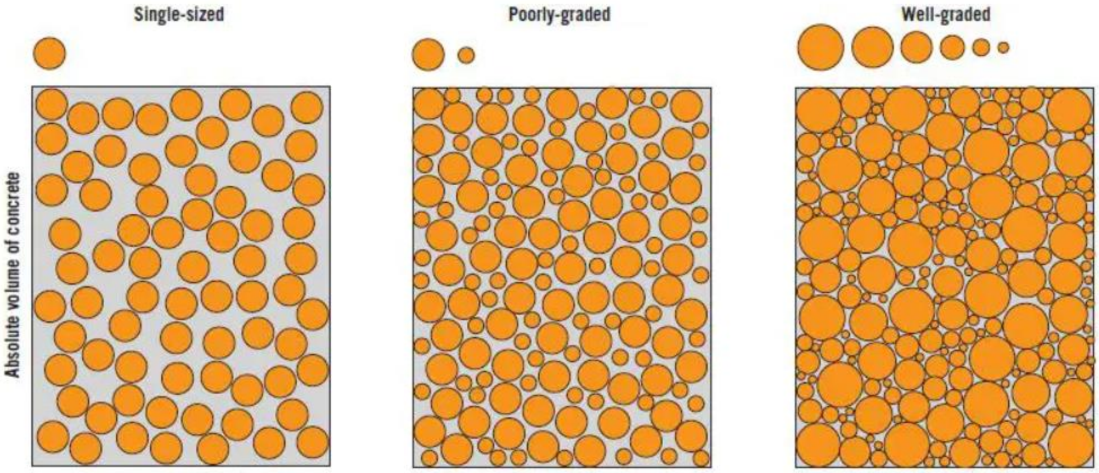


Figure 2-12: Aggregate grading (Baylinx, 2023)

2.7.2 Particle shape and texture

The particle shape and texture play an important role in water absorption, particles that are more rounded and spherical tend to absorb less water when compared to flaky or angular particles due to the increased surface area. The increased surface area may result in increased water demand but will also increase the mechanical interlock between the particles resulting in higher compressive strengths. Increase water demand is also seen in particles with rough surface textures because of the increased surface area. The particle shapes can be seen in Figure 2-13. (Alexander, 2021)

To achieve higher flexural strengths, more angular particles can be used because of the increased bond strength. Similarly, rougher textures can increase compressive strength in concrete. Aggregates can be selected based on the required concrete performance and the water to cement ratio must be adjusted accordingly. (Domone *et al.*, 2010)

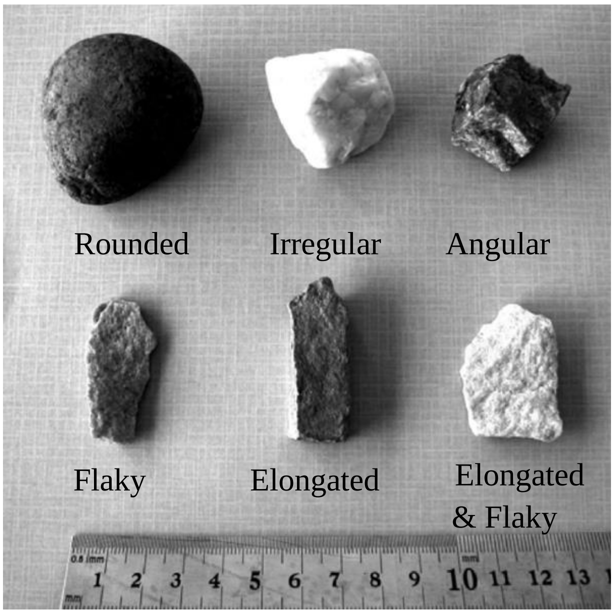


Figure 2-13: Aggregate particle shape (Alexander, 2021)

2.7.3 Absorption and surface moisture

Absorption of aggregates is relative to the internal pores, the larger the pore content, the higher absorption of the aggregate. This concept is illustrated in Figure 2-14 with pore and surface absorption shown. The various stages are classified as:

- Damp or wet: Pores and surface wet with excess free water
- Saturated surface-dry: Surface dry with pores fully saturated
- Air-dry: Surface dry but contains pore moisture
- Oven-dry: Fully absorbent

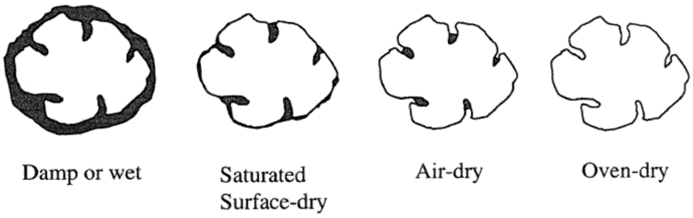


Figure 2-14: Moisture conditions of aggregates (Suchorski, 2018)

Batching plants must understand the moisture conditions of their aggregates to adjust the water to cement ratio of the concrete. Dry aggregates will absorb available mix water resulting in higher strengths with lower workability. Wet aggregates will increase the available mix water resulting in increased slump and lower concrete strength. Alexander (2021) notes that typically quarried aggregates in Southern Africa have absorption rates of below 0.5%.

2.8 Concrete density

The application of concrete will typically influence the density required to meet the design requirements. Low density or high-density concretes see a variation in the aggregates used with low density non-structural concrete often using light weight aggregates like polystyrene or air entraining admixtures to achieve higher thermal resistance and high-density concretes using magnetite or haematite aggregates. Segregation of the concrete can occur with the variation of aggregates and especially when concrete is transported, pumped, placed and compacted, this can also occur in conventional concrete. (Suchorski, 2018; Alexander, 2021)

The density of concrete plays an important role in the analysis of a structure as the self-weight of the items need to be considered. Along with this, the mass of a structure is used when analysing a structures ability to withstand vibration or dynamic actions often associated with seismic design. The density of non-structural low-density concrete will influence the concrete's ability to dampen noise or thermally insulate a structure. Concrete density typically ranges between 800 kg/m^3 for low density, 2 300 kg/m^3 for conventional concrete and 3 800 kg/m^3 for high density. Spherical or rounded aggregates are known to increase workability and concrete density in high density mix design while flay or angular particles reduce workability. When aggregates of varying densities are combined settlement of the coarse aggregate may occur. (Owen, 2009)

2.9 Closure

The wine industry in South Africa is a significant contributor to jobs and revenue for the country albeit only 1.2% of the global market. Whilst the six-stage wine making process remains an age-old tradition, little research into the use of pomace in concrete is available. Most applications of pomace include extraction of oils from the grape seeds or complex processing to extract wine for brandy, yeast or tartrates. Pomace is the term used for the substance remaining after crushing, pressing or mashing and is not unique to grapes, olive pomace is one of the largest by-products from the olive oil pressing process and this has been tested successfully as a binder replacement in asphalt. Pomace, after shock-burning, has also been proven to act as a pozzolanic material and can be substituted for clinker given the limitations listed.

Pomace, like other natural fibers is an organic material which will decompose when exposed to moisture and oxygen. Natural fibers when combined with a binding material are known as Biocomposites and can be seen in boards, bags, packaging and even the Plant Bottle manufactured by Coca-Cola. Organic materials in concrete have been tested by researchers and these include saw dust, rice husk, or coconut coir amongst others with varying levels of success. The organic material has either been a substitute for the fine aggregate or cement and in both scenarios, never exceeded 25% substitution. The South African National Standards on concrete and aggregates allows for minor organic impurities however, it does not recommend the use of organic material in concrete as they can be deleterious substances. The characteristics of aggregates has a direct link to their particle shape and texture and their substitution with alternative particle shapes and densities has proven to have varying results under testing. The material properties and testing methodology, for the experiments, will be discussed in Chapter 3.

3. Methodology

To quantify the influence of pomace on concrete compressive strength, experimental testing was required as the literature review provided no insight into this, and no tests of pomace concrete were identified. The methodology to test and evaluate the findings will be described in detail within this chapter along with all the materials and their properties.

Material properties had to be obtained for use in the mix design and this involved the selection of cement and aggregates as listed in the concrete components sub-section. Materials chosen are all locally available within the Western Cape and are typically used in conventional concrete. Laboratory testing was performed to obtain densities, fineness modulus and grading curves of materials which served as input data for the mix design. Pomace was substituted for fine aggregate on a volumetric basis and the six mix designs have been provided in Table 3-1 of sub-section 3.2. In addition, the design slump and failure modes have been provided along with the curing method for the cube specimens and compressive strength testing procedure performed.

3.1 Concrete components

3.1.1 Cement

CEM II A-L 52.5 N from PPC Cement was used. This cement is widely available for purchase in South Africa and is suitable for concrete construction. CEM II A-L is a blended cement comprising 80 – 94% clinker, 6 – 20% limestone, and 0 – 5% minor additional constituents. The cement has a relative density of 3.14. (Cement and Concrete Institute, 2009; PPC, 2018)

3.1.2 Fine aggregate

Philippi dune sand was used as the fine aggregate and is commonly used in concrete and widely available in Cape Town. The Klipheuwel variety of sand was omitted due to the high organic content expected in the sand and it is used mainly in mortars or plastering. (Owen 2019)

Vibratory sieve analysis was performed in the UCT laboratory on a specimen taken from the Philippi dune sand stockpile as documented in Table . The grading curve, plotted against a logarithmic scale, can be seen in Figure 3-1**.** The fine aggregate has a relative density of 2.65 and a consolidated bulk density of 1 728 kg/m^3.

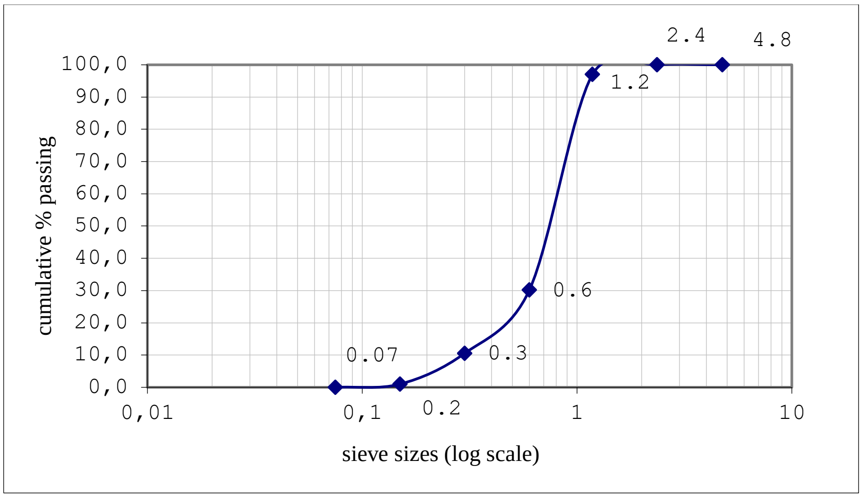


Figure 3-1: Grading curve of Philippi dune sand

3.1.3 Coarse aggregate

The coarse aggregate used was 19 mm Greywacke, graded by vibratory sieve analysis which is widely available in Cape Town and the Western Cape region. The coarse aggregate grading curve can be seen in Figure 3-2 respectively. The coarse aggregate has a relative density of 2.7 and bulk density of 1 650 kg/m^3.

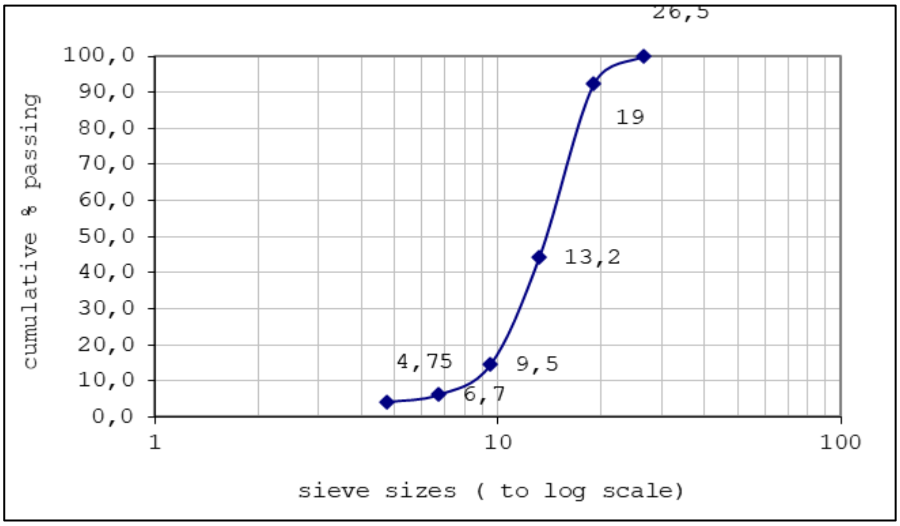


Figure 3-2: Grading curve of 19 mm greywacke

3.1.4 Grape pomace

Grape pomace was obtained from Lievland Wine Estate in Stellenbosch, the specimen weighed 100 kg before it was oven-dried, and ground using a disc grinder in the laboratory. The skins and seeds were used only, and no stalks included. The fresh grapes when brought to the cellar are still on the stalks and get put into a de-stemming machine which removes the grape from the stalk, the stalks are then dumped as they provide no value in the wine making process. When processing white wines, the grapes are pressed, and the juice is extracted while the pomace is immediately taken to a dump site. When processing red wines, the grapes are pressed, and the juice and pomace are left in contact for a period of between 1 and 21 days. This makes the sorting of red and white wine grapes much easier onsite. Only red wine grape pomace was used as white wine grape pomace may contain sugars which could have influenced the setting times and testing results of the concrete.

For applications outside of the laboratory, the pomace can be spread over concrete hardstands and sun dried during the summer harvest season taking up to 3 days to dry. The harvest season in the Western Cape typically starts in the summer month of February and continues to March or April, this will allow fast drying of the pomace with minimal rain expected. After drying the pomace, it must be collected and stored within an enclosed shed. To grind the pomace a hammer mill can be used which most farms own, these mills are typically used to grind grains for use in animal feed. The grinding process achieves a finer material which is better matched to that of the fine aggregate.

The grape pomace sieve analysis can be seen in Table while the grape pomace and Philippi dune sand grading curve have been shown in Figure 3-3 for comparative purposes. The pomace retained 65% of the specimen on the 1.18- and 2.36-mm sieve in comparison to only 3% retained on the similar Philippi dune sand grading. The Philippi dune sand retained 86% of the specimen on the 0.3- and 0.6-mm sieves. This variation allows for a better grading of the aggregate.

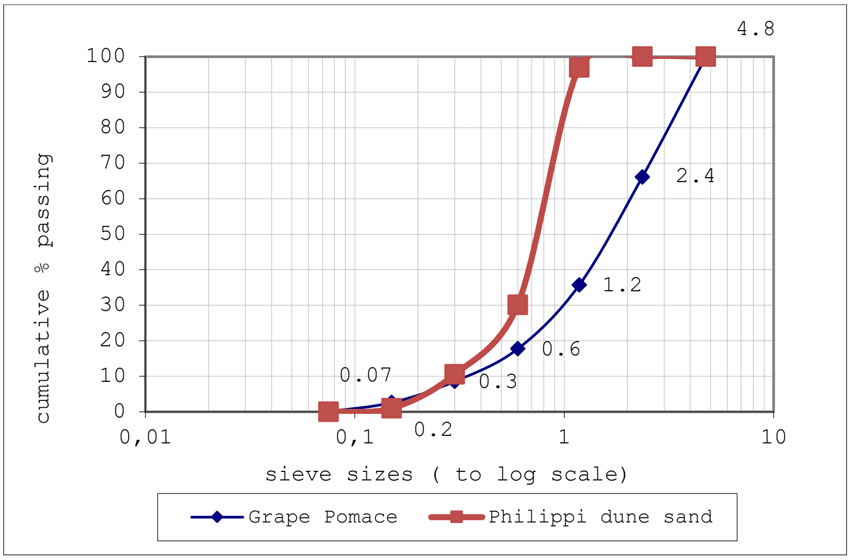


Figure 3-3: Grading curve of grape pomace & Philippi dune sand

The relative density of the pomace was determined using the SANS 5844:2006 methodology whereby oven dried and saturated surface dry material is used. The standard code stipulates that the result must be accurate to the nearest 0.01 and therefore a scale with equivalent accuracy was used. The testing results achieved an average relative density of 1.1. Moisture content of the specimen was determined by weighing a 10 kg fresh specimen and then oven drying it for 24 hours, the dried mass was then used to calculate an average moisture content of 56%. Loose bulk desnity and compacted bulk density was recorded as 543 and 652 kg/m^3 respectively while the fineness modulus was 3.7. The results for all these items can be seen in Appendix A.

A pomace specimen was tested for water absorption according to the test and analysis criteria provided in SANS 3001 AG21:2014. A total of six tests was performed with results yielding vastly different absorption values. Due to this it was decided that the results will not form part of the testing. The mix design has not compensated for water absorption and no additional water was added.

The pomace particle shape, before grinding, Figure 3-4 was well rounded with a high sphericity while after grinding, Figure 3-5 they became angular with a low sphericity. The texture of the fresh pomace is comparable to raisins, dried pomace is comparable to small nuts or seeds while the ground pomace is like a very coarse flour. The surface texture of the ground pomace is rough and this in combination with the angular shape will have a higher water requirement. No pre-treatment of the pomace was performed, and this included no washing or rinsing of the pomace, this was done to imitate the conditions that would be experienced on an actual wine farm.

Figure 3-4: Dried pomace prior to grinding

Figure 3-5: Dried Pomace post grinding

3.2 Mix design

The mix design of the control specimen was based on the Cement & Concrete Institue (C&CI) method with a 25 MPa compressive strength and a water to cement ratio of 0.6. This was selected for ease of reference against other tests conducted using organic material in concrete, researched commonly used 25 or 30 MPa mix design. Very few researchers used a mortar mix design, and it was expected that the relationship of strength loss to percentage pomace would be similar for mortar and concrete testing. Had the 25 MPa mix design yield favourable results, further testing of higher and lower strength concrete along with mortar specimens would have been investigated.

Given the w/c ratio of 0.6 and 210 L/m^3 water requirement for 19-mm stone combined with sand of average quality, the required cement content is 350 kg/m^3. The compacted bulk density of the coarse aggregate was 1 650 kg/m^3, K factor of 1.00 for moderate vibration, and fine aggregate fineness modulus of 2.6. The stone content was calculated using Equation 1 and equates to 1 070 kg/m^3. The sand content was calculated using Equation 2 and equates to 760 kg/m^3.

$$M_a = CBD(K - 0.1FM)$$ Equation 1 (Owen 2009)

where M_a = mass of stone (kg/m^3); CBD = dry compacted bulk density (kg/m^3); K = factor based on maximum stone size and FM = fineness modulus of sand.

$$M_s = D_s 10^3 \left[1 - \frac{M_c}{D_c 10^3} - \frac{M_a}{D_a 10^3} - \frac{M_w}{10^3}\right]$$ Equation 2 (Owen 2009)

where Ms = mass (kg/m^3); D = relative density; and subscripts s = sand; c = cement; a = coarse aggregate and w = water.

3.3 Test specimens

The concrete materials were weighed, and machine mixed in accordance with SANS 5861-1:2006 and sampling of the test specimen was performed in accordance with SANS 5861-2:2006. The cube mould size used for all specimens was 100 x 100 x 100 mm in accordance with SANS 5860:2006 with a total of 15 cubes cast per mix design which were tested at 1, 7, 14, 28 & 56 days.

The fine aggregate in the specimen was replaced with varying percentages of grape pomace on a volumetric basis as given in Table 3-1 and a total of 90 specimens were cast and tested. Each set of 15 specimens required a batch size of 15 l of concrete and a 20 l concrete mix design was provided.

Table 3-1: Mix design of test specimen per cubic metre of concrete

Specimen reference	**0% GP**	**5% GP**	**10% GP**	**15% GP**	**20% GP**	**30% GP**
Description	Control	5% Grape pomace	10% Grape pomace	15% Grape pomace	20% Grape pomace	30% Grape pomace
w/c	0,6					
Water (l/m^3)	210					
Cement (kg/m^3)	350					
Stone (kg/m^3)	1 068					
Sand (kg/m^3)	758	720	682	644	606	531
Pomace (kg/m3)	0	16	32	48	64	96
Density (kg/m^3)	2 386	2 364	2 342	2 320	2 298	2 254

3.4 Slump

The mix design of the control mix was 75 mm. Slump testing in accordance with SANS 5862-1:2006 was performed on each set of testing specimens before casting of the cubes and the slump recorded. Along with this, the slump mode was recorded as one of the three failure modes given in Figure 3-6. (SANS 5861-2, 2006) The slumpmode representative of all the specimens can be seen in Figure 3-7.

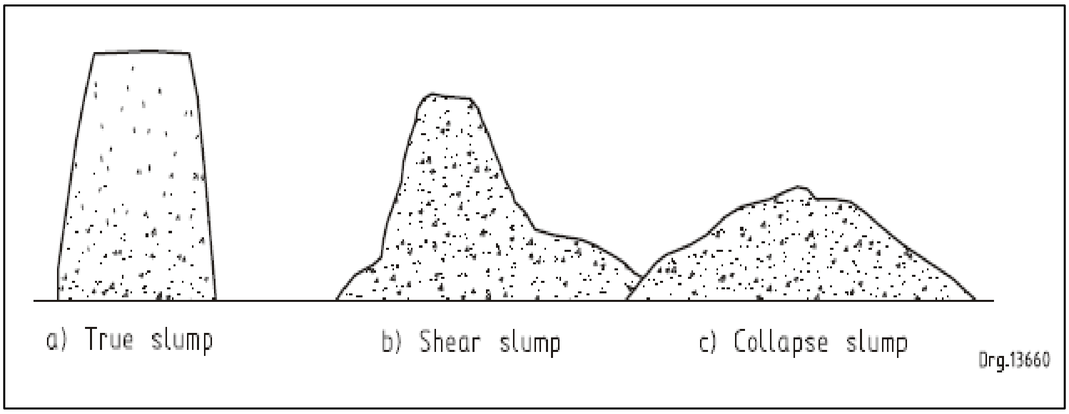


Figure 3-6: Slump failure modes (SANS 5861-2, 2006)

Figure 3-7: Slump mode

3.5 Curing

Curing of the test specimens was in accordance with SANS 5861-3:2006 with the specimens being placed in a temperature-controlled and vibration-free room and covered with an impervious sheet after casting. After 24 hours the specimens were removed from the moulds and placed in a temperature-controlled water bath and only removed just before testing. (SANS 5861-3, 2006)

3.6 Compressive strength of hardened concrete

Compressive strength testing of the hardened concrete cube specimens was conducted in the UCT laboratory, according to the methodology specified in SANS 5863:2006. The testing procedure included:

Remove the cube specimen from the curing bath and removal of any surface water or contaminants with a paper towel.

- Place the cube specimen on a scale and record the mass of each specimen. A photograph of each specimen was also taken.
- Check the test apparatus has been calibrated and the load-bearing surfaces have been wiped clean of any contaminants.
- Place the cube specimen in the test apparatus orientated such that the load-bearing surfaces are perpendicular to as-cast faces as seen in Figure 3-9 and Figure 3-10.
- Apply the compression load slowly and without shock, the load was increased continually at a uniform rate of 0.3 MPa / s ± 0.1 MPa / s until failure of the specimen occurs.
- The maximum applied load is documented along with specimen appearance and any unusual failure features. A photograph of each failed specimen was also taken.

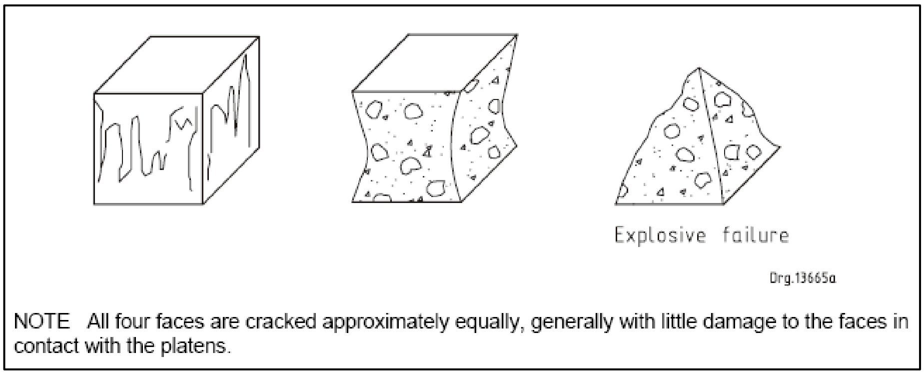
The compressive strength was calculated by taking the force applied in newtons and dividing this by the cross-sectional area of the cube in square millimetres for each specimen.

Figure 3-8: Compressive testing equipment

Figure 3-9: Concrete cube undergoing compressive testing

3.6.1 Cube failure mode

The expected cube failure mode, which is deemed satisfactory, can be seen in Figure 3-10. (SANS 5863, 2006) The slump mode identified during the application of the load can be seen in Figure 3-11 while the cube failure mode after loading is shown in Figure 3-12.



NOTE All four faces are cracked approximately equally, generally with little damage to the faces in contact with the platens.

Figure 3-10: Satisfactory cube failure mode (SANS 5863, 2006)

Figure 3-11: Cube failure during loading

Figure 3-12: Cube failure mode after loading

The testing performed to establish material properties yielded favourable results and no results have been omitted. The slump testing highlighted the water absorption of the grape pomace with a significant reduction in slump recorded, the failure mode of all specimens aligned with the true slump provided in the SANS 5861-2 **(**2006) as seen in Figure 3-7. All the specimens were tested for compressive strength according to the SANS 5863 (2006) methodology and the failure mode reflects the satisfactory failure mode as seen in Figure 3-12. The testing data and findings will be presented and discussed in Chapter 4.

4. Results & Discussion

The slump, density and compression testing results will be presented and discussed within this section. The slump and compression testing yielded significantly different readings to the control specimen and the possible causes of this have been discussed in Section 4.1 and 4.3 respectively.

4.1 Concrete Slump

A slump test was performed for each of the six mix designs and Figure 4-1 shows the relationship between the obtained slump results and the level of sand replacement. The slump mode was consistent for all specimens as a true slump and a representative specimen can be seen in Figure 3-7. The slump trendline is linear and the equation provided can be used to predict slump of varying percentages. The actual slump results recorded during laboratory testing can be seen in Appendix C while the slump reduction is shown in Table 4-1.

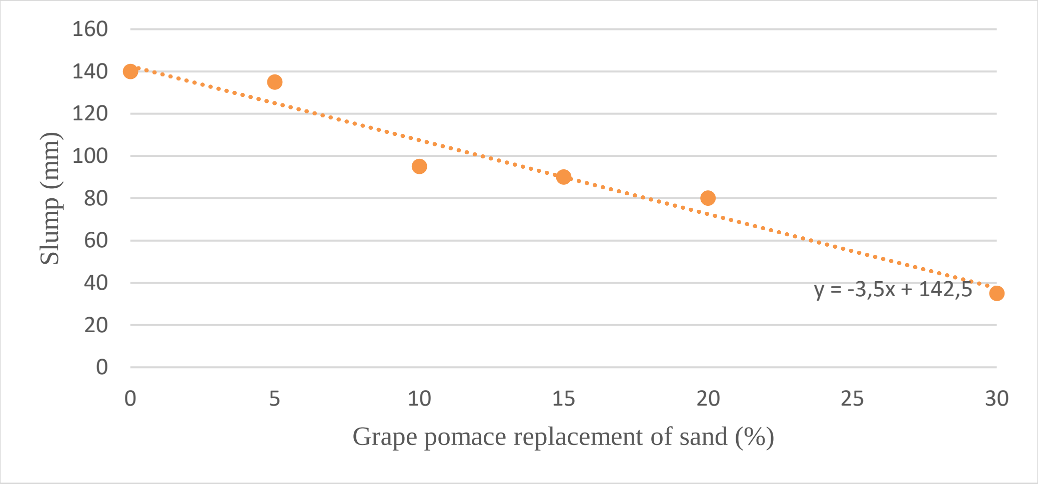


Figure 4-1: Slump test results of cube specimens

Table 4-1: Slump reduction

Specimen reference	**0% GP**	**5% GP**	**10% GP**	**15% GP**	**20% GP**	**30% GP**
Description	Control	5% Grape pomace	10% Grape pomace	15% Grape pomace	20% Grape pomace	30% Grape pomace
Slump reduction	-	4%	32%	36%	43%	75%

With the increase in grape pomace a reduction in slump was observed. The slump test for the control specimen was almost double that of the design slump however, it is within the 175 mm maximum as prescribed by SANS 5862:2006 and was therefore accepted.

Aggregates can be prewetted prior to batching to prevent absorption of the mix water. Slump loss can also be because of evaporation of the mix water or early hydration of the cement. Mixing times are crucial for uniform concrete slump as excessive mixing can cause evaporation of the mix water or attrition of aggregates resulting in lower slump and workability of the concrete. Prewetting of the aggregates was not performed and losses due to excessive mixing or evaporation are not considered applicable due to the controlled environment the testing was conducted in. (Alexander, 2021)

The lower slump values because of the pomace absorption were expected to result in higher compressive strengths, due to the now lowered water to cement ratio, and it was decided not to adjust the mix design at this stage. The results obtained during multiple water absorption tests of the pomace were non-uniform and absorption could not be accurately accounted for in the mix design. It is expected that adjusting the mix design to accommodate for water absorption of the pomace given more reliable testing would yield slump results closer to that of the control specimen; however, this would need to be tested as the particle shape and texture of the pomace compared to the dune sand differ significantly.

The particle shape and texture play an important role in water absorption with rounded or spherical particle shapes tending to absorb less water than flaky or angular particles. Suchorski (2018) notes that fine aggregates passing the 150 and 300 µm sieve during grading have the greatest influence on workability, cohesiveness and bleeding of fresh concrete. The pomace saw a cumulative percentage passing the 300 µm of 8.6% and 2.6% for the 150 µm sieve. The pomace having an angular shape, rough surface texture and being oven dried was expected to absorb the available mix water and this was evident in the testing as the increased pomace saw a decrease in slump and workability. A similar trend was seen by Boukhari (2023) as workability decreased in ground and oven dried olive pomace added to concrete. The loose bulk density of the olive pomace, 530 kg/m^3, was similar to of grape pomace at 543 kg/m^3.

Fathi & Fathi (2016) experienced slump variability when adding sugar beet fibres and tragacanth gum as organic plasticisers to self-compacting concrete. A flow test was performed and the addition of 6% sugar beet and 7% tragacanth gum, 13% total, resulted in a 100% increase in slump when compared to the control specimen. Pomace concrete displayed a 32% decrease in slump at similar replacement values of 10 and 15%.

To reduce the influence of water absorption on the slump of rice husk concrete, Sisman, Gezer & Kocaman (2011) placed the rice husk in a water bath for 30 minutes prior to mixing. The slump reading displayed a negligible difference for specimens containing 5, 10 and 15% rice husk while the 20, 25, and 30% displayed an increase of only 20mm or 125%. The testing was not performed with unsoaked material and if tested, the values may have been like the pomace concrete. Water absorption was determined by Memon et al (2021), in wheat straw ash to be 13.6%. in their slump tested, the ash was not soaked prior to mixing and the slump results increased by a maximum of 240%.

The slump results from the substitution of fine aggregate with ground mussel shells resulted in almost no variation Martínez-García et al. (2017) recorded a decrease in slump decrease given a 50% mussel shell substitution and this is reported to be because of the water absorption of the flaky mussel shell particle, entrained air and the increase in paste viscosity resulting in reduced fluidity of the mix. Dune sand in the Western Cape is known to contain shell fragments and this type of fine aggregate is predominantly used in concrete. Fine mussel shell sand displayed absorption values 86% higher when compared to other natural sands. The organic matter contains carbohydrates and perform like entrainment agents acting like surfactants stabilising the entrained air bubbles, this effect is increased with the small particle size given an increased surface area.

The addition of mussel shell displayed a reduction in slump like pomace concrete although far less than the pomace. Sugar beet, tragacanth gum, rice husk and wheat straw ash all displayed an increase in slump readings. The rice husk was pre-soaked while the ash is believed to have a lubricating effect and increase the fluidity of the mix. Pomace, like mussel shell, having large surface areas absorbed the available mix water and reduced the workability of the mix resulting in lower slump results.

4.2 Concrete density

The cube specimens were removed from the water bath and surface dried with a paper towel and their mass was recorded prior to compression testing. The average cube mass of the three specimens has been used to calculate density as given in

Table **4-2**. A minor variation between the design and actual density was recorded and this could be because of under or over filling of the cube moulds, air trapped in the mix or errors when testing material properties especially that of the grape pomace.

Table 4-3 displays the reduction in density given the percentage pomace replacement.

Table 4-2: Density of cube specimens

Specimen reference	**0% GP**	**5% GP**	**10% GP**	**15% GP**	**20% GP**	**30% GP**
Description	Control	5% Grape pomace	10% Grape pomace	15% Grape pomace	20% Grape pomace	30% Grape pomace
1 Day (kg/m^3)	2 430	2 335	2 327	2 245	2 265	2 247
7 Day (kg/m^3)	2 435	2 364	2 345	2 271	2 286	2 258
14 Day (kg/m^3)	2 414	2 382	2 350	2 304	2 285	2 267
28 Day (kg/m^3)	2 428	2 391	2 374	2 295	2 272	2 280

56 Day (kg/m^3)	2 425	2 387	2 365	2 266	2 252	2 263
Design Density (kg/m^3)	2 386	2 364	2 342	2 320	2 298	2 254

Table 4-3: Density reduction at 28 days

Specimen reference	**0% GP**	**5% GP**	**10% GP**	**15% GP**	**20% GP**	**30% GP**
Description	Control	5% Grape pomace	10% Grape pomace	15% Grape pomace	20% Grape pomace	30% Grape pomace
Density reduction	-	1.5%	2.2%	5.5%	6.4%	6.6%

The density of concrete plays a vital role in the mechanical performance of concrete. A dense concrete will yield higher compressive strengths while containing fewer voids resulting in lower permeability. The higher the porosity, the higher the water absorption and permeability of the concrete giving a reduction in concrete durability.

Specimens containing pomace were expected to have a lower density than the control specimen due to the difference in loose bulk density. The loose bulk density of the Philippi dune sand was recoded as 1728 kg/m^3 while the grape pomace was less than a third of that at 543 kg/m^3. This difference in density could see the coarse aggregate settling through the mortar. The fresh concrete is not expected to contain a higher void content than that of conventional concrete however, once degradation of the pomace occurs the void concrete will increase resulting in a lower density of concrete. For internal load bearing walls or locations with no exposure to environmental factors, the pomace may not degrade and no difference in density will be experienced.

Figure 4-2 is a graphical representation of the calculated specimen density at 1, 7, 14, 28 & 56 days of curing. The densities are linear with the control specimen, as expected, having the highest density while the 15, 20, and 30 % grape pomace replacement specimens had surprisingly similar densities. The densities are calculated from the three test specimens per stage of curing given their weight and dimensions and minor errors are to be expected.

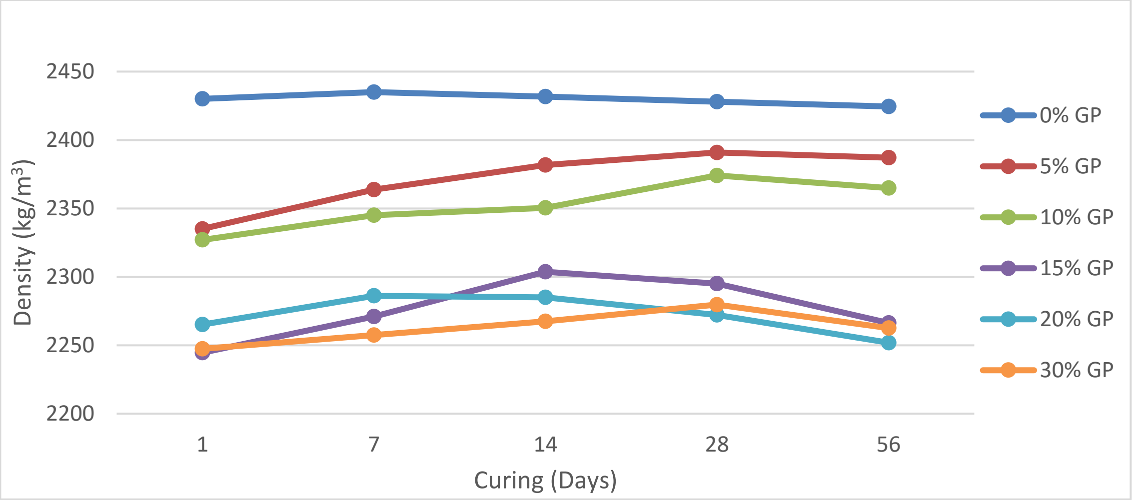


Figure 4-2: Density of cube specimens

The hardened concrete density of wheat straw ash specimens tested by Memon et al (2021) displayed an increase in density when compared to the control specimen. The relative density of pomace, 1.1, is below that of the ash at 1.9 and both specimens are well below the relative density of the fine aggregate used in the respective mix designs. Memon et al (2021) believe the increase in density is because of densification of the microstructure due to the formation of pozzolanic hydrates. Secondary calcium silicate hydrate gel is of a higher density due to the pozzolanic reaction and thereby replaces the lower density portlandite formed because of hydration. A similar trend was noticed with researchers who incorporated sugarcane ash as a filler in concrete.

4.3 Concrete compressive strength

4.3.1 Experimental results

The cube specimens, after surface drying and recording their mass, were placed in the hydraulic press for compression testing as described in Section 3.6.1. The average compressive strength for the three specimens at each stage of curing can be seen in Appendix C and graphically represented in Figure 4-3 while Figure 4-4 highlights the reduction in compressive strength with the increase in grape pomace.

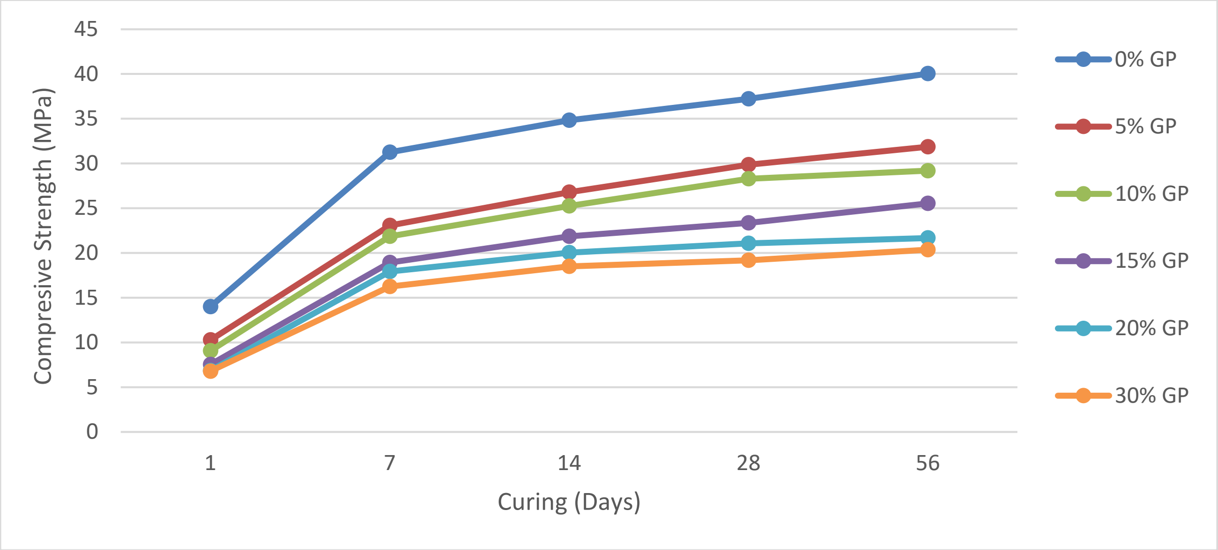


Figure 4-3: Compressive strength of cube specimens

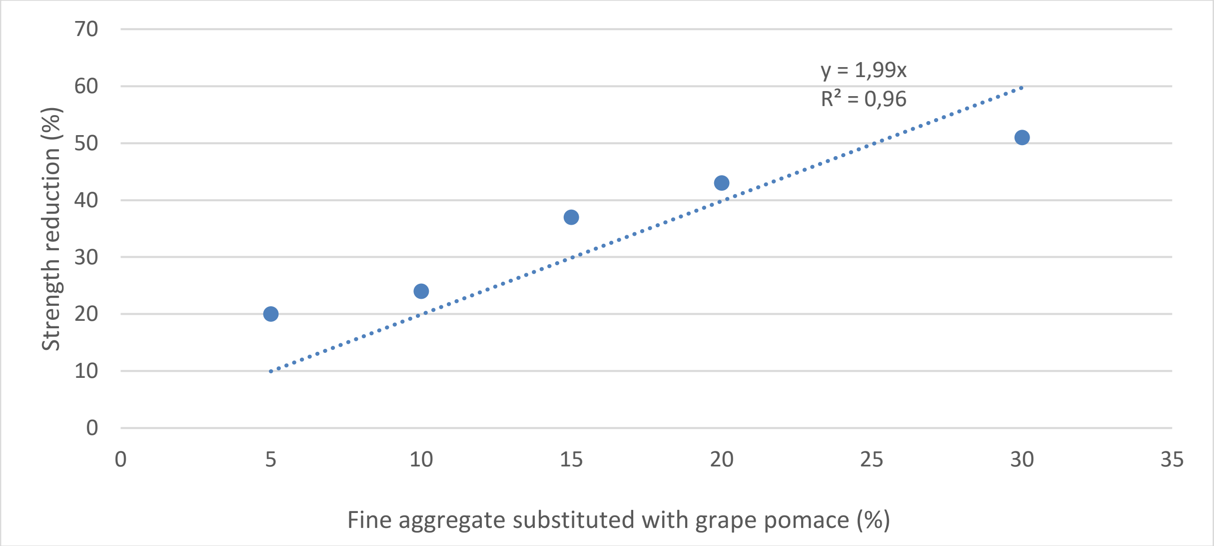


Figure 4-4: Compressive strength reduction at 28 days

The control specimen was designed as 25 MPa concrete and exceeded this at 7 days with the average of three specimens being 31.2 MPa, at 28 days the control specimen average was 37.2 MPa with a final 56-day strength of 40 MPa. When evaluating the pomace specimens, all the specimens failed to achieve the design strength after 7 days as seen with the control specimen and, only two specimens exceeded 25 MPa after 28-days. The two specimens that exceed the design strength were the 5 and 10% pomace specimens yielding 29.9 and 28.3 MPa respectively. The 15, 20 and 30% specimens displayed compressive strengths of 23.4, 21.1 and 19.2 MPa respectively. The 15% specimen reached 25.5 MPa at 56-days while the 20 and 30% specimens failed to achieve the design strength at 56-days.

The increase in fine aggregate replacement resulted in a decrease in compressive strength with the 5% specimens having the largest reduction of four times the pomace content while the remaining specimens reduced by approximately double the quantity of pomace content. Pomace concrete performed like testing of mussel shell and, sugar beet and tragacanth gum substitutes. The mussel shell 5 and 12.5% specimens achieved the design strength after 28-days like the 5 and 10% pomace specimens. The compressive strength reduction seen in the 10 and 15% sugar beet and tragacanth gum was double the organic content like the pomace specimens.

Researchers have identified possible causes for the decrease in compressive strength, given the addition of organic matter into concrete, and these are discussed below:

- Variable density of aggregates causing the coarse aggregate to settle due to the non-homogenous nature of the specimen. The upper layer would contain more fines with the lower layer containing a higher concentration of coarse aggregate. It must be noted that this was not identified in the crushed specimens visual inspection. It was expected that a uniform decrease in compressive strength be seen across all specimens however, the 5% specimen has a strength reduction of double the other pomace specimens.

- The water content was kept consistent in all the mix designs and the increased pomace content would therefore result in reduced available mix water, due to absorption effects, and lower water to cement ratios. This should result in varying strength reductions as the w/c differs per specimen. The 5% specimen should have the lowest difference and 30% the largest however the opposite was observed.

- The particle shape of the pomace is angular with a rough surface texture, although this is expected to absorb more available mix water, the shape should result in a denser matrix with a higher mechanical interlock when compared to rounded or spherical fine aggregate particles. Angular rough particles should result in increased compressive strengths and the opposite was observed during testing.

- Early strength gain, as seen in concrete having fine aggregate replaced with compost, was not seen in pomace concrete. Compost specimens, (Muthulakshmi *et al.* 2021), containing up to 30% fine aggregate replacement achieved the design strength of 25 MPa at 28-days. Fine aggregates are derived from weathered rock and their relative density will remain the same as the parent material. The specific gravity of the compost was 2.59, more than double the grape pomace at 1.12, and aligns closely with a fine aggregate. The specific gravity of the fine aggregate used in the compost concrete was not given, the Philippi dune sand in this research had a specific gravity of 2.6 identical to the compost. The specific gravity of the organic material and fine aggregate, if similar, would result in a more homogenous mix.

- Organic materials that were converted to ash saw an increase in compressive strength (Memon *et al.* 2021). The action of converting the organic material to ash as seen in olive pomace and wheat straw saw the material act as pozzolans and increase the strength of the concrete. Substitution of the fine aggregate with the ash saw an increase in compressive strength when compared to the control specimens. The grape pomace, in its dried and ground form, clearly didn’t act as a pozzolan in the concrete mix however, shock-burning could produce alternative findings.

- Researchers have noted that organic matter releases gasses forming micro voids resulting in lower compressive strengths. Along with this, the particle shape is believed to act as a barrier to bleed water making the bond between the cement paste and aggregate weaker as water is trapped below the sand particles.

- The reduction in compressive strength can be because of the grape pomaces' low pH or other chemical properties which can interfere with the cement hydration. Fine aggregates are required to be inert as the cement hydration products require an alkaline environment to remain stable and the low pH of the pomace could be restricting the development of the microstructure in the concrete.

The most noticeable factor contributing to compressive strength is the burning of the organic material into ash resulting in the formation of pozzolans and increasing the concrete compressive strength. All the other researchers used dried and ground material, like this research, and experienced a loss of compressive strength. The reduced water to cement ratio and mechanical interlock because of the angular shape and rough surface texture of the pomace should have resulted in an increased compressive strength. From the experimental observations and literature review, the specific gravity of the mix components plays a vital role in the compression strength. This is evident in the compost specimens where the replacement compost was almost identical to a typical fine aggregate and the design strength was achieved, the research had no control specimen to compare against and the material was used in its dried state without burning into ash.

Fine aggregate in concrete aids the binding of cement, water and coarse aggregate along with increasing workability, limiting shrinkage and reducing the cement content required to fill the voids between the coarse aggregate. The compressive strength of coarse aggregate has shown no influence on the compressive strength of hardened concrete (Owen, 2009). The particle shape of pomace, based on a visual inspection, is angular compared to the rounded shape of the dune sand and this angular shape will result in higher water absorption compared to the rounded sand particles, for dry material. The rough surface texture of the pomace should create a better mechanical interlock between the aggregates with the larger surface area. A reduction in mix water of a conventional concrete mix would lower the water to cement ratio and yield higher compressive strengths in concrete.

Given the testing and literature it is expected that the material properties of the grape pomace, were the cause of the reduction in the slump, lower density and reduced compressive strength. The density reduction is attributed to the different material densities seen between the pomace and fine aggregate while the slump variation is because of the absorption of available mix water by the pomace. Furthermore, the low pH of the pomace could be causing an unstable environment restricting the microstructure development.

4.3.2 Feasibility of pomace concrete

Compressive strength is only one criterion of hardened concrete properties, the 5 and 10% pomace specimens are deemed to meet SANS 1200G – 1982 requirements when evaluating compressive strength only. The 15% pomace specimen achieved the design strength after 56-days and in most practical applications this would not be feasible, the application of this mix would be very specific and require the additional curing time to achieve design strength. Almost all applications of 25 MPa concrete would require design strength after 28-days.

Wine farms wanting to reuse their waste pomace could produce concrete bricks or blocks for their own consumption and would have sufficient storage space to allow the products to cure for 56-days before use. However, a much lower strength concrete mix or mortar would be used, and it is expected that the percentage reduction in strength will be similar for lower strength concretes or mortars. A commercial brick or block producer would not have sufficient time or space to wait 56-days before the product can be used, additionally this creates a financial burden as the products cannot be sold for almost two months after production. Porosity would need to be considered given the use of the products. Bricks used for building would be porous, once the organic material degraded, and result in damp within the building. This porosity could be beneficial because of the light weight for internal non-structural walls or increased thermal capacity due to the internal voids formed.

The 20 and 30% pomace specimens displayed compressive strengths similar to that of a 20 MPa mix design. Although the use of pomace was primarily to reuse a waste product, the cement content must also not be forgotten. The cement content of a 20 MPa mix design would be approximately 10% lower than that of the 25 MPa. This results in a cement saving of R 80.00 per cubic metre of concrete which although relatively minor in the overall cost of concrete, the cost of drying and grinding the pomace must be considered along with the environmental footprint of pomace concrete as a whole.

SANS 1083:2006 allows the use of aggregates in concrete that fail to meet the acceptance criteria, on the basis that the use of the aggregate is unavoidable and all long-term durability concerns have been evaluated. Further testing for durability would be required to quantify the durability of pomace concrete. Tests were not performed on 100% replacement of fine aggregate with pomace as the strength loss experienced at 30% highlighted that pomace concrete is impracticable. Fine aggregate would therefore always be required in pomace concrete and the use of pomace is avoidable.

The influence of pomace concrete used in reinforced applications could yield favourable results for corrosion resistance. The research conducted by Kawaai et al (2019) displayed that reinforced concrete specimens containing 4% aerobic microorganisms increased corrosion resistance when using half-cell potential and microcell and microcell corrosion current density. The microorganisms displayed a 7% reduction in compression strength, this factor of 1.75 is significantly lower than the 5% pomace at a factor of 4.

4.4 Closure

The need for more sustainable materials in concrete with a lower environmental footprint is critical to reduce the reliance on natural resources. The use of organic material in concrete has been researched my many with the common trend being a reduction in slump, decreased density and reduced compressive strengths among others. An increase in compressive strength has been seen in organic material after been shock-burnt as the material acts like a pozzolan in the mix. Pomace performed like other dried and ground organic material with a reduction in slump, density and compressive strength. Although grape pomace is a waste product being repurposed, the additional processing and cement required negate any saving of fine aggregates. A lower strength mix design would yield similar results with lower cost along with a reduced environmental footprint. Pomace concrete can't be classified as light weight concrete in comparison to foamed or polystyrene concrete and it is expected that these products would perform equally as well in light weight and thermal insulation applications.

5. Conclusion

The construction industry is striving for a more sustainable approach to construction with the materials it uses, and this has seen significant research into the use of sustainable materials and the reuse of waste products, particularly in concrete. Various waste and recycled products have been investigated and tested for their suitability in concrete when used as either cement or aggregate substitutes with differing results achieved. Very few waste or recycled materials have been used in commercial or residential concrete. Rubber, rice husk, hemp, sugarcane, sawdust, bagasse and coir, amongst others, have been tested in concrete mix designs and like pomace, they are all organic materials.

Grape pomace is a waste by-product generated from the six-stage wine-making process comprising of skins, stalks, and seeds. Stalks are removed during destemming at stage two while white grape pomace is removed after the pressing process, stage 3, and red grape pomace after the fermentation process, stage 4. The waste is generated annually during the harvest season and is currently either used as a soil conditioner in the vineyards or taken to landfill sites. The abundance of pomace in the Western Cape of South Africa necessitates the need for valorisation of the material with the focus of this research being the partial replacement of fine aggregate with pomace in concrete.

The experimental testing comprised of red grape pomace from a single source in the Western Cape, Stellenbosch, incorporated into a concrete mix design, white grape pomace was omitted as it was expected to contain sugars which could retard the concrete setting. Only the skins and seeds were used in the testing as the stalks, by mass, make up far less than that of the skins and seeds. The pomace was oven dried in the laboratory and ground to a particle size of 0.6 to 2.4 mm for improved grading with the fine aggregate. Fine aggregate was substituted with the dried and ground pomace on a volumetric basis and five specimens; 5, 10, 15, 20 and 30%, along with the control were tested. For quality control, the specimens were all cast in the same laboratory, cured in the same temperature-controlled water bath and the measuring and testing equipment was calibrated.

5.1 Workability

The control specimen had a higher flowability during mixing in the pan mixer when visually compared later to the stiffer 30% pomace mix. Slump testing further highlighted the water absorption of the dried pomace as there was significant variation seen in the results, this is expected to be because of the increased surface area of the dry pomace particles due to the angular shape and rough texture noted during a visual inspection. Workability of the concrete reduced with the increased pomace content because of the water absorption. Testing was conducted to determine the water absorption of the dried pomace on multiple days with all of the findings differinf significantly, the results were omitted as they were deemed unreliable. The absorption resulted in less available mix water which lowered the water to cement ratio, a lower water to cement ratio in concrete containing no pomace would result in a higher compressive strength and for this reason, no adjustment was made for the pomace water absorption.

5.2 Compressive Strength

Three specimens from each mix design were subjected to compression testing at 1, 7, 14, 28 and 56 days. The results displayed an almost linear reduction in compressive strength as the percentage of pomace increased. Two pomace specimens, 5 and 10%, achieved the design strength after 28-days while the control specimen achieved 1.5 times the design strength after the same 28-day period. The remaining pomace specimens all failed to achieve the design strength after 28-days. The increase in fine aggregate replacement resulted in a decrease in compressive strength with the 5% specimen having the largest reduction of four times the pomace content while the remaining specimens reduced by approximately double the quantity of pomace content.

The controlled laboratory conditions allowed for the highest level of quality control, and it is possible that pomace concrete batched on-site could result in lower compressive strengths. The research conducted by others, into organic material in concrete, yield somewhat similar results for dried and ground organic material replacing cement or fine aggregate. All researchers observed a reduction in compressive strength and experienced water absorption of the organic material. The particle shape of the replacement material was identified as flaky or angular with a rough surface texture like pomace. Differing results were observed for organic material that had been shock-burnt with increased compression strengths seen that were attributed to the pozzolanic effects of the ash material.

The shape and specific gravity of the pomace are believed to played a vital role in the compressive strength of the concrete. The angular shape and rough surface texture although absorbing the available mix water and reducing workability, contributed to the mechanical interlock between the aggregates of the mix. The angular shape of the pomace likely caused blockage of the bleed water resulting in a weaker bond between the cement paste and aggregates. Pomace has a specific gravity of 1.1 compared to the Philippi dune sand fine aggregate at 2.6. Research’s conducted testing using compost with a specific gravity of 2.6 as a fine aggregate replacement and saw increased compression strength highlighting the effects of material properties. The reduced specific gravity of the pomace, the angular shape blocking the release of bleed water along with the low pH of the pomace creating an unstable environment for the microstructure development is believed to be the cause of the reduction in compression strength.

5.3 Durability

Concrete durability has no direct relationship to strength and depends largely on environmental exposure conditions and the concretes’ ability to resist deterioration. Concrete can be low in strength and have a high degree of durability or high in strength and a low degree of durability.

Durable concrete is directly related to the environment it is exposed to and a single type of concrete may not be durable in all environments.

Pomace, being organic in nature, will deteriorate in the presence of moisture and oxygen and this will increase the porosity of the concrete at a rate relative to the exposure conditions. If pomace concrete is used along coastal regions and exposed to an environment high in chlorides, the voids will allow penetration of chlorides into the concrete causing corrosion to reinforcement, if present. For inland structures, the presence of voids will have little to no influence on chloride penetration as chlorides will likely not be present. High porosity would accelerate carbonation in reinforced pomace concrete when used, for example, in parking garages. Not all instances of degradation of the pomace would be negative, the presence of voids would increase the fire resistance and thermal resistance while reducing the mass of the concrete.

5.4 Feasibility of pomace concrete

The durability of pomace concrete is of great concern and the need for surface coatings to prevent the decomposition of the pomace is uneconomical and would require routine maintenance. A more durable conventional concrete would require minimal maintenance over its lifespan. It would not be economically feasible to make use of pomace concrete in any structural applications and the increased cement content makes the mix design unsustainable. To achieve similar compressive strengths, a conventional concrete can be used which has no durability concerns. Although the SANS codes of reference allow for the use of organic material in concrete, when unavoidable and subject to testing, the use of pomace in concrete can be avoided as fine aggregate will always be required in the mix design and can’t be replaced entirely.

5.5 Concluding remarks

The relative density of the pomace is approximately half that of the Philippi dune sand fine aggregate and the particle compressive strength of the pomace is also assumed to be lower than the fine aggregate. The reduction in compressive strength can be because of the mechanical properties of the grape pomace, it’s low pH or other chemical properties which can interfere with the cement hydration process as experienced by other researchers when testing organic material in concrete. Fine aggregates are required to be inert as the cement hydration products require an alkaline environment to remain stable and the low pH of the pomace could be restricting the development of the microstructure in the concrete.

Concrete is designed for a specific compressive strength which requires a certain water to cement ratio and the experimental testing highlighted that pomace concrete, even at low replacement percentages, severely reduced the compressive strength. To make pomace concrete feasible a fine aggregate replacement of 30%, or more, would need to yield similar compressive strength results to the control specimen. The two pomace specimens that achieved the design strength, 5 and 10%, are well below this.

To achieve a 25 MPa pomace concrete the water to cement ratio would have to be lowered and this would result in an increased cement content. The lower strength concrete achieved with this testing can be more economically achieved with a conventional lower strength mix design which reduces the cement content required. Furthermore, durability testing of pomace concrete could reduce its areas of application.

The experimental testing has highlighted that pomace concrete is not a viable solution for the valorisation of pomace and results in an inferior concrete. Pomace concrete increases the carbon footprint of cement due to the lower water to cement ratio required and this, together with the workability and durability concerns, makes pomace concrete uneconomical.

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Appendix A

Aggregate properties

Table A-1: Sieve analysis of Philippi dune sand

Sieve opening (mm)	MASS Sieve (g)	MASS Sieve + aggr. (g)	MASS retained (g)	Mass retained %	cum. Retained (%)	cum. % passing (%)
4,75	480	480	0	0	0	100
2,36	415	415	0	0	0	100
1,18	350	380	30	3,0	3,0	96,9
0,6	505	1170	665	66,8	69,8	30,1
0,3	280	475	195	19,6	89,4	10,5
0,15	520	615	95	9,5	98,9	1,0
0,075	260	270	10	1,0	100	0
PAN	495	495	0	0		
		sum mass	995			

Table A-2: Philippi dune sand fineness modulus, loose and compacted bulk density

Description	Result
Fineness modulus	2.6
Loose bulk density (kg/m3)	1556
Compacted bulk density (kg/m3)	1728

Table A-3: Sieve analysis of 19mm greywacke aggregate

Sieve opening (mm)	MASS Sieve (g)	MASS Sieve + aggr. (g)	MASS retained (g)	Mass retained %	cum. Retained (%)	cum. % passing (%)
26,5	1630	1630	0	0	0	100
19	1505	1735	230	7,6	7,6	92,3
13,2	1360	2795	1435	47,9	55,5	44,4
9,5	1415	2310	895	29,8	85,4	14,5
6,7	1470	1720	250	8,3	93,8	6,1
4,75	1605	1665	60	2,0	95,8	4,1
PAN	1390	1515	125	4,1	100	0
		sum mass	2995			

Table A-4: Greywacke (19mm) fineness modulus, loose and compacted bulk density

Description	Result
Fineness modulus	3.4
Loose bulk density (kg/m^3)	1460
Compacted bulk density (kg/m^3)	1650

Appendix B

Grape pomace properties

Table A-5: Sieve analysis of grape pomace

Sieve opening (mm)	MASS Sieve (g)	MASS Sieve + aggr. (g)	MASS retained (g)	Mass retained %	cum. Retained (%)	cum. % passing (%)
4,75			0	0	0	100
2,36	408,5	442,5	33,9	33,8	33,8	66,1
1,18	541,6	572,0	30,4	30,4	64,3	35,6
0,6	340,0	358,0	18,0	17,9	82,2	17,7
0,3	280,8	290,0	9,1	9,1	91,4	8,5
0,15	489,1	495,1	5,9	5,9	97,4	2,5
0,075	251,9	254,5	2,5	2,5	99,9	0,1
PAN	494,7	494,7	0,0	0,0		
		sum mass	100,2			

Table A-6: Grape pomace fineness modulus, loose and compacted bulk density

Description	Result
Fineness modulus	3.7
Loose bulk density (kg/m3)	543
Compacted bulk density (kg/m3)	652

Table A-7: Moisture content of grape pomace

Tray 1			Tray 2			Tray 3		
Wet weight	10	kg	Wet weight	10	kg	Wet weight	10	kg
Dry weight	4,25	kg	Dry weight	4,15	kg	Dry weight	4,85	kg
Moisture	5,75	kg	Moisture	5,85	kg	Moisture	5,15	kg
Moisture content	**57,5**	**%**	**Moisture content**	**58,5**	**%**	**Moisture content**	**51,5**	**%**

Table A-8: Relative density testing results for grape pomace

Specimen 1 **Oven dried pomace**			**Specimen 2** **Saturated surface dry**			**Specimen 3** **Saturated surface dry**			**Specimen 4** **Saturated surface dry**		
Test 1											
Pycnometer	563,62	g	Pycnometer	563,96	g	Pycnometer	563,96	g	Pycnometer	563,96	g
Mb	258,33	g	Mb	307,86	g	Mb	357,46	g	Mb	383,16	g
Mc	1687,6	g	Mc	1674,35	g	Mc	1676,02	g	Mc	1681,5	g
Md	1640,38	g	Md	1641,06	g	Md	1641,06	g	Md	1641,06	g
RD	**1,22**		**RD**	**1,12**		**RD**	**1,11**		**RD**	**1,12**	
Test 2											
Pycnometer	567,06	g	Pycnometer	563,96	g	Pycnometer	563,96	g	Pycnometer	563,96	g
Mb	251,06	g	Mb	334,89	g	Mb	400,43	g	Mb	357,59	g
Mc	1677,95	g	Mc	1678,75	g	Mc	1682,46	g	Mc	1680,74	g
Md	1644,1	g	Md	1641,06	g	Md	1641,06	g	Md	1641,06	g
RD	**1,16**		**RD**	**1,13**		**RD**	**1,12**		**RD**	**1,12**	
Test 3											
Pycnometer	563,89	g	Pycnometer	563,96	g	Pycnometer	563,96	g	Pycnometer	563,96	g
Mb	263,96	g	Mb	379,8	g	Mb	406,99	g	Mb	365,56	g
Mc	1677,92	g	Mc	1681,33	g	Mc	1683,61	g	Mc	1679,31	g
Md	1640,52	g	Md	1641,06	g	Md	1641,06	g	Md	1641,06	g
RD	**1,17**		**RD**	**1,12**		**RD**	**1,12**		**RD**	**1,12**	

Mb – Mass of oven dried material
Mc – Mass of pycnometer + aggregate + water
Md – Mass of pycnometer + water
RD – Relative Density

Appendix C

Laboratory testing results

Table A-9: Compressive strength of cube specimens

Specimen reference	**1**	**2**	**3**	**4**	**5**	**6**
Description	Control	5% Grape pomace	10% Grape pomace	15% Grape pomace	20% Grape pomace	30% Grape pomace
1 Day (MPa)	14,0	10,3	9,1	7,5	6,9	6,8
7 Day (MPa)	31,3	23,1	21,9	18,9	17,9	16,2
14 Day (MPa)	34,8	26,8	25,3	21,9	20,0	18,5
28 Day (MPa)	37,2	29,9	28,3	23,4	21,1	18,2
56 Day (MPa)	40.0	31.9	29.2	25.5	21.7	20.4

Table A-10: Slump test results

Specimen reference	**0% GP**	**5% GP**	**10% GP**	**15% GP**	**20% GP**	**30% GP**
Description	Control	5% Grape pomace	10% Grape pomace	15% Grape pomace	20% Grape pomace	30% Grape pomace
Slump (mm)	140	135	95	90	80	35
Slump class	S3	S3	S3	S2	S2	S1