# PROPERTIES OF CEMENT MORTAR MIX CONTAINING COMBINED WASTE PLASTICS AND GLASS

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## Abstract

As the world's population increases so does the waste we produce. Global waste will double by 2050 and triple by 2100 unless more sustainable methods are implemented. Construction and demolition activities generate 30 to 40% of the total solid waste generated worldwide, 4.5 bi ton / year. In recent years there has been increasing interest in transitioning from a linear to circular economy; the key principles of which include avoiding waste materials, improving resource recovery, increasing the use and demand of recycled materials and better managing material flows.

In the 2020 to 2021 financial year Australia generated 75,8 Mt of waste. Key contributors to these waste flows were ash (from electricity production), building and demolition waste and organic materials. Glass waste in Australia accounted for approximately 2% of Australia's total waste flows while plastic waste accounted for 3.4% of total waste flows. There are significant proportions of glass and plastic waste currently going to landfill, which represent a missed economic opportunity. In Australia rubbish collected in the yellow lids is for loose container recyclables that include aluminium and steel cans, glass bottles and jars and is assumed to be sorted and recycled, however this is not always the case. A report in 2020 put Australia's waste at approximately 74 million tonnes yearly, with 84% of all plastic going straight to landfills. A component of solar panels is glass, and with the lifecycle of these panels is approximately 21 years and recycling options are currently limited, with only 17% of a panel by weight being recycled. The remaining 83% which includes glass, silicon and polymer back sheeting is currently not recyclable in Australia. Other glass that is not able to be recycled are microwave turntables, ovenware, crystal glass, mirrors and light bulbs, due to the items containing chemicals that do not allow the glass to melt at the same temperature as glass bottles and jars.

Traditional concrete structures are made of sand, cement, coarse aggregates, and water. Concrete by volume is the second most used material on the planet. Portland cement is the main binder of concrete and mortar, and large amounts of sand and gravel are extracted to provide the aggregate material for the concrete mix. The global total annual cement consumption in 2016 was 4.13 gigatons (Gt) and is anticipated to grow to 4.68 Gt per year by 2050.

Sand is now the most widely used construction material in the world, and recent studies have called it a 'declining resource'. Crushed glass is similar in its chemical and physical composition to sand, and studies have demonstrated its applicability when used as a sand

replacement in a structural concrete application at a replacement rate of up to 20%. From the literature it has been demonstrated that incorporating glass as a fine aggregate increases the compressive strength of the mortar / concrete, whilst also increasing the workability of the mix. Crushed glass aggregate has also been found to decrease water absorption, decrease thermal conductivity, and increase the electrical resistivity of a concrete mix.

Likewise, the incorporation of PET fibres has been found to increase the tensile strength of a concrete mix. Thereby improving the long-term durability of the structure. While there have been many studies on the use of glass and plastic for structural concrete applications, further studies are required to effectively promote its utilisation in the construction industry. The implications of incorporating both materials and their potential benefits are yet to be investigated.

The current gap in the literature is knowledge on the implications of incorporating both materials, therefore the main objective of the study is to investigate and identify which ratio of glass and plastic is best suited when replacing sand as a fine aggregate in mortar mixes. The purpose is to maximise the amount of recycled material into the mortar mix and to report the findings to create a viable alternative option for the use of mortar in the construction industry. The outcomes of the project may be upscaled and applied to standard structural concrete mixes. It is envisaged that a combination of glass aggregate and PET fibres may provide a synergistic effect enhancing the durability of a concrete mix, whilst reducing waste to landfill, and reducing cost.

# Contents

## 1.0 Introduction

As the world's population increases so does the waste we produce. Global waste will double by 2050 and triple by 2100 unless more sustainable methods are implemented (Ferdous et al. 2021). Construction and demolition activities generate large amounts of solid waste, and it is estimated it accounts for 30 to 40% of the total solid waste generated worldwide, 4.5 billion tonnes per year (Marvila et al. 2022). In recent years there has been increasing interest in transitioning from a linear to circular economy; the key principles of which include avoiding waste materials, improving resource recovery, increasing the use and demand of recycled materials and better managing material flows.

In the 2020 to 2021 financial year Australia generated 75,8 million tonnes (Mt) of waste. Key contributors to these waste flows were ash (from electricity production), building and demolition waste and organic materials (Pickin 2022). Glass waste in Australia accounted for approximately 2% of Australia's total waste flows while plastic waste accounted for 3.4% of total waste flows (Pickin 2022). There are significant proportions of glass and plastic waste currently going to landfill, which represent a significant missed economic opportunity.

Traditional concrete structures are made of sand, cement, coarse aggregates, and water. Concrete by volume is the second most used material on the planet. Portland cement is the main binder of concrete and mortar, and large amounts of sand and gravel are extracted. Global cement production is continually and increasing significantly due to increasing population and the flow on effect of urbanisation and infrastructure development. The global total annual cement consumption in 2016 was 4.13 gigatons (Gt) and is anticipated to grow to 4.68 Gt per year by 2050 (Schneider 2019). Sand is now the most widely used construction material in the world. It is the most-consumed natural resource on the planet besides water. In 2019 it was stated that 50 billion tonnes of sand and gravel are used for aggregate. Recent studies have called it a 'declining resource' due to sand for construction being most often mined from rivers which causes sediment to be churned up clouding the water, suffocating fish and limiting sunlight that sustains underwater vegetation (Beiser 2019).

Crushed glass is similar in its chemical and physical composition to sand, and studies have demonstrated its applicability when used as a sand replacement in a structural concrete application at a replacement rate of up to 20%. From the literature it has been demonstrated that incorporating glass as a fine aggregate increases the compressive strength of the mortar / concrete, whilst also increasing the workability of the mix. Crushed glass aggregate has also been found to decrease water absorption, decrease thermal conductivity, and increase the electrical resistivity of a concrete mix.

Likewise, the incorporation of PET fibres has been found to increase the tensile strength of a concrete mix. The PET fibres can hold the constituents of the concrete together, increasing tensile strength, enhancing flexural behaviour, and making the failure mode more ductile (Anas et al. 2022). Thereby improving the long-term durability of the structure.

While there have been many studies on the use of glass and plastic for structural concrete applications. The implications of incorporating both materials and their potential benefits are yet to be investigated.

## 1.1 Research Aims and Objectives

The main aim of the project is to evaluate the physical and mechanical properties of the cement mortar incorporating different percentages of glass and plastic waste. From the evaluation of the properties, highlighting which ratio of glass and plastic that would be best suited when replacing sand as a fine aggregate in mortar mixes will be proposed. The purpose is to maximise the amount of recycled material into the mortar mix and to report the findings to create a viable alternative option for the use of mortar in the construction industry. The outcomes of the project may be upscaled and applied to standard structural concrete mixes.

The objectives of the project are to:

1. Evaluation of the physical properties of the fresh mortar.
2. Evaluation of the physical and mechanical properties of the hardened mortar.
3. Assessment of the microscopic structure of the mortar.
4. Evaluation of the effect of the different percentages of glass and plastic wastes on the properties.
5. Analyse and interpret test data and develop a simple prediction equation that will reliably describe the properties of mortar mix.

Ultimately the findings will contribute to the research on fine aggregate replacement in mortar production whether there are appropriate applications for its use.

## 1.2 Scope

The general purpose of the study was to develop and characterise the physical and mechanical properties of cement mortar mix containing combined waste plastics and glass. The purpose is to maximise the amount of recycled material into the mortar mix and to report the findings to create a viable alternative option for the use of mortar in the construction industry. The project started on the 20$^{th}$ of February 2023 and concluded on the 15$^{th}$ of October 2023.

The main objective of the study is to investigate and identify which ratio of glass and plastic is best suited when replacing sand as a fine aggregate in mortar mixes, to identify the optimum proportion for a combined PET plastic fibre / glass aggregate mortar mix, and the resulting impact on strength, wet mortar properties and microstructural properties. Topics that will be covered include the testing of the mortar in two phases, the fresh mortar properties, and the hardened mortar properties of the proposed mix design. Regarding strength, the hardened mortar properties will also be analysed for compressive strength and indirect tensile strength. As displacement sensors were not available at the Springfield campus laboratory, the analysis of load displacement behaviour was not taken into consideration and durability and analysing the effect of ASR was not investigated and therefore outside of the scope of this project. The testing of the specimen's was conducted in the laboratory at the University of Southern Queensland, Springfield campus.

## 1.3 Thesis structure

The thesis is divided into seven chapters.

Chapter 1: Provides the aim, objectives, scope, and the expected outcomes for this project.

Chapter 2: In this chapter, section 2.1 outlines the waste scenario in Australia and identifies the manufacturing processes of glass and plastic waste aggregate. Section 2.2 reviews the literature on glass aggregate as a replacement to sand for concrete and mortar production, identifying both compressive and flexural strength properties. Section 2.3 reviews the literature regarding the PET fibres for concrete and mortar applications and highlights their strength properties. Section 2.4 reviews the combined glass and PET fibres for concrete and mortar applications. Section 2.5 identifies the research gaps.

Chapter 3: Section 3.1 introduces the methodology. Section 3.2 the standards complied with, section 3.3 states and evaluates the material used. Where the testing was conducted is mentioned in section 3.4. Section 3.5 provides the mortar mix design, mix quantities and testing the workability of the cement mortar. Section 3.6 outlines how the mix samples were prepared for testing. Section 3.7 presents the strength testing, both unconfined compressive strength and indirect tensile strength.

Chapter 4: Presents the resources required for the project, the amount of material that was needed for each sample, the approximate amount of material for the project, and the testing for the mixes.

Chapter 5: In this chapter, the results and observations are presented. Section 5.1 outlines the properties of fresh mortar and flow table results and corresponding photos. Section 5.2, physical properties of the hardened mortar, evaluating the compressive strength and splitting tensile strength with supporting literature. Section 5.3 contains the microscopic analysis of the testing mixes with illustration. Section 5.4 presents the compression and indirect-tensile test results and digital image correlation that was conducted to utilise technology to be able to understand deformation in the test piece before failure.

Chapter 6: Provides the discussion regarding the compressive strength prediction equation in section 6.1. The indirect tensile strength prediction equation is presented in section 6.2, while section 6.3 details the recommendations from the project.

Chapter 7: The concluding comments and answers to the objectives are presented. The key findings from the report are highlighted.

## 1.4 Expected Outcomes

The research of this project will provide viable information and results, giving a more detailed understanding on how the addition of combined glass and plastic wastes affect the mechanical properties and the determination of the ideal amount of wastes addition that will not significantly affect the properties of the produced cement mortar. The study will prove to contribute to the research of reducing the need for sand to be used as a fine aggregate in the production of mortar. This directly relates to one of the project's aims of utilising recycled glass and plastic waste which in turn helps limit the depletion of a non-renewable resource and consequently be more environmentally friendly.

The results of the two testing phases of the mortar will be presented, the fresh mortar properties, and the hardened mortar properties of the proposed mix design. Considering strength, the hardened mortar properties results will also be presented for both compressive strength and indirect tensile strength.

## 2.0 Literature Review

### 2.1 The waste scenario in Australia

In total 75.8 Mt of waste was generated in Australia in the 2020 to 2021 financial year, which included 2.6 Mt of plastic waste. The amount of waste generated is equivalent to 2.95 t per capita. The waste generated in 2016 to 2017 was 2.48 t per capita. Australia is committed to reducing waste generation by 10% per person by 2030. To do this an expanded version of the 'waste hierarchy' was developed. It extends the top levels to distinguish a range of distinct waste prevention activities and the preferential order of waste management options based on environmental benefit (Pickin 2022). See the waste hierarchy and the developed expanded waste hierarchy below in Fig. 1.

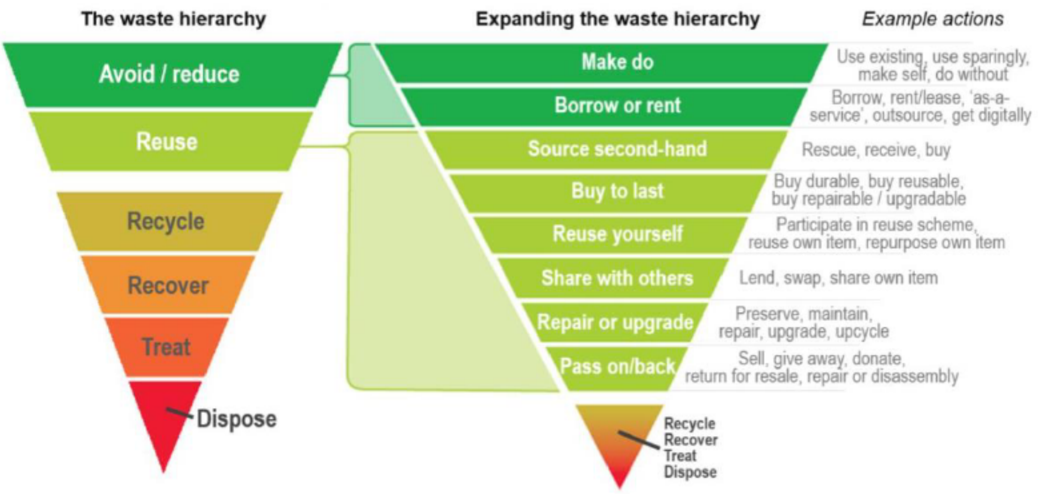



Fig. 1 (Pickin 2022).

Regarding reducing plastic waste, lightweight plastic shopping bags were banned and single-use plastic items. The Victorian Government commissioned modelling and the extrapolated results suggest that the bans could see 65,000 tonnes of plastic waste being prevented in Australia over 10 years (Pickin 2022).

The recovery rate of glass in the 2020 to 2021 financial year was 59% and plastics were only 13% in Australia (Pickin 2022). See Fig. 2 and 3 below illustrating the trends in waste generation and management methods for glass and plastics.

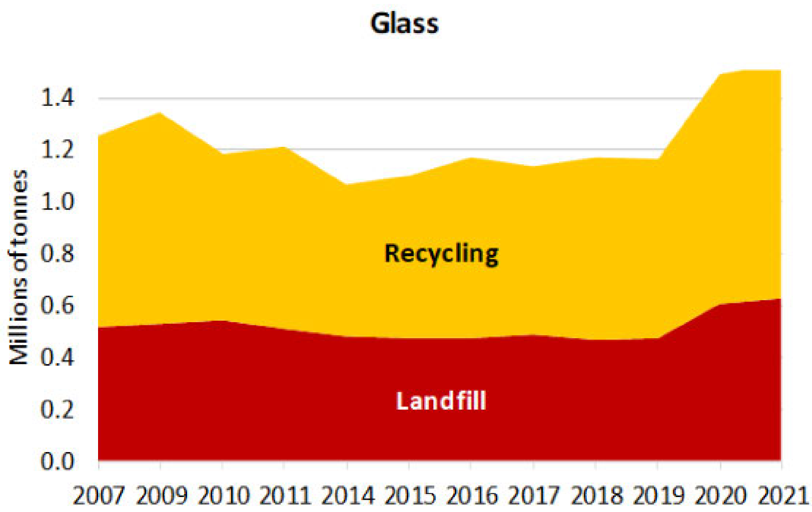



Fig. 2 (Pickin 2022).

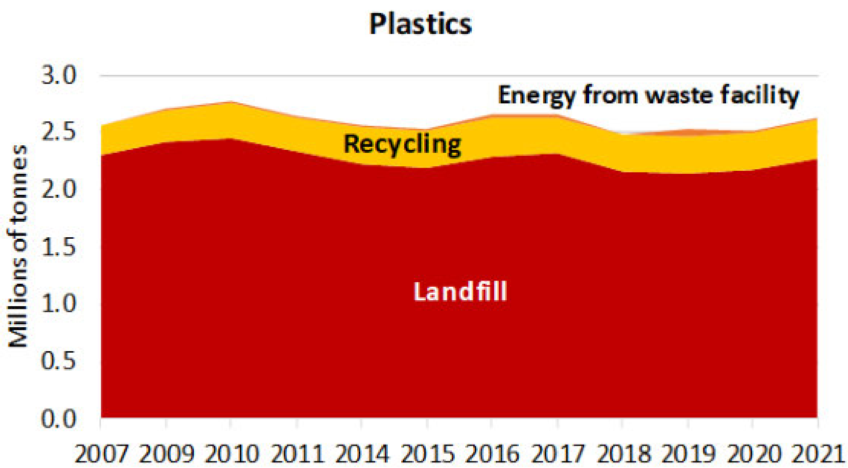



Fig. 3 (Pickin 2022).

### 2.1.2 Glass aggregate waste

Glass aggregates are produced from recycled glass food and beverage bottles and containers collected through kerbside recycling bins and the container refund scheme. The current manufacturing process of recycled crushed glass in Australia include (Group 2010):

1. Sorting: Select suitable glass (i.e., food and beverage containers) for fine glass cullet and eliminate undesirable glass (i.e., fluorescent tubes, glass from hazardous waste) from collected wastes.
2. Cleaning: This is required to reduce odours and eliminate sugar (organic pollutants).
3. Crushing and screening: Different nominal sizes and desired gradations are required for various applications.
4. Mixing and blending: To allow for a desired final product.

Recycled aggregate glass in Australia can make it into products depending on the type, colour, and quality. It can be used for decorative concrete, surface coatings and for lightweight and insulating applications.

### 2.1.3 Plastic aggregate waste

To utilise plastic aggregate waste, it must go through a series of stages which transform it from recycled plastic to a functional plastic aggregate.

The process involves:

1. The collection of the recycled waste
2. The sorting of the plastic from other material and the different types of plastic
3. The reprocessing stage where the plastic is washed to remove contaminants, the plastic is shredded or ground into smaller flakes, and the plastic is then melted and extruded and cut into new pellets.

Fig. 4 illustrates the manufacturing process of plastic flakes and plastic pellets (da Silva et al. 2014).

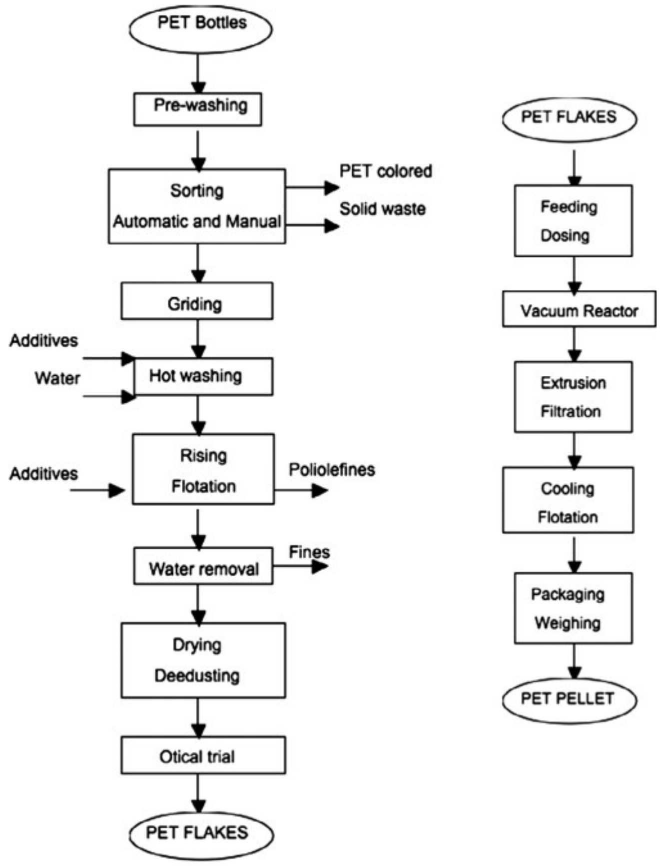



Fig. 4 (da Silva et al. 2014)

## 2.2 Glass aggregate as a replacement to sand for concrete and mortar applications

From the literature glass aggregate as a replacement for sand for concrete applications was found to improve compressive strength, splitting tensile strength, flexural strength, elastic modulus, energy capacity and bond strength by 3.36%, 14.12%, 1.7%, 6.01%, 52.63% and 57.32% respectively (Mohammed & Hama 2022). Utilising waste glass as aggregate replacement increases the workability of mortar due to the lower surface water absorption compared to sand (Mohammed & Hama 2022).

Other literature indicated that waste glass can effectively be used as a fine aggregate replacement (≤40%) without any substantial change in strength (Gautam et al. 2012). Tan & Du 2013 stated that the use of glass sand in mortar results in a lower compressive, flexural and splitting tensile strength, and elastic modulus due to the weakened bond at the interfacial transition zone between glass particles and the cement paste however, it was also stated that with a 25% replacement, the glass slightly increased the splitting tensile strength of the mortar.

### 2.2.1 Strength properties

Results for the compressive strength of mortar and cement mixes containing glass aggregates vary widely. In 2015, a study was conducted examining the effects that fine glass aggregate has on the compressive strength of concrete and the optimum percentage of post-consumer glass with respect to compressive strength. The mix design of the concrete was conducted in accordance with standards and that all mixes were proportioned to achieve 40MPa compressive strength. The results found that the optimum percentage of replacement of sand with glass was 30% and achieved 58.5MPa at 28 days, interestingly higher than that of just sand due to the angular nature of the fine glass aggregate (Adaway & Wang 2015). Similar findings were found when brown-coloured soda lime beer bottles were used as a fine glass aggregate. This study however found that the glass aggregate replacement of up to 100% ratio did not reduce the mechanical properties of concrete (Du & Tan 2014).

Other literature has supported the 100% fine aggregate replacement with glass resulting in the concrete showing significant strength increases, no obvious effect on the fresh properties of concrete, a slight reduction in fresh density, air content and did not reduce the mechanical properties. The recommendation from that research was that the best replacement of aggregates among the tested ratios were 1:3 coarse natural aggregates with 2:3 coarse glass aggregate for concrete (Gerges et al. 2018).

In contrast, other literature which observed the suitability of waste glass sand as partial sand replacement in concrete with the use of mixed coloured soda-lime glass (food and beverage containers) as a sand replacement for a target strength of 32 MPa with 20%, 40% and 60% glass replacement found that glass can be used up to 60% replacement, but at high levels admixtures must be used. The ideal percentage of glass is 20%, which gained a compressive strength of 34.2 MPa at seven days, 5.8% higher than the control (no glass) (Tamanna et al. 2020). This discrepancy in the published research merits further study especially regarding high substitution levels of recycled crushed glass as a fine aggregate with the use of plastic waste as a partial substitute for coarse aggregates.

A large amount of glass aggregate increases bleeding and creates a more porous microstructure due to the impermeable nature of glass which results in lower air voids within the mortar. On the contrary, the irregular shape of waste glass increases the surface area of the aggregate, trapping more air in the mortar mix. Other studies have attributed the change in air content to the geometry of the crushed waste glass (Małek et al. 2020).

A study where mortar was produced with a fraction of the sand being replaced by fine glass aggregates (0%, 20%, 50% and 100% by volume), with the aggregate size distribution remaining similar to sand. This allowed the aggregate material to be the single factor under analysis. The results were that mortars with fine glass aggregates are viable for replacement ratios around 20%, demonstrating exceptionally good mechanical performance and physical capability. Compressive and flexural strength of these mortars containing glass aggregate is generally greater than the mortar containing 100% sand. It was suggested that the mortar composing of 20% glass as a fine aggregate replacement may be used for interior applications and building facades (Penacho et al. 2014).

## 2.3 PET fibres for concrete and mortar applications

Applications that utilise PET fibres for partial or total substitution of steel in reinforced concrete have increased recently in the concrete and shotcrete industries for the construction of footpaths, non-structural precast products (i.e., culverts, pipes, sleepers, and cable pits), underground structures (i.e., mine gateway, tunnels), and roads. It has also been noted that it is desirable to apply PET fibres in the construction of bush, narrow, steep, and winding roads due to the negative effects of the traditional steel reinforcement ability to puncture tyres, corrode and reduce the workability of the concrete. PET fibres have been said to be gradually replacing the traditional reinforcement due to the ease of construction thus less labour and subsequent costs (Yin 2015). It was also stated that for a bridge pier where the concrete was placed, crack extension was substantially decreased.

Slump is used to evaluate and measure the workability / consistency of the fresh mortar mix. It has been noted that in most studies, the incorporation of plastic aggregates has a lower slump value due to the sharp edges and angular particle size of the plastic aggregate. On the contrary, a few studies have stated that incorporating plastic aggregate has increased the slump of concrete mixes due to presence of more free water, since the plastic aggregates inability to absorb water during the mixing of the concrete (Saikia & de Brito 2012). Concrete mixes containing the flaky plastic aggregates with different particle size required a much higher water content than the mixes with fine flaky plastic aggregate to achieve the same slump due to the angular and non-uniform nature. The shape and size of plastic aggregate has a significant influence on both the fresh and hardened concrete properties (Saikia & de Brito 2014).

Comparing the sieve analysis of the flaky plastic aggregate in the study by Saikia et al 2014 and the plastic used in for this research report, a correlation can be seen as the plastic aggregate closely matches in size and proportion. See Fig. 5, illustrating the correlation between size and proportions of the flaky plastic aggregates used.

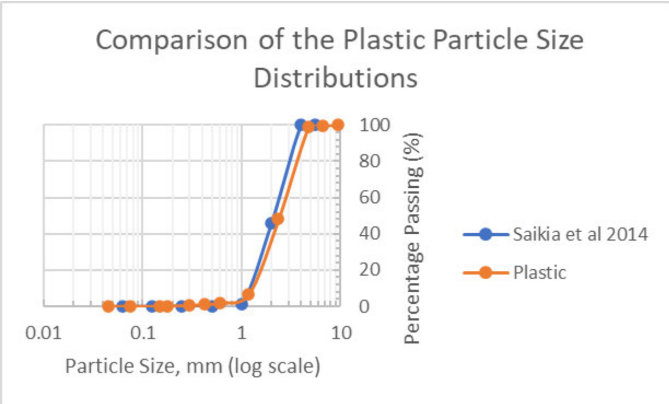



Fig. 5.

Satisfactory aggregate is well graded with a good proportion between rounded and angular particles with a surface texture that is not too smooth. Artificial aggregates (plastic) are elongated and their surface cavities as a result of the manufacturing process led to a rough texture which increases cement paste adhesion and the ability for the cement paste to penetrate inside voids (Coppola et al. 2016).

A main issue with plastic or lightweight aggregate dispersion is due to the low density which causes the aggregate to float if not well dispersed into the matrix. Both the shape and the permeability of the plastic aggregate affects the workability of mortar. The permeable structure influences the workability of fresh mortar due to water and cement paste absorption inside pores. The elongation and the rough texture of the plastic aggregates give rise to higher friction and also reduce consistency. It has been reported that weak adhesion between plastic aggregates and cement paste is due to the increased water content at the interface which results in increased porosity and decreased mechanical properties (Coppola et al. 2016).

### 2.3.1 Strength Properties

From the literature, the addition of recycled plastic fibre at low doses did not affect the compressive strength of concrete. It did however significantly improve the residual flexural tensile strength of concrete (Yin 2015).

It was stated by da Silva et al 2014, that the flexural and compressive strength tests results of the hardened mortar at 28 days declined with the substitution of natural aggregates by plastic aggregates. This was assumed to be because the plastic aggregates present a smooth surface, are impermeable, less resistant, and therefore limit the connection between the matrix. The study compared the use of plastic flakes and plastic pellets, which concluded that the plastic flakes with a substitution greater than 10% resulted in a significant decrease in mechanical strength. This was attributed to the plastic flake aggregate being thin, deformable flakes that have little strength by comparison with the plastic pellets and the natural aggregate, thus reducing the strength of the mortar. It was also stated that for an equivalent substitution ratio, there were nearly twice as many plastic aggregate particles in the mortar containing plastic flakes than that of the plastic pellets resulting in more points of weakness between the cement paste and the aggregates (da Silva et al. 2014).

Another article supports this by stating that almost all research related to plastic aggregate found that by incorporating plastic aggregate into the mix, compressive strength decreases due to the very low bond strength between the surface of the plastic waste and the cement paste, and plastic being hydrophobic in nature. Compressive strength reduction was noted to be more pronounced in mixes that contain large flaky plastic aggregate (Saikia & de Brito 2012). Adding waste plastic as fibres reduces the compressive strength and workability of mixes however it does improve tensile strength and decrease dry shrinkage by about 35% compared to a mix without plastic fibres (Mohammed & Hama 2022).

## 2.4 Combined glass aggregate and PET fibres for concrete and mortar applications

There are limited studies that combine both glass sand and PET fibres for structural concrete and mortar applications.

Mohammed et al 2020, utilised waste plastic as both a coarse and fine aggregate and waste glass as both coarse and fine aggregate for different percentages (5%, 10%, 15%, 25%). An increasing amount of waste plastic and waste glass resulted in a corresponding decrease in the compressive strength, flexural strength, and tensile strength. Whilst water absorption was found to increase. An optimum replacement ratio of 25% was found for both glass and plastic, which corresponded with a concrete structural application (Mohammed et al. 2020).

A study was also conducted incorporating recycled plastic waste and recycled crushed glass as a coarse aggregate replacement in concrete mixture to evaluate its feasibility for a concrete footpath construction. The replacement proportions were 10%, 20%, 30%, 40% and 50%. The study found that recycled plastic waste and recycled crushed glass can be a viable option in industrial applications. The study noted that due to the low adhesion between the recycled aggregates and the cement gel matrix, and the low aggregate crushing resistance, that coarse aggregate replacement was viable up to 20% by volume for recycled plastic waste and up to 30% by volume for recycled crushed glass (Mohammadinia et al. 2019).

In 2020, a literature field study was published on a concrete footpath with recycled plastic and crushed glass as filler materials. The prior research conducted by Mohammadinia et al (2019) led to the field study utilizing 10% recycled plastics and 10% crushed glass as coarse aggregate replacement in concrete. The findings highlight the effective use of utilizing a design mix of 10% recycled plastic waste and 10% recycled crushed glass in a M40 concrete and the concrete to meet the local council’s standard for concrete footpaths in Victoria Australia (Wong et al. 2020).

Mohammed et al (2022) conducted a study of 15% waste glass powder as a partial substitute for cement and 10 and 20% crushed waste plastic to be used as a partial substitute for fine aggregates. The results were that by using glass alone, the concrete properties improved compared to the control reference. However, by replacing sand with plastic for concrete with the 15% glass, the properties of concrete decreased especially when 20% crushed waste plastic was incorporated. The only improvement was the energy absorption under impact load which increased by 431.57% for the 20% plastic aggregate replacement when comparing it to the control reference (Mohammed & Hama 2022).

## 2.5 Identified research gaps

The results of existing studies on combined glass / PET fibre incorporation in concrete and mortars vary. Combining both glass and plastic waste into cement mortar will result in different properties when compared to only adding one waste product. By adding glass aggregate into cement, several studies have shown that the compressive strength increases generally up to a substitution of 20% to 30%, and even 100%. On the other hand, another study stated that 20% is the ideal replacement, and that when incorporating substitution greater than 20% admixtures must be used.

By adding plastic aggregate into concrete, it has been found that at low doses, the residual flexural tensile strength significantly improves, and the compressive strength was not affected. On the contrary, another study found that both the flexural and compressive strength results declined and that utilising plastic flakes with a substitution greater than 10% resulted in a significant decrease in mechanical strength. The literature on the combined use of both waste products, it was stated that as the replacement increases, resulted in a corresponding decrease in compressive, flexural, and tensile strength, with an optimal replacement ratio being 25%.

Due to the limited studies that have combined both waste products, and the gap in the literature is knowledge on the implications of incorporating both materials, so the main objective of the study is to investigate and identify which ratio of glass and plastic is best suited when replacing sand as a fine aggregate in mortar mixes. The purpose of this project is to identify the optimum proportion for a combined PET plastic fibre / glass aggregate mortar mix, and the resulting impact on strength, wet mortar properties and microstructural properties.

The incorporation of glass aggregate into concrete mixes is known to cause deterioration due to ASR. Future research may incorporate precautionary measures by using ASR suppressors to eliminate the ASR damage, the use of ground granulated blast furnace slag, metakaolin, pozzolanic glass powder and lithium nitrate which prove to be very effective to mitigate the ASR risk (Taha & Nounu 2009). As well as the impact of PET fibres on preventing or reducing ASR.

From the literature, incorporating glass can increase compressive strength, conflicting information regarding plastic has been reported to increase flexural tensile strength or reduce both flexural and compressive strength decreasing the mechanical strength. Utilising both glass and plastic was also said to decrease the mechanical strength. Due to inconsistent available data, it is hypothesised that by utilising both plastic and glass at different proportions, the results will vary. As the percentage of plastic increases, the compressive strength will decrease however it is assumed that the indirect tensile strength will increase. With the increase of glass, the compressive strength will increase, and by combining both aggregates the positives and negatives may counter each other or the benefits may compound and serve to provide a functional mortar mix utilising waste products.

# 3.0 Methodology

## 3.1 Introduction

In selecting the mix design, the basic requirement of mortar is to satisfy two essential requirements, workability and strength. Most importantly the workability, to limit segregation or bleeding due to the use of waste material. The workability of the mix impacts on the mortar's strength quality and appearance. To evaluate the workability, the flow test was conducted. Workability relates to the fresh mortar, and strength relates to the hardened state of mortar. Consequently, the methodology for the testing of the mortar entailed two phases, the fresh mortar properties, and the hardened mortar properties of the proposed mix design. Regarding strength, the hardened mortar properties will also be analysed for compressive strength and indirect tensile strength.

## 3.2 Australian Standards

AS2701:2001 - Methods of sampling and testing mortar for masonry construction

ASTM C 1437:2020 - Standard Test Method for Flow of Hydraulic cement Mortar

AS1012.9 - Methods of testing concrete: Compressive strength tests - Concrete, mortar and grout specimens

AS1012.10 - Methods of testing concrete: Determination of indirect tensile strength of concrete cylinders

## 3.3 Materials

- General purpose Portland cement (GP)
- Sand, fine aggregate
- Clean potable water
- Recycled crushed glass (G) to replace the sand as a fine aggregate
- Plastic waste (PET) to replace the sand as a fine aggregate
- Laboratory facilities and equipment at the University of Southern Queensland, Springfield campus

### 3.3.1 Material Sieve analysis

The aggregate materials were sieved to evaluate the particle size distribution to define the relative mass of particles according to size. From the results, the constituents of each type of aggregate vastly ranged in size and proportion. Refer to the particle size distribution curves below in Fig. 6.

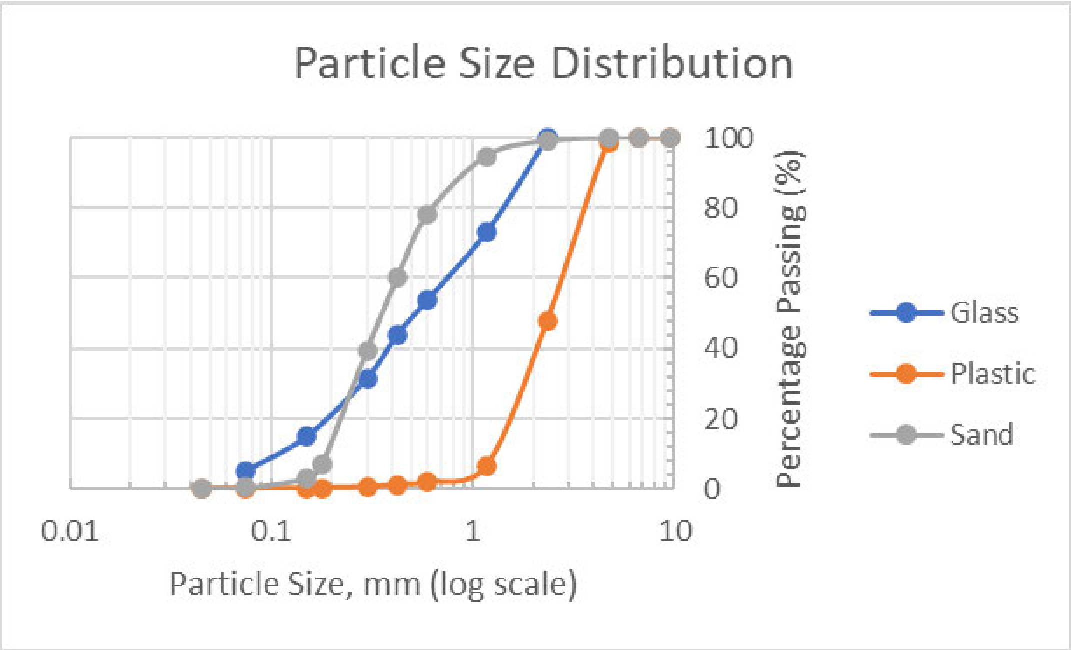



Fig. 6.

### 3.3.2 Glass Aggregate

The crushed and pulverised glass waste were collected / sourced from a supplier from daily used household waste in Australia. From sieve analysis the glass aggregate varied in size, refer to Fig. 7. See the results in table 1. The recycled crushed glass consisted mainly of bottle glass and jar glasses, photos illustrating the sieve analysis setup and glass retained in each sieve, refer to Fig 8 & 9.

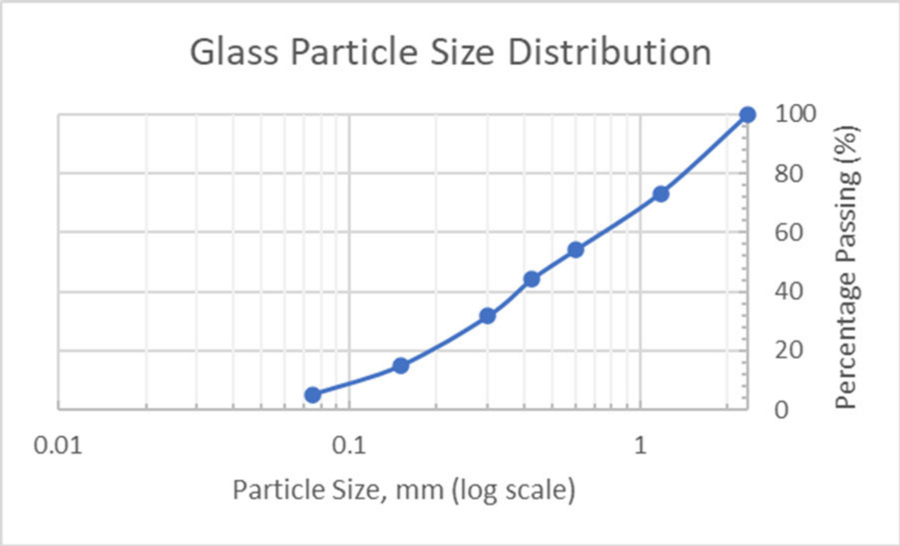



Fig. 7.

Fig. 8, Illustrating the general setup for sieve analysis.

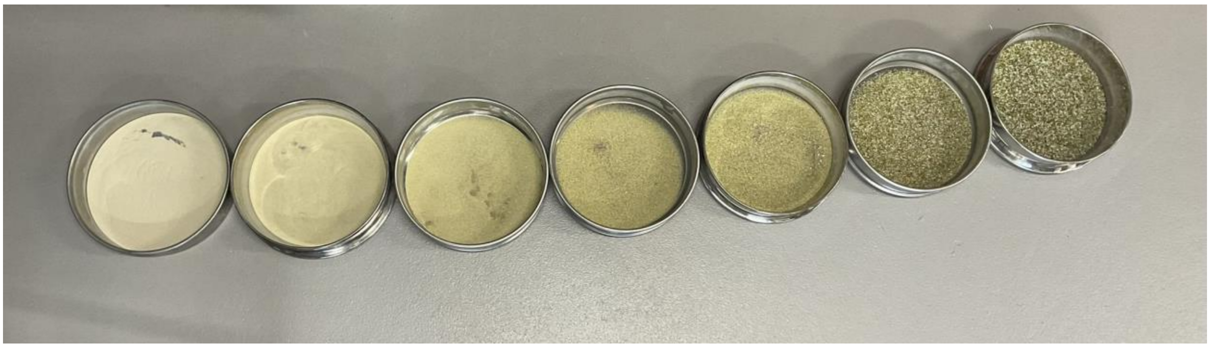


Fig. 9.

| Sieve size (mm) | Sieve Mass (g) | Sieve Mass with glass (g) | Mass of glass (g) | Retained (%) | Finer % |
|---|---|---|---|---|---|
| 2.36 | 397.5 | 397.5 | 0 | 0.000 | 100.000 |
| 1.18 | 494.8 | 642.4 | 147.6 | 26.671 | 73.329 |
| 0.6 | 310.6 | 417.7 | 107.1 | 19.353 | 53.975 |
| 0.425 | 412.3 | 467.1 | 54.8 | 9.902 | 44.073 |
| 0.3 | 280.5 | 349.2 | 68.7 | 12.414 | 31.659 |
| 0.15 | 266.2 | 359.3 | 93.1 | 16.823 | 14.836 |
| 0.075 | 414.6 | 468.1 | 53.5 | 9.668 | 5.168 |
| PAN | 477.1 | 505.7 | 28.6 | 5.168 | 0.000 |
| | | Total | 553.4 | | |

Table. 1.

### 3.3.3 PET fibres

The plastic material was sourced from Toowoomba by means of utilising recycled PET, that was supplied in shredded form, refer to Fig. 10. From sieve analysis the plastic aggregate varied in size, but the main constituents were 2.36 and 1.18mm in size and considered gap graded which resulted in greater segregation of the mix. See the results in table 2, particle size distribution (Fig 11), and plastic retained in each sieve (Fig 12).

Fig. 10.

| Sieve size (mm) | Sieve Mass (g) | Sieve Mass with Plastic (g) | Mass of Plastic (g) | Retained (%) | Finer % |
|---|---|---|---|---|---|
| 9.5 | 654.9 | 654.9 | 0 | 0.000 | 100.000 |
| 6.7 | 637.9 | 638.1 | 0.2 | 0.130 | 99.870 |
| 4.75 | 592.5 | 594.2 | 1.7 | 1.107 | 98.762 |
| 2.36 | 397.5 | 475.4 | 77.9 | 50.749 | 48.013 |
| 1.18 | 495.2 | 558.7 | 63.5 | 41.368 | 6.645 |
| 0.6 | 310 | 317.3 | 7.3 | 4.756 | 1.889 |
| 0.425 | 292.3 | 293.4 | 1.1 | 0.717 | 1.173 |
| 0.3 | 280.6 | 281.6 | 1 | 0.651 | 0.521 |
| 0.18 | 273.3 | 273.8 | 0.5 | 0.326 | 0.195 |
| 0.15 | 267 | 267.1 | 0.1 | 0.065 | 0.130 |
| 0.075 | 415.5 | 415.6 | 0.1 | 0.065 | 0.065 |
| 0.045 | 254.7 | 254.8 | 0.1 | 0.065 | 0.000 |
| Pan | 459.9 | 459.9 | 0 | 0.000 | 0.000 |
| | | Total | 153.5 | | |

Table. 2.

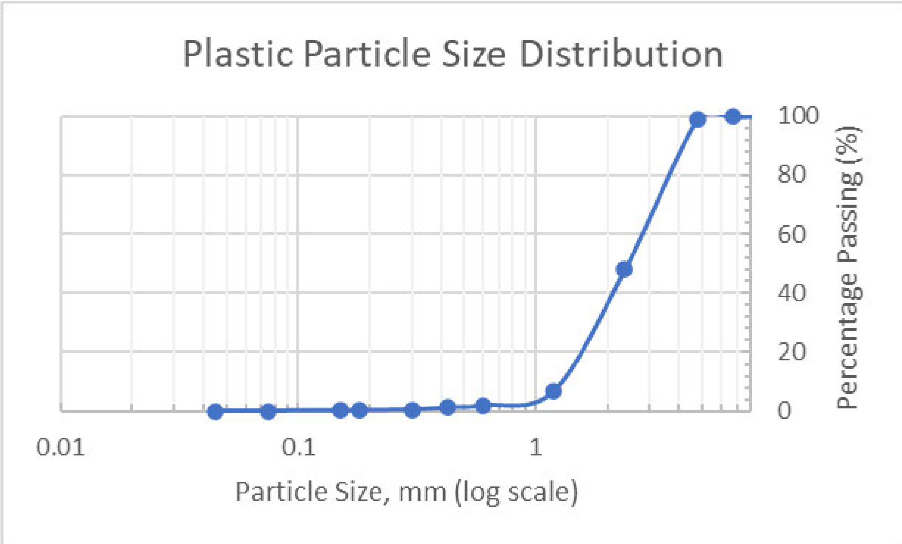



Fig. 11.

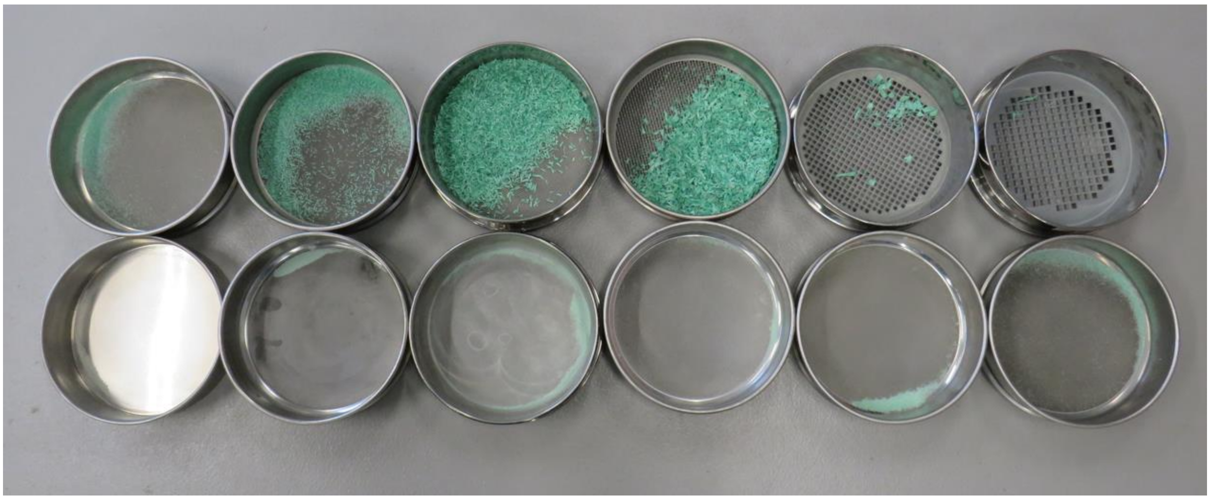


Fig. 12.

### 3.3.4 Cement

The general-purpose cement (GP) was sourced locally and is a cost-effective, high-quality building material that has been noted as having a level of consistency and versatility that makes it an ideal choice in virtually all construction applications. Table 3 lists the components of general-purpose Portland (GP) cement and table 4 lists the major cement types and composition.

| **Component** | **Percentage of mixture** |
|---|---|
| Calcium carbonate | 60–70% |
| Silica | 17–25% |
| Alumina | 3–8% |
| Iron oxide | 0.5–6% |
| Magnesia | 0.1–4.5% |
| Gypsum | 1–2% |

Table 3 (USQ 2021).

**MAJOR CEMENT TYPES AND COMPOSITION (PERCENTAGE BY MASS)**

| Cement type | Portland cement | Type GP (Note 1) | Mineral additions and minor additional constituents (7.5% combined maximum for Type GP and 20% combined maximum for Type GL) | | | Supplementary cementitious materials (SCM) (Note 4) | |
|---|---|---|---|---|---|---|---|
| | | | Mineral additions (Note 2) | | Minor additional constituents (Note 3) | Fly ash and/or slag | Amorphous silica |
| | | | Fly ash or slag | Limestone | | | |
| Type GP | 92.5 to 100 | – | 0 to 7.5 | | 0 to 5 | – | – |
| Type GL | 80 to 92 | – | – | 8 to 20 | 0 to 5 | – | – |
| Type GB | – | <92.5 | – | – | – | >7.5 | 0 to 10 |

NOTES:

1 If Type GB cement consists of Type GP and amorphous silica only, the proportion of Type GP shall be 90% or above

2 For Type GP the 'mineral additions' may comprise limestone, fly ash or slag, or a combination of these materials, at the discretion of the cement manufacturer.

3 The 'minor additional constituents' addition forms part of the allowable amount of 'mineral addition' in the cement.

4 Type GB cement may contain supplementary cementitious materials (SCMs) comprising either or both fly ash and slag at combined levels above 7.5%, and amorphous silica at a level not exceeding 10%.

Table. 4. (Australia 2010).

### 3.3.5 Sand

The sand was collected / sourced from a local supplier, refer to Fig. 13 for a photo of said sand. The sand varied in size and was considered well graded which allows for the space between larger particles to be effectively filled by smaller particles. See the results in table 5, particle size distribution (Fig 14), and sand retained in sieves (Fig 15).

Fig. 13

| Sieve size (mm) | Sieve Mass (g) | Sieve Mass with Sand (g) | Mass of Sand (g) | Retained (%) | Finer % |
|---|---|---|---|---|---|
| 9.5 | 654.9 | 654.9 | 0 | 0.000 | 100.000 |
| 6.7 | 637.9 | 638.6 | 0.7 | 0.070 | 99.930 |
| 4.75 | 592.5 | 593 | 0.5 | 0.050 | 99.880 |
| 2.36 | 397.5 | 406.8 | 9.3 | 0.930 | 98.950 |
| 1.18 | 495.2 | 537.6 | 42.4 | 4.240 | 94.710 |
| 0.6 | 310 | 474.6 | 164.6 | 16.460 | 78.250 |
| 0.425 | 292.3 | 473.2 | 180.9 | 18.090 | 60.160 |
| 0.3 | 280.6 | 487.6 | 207 | 20.700 | 39.460 |
| 0.18 | 273.3 | 596.1 | 322.8 | 32.280 | 7.180 |
| 0.15 | 267 | 308 | 41 | 4.100 | 3.080 |
| 0.075 | 415.5 | 442.7 | 27.2 | 2.720 | 0.360 |
| 0.045 | 254.7 | 255.2 | 0.5 | 0.050 | 0.310 |
| Pan | 459.9 | 463 | 3.1 | 0.310 | 0.000 |
| | | Total | 1000 | | |

Table. 5.

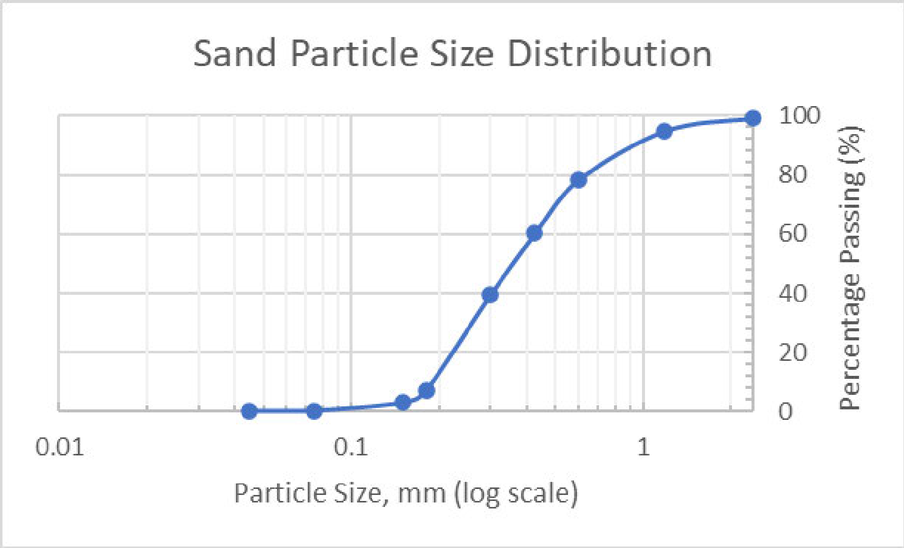



Fig. 14.

Fig. 15.

### 3.3.6 Water

Standard potable tap water was used to prepare all mixes. A study was conducted by Olajumoke et al. 2012 on the effects of non-potable water on the strengths of concrete, which compared 3 sources of water, tap (a), and 2 streams (b and c). These streams showed no sign of offensive odour, had no floating organic matter however stream (b) had a little turbidity and stream (c) was brackish in colour and is polluted by partially treated effluent from a biological treatment plant (Olajumoke et al. 2012). The pH for water (a, b, c) were 6.7, 9.5, and 6.7 respectively. The findings of the study concluded that concrete made with the two streams (b and c) did not perform as well and the mechanical properties decreased, both compressive and flexural strength were lower compared to that made with the tap water (a) (Olajumoke et al. 2012).

Potable tap water is generally considered satisfactory for mixing due to it being clean and free from harmful quantities i.e., organic material, salt, oils, sugar, acid, and alkalis. The pH of water should be no lower than 6.0, with a value between 6 to 8 being the most suitable for the construction of concrete (Joshi 2019). The potable tap water used had a pH 7.8 and falls within the limits for potable water defined by the Australian drinking water guidelines with a pH value of 6.5 to 8.5 (Seqwater 2023).

## 3.4 Testing

The testing of the specimens was conducted in the laboratory at the University of Southern Queensland, Springfield campus.

## 3.5 Mortar Mix Design

In selecting the mix design, the basic requirement of mortar is to satisfy two essential requirements, workability, and strength. AS2701:2001 Methods of sampling and testing mortar for masonry construction were adhered to (Australia 2001). In evaluating the essential requirements, tests will be conducted. For evaluating the workability of the mortar mix, the fresh mortar will be analysed using the flow table test in accordance with ASTM C 1437:2020. Regarding strength the hardened mortar properties will also be analysed for compressive strength in accordance with AS1012.9:2014 (Australia 2014c) and indirect tensile strength in accordance with AS1012.10 (Australia 2000). This project will produce 6 batches of mortar using the general-purpose Portland cement (GP), sand, glass (G) and plastic (PET) as a replacement for the sand.

The proposal is to use combined recycled glass (G) and waste plastics (PET) as fine aggregates in the mortar mix with different proportions of G and PET, i.e., 0%, 25%, 50%, 75% and 100%, see Fig.16.

| **Mortar Mix Design (%)** | | | | | | |
|---|---|---|---|---|---|---|
| Mix | 1 | 2 | 3 | 4 | 5 | 6 |
| Fine Aggregate (Sand) | 100 | 0 | 0 | 0 | 0 | 0 |
| Fine Aggregate (Glass) | 0 | 100 | 75 | 50 | 25 | 0 |
| Coarse Aggregate (Plastic) | 0 | 0 | 25 | 50 | 75 | 100 |

Fig. 16.

Regarding the compressive and indirect strength tests, 3 samples of the mortar will be casted into the 50 mm x 100 mm cylinders for each test per batch. For the flow table tests, one sample will be used from each batch.

See table 6 below for the required min volume of mortar required for testing.

| **Mortar Mix Design (kg)** | | | | | | |
|---|---|---|---|---|---|---|
| Mix | 1 | 2 | 3 | 4 | 5 | 6 |
| Fine Aggregate (Sand) (%) | 100 | 0 | 0 | 0 | 0 | 0 |
| Fine Aggregate (Glass) (%) | 0 | 100 | 75 | 50 | 25 | 0 |
| Fine Aggregate (Plastic) (%) | 0 | 0 | 25 | 50 | 75 | 100 |
| Cement (kg) | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Water (kg) | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Sand (kg) | 0.68 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Glass (kg) | 0.00 | 2.71 | 2.03 | 1.35 | 0.68 | 0.00 |
| Plastic (kg) | 0.00 | 0.00 | 0.15 | 0.30 | 0.46 | 0.61 |
| Total (kg) | 1.00 | 3.03 | 2.51 | 1.98 | 1.46 | 0.93 |

Table. 6.

From the literature, it was approximated on how much resources based on the mechanical properties of aggregates given in table 7.

**Table 4**
Mechanical properties of aggregates.

| Material | Specific gravity ($G_s$) | Water absorption (%) |
|---|---|---|
| Natural quartz | 2.65 | 10.2 |
| Fine sand | 2.46 | 4.2 |
| RCG | 2.50 | 0.002 |
| RPW | 1.18 | 0.001 |

Table. 7. (Mohammadinia, 2019).

### 3.5.1 Mix Design Quantities

The mix designs were selected by assuming a mortar mix 1:4:0.25. A control batch was produced to serve as a benchmark to evaluate and analyse the experimental batches. The control batch consisted of 4 mix variations. These variations were the different water content, 96mL, 110mL, 130mL, and 135mL. The assumed mortar mix ratio 1:4:0.25, resulted in a very dry mix, and the amount of water was increased until the workability was deemed appropriate.

Following AS2701, the quantity of water used in preparing the mortar will produce a flow of 110±5, in accordance with clause 5.5. This resulted in 96mL of water being added to the mix and the flow was recorded as 19.1% therefore unacceptable. Each trial was made with fresh mortar. The optimum mix consisted of 130mL of water and the resulting flow was 105.2%. Refer to table 8 below to see the results for all the trials.

| Description | Cement (g) | Sand (g) | Glass (g) | Plastic (g) | Water (mL) | Flow dia 1 | Flow dia 2 | Flow dia 3 | Flow dia 4 | Average | Internal diameter of base of flow mold (mm) | Calculated Flow = [(Davg-Do)/D0]*100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | 101 | 465 | 0 | 0 | 96 | 118.2 | 117.93 | 118.82 | 119.9 | 118.7125 | 99.68 | 19.1 |
| | 101 | 465 | 0 | 0 | 110 | 126.8 | 130.5 | 133.9 | 135.3 | 131.625 | 99.68 | 32.0 |
| | 101 | 465 | 0 | 0 | 130 | 203.1 | 209.3 | 205.9 | 199.98 | 204.57 | 99.68 | 105.2 |
| | 101 | 465 | 0 | 0 | 135 | 234.9 | 226.1 | 227.5 | 232.2 | 230.175 | 99.68 | 130.9 |

Table. 8.

Due to the purpose of the research is to utilise recycled material in the mortar mix, it was decided to focus on using the 110mL control batch for comparison. This was directly due to the flow recorded by a 75% glass + 25% plastic replacement for sand with 130mL of water exceeding the flow table of 150.8% and a lower water content was required. To calculate the required replacement of sand for the various experimental mixes, both plastic and glass were replaced on a volume basis of measurement. Plastic could not replace sand based on weight, see table 9 illustrating the volume ratios for mix design for the flow table tests.

Table. 9: **<u>Mortar Mix Design for Flow Table Tests</u>**

| Mix | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Fine Aggregate (Sand) % | 100 | 0 | 0 | 0 | 0 | 0 |
| Fine Aggregate (Glass) % | 0 | 100 | 75 | 50 | 25 | 0 |
| Fine Aggregate (Plastic) % | 0 | 0 | 25 | 50 | 75 | 100 |
| Cement (g) | 101 | 101 | 101 | 101 | 101 | 101 |
| Water (g) | 110 | 110 | 110 | 110 | 110 | 110 |
| Sand (g) | 465 | 0 | 0 | 0 | 0 | 0 |
| Glass (g) | 0 | 483.6 | 362 | 241.3 | 120.7 | 0 |
| Plastic (g) | 0 | 0 | 27.9 | 55.8 | 83.7 | 111.6 |
| $\sum$ (g) | 676 | 694 | 600.9 | 508.1 | 415.4 | 322.6 |

To measure the ratio replacements, i.e. 225mL of sand weighed 348 grams, 225mL of glass weighed 362 grams, 75mL of plastic weighed 27.9 grams. All measurements in mL were lightly tapped with a rod to ensure consistent compaction for reliability.

### 3.5.2 Testing of Workability

The strength of the concrete is mainly governed by the water to cement ratio, workability of the mortar is governed by the aggregate to cement ratio. Workability relates to the ability for the concrete to be placed and compacted and the main influencing factors are the water content, the water to cement ratio, the aggregate to cement ratio, the aggregate grading, and the mix design (USQ 2021).

The flow of the mortar was evaluated to give an indication of the workability and consistency of the mortar mix. To determine the flow of the mortar was in accordance with AS2701-2001, section 5.5 the quantity of water used in preparing the mortar should target a flow of 110 +-5.

AS2701-2001 Section 5.4 Preparation of mortar

AS2701-2001 Section 5.5 Determination of flow

AS2701-2001 Flow table and frame

ASTM C 1437:2020 Standard Test Method for Flow of Hydraulic cement Mortar

Note: More water was added to the original mortar mix ratio of 1:4:0.25 to allow for adequate workability and the subsequent mix designs will incorporate the same water ratio.

Flow table tests were carried out in the laboratory at UniSQ in accordance with AS2701-2001 to determine the fluidity of the mortar mixes.

To conduct the flow testing of the mortar mixes, the apparatus was clean, free from any debris, dry and setup in the correct position, ensuring the table is level and the mould is in the centre of the table. The mortar is then filled into the mould in two layers and a tamping rod is used 25 times on each layer. The mortar that overflows the mould is then removed. The mould is then lifted vertically and with haste the handle of the apparatus is turned 15 times in 15 seconds, allowing the table to be lifted and dropped 15 times. The average spread is calculated by taking 4 measurements of the mortar’s diameter.

The flow is then calculated by:

$$\text{Calculated Flow} = [(Davg-Do)/Do]*100$$

Note:

- Davg is the calculated average spread
- Do is the internal diameter of the base of the flow mould


Fig. 17 (left) and 18 (right), illustrating the flow table apparatus and correct setup.

See figures 19 through 23, photos illustrating the approximation of the correct ratio of the mix to allow for adequate workability.


Fig. 19. (66mL) Fig. 20. (96mL)



Fig. 21. (110mL) Fig. 22. (135mL) Fig. 23. (130mL & 100% glass)

## 3.6 Preparation of Samples

Samples were prepared as cylindrical moulds 50 mm in diameter * 100 mm high. Mortar mixes were prepared, measuring the required constituents by mass. Firstly, the dry ingredients were added to the mixer. Water was then added, and the mortar was mixed to a common consistency. Prior to moulding, the plastic moulds were greased to allow for easy demoulding using Valplex M an all-purpose grease made by Valvoline.

The samples were compacted in three (3) even layers and tamped with 25 blows per layer, see Fig. 24. After moulding the samples were left to dry for a period of 24 hours. They were then demolded and cured in a curing room for a period of 28 days at a temperature of 25°C and a humidity of 76%, see Fig. 25.


Fig. 24.


Fig. 25.

## 3.7 Strength Testing

### 3.7.1 Unconfined Compressive Strength

The 28-day compressive strength test, in accordance with AS1012.9:2014

The testing procedure was carried out as follows:

- Measuring and testing was promptly performed after removing the test specimens from the curing room.
- The testing machine was clean and free from films of oils or any other material during use including particles of grit.
- The test specimen's surfaces were free from loose particles of grit.
- The test piece was then placed in the machine ensuring it was centrally located prior to beginning testing.
- Bring the upper platen and the specimen together so that uniform bearing is obtained.
- Apply the force to the test specimen without shock, and then continuously increase the force at a constant rate equivalent to 20±2 MPa/min compressive stress until no increase in force can be sustained or the specimen fails.
- Record the maximum force recorded by the testing machine.

The calculation to find the compressive strength of the test specimens were conducted by dividing the maximum force applied by the mean of the cross-sectional area.

Fig. 26. The strength testing machine.

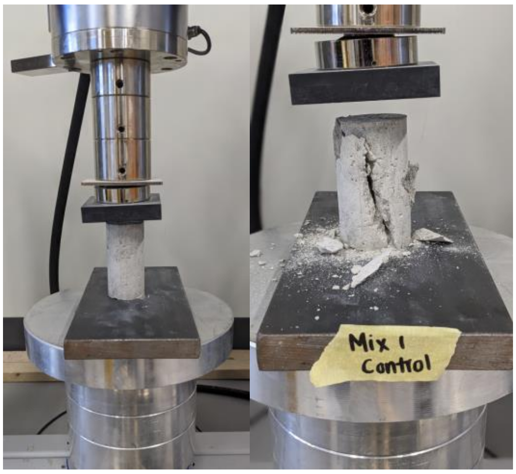



Fig. 27 (left) the compression testing machine prior to testing mix 1, and Fig. 28 (right) mix 1 after testing.

### 3.7.2 Indirect Tensile Strength

The 28-day indirect tensile strength test, in accordance with AS1012.10:2000

The testing procedure was carried out as follows:

- Measuring and testing was promptly performed after removing the test specimens from the curing room.
- The testing machine was clean and free from films of oils or any other material during use including particles of grit.
- The test specimen’s surfaces were free from loose particles of grit.

- The diameter of the test specimens was measured in the test plane to the nearest 0.2 mm by averaging three diameters measured near the ends and the middle. The length was also measured to the nearest millimetre by averaging three length measurements that were taken along the lines in contact with the bearing strips.
- The bearing strips were tempered grade hardboard that complied with AS 2458 and were free from defects.
- The bearing strips were aligned between the top and bottom platen of the specimen.
- The test piece was then ensured to be centrally located prior to beginning testing.
- A small amount of initial force was then applied to ensure there was no side movement.
- Force was then applied to the test specimen without shock, and then continuously increase the force at a constant rate equivalent to 1.5±0.15 MPa/min indirect tensile stress until no increase in force can be sustained or the specimen fails.
- Record the maximum force recorded by the testing machine and the appearance of the mortar and the type of fracture was noted.

Refer to Fig. 26 above for illustration of the testing machine.


Fig. 29 (left) the indirect tensile testing machine prior to testing mix 1, and Fig. 30 (right) mix 1 after testing.

## 4.0 Resources required:

| Control mix / benchmark Concrete Mix Design Proportions (kg) | | GP cement bag (kg) 20 | Min L per batch for testing 1.54 | L per 20 kg bag of Cement | Concrete Bags per batch 0.01 |
|---|---|---|---|---|---|
| | Parts | Total (kg) | Specific Gravity | Total (L) | Per Batch (kg) |
| Cement | 1 | 20 | 1.44 | 13.9 | 0.19 |
| Water | 0.9 | 18 | 1 | 18 | 0.17 |
| Sand @ 100% as fine aggregate | 4 | 80 | 2.46 | 32.5 | 0.75 |
| Plastic @ 100% as fine aggregate | 4 | 80 | 1.18 | 67.8 | 0.67 |
| Glass @ 100% as fine aggregate | 4 | 80 | 2.5 | 32.0 | 3.00 |
| **Total** | | **118** | | **164** | **4.8** |

Table. 10.

| Mortar Mix Design (kg) | | | | | | |
|---|---|---|---|---|---|---|
| Mix | 1 | 2 | 3 | 4 | 5 | 6 |
| Fine Aggregate (Sand) (%) | 100 | 0 | 0 | 0 | 0 | 0 |
| Fine Aggregate (Glass) (%) | 0 | 100 | 75 | 50 | 25 | 0 |
| Fine Aggregate (Plastic) (%) | 0 | 0 | 25 | 50 | 75 | 100 |
| Cement (kg) | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 |
| Water (kg) | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Sand (kg) | 0.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Glass (kg) | 0.00 | 3.00 | 2.25 | 1.50 | 0.75 | 0.00 |
| Plastic (kg) | 0.00 | 0.00 | 0.17 | 0.34 | 0.51 | 0.67 |
| Total (kg) | 1.11 | 3.35 | 2.77 | 2.19 | 1.61 | 1.03 |

Table. 11.

Above in table 11 illustrates the amount of material that is needed for each sample, ie mix 1 through 6.

| Resources Needed: | Total (kg) |
|---|---|
| Cement | 1.12 |
| Water | 1.012 |
| Sand | 0.75 |
| Plastic | 1.7 |
| Glass | 7.5 |

Table. 12.

Above in table 12 are the approximate amount of material that is needed for the project.

Testing per mix / batch:

1. Flow table tests were carried out in accordance with AS2701-2001
2. 28-day compressive strength test, in accordance with AS1012.9:2014
3. 28-day indirect tensile strength test, in accordance with AS1012.10:2000

All mixes were cured for 28 days, and the preparation and testing of the specimens were conducted to Australian standards. Tests on fresh mortar were conducted for consistency, workability, and bulk density per unit volume (sand, glass and plastic). The flow test was used to determine the adequate amount of water and workability. Tests on the hardened properties of mortar included the compressive strength tests and the indirect tensile strength testing as they are carried out on mortar cylinders. The tests were conducted in accordance with AS1012.9:2014, AS1012.10:2000.

The limitation of the project was the small sample size of each mix, especially mix 4 due to lack of material on hand from using material to find the appropriate flow.

## 5.0 Results and Observations

The impact of using recycled crushed glass (RCG) and recycled plastic waste (RPW) as a sand replacement on the properties of both fresh and hardened mortar, and the mechanism of the different amounts of glass and plastic wastes as well as how they affect the physical, mechanical and microstructure of the cement mortar will be discussed in the relevant sections below.

### 5.1. Properties of Fresh Mortar

The consistency of the mortar was reduced when glass and plastic waste was used in the mortar as a sand replacement. This resulted in a greater flow compared to the control mix. By referring to Fig. 31, the highest flow was recorded by mix 3 (75% glass and 25% plastic) and the lowest flow was seen in the control mix. As the plastic content increased and glass content decreased, increased segregation and bleeding became more apparent. The homogeneity of the mortar mixes is at its worst as the plastic content increases. The flow regarding establishing the amount of water in the mixes are displayed in Fig. 32.

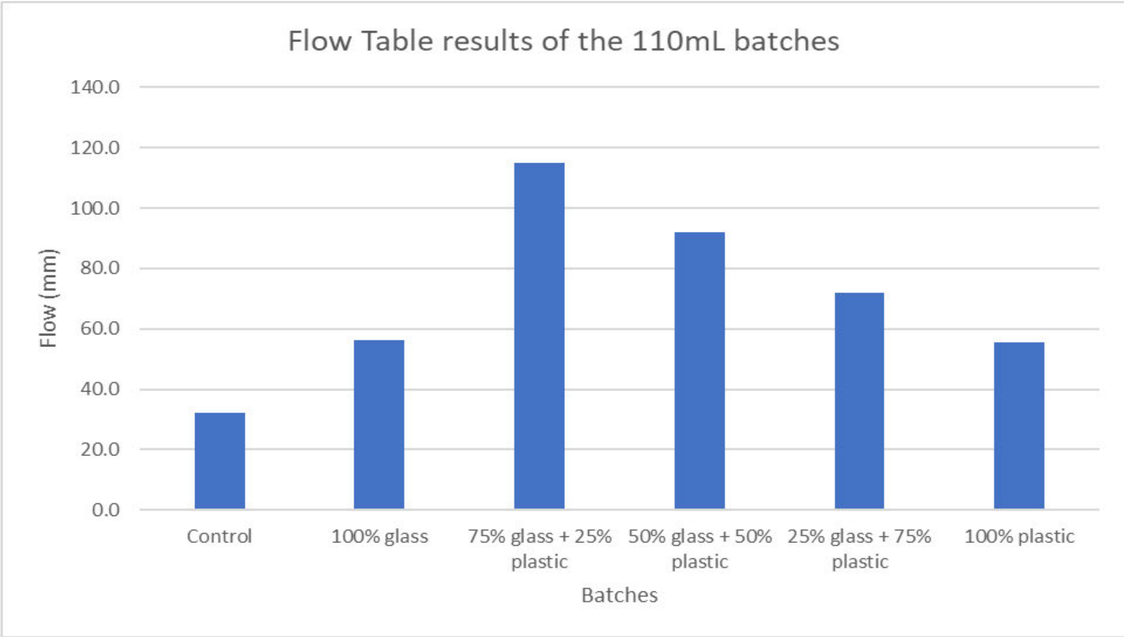

Flow Table results of the 110mL batches
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Flow (mm)
Control
100% glass
75% glass + 25% plastic
50% glass + 50% plastic
25% glass + 75% plastic
100% plastic
Batches

Fig. 31.

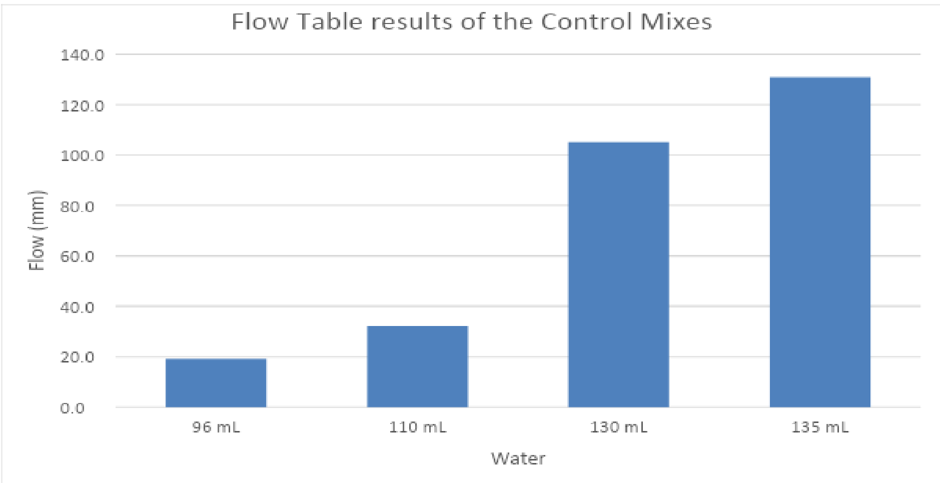

Flow Table results of the Control Mixes
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Flow (mm)
96 mL
110 mL
130 mL
135 mL
Water

Fig. 32.

### 5.1.1 Flow Table Test Results

Location Springfield Campus UniSQ
Testing by Steven Perren

| | | | | | | | Flow testing (done in accordance with AS2701) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Description | Cement (g) | Sand (g) | Glass (g) | Plastic (g) | Water (mL) | Flow dia 1 | Flow dia 2 | Flow dia 3 | Flow dia 4 | Average | Internal diameter of base of flow mould (mm) | Calculated Flow = [(Davg-Do)/Do]*100 |
| 1 | Control | 101 | 465 | 0 | 0 | 96 | 118.2 | 117.93 | 118.82 | 119.9 | 118.7125 | 99.68 | 19.1 |
| | | 101 | 465 | 0 | 0 | 110 | 126.8 | 130.5 | 133.9 | 135.3 | 131.625 | 99.68 | 32.0 |
| | | 101 | 465 | 0 | 0 | 130 | 203.1 | 209.3 | 205.9 | 199.98 | 204.57 | 99.68 | 105.2 |
| | | 101 | 465 | 0 | 0 | 135 | 234.9 | 226.1 | 227.5 | 232.2 | 230.175 | 99.68 | 130.9 |
| 2 | 100% glass | 101 | 0 | 483.6 | 0 | 110 | 155.8 | 155.5 | 154 | 157.84 | 155.785 | 99.68 | 56.3 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| 3 | 75% glass + 25% plastic | 101 | 0 | 362 | 27.9 | 96 | 188.6 | 188 | 182.1 | 185.2 | 185.975 | 99.68 | 86.6 |
| | | 101 | 0 | 362 | 27.9 | 110 | 217.2 | 215.4 | 212 | 212.5 | 214.275 | 99.68 | 115.0 |
| | | 101 | 0 | 362 | 27.9 | 130 | 250 | 250 | 250 | 250 | 250 | 99.68 | 150.8 |
| 4 | 50% glass +50% plastic | 101 | 0 | 241.3 | 55.8 | 110 | 194.2 | 188.9 | 188.92 | 193.9 | 191.48 | 99.68 | 92.1 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| 5 | 25% glass + 75% plastic | 101 | 0 | 120.7 | 83.7 | 110 | 137.5 | 130.7 | 134.6 | 121.2 | 131 | 99.68 | 31.4 |
| | | 101 | 0 | 120.7 | 83.7 | 110 | 166.6 | 164.8 | 171.1 | 183.2 | 171.425 | 99.68 | 72.0 |
| | | | | | | | | | | | | | |
| 6 | 100% plastic | 101 | 0 | 0 | 111.6 | 110 | 155.7 | 159.6 | 151.1 | 153.5 | 154.975 | 99.68 | 55.5 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

Table. 13.

*Note* - Due to segregation, mix 5 flow value of 31.4 is the material inner flow, and mix 5 flow value of 72 is the water outer flow.

The changes in the properties of the fresh mortar may be due to:

- The density of the mortar containing the waste aggregate is different to that of the control mix. The plastic having the lowest specific density, followed by sand and then glass.
- The glass aggregate exhibiting sharp edges that would increase friction forces within the mortar mix during mixing that decreases the consistency of mortar.
- The lack of fines in the plastic and glass compared to the sand. Sand had a greater proportion of smaller fines, using sieve size 600 mm, 78.25% of the sand, 53.98% of the glass, and only 1.89% of plastic aggregate passed through the sieve.
- Although the glass aggregate had sharp edges, glass intrinsically has a smooth surface with negligible water absorption, resulting in segregation and bleeding.
- Plastic aggregate also has negligible water absorption due to its impermeable characteristic, and due to the angular and irregular shape of the particles allowed voids in the mix.

By referring to the photos in section 5.1.2, Fig. 33 through 38, the flow table tests, visual inspection can describe the mixes by:

- Mix 1 (control), consistent and homogeneous.
- Mix 2 (100% glass), homogeneous but less consistent and some bleeding.
- Mix 3 (75% glass, 25% plastic), bleeding and less consistent.
- Mix 4 (50% glass, 50% plastic), bleeding and harsh.
- Mix 5 (25% glass, 75% plastic), severe bleeding, harsh, segregated and inconsistent.
- Mix 6 (100% plastic), bleeding, harsh, segregated, and inconsistent.

### 5.1.2. Mix flow table photos

*Note: Control 130mL photo file was corrupt and not able to be presented*


Fig. 33, Mix 1 Control


Fig. 34, Mix 2 (100% glass)

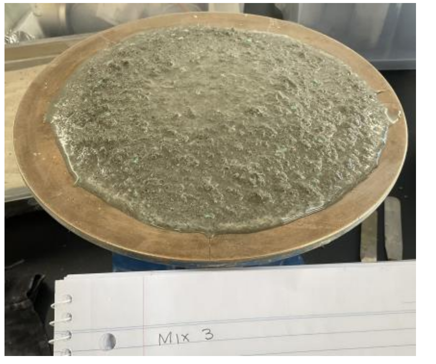



Fig. 35, Mix 3 (75% glass, 25% plastic)


Fig. 36, Mix 4 (50% glass, 50% plastic)

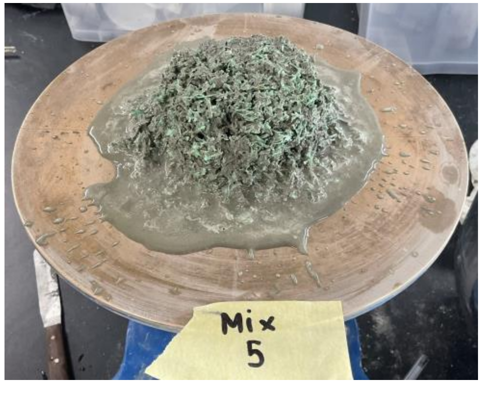



Fig. 37, Mix 5 (25% glass, 75% plastic)

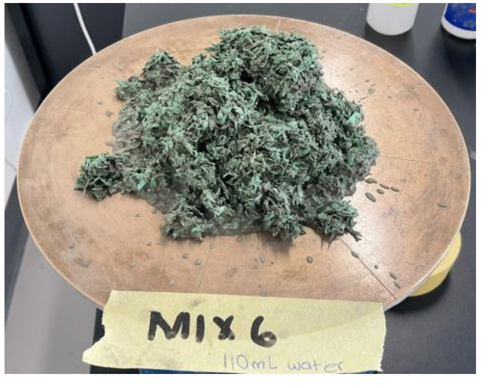



Fig. 38, Mix 6 (100% plastic)

## 5.2. Physical Properties of the Hardened Mortar

The results of the mechanical properties of the hardened mortar are reported in Table 14, i.e., compressive, and indirect tensile strength. As anticipated with the increasing plastic content, the mechanical properties decrease. As the plastic content increased and the glass content decreased, a less brittle behaviour was noticed and a reduction in the density due to the density of the plastic aggregate being lower than the natural sand and glass aggregate.

| ID | Di 1 | Dia 2 | Dia 3 | Average | Height 1 | Height 2 | Height 3 | Average | (kN) | Test | Failure mode | Strength (Mpa) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mix 1 (1) | 52.53 | 52.82 | 52.62 | 52.657 | 107.8 | 107.38 | 107.63 | 107.603 | 21.14 | compression | Diagonal | 9.71 |
| Mix 1 (2) | 52.68 | 52.79 | 53.21 | 52.893 | 110.06 | 109.26 | 109.4 | 109.573 | 25.43 | compression | Diagonal | 11.57 |
| Mix 1 (3) | 53.04 | 52.3 | 53.3 | 52.880 | 108 | 108.71 | 109.68 | 108.797 | 16.98 | compression | Diagonal | 7.73 |
| Mix 1 (4) | 52.43 | 53.48 | 53.46 | 53.123 | 109.49 | 109.22 | 110.46 | 109.723 | 17.62 | indirect tensile | Split | 1.92 |
| Mix 1 (5) | 53.03 | 52.09 | 52.91 | 52.677 | 110.97 | 108.91 | 108.57 | 109.483 | 16.35 | indirect tensile | Split | 1.80 |
| Mix 1 (6) | 52.91 | 53.33 | 52.67 | 52.970 | 110.13 | 109.94 | 110.55 | 110.207 | 15.14 | indirect tensile | Split | 1.65 |
| Mix 2 (1) | 52.51 | 52.36 | 52.42 | 52.430 | 108.25 | 108.9 | 108 | 108.383 | 17.78 | compression | Diagonal | 8.24 |
| Mix 2 (2) | 53 | 52.45 | 52.3 | 52.583 | 109.5 | 108.44 | 108.72 | 108.887 | 15.43 | compression | Diagonal | 7.11 |
| Mix 2 (3) | 52.75 | 52.36 | 52.61 | 52.573 | 110.72 | 110.79 | 109.9 | 110.470 | 19.66 | indirect tensile | Split | 2.16 |
| Mix 2 (4) | 54 | 51.59 | 52.5 | 52.697 | 109.74 | 109.55 | 110.59 | 109.960 | 17.05 | indirect tensile | Split | 1.87 |
| Mix 3 (1) | 52.81 | 52.85 | 52.44 | 52.700 | 108.49 | 106.64 | 109.15 | 108.093 | 15.50 | compression | Diagonal | 7.11 |
| Mix 3 (2) | 52.25 | 52.22 | 53.5 | 52.657 | 106.09 | 107.11 | 106.12 | 106.440 | 19.61 | compression | Diagonal | 9.00 |
| Mix 3 (3) | 53.25 | 53.26 | 52.75 | 53.087 | 106.35 | 106.31 | 107.77 | 106.810 | 11.99 | compression | Crushing | 5.42 |
| Mix 3 (4) | 53.55 | 52.67 | 52.53 | 52.917 | 105.67 | 105.85 | 106.36 | 105.960 | 13.83 | indirect tensile | Split | 1.57 |
| Mix 3 (5) | 53.76 | 55.04 | 52.88 | 53.893 | 108.65 | 106.86 | 106.09 | 107.200 | 12.30 | indirect tensile | Split | 1.36 |
| Mix 3 (6) | 53.27 | 52.61 | 53.78 | 53.220 | 107.7 | 106.23 | 108.21 | 107.380 | 15.14 | indirect tensile | Split | 1.69 |
| Mix 4 (1) | 52.76 | 52.33 | 51.89 | 52.327 | 107.89 | 107.9 | 107.82 | 107.870 | 14.08 | compression | Crushing | 6.55 |
| Mix 4 (2) | 52.61 | 52.2 | 52.17 | 52.327 | 107.3 | 107.6 | 107.22 | 107.373 | 13.75 | compression | Shear | 6.39 |
| Mix 4 (3) | 52.19 | 52.44 | 52.51 | 52.380 | 107.31 | 107.7 | 107.3 | 107.437 | 11.11 | indirect tensile | Split | 1.26 |
| Mix 4 (4) | 52.32 | 52.31 | 52.22 | 52.283 | 107.4 | 107.38 | 106.75 | 107.177 | 7.84 | indirect tensile | Split | 0.89 |
| Mix 5 (1) | 51.79 | 51.95 | 51.16 | 51.633 | 109.64 | 110.21 | 109.46 | 109.770 | 7.90 | compression | Crushing | 3.77 |
| Mix 5 (2) | 54.9 | 53.15 | 52.38 | 53.477 | 109.18 | 108.56 | 108.73 | 108.823 | 8.49 | compression | Diagonal | 3.78 |
| Mix 5 (3) | 53.14 | 53.47 | 52.71 | 53.107 | 110.26 | 108.88 | 108.87 | 109.337 | 11.44 | indirect tensile | Split | 1.25 |
| Mix 5 (4) | 53.09 | 52.37 | 53.03 | 52.830 | 109.35 | 109.74 | 108.64 | 109.243 | 12.36 | indirect tensile | Split | 1.36 |
| Mix 5 (5) | 53.81 | 53.04 | 52.51 | 53.120 | 111.18 | 109.12 | 108.81 | 109.703 | 9.60 | indirect tensile | Split | 1.05 |
| Mix 6 (1) | 52.21 | 52.61 | 52.12 | 52.313 | 110.81 | 111.69 | 111.73 | 111.410 | 6.16 | compression | Crushing | 2.87 |
| Mix 6(2) | 52.33 | 51.84 | 52.48 | 52.217 | 112.63 | 111.13 | 110.45 | 111.403 | 3.70 | compression | Crushing | 1.73 |
| Mix 6(3 | 52.4 | 52.06 | 52.86 | 52.440 | 112.29 | 111.91 | 112.01 | 112.070 | 5.99 | compression | Crushing | 2.77 |
| Mix 6 (4) | 52.19 | 51.72 | 52.41 | 52.107 | 113.04 | 112.93 | 112.8 | 112.923 | 4.55 | indirect tensile | Crushing | 0.49 |
| Mix 6 (5) | 52.31 | 52.64 | 52.34 | 52.430 | 112.33 | 111.81 | 111.04 | 111.727 | 8.35 | indirect tensile | Crushing | 0.91 |
| Mix 6 (6) | 52.3 | 52.29 | 52.07 | 52.220 | 110.89 | 110.5 | 110.16 | 110.517 | 6.78 | indirect tensile | Crushing | 0.75 |
| Control 130 mL (1) | 52.83 | 53 | 52.49 | 52.773 | 107.48 | 107.29 | 107.48 | 107.417 | 11.98 | compression | Failure not complete | 5.48 |
| Control 130 mL (2) | 51.08 | 51.06 | 50.98 | 51.040 | 105.07 | 105.37 | 104.53 | 104.990 | 19.11 | compression | Shear | 9.34 |
| Control 130 mL (3) | 51.23 | 51.22 | 51.15 | 51.200 | 104.66 | 104.27 | 104.69 | 104.540 | 19.15 | compression | Shear | 9.30 |
| Control 130 mL (4) | 52.01 | 53.13 | 52.92 | 52.687 | 107.27 | 107.25 | 107.3 | 107.273 | 17.03 | indirect tensile | Split | 1.92 |
| Control 130 mL (5) | 51.03 | 51.27 | 51.14 | 51.147 | 104.77 | 104.99 | 104.45 | 104.737 | 16.00 | indirect tensile | Split | 1.90 |
| Control 130 mL (6) | 51.05 | 51.14 | 51.16 | 51.117 | 103.13 | 103.08 | 104 | 103.403 | 12.91 | indirect tensile | Split | 1.55 |

Table. 14. Compression and indirect-tensile test results.

### 5.2.1. Compressive Strength

The average 28-day compressive strength of the waste aggregate mortars and control mortar under standard moist curing (25°C and a humidity of 76%) are shown in Fig. 39. These results indicate that the control mix (mix 1) achieved the highest compressive strength followed by mix 2 (100% glass). As plastic is included into the mix the compressive strength decreases as the plastic content increases, resulting in mix 6 (100% plastic) recording the lowest compressive strength of all the mixes. The reduction of strength from the control mix compared to the other mixes was presumed to be due to glass and plastic aggregates reduced absorption of water, because of their impermeable characteristics. The reduction in strength by utilising glass may be attributed to the sharp edge and smooth surface of glass aggregate which creates a weaker bond between the glass particles and the cement paste (Ferdous et al. 2021).

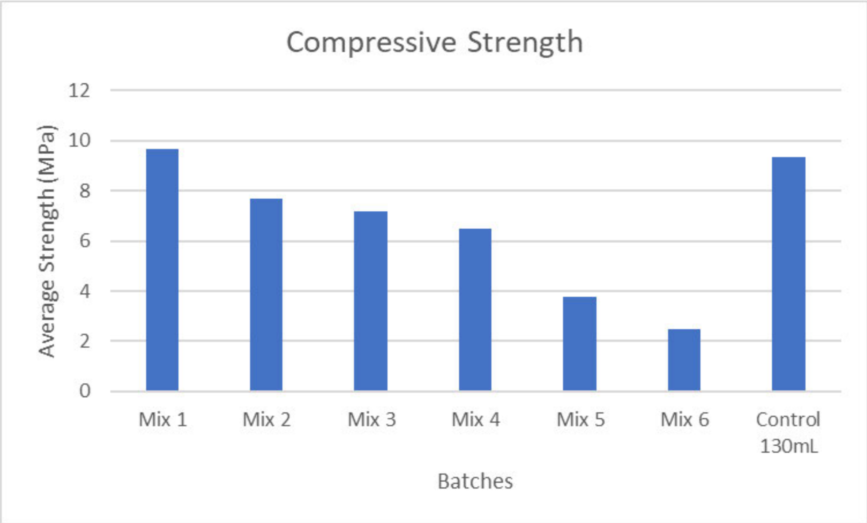



Fig. 39.

It is also possible that the shape of the glass and plastic aggregates may have contributed to the decrease in strength, due to their angular and irregular particles, which increases voids allowing increased absorption of water (Cortes et al. 2008). The excess water in these voids evaporates and seriously degrades the strength and durability of concrete and mortar, leaving interconnected fine porous structures which result in poor mechanical properties (Nematzadeh & Naghipour 2012). This excess water resulted in an increased flow, bleeding, and ultimately led to lower compressive strength, increased segregation, and permeability, with mix 6 gaining the lowest strength, greatest segregation, and permeability.

With the increasing content of plastic aggregate, the mechanical properties are seen to decrease, due to the decreased bond strength between the plastic aggregate and the cement paste. Literature supports this, as it has been noted that unlike natural aggregate, the plastic cannot interact with cement paste and consequently the interfacial transition zone in the mortar is weaker resulting in a lower compressive strength. The decrease in bond strength between the plastic and cement paste and the inhibition of cement hydration was due to the hydrophobic nature of the plastic aggregates (Saikia & de Brito 2014). Another cause for the decrease in compressive strength may be attributed to the plastic aggregate having a lower elastic modulus compared to the natural aggregate (Lazorenko et al. 2022).

Increasing water content results in reduced solids volume concentration and interparticle friction associated with the increased porosity, which results in a decreased compressive strength (Nematzadeh & Naghipour 2012). This is evident when comparing the results between mix 1 (control with 110 ml of water) and the control mix with 130 ml of water, shown in Table 15 below. The higher than optimal water content in the mixes that contain plastic, resulted in a higher fluidity (mix 3), and eventually segregation occurred, and the various components of the fresh concrete separated, refer to Fig. 35 and the flow table photos containing plastic.

At a 28-day cure, the decrease in strength was as much as 74.6% between the control specimen (mix 1) and mix 6 (100% plastic). The decrease between the control and mix 1 (100% glass) was 20.7%. With the inclusion of plastic into the mix, mixes 3, 4, 5, and 6 had a decrease of 25.7%, 33.1%, 60.9%, and 74.6% respectively.

| Compressive Strength | |
|---|---|
| **ID** | **Average Strength (Mpa)** |
| Mix 1 | 9.67 |
| Mix 2 (100% Glass) | 7.67 |
| Mix 3 (75% Glass & 25% Plastic) | 7.18 |
| Mix 4 (50% Glass & 50% Plastic) | 6.47 |
| Mix 5 (25% Glass & 75% Plastic) | 3.78 |
| Mix 6 (100% Plastic) | 2.46 |
| Control 130mL | 9.32 |

Table. 15.

Regarding the results of the mixes and trying to identify which ratio of glass and plastic is best suited when replacing sand as a fine aggregate in mortar mixes to utilise waste products.

Mix 2 (100% glass) would be the obvious choice with the highest compressive strength of the recycled aggregates, however, mix 3 also recorded a respectable result only 25.7% less than the control mix.

The failure modes for all tested specimens regarding the compressive strength can be seen in Table 14. From the results, as the plastic content increases the failure shifts from a shear failure to a crushing failure. Crushing of the samples indicate that the constituents of the mix were poorly distributed and with the plastic aggregate being flaky they can bend and deform, thus with the increased content of the plastic, the samples were less rigid. During the testing, mix 6 was seen to displace and deform to a higher degree before failure than compared to mix 1 and 2 due to plastic having a much lower modulus of elasticity than that of glass and sand. The glass and sand aggregate has a much higher resistance to be deformed elastically.

See some examples of the failures for the test specimens below in Figures 40 through 48.

Fig. 40, Mix 1: Shear

Fig. 41, Mix 2: Shear

Fig. 42, Mix 3: Shear

Fig. 43, Mix 3: Crushing

Fig. 44, Mix 4: Shear

Fig. 45, Mix 5: Shear

Fig. 46, Mix 5: Crushing

Fig. 47,Mix 6: Crushing

Fig. 48, Control 130mL: Shear

### 5.2.2. Splitting tensile strength

The average 28-day indirect tensile strength of the waste aggregate mortars and control mortar under standard moist curing (25°C and a humidity of 76%) are shown in Table. 16. These results indicate interestingly that mix 2 (100% glass) achieved the highest indirect tensile strength of 2.01MPa followed by the control mix (mix 1) with 1.79MPa. As plastic is included into the mix the indirect tensile strength decreases as the plastic content increases, except for mix 4. The source of this error and the anomaly regarding the results for mix 4 is presumed to be due to the lack of samples for testing and the inability to not include outlier data. Of the two results available for mix 4, one is significantly lower than the other and with increased samples, the outlier would not be included in the calculation of the average indirect tensile strength. To overcome this for future research, an increased sample size of each mix is suggested.

| Indirect Tensile Strength | |
|---|---|
| **ID** | **Average Strength (Mpa)** |
| Mix 1 | 1.79 |
| Mix 2 (100% Glass) | 2.01 |
| Mix 3 (75% Glass & 25% Plastic) | 1.54 |
| Mix 4 (50% Glass & 50% Plastic) | 1.07 |
| Mix 5 (25% Glass & 75% Plastic) | 1.22 |
| Mix 6 (100% Plastic) | 0.82 |
| Control 130mL | 1.79 |

Table. 16.

To allow for an acceptable R-Squared value, the possible outlier result for mix 4 was excluded and the results are illustrated below in Table 17 and Fig 49.

With the lower value ignored for mix 4, the strength decreases as the plastic content increases and thus would be seen to be somewhat linear as the strength for mix 4 would be 1.26 MPa and not 1.07 MPa.

| Indirect Tensile Strength | |
|---|---|
| **ID** | **Average Strength (Mpa)** |
| Mix 1 | 1.79 |
| Mix 2 (100% Glass) | 2.01 |
| Mix 3 (75% Glass & 25% Plastic) | 1.54 |
| Mix 4 (50% Glass & 50% Plastic) | 1.26 |
| Mix 5 (25% Glass & 75% Plastic) | 1.22 |
| Mix 6 (100% Plastic) | 0.82 |
| Control 130mL | 1.79 |

Table. 17.

The control mix consisted of 110mL of water, for comparative reasons another control mix was batched with 130mL of water. The results support the literature that states that with increased water to cement ratio, compressive strength decreases however there was no decrease in indirect tensile strength as the 110ml and 130ml mixes recorded the same value of 1.79MPa. Mix 2 (100% glass) interestingly recorded the highest strength of 2.01MPa, presumably achieved due to the shape and size of the glass aggregate.

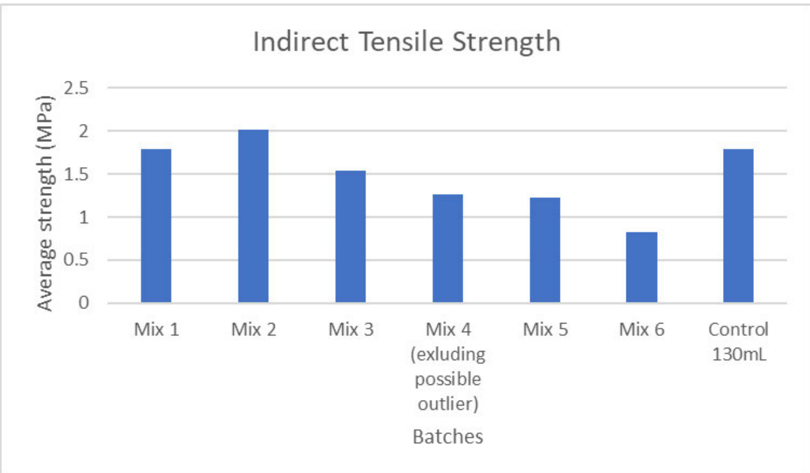



Fig. 49.

The results found in this study regarding the higher tensile strength at 28-days for 100% glass is consistent with the observations of Du and Tan 2014, who attribute this to the elongated shape of the glass particles which have a greater degree of mechanical interlock, internal friction, and increased surface area associated with angular aggregates (Du & Tan 2014). With the aid of Fig. 50, the difference in the particle size distribution can be seen.

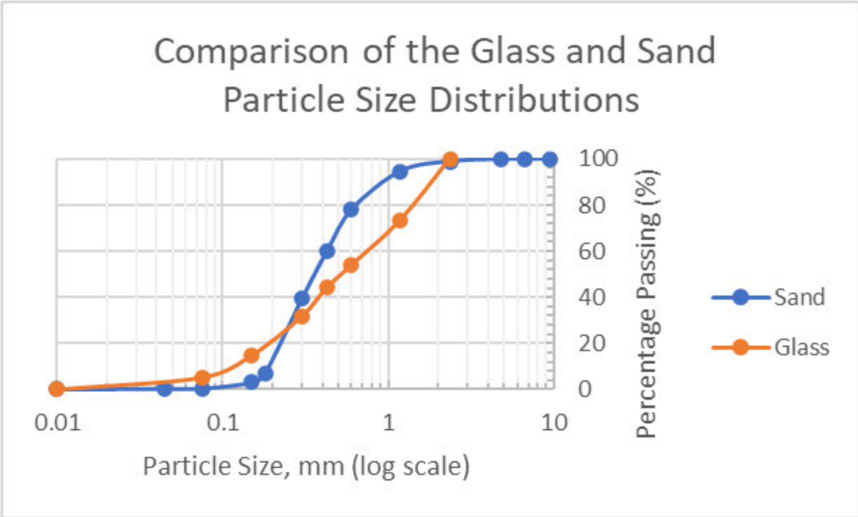



Fig. 50.

The different glass particle sizes can be seen to be distributed evenly compared to the sand particles, refer to Table 18. The distribution of glass compared to the sand is thought to allow the particles to interlock and provide more bridging contacts between the aggregate particles and thus improve mechanical strength.

| Sieve size (mm) | Glass Retained (%) | Sand Retained (%) |
|---|---|---|
| 1.18 | 26.671 | 4.24 |
| 0.6 | 19.353 | 16.46 |
| 0.425 | 9.902 | 18.09 |
| 0.3 | 12.414 | 20.7 |
| 0.15 | 16.823 | 36.38 |
| 0.075 | 9.668 | 2.72 |
| Pan | 5.168 | 0.36 |

Table. 18.

Other studies have reported that glass may act as a pozzolan, densifying the matrix due to its chemical structure consisting of reactive amorphous silica for very small glass aggregate (<0.3mm), and can slightly increase splitting tensile strength (Kangavar et al. 2023). This may explain the enhanced tensile strength that was seen for mix 2 (100% glass) as 44% of the glass aggregate consisted of particles ≤0.3mm, and thus enhanced the tensile strength of the mortar mix containing 100% glass.

With the increasing plastic content, the strength decreases which is presumed to be related to the increase in water content in the mixes due to the inability of the plastic to absorb water due to the hydrophobic nature of plastic, resulting in a decreased bond strength between the plastic aggregate and the cement paste. The characteristics of the interfacial transition zone strongly influences the tensile splitting strength, the plastic particles and the free water at the surface causes a weaker bonding between the surface of the plastic particles and the cement paste (Saikia & de Brito 2014).

The mixes with the plastic aggregate were able to take the highest deformation before failure due to the planar shape of the aggregate particles, which allowed it to be more ductile. This was prominent in mix 5, where the mortar test cylinder deformed significantly before it split.

The shape of the plastic aggregates may have contributed to the decrease in strength, due to their angular and irregular particles, which increases voids allowing increased absorption of water (Cortes et al. 2008). As the excess water in these voids evaporates it leaves interconnected fine porous structures which result in poor mechanical properties (Nematzadeh & Naghipour 2012). This excess water resulted in an increased flow, bleeding, and ultimately led to lower indirect tensile strength, increased segregation, and permeability.

Regarding the results of the mixes and trying to identify which ratio of glass and plastic is best suited when replacing sand as a fine aggregate in mortar mixes to utilise waste products. Mix 2 (100% glass) would be the obvious choice with the highest indirect tensile strength of 2.01MPa followed by mix 3 (75% glass and 25% plastic) with 1.54MPa.

The failure modes for the tested specimens regarding the indirect tensile strength can be seen in Table 14. From the results, as the plastic content increases the failure shifts from a splitting failure for mixes 1 through 5 and then due to 100% plastic being used in mix 6, the specimens were crushed. Splitting failure occurs when the maximum tensile capacity is less than the forces generated between the aggregate and the surrounding cement paste (Kangavar et al. 2023). Crushing of the samples indicate that the constituents of the mix were uneven and poorly distributed, and with the plastic aggregate being flaky they are able to bend and deform.

The hydrophobic nature of the plastic aggregates also resulted in a higher water to cement ratio, increasing segregation, bleeding, and reduced strength of the specimen. The poor bond between the plastic aggregate particles and the cement paste resulting in mix 6 having the lowest indirect tensile strength is supported by literature from Saikia et al 2014 and Coppola et al 2016, due to the plastics inability to interact with cement paste, therefore weakening the interfacial transition zone. The elongation and rough texture of plastic flakes increases friction but reduces consistency, decreasing the mechanical properties. From the photos of the mixes, as the plastic content increases it is evident that the samples demonstrate an increase in voids and air bubbles, as the flaky plastic aggregate allowed air to be entrapped close to its surface because of its hydrophobic nature.

Examples of the failures for the test specimens are in Fig. 51 through 57.

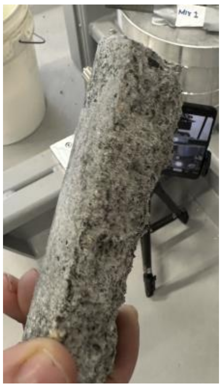




Fig. 51, Mix 1: Split Fig. 52, Mix 2: Split Fig. 53, Mix 3: Split



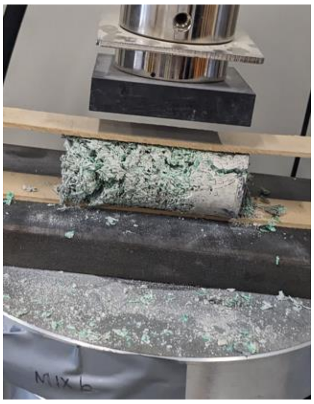


Fig. 54, Mix 4: Split Fig. 55, Mix 5: Split Fig. 56, Mix 6: Crushed

Fig. 57, Control 130mL: Split

## 5.3 Microscopic Analysis



Fig. 58. Fig. 59.

Fig. 58, a photograph of the microscope with camera and the computer program 'Image View' used to capture the microscope photos. Fig. 59, illustrating the magnification used.

See figures 60 through 81 illustrating as the plastic content increases so does the porosity of the mortar. The increase of pores and open interfaces is evident in mix 2 to 6, as the plastic content increases.

Comparing mix 1 (control) and mix 2 (100% glass), the crushed glass resulted in a decrease in compressive strength by 20.7%. This is attributed to the weak bond between the glass aggregate and the cement matrix, illustrated in the photos of mix 2, with the glass aggregate seen to be debonded from the cement paste. The photos of the mixes containing plastic aggregate, Fig. 75 for example, illustrates the poor bond between the plastic and the cement paste as the flaky particles lack cohesion of the cement matrix, exhibiting cleaner surface and were debonded from the paste and slipped away. The surface of the glass aggregate however can be seen to contain some of the cement matrix. The presence of air bubbles and voids can also be seen to increase from mix 1 through 6, thus weakening the mechanical properties.

### 5.3.1 Microscope Photos

Fig. 60. Mix 1

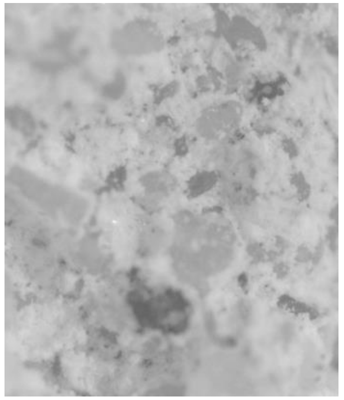


Fig. 61. Mix 1

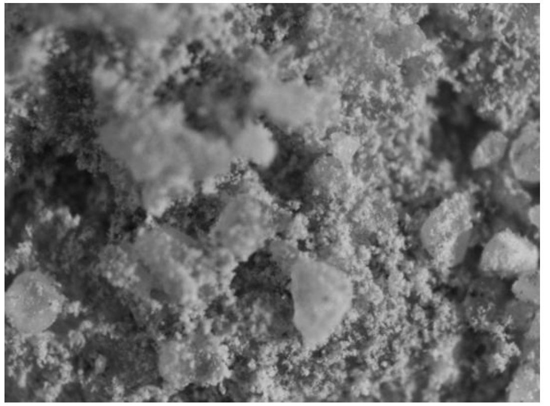


Fig. 62. Mix 1

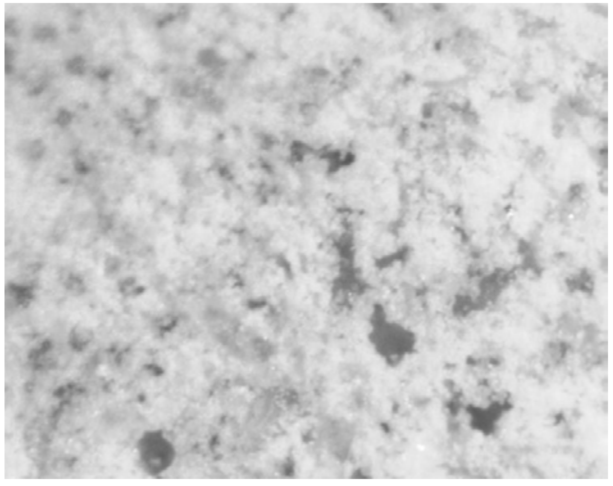


Fig. 63. Mix 2 (dark spots are air voids)

Fig. 64. Mix 3

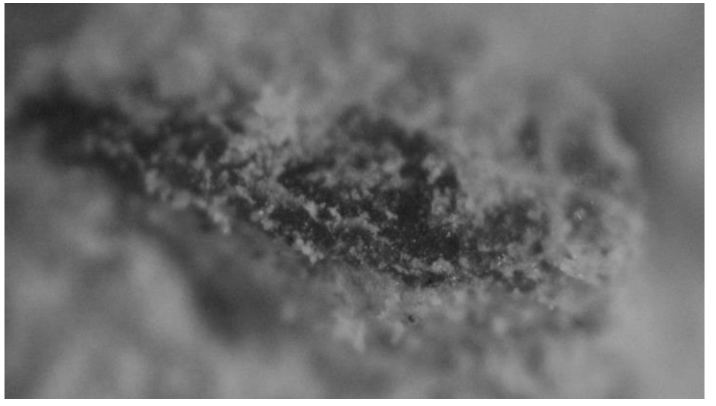


Fig. 65. Mix 3

Fig. 66. Mix 4

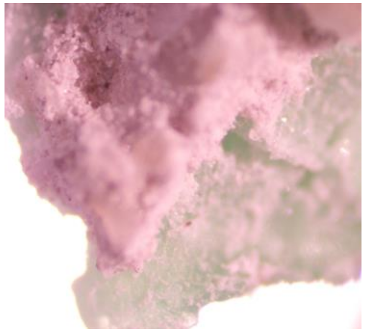


Fig. 67. Mix 5

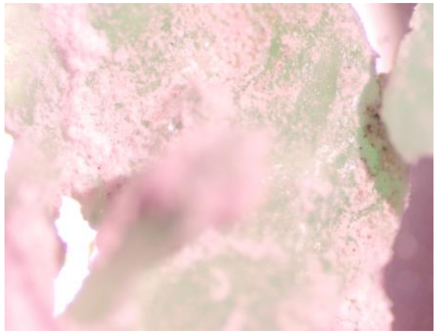


Fig. 68. Mix 6

### 5.3.2 iPhone Photos

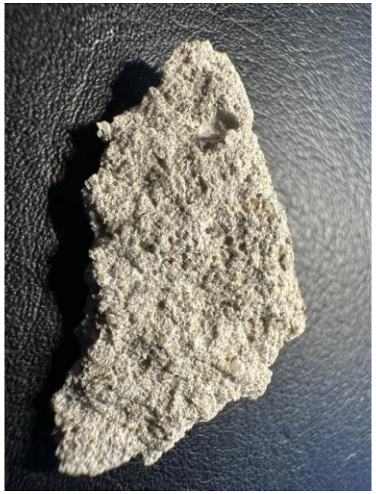


Fig. 68. Mix 1

Fig. 69. Mix 1 (zoomed in)

Fig. 70. Mix 2

Fig. 71. Mix 2 (zoomed in)

Fig. 72. Mix 3

Fig. 73. Mix 3 (zoomed in)

Fig. 74. Mix 4

Fig. 75. Mix 4 (zoomed in)

Fig. 76. Mix 4

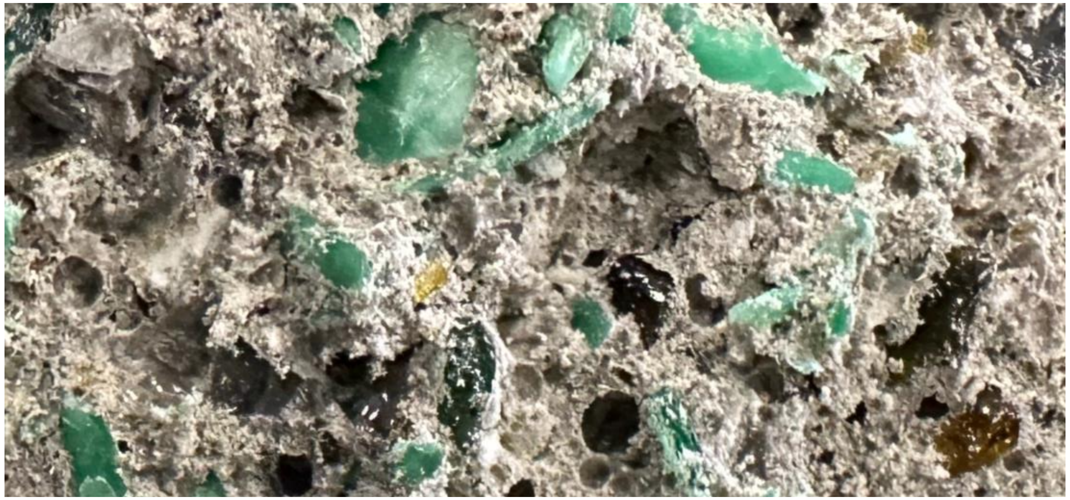


Fig. 77. Mix 4 (zoomed in)

Fig. 78. Mix 5

Fig. 79. Mix 5 (zoomed in)

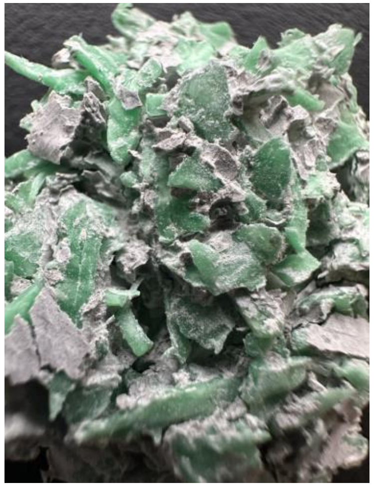


Fig. 80. Mix 6

Fig. 81. Mix 6 (zoomed in)

## 5.4 Digital image correlation summary

Digital Image Correlation (DIC) is a non-contact optical technique that measures both strain and displacement. It uses digital photographs of a component or test piece at different stages of deformation and by tracking blocks of pixels, it can measure the surface displacement and create both 2D and 3D deformation vector fields and strain maps (McCormick & Lord 2010).

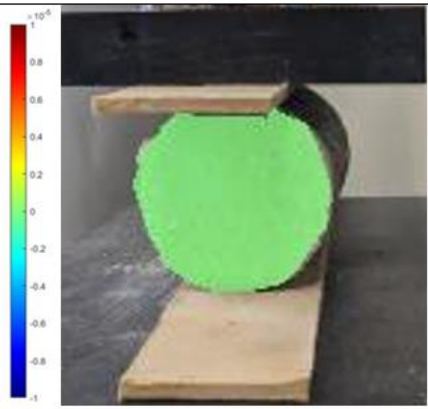
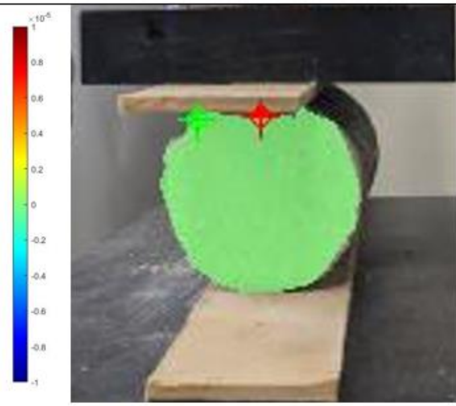
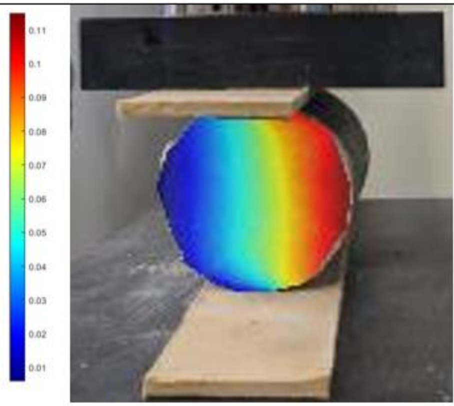
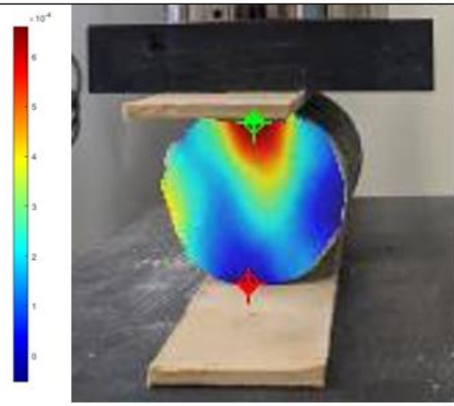
DIC was conducted to utilise the technology to be able to understand the deformation in the test piece before failure. DIC is ideally suited for the study of crack propagation and material deformation in real-world applications. It has been said that DIC is simple to use and is very cost effective when compared to laboratory techniques like speckle interferometry and is more accurate than manual measurement methods (McCormick & Lord 2010). A study was conducted where DIC and linear variable differential transformers (LVDT) were compared. This study concluded that both the displacement and the strain fields determined by the DIC technique were valid and therefore demonstrating its advantages for civil engineering applications by its low-priced, easier, and competitive monitoring (Ramos et al. 2015).

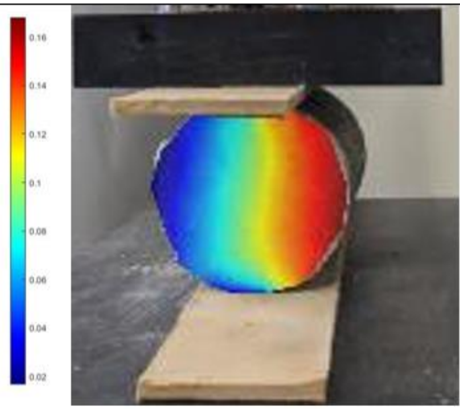
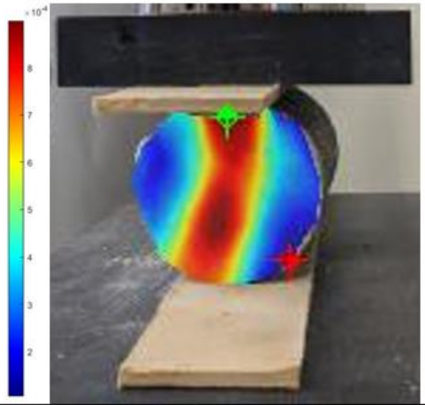
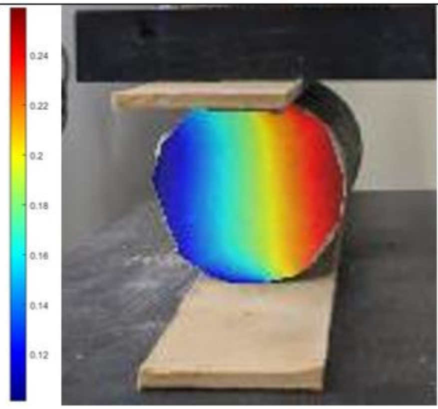
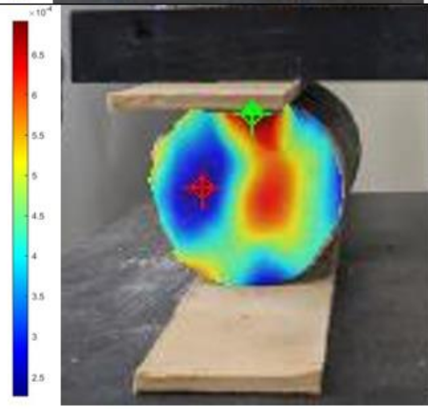
The ability of DIC to measure surface displacement not just in the laboratory but out in the field, provides a practical technique that can be used in a wide range of applications. An example of such application in the civil engineering field is DIC being used to monitor displacements in rail and road bridges and for measuring crack opening in components (McCormick & Lord 2010).

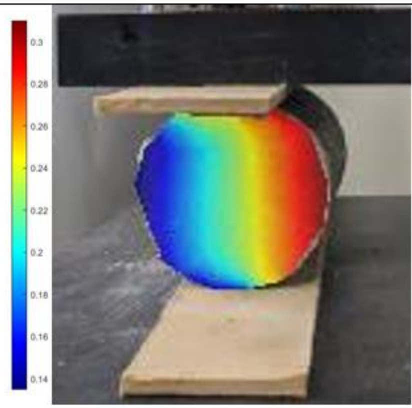
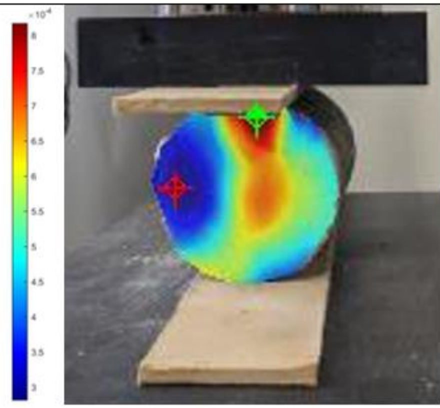
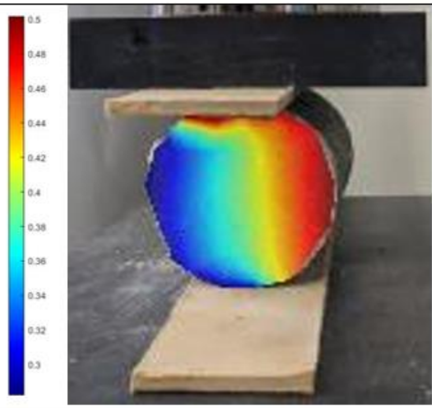
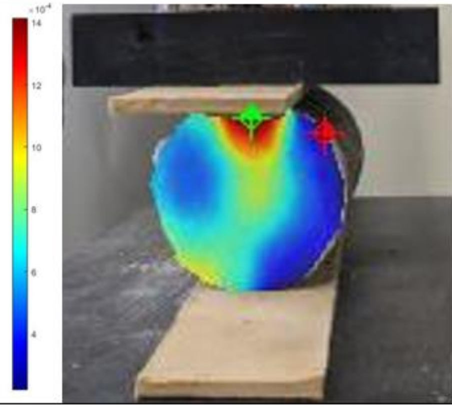
The specimen was placed horizontally between two plates for indirect tensile testing. A digital camera was mounted in front of the specimen, and photos were taken at regular intervals while compressing the sample. DIC MATLAB software (NCorr), was used to trace two-dimensional displacement and strains that occurred throughout the deformation process. See the load / time plot in Fig. 82.

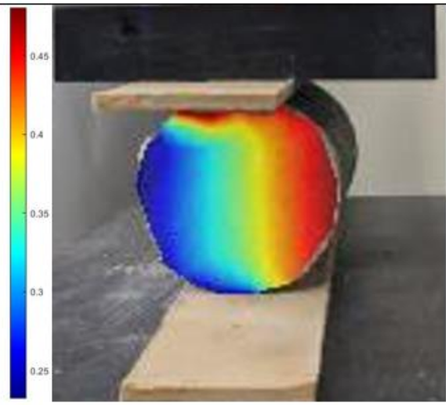
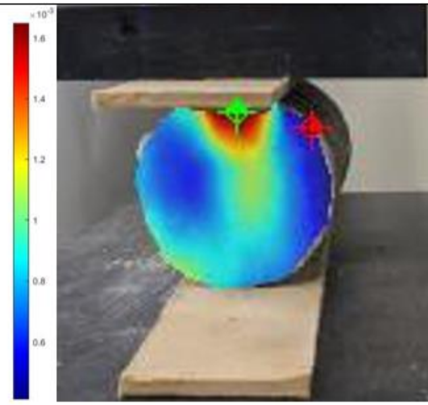
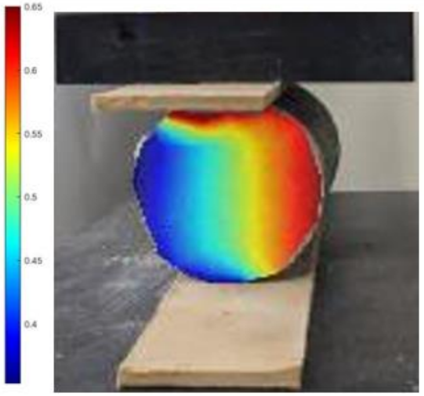
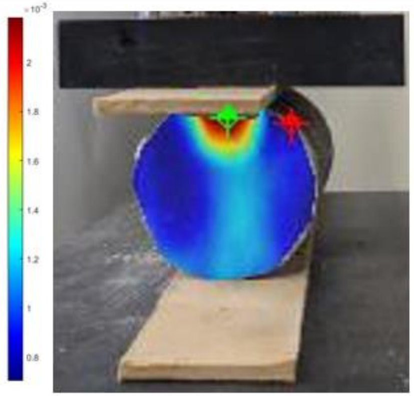

Fig. 82.

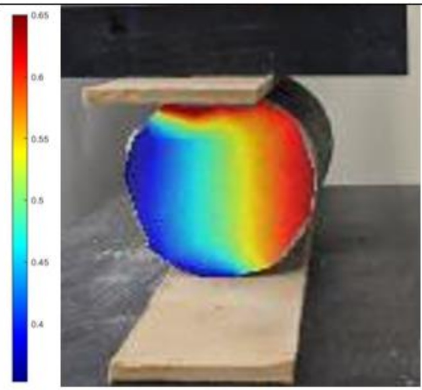
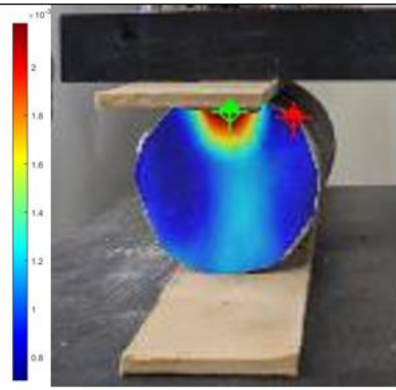
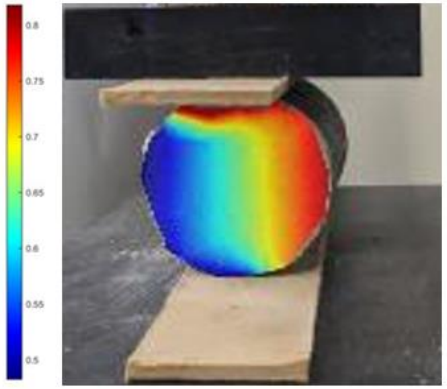
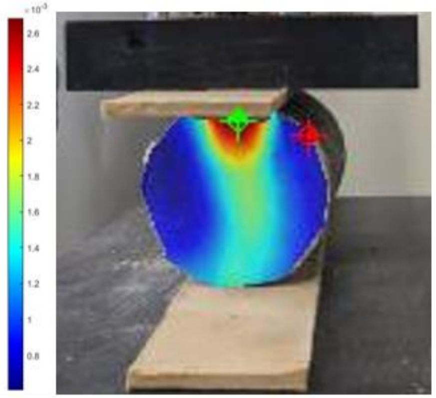
Mix 2 was selected for the analysis. Mix 2 comprises 100% replacement of sand with glass. Due to the high proportion of glass in the mix the specimen failed suddenly at 17.05 kN. The results of the digital image correlation are shown in Table 19. These results illustrate that as the force is exerted on the test piece, the vertical displacement and strain images can adequately show at 17.6% of the force required for the failure of the specimen where it would eventually fail. Even at 76.25%, there were no visible cracks to the naked eye until the dramatic failure where the specimen split abruptly. Mix 2 was seen to split suddenly and dramatically, by incorporating plastic into mix 3, the strength was decreased however the failure was not as sudden, therefore the positives and negatives of both waste aggregates are mitigated.

| Load applied (kN) | Percentage of total load | Original image | Vertical displacement | Vertical strain |
|---|---|---|---|---|
| 0 | 0% |  |  |  |
| 1 | 5.9% |  |  |  |

| Load applied (kN) | Percentage of total load | Original image | Vertical displacement | Vertical strain |
|---|---|---|---|---|
| 3 | 17.6% |  |   |   |
| 5 | 29.33% |  |   |   |

| Load applied (kN) | Percentage of total load | Original image | Vertical displacement | Vertical strain |
|---|---|---|---|---|
| 6 | 35.19% |  |  |  |
| 7 | 41.06% |  |  |  |

| Load applied (kN) | Percentage of total load | Original image | Vertical displacement | Vertical strain |
|---|---|---|---|---|
| 8 | 46.92% |  |  |  |
| 9 | 52.79% |  |  |  |

| Load applied (kN) | Percentage of total load | Original image | Vertical displacement | Vertical strain |
|---|---|---|---|---|
| 10 | 58.65% |  |   |   |
| 13 | 76.25% |  |   |   |

| Load applied (kN) | Percentage of total load | Original image | Vertical displacement | Vertical strain |
|---|---|---|---|---|
| 17.05 | 100% (Failure) |  | | |

Table. 19.

# 6.0 Discussion

## 6.1 Compressive Strength prediction equation

**Prediction equation for the compressive strength of cement mortar mixes utilising plastic and glass.**

$y = -1.382x + 9.658$

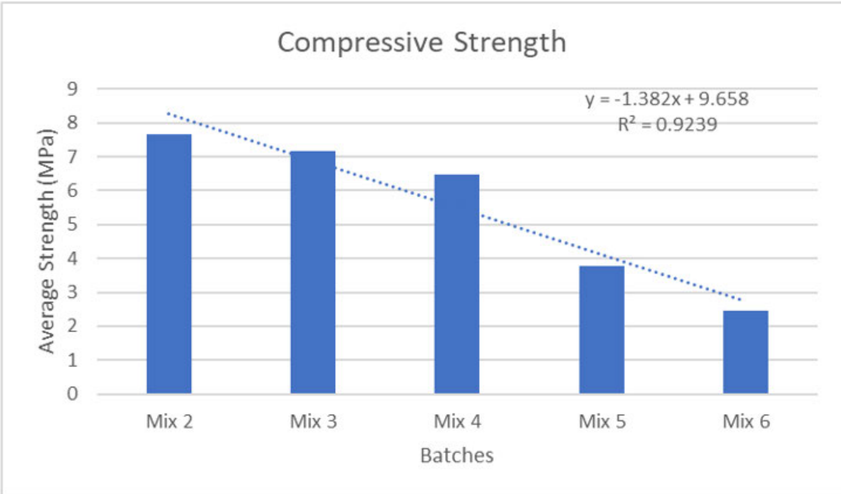



Fig. 83.

With the estimated slope of -1.382, shown above in Fig. 83, it can be concluded that the mix decreases in average compressive strength by 1.382 MPa as the plastic content increases. With a R-Squared value of 0.9239, the relationship between the variables is considered acceptable and the equation can be used as a prediction tool.

## 6.2 Indirect tensile strength prediction equation

**Prediction equation for the indirect tensile strength of cement mortar mixes utilising plastic and glass.**

$y = -0.27x + 2.18$

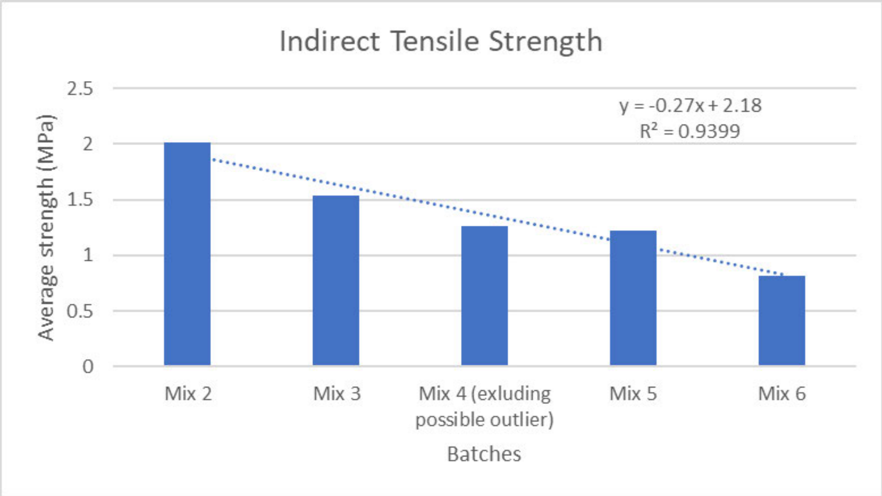



Fig. 84.

The estimated slope of -0.27, shown above in Fig. 84, it can be concluded that the average indirect tensile strength decreases by 0.27 MPa as the plastic content increases in the mix. The R-Squared value of 0.9399, the relationship between the variables is considered acceptable and the equation can be used as a prediction tool.

## 6.3 Recommendations

Due to the limitation (small sample size of each mix), and the possible outlier of mix 4 being excluded, the accuracy of the results may be affected. Therefore, it can be suggested that future research into this should include an increased sample size of each mix, thus increasing the validity of the results. The relationships observed in this study correspond to the literature however they should be verified with further tests, regarding sand, glass, and plastic aggregate particle size distribution, and the resulting alkali-silica reaction. Further research could examine both compressive and indirect tensile strength of cement mortar samples with identical particle size and distributions for sand and glass, to advance the knowledge from the significant findings regarding the higher indirect tensile strength for 100% glass.

## 7.0 Conclusion

The aim of this project was to identify which ratio of glass and plastic is best suited when replacing sand as a fine aggregate in mortar mixes to utilise waste products that are difficult to recycle and that are stored in large quantities in landfills.

Combined recycled glass (G) and waste plastics (PET) were used as fine aggregates to replace sand in the mortar mixes with different proportions of G and PET, i.e., 0%, 25%, 50%, 75% and 100%. The results of the investigation indicate that the different proportions of wastes in mortar influences the properties of mortar. Based on the results of this experimental investigation, the following conclusions may be drawn:

- Utilising waste aggregate increases the flow compared to sand aggregate.
- As the plastic content increases and glass content decreases so too does the flow of the fresh mortar.
- Mortar mixes with recycled aggregate demonstrated reductions in compressive and indirect-tensile strength compared to normal mortar except for mix 2, 100% glass (indirect-tensile strength).
- With the % content of glass decreasing and plastic increasing, compressive strength decreases.
- Mix 2 (100% glass) had the highest compressive strength and indirect tensile strength of the mixes containing recycled aggregates.
- As the plastic content increases in the mixes, both compressive and indirect tensile strength decreases by 1.38 MPa and 0.27 MPa respectively.

Identifying which ratio of glass and plastic is best suited when replacing sand as a fine aggregate in mortar mixes to utilise waste products with respect to both compressive and indirect tensile strength, mix 2 (100% glass) would be the obvious choice with the highest compressive strength of the recycled aggregates, followed by mix 3 that recorded a respectable result only 25.7% less than the control mix.

Regarding indirect tensile strength mix 2 (100% glass) would be the obvious choice with the highest strength of 2.01MPa, 112% more than the control mix, followed by mix 3 (75% glass and 25% plastic) with 1.54MPa, approximately 14% less than the control mix. Therefore the first choice would be mix 2 followed by mix 3.

If compressive strength is the focus in the design of the mix, the choice would be mix 2, limiting the strength reduction compared to the control mix followed by mix 3 whilst including plastic into the mortar, maximising recycled material into mortar. Mix 2 was seen to split suddenly and dramatically, by incorporating plastic into mix 3, the strength was decreased however the failure was not as sudden, therefore the positives and negatives of both waste aggregates are mitigated.

The key finding from the research project is that by replacing sand with glass, resulted in higher indirect tensile strength. The high strength at 28-days for 100% glass was attributed to the distribution of glass particle sizes compared to the sand particles, which allowed for a greater degree of mechanical interlock, internal friction, and more bridging contacts between the aggregate particles. The glass aggregates also contained a high proportion of very small glass aggregates ≤0.3mm thus also enhancing the tensile strength due to the pozzolan effect of the particles. The results advance the field as there is limited literature of 100% glass replacement for sand achieving a higher indirect tensile strength for cement mortar and can serve to support the use of maximising the amount of recycled material into the mortar mix for the use of mortar in the construction industry. This paper studied the properties of cement mortar mix containing combined waste plastics and glass to increase resource utilisation of waste products to reduce the mining of natural river sand. This study differs from other studies as different substitution rates were evaluated and some of the mixes were experimental.

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# Appendix

## A: Project Specification

ENG4111/4112 Research Project

Project Specification

For: Steven Perren

Title: Properties of mortar mix containing combined waste plastics and glass.

Major: Civil Engineering

Supervisors: Professor Allan Manalo and Dr Hannah Seligmann

Enrollment: ENG4111 – ONC S1, 2023

ENG4112 – ONC S2, 2023

Project Aim: To develop and characterise the physical and mechanical properties of mortar mix containing combined waste plastics and glass.

**Programme: Version 1, 10th March 2023**

1. Conduct background research and related review of literature on sustainable mortar and concrete, and recycled aggregate. Identify current state of practice in using recycled glass and recycled plastic wastes as aggregate replacement in a mortar mix.
2. Evaluate the effects of using combined recycled glass (G) and waste plastics (P) as aggregates in mortar mix with different proportions of G and P, i.e. 0%, 25%, 50%, 75% and 100% on the physical and mechanical properties of the produced mortar mix.
3. Characterise the physical and mechanical properties of mortar mixes at 28 days.
4. Analyse and interpret the test data.
5. Develop a simple prediction equation that will reliably describe the properties of mortar mix with combined recycled glass and waste plastics as aggregates.
6. Prepare and submit a high-quality project thesis.

*If time and resource permit:*

7. Identify an optimal mortar mix design for a viable alternative option for non-structural applications.

# B: Project Schedule

Project Schedule

University of Southern Queensland
Project Lead: Steven Perren
Project Start: 20/02/2023

| | | | Semester 1 | | | | | | | | | | | | | | | | | Semester 2 | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Week | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **TASK** | **START** | **END** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| Project work | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Organise and engage with relevant people about the project | 20/02/23 | 24/02/23 | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Finalise the project details and arrange for induction to USQ labs | 27/02/23 | 10/3/2023 | | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Induction to USQ labs and arrange material to be available at USQ Springfield | 6/3/2023 | 24/3/2023 | | | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ensure material is on hand | 13/03/23 | 24/03/23 | | | | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Finalise the amounts needed of each product | 20/03/23 | 30/03/23 | | | | | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Batch the mixes of motar | 27/3/2023 | 18/5/2023 | | | | | | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | |
| Conduct flow table tests | 27/3/2023 | 18/5/2023 | | | | | | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | |
| Prepare test specimens and allow to cure | 27/3/2023 | 21/5/2023 | | | | | | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | |
| Compressive Strength and indirect tensile strength tests of 28-day cure | 11/4/2023 | 18/5/2023 | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | |
| Take microscopic photos of the samples, analyse results and report progress | 24/4/2023 | 18/5/2023 | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | |
| Exam Revision | 22/05/23 | 2/6/2023 | | | | | | | | | | | | | | ■ | ■ | | | | | | | | | | | | | | | | | | | |
| Exam Sessions | 5/6/2023 | 16/06/23 | | | | | | | | | | | | | | | | ■ | ■ | | | | | | | | | | | | | | | | | |
| Semester Break | 19/06/23 | 7/7/2023 | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | | | | | | | | | | | | | | |
| Prepare dissertation draft | 6/3/2023 | 16/06/23 | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | |
| Write up the report and experiment data, draft submission | 10/7/2023 | 1/9/2023 | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| Prepare a presentation of the project | 4/9/2023 | 15/09/23 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | | | | |
| ENG4903 Project Conference Seminar | 18/09/23 | 29/09/23 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | | |
| Finalise the project and report for submission. | 18/09/23 | 15/10/23 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ |

## C: Risk Management

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland **Offline Version**

# USQ Safety Risk Management System

**Note**: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

| Safety Risk Management Plan – Offline Version | | | |
|---|---|---|---|
| Assessment Title: | ENG4111 / ENG4112 – Research Project | Assessment Date: | 15/10/2023 |
| Workplace (Division/Faculty/Section): | University of Southern Queensland, Faculty of Engineering, Civil | Review Date:(5 Years Max) | 6/01/2023 |
| Context | | | |
| **Description:** | | | |
| What is the task/event/purchase/project/procedure? | Batching and mixing of concrete and the physical and mechanical testing of the specimens | | |
| Why is it being conducted? | To improve the sustainability of producing concrete with recycled material and to find the strength of the experimental mix designs to allow various applications of the concrete to be used in. | | |
| Where is it being conducted? | University of Southern Queensland, Springfield Campus, Laboratory | | |
| Course code (if applicable) | ENG4111 / ENG4112 | Chemical name (if applicable) | |
| **What other nominal conditions?** | | | |
| Personnel involved | Steven Perren | | |
| Equipment | Mixer, Flow table test, Compressive Strength test, Indirect Tensile Strength test | | |
| Environment | Laboratory | | |

| | |
|---|---|
| Other | |
| Briefly explain the procedure/process | Batch the mortar mix to the design, perform flow table tests on the fresh mortar, put the fresh mortar into the moulds and allow to cure. Then after a 7-day cure perform compressive strength tests and indirect strength tests on the specimens and record the data during the whole project. |
| Assessment Team - who is conducting the assessment? | |
| Assessor(s) | Associate Professor Belal Yousif |
| Others consulted: | Professor Allan Manalo and Dr Hannah Seligmann |
| | |

Eg 1. Enter Consequence

Eg 2. Enter Probability

| | Consequence | | | | |
|---|---|---|---|---|---|
| **Probability** | **Insignificant**<br>No Injury<br>0-$5K | **Minor**<br>First Aid<br>$5K-$50K | **Moderate**<br>Med Treatment<br>$50K-$100K | **Major**<br>Serious Injuries<br>$100K-$250K | **Catastrophic**<br>Death<br>More than $250K |
| Almost Certain<br>1 in 2 | M | H | E | E | E |
| Likely<br>1 in 100 | M | H | H | E | E |
| Possible<br>1 in 1000 | L | M | H | H | H |
| Unlikely<br>1 in 10 000 | L | L | M | M | M |
| Rare<br>1 in 1 000 000 | L | L | L | L | L |

**Recommended Action Guide**

Eg 3. Find Action

| Recommended Action Guide |
|---|
| **E**=Extreme Risk – Task ***MUST NOT*** proceed |
| **H**=High Risk – Special Procedures Required (See USQSafe) |
| **M**=Moderate Risk – Risk Management Plan/Work Method Statement Required |
| **L**=Low Risk – Use Routine Procedures |

| Step 1 (cont) | Step 2 | Step 2a | Step 2b | Step 3 | | | Step 4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Hazards***: From step 1 or more if identified | ***The Risk:*** What can happen if exposed to the hazard without existing controls in place? | ***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place? | ***Existing Controls:*** What are the existing controls that are already in place? | ***Risk Assessment:*** Consequence x Probability = Risk Level | | | ***Additional controls:*** Enter additional controls if required to reduce the risk level | ***Risk assessment with additional controls:*** | | | |
| | | | | **Probability** | **Risk Level** | **ALARP? Yes/no** | | **Consequence** | **Probability** | **Risk Level** | **ALARP? Yes/no** |
| **Example** | | | | | | | | | | | |
| Working in temperatures over $35^0$ C | Heat stress/heat stroke/exhaustion leading to serious personal injury/death | catastrophic | Regular breaks, chilled water available, loose clothing, fatigue management policy. | possible | high | No | temporary shade shelters, essential tasks only, close supervision, buddy system | catastrophic | unlikely | mod | Yes |
| Manual Tasks | Overexertion or repetitive movement can cause strain on the body and result in both short- and long-term injuries. | Moderate | Use pallet jacks, trolleys, forklifts to move heavy objects. Ensure there is a clear path with no obstacles. If not heavy, and is manageable, employ a team lift. Get the materials in a smaller quantity to reduce the weight. | Unlikely | Moderate | No | Limit the movement of objects 20 kg or more to lifting and moving aids and or team lifts. Always use correct lifting procedures when lifting anything. | Minor | Rare | Low | Yes |
| Electricity | Death, shock, burns can result from exposure to live wires or an incorrectly wired machine. | Catastrophic | Ensure all electrical items are test tagged to Australian Standards. If no tag is present or is out of date, do not use it until it has been passed off by a qualified electrician. Keep away from ignition sources and water. | Rare | Low | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| Machinery and equipment | Being run over by a forklift, hit by a troller, being caught by the moving parts of machinery can cause serious injuries. From death to loss of limbs to fingers, broken bones, lacerations, dislocations, and bruises. | Catastrophic | Machinery complies with AS4024.1:2019<br>Walking zones for pedestrians<br>Follow the machinery or equipment manufacturers instructions. | Unlikely | Moderate | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |

| Step 1 (cont) | Step 2 | Step 2a | Step 2b | Step 3 | | | Step 4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Hazards*: From step 1 or more if identified | *The Risk:* What can happen if exposed to the hazard without existing controls in place? | *Consequence:* What is the harm that can be caused by the hazard without existing controls in place? | *Existing Controls:* What are the existing controls that are already in place? | *Risk Assessment:* Consequence x Probability = Risk Level | | | *Additional controls:* Enter additional controls if required to reduce the risk level | *Risk assessment with additional controls:* | | | |
| | | | | **Probability** | **Risk Level** | **ALARP? Yes/no** | | **Consequence** | **Probability** | **Risk Level** | **ALARP? Yes/no** |
| **Example** | | | | | | | | | | | |
| Working in temperatures over $35^0$ C | Heat stress/heat stroke/exhaustion leading to serious personal injury/death | catastrophic | Regular breaks, chilled water available, loose clothing, fatigue management policy. | possible | high | No | temporary shade shelters, essential tasks only, close supervision, buddy system | catastrophic | unlikely | mod | Yes |
| | | | Only trained operators can use the machinery and or equipment. | | | | | | | | |
| Gravity - Slips and Trips, falling objects. | Concussion, brain damage, broken bones, Bruising, lacerations, and dislocations, permanently disabled and even death | Catastrophic | Clean and dry floor. If not, safety footwear is to be to Australian Standard and have enough grip. Wear the appropriate PPE. Steel capped boots.<br>Keep material stored correctly and always ensure there is a clear path with no obstacles or tripping hazards away from walking paths. Keep heavy objects lower and lighter objects high up on racking with appropriate safety device to ensure nothing will fall. E.g. a mesh door. | Unlikely | Moderate | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| Extreme temperature | Extreme heat can cause heat stroke which can lead to dehydration, fatigue and even death | Catastrophic | Wear loose fitting clothing, keep your water intake up, use fans and or air conditioning. | Rare | Low | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| Noise | The machinery and equipment can cause hearing damage | Moderate | Correct use of PPE. Ear plugs, earmuffs. If possible, use noise barriers. | Rare | Low | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |

| **Step 1 (cont)** | **Step 2** | **Step 2a** | **Step 2b** | **Step 3** | | | **Step 4** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Hazards:*** From step 1 or more if identified | ***The Risk:*** What can happen if exposed to the hazard without existing controls in place? | ***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place? | ***Existing Controls:*** What are the existing controls that are already in place? | ***Risk Assessment:*** Consequence x Probability = Risk Level | | | ***Additional controls:*** Enter additional controls if required to reduce the risk level | ***Risk assessment with additional controls:*** | | | |
| | | | | **Probability** | **Risk Level** | **ALARP? Yes/no** | | **Consequence** | **Probability** | **Risk Level** | **ALARP? Yes/no** |
| **Example** | | | | | | | | | | | |
| Working in temperatures over $35^0$ C | Heat stress/heat stroke/exhaustion leading to serious personal injury/death | catastrophic | Regular breaks, chilled water available, loose clothing, fatigue management policy. | possible | high | No | temporary shade shelters, essential tasks only, close supervision, buddy system | catastrophic | unlikely | mod | Yes |
| Hazardous Material | Batching the mortar, the exposure to handling the crushed glass and dry cement could lead to eye, throat, lung, skin irritations. Lead to permanent sight loss, breathing problems and rashes. | Major | Correct use and implementation of PPE, eye safety googles, face shield, breathing mask (P2), gloves, long sleeve shirt, long pants, steel cap boots. Appropriate ventilation and dust extractors. | Rare | Low | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | Select a consequence | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | Select a consequence | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | Select a consequence | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | Select a consequence | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | Select a consequence | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | Select a consequence | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| | | | | Select a probability | Select a Risk Level | Yes or No | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |

Step 5 - Action Plan (for controls not already in place)

| *Additional controls:* | *Resources:* | *Persons responsible:* | *Proposed implementation date:* |
|---|---|---|---|
| Limit the movement of objects 20 kg or more to lifting and moving aids and or team lifts. Always use correct lifting procedures when lifting anything. | Health and safety officer | Health and safety representative | 20/02/2023 |
| | | | Click here to enter a date. |
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| Step 6 - Approval | | | |
|---|---|---|---|
| Drafter's name: | | Draft date: | Click here to enter a date. |
| Drafter's comments: | | | |
| Approver's name: | | Approver's title/position: | |
| Approver's comments: | | | |
| I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided. | | | |
| Approver's signature: | | Approval date: | Click here to enter a date. |