Effect of the different Expanded Polystyrene (EPS) densities on the mechanical properties of the EPS

A dissertation submitted by

Murtaza Aziz Ahmad

B. Eng (Civil)

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School of Engineering
University of Southern Queensland
Toowoomba, Queensland 4350
Australia

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Statement of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at UniSQ or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at UniSQ or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.

Murtaza Aziz Ahmad

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Abstract

This project examined the mechanical properties of waste Expanded Polystyrene (EPS) under various densities. The key parameters used to obtain desirable mechanical properties of waste EPS were temperature, pressure, and time. Therefore, it examined the effect of each density on the mechanical strength of EPS by implementing procedures developed in this project to obtain the maximum capacity of waste EPS and suggesting applications for each density. Moreover, the concern is that increased worldwide attention to waste polystyrene and mixed waste have limited uses for recycling (Ayse & Filiz, 2016). These wastes are accumulating due to the new export bans on such waste products. The cost of burying this waste in a landfill in Australia varies from $80 - $200 per tonne for the waste levy application. It is not economically suitable for landfill or recycle these materials due to their expensive cost of processing (Zhuang et al. 2016). Further, the experiment demonstrated finding the ideal density, and mechanical strength, under the correct parameters, such as temperature, pressure, and time to provide optimal mechanical strength.

Furthermore, the row waste EPS is collected and then placed under the heat press machine to modify density into 220, 450, 600, 850, and 1000 (kg/m^3). Three specimens were tested in each density under the Tensile, Compressive and Flexural tests to demonstrate their maximum capacity in following ASTM Standards. Followed, by develop a comprehensive method to optimise waste Expanded Polystyrene (EPS) production across various densities by manipulating temperature, pressure, and time. Through experimentation (Figure 1), it highlighted distinct mechanical strengths tied to different densities showcasing the importance of tailored manufacturing for enhanced performance and sustainable EPS utilisation. It demonstrated by increasing the density can increase the stiffness and strength of waste EPS. The range of tensile strength can be between 1-22 MPa with stiffness of 0.3-3.2 GPa. Similarly, the compressive strength sits between 18-93 MPa and stiffness of 0.6-2.3 GPa. Likewise, the flexural strength lay between 11-37 MPa and stiffness of 1.3-3 GPa. The execution procedure and adoption of the correct temperature, pressure, and time are critical to achieving the maximum capacity of waste EPS. It is proven and demonstrated that waste EPS has unique strength under various densities.

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Chapter 1 Introduction

1.1 General

Expanded Polystyrene (EPS) is one of the most important plastics utilised worldwide. It has a similar structure to the polyethene. The only difference between polyethene and polystyrene is to remove one of the hydrogens (H) and replace it with a Benzene ring. It is commercialised in many forms worldwide. The most common form that we see is in the form of Styrofoam. If it is rigid, then it is hard and has brittle properties. Polystyrene was first discovered in 1839 by a German Apothecary Eduard Simon. It is also formed into foam, called expanded polystyrene. It has properties of low melting point, and poor thermal conductivity, surrounded by almost 95% Air and 5% Polystyrene.

Expanded Polystyrene (EPS) is utilised in various applications worldwide such as automotive, electronics, food services, insulation, water desalination, land conservation, flood prevention, medical, packaging and other uses Siddique et al. (2008). It is used in the form of rigid and foam for a specific application. Most applications use EPS because it doesn't react with other materials, it is durable and long-lasting and cost-effective (Arvanitoyannis 2007).

The purpose of this project is to investigate that waste-expanded polystyrene (EPS) has sufficient mechanical strength to build houses for habitat people in Toowoomba. The experiment was done to find the right density, mechanical strength, under the right parameters such as Temperature, Pressure and Time to provide optimal mechanical strength.

1.2 Background of Expanded polystyrene (EPS)

Expanded Polystyrene (EPS) is a type of plastic used worldwide. Its base structure type is polyethylene but includes the replacement of hydrogen (H) with benzene molecules. It compromises 98% Air and 2% polystyrene (Ayse & Filiz 2016). If it is hard, then it is rigid, brittle, and impact resistant. It is used in a wide range of applications such as automotive, electronics, food services, insulation, medical, and packaging.

Chemical Composition of EPS. It is transformed from polymerised styrene. The chemical formula is C_8H_8n. Each densification process varies based on the method used and how much the material can be densified. Before waste EPS densification it has a thermal conductivity of

0.033 w/ (m.k) and a density of 50 kg/m^3. After waste EPS densification it has a density of 960-1050 kg/m^3.

1.3 Problem statement

The concern is that increased worldwide attention to waste polystyrene and mixed waste have very limited uses for recycling. These wastes are currently accumulating due to the new export bans on such waste. The cost of burying this waste in a landfill in Australia varies from $80 - $200 per tonne for the waste levy application. It is not economically suitable to either bury or recycle these materials due to their expensive cost of processing.

Based on the literature review there is no paper published showing the effect of EPS density on the mechanical strength of EPS. There is a significant gap in the Field of research. It is important to understand the behaviour of EPS by itself without combining it with other materials. This will assist to understand in depth the characteristic of EPS by itself and identifying the advantage and disadvantages of the EPS.

The EPS plastic products have become a major and important part of our lives. Over the past several years this product become a major issue in Australia and worldwide. The amount of utilising these products and constantly growing products has increased solid plastic usage worldwide. Recently there was a global production of 1.3 billion tons/year of plastics globally (Zhuang et al. 2016). The use of EPS based on the low density, strength, user-friendly designs, fabrication, long life, lightweight, and low cost are the main factors that lead to the significant growth of the product. The world's plastic consumption increased significantly from approximately 5 million tons in the 1950s to 100 million tons in 2001 (Siddique et al. 2008).

The amount of plastic consumption has remarkably grown in the last two or three decades (Nkwachukwu et al. 2013). Especially in developed countries, it has a major environmental risk where disposal facilities are lacking and leading to environmental damage and even health risk (Sofie Huysman 2015).

1.4 Objective of thesis

To measure the performance of the expanded polystyrene (EPS) it is important to evaluate and appraise the concept and its effecting. This project explores and investigate the effects of the different expanded polystyrene density on the mechanical properties of the expanded polystyrene to understand its strength and main objective are to:

a) Develop a design procedure for expanded polystyrene that is most suitable for the lab experiment.
b) Identify the suitable temperature, pressure, and time for lab experiments of the expanded polystyrene.
c) Modify the various expanded polystyrene to find the optimum EPS density that is suitable for the lab experiment.
d) Investigate the mechanical strength of expanded polystyrene under different expanded polystyrene densities.
e) Identify and analyse each expanded polystyrene density and what will be the most suitable application for it.

1.5 Scope of thesis

This project examines the feasibility of different expanded polystyrene densities. It is focused on:

(a) A review of the existing expanded polystyrene density used in construction.
(b) Discussing specific problems of waste-expanded polystyrene.
(c) Manipulating various expanded polystyrene densities to identify the mechanical strength of each EPS density.
(d) Identification of suitable temperature, pressure, and time for lap experiments.
(e) Analysis of the pure expanded polystyrene material without any mixed design.

Although a necessary approach was taken to establish the fundamental knowledge of the effect of various expanded polystyrene on the mechanical strength of expanded polystyrene which further research could continue, the following issues were beyond the scope of this project.

(a) The effect of additive mix design with expanded polystyrene.
(b) The durability and environmental effect of the design.
(c) The impact of fire on the expanded polystyrene.
(d) The 3D modelling for the final application.

1.6 Organisation of thesis

This dissertation consists of five chapters which describe the difference investigations conducted in the research project.

Chapter 1 presents a general introduction and background to the current research, the problem statement, the objective and scope, and the organisation of the dissertation.

Chapter 2 reviews the existing material used with waste EPS and their specific problems. Possible alternative solutions and arguments in support of this study's hypothesis are discussed.

Chapter 3 is concerned with specific considerations and methods for the design experimental of waste EPS, and the mechanical performance requirements for waste EPS according to the relevant Standards.

Chapter 4 discuss and analysis the results of mechanical properties of waste EPS under various waste EPS densities, demonstrating the relationship and performance between mechanical properties and waste EPS densities.

Chapter 5 summarise the main findings of the research project, presents its conclusions and provides recommendations for future research.

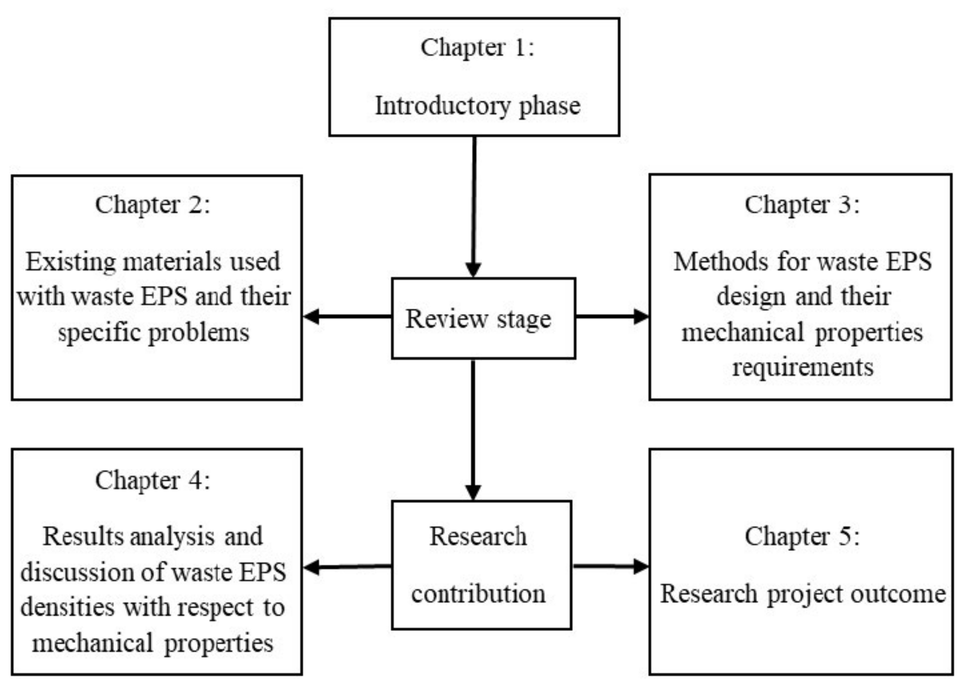


Figure 1: Flow diagram of the dissertation

Chapter 2 Literature Reviews

2.1 General

Polystyrene (PS) and Expanded Polystyrene (EPS) are forms of the polymer family. It is a well-known plastic that people utilised worldwide (Zhuang 2016). The EPS based on its low density and high volume is more popular among the plastic family. The application of EPS varies based on the specific purpose of the application. The application is such as automotive, Electronics, food services packages, insulation, water desalination, land conservation, flood presentation, Medical, packaging and many more uses(Siddique 2007).

In the last 30 years, EPS gained much attention as it is an attractive material in combination with other materials and reuses the waste EPS to produce brand new material it. It is beneficial for the industry as it is easy to produce and requires less work crew to produce the end products as well as it is last-long products (Reza Abedini 2010).

2.2 Related Research

There are several papers published, demonstrating the importance of EPS with a combination of other materials. It shows the significance of the EPS with the combination of other materials and applications has been used for. The following paper shows the use of waste EPS in various applications.

Using waste EPS with waste cooking oil as composite materials in construction (Sarmiento et al. 2016). Replacement of cement with waste EPS in mortars for masonry construction (Milling et al. 2020). Using waste EPS as aggregate mixed in concrete to produce lightweight concrete (Ayse & Filiz 2016). Dissolved waste EPS with natural solvents such as d-limonene, Tetrahydrofuran (THF), Dimethylformamide (DMF), and Dimethylacetamide (DMAc) (Shin & Chase 2005). Developing waste EPS for hollow block masonry with the use of steel mesh bars as reinforcement (Ali et al. 2020). Using waste EPS as aggregates using heat processing reduces the volume by twenty times the original size (Kan & Demirboğa 2009). The significant EPS particle size plays an important role in lightweight concrete (Miled et al. 2004). The combination of EPS with Pumice stone as sandwich blocks for the construction with thermal conductivity and compressive strength proportional to the thickness of EPS (Demirel 2013). Showing the relationship between pressure, temperature and timing of the microstructure of EPS (Doroudiani & Kortschot 2003).

However, there is hardly any paper published discussing the effect of the mechanical strength of waste EPS under various densities. Therefore, this study was undertaken to identify the effects and behaviour of waste EPS under different densities. Moreover, there are hardly any papers published discussing the effect of temperature, pressure, and time on waste EPS. This study successfully identified the suitable temperature, pressure and time that can maximise the capacity of purely waste EPS without a combination of other materials.

It is noted that most of the papers published focus on waste EPS with a combination of other materials rather than exploring the behaviour of pure waste EPS. Therefore, this study demonstrates and develops a design procedure that is most suitable for lab experiments. Identified the suitable temperature, pressure, and time to maximise waste EPS capacity and performance. Evaluated the mechanical strength of waste EPS under different densities and identified of most suitable applications for each density.

This project investigates various waste EPS with different densities with a range of 10-1050 kg/m^3. Utilised the waste EPS with different densities from 10-100 kg/m^3 for sample preparation. These various densities were collected and used as the preliminary sample in the Lab to provide with required density for testing.

2.3 Hypothesis

This project investigated the effects of the different EPS densities on the mechanical properties of the EPS. It is believed that different EPS density has various mechanical strength, and it is applications. Each EPS density might be used for each specific construction application. For instance, it is believed that this material with modification of density might be suitable for the construction of houses for homeless people in Toowoomba.

2.4 Conclusions

The cost of burying waste EPS in a landfill is estimated between $80-$220 per tonne. Further, the concern is that increased worldwide attention to waste EPS, which has limited use for recycling. It is estimated around 12,000 tonnes are sent to landfill every year and contain around 240,000 m^3 of landfill space. The challenge is that waste EPS is accumulating in Australia due to new export bans. Moreover, waste EPS have limited research regarding mechanical properties and has limited contribution to the circular economy.

Chapter 3 Methodology

The project is planned for the research to be carried out in 5 phases:

- Phase 1: Collection of waste EPS and construction of the aluminium mould for the heat press to manipulate the density of EPS under three factors such as time, pressure, and temperature.
- Phase 2: Collection and preparation of EPS samples with different densities.
- Phase 3: Testing is undertaken at the USQ laboratory to determine the mechanical strength of each ESP density, using Standard mechanical testing.
- Phase 4: Manipulation and analysis of tests results
- Phase 5: Dissertation report.

3.1 Material and Instrument

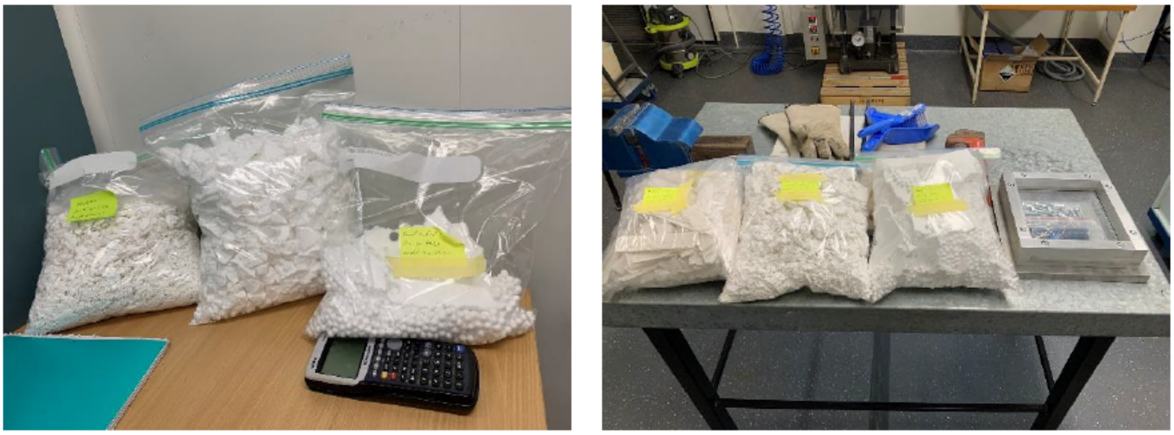
Using waste EPS with different densities. The material is collected as waste EPS and then place under the heat press machine to modify the density of the EPS. Based on the previous study on the waste EPS demonstrated that it has different mechanical strengths based on the density of the materials. The material used for the experiment was waste EPS.

3.2 Design of Experiments

The specimens were prepared with five different densities such as 220, 450, 600, 850, and 1000 kg/m^3. These specimens were modified in the heat press machine to find the suitable density for the further testing. These specimens were tested using the heat press test, density test, tensile test, flexural test, impact test, and compression test.

3.3 Sample Preparation

Utilised waste-expanded polystyrene (EPS) with different densities. First, using the waste EPS with a density of 1:95 ratio as the waste EPS containing 98 % air and 2 % PS. Then, cut the waste EPS into the desired shape for the mechanical experiment to collect the date regarding of mechanical experiments of the waste EPS with a density of 1:95 ratio. Placed the waste EPS into the tensile, flexural, compression, and impact testing machine to collect data. The following samples' size and quantity have been tested and the results have been recorded and collected. Five samples for the tensile test with dimensions of 200 × 20 × 10 mm. Five samples for the flexural test with dimensions of 200 × 20 × 10 mm. Five samples for the impact test with dimensions of 10 × 10 × 40 mm. Five samples for the compression test with dimensions of 25 × 25 × 25 mm. Five samples for the density test with dimensions of 10 × 10 × 40 mm.



(a) Excessive samples (b) Initial sample preparation

Figure 2: Samples preparation of waste EPS with initial density

3.4 Procedure and Inventions

The various EPS density used for the mechanical testing in the USQ laboratory. The following procedures executed as heat press manipulation to achieve the required density, Tensile testing, Flexural testing, Impact testing, Compression testing, and Density test (Sachin S Raj 2021).

3.4.1 Construction of Mould

The experimental mould has been designed and constructed for this project. The mould has been constructed using aluminium material as it has good thermal conductivity and is lighter compared to steel mould. The effective size of the mould is 200 × 200 mm^2 with adjustable frame thicknesses such as 25, 20, and 10 mm. Based on these three-thickness frames can be producing a combination of 10, 20, 25, 30, 35, 45, and 55 mm thicknesses.

Figure 3: Different orientation of aluminium mould

3.4.2 Heat press test

In this experiment using the heat press machine modified the density of the waste EPS with various initial densities such as 50 kg/m^3 (general waste collected from The University Centre of Future Material), 300 kg/m^3 (Toowoomba Grand Central), and 600 kg/m^3 (Toowoomba Regional council).

The optimum temperature, pressure, and time used in this experiment are as follows:

- Temperature = 160 degrees
- Duration = 30 minutes
- Pressure = 500 kPa
- Cooling duration = 3 – 12 hours

(a) Heat press machine (b) Adjusting the pressure

Figure 4: Placing sample mould into the heat press machine.

3.4.3 Tensile test

This test method is used to determine the tensile strength of unreinforced EPS in the form of rectangular shape test specimens when tested under defined conditions of temperature, pressure and time with different densities (ASTM_D638 2022). This test method is applicable for testing material of a thickness range of 5-12 mm and width range of 19-21 mm with a standard length of 180-200 mm.

Five samples were used for the tensile test as shown in Table 1. The specimen was carefully placed in the tensile machine. The tensile machine pulled the sample apart from top and bottom until failure. Once the cracking happens then can remove the samples carefully and record the data. There are five samples used and each sample data is recorded individually. Collecting all data and getting the average tensile strength of the samples as shown in Table 1.

Table 1: Tensile specimen dimension and properties

Density (kg/m^3)	Samples	Dimensions (mm)	Standard
220	A	180 × 19.66 × 6.44	(ASTM_D638 2022)
450	B	180 × 20.04 × 5.91	
600	B	201 × 19.87 × 10.04	
850	A	180 × 20.30 × 10.45	
1000	D	180 × 20.10 × 11.43	

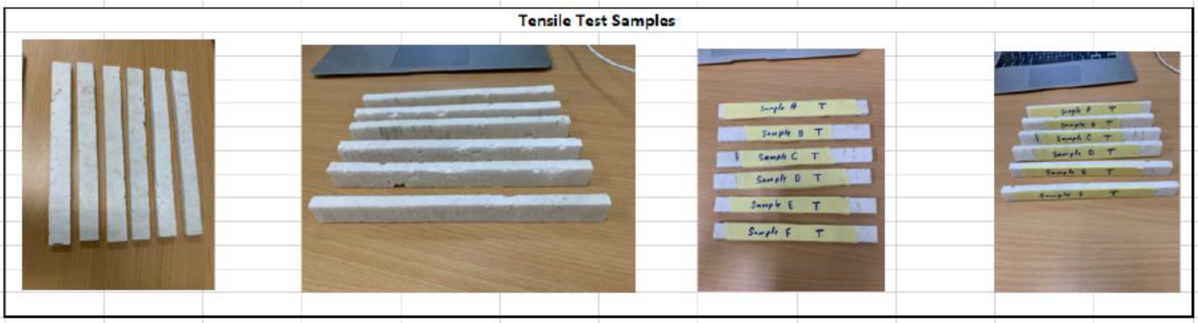
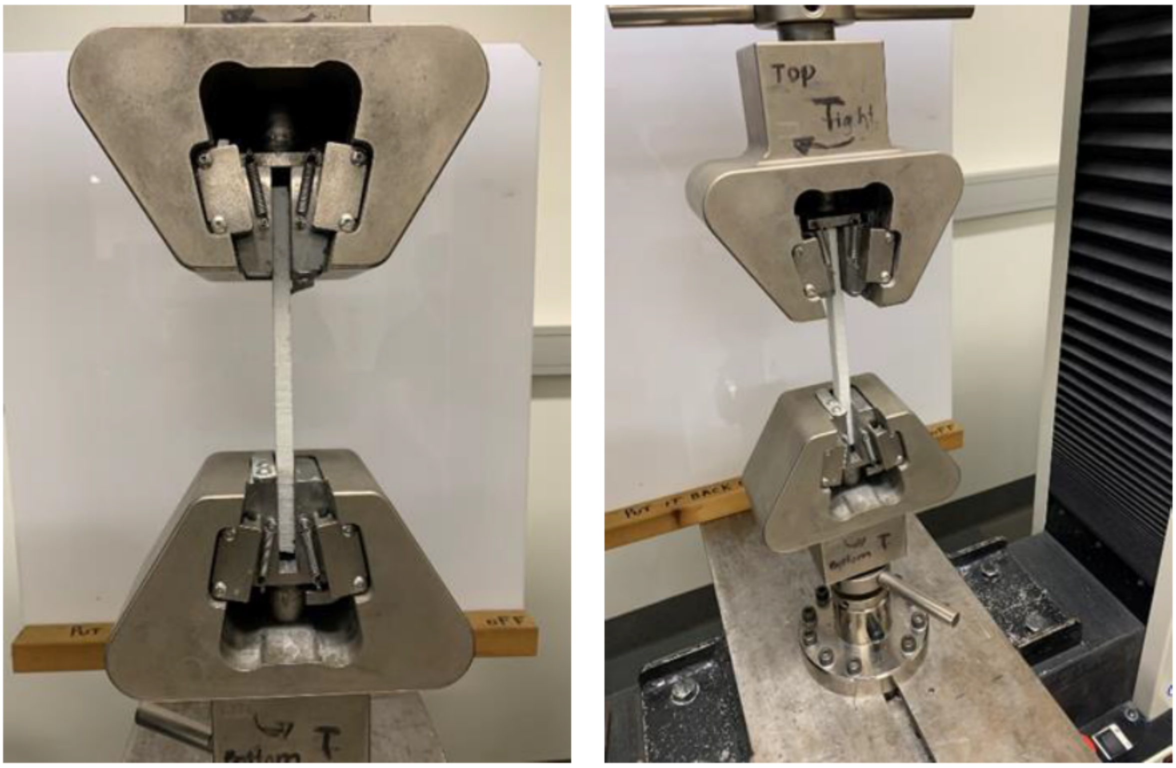


Figure 5: Tensile specimen



(a) Specimen under tension (b) Specimen reaches yield

Figure 6: Tensile strength test with specimens

3.4.4 Flexural test

This test method is used to determine the flexural strength of unreinforced EPS in the form of rectangular shape test specimens when tested under defined conditions of temperature, pressure and time with different densities (ASTM_D790 2017). This test method is applicable for testing material of a thickness range of 6-12 mm and width range of 19-21 mm with a standard length of 150 mm.

Five samples were used for the flexural test as shown in Table 2. The specimen was carefully placed in the flexural machine. It applied loads as a three-point force. The two-end side of the samples was fixed, and loads were applied in the mid-span until its failure. The data of each sample was recorded individually. Collected all data and got the average flexural strength of the samples as shown in Table 2.

Table 2: Flexural specimen dimension and properties

Density (kg/m^3)	Samples	Dimensions (mm)	Standard
450	D	150 × 20.10 × 6.15	(ASTM_D790 2017)
600	B	150 × 20.10 × 9.91	
850	A	150 × 20.25 × 10.45	
1000	A	150 × 20.25 × 11.25	

(a) Flexural specimens (b) Specimen under bending

Figure 7: Flexural strength test with specimens

3.4.5 Compression test

This test method is used to determine the compressive strength of unreinforced EPS in the form of cubed shape test specimens when tested under defined conditions of temperature, pressure and time with different densities (ASTM_D695 2023). This test method is applicable for testing material of a thickness range of 8-26 mm and width range of 5-26 mm with a standard length of 19-27 mm.

Five samples were used for the compression test as shown in Table 3. The specimen was carefully placed in the compression test machine. Once we place the samples on the machine the loads are applied from the top and bottom to the samples until they fail. Each sample data was collected individually. The average compression strength recorded is shown in Table 3.

Table 3: Compressive specimen dimension and properties

Density (kg/m^3)	Samples	Dimensions (mm)	Standard
220	B	19.80 × 7.80 × 9.90	(ASTM_D695 2023)
450	C	19.90 × 5.80 × 10.10	
600	D	26.60 × 26.00 × 26.00	
850	C	20.00 × 10.60 × 10.30	
1000	B	22.20 × 12.10 × 10.50	

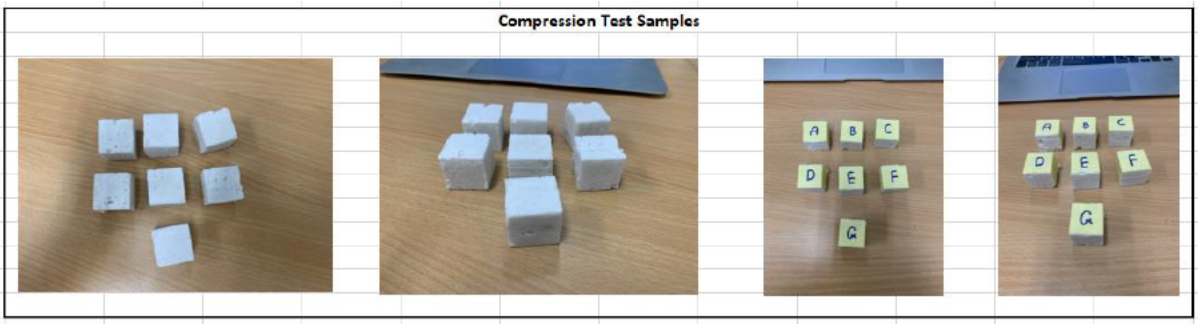
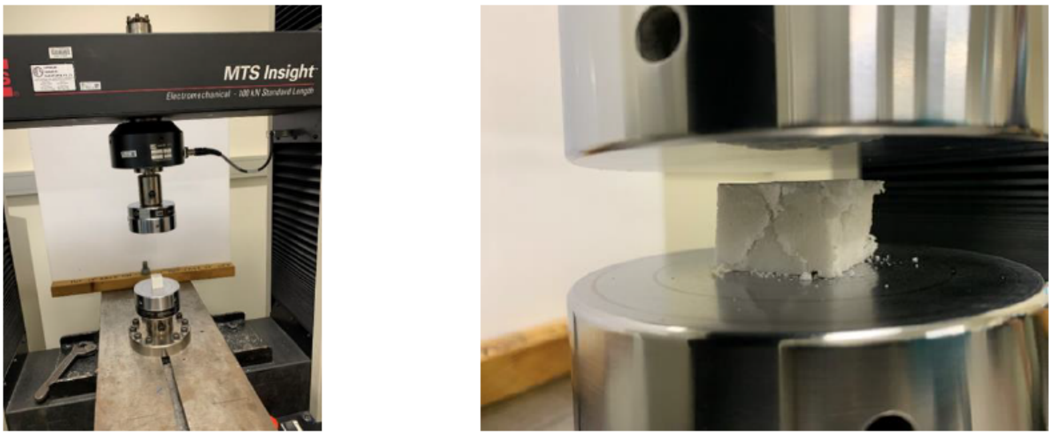


Figure 8: Compression specimens



(a) Compressive test (b) Specimen under vertical load

Figure 9: Compressive strength test with specimens

3.5 Conclusions

In this chapter, a detailed procedure for the design of waste EPS has been proposed and illustrated using an example. A range of waste EPS densities from 220, 450, 600, 850, and 1000 kg/m³ made to test the mechanical properties of each density. Five specimens were cut from each density to be tested and illustrate the mechanical performance of waste EPS. Further, developed a procedure of a heat press machine that manipulated the waste EPS densities under unique parameters such as temperature, pressure, and time. Each waste EPS density have been tested under tensile, flexural, and compressive test according to the relevant Standards. It was found that the mechanical properties of waste EPS increased linearly with increases in densities. This observation agrees with the basic principle of other materials such as hardened concrete, fibre-reinforced concrete, and lightweight fibre-reinforced foamed concrete.

Chapter 4 Results Analysis and Discussion

4.1 Density test

Five samples used for the density test with dimensions of 10 x 10 x 40 mm. The density test used the formula.

$$\rho = \frac{m}{V}\ kg/m^3 \qquad \text{Equation (1)}$$

Each sample tested individually. The data collected and got the average density of the material.

4.2 Analysis

4.2.1 Analysis of tensile test results

This test method includes the option of determining the relationship between tensile strength, modulus of elasticity and different densities. Demonstrates the relationship between tensile strength and densities under defined parameters of temperature, pressure, and time.

The tensile strength test involves placing five specimens in the tensile testing machine and slowly extending them until they are fractured. In this process, the elongation of the gauge section is recorded against the applied force. The data has been collected and manipulated so that is specific to the test specimen. The elongation measurement was utilised to calculate the strain (ε) utilising the following equation (ASTM_D638 2022).

$$\varepsilon = \frac{\Delta L}{L_o} = \frac{L - L_o}{L_o} \qquad \text{Equation (2)}$$

Where ΔL (mm) is the change in gauge length, L_o (mm) is the initial length gauge length, and L (mm) is the final length. The force measurement is used to calculate the stress (σ) utilising the following equation.

$$\sigma = F/A \qquad \text{Equation (3)}$$

Where F (N) is the tensile force and A (mm^2) is the nominal cross-section of the specimen. The tensile machine recorded data in terms of Force (N), Displacement (mm), and Time (s). The data was then loaded into Microsoft Excel to produce a stress (MPa) vs. strain (%) graph (Figure 8 (a)). The stress (σ) vs. strain (ε) slope measurement is used to calculate the Modulus of Elasticity E (GPa) utilising the following equation.

$$E = \frac{\sigma 1 - \sigma 2}{\varepsilon 1 - \varepsilon 2}$$ Equation (4)

Where the difference between stress σ1 & σ2 is the rise and the difference between strain ε1 & ε2 is the run.

The specimen data was collected and analysed to identify the maximum capacity of waste EPS under tensile strength. Thus, the average tensile strength of each density is to investigate a comprehensive analysis of tensile strength concerning its densities as shown in Table 4.

Table 4: Display tensile test specimen with different densities.

Tensile Test with Different Densities										
Specimen NO	220 (kg/m^3)		450 (kg/m^3)		600 (kg/m^3)		850 (kg/m^3)		1000 (kg/m^3)	
	Strength (MPa)	SD	Strength (MPa)	SD	Strength (MPa)	SD	Strength (MPa)	SD	Strength (MPa)	SD
A	1.06		3.39		1.86		12.53		24.02	
B			5.60		2.13		12.72		16.00	
C		N/A	12.18	4.07	2.11	0.27	18.24	2.56	15.60	3.68
D			8.79		2.30		12.55		22.00	
E			12.77		1.61		12.30		19.00	

4.2.2 Analysis of flexural test results

This test method includes the option of determining the relationship between flexural strength, modulus of elasticity and different densities. Demonstrates the relationship between flexural strength and densities under defined parameters of temperature, pressure, and time.

The flexural strength test involves placing five specimens in the flexural testing machine subjected to load in a three-point bending setup and slowly applying load on them until the fractures or deformation exceed its yield point. In this process, the elongation of the extended length is recorded against the applied force. The data has been collected and manipulated so that is specific to the test specimen. The elongation measurement was utilised to calculate the strain (ε) utilising the following equation (ASTM_D790 2017).

$$\varepsilon = \frac{6Dd}{L^2}$$ Equation (5)

Where L (mm) is the support span, D (mm) is the maximum deflection of the centre of the specimen, and d (mm) is the depth or thickness of the tested specimen. The force measurement is used to calculate the stress (σ) utilising the following equation.

$$\sigma = \frac{3FL}{2bd^2} \quad \text{Equation (6)}$$

Where F (N) is the load at a given point on the load-deflection curve, and b (mm) is the width of the test specimen. The flexural machine recorded data in terms of Force (N), Displacement (mm), and Time (s). The data was then loaded into Microsoft Excel to produce a stress (MPa) vs. strain (%) graph (Figure 11 (a)). The slope measurement is used to calculate the flexural modulus (E) utilising the following equation.

$$E = \frac{L^3 m}{4bd^3} \quad \text{Equation (7)}$$

The force (N) vs. displacement (mm) slope measurement is used to calculate m (N/mm). The specimen data was collected and analysed to identify the maximum capacity of waste EPS under flexural strength. Thus, the average flexural strength of each density is to investigate a comprehensive analysis of flexural strength concerning its densities as shown in Table 5.

Table 5: Display flexural test specimen with different densities.

Flexural Test with Different Densities								
Specimen NO	450 (kg/m^3)		600 (kg/m^3)		850 (kg/m^3)		1000 (kg/m^3)	
	Strength (MPa)	SD	Strength (MPa)	SD	Strength (MPa)	SD	Strength (MPa)	SD
A	23.69		15.83		28.49		35.51	
B	18.88		12.35		21.36		36.32	
C	21.30	1.97	8.84	2.61	19.24	5.68	31.58	2.81
D	21.05		13.94		31.70		37.62	
E			13.81		19.53		31.49	

4.2.3 Analysis of compressive test results

This test method includes the option of determining the relationship between compressive strength, modulus of elasticity and different densities. Demonstrates the relationship between compressive strength and densities under defined parameters of temperature, pressure, and time.

The compressive strength test involves placing five specimens in the compressive testing machine and slowly compressing them until they are fractures or deformation exceed their yield point. In this process the elongation of the shortened in length and spread laterally is recorded against the applied force. The data has been collected and manipulated so that is specific to the test specimen. The elongation measurement was utilised to calculate the strain (ε) utilising the following equation (ASTM_D695 2023).

$$\varepsilon = \frac{\Delta L}{L_o} = \frac{L - L_o}{L_o} \qquad \text{Equation (8)}$$

Where ΔL (mm) is the change in specimen length, L_o (mm) is the initial specimen length, and L (mm) is the final length. The force measurement is used to calculate the stress (σ) utilising the following equation.

$$\sigma = F/A \qquad \text{Equation (9)}$$

Where F (N) is the uniaxial compressive force and A (mm^2) is the nominal cross-section of the specimen. The compressive machine recorded data in terms of Force (N), Displacement (mm), and Time (s). The data was then loaded into Microsoft Excel to produce a Stress (MPa) vs. strain (%) graph (Figure 12 (a)). The Stress (σ) vs. strain (ε) slope measurement is used to calculate the Modulus of Elasticity E utilising the following equation.

$$E = \frac{\sigma 1 - \sigma 2}{\varepsilon 1 - \varepsilon 2} \qquad \text{Equation (10)}$$

Where the difference between stress σ1 & σ2 is the rise and the difference between strain ε1 & ε2 is the run.

The specimen data was collected and analysed to identify the maximum capacity of waste EPS under compressive strength. Thus, the average compressive strength of each density is to investigate a comprehensive analysis of compressive strength concerning its densities as shown in Table 6.

Table 6: Display compressive test specimen with different densities.

Compressive Test with Different Densities										
Specimen NO	220 (kg/m^3)		450 (kg/m^3)		600 (kg/m^3)		850 (kg/m^3)		1000 (kg/m^3)	
	Strength	SD	Strength	SD	Strength	SD	Strength	SD	Strength	SD
A	17.59		35.06		19.02		47.81		87.67	
B	18.83		43.69		20.36		58.45		93.05	
		0.88	46.32	7.32	19.81	2.06	62.00	6.31	100.18	4.58
			55.51		20.22		63.66		94.31	
			46.50		15.40		60.94		91.39	

4.3 Discussion

4.3.1 Effect of density on tensile properties

This test method undertook five EPS densities to identify the relationship between densities and tensile strength. The results displayed in Figure 10 (b) shows the relationship between various density and tensile strength. It demonstrates that increasing EPS densities it increases the tensile strength. Thus, can say there is a decent relationship between tensile strength and densities under defined parameters of temperature, pressure, and time.

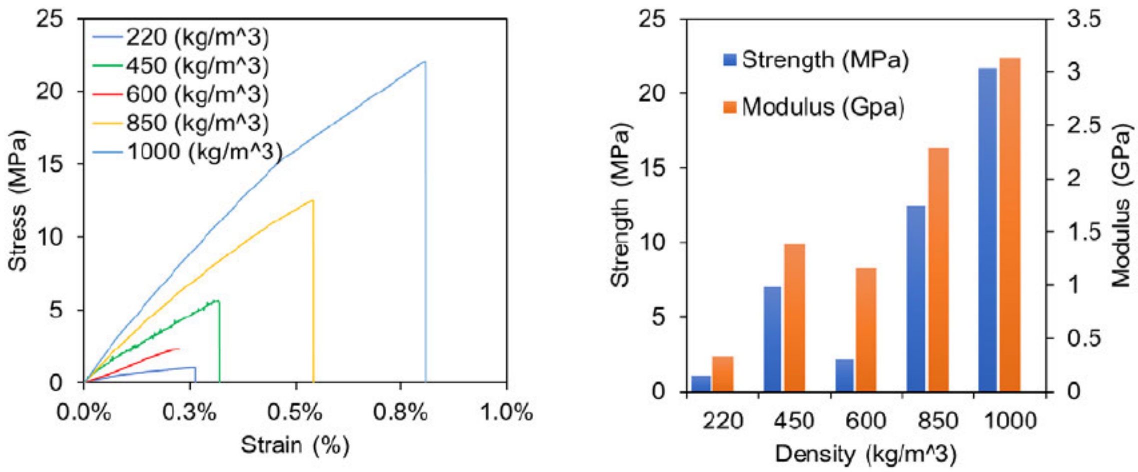
For instance, the test results for waste EPS with 600 kg/m^3 show a significant reduction in tensile strength Figure 10 (b). The reason that 600 kg/m^3 shows a significant reduction in tensile strength was these raw materials were provided by Toowoomba Regional Council (TRC) (Toowoomba_Regional_Council 2021) . The procedure that TRC has been utilised is an extruded machine. Which chops, heats, and extrudes the waste EPS without defining the optimum temperature, pressure, and time.

This test method demonstrated the importance of temperature, pressure, and time to produce the maximum capacity of waste EPS. Therefore, the TRC raw material has not reached its maximum capacity yet to be maximised.

The range of tensile strength obtained from tensile test under defined conditions of temperature, pressure, and time is between 1-22 MPa. The range of modulus of elasticity under defined conditions of temperature, pressure, and time is between 0.3-3.2 GPa Figure 10 (b). These results depend on waste EPS densities. When the densities of EPS increase the tensile and modulus of elasticity increases. Thus, can say there is a relationship between tensile and modulus of elasticity with different EPS densities Figure 10 (b).

The relationship between tensile strength and different densities of fibre-reinforced concrete suggests that as densities of fibre-reinforced concrete increase, the tensile strength increases. It is demonstrated the critical role of densities in the tensile strength. Further, suggested it has a limited range of densities to obtain accurate results. Thus, can conclude the importance of densities on the tensile strength of fibre-reinforced concrete (Hak-Young Kim 2023). This shows that not only waste EPS gained strength by increasing the densities but also the fibre-reinforcement concrete behaves the same way as waste EPS.

Further investigation into the tensile strength with high-density polyethylene suggested that as the crease the density of polyethylene can increase the tensile strength by about 0.16 MPa. The increase in density of polyethylene can increase the modulus of elasticity by about 41 MPa. And reduce yield strain by about 0.00083 mm/mm. Thus, can say there is a significant relationship between tensile strength and density in polyethylene in the same way as is demonstrated in this project (Daniel.A.I. Malyuta 2023). The increased density on waste EPS would increase the tensile strength in the same way that other material behaves such as fibre-reinforcement concrete and polyethylene with high-density.



(a) Tensile stress vs strain (b) Tensile properties vs density

Figure 10: Variation of tensile properties with the densities of waste EPS

4.3.2 Effect of density on flexural properties

This test method undertook five EPS densities to identify the relationship between densities and flexural strength. The results displayed in Figure 11 (b) shows the relationship between various density and flexural strength. It demonstrates that increasing EPS densities it increases the flexural strength. Thus, can say there is a decent relationship between flexural strength and densities under defined parameters of temperature, pressure, and time.

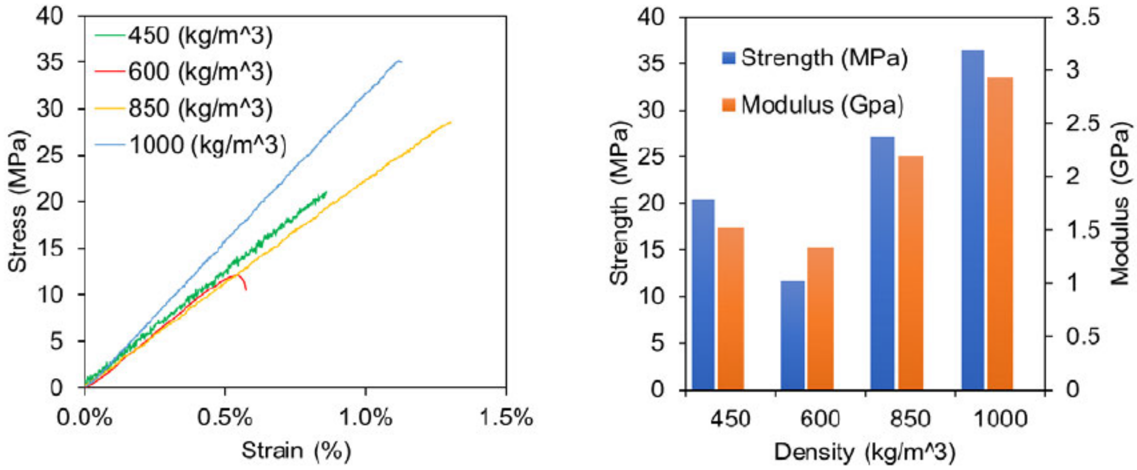
For instance, the test results for waste EPS with 600 kg/m^3 show a significant reduction in flexural strength Figure 11 (b). The reason that 600 kg/m^3 shows a significant reduction in flexural strength was these raw materials were provided by the Toowoomba Regional Council (TRC) (Toowoomba_Regional_Council 2021) . The procedure that TRC has been utilised is an extruded machine. Which chops, heats, and extrudes the waste EPS without defining the optimum temperature, pressure, and time.

This test method demonstrated the importance of temperature, pressure, and time to produce the maximum capacity of waste EPS. Therefore, the TRC raw material has not reached its maximum capacity yet to be maximised.

The range of flexural strength obtained from the flexural test under defined conditions of temperature, pressure, and time is between 11-37 MPa. The range of modulus of elasticity under defined conditions of temperature, pressure, and time is between 1.3-3 GPa Figure 11 (b). These results depend on waste EPS densities. When the densities of EPS increase the flexural and modulus of elasticity increases. Thus, can say there is a relationship between flexural and modulus of elasticity with different EPS densities Figure 11 (b).

The relationship between flexural strength and different densities of lightweight fibre-reinforced foamed concrete suggests that as densities of lightweight fibre-reinforced concrete foamed increase, the flexural strength would increase. It has demonstrated the critical role of densities in flexural strength (Hak-Young Kim 2023). Further, suggested it has a significant performance by mixed design of polypropylene microfibre. Thus, can conclude the importance of densities on the flexural strength of lightweight fibre-reinforced foamed concrete (Devid Falliano 2022). This shows that not only waste EPS gained strength by increasing the densities but also the lightweight fibre-reinforcement foamed concrete behaves the same way as waste EPS.

Further investigation into the flexural strength relationship of fibre-reinforced concrete with different densities suggested that the increase in the density of fibre-reinforced concrete can increase the flexural strength concerning the load-displacement curve. The increase in density of fibre-reinforced concrete can increase the modulus of elasticity and reduce yield strain concerning the flexural load-displacement curve and tensile stress-strain curve. Thus, can say there is a significant relationship between flexural strength and density in fibre-reinforced concrete in the same way as is demonstrated in this study (Hak-Young Kim 2023). The increased density of waste EPS would increase the tensile strength in the same way that other material behaves such as fibre-reinforced concrete, polyethylene with high density, and lightweight fibre-reinforced foamed concrete.



(a) Flexural stress vs strain (b) Flexural properties vs density

Figure 11: Variation of flexural properties with the densities of waste EPS

4.3.3 Effect of density on compressive properties

This test method undertook five EPS densities to identify the relationship between densities and compressive strength. The results displayed in Figure 12 (b) shows the relationship between various density and compressive strength. It demonstrates that increasing EPS densities it increases the compressive strength. Thus, can say there is a decent relationship between compressive strength and densities under defined parameters of temperature, pressure, and time.

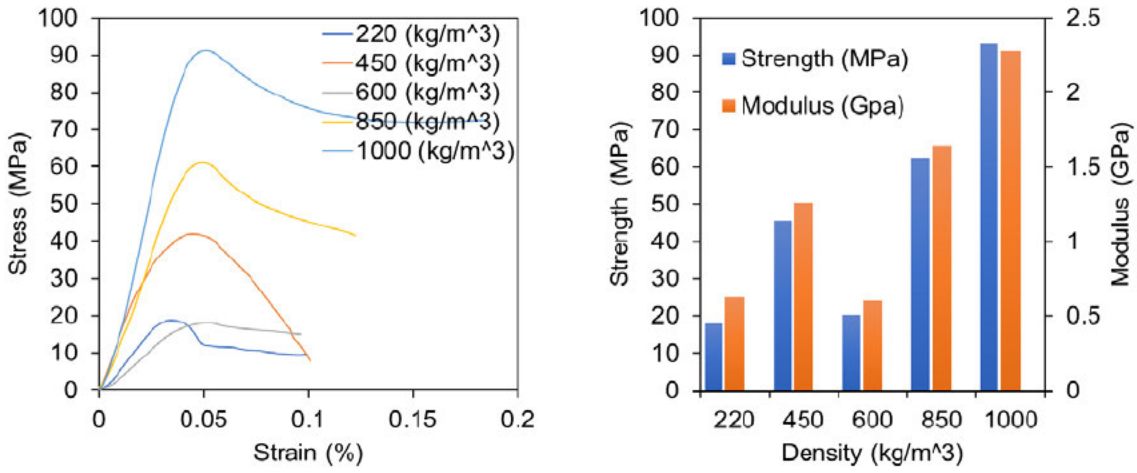
For instance, the test results for waste EPS with 600 kg/m^3 show a significant reduction in compressive strength Figure 12 (b). The reason that 600 kg/m^3 shows a significant reduction in compressive strength was these raw materials were provided by Toowoomba Regional Council (TRC) (Toowoomba_Regional_Council 2021). The procedure that TRC has been utilised is an extruded machine. Which chops, heats, and extrudes the waste EPS without defining the optimum temperature, pressure, and time.

This test method demonstrated the importance of temperature, pressure, and time to produce the maximum capacity of waste EPS. Therefore, the TRC material has not reached its maximum capacity yet to be maximised.

The range of compressive strength obtained from the compressive test under defined conditions of temperature, pressure, and time is between 18-93 MPa. The range of modulus of elasticity under defined conditions of temperature, pressure, and time is between 0.6-2.3 GPa Figure 12 (b). These results depend on waste EPS densities. When the densities of EPS increase the compressive strength and modulus of elasticity increase. Thus, can say there is a relationship between compressive and modulus of elasticity with different EPS densities Figure 12 (b).

The relationship between density and compressive strength of concrete suggests that as densities of concrete increases, the compressive strength would increase. It is demonstrated the critical role of densities in compressive strength. Further, it has a significant performance with an increase in compressive strength performance of 13%, 15%, 35%, and 44% in each specimen. The density was improved by 1.3%, 2%, 1.4%, and 1.3% in each specimen (Kaiyin Zhao 2021). Thus, can conclude the importance of densities on compressive strength of concrete. This shows that not only waste EPS gained strength by increasing the densities but also the concrete behaves the same way as waste EPS.

Further investigation into the relationship between the density and compressive strength of hardened concrete suggested that the mechanical properties of concrete are highly influenced by its density. As can increase the density of concrete can result in high performance and high compressive strength with fewer voids and porosity. The increase in density of hardened concrete can increase the compressive strength of concrete and minimum voids and absorption capacity reduce water permeability of concrete (Iffat 2015). Thus, can say there is a significant relationship between compressive strength and density in hardened concrete in the same way as is demonstrated in this study. The increased density of waste EPS would increase the compressive strength in the same way that other material behaves such as hardened concrete, fibre-reinforced concrete, and lightweight fibre-reinforced foamed concrete.



(a) Compressive stress vs strain (b) Compressive properties vs density

Figure 12: Variation of compressive properties with the densities of waste EPS

4.4 Conclusions

In this chapter, a detailed analysis and discussion of the mechanical properties of waste EPS with various densities has been investigated. The experimental data has been analysed and plotted for each density according to relevant Standards. A series of equations has been used to demonstrate the relationship between mechanical properties and relevant density of waste EPS following relevant Standards. It was observed that the mechanical performance of waste EPS linearly increased when increases the density of waste EPS. It is demonstrated by utilising the test data for tensile, flexural, and compressive tests. It is noted that the 600 kg/m³ does not perform well in comparison to other densities. The 600 kg/m³ densities were supplied by Toowoomba Regional Council without going through the procedure outlined in this research. As a result, the 600 kg/m³ densities were noted to achieve the maximum capacity of waste EPS. The execution of the procedure and adoption of the correct temperature, pressure and time are critical to achieving the maximum capacity of waste EPS. It highlights distinct mechanical strengths tied to different densities showcasing the importance of tailored manufacturing for enhanced performance and sustainable EPS utilisation. Finally, the observation agrees with the basic principle of other materials such as hardened concrete, fibre-reinforced concrete, and lightweight fibre-reinforced foamed concrete.

Chapter 5 Conclusions and Future Recommendations

5.1 Summary

The concern is that increased worldwide attention to waste EPS, has limited use for recycling. Thus, the landfill burying cost of waste EPS is estimated between $80-$220 per tonne. The challenge is that waste EPS is accumulating in Australia due to new export bans. Moreover, waste EPS have limited research regarding mechanical properties and has limited contribution to the circular economy. However, in this research, it is observed that waste EPS can be recycled with high performance in strength. It is suggested that this material can produce high-strength properties by manipulation of densities. Thus, illustrated that there is a significant relationship between mechanical properties and waste EPS densities.

5.2 Major Conclusion of the Research Project

This research project has been focused on the effect of different waste EPS densities on the mechanical properties of waste EPS and the following conclusion can be drawn:

- Increased performance and durability. It illustrated in the experimental investigation that waste EPS can have various mechanical properties and performance under different densities. It is suggested as increases the waste EPS density, it increases the mechanical strength and performance.
- Improve and maintain environmental sustainability. It shows in this research project that waste EPS can be a sustainable building material and hence has a wide range of applications. For instance, this material can be used for construction applications such as the construction of site offices, the backbone of solar panels, temporary houses, bridge handrails, kitchen benches, bathroom tails, construction bricks and many more applications.

This experiment demonstrates the importance of defined parameters such as temperature, pressure, and time in waste EPS to obtain the maximum capacity. The experiment proves that as one can increase the density of waste EPS can increase the mechanical strength of waste EPS. It is proven in the laboratory experiments undertaken tensile, flexural, and compressive tests to determine the mechanical strength of waste EPS under different densities. It shows the critical role of parameters in achieving the maximum capacity of waste EPS.

In the tensile, flexural, and compressive strength tests it is demonstrated as the density increases, the strength increases. One can say the relationship of strength and density forms a linear relationship under the defined parameters. Thus, can be proven that as density increases the stiffness of waste EPS can increase.

Therefore, the waste EPS under defined parameters can reach its maximum capacity and provide high-quality performance. On the other hand, the raw material that was not under defined control of temperature, pressure, and time demonstrated that it would not perform well and couldn't reach its maximum capacity. For instance. The 600 kg/m^3 density provided by the Toowoomba regional council showed that when chopped, heated, and extruded waste EPS can achieve its maximum capacity. The 600 kg/m^3 shows less strength in comparison to other densities in this experiment due to a lack of procedure and not controlling the parameters. Thus, can say that the waste EPS under the procedure outlined in this project can make waste EPS reach its maximum capacity and high-quality performance.

5.3 Possible Area for Future Research

It is recommended to further validate these defined parameters to build a 1:1 scale prototype and experiment with the mechanical strength of waste EPS. The study of environmental effects and fire resistance is yet to be studied in further stages of the project to fully validate this material for use in the construction and commercialisation phase. The consumption of energy to produce each density and its effect on climate change are yet to be studied in further research to fully be aware of this novel material. The life cycle and cost-benefit analysis of waste EPS are yet to be studied for further validation and better understanding to improve environmental sustainability and contribute to the circular economy.

Appendix A

1. *Students who wish to undertake a project from the faculty "Offer" of Topics, complete section A and B only.*
2. *Students who wish to undertake an "Own Project" (eg.one proposed by yourself or your employer) complete sections A and C only.*

PART A

Full Name: MURTAZA AZIZ AHMAD

Student Number: [redacted]

Program: Bachelor of Engineering Honours

Proposed study mode for your project work: ONC

Major: CIVIL ENGINEERING

PART B (FACULTY OFFER PROJECT PROPOSAL ONLY)

PROJECT PREFERENCES:

1st Preference: Design and production of 'waste' polystyrene and mixed plastics materials

for habitat applications

Proposed Supervisor: Dr Wahid Ferdous

Expanded Polystyrene (EPS) is one of the most important plastics utilised worldwide. The most common form that we see is in the form of Styrofoam. It has a similar structure to polyethene and is transformed from polymerised styrene. It compromises 98% Air and 2% polystyrene. It is utilised in various applications worldwide such as automotive, electronics, food services, insulation, water desalination, land conservation, flood prevention, medical, packaging, and other uses. The concern is that increased worldwide attention to waste polystyrene and mixed waste have very limited uses for recycling. The amount of utilising these products and constantly growing products has increased solid plastic usage worldwide.

The purpose of this paper is to prove that waste-expanded polystyrene (EPS) has sufficient mechanical strength to build houses for habitat people in Toowoomba. Based on the literature review there is no paper published showing the effect of EPS density on the mechanical strength of EPS. This paper will demonstrate the effect of the different EPS density on the mechanical properties of the EPS. Analysis and evaluated the different densities of EPS and showing the significance of each EPS density on the mechanical strength of the EPS. Will be using the waste EPS with different densities from 10-1000 kg/m^3.

Undertaken the laboratory experiment for densities of 200, 400, 600, 800, and 1000 kg/m^3 with five samples each, per each mechanical testing such as heat press, tensile testing, compression testing, flexural testing, and impact testing following Australian Standards for the mechanical testing.

For the completion of this project, certain resources will be required to ensure the success of the project. In terms of investment time for the completion of this project, it is estimated that students are required to spend approximately 350 hours on the entire project which will be accomplished within 35 weeks. This project is planned for the research to be carried out in 5 phases. The Grant Chart was developed to track the process of work required to complete the project within 35 weeks. Followed by the risk assessment in place to analyse and evaluate the risks associated with this project. To ensure the quality and accuracy of this research various measurements and checks will be implemented to accomplish this project.

Appendix B

ENG4111/4112 Research Project

Project Specification

For: Murtaza Aziz Ahmad

Title: Investigation of the effect of the different waste Expanded Polystyrene (EPS) densities on the mechanical properties of the EPS.

Major: Civil Engineering

Supervisors: Dr. Wahid Ferdous

Enrollment: ENG4111 – ONC S1, 2023

ENG4112 – ONC S2, 2023

Project Aim: This project investigates the effect of different densities of Expanded Polystyrene (EPS) on its mechanical properties under varying temperatures, pressure, and time conditions. The goal is to identify the optimal densities of EPS that can provide sufficient mechanical strength and recommendations for suitable application.

Programmed: Version 2, 5th April 2023

1. Research background information related to Expanded Polystyrene (EPS) by identifying the appropriate parameter such as temperature, pressure, and time.
2. Design and construct a suitable mould to manipulate EPS at various densities.
3. Design an experimental measurement method to identify the optimal temperature, pressure, and time associated with different EPS densities.
4. Analyse the experimental data and present it in the required report format.
5. Analyse the experimental data and identify the critical parameter that affect the mechanical strength of EPS at different densities.
6. Evaluate different EPS densities using temperature, pressure, and time and their associated applications.
7. Analyse and evaluate the effect of different EPS densities on mechanical strength and capabilities.

If time and resources permit:

8. Research the mechanical behaviour of EPS in combination with other materials.
9. Design a prototype at an appropriate scale.

Project Planning

Resource Requirements

For the completion of this project, certain resources will be required to ensure its success. The primary resource required will be investment of time. Materials, such as waste EPS, are required to produce samples and then test each sample according to Australian standards. The secondary resources required include a sufficient budget for the completion of the project. The construction of an aluminium mould for the heat press requires enough money for the materials and manufacturing process. Additionally, the cutting process required to produce the samples to the ideal shape as required by the standards also incurs costs.

In terms of time investment, it is estimated that the student will need to spend approximately 350 hours over the entire 35-week project period. This time will be allocated to the different phases of the project, from phase 1 to phase 5. It is critical that the student spends a good amount of time planning, reviewing, experimenting, and writing dissertation reports. Communication with the direct supervisor and stakeholders is necessary and plays an important role in the success of the project. Effective feedback from the direct supervisor and listening to stakeholders will be critical for the success of the project.

The resources such as a computer and software are also required for the project. The use of a computer is essential for the project for the computation and analysis of data. Microsoft Office is required for writing reports and computing data. It is recommended to use MATLAB and other powerful software for lengthy and complex data analysis.

Project Schedule

Table 7: Phase break down by task.

Phase 1	**Project Preparation Phase**
1A	Project commencement approval: Obtain official approval to commence the project.
1B	Collecting waste EPS to produce the required samples. This can be achieved by communicating with providers and stakeholders, such as collecting waste EPS from Grand Central and Toowoomba Regional Council.
1C	Designing the aluminium mould for the heat press to manipulate the various EPS densities for the required task, such as 200, 400, 600, 800, 1000 kg/m^3 required for testing.
1D	Producing bulk sample sheets from each density mentioned in 1C.
1E	Finalising the project resources and budget for the completion of the project.
Phase 2	**Preparation of samples**
2A	Calculation of each sample's dimensions according to the Australian Standards for mechanical testing.

2B	Sending sample sheets to the workshop to cut the shape and size based on the calculation of 3A.
2C	Preparation and labelling of each sample for the mechanical testing.
Phase 3	**Undertaken laboratory experiments**
3A	Testing the mechanical strength of EPS with a density of 200 kg/m^3.
3B	Testing the mechanical strength of EPS with a density of 400 kg/m^3.
3C	Testing the mechanical strength of EPS with a density of 600 kg/m^3.
3D	Testing the mechanical strength of EPS with a density of 800 kg/m^3.
3E	Testing the mechanical strength of EPS with a density of 1000 kg/m^3.
Phase 4	**Manipulation and analysis of test results**
4A	Evaluating and analysing data for EPS with a density of 200 kg/m^3.
4B	Evaluating and analysing data for EPS with a density of 400 kg/m^3.
4C	Evaluating and analysing data for EPS with a density of 600 kg/m^3.
4D	Evaluating and analysing data for EPS with a density of 800 kg/m^3.
4E	Evaluating and analysing data for EPS with a density of 1000 kg/m^3.
4F	Comparison and identification of the optimum EPS density
Phase 5	**Dissertation report**
5A	Write a draft dissertation and submit it for supervisor review and feedback.
5B	Attend the ENG4903 conference to present current results, analysis, and outcomes.
5C	Write the final dissertation after applying the supervisor's feedback and submit it for final marking.

Activity	Week																																		
	Week Commence 26 February 2023																																		
	Semester 1															Exams/Break				Semester 2															
Phase 1 - Project preparation	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	35
1A																																			
1B																																			
1C																																			
1D																		Normal working flow throughout the project																	
1E															Extension in case of sickness and unexpected circumstances																				
Phase 2 - Sample & Experiment																																			
2A																																			
2B																																			
2C																																			
Phase 3 - Experimental result analysis																																			
3A																																			
3B																																			
3C																																			
3D																																			
3E																																			
Phase 4 - Parameter investigation																																			
4A																																			
4B																																			
4C																																			
4D																																			
4E																																			
4F																																			
Phase 5 - Dissertation report																																			
5A																																			
5B																																			
5C																																			

Quality assurance

To ensure the quality and accuracy of this research, various measurements and checks will be implemented, including:

I. Checking all samples prior to the experiment to ensure their purity and freedom from other materials such as different types of plastics, dust, or outsider material. This ensures that the materials are pure or within acceptable limits.
II. Ensuring that the mechanical strength test follows the Australian Standard, which includes the right dimensions and size of samples with acceptable loads and forces.
III. Using five samples from each density and producing an average result to minimize the accuracy results that might occur during the experiments.
IV. Carefully computing and analysing all result data to avoid misinterpreting the results data. Comparing experiment data and benchmarking to ensure that the results are within acceptable limits.
V. Providing sufficient time for the analysis of results data to ensure the data's accuracy. In case of inaccuracy, repeating the experiment for the respective sample. This process will provide more accurate results.
VI. Recording all data and experiment processes, regardless of the success or failure's nature. Working on a draft paper by dividing it into smaller tasks ensures that the final dissertation report will be accurate and have more achievable results.

Risk Assessment

The risk assessment template will be used to assess the risks associated with the project timeline. This risk assessment will identify the probability and severity of risks based on each phase of the project. The project risk assessment will be used to identify the risks and consequences associated with the project and how to minimize them.

Table 8: Risk Assessment Matrix

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Table 9: Risk Assessment Template

Risk Level	Phase	Hazard	Minimisation
E4: Low	1B	Unable to collect waste EPS from stakeholders and providers.	Communication with providers and stakeholders and arrange a meeting to ensure you receive waste EPS materials on time.
E2: Medium	1C	Unable to finish the mould design online and manufacture the mould.	Plan and design the mould in advance and communicate with the workshop or manufacturer to provide you with the mould on time.
D3: Medium	2B	Unable to cut samples in the right size and deliver on time.	Provide a clear communication channel with the workshop regarding the sample size, shape, and delivery time.
E3: Medium	2C	Not given sufficient time for the preparation of samples.	Given enough time for the preparation of each sample and make sure each sample has a name and date on it.
D2: Medium	3A	Not following the correct procedure for mechanical testing.	Ensure to follow the correct procedure for mechanical testing and always wear PPE during the experiments.
D2: Medium	4A	Not given enough time to analyse data will affect the results.	Provide sufficient time to analyse data and make sure the computation and calculation are correct by double-checking the work.
C2: Serious	5A & 5C	Loss of work data and not able to have a backup.	Make sure to regularly update your work data by using online data storage such as iCloud. Make sure you save several copies of your work onto different hard drives. Make sure you update your data every week.

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