Pertanika J. Sci. & Technol. 32 (1): 143 - 159 (2024)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

The Mechanical Performance of Polymer Concrete Incorporating Waste Tin Fibres

Hosseinkhah Ashkan[1], Shuhairy Norhisham[1], Mohd Supian Abu Bakar[2], Agusril Syamsir[1,2]*, Mohammed Jalal Abdullah[1], Muhammad Rizal Muhammad Asyraf[3], Maiyozi Chairi[4], Mutiara Yetrina[4], Jihan Melasari[4] and Muhammad Farid[4]

[1]*Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional, Jalan IKRAM - UNITEN, 43000 Kajang, Selangor, Malaysia*
[2]*Institute of Energy Infrastructure, Universiti Tenaga Nasional, Jalan IKRAM - UNITEN, 43000 Kajang, Selangor, Malaysia*
[3]*Centre for Advanced Composite Materials (CACM), Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru, Johor, Malaysia*
[4]*Faculty of Engineering, Universitas Putra Indonesia YPTK, Padang, Indonesia*

ABSTRACT

Concrete is the most widely used construction material in the world. It is now possible to construct structures out of concrete because this durable compound that consists of water, aggregate, and Portland cement not only gives us many scopes of design but also has a very high compressive strength at a low cost. This paper deals with alternative materials for the most common construction material, cement-based concrete and polymer concrete (PC), containing waste tin fibres. The study covers the fabrication of polymer concrete and the execution of three tests: compressive strength, flexural tensile, and splitting tensile. Tests were conducted to determine the mechanical properties of the PC, and the results were analysed and evaluated on several PC specimens with different ratios of waste tin fibre. The results showed that using waste tin as fibre reinforcement in PC would substantially enhance the overall mechanical performance. Specifically, the optimum amount of waste tin as reinforcement in PC was 0.16% for compressive and splitting tensile strengths, while 0.20% was the optimum fibre loading for the flexural tensile strength. In this case, a positive outcome

ARTICLE INFO

Article history:
Received: 31 December 2022
Accepted: 20 July 2023
Published: 24 November 2023

DOI: https://doi.org/10.47836/pjst.32.1.09

E-mail addresses:
ashkan_hosseinkhah@yahoo.de (Hosseinkhah Ashkan)
Shuhairy@uniten.edu.my (Shuhairy Norhisham)
mohdsupian7779@gmail.com (Mohd Supian Abu Bakar)
Agusril@uniten.edu.my (Agusril Syamsir)
eng.mj96@hotmail.com (Mohammed Jalal Abdullah)
muhammadasyraf.mr@utm.my (Muhammad Rizal Muhammad Asyraf)
maiyozzi@upiyptk.ac.id (Maiyozi Chairi)
mutiarayetrina@upiyptk.ac.id (Mutiara Yetrina)
jihan_melasari@upiyptk.ac.id (Jihan Melasari)
farid2500@gmail.com (Muhammad Farid)
* Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

was found at a constant resin-to-filler ratio of 40:60 by volume and a matrix-to-aggregate ratio of 1:1.35 by weight.

Keywords: Compressive strength, flexural tensile strength, polymer concrete, splitting tensile strength, waste tin

INTRODUCTION

Polymer concrete is a composite material of polymeric resins that serve as binder materials for aggregates and micro fillers, resulting in a hardened composite when catalysts and accelerators are added. A polymer resin must be used for concrete to be poured, trowelled, and subsequently cured. The most common polymer resins used in concrete are polyester, vinyl ester, and ordinary epoxy (Afroughsabet & Ozbakkaloglu, 2015; Ahmadi et al., 2021; Martínez & López et al., 2021; Muda, Kamal et al., 2016; Oyebisi et al., 2020; Supian et al., 2016). The polymer material causes a chemical reaction that leads to hardening and curing. Using different resins leads to different benefits, e.g., acrylic binders set very quickly and thus lead to higher weathering resistance, while epoxies create a very strong material that shrinks very little as it cures. It must be considered that the mixing of polymer concrete should be done very precisely and very thoroughly (Al-Nini et al., 2020; Ismail et al., 2022; Reddy & Santhosha, 2018; Yan et al., 2016; Zabihi et al., 2017). It cannot be mixed beforehand and kept turning (to avoid curing like cement-based concrete). The chemical reaction happens as soon as the mixture begins (Mohamad, 2014; Supian et al., 2018).

Research has shown that polymer concrete, compared to cement-based concrete, is stronger, more durable, and has lower maintenance requirements (Afroughsabet & Ozbakkaloglu, 2015; Kamal et al., 2019; Martínez-López et al., 2021; Muda, Alam et al., 2016; Parikh & Modhera, 2012; Reddy & Santhosha, 2018). Polymer concrete's mechanical strength can reach four to five times higher than cement-based concrete. Furthermore, it has a high resistance against chemicals and corrosive agents, resistance to frost, good abrasion, fast curing times, excellent durability, and water permeability (ACI 318-11, 2011). Therefore, polymer concrete is widely used in civil engineering applications, such as underground pipes, trench lines, overlays of bridges, building and highway repairs, and swimming pools (Ali & Ansari, 2013). Nevertheless, producing polymer concrete requires attention during the casting process and to curing temperature, composition, and selecting resins and additional particles carefully. Furthermore, because PC is about 5–10 times more expensive than regular concrete, its use is now confined to constructions where the increased cost justifies the improved performance.

Polymer concrete is composed of various aspects, including the type and amount of resin and filler, curing process, curing temperature, humidity, and matrix-to-aggregate ratio (Atiqah et al., 2021; Esfahani et al., 2016; Frigione, 2013; Kumlutaş et al., 2003; Mohamad et al., 2022; Sakai et al., 2005; Sosoi et al., 2018; Vaggar et al., 2021). Various studies have shown that unsaturated polyester (UP) resin is a good mix of mechanical, electrical, and chemical properties that enhance splitting tensile and flexural strength by a maximum of 30% and a minimum of 20% compared to Portland cement concrete. It is also used as a cement substitute in 20%, 25%, and 30% concentrations (Gao et al., 2019; Hashemi et al., 2018; Yeon et al., 2020). Meanwhile, the studies by Bulut and Şahin (2017) and Hameed and Hamza (2019) investigated the mechanical and physical properties of polymer concrete using waste components and natural and river sand, revealing that increasing the amount of polymer resin in the compressive strength test increased its strength. A mixture of 70% ceramic waste and 30% polyester resin gave a maximum strength of 132 MPa, while a mixture of 80% concrete waste and 20% plastic resin gave a minimum strength of 28 MPa. The increasing polymer resin also enhances the concrete's splitting tensile strength and flexural strength.

Furthermore, the study by Sosoi et al. (2018) on the workability of both substitution mixes of fresh concrete improved when the PET quantity was raised and decreased as the sawdust amount was increased. Besides, the results showed that the chipped PET as a replacement had a greater compressive strength value than sawdust blends, with 25-50% sawdust and 50% and 75% chopped PET being the most common results. Polymer concrete with waste substitution developed fractures gradually until they were destroyed. Otherwise, the study by Niaki et al. (2018) has defined basalt fibre-reinforced polymer concrete (BFRPC) and examined the effect of temperature on the mechanical properties of a polymer concrete sample with 2% basalt fibre and one without basalt fibre, which was subjected to compressive, three-point bending, and splitting tensile tests. Based on the results, plain PC has a lower residual strength than basalt fibre polymer concrete at elevated temperatures.

Besides, many studies have conducted various works on waste material as filler material in PC (Hameed & Hamza, 2019; Sonebi et al., 2022), waste materials such as waste glass (Ramadan et al., 2023; Saribiyik et al., 2013), electronic plastic waste (Bulut & Şahin, 2017) and PET bottle (Asdollah-Tabar et al., 2021), which is used as a reinforcement material in polymer composites.

Hence, this research paper presents an innovative investigation of the mechanical performance of polymer concrete using wasted tin fibres. The study intends to analyse the impact of these common fibres on improving the mechanical properties of polymer concrete by investigating their utilisation. Using scrap tin fibres in this context is a distinctive and creative strategy that advances the growing areas of sustainable building materials and waste utilisation. The results of this study will provide important information for potential advances in composite materials, and sustainable engineering practises by providing insight into the feasibility and possible advantages of incorporating scrap tin fibres into polymer concrete. At the end of this research, potential applications and insights into waste tin fibre-reinforced polymer concrete were highlighted and recommended.

METHODOLOGY

Materials

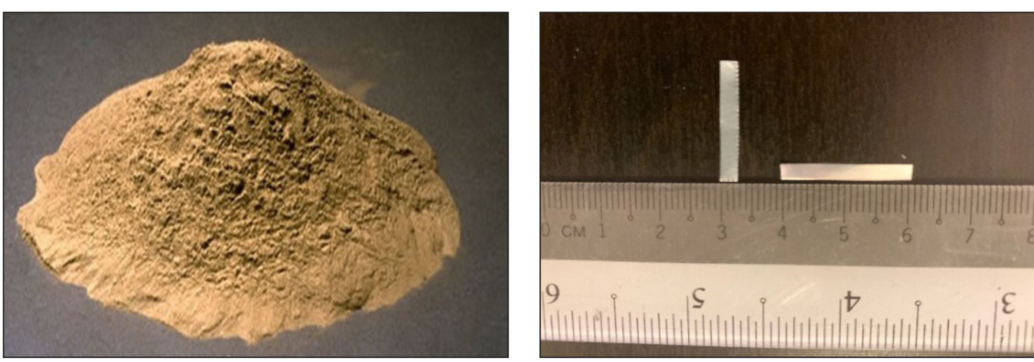
Polymer concrete (PC) is a composite that uses liquid resins as a binder instead of the traditional cement-hydrate binders found in ordinary concrete. Resin, hardener, fly ash, aggregates, and scrap tin fibre are all used to make polymer concrete.

Resin and Hardener. An unsaturated polyester resin, Reversol P 9509, was combined with PC samples to create a stiff and low-reactive composition. Unsaturated polyester resin is less expensive and more commercially accessible than epoxy resin and has superior mechanical and chemical properties. Meanwhile, the hardener, combined with the resin, creates a chemical reaction that changes from a liquid to a solid state. Therefore, it is also called a catalyst that causes the transformation, referred to as "curing" or "polymerisation." As shown in Table 1, the chemical hardener used with polyester resin is called Methyl Ethyl Ketone Peroxide (http://kawamia.com/files/Mepoxe_new.pdf). The specifications and properties of the resin are shown in Table 1.

Table 1
Polyester resin properties of Reversol P 9509 (Luxchem, 2018)

Specifications of Reversol P 9509	
Appearances	Hazy, pinkish
Non-volatile, %	56–59
Viscosity @ 25ºC, cps - Brookfield, #3/60 - Brookfield. #3/6	 450–600 900–1350
Thixotropic index	1.5–2.8
Gel time @ 25ºC, mixture - 1% MEKP	18–23
Acid value, mgKOH/g Solid resin	29–34
Typical properties	
Specific gravity	1.12
Volumetric shrinkage, %	8

Fly Ash. Fly ash is a fine powder that is a by-product of burning pulverised coal in electric power plants (Figure 1a). Mixing fly ash with resin forms a compound similar to Portland cement, which makes fly ash a prime material in PC. Fly ash can be used as a replacement for river sand and as a fine



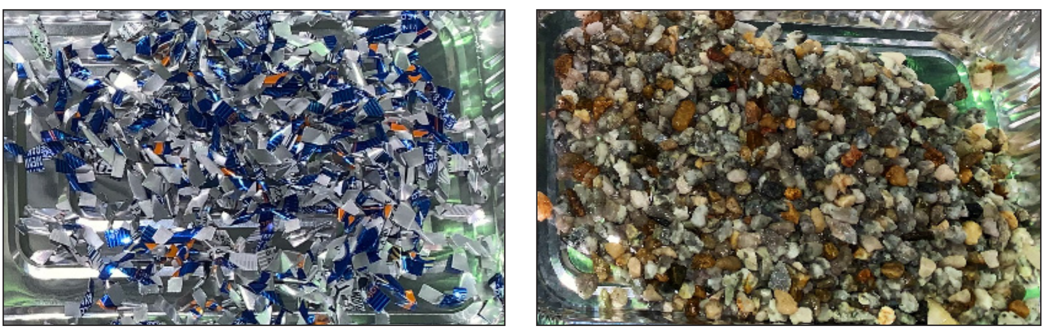
(a) (b)

Figure 1. (a) Sample of fly ash; and (b) Sample of 5 mm aggregates

aggregate material. There are two different classes of fly ash: class C and class F. This study used class C fly ash, which generally has a high calcium ratio.

Aggregates. Coarse aggregates were sieved, and only aggregates with a size of 5 mm were separated and used for the mixture (Figure 1b). This size of aggregates guarantees a low void and an equal distribution of the aggregates while leaving enough space for the waste in fibre. In order to achieve good bond strength between the polymer binder and the aggregates, they should be free of dust and debris, clean, and dry.

Waste Tin Fibre. Aluminium cans were cut into 20 mm × 3 mm strips and twisted spirally to reinforce and to produce a sustainable product. This size ensures the resin fully covers the tin fibres while well distributed between the aggregate gaps (Figures 2a and 2b).



(a) (b)

Figure 2. (a) Sample of cut waste tin fibre; and (b) Sample of twisted tin fibre

Mixture Composition

Based on previous research, mainly referred to by Ferdous et al. (2016), where the effect of resin-to-filler ratio and matrix-to-aggregate ratio on mechanical and durability properties was investigated, the optimum resin-to-filler ratio of 60:40 and the optimum matrix-to-aggregate ratio of 1:1.35 were chosen for the preparation of polymer concrete. These ratios ensure a uniform distribution of aggregates and are highly recommended to balance mechanical performance and cost. This study used a volume ratio 60:40:135 for resin/hardener, fly ash, and coarse aggregates. Additionally, to increase the mechanical properties, waste tin fibre with percentages of 0%, 0.12%, 0.16%, and 0.2% was added to the polymer concrete composite as reinforcement.

Basically, from the volume of the cylindrical and prismatic moulds, the density of the materials, and the ratio given, the mass of each material for the different specimens was calculated. The amount of hardener used depends on the mass of the resin. Finally, waste tin fibre was calculated based on the percentage used and the mould volume. Table 2 shows the calculation for each material used.

Table 2
Total material amount for each sample

Mixes	Tin Fibre ratio (%)	Aggregate (kg/m^3)	Resin (kg/m^3)	Filler (kg/m^3)	Waste Tin Fibre (kg/m^3)
SP0	0	2929	1095	2006	2700
SP12	0.12	2929	1095	2006	2700
SP16	0.16	2929	1095	2006	2700
SP20	0.2	2929	1095	2006	2700

Specimen Preparation

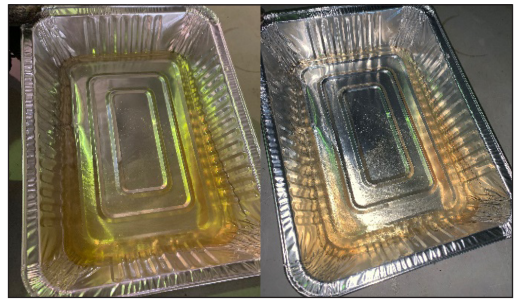
Thirty-six specimens were prepared and subjected to three tests To investigate the mechanical properties of polymer concrete containing waste tin fibre: the compressive strength test, the splitting tensile test, and the flexural tensile test. Twelve (12) cylindrical samples with a diameter of 50 mm and a height of 100 mm were cast in PVC pipes (Figure 3). The flexural strength test requires 12 prismatic samples from 25 mm and 250 mm, while the sieving of coarse aggregates with a maximum size of 5 mm was used to create a mixture that guarantees a low void and an equal distribution of the aggregates while leaving enough space for the waste gin fibre. Polymer concrete composite was cut into 3 mm × 20 mm stripes and added to the polymer concrete composite at different percentages (0%, 0.12%, 0.16%, and 0.25%). A constant ratio of resin, aggregate, and fly ash was tested three times, requiring 12 specimens for each test.

The composite mixing began with polyester resin with hardener at a resin-to-hardener weight ratio of 100:32. The exact amount and weight of the materials for each specimen were calculated (Table 2). The mixture was then poured over the aggregates and mixed for three minutes until the amount of waste tin fibre strips were added and stirred for another minute until a brownish, viscous, and homogeneous mixture was observed. The aggregates must be of good quality, free of dust and other debris, and dry, and the materials must be soaked in polymer.

The mixture was poured into the moulds in two to three layers and was subjected to vibration for two minutes after each layer. The samples were demoulded 24 hours later and cured at room temperature. Due to the closure of the laboratory caused by the pandemic in 2020 and because polymer

Figure 3. Example of cylindrical and prismatic mould

concrete reached 90% of its 28-day strength in only seven days, the specimens were tested after seven days of curing. Due to the small specimens used in this study, all mixing was done by hand. All steps are previewed in Figure 4, which is the production procedure for the specimens for this study.



(a)

(b)

(c)

Figure 4. Fabrication process of PC specimens: (a) Mixing process – Resin and hardener; (b) Mixing process – Resin mixture with fly ash and aggregates; and (c) Demoulded cylindrical and prismatic specimens

Experimental Design

All tests were done in the laboratory at Universiti Tenaga Nasional with the specific standards of compression strength, flexural tensile, and splitting tensile tests.

Compressive Strength Test. The compressive strength test is the most popular test performed on concrete, as it gives a general idea of the characteristics of concrete (Figure 5). Based on the test, the use of the concrete can be determined. The ASTM C39/C39M-01 (2001) was used in this study. After a curing period of seven days, the polymer concrete specimens were tested by the compression testing machine. The cylindrical specimens were placed vertically in the appropriate locations in the test machine. The specimens were aligned centrally on the base plate of the

Figure 5. Compressive strength test

machine. The movable part of the machine touches the specimen's top surface, and the load is applied to the face perpendicular to the casting direction. A 0.4 N/mm^2/sec load was applied gradually until the specimen failed. It must be secured to avoid the load from being applied with shock. Three specimens for each ratio of waste tin fibre (a total of 12 specimens) were tested, and the maximum load of each implementation was recorded. Meanwhile, the Fck (N/mm^2) is the characteristic compressive strength of each grade of concrete. The average of the maximum load of the specimens (N) divided by the area of the specimen under load (mm^2) will give this value in Equation 1.

$$Compressive\ Strength = \frac{Load}{Cross - Section\ Area} \tag{1}$$

Flexural Tensile Test. The flexural test was a method to evaluate concrete's tensile strength indirectly. Thereby, unreinforced concrete's ability to withstand bending failure was tested. The modulus of concrete rupture was the result gained through the flexural test. There were two ways to conduct the flexural test: the three-point load test (ASTM C78/C78M-18, 2016) or the centre point load test (ASTM C293/C293M-16, 2016). This study used ASTM C78/C78M-18 since the laboratory provides the three-point load test.

Specimens should be tested immediately after being taken out of the curing condition to prevent surface drying to avoid reducing flexural strength (Figure 6). The specimens were placed on two circular rollers manufactured of steel, which will support the specimen from the bottom left and bottom right sides. The length of the rollers was at least 10 mm longer than the width of the specimen. One other roller provided the load from the top side of the specimen. The specimen was placed in the machine correctly centred, with the longitudinal axis of the specimen orthogonal to the rollers. Any gap greater than 0.1 mm between the specimen and the rollers was eliminated. The load applied to the specimen had a rate of 0.2 MPa/s as per ASTM C78/C78M-18 and should not be applied with shock. The modulus of rupture was estimated using the following Equation 2:

$$MR = \frac{3PL}{2bd^2} \tag{2}$$

where, MR: modulus of rupture, P: ultimate applied load indicated by testing machine, L: span length, b: average width of the specimen, d: average depth of the specimen.

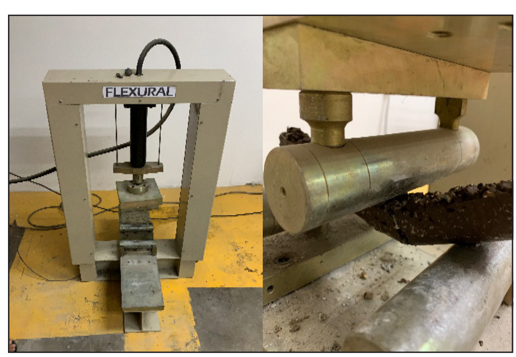


Figure 6. Flexural strength test

Splitting Tensile Test. Due to its brittle nature, concrete is weak when it comes to tensile force. When the tensile forces exceed the concrete's tensile strength, it develops cracks. Therefore, it is necessary to determine the load at which the concrete may crack. In order to achieve this information, the splitting tensile test was implemented after the 7-day curing period. Diametrical lines were drawn on the specimen's two ends to ensure they were on the same axial plane (Figure 7). The weight and dimension of the specimens were recorded, and the compression testing machine was set for the required range. The specimen was placed between two plates. The load will be applied continuously without shock at a 0.4 N/mm^2/sec rate from the upper plate until failure. The maximum load was noted at the end. The splitting tensile strength was calculated as in Equation 3:

$$\boldsymbol{T} = 2P/\pi LD \tag{3}$$

where, P = Maximum load, L = Length, D = Diameter

Figure 7. Splitting tensile test

RESULTS AND DISCUSSION

Experiments were carried out for 7 days to determine the axial compressive, flexural tensile, and splitting tensile strengths of the specimens of PC containing waste tin fibre in ratios of 0%, 0.12%, 0.16%, and 0.20%. Three specimens for each test and each ratio were produced. The experimental results were obtained through the testing machines and calculated with the designated formula for each test.

Compressive Strength Test

Twelve cylinders with a diameter of 50 mm and a length of 100 mm, containing different amounts of waste in fibre, were tested, and the results are in Table 3. The values of the maximum load that differ by more than 25% were initially ignored when evaluating the results (Table 4). Wrong results could be caused by possible errors occurring during the mixing procedure or by not perfectly compacting the mixture due to the small specimen size. From the other values, the average was calculated as the maximum load divided by the cross-sectional area. The samples with a 0.20% waste tin fibre ratio show the lowest compressive strength, 6.94 N/mm^2, while the highest compressive strength observed is 10.85 N/mm^2 and belongs to the samples with a 0.16% waste tin fibre ratio. Samples with 0.12% and 0% waste tin fibre show a compressive strength of 10.64 and 7.73, respectively (Figure 8).

The results show that the compressive strength of the PC in this study is low compared to other studies. The reason for that is the use of different resins. This study used polyester resin, unlike most studies that use epoxy resin. Epoxy resin is generally better than polyester resin due to its higher strength and greater shelf life. Epoxy resin is also odourless and non-flammable, which makes it safer. However, epoxy resin is more expensive and much harder to obtain. If it is possible to overcome these issues, it is recommended to use epoxy resin to produce PCs.

Table 3
Compressive test results for various sample ratios

No.	Sample	Length (mm)	Diameter (mm)	Area (mm^2)	Elastic modulus (MPa)	Stress (N/ mm^2)	Max. Load (kN)
1	SP0				3.95	0.09	1.45
2	SP0				3.94	0.07	1.10
3	SP0				2.11	0.09	1.42
4	SP12				2.96	0.13	1.99
5	SP12				1.94	0.13	2.11
6	SP12				1.92	0.14	2.17
7	SP16	100	50	15708	-	0.03	0.51
8	SP16				2.25	0.12	1.93
9	SP16				2.61	0.15	2.33
10	SP20				2.82	0.08	1.30
11	SP20				2.19	0.10	1.60
12	SP20				2.27	0.08	1.19

Table 4
Compressive strength test result of various tin fibre percentage

Samples	Compressive test			
	Tin fibre amount	Force in N	Average Force in N	F/A (N/mm^2)
		1450		
1	0 %	1100	1435	7.73
		1420		
		1990		
2	0.12 %	2110	2090	10.64
		2170		
		510		
3	0.16 %	1930	2130	10.85
		2330		
		1300		
4	0.20 %	1600	1363	6.94
		1190		

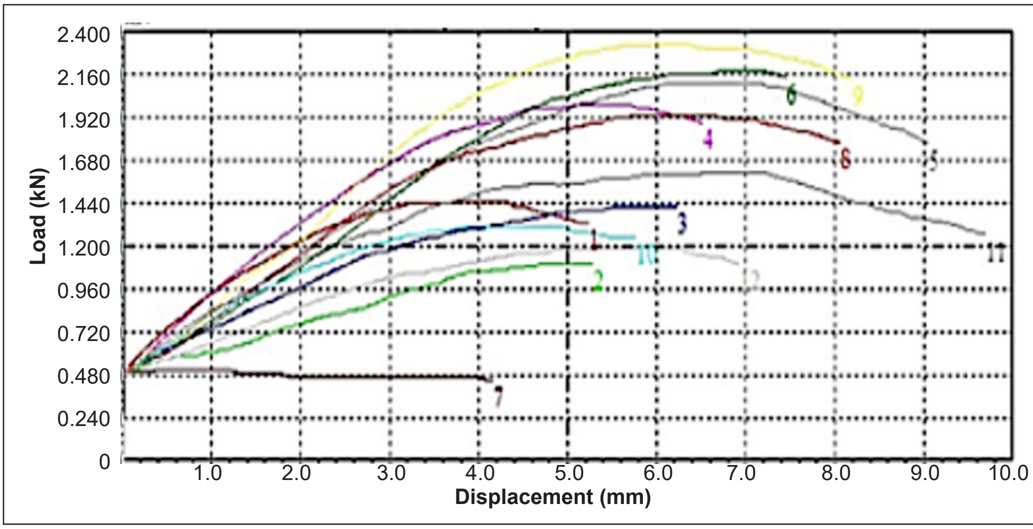


Figure 8. Compressive strength versus displacement of various sample ratios

Splitting Tensile Test

Table 5 shows the results of the splitting tensile test done on 12 cylindrical samples in the same way as the compressive test. Furthermore, values differing by more than 25% are not considered in the result evaluation. After analysing the results presented in Table 6, it was found that the highest splitting tensile strength of 295 N/mm^2 was obtained from the samples containing 0.16% of waste tin fibre, which also had the highest average maximum load. In descending order, the splitting tensile strengths are 271 N/mm^2 (SP12), 257 N/mm^2 (SP0), and 241 N/mm^2 for the samples with 0.2% of waste tin fibre (Figure 9).

Table 5
Splitting tensile test results for various sample ratios

No	Sample	Length (mm)	Diameter (mm)	Area (mm^2)	Elastic modulus (MPa)	Stress (N/mm^2)	Max. Load (kN)
1	SP0	100	50	15708	9.36	0.13	2.12
2	SP0				7.27	0.11	1.77
3	SP0				8.65	0.14	2.18
4	SP12				7.98	0.16	2.45
5	SP12				5.42	0.11	1.80
6	SP12				8.17	0.14	2.14
7	SP16				8.51	0.15	2.32
8	SP16				-	0.06	0.98
9	SP16				5.73	0.09	1.41
10	SP20				8.58	0.07	1.17
11	SP20				5.30	0.12	1.89
12	SP20				7.07	0.18	2.82

Table 6
Splitting tensile test results of various tin fibre percentage

Samples	**Splitting tensile**			
	Tin fibre amount	**Force in N**	**Average Force in N**	**T= 2P/π L D (N/mm²)**
		2120		
1	0%	1770	2023	257
		2180		
		2450		
2	0.12%	1800	2130	271
		2140		
		2320		
3	0.16%	980	2320	295
		1410		
		1170		
4	0.2%	1890	1890	241
		2820		

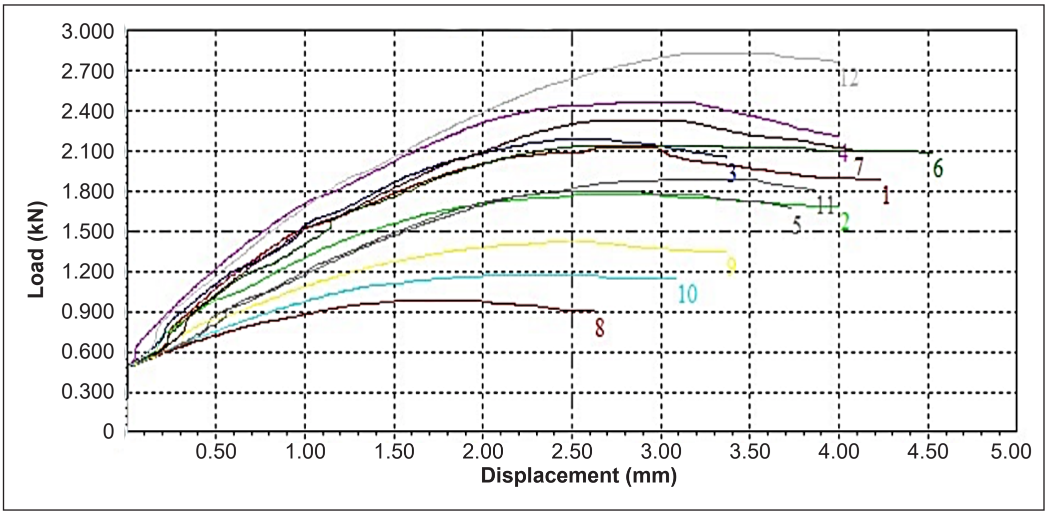


Figure 9. Splitting tensile strength versus displacement of various sample ratios

Compared to cement-based concrete, polymer concrete has a special characteristic: higher bending ability. The bending of the PC before failure causes very high flexural strength. This study shows that the flexural strength of PC is around two times higher than its splitting tensile strength. Increasing the waste tin fibre to a specific amount ensures the adherence between the resin and the tin fibres due to the resin filling the gaps in the desired way. However, increasing the waste tin ratio more than the specific amount decreases the adherence between the resins due to the even surface of aluminium, which leads to a decrement in the mechanical properties (Ferdous et al., 2016; Mohammed, 2018).

Flexural Tensile Test Results

For the flexural tensile test, 12 prismatic specimens with 25 mm × 25 mm × 250 mm were tested. For each sample listed in Table 7, the maximum load displayed on the testing device's panel was manually recorded (Figure 10). As shown in Table 8, the average maximum flexural tensile strength was determined from the test results and the flawed values were removed.

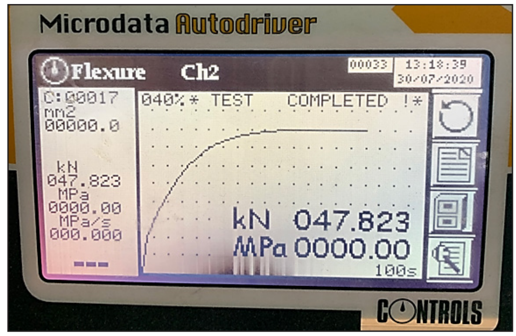


Figure 10. Flexural tensile machine (Microdata control flexure)

Table 7
Flexural tensile test results for various sample ratios

No.	Sample	Length (mm)	Depth (mm)	Width (mm)	Max. Load (kN)
1	SP0				7.98
2	SP0				24.52
3	SP0				36.17
4	SP12				32.22
5	SP12				20.83
6	SP12	250	25	25	20.74
7	SP16				25.59
8	SP16				23.51
9	SP16				24.44
10	SP20				51.61
11	SP20				42.82
12	SP20				47.82

Table 8
Flexural tensile test results for various sample ratios

Samples	Tin fibre amount	Flexural tensile test		
		Force in N	Average force in N	$\sigma_{f = 3FL/2bd^2}$ (N/mm²)
		7980		
1	0 %	24520	24520	588.48
		36170		
		32220		
2	0.12 %	20830	20785	498.84
		20740		
		25590		
3	0.16 %	23510	24510	588.24
		24440		
		51610		
4	0.20 %	42820	47416	1137.984
		47820		

PC's flexural and splitting tensile strengths are much higher than conventional Portland cement concrete (1.5-7 MPa) because of the better bonding characteristics between the matrix and aggregates. Also, using small aggregates (5 mm) leads to fewer voids in the composite, so the composite is denser and gains higher mechanical properties. These results are consistent with studies by Berrocal et al. (2018) and Pil et al. (2016).

CONCLUSION

This study demonstrates that employing waste tin fibre as reinforcement in PC enhances its overall mechanical qualities. The effect of waste tin fibre on the mechanical properties of concrete was determined; the ideal waste tin fibre ratio for mechanical performance is 0.16%, while the optimal ratio for flexural tensile strength is 0.20%. From the experimental results, the compressive strength improved by 40% and the split tensile strength improved by 15% when a 0.16% waste tin fibre ratio was employed instead of a 0% waste tin fibre ratio. Meanwhile, a 20% waste tin fibre ratio in concrete resulted in a significant 93% improvement in flexural tensile strength. As a result of the findings, it has been demonstrated through the performance of polymer concrete, including waste tin fibres, that adding polymer during the formation of polymer concrete improves the mechanical strength of concrete by altering its properties. In addition, it has been demonstrated that polymers have enhanced the mechanical characteristics of concrete, including increased compressive strength, splitting tensile strength, and flexural strength, as well as good performance in durability and the growth and decrease of landfill wastes.

ACKNOWLEDGEMENTS

The authors thank Universiti Tenaga Nasional (UNITEN), Malaysia, for supporting this research under BOLD 2022 through Project No: J510050002/2022004. A special thanks to those who contributed to this project directly or indirectly.

REFERENCES

ACI 318-11. (2011). *Building code requirements for structural concrete (ACI 318-11) and commentary*. American Concrete Institute. https://www.pecivilexam.com/Study_Documents/Struc-Materials-Online/ACI_318-Building-Code-2011.pdf

Afroughsabet, V., & Ozbakkaloglu, T. (2015). Mechanical and durability properties of high-strength concrete containing steel and polypropylene fibers. *Construction and Building Materials, 94*, 73-82. https://doi.org/10.1016/j.conbuildmat.2015.06.051

Ahmadi, M., Shafabakhsh, G. A., Di Mascio, P., & Hassani, A. (2021). Failure behavior of functionally graded roller compacted concrete pavement under mode I and III fracture. *Construction and Building Materials, 307*, Article 124942. https://doi.org/10.1016/j.conbuildmat.2021.124942

Al-Nini, A., Nikbakht, E., Syamsir, A., Shafiq, N., Mohammed, B. S., Al-Fakih, A., Al-Nini, W., & Amran, Y. H. M. (2020). Flexural behavior of double-skin steel tube beams filled with fiber-reinforced cementitious composite and strengthened with CFRP sheets. *Materials, 13*(14), Article 3064. https://doi.org/10.3390/ma13143064

Ali, A., & Ansari, A. A. (2013. April 12-13). Polymer concrete as innovative material for development of sustainable architecture. In *2nd International Conference on Emerging Trends in Engineering & Technology* (pp. 1-4). Teerthanker Mahaveer University, India. https://doi.org/10.13140/2.1.4761.5040

Asdollah-Tabar, M., Heidari-Rarani, M., & Aliha, M. R. M. (2021). The effect of recycled PET bottles on the fracture toughness of polymer concrete. *Composites Communications, 25*, Article 100684. https://doi.org/10.1016/j.coco.2021.100684

ASTM C39/C39M-01. (2001). *Standard test method for compressive strength of cylindrical concrete specimens*. ASTM International. https://normanray.files.wordpress.com/2010/10/kuliah-7b-beton-segar-astm-c39.pdf

ASTM C78/C78M-18. (2016). *Standard test method for flexural strength of concrete (using simple beam with third-point loading)*. ASTM International. https://www.scribd.com/document/426461328/ASTM-C78-Flexural-Strength-of-Concrete

ASTM C293/C293M-16. (2016). *Standard test method for flexural strength of concrete (using simple beam with center-point loading)*. ASTM International. https://webstore.ansi.org/standards/astm/astmc293c293m16

Atiqah, A., Ismail, N., Lim, K. K., Jalar, A., Bakar, M. A., Maleque, M. A., Ilyas, R. A., & Supian, A. B. M. (2021). Properties of recycled metal matrix composites. In R. A. Ilyas, S. M. Sapuan, & E. Bayraktar (Eds.), *Recycling of Plastics, Metals, and Their Composites* (pp. 93-108). CRC press. https://doi.org/https://doi.org/10.1201/9781003148760

Berrocal, C. G., Löfgren, I., & Lundgren, K. (2018). The effect of fibres on steel bar corrosion and flexural behaviour of corroded RC beams. *Engineering Structures, 163*, 409-425. https://doi.org/10.1016/j.engstruct.2018.02.068

Bulut, H. A., & Şahin, R. (2017). A study on mechanical properties of polymer concrete containing electronic plastic waste. *Composite Structures, 178*, 50-62. https://doi.org/10.1016/j.compstruct.2017.06.058

Esfahani, M. S., Janbaz, S., & Mirmazhari, S. (2016). Effect of various types of fillers on mechanical properties of concrete. *International Journal of Civil Engineering, Construction and Estate Management, 4*(3), 20-28.

Ferdous, W., Manalo, A., Aravinthan, T., & Erp, G. V. (2016). Properties of epoxy polymer concrete matrix: Effect of resin-to-filler ratio and determination of optimal mix for composite railway sleepers. *Construction and Building Materials, 124*, 287-300. https://doi.org/10.1016/j.conbuildmat.2016.07.111

Frigione, M. (2013). Concrete with polymers. In *Eco-Efficient Concrete* (pp. 386-436). Woodhead Publishing Limited. https://doi.org/10.1533/9780857098993.3.386

Gao, Y., romero, P., Zhang, H., Huang, M., & Lai, F. (2019). Unsaturated polyester resin concrete: A review. *Construction and Building Materials, 228*, Article 116709. https://doi.org/10.1016/j.conbuildmat.2019.116709

Hameed, A. M., & Hamza, M. T. (2019). Characteristics of polymer concrete produced from wasted construction materials. *Energy Procedia, 157*(2018), 43-50. https://doi.org/10.1016/j.egypro.2018.11.162

Hashemi, M. J., Jamshidi, M., & Aghdam, J. H. (2018). Investigating fracture mechanics and flexural properties of unsaturated polyester polymer concrete (UP-PC). *Construction and Building Materials, 163*, 767-775. https://doi.org/10.1016/j.conbuildmat.2017.12.115

Ismail, A. S., Jawaid, M., Hamid, N. H., Yahaya, R., Hassan, A., Asim, M., & Supian, A. B. M. (2022). Effect of curing temperature on mechanical properties of bio-phenolic/epoxy polymer blends. *Journal of Polymers and the Environment, 30*, 878-885. https://doi.org/10.1007/s10924-021-02244-w

Kamal, N. L. M., Beddu, S., Syamsir, A., Mohammad, D., Itam, Z., Hamid, Z. A. A., & Manan, T. S. A. (2019). Immobilization of heavy metals for building materials in the construction industry - An overview. *Materials Today: Proceedings, 17*, 787-791. https://doi.org/10.1016/j.matpr.2019.06.363

Kumlutaş, D., Tavman, I. H., & Turhan Çoban, M. (2003). Thermal conductivity of particle filled polyethylene composite materials. *Composites Science and Technology, 63*(1), 113-117. https://doi.org/10.1016/S0266-3538(02)00194-X

Luxchem, P. I. (2018). *Material Safety Data Sheet - Unsaturated Polyester Resins*. LUXCHEM. http://www.luxchem.com.my/img/pdf/reversol_resin.pdf

Martínez-López, M., Martínez-Barrera, G., Salgado-Delgado, R., & Gencel, O. (2021). Recycling polypropylene and polyethylene wastes in production of polyester based polymer mortars. *Construction and Building Materials, 274*, Article 121487. https://doi.org/10.1016/j.conbuildmat.2020.121487

Mohamad, N. J. (2014). *Timber Reinforcement in Reinforced Concrete Beam for Light Structure* (Doctoral dissertation). University Malaysia Pahang, Malaysia. https://core.ac.uk/download/pdf/159184667.pdf

Mohamad, N., Muthusamy, K., Embong, R., Kusbiantoro, A., Hashim, M. H., & Hanafi, M. (2022). Environmental impact of cement production and solutions : A review. *Materials Today: Proceedings, 48*, 741-746. https://doi.org/10.1016/j.matpr.2021.02.212

Mohammed, A. A. (2018). Mechanical strength of concrete with PVC aggregates. In *Use of Recycled Plastics in Eco-efficient Concrete* (pp. 115-135). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102676-2.00006-2

Muda, Z. C., Alam, M. A., Syamsir, A., Sulleman, S., Beddu, S., Mustapha, K. N., Thiruchelvam, S., Ismail, F. B., Usman, F., Kamal, N. L. M., Birima, A. H., Itam, Z., & Zaroog, O. S. (2016). The effect of thickness and mesh spacing on the impact resistance of ferrocement slab. *IOP Conference Series: Earth and Environmental Science, 32*, Article 012027. https://doi.org/10.1088/1755-1315/32/1/012027

Muda, Z. C., Kamal, N. L. M., Syamsir, A., Sheng, C. Y., Beddu, S., Mustapha, K. N., Thiruchelvam, S., Usman, F., Alam, M. A., Birima, A. H., & Zaroog, O. S. (2016). Impact resistance performance of kenaf fibre reinforced concrete. *IOP Conference Series: Earth and Environmental Science, 32*, Article 012019. https://doi.org/10.1088/1755-1315/32/1/012019

Niaki, M. H., Fereidoon, A., & Ahangari, M. G. (2018). Mechanical properties of epoxy/basalt polymer concrete: Experimental and analytical study. *Structural Concrete, 19*(2), 366-373. https://doi.org/10.1002/suco.201700003

Oyebisi, S., Ede, A., Olutoge, F., & Omole, D. (2020). Geopolymer concrete incorporating agro-industrial wastes: Effects on mechanical properties, microstructural behaviour and mineralogical phases. *Construction and Building Materials, 256*, Article 119390. https://doi.org/10.1016/j.conbuildmat.2020.119390

Parikh, K., & Modhera, C. D. (2012). Application of GFRP on preloaded retrofitted beam for enhancement in flexural strength. *International Journal of Civil and Structural Engineering, 2*(4), 1070-1080.

Pil, L., Bensadoun, F., Pariset, J., & Verpoest, I. (2016). Why are designers fascinated by flax and hemp fibre composites? *Composites Part A: Applied Science and Manufacturing, 83*, 193-205. https://doi.org/10.1016/j.compositesa.2015.11.004

Reddy, S. V. B., & Santhosha, V. (2018). Experimental study on fibre reinforced polymer concrete. *International Journal of Applied Engineering Research, 13*(15), 11844-11856.

Ramadan, R., Jahami, A., Khatib, J., El-Hassan, H., & Elkordi, A. (2023). Improving structural performance of reinforced concrete beams with phragmites australis fiber and waste glass additives. *Applied Sciences, 13*(7), Article 4206. https://doi.org/10.3390/app13074206

Sakai, E., Miyahara, S., Ohsawa, S., Lee, S. H., & Daimon, M. (2005). Hydration of fly ash cement. *Cement and Concrete Research, 35*(6), 1135-1140. https://doi.org/10.1016/j.cemconres.2004.09.008

Saribiyik, M., Piskin, A., & Saribiyik, A. (2013). The effects of waste glass powder usage on polymer concrete properties. *Construction and Building Materials, 47*, 840-844. https://doi.org/10.1016/j.conbuildmat.2013.05.023

Sonebi, M., Abdalqader, A., Fayyad, T., Amziane, S., & El-Khatib, J. (2022). Effect of fly ash and metakaolin on the properties of fiber-reinforced cementitious composites: A factorial design approach. *Computers and Concrete, 29*(5), 347-360. https://doi.org/10.12989/cac.2022.29.5.347

Sosoi, G., Barbuta, M., Serbanoiu, A. A., Babor, D., & Burlacu, A. (2018). Wastes as aggregate substitution in polymer concrete. *Procedia Manufacturing, 22*, 347-351. https://doi.org/10.1016/j.promfg.2018.03.052

Supian, A. B. M., Sapuan, S. M., Zuhri, M. Y. M., & Ya, H. H. (2016, December 28). A review of the development hybrid nature-synthetic fibre-reinforced composite in energy absorption tube applications. In *Proceedings of 5th Postgraduate Seminar on Natural Fiber Composites* (pp. 1-6). Universiti Putra Malaysia, Malaysia.

Supian, A. B. M., Sapuan, S. M., Zuhri, M. Y. M., Zainudin, E. S., & Ya, H. H. (2018). Hybrid reinforced thermoset polymer composite in energy absorption tube application: A review. *Defence Technology, 14*(4), 291-305. https://doi.org/10.1016/j.dt.2018.04.004

Vaggar, G. B., Sirimani, V. B., Sataraddi, D. P., Hiremath, N. M., & Bhajantri, F. (2021). Effect of filler materials on thermal properties of polymer composite materials: A review. *International Journal of Engineering Research & Technology (IJERT), 10*(08), 1-5.

Yan, L., Kasal, B., & Huang, L. (2016). A review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering. *Composites Part B: Engineering, 92*, 94-132. https://doi.org/10.1016/j.compositesb.2016.02.002

Yeon, J. H., Lee, H. J., & Yeon, J. (2020). Deformability in unsaturated polyester resin-based concrete: Effects of the concentration of shrinkage-reducing agent and type of filler. *Materials, 13*(3), 1-16. https://doi.org/10.3390/ma13030727

Zabihi, O., Ahmadi, M., Nikafshar, S., Preyeswary, K. C., & Naebe, M. (2017). A technical review on epoxy-clay nanocomposites: Structure, properties, and their applications in fiber reinforced composites. *Composites Part B: Engineering, 135*, 1-24. https://doi.org/10.1016/j.compositesb.2017.09.066