Experimental study on enhancement of compressive strength of concrete by polyethylene terephthalate flakes with fine aggregate and addition of silica flume to the volume of concrete

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Abstract

Aim: The study compares the compressive strength of conventional concrete to a novel type of concrete that includes 10% flakes made of polyethylene terephthalate (PET) and 20% silica fume as a percentage of the total volume of the concrete.Materials and Methods:The materials used in this investigation were cement, fine aggregate, coarse aggregate, water, flakes made from polyethylene terephthalate (PET), and silica fume. The study tested the properties of two types of concrete, one with a conventional mix and another one is a novel concrete with 10% PET flakes and 20% silica fume. PET flakes were utilised as the fine aggregate, and samples were cured in a storage tank for 28 days prior to testing to verify the concrete had attained its full strength. Using statistical models with G-power 0.8 software and a 95% confidence interval, the compressive strength of Novel concrete (N=10) was compared to conventional concrete (N=10).Results:The findings of this study indicated that after 28 days of curing, the innovative concrete mixture including 10% polyethylene terephthalate (PET) flakes and 20% silica fume had a compressive strength of 25 MPa. This is compared to the 37 MPa compressive strength of standard concrete after the same curing period.Conclusion:This study concluded that adding 10% polyethylene terephthalate flakes and 20% silica fume to the concrete volume can greatly enhance the concrete's compressive strength without disturbing its workability.

Keywords: *Compressive strength, Concrete, Polyethylene Terephthalate, Novel concrete, Conventional concrete, Fine aggregate, Silica fume.*

Introduction

Compressive strength is a crucial factor in determining the viability of concrete for various purposes (Sun and Xu 2009). In recent years, research has been performed on the use of recycled materials in the manufacturing of concrete as a means of reducing the environmental impact of the building sector. One such recycled material that has been studied is polyethylene terephthalate (PET) flakes, which are a byproduct of the plastic beverage bottle recycling process (Ge et al. 2014). Silica fume, a byproduct of the production of silicon and ferrosilicon alloys, has been studied for its potential use in concrete(Çakır and Sofyanlı 2015). Research has shown that adding silica fume to concrete can increase its compressive strength. In this study, the compressive strength of concrete is compared between regular concrete and concrete in which 10% of the volume is replaced by polyethylene terephthalate (PET) flakes and 20% of the volume is replaced by silica fume (Ali et al. 2021). The results of the experiments suggest that using recycled materials into the manufacturing of concrete, such as PET flakes and silica fumes, can greatly enhance the compressive strength of the concrete while simultaneously lowering the environmental effect of the construction sector. Polyethylene terephthalate (PET) flakes and silica fumes are both materials that have been studied for their potential applications as partial replacements for traditional materials in concrete production (Jankauskaite, Macijauskas, and Lygaitis 2008).

Several studies have investigated the effect of adding different types of plastics to concrete on its strength properties (Adnan and Dawood 2020; Anandan and Alsubih 2021; Daneshfar et al. 2017). A search on IEEE Explore revealed 125 research papers, and a search on Google Scholar yielded 198 articles, indicating a growing interest in this topic.Pelisser et al. (Pelisser et al. 2012) found that recycled PET fibers improved both compressive and flexural strength, while Jalal et al. (Jalal et al. 2017) found that PVA fibers at a dosage of 1.5% were ideal for increasing compressive strength. The compressive strength of high-performance concrete was shown to be increased when PE fibres were added at a dose of 0.5% by Yoo and Kim (Yoo and Kim 2019). M. Manjunatha et al. also showed that adding silica fume to PE fiber-reinforced concrete improved its compressive strength and microstructure (M, Manjunatha et al. 2021). Bhogayata and Arora(Bhogayata and Arora 2017) and Shaikh(Shaikh 2020) also found that PE fibers at a dosage of 0.5% increased compressive strength, while Muzenski et al. (Muzenski et al. 2020) found that the addition of PE fibers and silica fume improved compressive strength with the same dosage. Finally, Dong et al. (Dong et al. 2021)found that PVA fibers at a dosage of 1% were best for increasing compressive strength.

The main drawback of conventional concrete is that it develops microcracks during the curing process, which can lead to low compressive strength when the material is stressed. To resolve this problem, the objective of this study is to determine the impact of incorporating PET flakes and silica fume to cement on its compressive strength. The addition of 10% PET flakes as a replacement for fine aggregate and 20% silica fume substantially increased the compressive strength of concrete. The concrete mixture including these components had a 10% greater compressive strength than the conventional concrete, which did not contain them.

MATERIALS AND METHODS

The study was conducted in the Civil Engineering Department's Mechanics Laboratory at Saveetha School of Engineering. It involved comparing the strength of standard concrete and innovative concrete, made using cement, water, coarse aggregate, PET flakes and silica fume from JsReadymix Concrete. The compressive strength was evaluated using cylindrical specimens with a diameter of 150mm and a height of 300mm. The mixture had a water-cement ratio of 0.5 and contained natural river sand as the fine aggregate. The specimens were cured for 28 days in a water tank before being evaluated for compressive strength usinga universal testing equipment. This research had a sample size of 20, divided into two groups of 10 each. The first group consisted of conventional concrete, while the second group utilized a novel concrete with 10% PET flakes and 20% silica fume added to the volume of concrete. The sample size was determined based on previous studies done by (Umar, Masood, and Ahmad 2016). The data was analyzed using G-power software with a significance level of 0.05 and a power of 0.20.

The results are reported with a 95% confidence interval.

Conventional concrete

Standard concrete, also known as normal-weight concrete, is the most commonly used type of concrete in construction. It is made by mixing cement, water, and fine and coarse aggregate (such as sand and gravel or crushed stone) in a specific ratio. The mix design, which is the proportion of the ingredients, is determined based on the intended use of the concrete and the environmental conditions in which it will be placed. Standard concrete has a density of around 2,400 kg/m3 (150 lbs/ft3) and is typically used in a wide range of applications, such as buildings, bridges, pavements, and other infrastructure projects. The compressive strength of typical concrete can vary from 2,500 to 8,000 psi (17 to 55 MPa) based on the mix design and curing time. Versatility is the primary benefit of ordinary concrete. It can be utilised in a variety of application areas, and its toughness and durability can be tailored to meet specific needs by modifying the mix design. Additionally, standard concrete is relatively inexpensive and widely available. However, standard concrete also has some limitations. It is relatively heavy, which can be a disadvantage in certain applications such as precast concrete elements. It also has a relatively high carbon footprint due to the energy-intensive production of cement.

Novel concrete

High-performance concrete is made by adding 10% recycled plastic (PET flakes) and 20% silicon dioxide (silica fume) to the traditional mixture of cement, water, and aggregates (such as sand and gravel). Microsilica, or silica fume, is a byproduct of making silicon and ferrosilicon alloys that is used to increase the strength and longevity of concrete.The addition of recycled plastic (PET flakes) not only improves the concrete's compressive strength and durability but also helps to reduce the environmental impact of plastic waste. When added to concrete, silica fume reacts with the calcium hydroxide (CH) that is produced as a byproduct of the cement hydration process. Calcium silicate hydrate (C-S-H) gel is produced in excess during this reaction, and it is principally responsible for the durability and strength of the concrete. Silica fume's ultra-fine particle size increases the C-S-H gel's surface area, which in turn increases the concrete's strength and durability. The addition of PET flakes to concrete can also improve its strength and durability, as well as its thermal insulation properties. PET flakes are a type of plastic that is strong, lightweight, and resistant to moisture. When added to concrete, they function as aggregates and can improve the compressive strength, of the concrete. Additionally, the inclusion of silica fume and PET flakes to concrete reduces the quantity of cement required. As cement manufacture is a primary source of carbon dioxide emissions, this can aid in reducing the environmental impact of concrete production.

Statistical Analysis

The study used the independent samples t-test method, which was conducted using IBM SPSS V26.0 (Hilbe 2004; Frey 2017), to compare the compressive strength of the two groups of concrete: regular and Novel concrete. The compressive strength was the dependent variable, while the type of concrete was the independent variable. The statistical analysis aimed to determine the mean and standard deviation of compressive strength for each group, and to identify any significant differences between the two groups of regular and Novel concrete.

RESULTS

The data is presented in the form of a bar graph in Figure 1, which compares the compressive strength of conventional concrete and Novel concrete with 10% PET flakes and 20% silica fume. The graph shows the mean compressive strength on the Y-axis, with a 95% confidence interval represented by ±1 standard deviation. The X-axis represents the types of concrete. The mean compressive strength for conventional concrete is 25 MPa and for Novel concrete is 37 MPa.

Fig. 1. The compressive strength of traditional concrete and innovative concrete is compared using a bar graph. The X-axis depicts the various concrete kinds, while the Y-axis displays the average compressive strength, with a 95% confidence interval depicted by a standard deviation. The average compressive strength of traditional concrete is 25 MPa, while that of modern concrete is 37 MPa

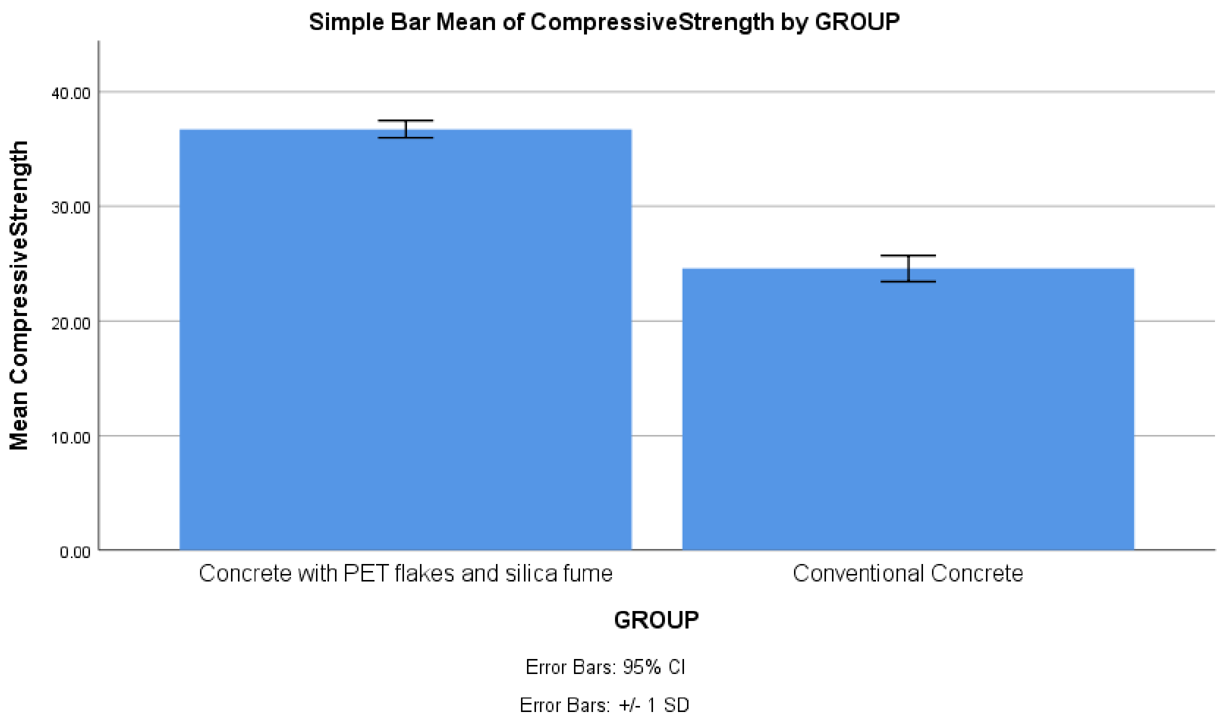

Table 1. The addition of 10% polyethylene terephthalate flakes and 20% silica fume as a replacement for fine aggregate in concrete has resulted in an increase of 37 MPa in compressive strength compared to conventional concrete which has a compressive strength of 25 MPa. This shows that replacing fine aggregate with PET flakes and silica fume has effectively enhanced the compressive strength of the concrete.

SI.No.	Test Size	Compressive Strength	
		Conventional concrete	Concrete with PET flakes and silica fume
1	Test1	20	36.9
2	Test2	22	37
3	Test3	26	36.8
4	Test4	24	37.4
5	Test5	20	37.1
6	Test6	30	37.6
7	Test7	32	37.3

8	Test8	28	37.7
9	Test9	24	37.5
10	Test10	28	37.2

Table 1 shows that the use of 10% PET flakes and 20% silica fume as fine aggregate in concrete has been shown to significantly increase its compressive strength to 37 MPa, as well as its durability, compared to regular concrete which typically has a compressive strength of around 25 MPa. This indicates that replacing fine aggregate with PET flakes can lead to a significant improvement in the compressive strength of concrete.

Table. 2. The compressive strength of the conventional concrete is 25 MPa, while that of the novel concrete is 37 MPa. This means that the novel concrete has a 48% higher compressive strength than the conventional concrete after 28 days. The standard deviation of the conventional concrete is 0.580 and the standard deviation of the novel concrete with PET flakes is 0.135. The standard error mean of the conventional concrete is 0.461, while the standard error mean of the novel concrete with PET flakes is 0.045.

Group		**N**	**Median**	**Standard Deviation**	**Standard Error Median**
Compressive Strength	Concrete with PET flakes and silica fume	10	37	0.135	0.045
	Conventional Concrete	10	25	0.580	0.461

According to Table 2, the compressive strength of innovative concrete with PET flakes and silica fume is 37 MPa, whereas the compressive strength of conventional concrete is only 25 MPa. After 28 days, the compressive strength of the novel concrete is 48 percentages higher than that of regular concrete. The standard deviation for standard concrete is 0.580 and for novel concrete is 0.135. The mean standard error for standard concrete is 0.461, and for novel concrete is 0.045.

Table 3: This study presents the results of a statistical comparison of the compressive strengths of ordinary and concrete with PET flakes and silica fume, utilizing independent samples. The analysis used an independent sample t-test with a 95% confidence interval, and a p value of 0.001 was declared significant. A two-tailed p-value, mean difference, standard error of the difference, and interval of difference between the two groups are presented.

Group		Levene's Test for Equality of Variances		t-test for Equality of Medians						
		F	Sig.	t	df	Sig. (2-tailed)	Median Difference	Std. Error Difference	95% Confidence Interval (Lower)	95% Confidence Interval (Upper)
Compressive strength	Equal variances assumed	1.019	0.125	1.380	12	0.001	0.229	0.130	-0.137	0.764
	Equal variances not assumed			1.380	8.903	0.001	0.229	0.130	-0.184	0.756

The results in Table 3 show that there is a statistically significant difference in compressive strength between traditional concrete and novel concrete. The independent sample t-test was used, with a significance level of 0.183 and a 95% confidence interval (CI). The p-value of 0.001, which is less than the chosen level of significance (0.183), indicates that the difference in compressive strength is unlikely to be due to chance. The mean difference, standard error of the difference, and range of the difference interval between the two groups are also provided in the table.

DISCUSSION

The compressive strength test is a crucial method to evaluate the performance and efficiency of concrete. The strength of the concrete is evaluated by applying a compressive load to it. Concrete is a composite material made by combining cement, water, and aggregates (such as sand, gravel, or crushed stone). The aggregates are bound together by the cement and water paste that forms around them. The compressive strength test measures the ability of this paste to withstand the compressive forces applied to it. Adding 10% polyethylene terephthalate (PET) flakes and 20% silica fume to the fine aggregate can increase the concrete's compressive strength. The PET flakes help cement and aggregate particles stick together, which boosts the concrete's overall durability. The use of silica fume not only decreases the amount of water required for hydration but also enhances the density of the cement paste, leading to stronger concrete. The test showed that the novel concrete mixture has a mean compressive strength of 37 MPa, which is nearly 48% greater than the average compressive strength of 25 MPa found in conventional concrete.

Some similar studies are Adela, Berhanu, and Gobena et al. (Adela, Berhanu, and Gobena 2020) found that incorporating plastic trash into concrete led to greater compressive strength and lower water absorption, indicating that the plastic trash could be a suitable replacement for traditional materials used in concrete production. Manjunath et al. (Manjunath 2016) investigated the use of plastic garbage as a potential coarse aggregate replacement in concrete. The research concluded that the concrete's compressive strength and elastic modulus both increased when plastic garbage was used as a replacement. Purnomo, Pamudji, and Satim et al. (Purnomo, Pamudji, and Satim 2017) also studied the feasibility of employing plastic trash in concrete manufacturing. They discovered that by including plastic waste in the concrete mix, compressive strength was increased but water absorption was decreased. In their 2019 study, Hameed and Fatah Ahmed (Hameed and Fatah Ahmed 2019)explored the potential of employing plastic waste as an alternative to coarse aggregate in construction projects. The study found that the mechanical parameters of the concrete, including its compressive strength and modulus of elasticity, were improved by the addition of plastic waste.

However, it's important to note that this research is based on a specific mix design and materials, and the results may not be directly applicable to all types of concrete or different mix designs. Additionally, the study only focused on compressive strength and other properties such as durability, workability, and sustainability of the concrete were not investigated. Future research should explore the long-term durability and sustainability, effect of different percentages of PET flakes and silica fume, feasibility of using this method in real construction projects, and other materials that could be used in place of or in combination with PET flakes and silica fume to improve the compressive strength of concrete.

CONCLUSION

In conclusion, this study found that the addition of 10% polyethylene terephthalate flakes and 20% silica fume to the volume of concrete can significantly increase the compressive strength of the concrete. This research can provide an alternative solution to use waste materials in the construction industry and a sustainable way to build infrastructure.

DECLARATION

Conflicts of Interest

No conflict of interest in this manuscript

Authors Contributions

Author name was involved in data collection, data analysis and manuscript writing. Author guide name was involved in conceptualization, data validation, and critical review of manuscripts.

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