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Article

Assessment of Strength and Bending of Concrete Containing Crushed Glass and Fibers

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ABSTRACT

This paper presents proposed investigations of the impact of crushed-glass and fibers on the concrete. Conventional concrete has lack tension in order to improve its flexural strength and compressive strength. This study has adopted the addition of PET fibers and recycled waste glass fibers to concrete. The study uses M25 grade concrete to study the effects of adding crushed waste glass at a weight of 0, 5, 10, and 15%. The PET fibers were extracted from waste bottles used for packaging drinks and hand-cut into very small rectangular pieces (with an average size of 3×10mm). For the mix design, the addition of 0, 3, 5, and 10% dosages of PET fiber was adopted to compare their influence against plain concrete with no fiber addition. Both fiber samples were cured for 7, 28, 56, and 90 days before being tested for compressive strength and flexural strength. The combined use of broken glass and PET fibers had a substantial impact on the compressive strength (i.e., 122%) and flexural beam test (i.e., 56%) for 90 days of cured samples, according to the results.

1. Introduction

Concrete is simply a combination of cement paste and fine and coarse aggregates. Cement paste is made up of Portland cement and water, and it covers the surface of the fine and coarse aggregates. The paste strengthens and hardens to form the rock-like mass known as concrete [1]. The terms cement and concrete are frequently used interchangeably, however cement is an ingredient of concrete. It is the soft powder that, when blended with water, sand, and gravel, forms the rock-like mass known as concrete. Prosper [2] states that concrete structures in buildings or other constructions could be exposed to accidental conditions like fire. The safety of the structures is dependent on the mechanical properties of the concrete. Currently, it upholds the trend of new generation concrete production focused on satisfying basic building needs. While concrete maintains its capability of sustaining compression loads, which is the key task of its structure, it is also desired to meet its supplementary needs. For this reason, a lot of research and applications are carried out. Along with the carrying capacity of the concrete, it is also desired that it will be resistant to the environmental effects it may come across during its service life. Feng Shi [3] states that concrete is strong in compression but has a low tensile strength. In addition to that, concrete is a quasi-brittle material, which means it breaks and fails due to fracture rather than plastic yield and it absorbs relatively little energy during fracture.

Concrete, like other construction and building materials moves with moisture content and shrinks due to loss of moisture making cracking in plain concrete almost inevitable and may occur due to various reasons. Pietro Lura [4] explained that even though modern concrete has advantageous characteristics such as improved durability, high ductility and low permeability, they may also pose undesirable behavior like autogenous strain which is the self-created bulk strain of cement paste, mortar or concrete during hardening at constant temperature. The author continued to state that restraint of the autogenous strain by aggregates or adjoining structural members may result in formation of micro and macro cracks that weaken the strength and durability of concrete. Although shrinkage cracking is the most common form of cracking, it may occur also due to design defects, settlement of the concrete, movement of the formwork before the concrete member is able to sustain its own weight, or due to changes in the temperature of the concrete and the resulting thermal movement. Cracks may also be categorized in terms of age of concrete because some cracks may occur before hardening of concrete or just placing of concrete and some occur after hardening of concrete.

According to Szeląg [5] a cracking pattern on the surface of cementitious materials develop from the complex processes involved in the formation of cracks in the material. A crack forms and spread in the weakest part of the material because of exposure to stresses that exceed its local strength. The author continues to mention that the differentiating feature of cementitious composites is their brittleness and even small deformations may cause the break of the structure's continuity. Environmental loads such as increased temperature, mechanical stress, drying of the material, reaction with an aggressive chemical agent, etc., lead to prolonged deformation as a function of time, causing it to crack. The resulting cracks in the course of propagation fuse and interconnect to create a cracking pattern on the surface of the material.

Vairagade [6] explained that different types of fibers have been introduced into the concrete mixture to increase various properties such as its toughness and ability to resist crack growth. These fibers aid in transferring loads at the internal micro cracks. Concrete consisting of these fibers is called fiber-reinforced concrete (FRC). Thus, the fiber-reinforced concrete is a composite material essentially consisting of conventional concrete or mortar reinforced by fine fibers. The difference between fiber and other reinforcements is that it is embedded in concrete forming a composite material. Rebar only provides strength at distinct locations while steel fibers form a network through the entire concrete structure. The author continues to mention that the choice of fibers varies from synthetic organic materials such as polypropylene or carbon, synthetic inorganic such as steel or glass, natural organic such as cellulose or sisal to natural inorganic asbestos. Fraternali et al., [7] stated that reinforcing fibers can be extracted from polyethylene terephthalate (PET), polypropylene (PP), polyethylene, nylon, aramid, and polyester recycled products; wasted glass, rubber and cellulose, among other materials. According to Jansson [8] the advantages of using fibers as reinforcement have been known since ancient times. In modern times, in the early 1900s, asbestos cement was the first widely used manufactured composite but due to their high stiffness, the steel and polypropylene fibers are probably the most used fiber materials. However, the use of asbestos fiber in cement paste posed some health risk and alternative fibers were introduced as a replacement. The fiber-reinforced concrete materials may be classified as strain hardening or strain softening, to a large extent depending on the number of fibers added. Strain hardening is recognized by an increasing tensile stress after the first cracking, and it is accompanied by multiple cracking; strain-softening materials exhibit a decreasing tensile stress after the first cracking [8]. These fibers are produced in varying geometrical forms in order to enhance the bond between the fiber and concrete matrix.

According to FRCA [9] various are materials used to produce fibers used in concrete. The main types of fibers used in concrete are steel fibers, synthetic fibers, glass fibers and organic- or natural fibers. Steel fibers are generally used to enhance concrete toughness and post-crack load carrying capacity. Glass fibers are used to avoid concrete cracking over time due to mechanical or thermal stresses and improve concrete hardness. Synthetic fibers are normally made from polypropylene, polyethylene, and other polymer blends. These fibers help prevent concrete cracking due to thermal effects and are further broken down in to two categories called micro-synthetic and macro-synthetic fibers. Macro-synthetic fibers are generally used as a non-corrosive substitute to steel fibers since they provide similar characteristics while micro-synthetic fibers are used for protection and mitigation of plastic shrinkage cracking in concrete. Natural fibers are more prone to rotting and can cause harm to the concrete strength. These fibers are no longer used in commercial applications. Other types of fibers include cellulose fibers which are used in a similar manner as micro-synthetic fibers for the control and mitigation of plastic shrinkage cracking and poly-vinyl alcohol fibers which can alter the flexural and compressive performance of concrete when used at higher volumes.

According to Zainab and Ismail [10] glass is one of the oldest man-made materials produced in various forms, including packaging or container glass, flat glass, bulb glass, and cathode ray tube glass, all of which have a limited life in the forms in which they are produced and need to be reused/recycled in order to avoid environmental problems that would be created if they were to be stockpiled or sent to landfills. The author continues to explain that the construction and building industry has shown great gains in the recycling of industrial by-products and waste, including waste glass. Recycling of this waste by converting it to aggregate saves landfill space and reduces the demand for extraction of natural raw material for construction activity. Gautam et al., [11] pointed out that using waste glass in the concrete construction sector is an advantage, as the production cost of concrete will go down. The author also explained that crushed glass, if properly sized and processed, can show characteristics similar to that of gravel or sand. Mardani [12] observed that a major problem concerning the use of glass aggregate in concrete is the alkali silica reaction. This reaction can be very harmful to the stability of concrete, when coarse glass aggregate is used. The author elaborated by mentioning that the chemical reaction between the alkali in Portland cement and the silica in aggregates forms silica gel that causes crack upon expansion and weakens the concrete and shortens its life.

According to Fraternali et al., [7] various waste materials, like, recycled plastics, glass, tire cords, and wood, show extreme versatility, light weight, durability, resistance to chemicals, excellent thermal and electrical insulation properties. These properties are desirable, particularly in concrete reinforcement with fibers made up of recycled materials, which stands as a low-cost strengthening technique able to enhance tensile strength, structural ductility and thermo-electrical insulation of the concrete matrix. Rahmani et al., [13] described Polyethylene Terephthalate as a kind of polyesters made of the ethylene glycol and terephthalic acid's composition and its chemical name is Polyethylene Terephthalate or ''PET''. PET is one of the most widely used plastics in the package industry because of high stability, high pressure tolerance, non-reactivity with substances and great quality of gas trapping which can preserve the gas in the gaseous drink. The author continues to mention that the most economical way is using PET particles as a substitute of aggregates and mortar. As a result, using PET waste as an aggregate in concrete has some benefits such as decreasing the usage of natural resources, the wastes consumption, preventing the environmental pollution and economizing energy. Concrete reinforced with plastic PET bottles can improve concrete properties such as tensile strength, compressive strength etc. PET fibers in concrete have the ability to resist the growth of minor internal cracks in the crack width from widening under an applied load. The addition of PET fibers in concrete provides crack resistance and control to minor cracks originating internally from the concrete mix, eventually improving waste plastic bottle fibers has many advantages because the waste material is readily available, low in cost and it can solve the problem of disposal of plastic bottles up to some extent [14].

Asadi [15] studied different properties and crack evolution of concrete with fly ash and hybrid fibers. Different tests were conducted for different concrete properties including compressive strength, tensile strength, and crack analysis for both fiber reinforced concrete and plain concrete. The tests were also conducted to check the workability for the specimens of concrete when the cement is replaced with fly-ash and the addition of fibers. The results showed that the addition of basalt of percentage 2.1% to 0.3% basalt led to a decrease in compressive strength while addition of steel fibers at higher volumes lead to an increase in compressive strength. Lura [4] carried out research on cracking in cement paste induced by autogenous shrinkage. In the study, the author used scanning electron microscope (SEM) to analyze microcracks in the samples and found out that convenient technique for detection of cracks and analysis is optical microscopy combined with SEM analysis of the microcracks to reveal presence of gallium. The author also discovered that microcracking depended both on the autogenous shrinkage of the cement paste and on the dimension of the restraining steel rod as cracks were observed in samples with larger steel rods and higher autogenous shrinkage. Studies have shown that recently, the application of steel fibers is frequently at industrial and residential areas. It is used in flooring and suspended slab on piles, shotcrete application, overlays, floor topping, precast products, segmental lining, cellar walls, blast-proof structures, safety vaults etc., [16].

Irvan [17] investigated the optimization of fiber size, fiber content and other parameters. In the research, the author found out that different fiber sizes contributed to their physical properties as well as their mechanical properties. Addition of a small fraction of fiber type to the concrete mix will impact its compressive strength and also slightly it's splitting tensile strength. Addition of larger fiber type increased its opposite mechanical effects, which were extra encouraged by optimization of the aspect ratio. The effect of steel fiber size (mention about the sizes from their article) is due to the different cracking magnitudes made by the different testing modes. Finally, ordinary plain concrete is brittle and performs poorly under impact loading. Cracks immediately emerge on the concrete when subjected to tensile stresses and high loading. This heavily affects the strength and durability of concrete and makes it susceptible to chemical and thermal attacks which will eventually lead to collapse of the structure. Studies have been done to find ways of minimizing concrete weakness and improve its tensile strength. Since concrete is only strong in compression but weak in tension the use prestressed steel and reinforcing bars was applied to improve the tensile strength of concrete but this was found to be dependent on environmental conditions [18]. Some of these environmental conditions lead to corrosion of steel causing considerable damages and costs due to maintenance and repair needs. This corrosion can also cause formation of cracks in the concrete cover as well as cross sectional reduction of reinforcement area affecting strength and serviceability of reinforced concrete structures. Since cracking begins at the surface of concrete, by the time it reaches the steel rebar or reinforcement, it would have developed into a macro-crack which is not desirable therefore it is important to control cracking while it is at the micro level to decrease the deterioration and damage by chemical ingress which cause further deterioration of concrete. To further improve the tensile performance of concrete, strength and crack resistance different types of fibers have been developed to provide remedy for such problems. The aim of this research is to evaluate the cracking patterns and strength of concrete containing PET waste plastic fibers and crushed glass.

2. Materials and Methods

Ordinary Portland Cement (OPC), with specific gravity 2.65, initial setting time equal or greater than 60 minutes and final setting time about 110 minutes, and 7days compressive strength of 29MPa and 28 days compressive strength of 42.5 MPa, complying with IS: 12269 – 2001 was used. Also, locally available coarse aggregates of 13mm and down size having a specific gravity of 2.74, complying with IS: 383 – 1970 was used. In addition, locally available sand with specific gravity of 2.67, complying with IS: 383 – 1970 was used. Potable fresh water available from local sources free from deleterious materials used for mixing and curing of all the mixes tried during the investigation. 30 kg of crushed glass (green glass) reinforcing fibres were purchased from Maun, Botswana. The samples, beams and cubes were casted at the materials laboratory in the University of Botswana. Figure 1 shows the PET fibres and recycled crushed glass that used in this study.

(a) PET waste plastic fiber (3×10mm) (b) recycled crushed glass

Fig. 1 PET and recycled crushed glass

A sieve analysis of both fine and for crushed glass was done to determine the particle size distribution or gradation. The results from sieve analysis were used to calculate important parameters such as Fineness Modulus and % passing 600µm sieve so as to make the appropriate mix design. Standard sieves were placed and arranged in descending order from the top until the bottom where a pan was placed. All sieve masses were determined and recorded. A 1000g sample was weighed and then poured into the top sieve. A mechanical sieve shaker was used to shake the sample for approximately 10 minutes before reading could be taken. The mass of soil in each sieve was recorded in the appropriate table. A brush was used to remove particles that got stuck in the sieves. According to ASTM E11, sieves used for the grading of fine aggregates should of sizes 9.5mm, 4.75mm, 2.36mm, 1.18mm, 600-micron, 300 micron and 150 micron. Concrete mixing was done manually (Table 1) and following the procedure adapted from.

- Measured amounts of sand and coarse aggregates were spread out uniformly in a clean mixing area. Precaution was taken when dumping the coarse aggregates by not dumping them all at once. This was done so that the bigger particles do not roll out of the mixing area.
- Cement of measured quantity was dumped onto the mixture of coarse and fine aggregates and uniformly distributed.
- The materials were mixed by hand using shovels by turning the mixture over and over until it is uniform
- The above step was repeated three times by shoveling from the center to side, and then back to the center and again to the side.
- A depression was made in the middle of the mixed pile and water was poured slowly into half to three-quarters of the total quantity of water required. While the material is turned in towards the center with

shovels, the remainder of the water was added slowly, turning the mixture over and again until the color and consistency are uniform throughout the mixed pile. This was an indication that all ingredients are thoroughly combined.

Table 1 Concrete mix proportions for different percentage of fibre fraction.

crushed waste glass (%)	Fibre fraction (%)	Cement (kg)	Water (lit)	Sand (kg)	Coarse aggregates (kg)
0, 5, 10, 15	0	22.2	11.2	80	87
0, 5, 10, 15	3	21.09	11.2	80	87
0, 5, 10, 15	5	19.98	11.2	80	87
0, 5, 10, 15	10	18.87	11.2	80	87

Both the moulds for cubes and for beams were firstly oiled to avoid concrete sticking to the moulds when de- moulding. Cubes measuring 150×150×150 mm were casted (Fig. 2) and for flexural test beams measuring 150×150×600 mm were also casted (Fig. 3), hand compaction was carried out for each layer put in the moulds. Finally, the moulds would be placed on a vibrating table compactor for further compaction before covering the specimen with plastic bag. After casting for 24 hours, beam and cube specimens were de-moulded and immersed in a water tank. Cubes were cured for the 7, 28, 56, and 90-days period only. Same applies to the beams, all of them were cured for 7, 28, 56, and 90 days. At the end of each cured days, three samples were examined and we take it average for the results. The standard used was ASTM C143 for the slump. The apparatus used includes tamping rod, cone and a ruler and following the procedure adapted from.

● The mould for the slump test is a frustum of a cone, 300 mm of height. The base is 200 mm in diameter and it has a smaller opening at the top of 100 mm.

● The base was placed on a smooth surface and the container was filled with concrete in three layers and poked.

● Each layer was tempered 25 times with a standard 16 mm diameter steel rod, rounded at the end.

●When the mould was completely filled with concrete, the top surface is struck off (levelled with mould top opening) by means of screening and rolling motion of the temping rod.

● The mould was firmly held against its base during the entire operation so that it could not move due to the pouring of concrete which was done by means of handles or foot - rests brazed to the mould.

● Immediately after filling was completed and the concrete was levelled, the cone was slowly and carefully lifted vertically, an unsupported concrete difference from height of the cone height was then considered as slump i.e., the decrease in the height of the center of the slumped concrete is called slump.

● The slump was measured by placing the cone just besides the slump concrete and the temping rod was placed over the cone so that it should also come over the area of slumped concrete. The decrease in height of concrete to that of mould is noted with scale. When the slump test is carried out, the following are shapes of the concrete slump that can be observed:

Fig. 2 Cube specimen in a compression test machine

(a) Beam specimen on flexural machine beam before loading

(b) Ultimate failure of a specimen due to flexural load

Fig. 3 Scheme of flexure test machine in this study

3. Results and discussion

The test results for compressive strength test are shown in Figs. 4 to 8. Furthermore, the following Figs. 9 to 11 show the develop of flexure test with additional variable of percentages of crushed glass and PET. From Fig. 4, with additional 15% of crushed glass the compressive strength increases from 27 to 47 kN/m^2 (74%) for 90 days cured samples. While,

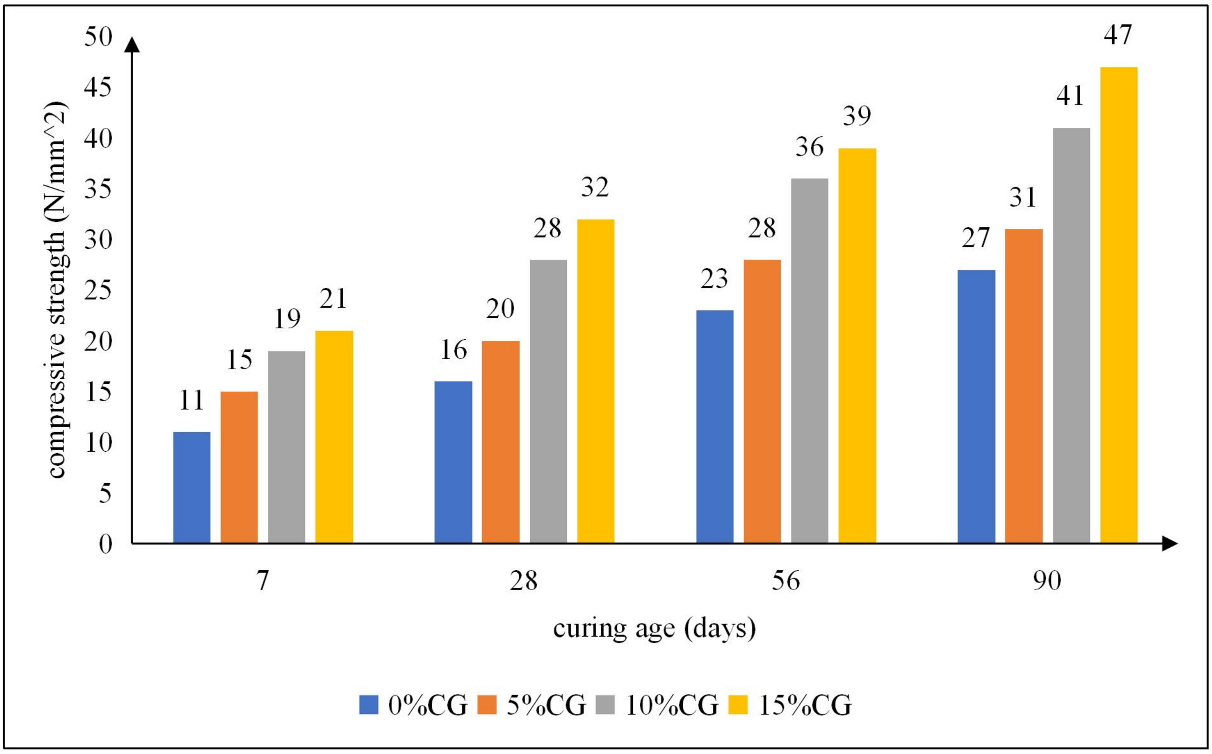

Fig. 4 Compressive strength results for additional different % of crushed glass

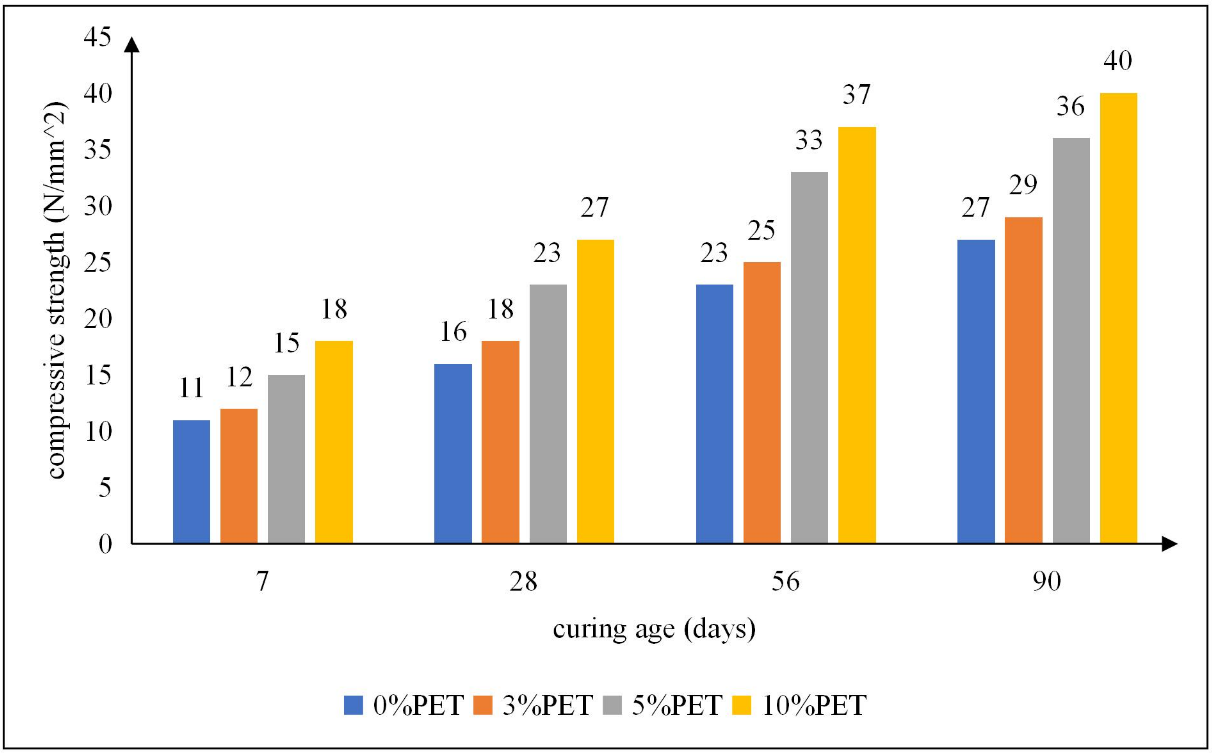

Fig. 5 Compressive strength results for additional different % of PET

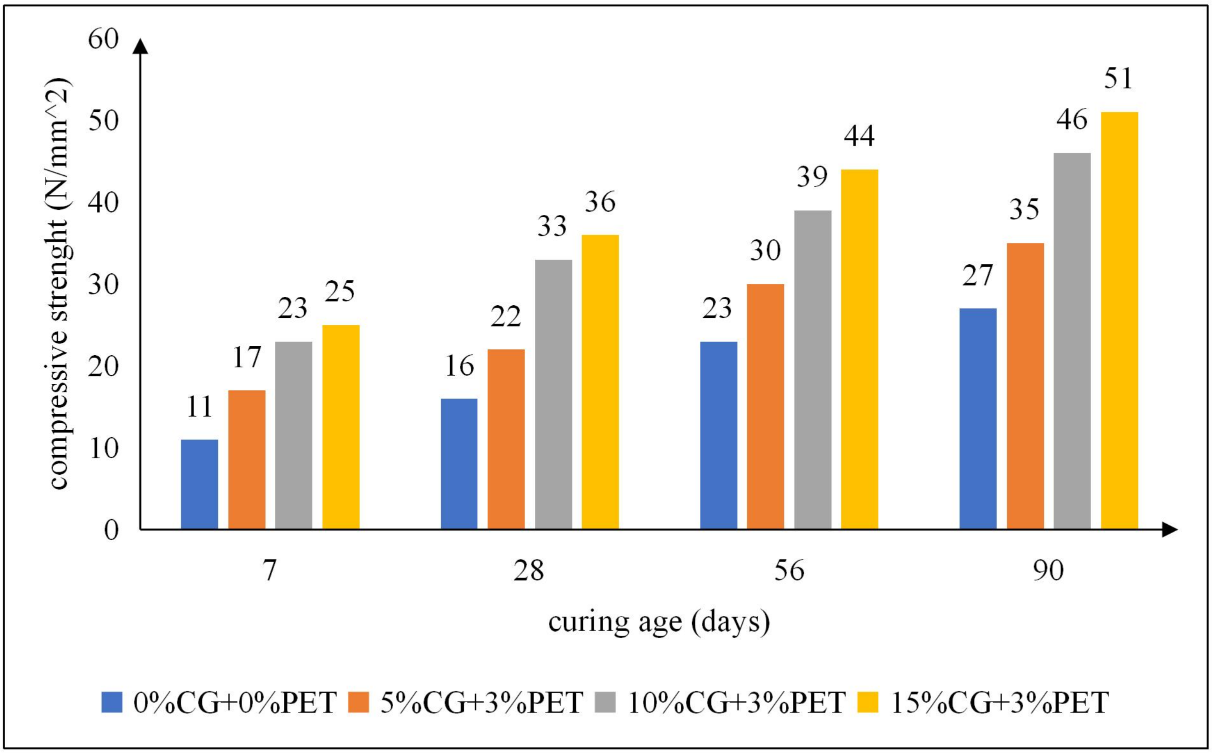

Fig. 6 Compressive strength results for additional different % of crushed glass & 3%PET

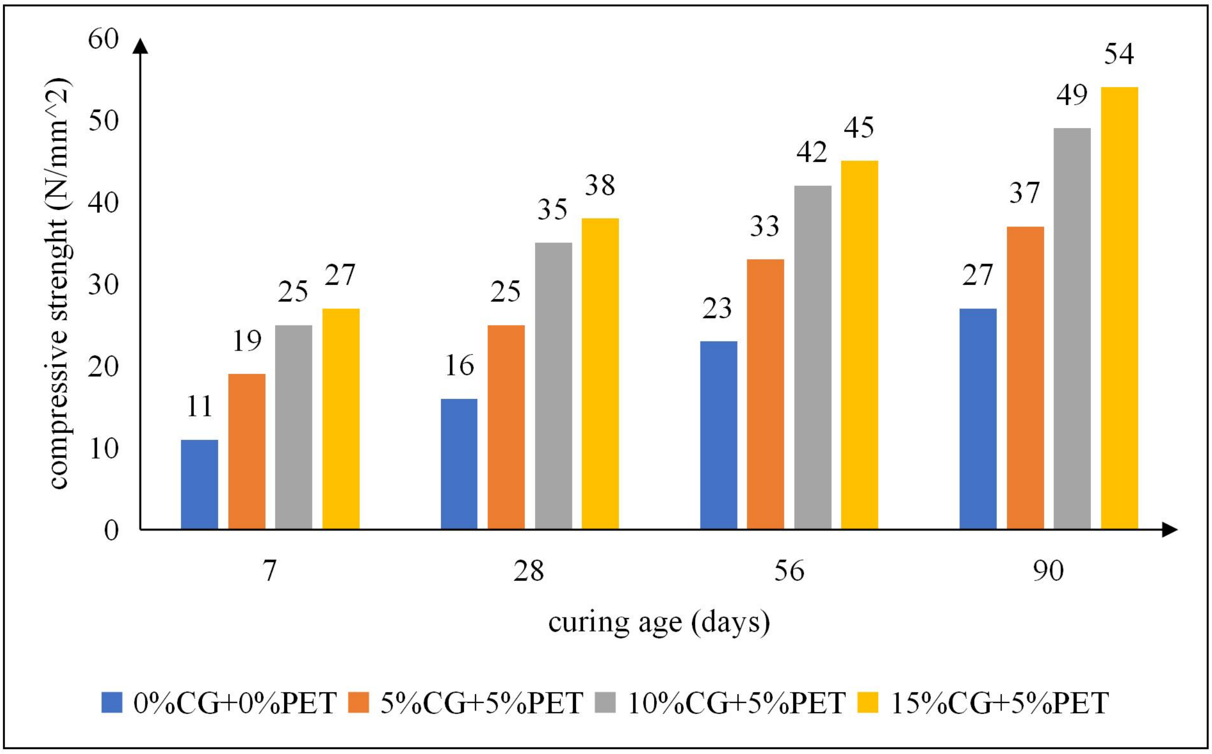

Fig. 7 Compressive strength results for additional different % of crushed glass & 5%PET

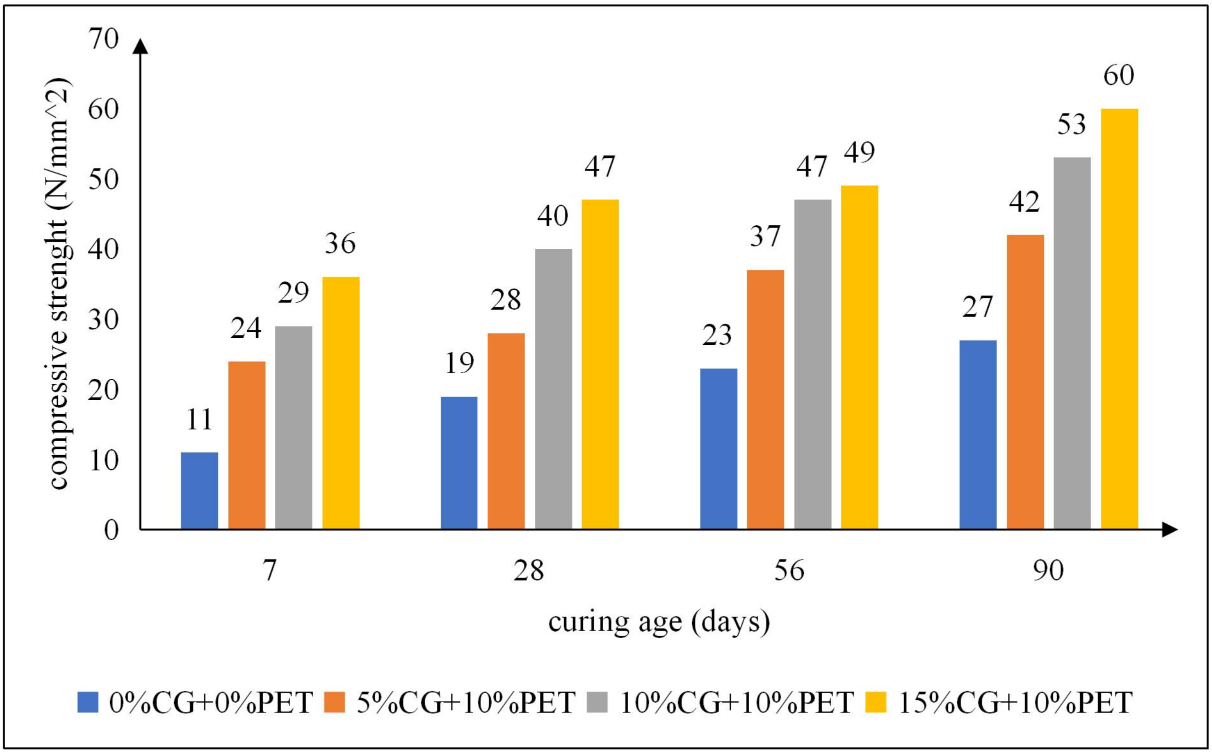

Fig. 8 Compressive strength results for additional different % of crushed glass & 10%PET

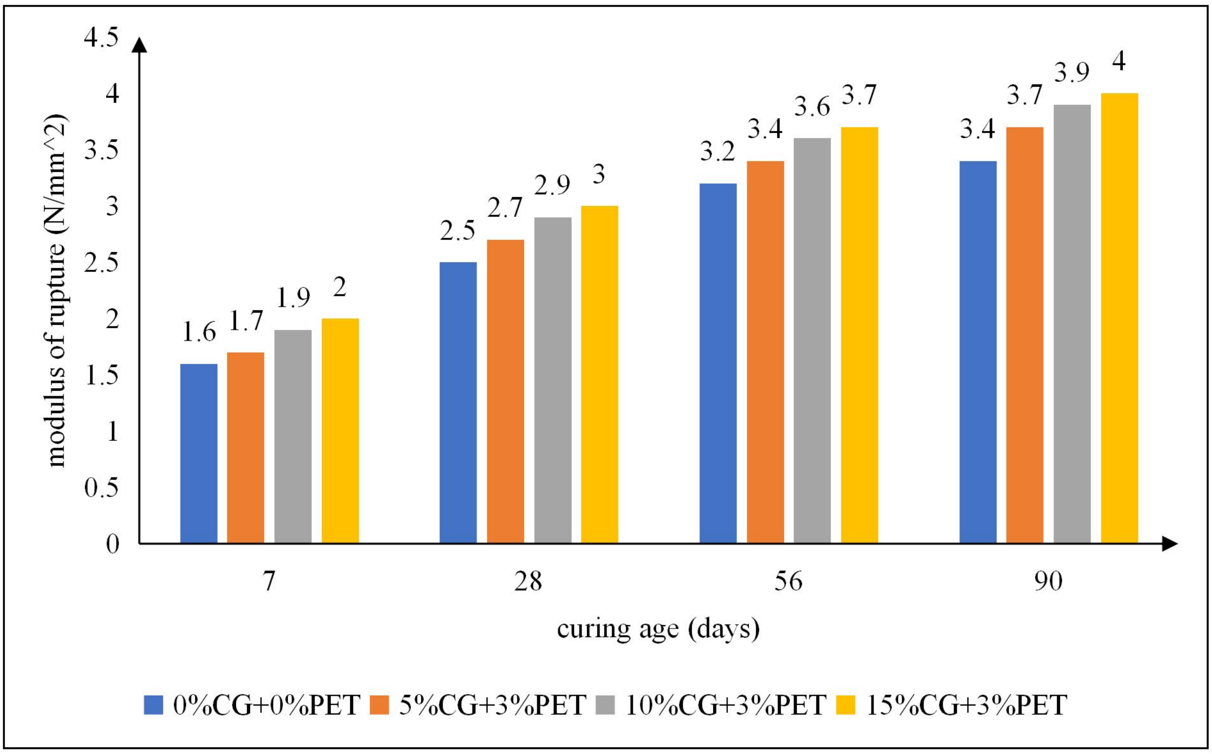

Fig. 9 Flexural strength development for additional different % of crushed glass & 3%PET

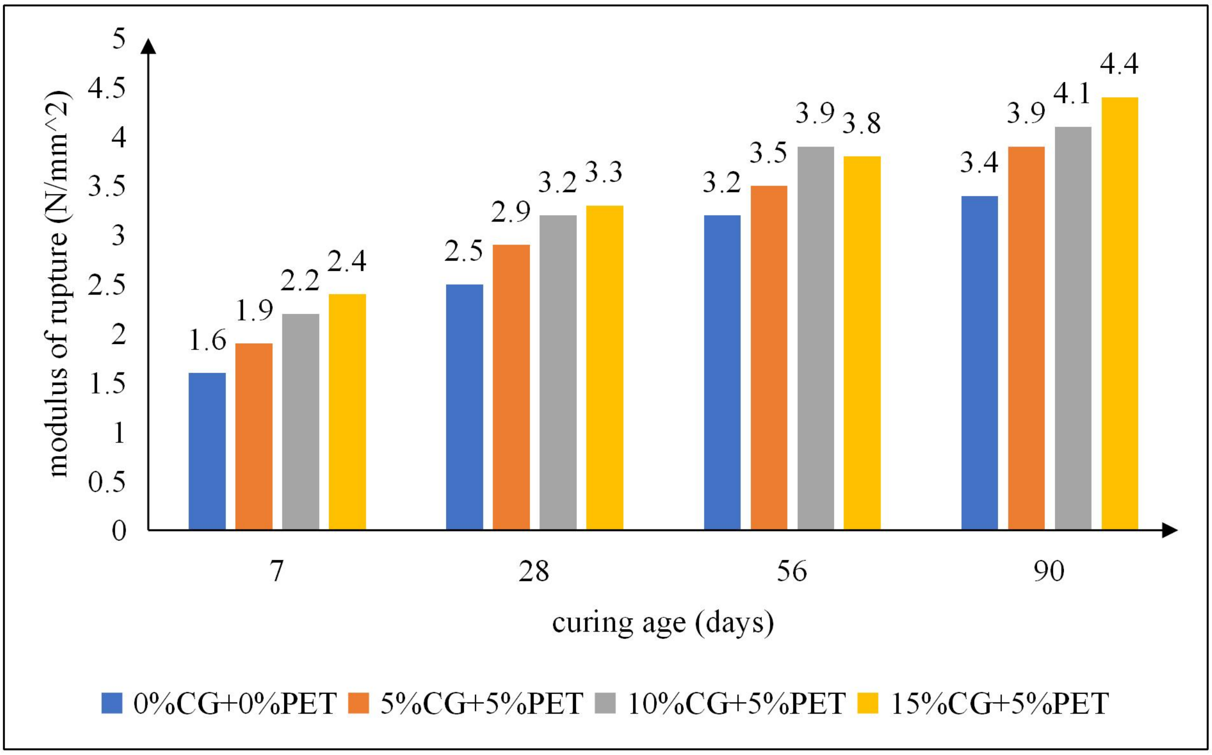

Fig. 10 Flexural strength development for additional different % of crushed glass & 5%PET

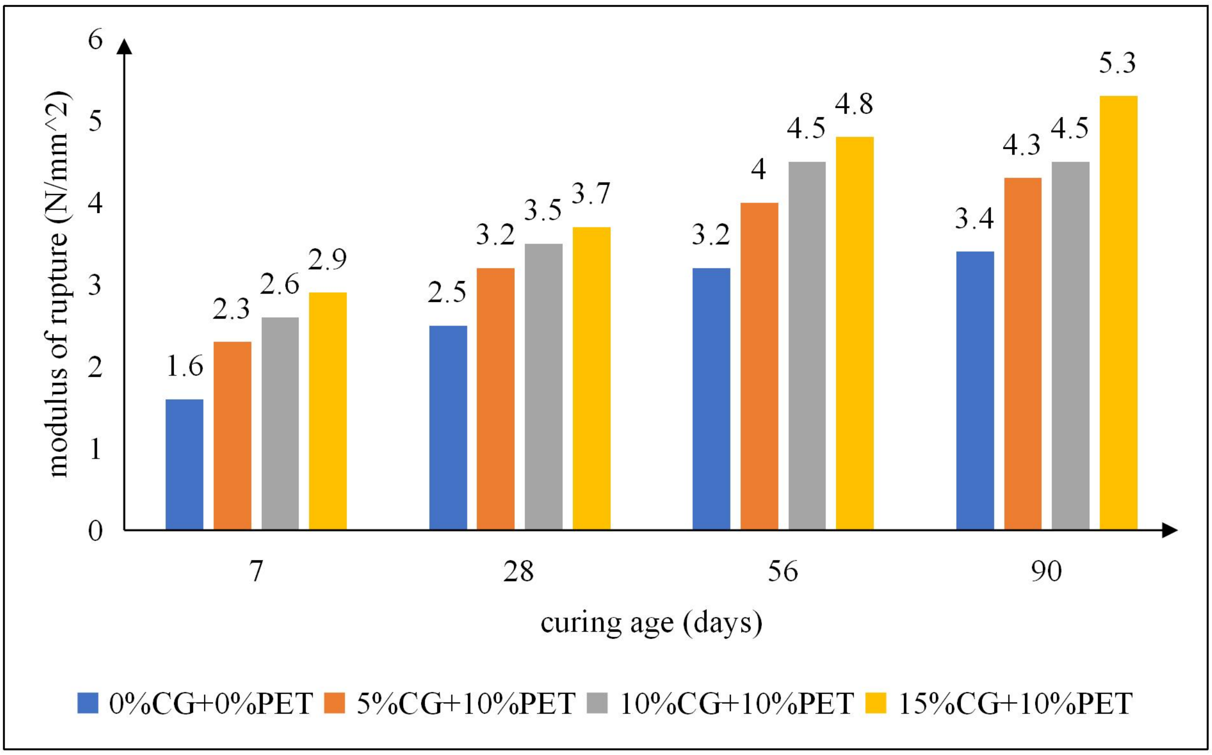

Fig. 11 Flexural strength development for additional different % of crushed glass & 10%PET

4. Conclusion

Up to now, there has been researches on different synthetic fibers and their significance in enhancing the performance of cement paste and concrete. In addition, the use of sustainable materials has been observed in many fields due to the environmental and economic considerations, where the utilizing of recycled plastic fibers certainly an important step towards sustainability. Many structures fail in shear and this type of failure often catastrophic and brittle without sufficient warning before the collapse. As is well known, fibers reinforcement is used to improve the structural performance and mechanical properties of the concrete member, but little is known about the influence of waste plastic fibers on the performance of concrete. For this reason, the influence of PET fibers on the strength and mechanical properties of concrete are investigated in this study. The findings from this research will give basis on the most suitable crushed glass and PET fibre content by percentage to be used in different construction projects. Also, it easier to understand how the use of PET fibre reinforced concrete can lead to cost savings, reduced material volume, reduced labor costs and improved abrasion in construction projects. Results show that the improve of compressive strength, flexural and cracks at the surface of concrete. They therefore need to be at an optimum volume or weight content to give the best results. The optimum crushed glass fibre dosage is between 10% and 15% by weight. This means that adding around 12% of crushed glass fibres and 5% of PET fibres give the best results of concrete strength parameters.

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7. Competing interests

The authors declare that they have no competing interests.

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