

Influence of nano-silica and shredded plastics in pervious concrete

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ABSTRACT

Regular concrete uses a lot of cement, which is bad for the environment. Adding plastic waste to concrete as a substitute reduces pollution, but it can weaken the concrete. This study tackles this problem by creating an eco-friendly concrete alternative. The researchers mixed shredded PET plastic bottles (up to 10%) with concrete and replaced some cement (up to 10%) with nano-silica. They tested how this affected the concrete's strength in different ways (bending, splitting, and compression). Interestingly, they found that using a specific mix (4% plastic and 4% nano-silica) actually made the concrete stronger! This suggests a promising new way to use recycled plastic to create a more sustainable and even stronger building material.

Keywords: Plastic pollution; Green concrete; PET bottles; Nano-silica; Mechanical properties.

1. INTRODUCTION

In recent years, the construction sector has been aggressively researching new materials and processes to address numerous concerns connected to sustainability and environmental impact. Plastic has become one of the world's most pressing environmental issues. More than 3.5 million metric tonnes of plastic garbage are generated annually in India, and over the past five years, it has nearly doubled per person. Our ecosystems are harmed by plastic pollution, which is also related to air pollution. Pervious concrete, also known as porous or permeable concrete, has emerged as a promising alternative for minimizing stormwater runoff, refilling groundwater supplies, and reducing the heat island effect in urban areas. This distinct type of concrete has a highly porous structure that allows water to permeate and travel through, making it an environmental friendly alternative to standard impermeable surfaces. Researchers and engineers have been researching the use of nano-scale additives such as nano-silica and shredded plastics to further improve the characteristics and performance of pervious concrete. Nano-silica, a nanostructured form of silica particles, and other forms of plastic additives have recently gained popularity because of their potential to improve the mechanical, hydraulic, and durability properties of pervious concrete [1].

There are various advantages of adding nano-silica to pervious concrete. Nano-silica particles have a significant surface area due to their nanoscale size, allowing for greater reactivity and strength development within the concrete matrix. Furthermore, the addition of nano-silica can result in improved workability, less bleeding, higher chemical resistance, and increased durability against freeze-thaw cycles. Because of these qualities, nano-silica is an appealing choice for improving the performance and longevity of pervious concrete structures [2, 3]. Using recycled waste plastic (RWP) to partially replace natural aggregates in concrete. While this is good for the environment, the bonding between RWP and cement is weak, limiting its use. The study investigates using ethylene-vinyl acetate (EVA) and nanosilica (NS) to improve this bonding for a more eco-friendly concrete alternative [4–6]. Similarly, the use of plastic additives in pervious concrete has yielded encouraging results. Plastics, when correctly processed and added to the concrete mixture, can help to increase strength, impact resistance, and cracking resistance. Furthermore, plastic materials can operate as a pore-blocking agent, reducing pervious concrete permeability while retaining porosity for water infiltration. The use of plastic additives in pervious concrete provides a potential solution to issues about pore-clogging over time and pavement lifespan [7–9].

A study on the fresh rheological characteristics and hardening characteristics of nano-silica-modified pervious concrete showed that the inclusion of nano silica enhanced permeable concrete's compressive strength by boosting slurry strength [2]. A similar study by TARANGINI *et al.* [3], showed that the characteristics of porous concrete mixtures are drastically altered by the nano-silica integration wherein, a drop in water

permeability corresponds with a rise in compressive strength. Substitution of LDPE pellets for natural aggregate increased the abrasion resistance of the concrete. However, this improvement came at the expense of the product's other desirable characteristics. It was established that the level of voids as well as penetration rate in pervious concretes increased as a result of the addition of LDPE pellets, but the fresh and dehydrated densities decreased as a result [10–12]. Evaluation on the impact of superplasticizer and NS on the behavior of PCPC showed that the specimens with NS fared better than the specimens made from the control mix [7]. Addition of NS to pervious concrete as a replacement for burned bricks showed that, despite an increase in material's, it showed detrimental impact towards pore characteristics [8]. Tests were also conducted to design interlocking pavement using the concrete mixes studied. The good news is that all three mixes absorbed less than 6% of water on average, which meets regulatory requirements [13–16]. Improvement in the durability of concrete upon addition of recycled plastic has also been reported [14, 17–19].

However, the effect of nano-silica and shredded plastics on the characteristics of pervious concrete deserves further exploration. To optimize the performance of pervious concrete integrating these additives, various parameters like dosage, particle size, mixing technique, and compatibility with other materials must be thoroughly investigated. Understanding how nano-silica and plastics affect the mechanical strength, permeability, porosity, and durability of pervious concrete is critical for its effective deployment in real-world applications [2, 5].

The purpose of this research is to investigate the effect of nano-silica and plastics on the performance of pervious concrete. We hope to provide valuable insights into the effects of these additions on the characteristics and behavior of pervious concrete by conducting a series of laboratory tests and analyzing the findings. The outcomes of this research project will add to the body of knowledge about the development of sustainable and high-performing pervious concrete materials, thereby promoting breakthroughs in the field of civil engineering and construction.

2. MATERIALS AND METHODS

2.1. Cement

This study employed ordinary Portland cement (OPC), the most popular kind of cement. 53-grade OPC cement was utilized in this experiment. Regular Portland cement that complied with IS 8112-1989 was used in the investigation. Cement has physical characteristics like a specific gravity of 3.13, a consistency of 31%, a fineness of 7%, and initial and final 32-minute as well as 320-minute setup times respectively.

2.2. Coarse aggregate

Crushed aggregates were obtained from local crushing plants and those aggregates that only passes through a 12.5 mm filter was used for the study. Grading values, tensile modulus, specific gravity, as well as bulk density, were measured and analyzed for the aggregates following IS: 2386-1963. All of the aggregates were mixed until the desired consistency was achieved. Crushed rock possesses a specific gravity of about 2.71 as well as absorbs just 1% of the water it is exposed to.

2.3. Fine aggregate

In the procedure, commercially available M sand was used. Fineness gradation, tensile modulus, as well as particular gravity were measured and analyzed for the mixture in line utilizing IS: 2386-1963. This sand has been employed after being dried out on the outside. Fine aggregates have a specific gravity equal to 2.66 with a water absorption rate of 2.0%.

2.4. Nano silica

Nanosilica, commonly known as quartz dust or silica dust, is a substance distinguished by a high SiO₂ content of above 99%. The properties of NS is shown in Table 1.

2.5. Shredded plastics

Shredded HDPE plastics were employed. Bottles for laundry detergent, bleaching shampoo, conditioner, dairy products, engine oil and even soap are commonly made from Type 2 plastic HDPE. The properties of HDPE Shredded Plastics are listed in Table 2.

2.6. Water

The concrete was made with potable water that is safe to drink and has a pH value of 6.5.

Table 1: Properties of nano-silica.

PHYSICAL PROPERTIES	VALUE OBSERVED IN THE INVESTIGATION
Average particle size	20–50 nm
SSA	220 m ² /g
Bulk density	0.25 g/cm ³
Specific gravity	2.2

Table 2: Properties of HDPE shredded plastics.

PHYSICAL PROPERTIES	VALUE OBSERVED IN THE INVESTIGATION
Specific gravity	0.92%
Water absorption	0.95%

2.7. Admixture

As an admixture, Auramix 200 is added to the mixture. For both low- and high-grade concrete, Auramix 200 is a high-performance superplasticizer. It is intended for applications where significant water reduction and prolonged workability retention are necessary. The properties of admixtures such as values of pH were obtained near 6.0 along with a specific gravity value of 1.03.

2.8. Mix proportion design

The method used in this research for designing pervious concrete mixes was inspired by the requirements of IS 10262:2009. In these tests, Nano-silica ranging from 0 to 10% was added at a rate of 2% intervals and plastics added ranging from 0 to 10 % at an increment of 2%. For each percentage of nano-silica, six different percentages of shredded plastics were used and a total of 36 combinations were investigated. The water-to-binder ratio in the present study was 0.33. Both IS 10262.2009 and ACI 522R-10 were followed during this experimental investigation.

Splitting tensile, compressive, as well as flexural strength tests, were performed on 7 and 28-day-old specimens of hard concrete. The suggested mix composition for pervious concrete calls for the following quantities: 1260 kg/m³ of coarse aggregate, 405 kg/m³ of cement, 100 kg/m³ of fine aggregate, 135.04 kg/m³ of water, and 8.18 kg/m³ of admixture.

2.9. Compressive strength of concrete

Thirty-six cubes, thirty-six cylinders, and thirty-six beams are included in each set wherein, totally 216 cubes, 216 cylinders, and 216 beams were made, as shown in Figure 1. Cubes of 150 × 150 × 150 mm were employed to evaluate the concrete's compressive strength. The necessary components were weighed under the mixed proportion. Concrete is applied to the cube mould after being mixed. IS code 516-1959 was followed in the building of the cube. The mould has had three layers of concrete poured into it. Regular tamping with a bar compacts each successive layer. These strokes of the bar must be evenly spaced over the cross-section of the mould. The samples are compacted by being smashed with a rodding rod 35 times for each layer. After compaction, the pervious concrete samples were allowed to sit in the mould for 24 hours [10].

2.10. Tensile strength of concrete

The splitting tensile strength test on a concrete cylinder constitutes a single approach to determine the tensile strength of the material, as shown in Figure 2. The procedure adheres to the guidelines outlined in IS 5816:1999. The tensile strength has been assessed using a cylinder mould that was 150 mm overall diameter as well as 300 mm length. Upon completion of heating, the mixture is poured into a mould that has been prepared with 5 cm of oil at a time followed by manual compression of each layer. The layer-specific taming bars' stroke is represented by the number 30. The moulds are taken off the pervious concrete specimen after twenty-four hours, and it is then marked and allowed to cure by being allowed to bury in a watery pond. Between the ages of 7 and 28 days, tensile splitting strength is tested using apparatus intended for compressive strength testing. By shattering a concrete cylinder, one may assess the material's resistance to stress. The process is made simpler by using codes from the IS 5816 1999 standard [20].



Figure 1: Compressive strength test setup.



Figure 2: Splitting tensile strength test setup.

2.11. Flexural strength of concrete

As per Figure 3, to evaluate the flexure strength in concrete, beams of 150 mm × 150 mm × 700 mm were created. The required ingredients were measured out based on the mix ratio. The mould for the concrete has three separate layers. To condense the layers, a standard tamping bar is utilized. The number of bar strokes used on each region of the mould need to be the same. To compact the samples, a steel rod is used to tamp down each layer 35 times. After the concrete samples were consolidated, they were left in the mould for 24 hours to allow the pervious concrete to fully cure. After 24 hours, the formwork is removed, and the pervious concrete specimen is marked as well as water-ponded to cure. The flexural strength test is performed between the ages of 7 and 28 days, and the procedure follows IS code 516–1959 [21].

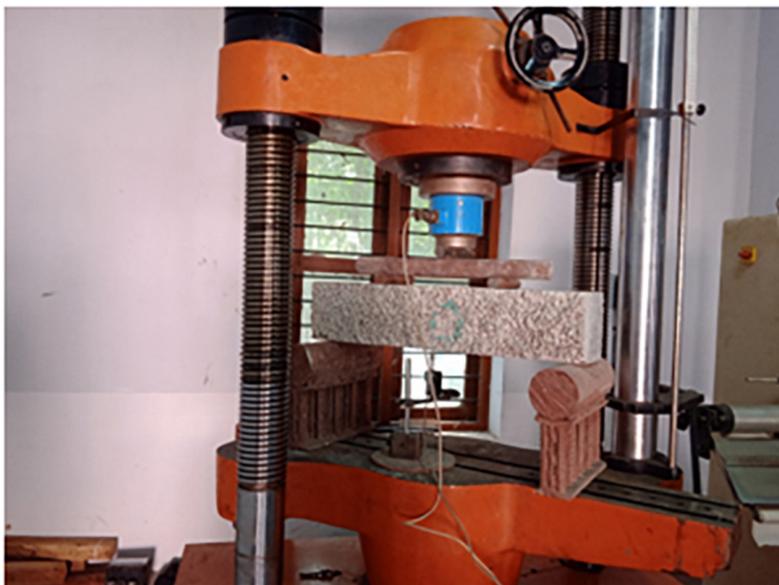


Figure 3: Flexural strength test setup.

3. RESULT AND DISCUSSION

3.1. Compressive strength

In this study, each set of six cubes ($150 \times 150 \times 150$ mm) replaced coarse aggregate with 0%, 2%, 4%, 6%, 8%, and 10% shredded plastics and cement with 0%, 2%, 4%, 6%, 8%, and 10% nano-silica. Six different percentages of shredded plastics were used for each percentage of nano-silica. As a result, 36 different combinations were investigated. A total of 216 cubes were cast. Compressive strength of pervious concrete having 0% nano-silica and 0–10% plastics is shown in Figure 4. Compressive strength of pervious concrete having 2% nano-silica and 0–10% plastics is shown in Figure 5. Compressive strength of pervious concrete having 4% nano-silica and 0–10% plastics is shown in Figure 6.

The pervious concrete's compressive strength increased from 33.35 N/mm^2 after 7 days to 44.89 N/mm^2 after 28 days because of the integration of 4% nano-silica and 4% pulverized polymers. This illustrates pervious concrete strengths improve as more nano sand and pulverized polymers are added to the mixture. When the right amount of plastic powder and nano-silica is applied, we have arrived at this stage. Only compressive strength testing findings that strictly adhered to the IS12727-1989 [17] standard were used in the present investigation. Compressive strength of pervious concrete was tested after 7 and 28 days along with the effect of increasing concentrations of nano-silica and pulverized plastic. Compressive stress was found to rise by 8.09% after 28 days when using 4% nano-silica and by 8.1% after 7 days when using shredded polymers at the same concentration. All types of pervious concrete showed improved compressive strength with curing of 28 days, compared to the initial 7 days. Compressive strength in rodding-compacted pervious concrete is 18.11 N/mm^2 after seven days and 24.78 N/mm^2 after 28 days, as determined by tests. Compressive strength of pervious concrete having 6% nano-silica and 0–10% plastics is shown in Figure 7. Compressive strength of pervious concrete having 8% nano-silica and 0–10% plastics is shown in Figure 8. Compressive strength of pervious concrete having 10% nano-silica and 0–10% plastics is shown in Figure 9. The concrete mixes with the greatest compressive strength included both nano-silica (4% by weight) as well as plastic shreds (4% by weight). These criteria were responsible for explaining the overwhelming bulk of the information that was gathered. The normal impact that aggregate size has on the modulus of tensile force of pervious concrete was nullified because the aggregate was maintained at the same size throughout the process. Shredded Plastic was originally used as a stress test for concrete. For this task, we utilized shredders.

Compressive strengths in concrete tend to be higher in older formulas with lower a/c ratios. One of the most difficult parts of making pervious concrete is obtaining a coating of cement slurry that is just the right thickness. The cement compound's porous connections, which allow water to infiltrate the substance, would be interrupted if it were made thicker. Therefore, when creating pervious concrete, it is crucial to pay particular attention to the proportions. Therefore, increasing the amount and quality of cement paste is the most efficient

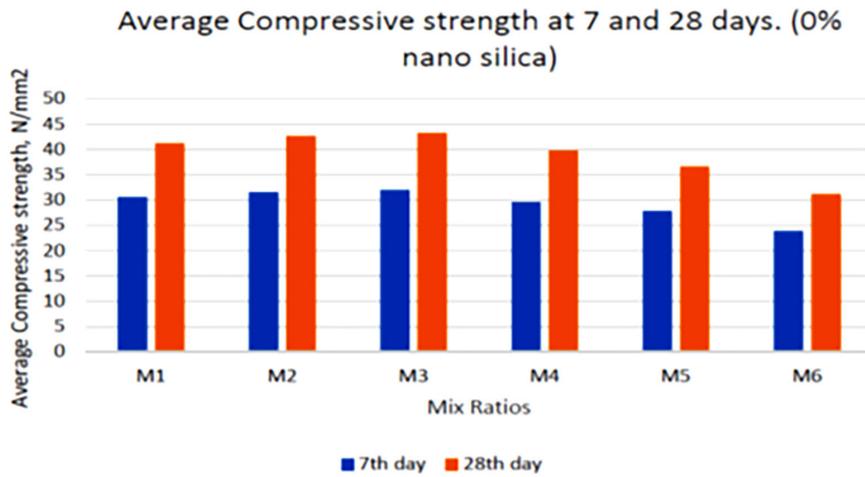


Figure 4: Compressive strength of pervious concrete having 0% nano-silica & 0–10% plastics.

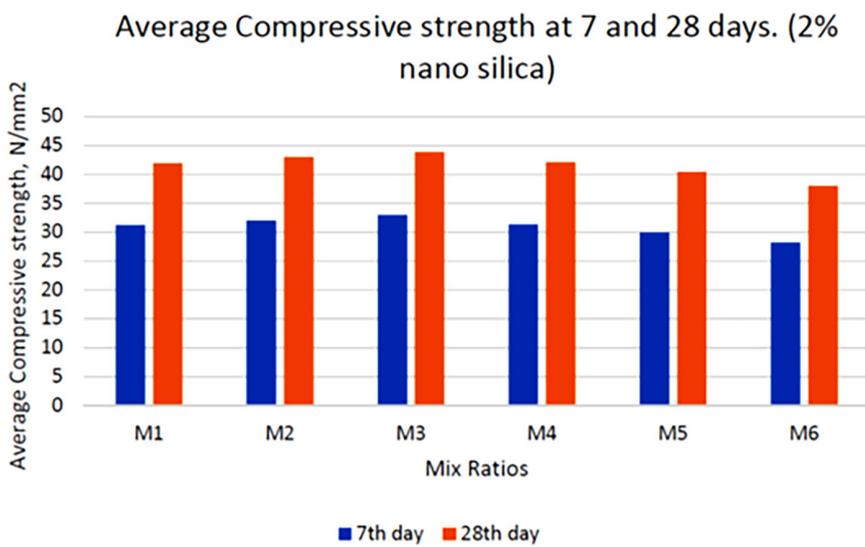


Figure 5: Compressive strength of pervious concrete having 2% nano-silica & 0–10% plastics.

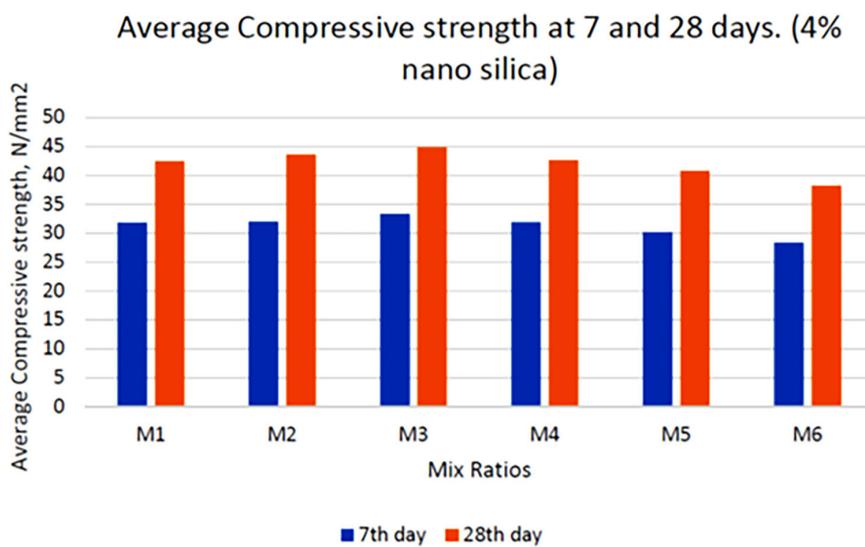


Figure 6: Compressive strength of pervious concrete having 4% nano-silica & 0–10% plastics.

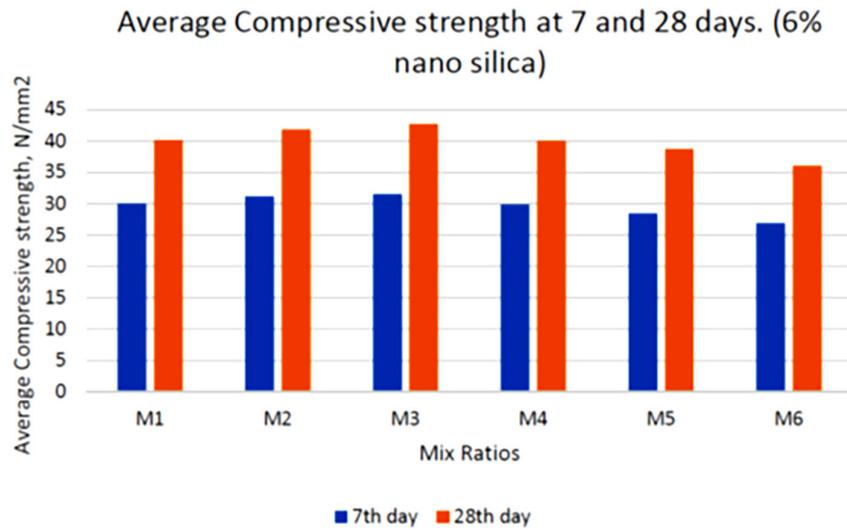


Figure 7: Compressive strength of pervious concrete having 6% nano-silica & 0–10% plastics.

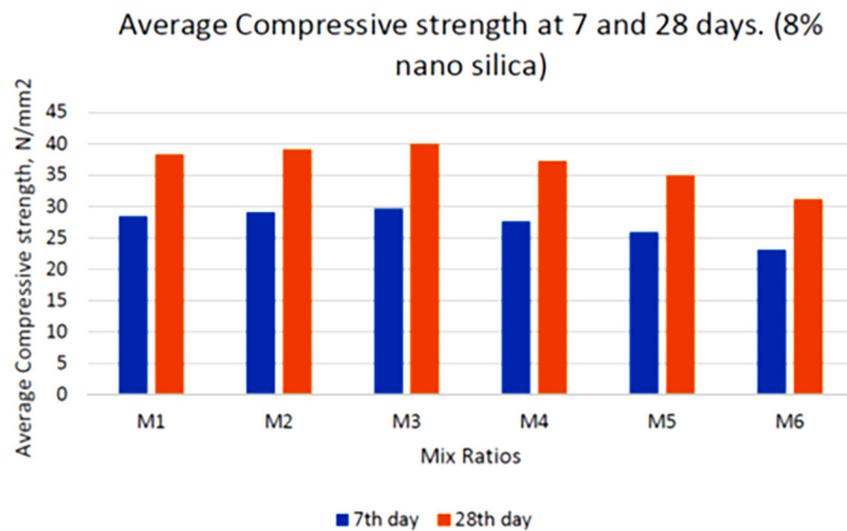


Figure 8: Compressive strength of pervious concrete having 8% nano-silica & 0–10% plastics.

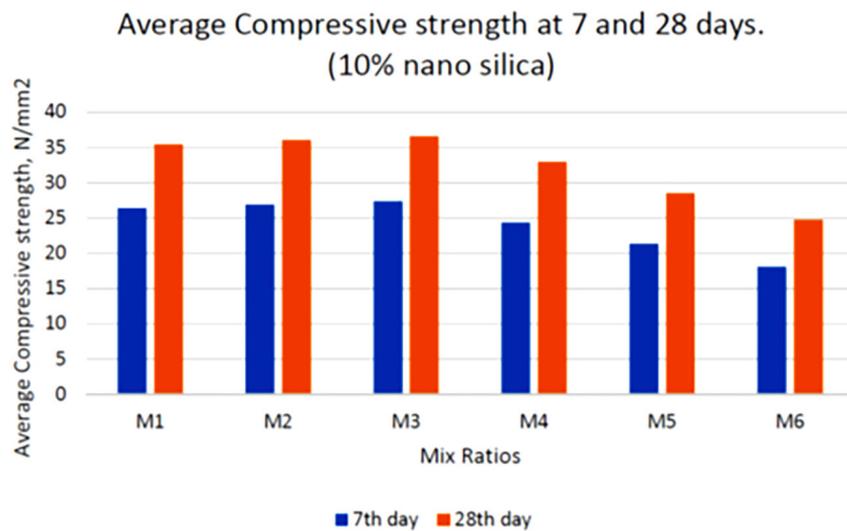


Figure 9: Compressive strength of pervious concrete having 10% nano-silica & 0–10% plastics.

way to raise compressive strength [21]. In addition, the amount of pulverized plastics in the material is inversely proportionate to the loss in compressive strength. The concrete's compressive strength drops dramatically when polymers are included in the manufacturing process. Plastics give under pressure more easily than natural aggregate because they are softer. Cement paste, which is less elastic than shredded plastic, is distorted together with both of them because of the low elasticity modulus of plastics. When polymers come into contact with pervious concrete, the cement material begins to fracture, leading to the collapse of the concrete at the cracks. The original concrete crumbles at lower compressive strengths due to the interaction between polymers and cement particles [22]. This is because cracks have appeared in the cement.

3.2. Split tensile strength

Aged concrete containing varying amounts of nano silica and shredded plastics showed an increased tensile strength at 7 and 28 days of aging. Splitting tensile strength of pervious concrete having 0% nano-silica and 0–10% plastics is shown in Figure 10. Splitting tensile strength of pervious concrete having 2% nano-silica and 0–10% plastics is shown in Figure 11. Splitting tensile strength of pervious concrete having 4% nano-silica and 0–10% plastics is shown in Figure 12. Splitting tensile strength of pervious concrete having 6% nano-silica and 0–10% plastics is shown in Figure 13. Splitting tensile strength of pervious concrete having 8% nano-silica and 0–10% plastics is shown in Figure 14. Splitting tensile strength of pervious concrete having 10% nano-silica and 0–10% plastics is shown in Figure 15. Nano-silica concrete and recycled plastic demonstrated an initial difference in splitting tensile strengths at 7 and 28 days, as indicated by the general contour of the strength graph. This was true regardless of how long ago the concrete had been poured. When nano-silica as well as polymers were added, the splitting tensile strength went up after a certain point. However, nano-silica along with polymers was institute to significantly reduce splitting tensile strength. Therefore, the tensile strength against cracking in the existing concrete was increased. The tensile strengths at the failure of older concrete mixes prepared at the a/c ratio have been examined. When concrete cracks, the damage spreads throughout the material, including the aggregate, the cement paste, and the grout between the two surfaces. The cracking route goes right through the concrete's weak spot. In concrete's with typical or poor strength, the most vulnerable parts are frequently the paste consisting of cement as well as the transition zone between the two surfaces. We can make concrete stronger by improving the consistency of the mortar as well as the zone where the two parts meet [21].

The relationship between compressive stress and splitting tensiles strength of pervious concrete on the 7th day is shown in Figure 16. Figure 17 shows the relationship between compressive stress and splitting tensile strength of pervious concrete on the 28th day.

Pervious concrete containing no nano-silica or polymers had a tensile strength of 3.78 N/mm² after 7 days and 5.02 N/mm² after 28 days when tested for splitting strength. Tensile strength at break was greatest when 4% nano-silica and 4% shredded plastics were utilized for 7 days, and 6.85 N/mm² and 28 days, respectively. This was the case during the testing of the drug. Using 10% nano-silica and 10% polymers resulted in the lowest strength. The 7-day and 28-day minimums were 2.75 and 3.76, respectively. The R-squared values of 0.973982 for the seventh day and 0.969996 for the twenty eighth day, as shown in Figures 16 and 17, a correlation with the compressive as well as splitting tensile strengths was found in the concrete used in the prior experiments.

When the plastic component was increased by more than 4%, the tensile strength of the concrete drastically dropped. The findings of the test were affected by the same problem that reduced the material's compressive strength. Since shredded plastic is more malleable than the natural aggregate particles, it had an immediate and noticeable influence on the pervious concrete's overall strength. The stiffness of the natural aggregate particles led to this effect. Flexural strength is favoured above tensile strength due to the increased likelihood of an object breaking under stress. After 7 days of curing, the tensile strengths of the experimentally manufactured pervious concrete mixes ranged from 5.1% to 2.75%, and after 28 days, they ranged from 6.85% to 3.763%. After the relationship between the two types of strength has been established, it will be evident that the tensile strengths used in this study range from 6.5% to 8.1% of the compressive strength values. This will become evident after the relationship between the two sorts of power is established. After the relationship between the two sorts of power is established, the finer details will become evident.

3.3. Flexural strength

The flexural strength assessment was done at both 7 and 28 days. After 7 days, the highest flexural strength was 5.40 N/mm², and after 28 days, it was 7.27 N/mm². Combining 4% nano-silica with 4% polymers yielded the best results. After 7 days, the minimum value was 2.93 N/mm², and after 28 days, it was 4.01 N/mm², which was achieved with 10% nano-silica and 10% shredded plastics. With no nano-silica or polymers added, the flexural strength increased from 4.97 N/mm² on day 7 to 6.68 N/mm² on day 28.

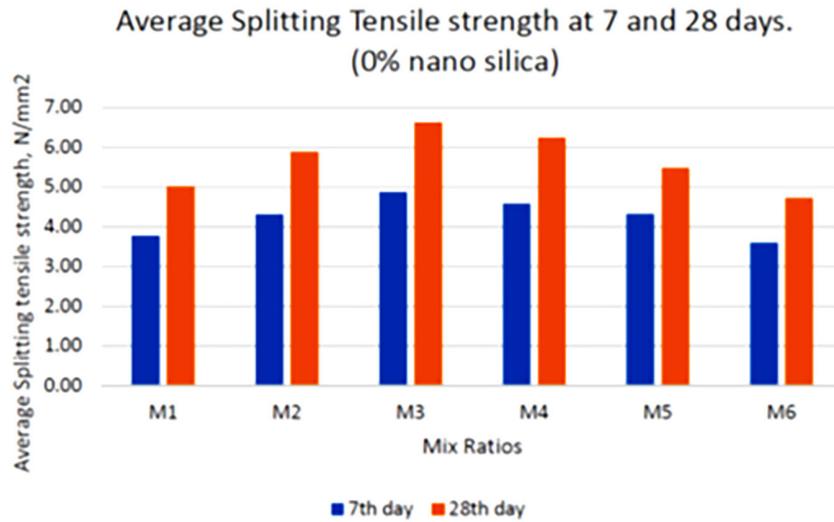


Figure 10: Splitting tensile strength of pervious concrete with 0% nano-silica and 0–10% plastics.

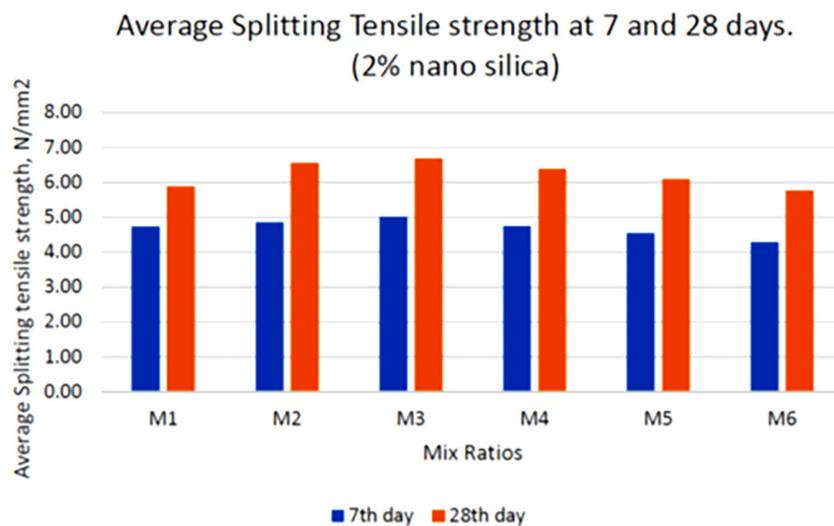


Figure 11: Splitting tensile strength of pervious concrete with 2% nano-silica and 0–10% plastics.

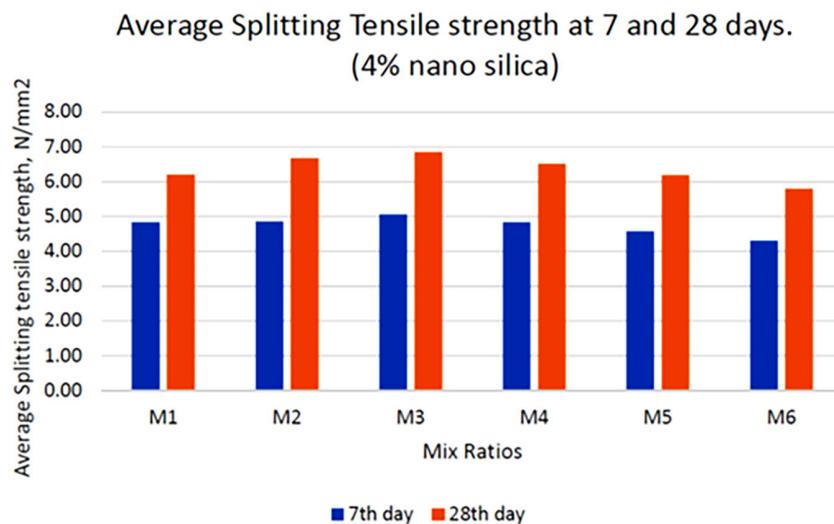


Figure 12: Splitting tensile strength of pervious concrete with 4% nano-silica and 0–10% plastics.

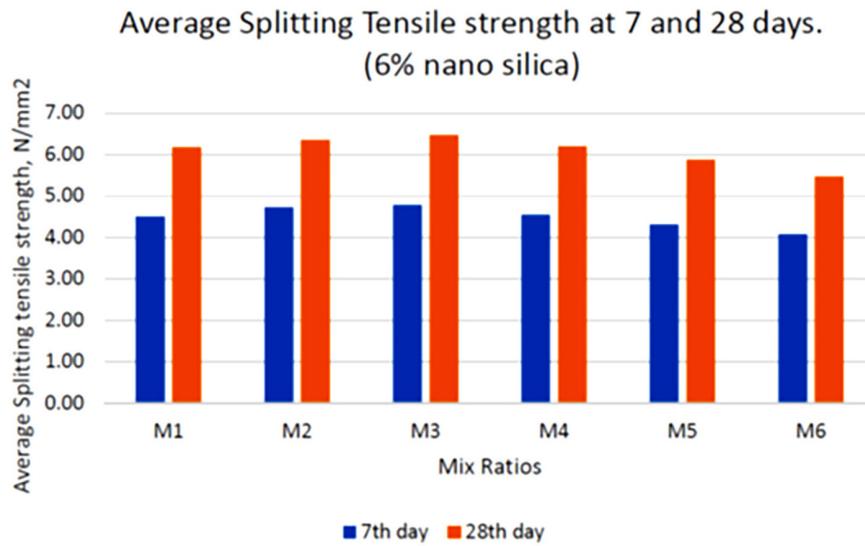


Figure 13: Splitting tensile strength of pervious concrete with 6% nano-silica and 0–10% plastics.

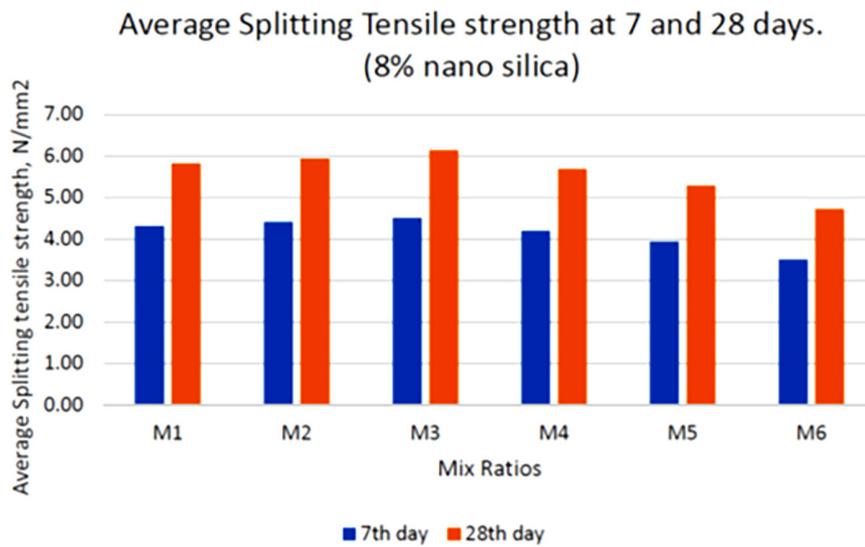


Figure 14: Splitting tensile strength of pervious concrete with 8% nano-silica and 0–10% plastics.

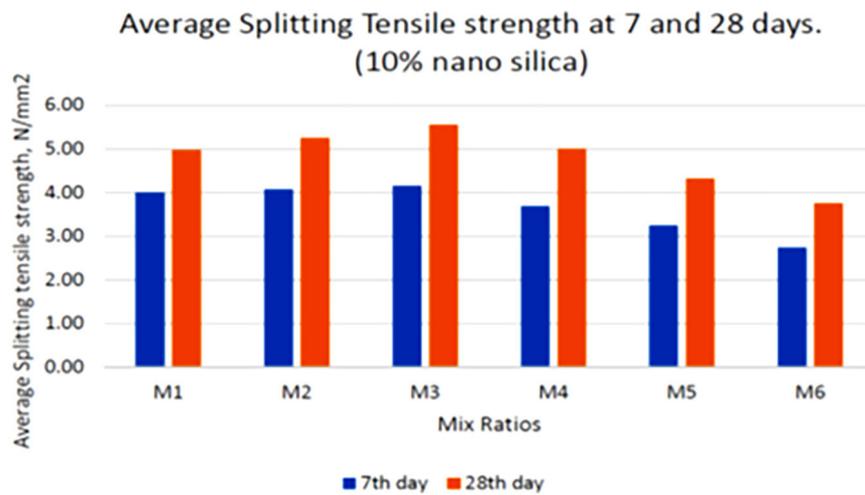


Figure 15: Splitting tensile strength of pervious concrete with 10% nano-silica and 0–10% plastics.

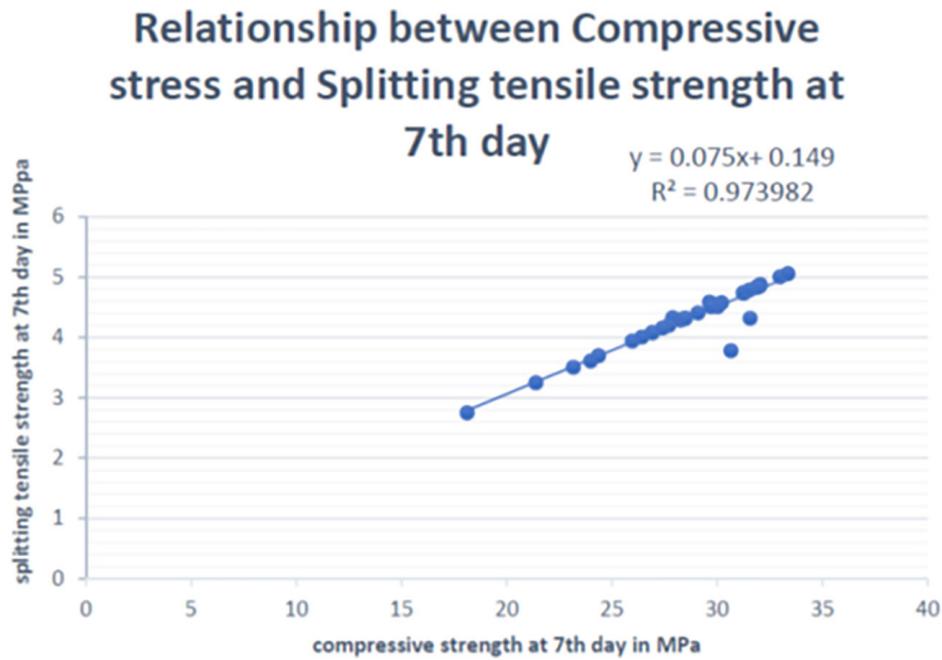


Figure 16: Relationship between compressive stress and splitting tensile strength of pervious concrete on the 7th day.

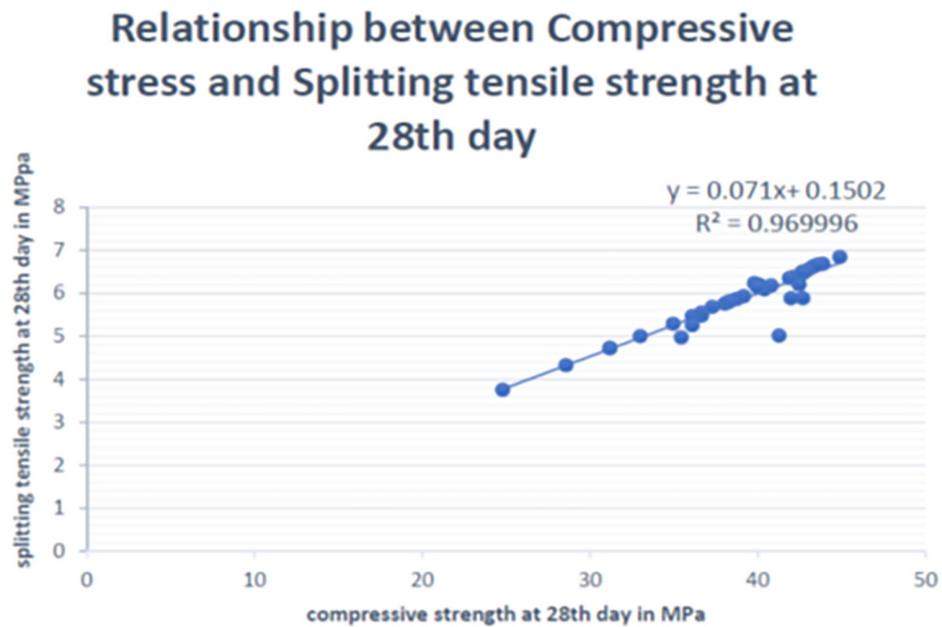


Figure 17: Relationship between compressive stress and splitting tensile strength of pervious concrete on the 28th day.

The flexural strength of pervious concrete having 0% nano-silica and 0–10% plastics is shown in Figure 18. Figure 16 shows that the flexural strength of the mixtures improved up to a certain degree with the addition of plastics. Figures 19 and 20 also showed that nano silica improved the mixtures' flexural strength, but only up to a point. Flexural strength increased up to a certain limit when nano-silica and shredded polymers were used. The reason for this is that the bending energy absorption and elasticity of plastic fibers have a significant impact on concrete's flexural strength. Flexural strength is enhanced when nano-silica was used to replace 4% of the cement and shredded plastics were used to replace 4% of the coarse aggregate. The gel can be introduced into the matrix by a reaction between nano-silica and hydration products like Ca(OH)_2 , as reported in the literature. Nano-silica's pozzolanic reactivity allows it to quickly consume Ca(OH)_2 , which boosted early-age strength when added to concrete mixtures as a PR of cement [22]. The results demonstrate that

adding the right quantity of nano-silica as well as plastics to previously used concrete may increase its flexural strength. The best flexural strength was achieved with a combination of 4% nano-silica and 4% polymers. All of the flexural strength test results in this research are under the international standard IS12727-1989 [17]. Flexural strength of pervious concrete having 6% nano-silica and 0–10% plastics is shown in Figure 21. Flexural strength of pervious concrete having 8% nano-silica and 0–10% plastics is shown in Figure 22. Figure 23 shows flexural strength of pervious concrete having 10% nano-silica and 0–10% plastics.

Compressive and flexural strengths were shown to correlate well in Figure 24 for the 7th day and Figure 25 for the 28th day. On day 7, the R-squared value was 0.999996, and on day 28, the value was 0.999986. This result suggests that there is a robust correlation among those splitting tensile as well as compressive strengths of the created concrete in the study.

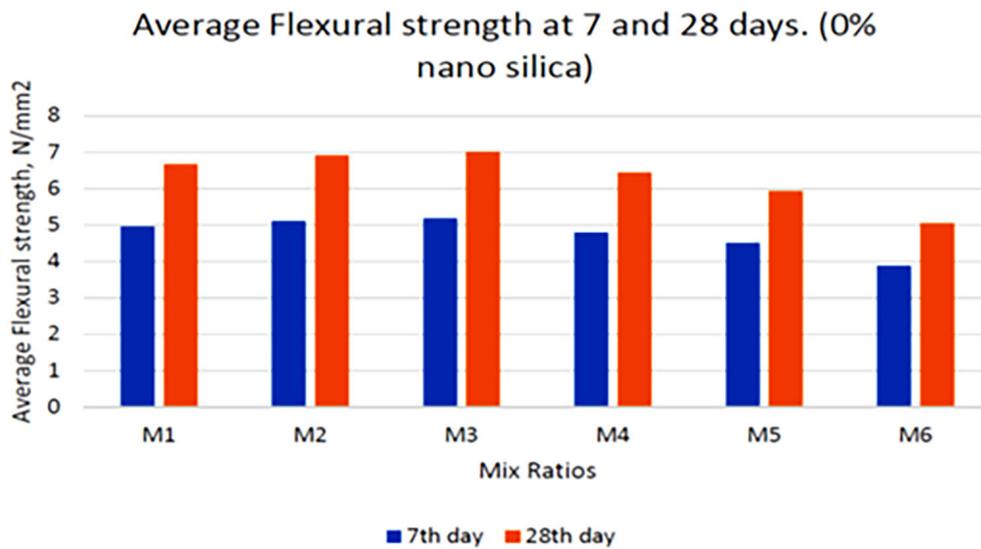


Figure 18: Flexural strength of pervious concrete having 0% nano-silica & 0–10% plastics.

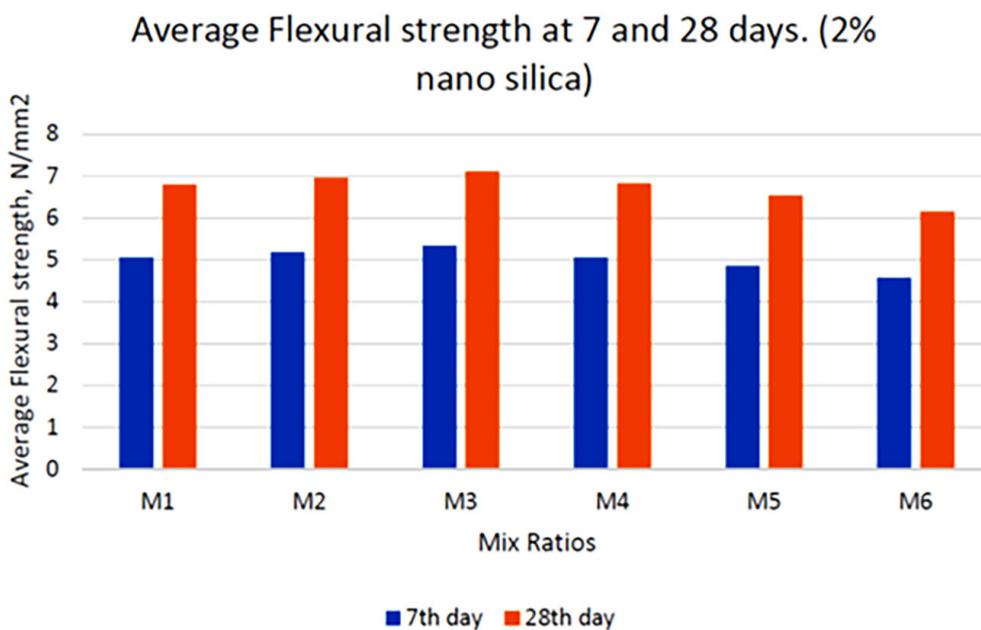


Figure 19: Flexural strength of pervious concrete having 2% nano-silica & 0–10% plastics.

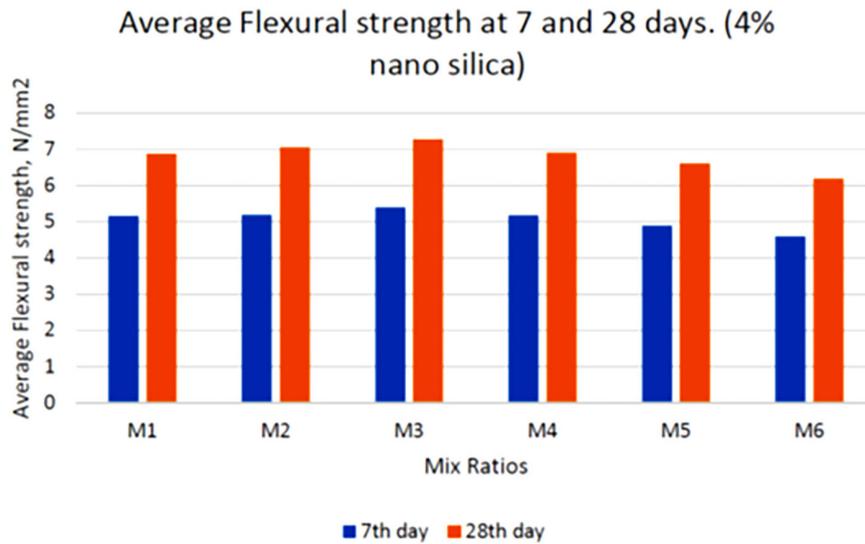


Figure 20: Flexural strength of pervious concrete having 4% nano-silica & 0–10% plastics.

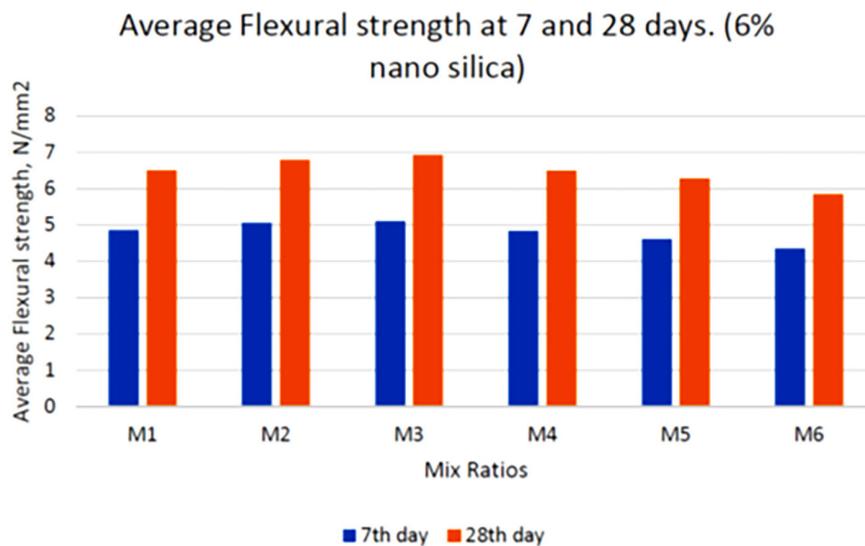


Figure 21: Flexural strength of pervious concrete having 6% nano-silica & 0–10% plastics.

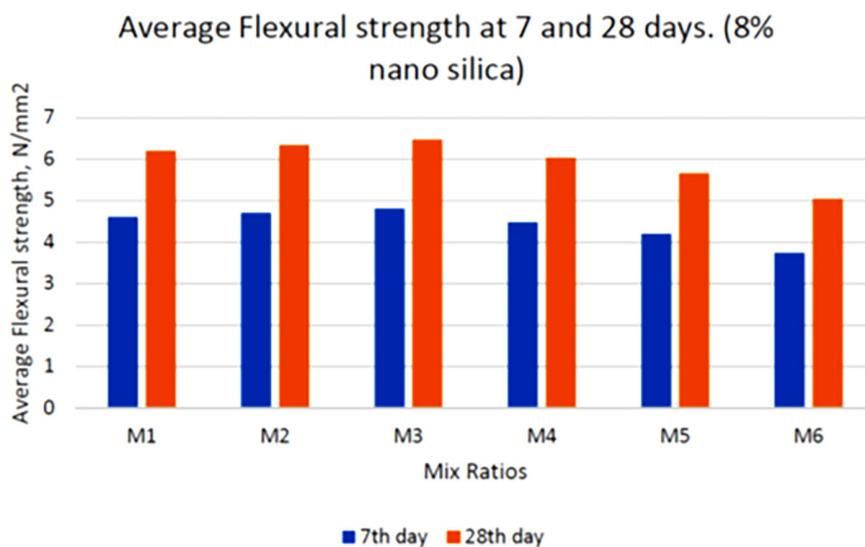


Figure 22: Flexural strength of pervious concrete having 8% nano-silica & 0–10% plastics.

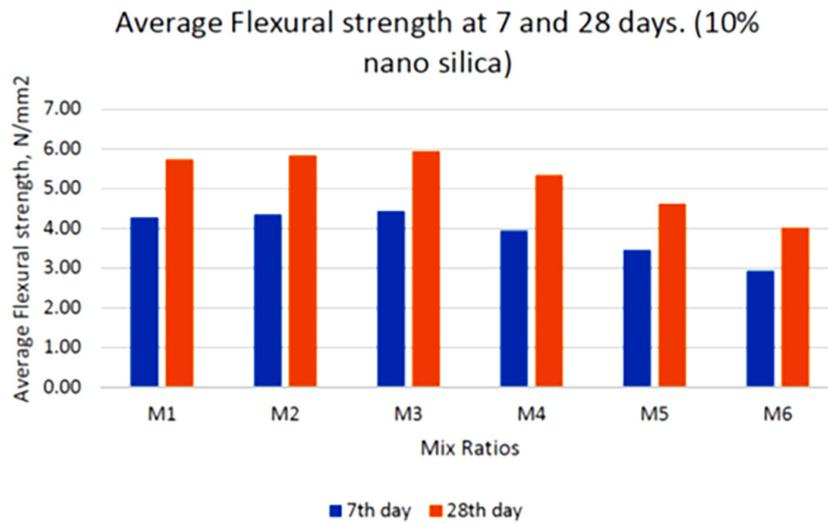


Figure 23: Flexural strength of pervious concrete having 10% nano-silica & 0–10% plastics.

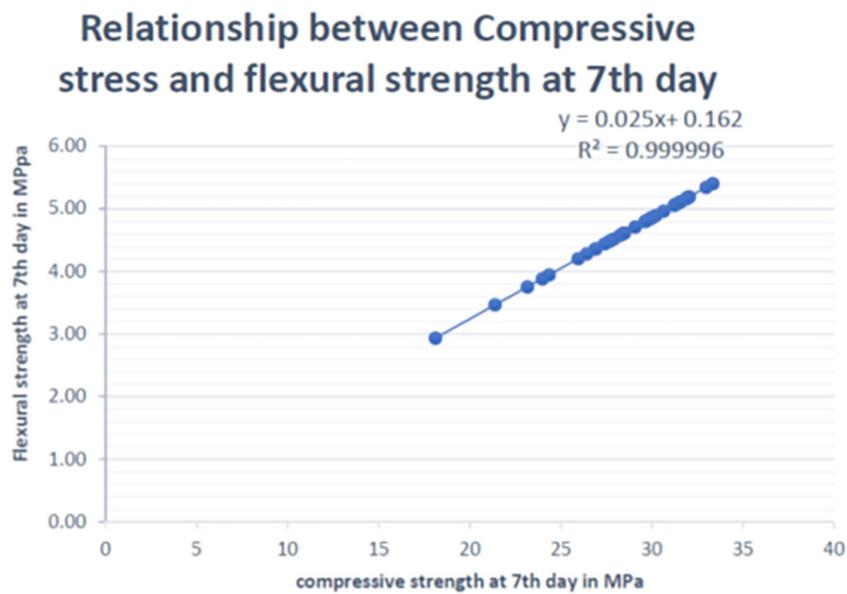


Figure 24: Flexural strength and compressive stress of pervious concrete on the 7th day.

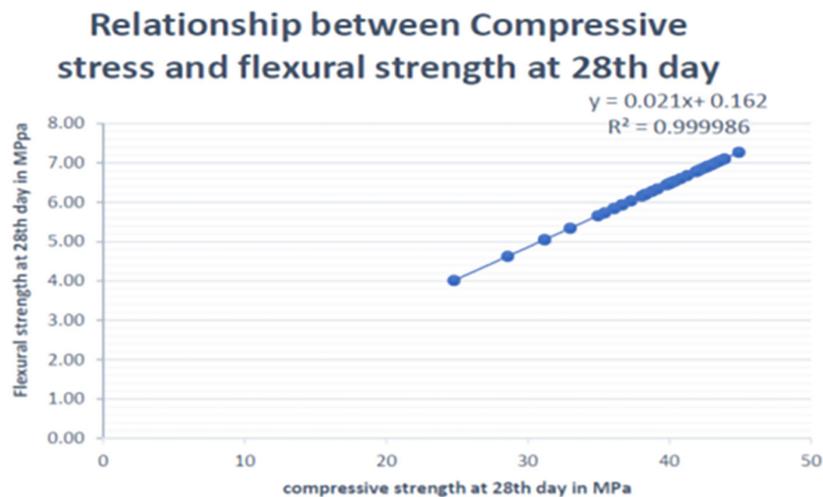


Figure 25: Flexural strength and compressive stress of pervious concrete on the 28th day.

4. SUMMARY AND CONCLUSION

To assess the effectiveness of pervious concrete constructed using crushed plastic being coarse aggregate with nano-silica as the cement, a test method was created. The conclusion was arrived at after extensive testing as follows:

- Recycled plastic and nano-silica in concrete could be a major eco-friendly breakthrough for construction. It reduces waste, improves water management, and offers a sustainable use for disposable plastics.
- Tests showed the best strength in concrete mixes with a 4% blend of plastic and nano-silica. Higher or lower ratios of nano-silica to plastic resulted in lower compressive strength. This suggests an optimal balance between these two components for maximum strength.
- Tests showed the best splitting tensile strength in concrete mixes with a 4% blend of plastic and nano-silica. Higher or lower ratios of nano-silica to plastic resulted in lower tensile strength. This suggests an optimal balance between these two components for maximum strength.
- Similar to the other tests, the best flexural strength was achieved with a 4% mix of nano-silica and shredded plastic. Higher or lower ratios resulted in weaker concrete, with the 10:1 ratio of nano-silica to plastic having the lowest strength. This suggests an optimal balance between these components for maximum flexural strength.
- Adding plastic to pervious concrete can be a double-edged sword. While plastic fills gaps between larger aggregate particles, it also reduces the overall air void space in the concrete. This can be countered by increasing the water-to-cement ratio, but that's not ideal for concrete strength.
- Adding shredded plastic to pervious concrete reduces its overall density because plastic is lighter than natural aggregate. Permeable qualities are also affected. Plastic fills gaps between aggregate particles, reducing water flow (permeability). This can be countered somewhat by adding more water to the cement mix, but that's not ideal for strength. The study found that despite some reduction in permeability due to plastic, it remained within acceptable limits.

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