Global NEST Journal, Vol 26, No 1, pp 05402

Influence of utilizing prosopis juliflora ash as cement on mechanical properties of cement mortar and concrete

Karthikeyan G.[1]*, Leema Margret A.[1], Muruganantham R.[1] and Harshani R.[2]
[1]Department of Civil Engineering, Ramco Institute of Technology, Rajapalayam–626117, Tamilnadu, India
[2]Department of Civil Engineering, National Engineering College, Kovilpatti–628503, Tamilnadu, India
Received: 24/09/2023, Accepted: 13/11/2023, Available online: 14/11/2023
*to whom all correspondence should be addressed: e-mail: karthikeyang@ritrjpm.ac.in
https://doi.org/10.30955/gnj.005402

Graphical abstract

Abstract

The infrastructure of the country heavily depends on the construction material concrete. The primary ingredient in conventional concrete is cement, fly ash, or another cementitious substance. The need to explore alternative sources is driven by the challenges posed by global environmental warming, which stems from widespread factors, and the escalating costs associated with the extraction of cement from quarries. To replace cement, sand, and aggregate, numerous research investigations have been conducted. The Prosopis Juliflora Ash (PJA) as an additional cementitious component in cement mortar and concrete are examined in this experimental study. The amount of cement produced in the nation will decrease if PJA is used as an additional substitute. It will also encourage the use of sustainable materials for concrete and mortar. The objective of this research is to investigate the impact of incorporating PJA as a binding agent on the compressive strength, split tensile strength, and flexural strength of both concrete and cement mortar. In this research, Prosopis Juliflora Ash (commonly known as Seemaikaruvelam) was employed to substitute cement in both cement mortar and concrete, with varying proportions of 10%, 20%, 30%, 40%, and 50%.According to the results of this experiment, 30% of PJA has the requisite strength qualities. This experimental investigation provides valuable insights into the mechanical characteristics of concrete and mortar incorporating PJA and emphasizes its potential as a sustainable alternative in the construction industry.

Keywords: Prosopis juliflora, mechanical properties, cement mortar, concrete, compressive strength

1. Introduction

The construction sector contributes significantly to environmental degradation and resource depletion. Cement, the most extensively used building material, emits a significant amount of carbon dioxide (CO_2) due to the energy-intensive manufacturing process. Furthermore, rising cement demand has resulted in the loss of natural resources such as limestone and clay. As a result, it is critical to look for sustainable alternatives that might reduce the environmental risks associated with cement use. [Kathirvel *et al.* 2019]. One such option is to use waste materials as Supplementary-Cementitious Materials (SCMs) in construction applications. SCMs not only help to conserve natural resources, but they also aid to reduce CO_2 emissions. Prosopis Juliflora Ash (PJA), a waste substance formed from the combustion of Prosopis Juliflora, an invasive plant species found worldwide, has recently attracted attention as a possible SCM in construction materials [Dharmaraj *et al.* 2020]. Prosopis juliflora, also known as mesquite, is a highly invasive shrub that causes significant ecological and socioeconomic issues. It colonises enormous swaths of land, depleting water supplies and displacing local flora and animals. Control and eradication strategies for PJA have proven to be expensive and difficult. Prosopis Juliflora decreases soil fertility by restricting biological nitrogen fixing and depletes the water table via deep penetrating roots that can suck water from deeper strata. Thus, developing long-term, ecologically acceptable ways to managing this invasive plant species is critical [Kumar and Singh 2017, Manisha Sri *et al.* 2018]. When PJA is used in concrete, it becomes less of an environmental hazard and more of a valuable resource for making an extremely successful substitute cement. It has pozzolanic properties, and utilising it as a partial replacement for cement may be one of the better applications in the present environment scenario [Kamesh *et al.* 2018]. The compressive strength of the cubes at the 28-day mark the strength requirement for all three replacement percentages. The study identified that the most favorable outcome was achieved when 25% of the cement was replaced with PJA, resulting in improved compressive strength at 3, 7, 14, and 28 days [Shyamala *et al.* 2020].

The impact of PJA on the mechanical behaviour and microstructure of mortar was investigated by the researcher. The observation of the workability of the blends revealed that the mixtures combining cement and PJA, specifically those with 10% and 20% PJA, exhibited optimal workability within a water range of 35%, ensuring the desired consistency. However, for mixtures containing 30% and 50% PJA, the consistency value increased to 38%. This research found that the incorporation of PJA as a substitute for cement resulted in an improvement in compressive strength and a reduction in the porosity of the mortar [Sarala 2008, Murugan *et al.* 2017]. The researchers linked these benefits to the pozzolanic properties of PJA, which promoted the formation of calcium silicate hydrate (C-S-H) gel. This gel is known for enhancing the strength and durability of cementitious materials [Raguraman *et al.* 2021, Praveena *et al.* 2018]. In this investigation, paver blocks with varying proportions of fly ash (ranging from 0% to 25%) were subjected to compressive strength testing. The findings indicated that when 20% of the fly ash was substituted for OPC 33 grade cement, the resulting combination exhibited superior strength compared to the conventional mix. While it initially seems that the Compressive Strength increases with higher levels of Fly Ash incorporation, there appears to be a decrease in strength beyond a 20% replacement. Notably, after a 28-day period, paver blocks exhibit robust compressive strength when 20% Fly Ash partially replaces cement. Specifically, at 7, 21, and 28 days, the peak compressive strength for paver blocks utilizing OPC 33 grade cement with a 20% Fly Ash content measures at 28, 36, and 42 MPa respectively. While the use of PJA as an SCM in concrete and mortar has been investigated, its application in paver blocks has received less attention. However, more research is required to investigate the unique properties and performance of paver blocks containing PJA. In comparison to a control mix that only contained natural aggregate, five mixes were developed, each containing waste glass in amounts of 15, 20, 25, 30, and 40% as a partial substitution for fine aggregates [Saranya *et al.* 2022].

The experimental findings indicate that the partial replacement of cement with PJA does not lead to any discernible alterations in the mechanical properties of cement concrete and 20% replacement results in mechanical qualities that are comparable to those of regular cement concrete mixtures. Due to its elevated SO3 content in comparison to cement, PJA can effectively replace up to 20% of the cement in concrete production. As a result, the formation of ettringite takes a prolonged period to initiate. Alite formation may also be hampered. This results in a large decrease in groundwater loss brought on by PJA expansion, as well as a decrease in pollution rate brought on by the effective use of PJA and lower cement production. The reduction in mechanical properties of OPC (Ordinary Portland Cement) with higher PJA (Plazolite) replacement levels can be primarily attributed to the increased intensity of Plazolite formation. However, as the volume of PJA rises, the expansion of the mixes diminishes due to the constrained availability of free MgO within PJA. Interestingly, this reduction in expansion improves the ductility of reinforced concrete beams [Kathirvel *et al.* 2019].

To ensure that the desired levels of both strength and workability were upheld, slight adjustments were required in each mix design. This was due to the fact that broken glass exhibited a lower fineness modulus compared to fine aggregate. Using a water cement ratio of 0.45, In this study, three distinct concrete mix categories, which encompassed the control mix (involving substitutions of natural aggregate at 5%, 10%, 15%, and 20%). From the results of such investigations will advance our understanding of how to use waste materials and shed light on sustainable construction methods. Cement, sand, coarse aggregates, and various concentrations of PJA were combined to create the paver blocks, which served as a cement substitute. The specimens were crafted in accordance with the relevant requirements and strictly inspected while they dried. The compressive strength of the paver blocks was assessed following the essential curing period employing a Compression Testing Machine (CTM). To understand the influence of PJA content on the strength attributes of the paver blocks, an analysis and comparison of the results obtained from the compressive strength test were conducted. Paver blocks are frequently used in pavements, walkways, and driveways because of their durability and aesthetic appeal [Kathirvel *et al.* 2019]. In terms of strength, toughness, and environmental sustainability, using PJA in paver block production may be very advantageous. Last but not least, one way to build sustainably is to use PJA as a substitute for some of the cement in paver bricks. As per prior research, PJA has been shown to improve the mechanical and durability properties of both mortar and concrete.

One of the fundamental and critical attributes influencing the extent and occurrence of cracks in structures is the tensile strength of concrete. Concrete exhibits significant vulnerability to tension due to its inherent brittleness, making it unsuitable for direct tension loads. When the tensile stresses exceed the material's tensile strength, concrete inevitably develops cracks. To establish the point at which concrete members may experience cracking, it becomes imperative to ascertain the concrete's tensile strength. A means of determining this is through a splitting tensile strength test conducted on a concrete cylinder, which offers a method for evaluating concrete's resistance to tensile forces [Dharmaraj and SivaKumar 2020].

This research stands out for its utilization of Prosopis Juliflora Ash (PJA) as a partial replacement for cement, spanning a range from 0% to 50% by weight. Its aim was to delve into the mechanical characteristics of both cement mortar and concrete.

2. Materials and methods

2.1 Cement

Ordinary Portland Cement (OPC) with a grade of 53, adhering to the specifications outlined in IS: 12269-2013, was obtained from Virudhunagar and tested for consistency, fineness, and soundness in accordance with IS 4031:1988. Similarly, the cement's specific gravity was calculated in line with IS 2720-1980. The specific gravity is 3.12 and the soundness is 4.6mm. Table 1 displays the attributes of the cement.

Table 1. Physical Properties of Cement

Test	Result
Specific gravity	3.12
Cement Consistency	31.5 %
IST of cement	70 minutes
FST of cement	395 minutes
Soundness	4.6mm

2.2 Prosopis juliflora ash (PJA)

Prosopis Juliflora Ash was obtained from Rajapalayam. It was made by uncontrolled burning of wood (Prosopis Juliflora) and fired in a furnace at 550^0 degrees Celsius for 240 minutes. The PJA was sieved via an IS 90 m sieve. PJA has been added to concrete and mortar to boost their durability. To partially substitute cement, Prosopis Juliflora Ash (PJA), which possesses a specific gravity of 3.10 and an average particle size measuring 35 microns, was employed in this study (Table 2).

Table 2. Physical Properties of Prosopis Juliflora Ash

Test	Result
Specific gravity	3.10
Standard Consistency	29 %
IST of PJA	65 minutes
FST of PJA	400 minutes
Soundness	5.5mm

3. Experimental work

Cement is a material that can bind different substances together and then hardens and sets. In general, cement can be defined as a substance with excellent adhesive and constructive properties that allow it to join with other materials to form compact masses. The cement mortar and concrete is made of OPC grade 33 cement. The compressive strength of the cement after a 28-day test is 33 MPa, according to IS requirements. A granular material that remains once it has passed through a 4.75 mm IS sieve, including substances like sand, gravel, crushed stone, or aggregates. The fine aggregate's role is to act as a workability agent and to fill the gaps left by the coarse aggregate. The cement mortar and concrete are made with PJA as a component (Table 3).

Table 3. Chemical Properties of PJA

Element	%
Ca	76.9
Mg	0.5
Si	0.2
O	17.8
K	0.3

Figure 1 shows a SEM picture of PJA that clearly displays a micro porous surface with honeycomb shaped pores. Figure 1 depicts the elemental analysis of ash performed using EDX analysis. Table 4 shows that PJA is used in amounts of 0%, 10%, 20%, 30%, 40%and 50% by weight of cement. In this study, Prosopis Juliflora Ash (PJA), possessing a specific gravity of 3.10 and an average particle size of 35 microns, was employed as a partial replacement for cement. The preparation of the mixes was carried out in accordance with the Indian standard IS 10262:2009 [IS: 456(2000) – code of practice for plain and reinforced concrete]. Before putting the mixes into the cube moulds, they were crushed in three layers. The moulds were dried in a water bath at room temperature for the length of the testing. PJA has been added to concrete and mortar to boost their durability. M30 grade concrete (Cement (binder): Fine aggregate: Coarse Aggregate: Water = 1: 1.598: 2.85:0.45) was used. The concrete mix designs in this study were formulated following the guidelines specified in the Indian Standards (IS). Each mix was proportioned to achieve a target compressive strength of 30 MPa after a curing period of 28 days [IS:10262(2009)- Concrete Mix Proportioning Guidelines, IS:15658(2006)- Precast concrete blocks for paving -Specification].

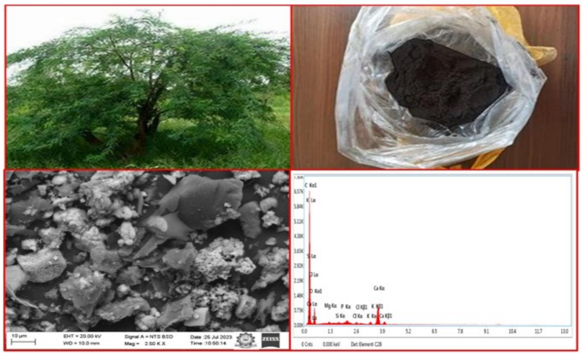

Figure 1. Prosopis Juliflora Ash and SEM Analysis

Table 4. Symbol Description

DESCRIPTIONS	SYMBOLS
Control Mix	PJA 0
10% of PJA by using weight of cement	PJA 10
20% of PJA by using weight of cement	PJA 20
30% of PJA by using weight of cement	PJA 30
40% of PJA by using weight of cement	PJA 40
50% of PJA by using weight of cement	PJA 50

4. Results and discussion

4.1 Mechanical properties of concrete

4.1.1Compressive strength

Figure 2 shows the casted PJA concrete samples are being tested for compressive strength using compression testing equipment with a 200 Tonne capacity. Before the process began, the machine's bearing surface was thoroughly cleaned of filth and other contaminants. A continuous load is imparted to the specimen until it can no longer sustain itself and eventually falls apart. The applied pressure had been constantly monitored. The highest load applied to the specimens was recorded. Table 5 presents the outcomes of the crushing strength assessments conducted on the specimens after 7 and 28 days. The control and PJA mixes are very similar. PJA 30% has greater compressive strength than any other mix proportion. As per the study's findings, the fine structure of Prosopis Juliflora ash exhibits the ability to occupy more voids and create an improved pore structure. This characteristic enhances its strength, particularly in later stages, by reducing permeability when used as a replacement for up to 30% of cement. The effectiveness of Prosopis Juliflora Ash in substitution is attributed to its minuscule particle size and its capacity to fill voids efficiently. However, increasing the amount of PJA causes ettringite formation to be delayed due to a higher SO_3 content, which may also inhibit alite formation. Moreover, in line with the available literature, it was observed that the compressive strength experienced a decline post a 30% replacement. This reduction was attributed to a decrease in the formation of C-S-H gels and an escalation in the severity of Plazolite formation. This could possibly be the result of PJA adding more alkali in the form of Na_2O and K_2O when the replacement level rises [Kathirvel *et al.* 2019] Figure 3.

Figure 2. Overview of the project

Table 5. Mechanical Properties of Concrete

Mix ID	Compressive Strength in N/mm²		Split Tensile Strength in N/mm²		Flexural Strength in N/mm²	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
PJA 0	20.1	31	2.3	3.6	2.9	6
PJA 10	20.8	32	2.1	3.6	3.1	6.1
PJA 20	21.2	32.6	2	3.7	3.5	6.2
PJA 30	21.3	32.8	2	3.8	3.6	6.3
PJA 40	18.2	28	1.6	2.9	2.7	5.7
PJA 50	16.9	26	1.5	2	2.3	4.5

4.1.2 Flexural strength

The loading and securing rollers must have a diameter of 25 to 40 mm. The spacing between the two supporting rollers, measured from center to center, should be set to the entire length of the specimen minus 50 mm. The loading roller must be positioned so that it applies force from the top of the specimen down the vertical centre line between the supporting rollers. They must extend at least 10 mm beyond the measurements of the specimens on both sides. Figure 4 depicts the flexural strength of a concrete computed using this formula. Flexural strength is stronger in PJA 30% than in any other mix component. The control and PJA mixes are very similar. As a result, it is possible to conclude that PJA supplementation has no effect on bending strength at any age. The determination of the specimen's flexural strength shall be carried out using the following procedure:

$$F = 3PL / 2BD^2$$

Where,

F = Flexural strength, measured in N/mm²

P = Maximum load applied, measured in N

L = Span length between the central lines of the rollers, measured in mm

B = Width of the block, measured in mm

D = Average thickness of the specimen, measured in mm

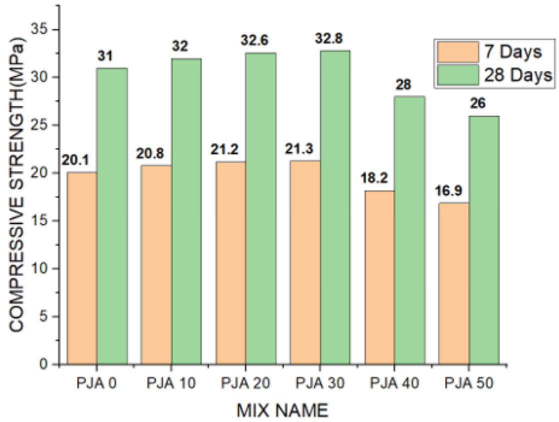

Figure 3. Compressive strength

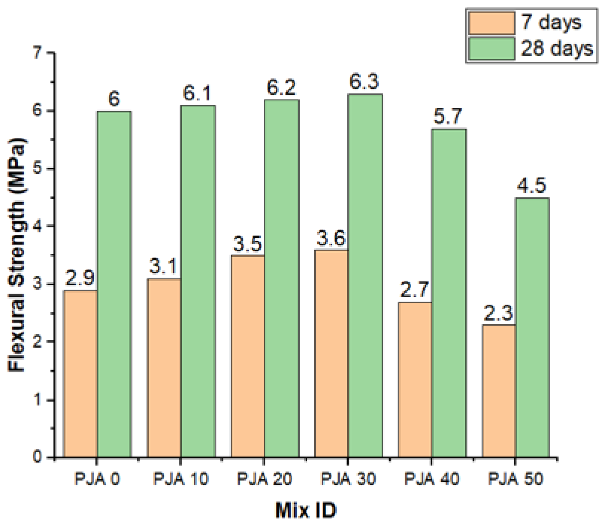

Figure 4. Flexural strength

In contrast to the control specimen, the PJA30% sample exhibited notable performance improvements concerning flexural strength. The observations indicated a reduction in flexural strength with higher replacement percentages, primarily attributed to the development of cracks within the tension zone of the prism.

4.1.3 Split tensile strength

The measurement was conducted using a cylindrical specimen sized at 150 by 300 mm. The calculation involved the equation $T = 2P/\pi ld$, with testing carried out at curing periods of both 7 and 28 days. The outcomes are detailed in Table 5 and illustrated in Figure 5. Figure 2 depicts the test setup. It's worth noting that after introducing PJA30, there's a noticeable decline in the required values. Because of the fine particle size of Prosopis Juliflora Ash, the mixes PJA 0 to PJA 30 produced good results, With a minor variance in the results for PJA 20 and PJA 30. Except for the PJA 40 and PJA 50 cylindrical specimens, the marginal tensile strength gain was greater than the control specimen. PJA30 exhibits a peak split tensile strength of 3.8 N/mm^2. In comparison, the strength of PJA20 and PJA30 samples has increased by 2.7% and 5.5%, respectively. These results underscore the greater crack resistance of finer PJA particles. Since these specimens are not made of fibers, there is no discernible variation in the fracture pattern, which is dependent upon the inclusion of PJA.

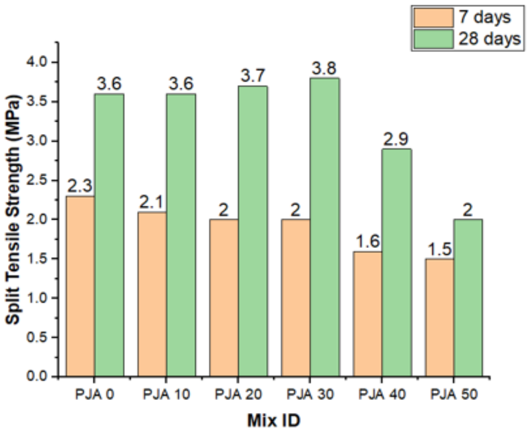

Figure 5. Split Tensile Strength

4.2 Mechanical properties of cement mortar

4.2.1 Compressive strength

Compressive strength testing was conducted on mortar cubes measuring 7.06 x 7.06 x 7.06 cm using a Compression Testing Machine (CTM) after 7 and 28 days of curing. Three samples were employed to establish the average strength for each blend. The test results, as illustrated in Figure 6 and detailed in Table 5, reveal that the compressive strength of the PJA 10 to PJA 30 mixtures surpasses that of the control specimen. This is attributed to the mortar matrix formed between cement and PJA. For M30 grade concrete, the maximum compressive strength of 33 MPa is achieved with the PJA 30 mix, while the minimum compressive strength values are observed in the PJA 40 and PJA 50 blends. In particular, the compressive strength values for PJA 10, PJA 20, and PJA 30 consistently increase when compared to the control specimens.

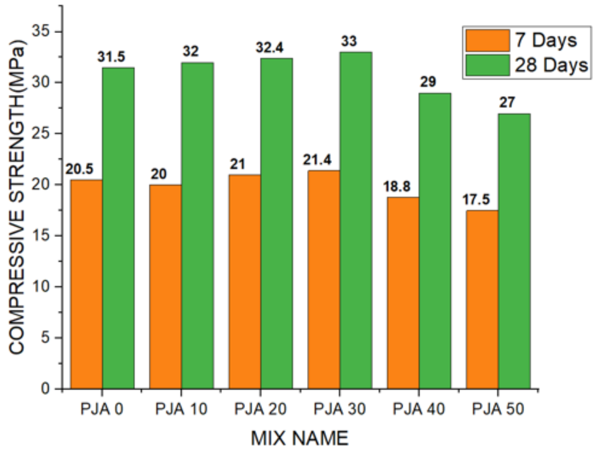

Figure 6. Compressive Strength

Specifically, in comparison to the control concrete, PJA 10, PJA 20, and PJA 30 exhibit strength improvements of 1.6%, 2.9%, and 4.8%, respectively. This significant enhancement in compressive strength values, up to 30%, can be attributed to the minute particle size of PJA and its effective bonding within the mortar matrix [Karthikeyan *et al.* 2022, 2023].

Table 6. Mechanical Properties of Mortar

Mix ID	Compressive Strength in N/mm^2		Split Tensile Strength in N/mm^2		Flexural Strength in N/mm^2	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
PJA 0	20.5	31.5	1.5	3	2.3	3.7
PJA 10	20	32	1.54	3.1	2.4	3.7
PJA 20	21	32.4	1.6	3.2	2.5	3.8
PJA 30	21.4	33	1.86	3.4	2.6	3.9
PJA 40	18.8	29	1.34	2.7	2.2	3.4
PJA 50	17.5	27	1.2	2.6	1.9	3.2

4.2.2 Flexural strength

The assessment of flexural strength involved prism specimens measuring 40 x 40 x 160 mm [Karthikeyan *et al.* 2023]. These specimens were subjected to three-point loading using a Universal Testing Machine (UTM) with a capacity of 400 kN at both 7 and 28 days of age [Leema Margret *et al.* 2023]. The results pertaining to the flexural strength of the mortar, as depicted in Figure 7, exhibited a behavior pattern consistent with that of the compressive strength. Following PJA30, the measurements are a little bit declining. PJA 0 and PJA 10 to PJA 30 mixes both produced successful results. Flexural strength values for the mixtures PJA 40 and PJA 50 have fallen to 3.4 MPa and 3.2 MPa, respectively.

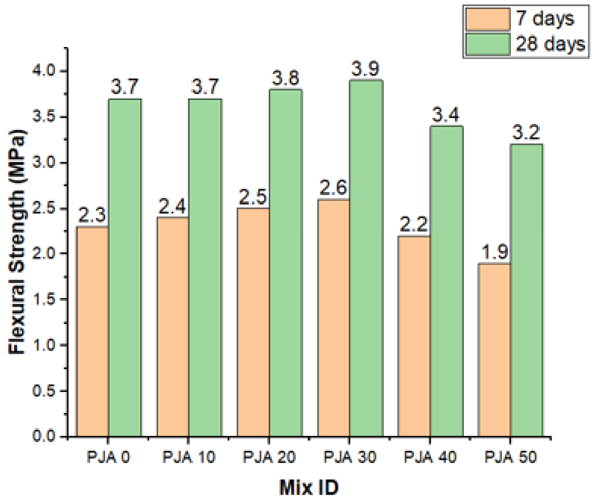

Figure 7. Flexural Strength

Flexural strength values for PJA 10, PJA 20 and PJA 30 samples are increased by 3.3%, 6.6% and 13.3% respectively.

4.2.3 Split tensile strength

To evaluate the strength characteristics, cylindrical specimens were positioned horizontally on a Universal Testing Machine (UTM) with a capacity of 400 kN, following curing periods of 7 and 28 days. The average strength for each set was determined using three test specimens. The readings of the tensile strength are seen to respond similarly to the compressive strength after PJA 30. The sample mixes for PJA 0 through PJA 30 produced successful outcomes [Jayaprakash *et al.* 2023]. The data for PJA 10, PJA 20, and PJA 30 have slightly different results (Figure 8). The split tensile strength of PJA 20 and PJA 30 samples increased 2.7% and 5.4%, respectively, in comparison to control concrete. Due to PJA's crack resistance, it has been marginally improved up to 30% replacement.

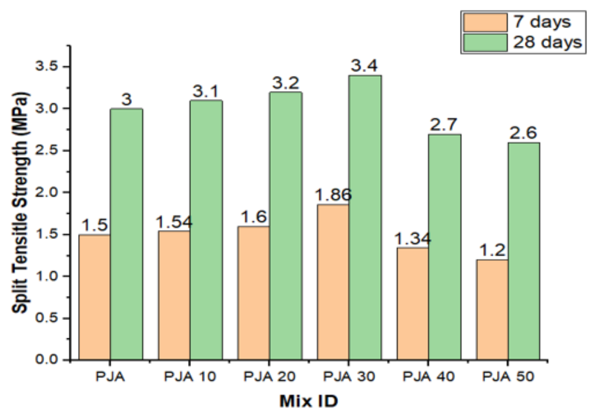

Figure 8. Split Tensile Strength

5. Conclusions

- The PJA material examination highlights its potential as an additional cement substitute in the production of cement mortar and concrete. Characterization investigations proved the pozzolanic characteristics, fine particle size distribution, and acceptable chemical composition of PJA. These traits demonstrate its capacity to support the growth of strength.
- The use of PJA as a sustainable alternative not only reduces waste and promotes resource conservation, but it also offers the construction sector a solution that is acceptable to the environment [Karthikeyan *et al.* 2022, 2023]. To generate additional calcium silicate hydrate (C-S-H) gel, calcium hydroxide, which is a byproduct of cement hydration, is utilized, was allowed to react with PJA to measure its pozzolanic activity.
- Due to its extremely fine structure, PJA covers more gaps and has superior pore structure, which ater enhances strength due to decreased permeability. The creation of CSH gel increases the crushing strength in M30 grade when PJA is used in place of cement up to 30% enhanced PJA addition leads to higher aluminium and silica content and enhanced compressive strength. It proved that waste wood from burning operations may be used as cement ash to make environmentally friendly mortar and concrete. Consequently, Prosopis Juliflora Ash (PJA) can find application in construction contexts as a substitute for up to 30% of cement in both mortar and concrete.

Acknowledgments

The authors are grateful to the Management and Principal of Ramco Institute of Technology, Rajapalayam, Tamil Nadu, India for providing the necessary facilities for carrying out the research work.

References

Anusuya R., Chandraleka D., Sarumathi S., Karthikeyan G. (2018), Experimental Study on Concrete by replacement of Fine Aggregate with Copper Slag, GGBS and MSand, International Journal of Innovative Science and Research Technology, 3(3), 418 – 421

Dharmaraj R. and SivaKumar B. (2020). “A feasibility study on cement with addition of prosopis juliflora ash as in concrete,” in *Materials Today: Proceedings, Elsevier Ltd*, 1212–1217, doi: 10.1016/j.matpr.2020.06.374.

IS: 456(2000) – code of practice for plain and reinforced concrete.

IS:10262(2009)- Concrete Mix Proportioning Guidelines.

IS:15658(2006)- Precast concrete blocks for paving -Specification

Jayaprakash S., Deivasigamani V. and Ravindran G. (2023). “Influence of Prosopis juliflora ash in mechanical properties of concrete”, materials today proceedings, **80**, part 2, https://doi.org/10.1016/j.matpr.2022.12.127

Kamesh M., Karthik T., Ramakrishnan M., Kumar S.S. and Suresh Kumar P. (2017). “Experimental project on concrete-partial replacement of cement by prosopis juliflora ash,” [Online]. Available: www.ijrte.org

Karankumar M., Sujith S., Karthikeyan G. (2019), Structural Rehabilitation and Strengthening of Column using Micro Concrete and additional reinforcement, International Journal of Engineering Research & Technology (IJERT), 7(6).

Karthikeyan G., Dharmar S., Ragavan V. and Harshani R. (2023) “Study on performance of paver block using prosopis juliflora ash”, *Global NEST Journal*, https://doi.org/10.30955 /gnj.005279

Karthikeyan G., Leema Margret A., Vineeth V. and Harshani R. (2023). "Experimental study on mechanical properties of Textile Reinforced Concrete (TRC)", *E3S Web of Conferences* **387**, 04002, Doi:10.1051/e3sconf/202338704002

Karthikeyan G., Vijai K. and Jerlin Regin. (2022). "Influence of marine sand as fine aggregate on mechanical and durability properties of cement mortar and concrete," *Materials Research Express*, **9(3)**, https://doi.org/10.1088/2053-1591/ac5f88.

Kathirvel P., Anik G. A. & Kaliyaperumal S.R.M. (2019). "Effect of partial replacement of cement with Prosopis juliflora ash on the strength and microstructural characteristics of cement concrete", *Construction and Building Materials*, 225, 273–282. https://doi.org/10.1016/j.conbuildmat.2019.07.165

Kathirvel P., Anik G.A. and Kaliyaperumal S.R.M. (2019). "Effect of partial replacement of cement with Prosopis juliflora ash on the strength and microstructural characteristics of cement concrete," *Construction and Building Materials*, **225**, 273–282, doi: 10.1016/j.conbuildmat.2019.07.165.

Kumar P.V. and Singh V.V. (2017). "An experimental investigation on precast cement concrete paver blocks using fly ash," [Online]. Available: www.ijariit.com

Leema Margret A., Karthikeyan G., Ajandhadevi S. and Jenitha G. (2023). Numerical study on flexural behavior of reinforced concrete beam using MATLAB", *AIP Conference Proceedings*, **2381**, 060004, https://doi.org/10.1063/5.0162709

Manisha Sri P., Nithya M., Poornima P. and Dhiviya M.K. (2018). "An experimental investigation on prosopis juliflora ash as a partial replacement of cement in paver block," [Online]. Available: www.ijcrt.org

Murugan A.D., Muthuraja M. and Student P.G. (2017). "Experimental Investigation on Prosopis Juliflora Ash as a Partial Replacement of Cement in Conventional Concrete," doi: 10.15680/IJIRSET.2017.0605169.

Praveena M., Nalina V., Sowmiya S. and Sampath V. (2018). "Effect on Strength Properties of Concrete by using Prosopis Juliflora Wood Powder as Partial Replacement of Sand," *GRD Journal for Engineering*, **3**, [Online]. Available: www.grdjournals.com

Raguraman V. et al. (2021). "Utilization of plastic waste and ProsopisJuliflora Ash in making floor tiles," in *Materials Today: Proceedings, Elsevier Ltd*, 1658–1663, doi: 10.1016/j.matpr.2021.07.444.

Sarala P. (2008). "Experimental study of partially replacement of cement by prosopis juliflora concrete," *Certified Journal | Page*, 9001, [Online]. Available: www.irjet.net

Saranya S., Saranya S., Faizuneesa A. and Kanniyappan S.P. (2022). "Experimental study on partial replacement of cement by prosopis juliflora in concrete,". [Online]. Available: https://www.researchgate.net/publication/358278242

Shyamala G., Swaminathen A.N. and Rajasri Reddy I. (2020). Performance evaluation of concrete using prosopis juliflora as partial replacement of coarse aggregate," in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing Ltd, doi: 10.1088/1757-899X/981/3/03267.