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Mathematical Models Viability for Bi-Material Forte Appraisal

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Abstract

This study examines the mechanical traits of bi-material concrete containing polypropylene fiber. This analysis aims to establish a relationship between bi-material concrete's compressive strength (CS), split tensile strength (STS), and flexural strength (FS). M25 grade of bi-material concrete is designed, and polypropylene fiber is added to half of the concrete. Polypropylene fiber (PPF) was included in concrete with 0.20, 0.35, 0.50, 0.75, 1.00, and 1.50% by the weight of cement. Different test (CS, FS, STS) was performed over the bi-material concrete after 28 days of the curing period. Mathematical models were made by performing regression analysis over the experiment data and matched with the other models in the previous studies. Mechanical properties of the definite increase when the polypropylene fiber increases up to 0.5% compared to conventional concrete. It is seen that the empirical values fall within reach of expected values when the predicted values are compared to the experimental results. In this study, the existing analytical models and the relationship between mechanical traits of bi-material concrete are evaluated and matched with the models present in previous studies, and a new model is proposed.

Keywords: Bi- materials, Polypropylene fiber, Mechanical properties, Reutilized material, Mathematical models.

1. Introduction

Bi-material interfaces that separate into different elements can be found in significant fault zone structures and concrete made of various materials boundaries. Effective motion across major faults forms the center of interfaces, and at the junction, cumulative faulting process damage occurs in concrete and other materials. Technology makes it possible to work more efficiently. Still, it also significantly impacts the quality of the parts and necessitates accurate knowledge of how heterogeneous concrete causes nonelastic deformation. Recycled materials and polypropylene have remarkably heterogeneous structures, making them suitable candidates for composite structures. This material's remarkable mechanical properties result from melting various properties, including flexibility and hardness. Bi-material is essentially defined as the combination of two or more materials that are improperly bonded. Knowing how the bond behaves at the interface is crucial for composite concrete because it affects the structure's durability and safety [1]. Once the concrete has dried and become hard, defects may remain inside the bi-material [2]. The collaboration of numerous interior components that make up material complicates concrete behavior [3], [4]. High-rise structures, overpasses, water barriers, and other large structures have used bi-materials made of different constituents in recent decades. Numerous coatings of concrete are frequently utilized to protect concrete structures. The cement's hydration state and weight/cement ratio have the most noticeable impacts on the CS of traditional concrete. Additionally, among all other parameters, it is an essential quality. Due to the difficulty of conducting direct tests, the STS and FS are typically assessed through secondary methods. Raphael [5] developed pragmatic interactions among the STS and CS and produced reliable results. [6]. Relationships between the mechanical strengths of glass concrete were drawn by Brain Mwendwa Mutua et al. [7]. They discovered that the polynomial equations' predicted values fell within the necessary range. Tensile strength values are typically between 10 and 15 percent, and CS is roughly 8 to 10 times greater than FS. According to Mohd et al. [8], several variables, including aggregate properties, admixture type, concrete age, curing conditions, and confinement conditions, significantly impact the ability to derive balance interactions and equations for STS and FS. Therefore, the current study aims to establish links between mechanical traits and PPF content in the mathematical model for bi-material concrete.

2. Experiment approach

2.1. Material and mix ratio

The M25 grade of bi-material concrete was prepared in this investigation using Portland Pozzolana cement [9]. The specimens were created using cement with a regular consistency of 36% and a specific gravity of 3.11. The cement's

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preliminary and decisive setting times were 128 and 292, individually. The CS of cement after 28 days of curing is 42.9 MPa. The used fine aggregate has a specific gravity of 2.67 and passes through a sieve with a mesh dimension of 4.75 mm with water incorporation of 0.95%. Sizes of coarse aggregates are 20 mm and 10 mm, with specific gravities of 2.64 and 2.63, correspondingly [10]. Both fine and coarse aggregate absorbed 0.5 % of water. The fineness moduli of size 20 mm and 10 mm aggregates are 7.14 and 5.80, individually. Numerous applications call for the lightweight, strong thermoplastic polymer known as polypropylene. Synthetic polypropylene fibers are utilized in several different industries. This experiment employed 12 mm polypropylene fiber with 0.91 g/cm^3 specific gravity and 175°C. Seven different types of mixes were prepared with or without polypropylene fiber incorporation are displayed in table 1 [11].

3. Outcome and conversations

3.1. Compressive strength (CS)

The CS experiment was performed on the bi-material concrete specimen (cube) size of 15 cm. The CS with or without polypropylene fiber of the concrete cube after 28 days of curing is depicted in Fig. 1. Bi-material concrete's CS has grown due to the incorporation of polypropylene fibers in the lower half portion of the cube. When the quantity of polypropylene fiber was increased from 0.0 to 0.50%, the bi-material concrete showed significant growth in CS. Compared to conventional concrete, there was an increment of 10.23% of CS. When polypropylene fiber was added beyond 0.5%, the CS of the bi-material concrete diminished. Maximum decrement was observed at 1.5% of the polypropylene fiber addition, around 16.80%, compared to the conventional concrete. The increased CS of bi-material concrete could be attributed to the prevention of crack propagation because of the effectiveness of the polypropylene fiber in the concrete.

Table 1: Weight of ingredients for making bi-material concrete

Mix ID	Weight per cubic meter (kg/m^3)					
	Water	Cement	Coarse aggregate		Fine aggregate	Polypropylene fiber
			10mm	20mm		
PC0.0	157.6	394	420	631	842.00	0.000
P0.20	157.6	394	420	631	842.00	0.842
P0.35	157.6	394	420	631	842.00	1.473
P0.50	157.6	394	420	631	842.00	2.105
P0.75	157.6	394	420	631	842.00	3.157
P1.00	157.6	394	420	631	842.00	4.210
P1.50	157.6	394	420	631	842.00	6.315

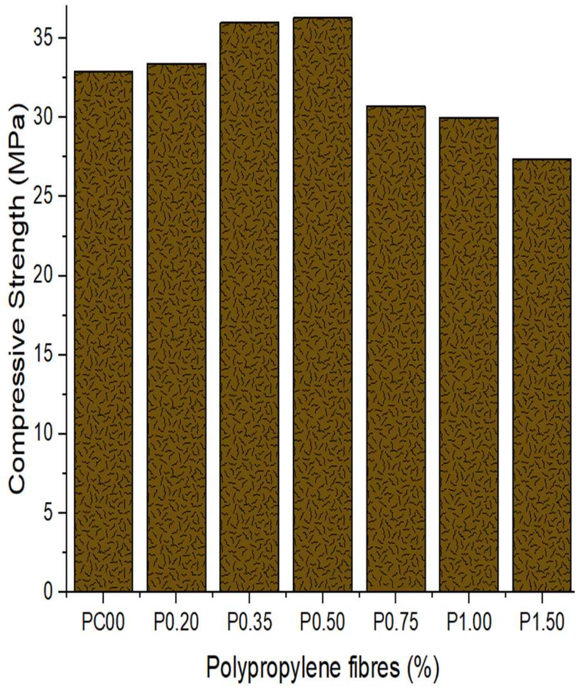

Fig. 1. Empirical values of CS at the different proportions of PPF

3.2. Split tensile strength (STS)

The experiment was performed over a bi-material concrete specimen (cylinder) of 15 cm thickness and 30 cm elevation. The STS with or without polypropylene fiber of the concrete cube is depicted in Fig. 2. STS has intensified due to the incorporation of polypropylene fibers in the lower half portion of the specimen. When the proportion of polypropylene fiber was increased in concrete from 0.0 to 0.50%, the bi-material concrete showed growth in STS. Concerning conventional concrete, there was an increment of 4.53% of STS. When polypropylene fiber was added beyond 0.5% to the concrete, the STS of the bi-material concrete decreased. Maximum decrement was observed at 1.5% of the polypropylene fiber addition, around 9.63%, compared to the conventional concrete. The stronger physical connection between the polypropylene fibers and the cement concrete is responsible for the increased tensile strength at 28 days. However, once the chemical collaboration among the aggregates and the cement starts, the impacts on surface roughness might not be as significant.

3.3. Flexural strength (FS)

The experiment was performed on a bi-material concrete specimen (beam) of 15×15×70 cm. FS with or without polypropylene fiber of the concrete cube after 28 days of curing is represented in Fig. 3. FS has strengthened due to the incorporation of polypropylene fibers in the lower half portion of the specimen. When the fraction of polypropylene fiber was increased in concrete from 0.0 to 0.50%, the bi-material concrete showed growth in FS. Compared to conventional concrete, there was an increment of 3.23% FS. When polypropylene fiber was added beyond 0.5% to the concrete, the FS of the bi-material concrete decreased. Maximum decrement

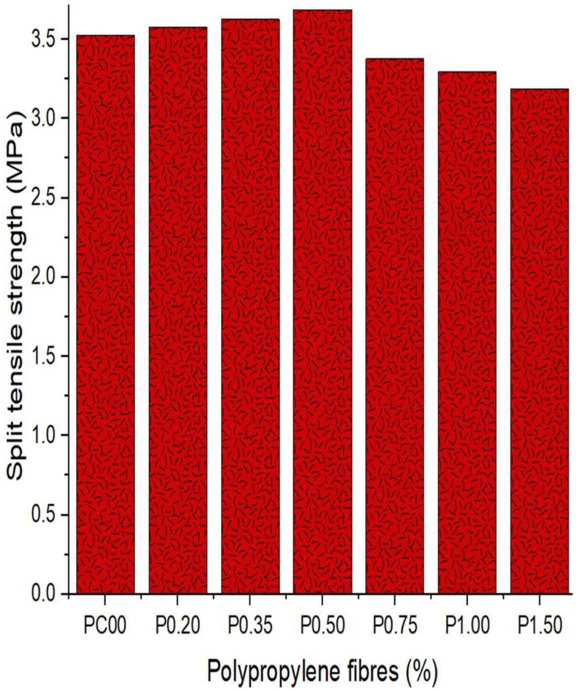

Fig. 2. Experimental values of STS at the different proportions of PPF

was observed at 1.5% of the polypropylene fiber addition, around 10.97%, compared to the conventional concrete. When the load is raised, a crack in plain concrete can be seen soon after a reduction in load. The load then rises once more as a result of fiber bridging.

3.3. Flexural strength (FS)

The experiment was performed on a bi-material concrete specimen (beam) of 15×15×70 cm. FS with or without polypropylene fiber of the concrete cube after 28 days of curing is represented in Fig. 3. FS has strengthened due to the incorporation of polypropylene fibers in the lower half portion of the specimen. When the fraction of polypropylene fiber was increased in concrete from 0.0 to 0.50%, the bi-material concrete showed growth in FS. Compared to conventional concrete, there was an increment of 3.23% FS. When polypropylene fiber was added beyond 0.5% to the concrete, the FS of the bi-material concrete decreased. Maximum decrement was observed at 1.5% of the polypropylene fiber addition, around 10.97%, compared to the conventional concrete. When the load is raised, a crack in plain concrete can be seen soon after a reduction in load. The load then rises once more as a result of fiber bridging.

Compared to a conventional mix, fibers have a higher capacity to support a load. The author noticed that fiber performance degraded as adding levels increased and became more challenging because they interacted less with the cement matrix.

3.4. Relation among STS (f_{st}) and CS (f_{ck})

The most important characteristics of concrete are its CS and STSs. Since conducting a direct tensile test is challenging, STS

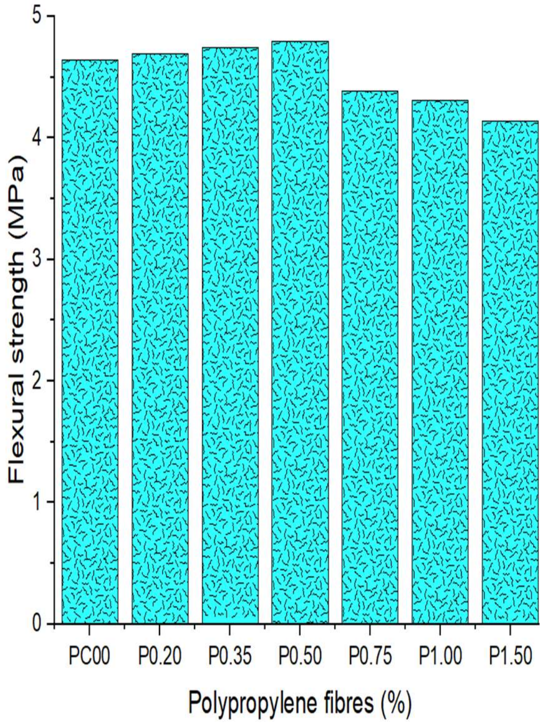

Fig. 3. Experimental values of FS at the unique proportions of PPF

and FS tests are carried out instead. One of the most crucial traits of concrete is STS, which is used to construct structural sections of concrete subject to torsion, shear, contraction, etc. However, numerous studies using power-type equations were directed to ascertain the relationship between CS and STS for traditional concrete and discovered that the CS's power varies.

$$\text{STS } (f_{st}) = af_{ck}{}^{b} \quad (1)$$

Where "a" and "b" are the coefficient of regression analysis, f_{ck} = CS of the sample.

The literature has a broad range of relationships between STS and CS. Table 2 illustrates the correlation (from S01 to S13) between STS and CS taken from codes of the different countries and other relationships provided by the authors from their experiment work. Experimental data of CS and STS of bi-material and conventional concrete were obtained after 28 days of curing. This empirical data is used to perform regression analysis.

The coefficient of regression "a" and "b" was found, and a relationship among STS and CS developed, which is demonstrated in table 2, named "S00". The coefficient of determination for the present study equation is around 0.97. Fig. 4 shows the value of STS acquired from different mathematical models in the literature. From fig. 4, one can also see the comparison between the values obtained from the present study and other mathematical models. When the STS model of the present study is compared to other models, Ismeik et al. (2009), Bhanjaa et al. (2005), Zhang et al. (2006), Kothai and Malathy et al. (2012), Lavanya and Jegan et al. (2015), and Saudi Building Code (SBC-304-2007) overestimate the STS. The rest of the other models underestimate the strength.

Table 2: Correlation among STS and CS present in literature

Term	Literature	Relationship	Comparison with the present model (%)	
			Increment	Decrement
S00	Present study	$f_{st} = 0.61f_{ck}^{0.5}$	-	-
S01	ACI committee 318 (2014) [12]	$f_{st} = 0.56f_{ck}^{0.5}$	-	8.6
S02	Euro-International Committee for Concrete (CEB-FIB-1991) [13]	$f_{st} = 0.3f_{ck}^{0.66}$	-	13
S03	Saudi Building Code (SBC-304-2007) [14]	$f_{st} = 0.626f_{ck}^{0.5}$	2.7	-
S04	Standards Association of Australia (AS3600-2001) [15]	$f_{st} = 0.60f_{ck}^{0.5}$	-	2.1
S05	New Zealand Building Code (NZS-3101-2006) [16]	$f_{st} = 0.60f_{ck}^{0.5}$	-	2.1
S06	Bhanjaa and Sengupta et al. (2005) [17]	$f_{st} = 0.275f_{ck}^{0.81}$	36	-
S07	Xiao et al. (2006) [18]	$f_{st} = 0.75f_{ck}^{0.5}$	22	-
S08	Selim et al. (2006) [19]	$f_{st} = 0.106f_{ck}^{0.948}$	-	13
S09	Arioglu et al. (2007) [20]	$f_{st} = 0.387f_{ck}^{0.63}$	0.8	-
S10	Ismeik (2009) [21]	$f_{st} = 1.20f_{ck}^{0.5}$	95.	-
S11	Kothai and Malathy et al. (2012) [22]	$f_{st} = 0.657f_{ck}^{0.5}$	7.6	-
S12	Lavanya and Jegan et al. (2015) [23]	$f_{st} = 0.249f_{ck}^{0.772}$	7.80	-
S13	V.B. Reddy Suda et al. (2022) [24]	$f_{st} = 0.208f_{ck}^{0.764}$	-	12

3.5. Relation among FS (f_{fs}) and CS (f_{ck})

The FS is a crucial parameter for calculating deflection, the minimum amount of flexural reinforcement, and the beginning of noticeable cracks in a concrete section under flexure. It was discovered that this relationship is not a direct proportion, however. The connection between CS and FS has been recommended using several empirical equations. The majority of these equations are power equations.

$$FS\ (f_{fs}) = af_{ck}^{\ b} \qquad (2)$$

Where “a” and “b” are the coefficient of regression analysis, f_{ck} = CS of the sample.

The literature has a broad range of relationships between FS and CS. Table 3 illustrates the correlation (from F01 to F07) among FS and CS taken from codes of the different countries and other relationships provided by the authors from their experiment work. Investigational data of CS and FS of bi-material and conventional concrete were obtained after 28 days of curing, and this experimental data is used to perform regression analysis. Coefficient of regression “a” and “b” was found, and a relationship between FS and CS developed, which is shown

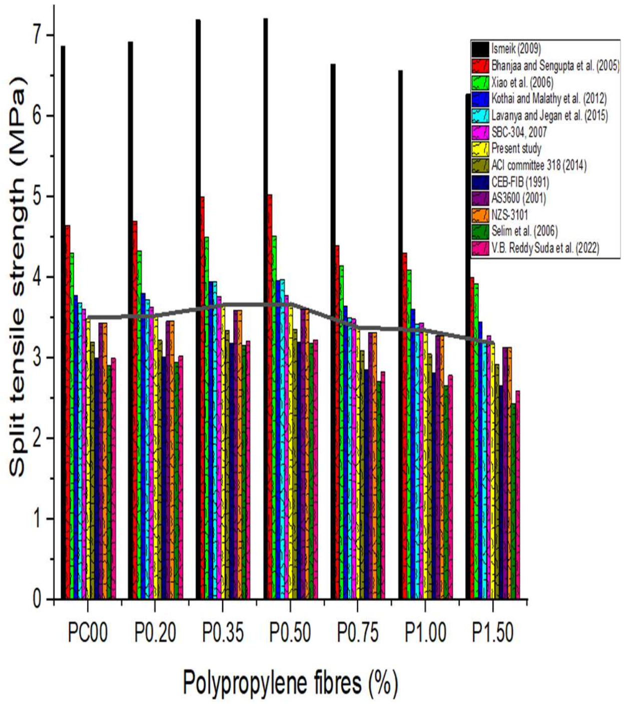

Fig. 4. Comparison between the STS model for the present study and models present in the literature

Table 3: Correlation among FS and CS present in literature

Term	Literature	Relationship	Comparison with the current model (%)	
			Increment	Decrement
F00	Present study	$f_{fs} = 0.80f_{ck}^{0.5}$	-	-
F01	New Zealand Building Code (NZS-3101-2006) [16]	$f_{fs} = 0.54(f_{ck} * 0.81)^{0.5}$	-	39.25
F02	American Concrete Institute (ACI:318-R99) [12]	$f_{fs} = 0.62(f_{ck} * 0.81)^{0.5}$	-	30.25
F03	American Concrete Institute ACI:363-R92 [25]	$f_{fs} = 0.59f_{ck}^{0.5}$	-	26.25
F04	Bureau of Indian Standards IS 456–2000 [26]	$f_{fs} = 0.70f_{ck}^{0.5}$	-	12.50
F05	Mindess et al. (2003) [27]	$f_{fs} = 0.11f_{ck}^{1}$	-	16.81
F06	Legeron et al. (2000) [28]	$f_{fs} = 0.94f_{ck}^{0.5}$	18.75	-
F07	V.B. Reddy Suda et al. (2022) [24]	$f_{fs} = 0.245f_{ck}^{0.823}$	-	1.887

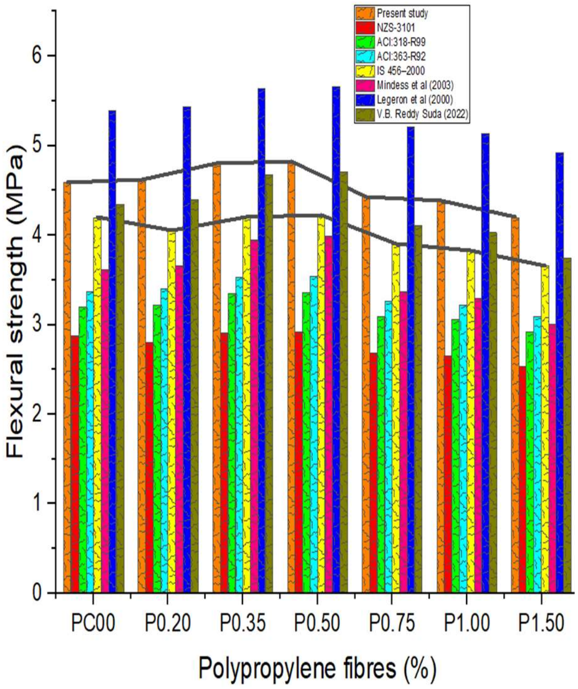

Fig. 5. Comparison between the FS model for the present study and models present in the literature

in table 3, named "F00". The coefficient of determination for the present study equation is around 0.95. Fig. 5 shows the value of FS obtained from different mathematical models in the literature. From fig. 5 shows the comparison between the values obtained from the present study and other mathematical models and those obtained from the IS 456:2000.
When the FS model of the present study is compared to other models, Legeron et al. (2000) and V.B. Reddy Suda et al. (2022) overestimate the FS. The rest of the other models underestimate the FS.

4. Conclusion remarks and future scope

This paper aims to deliver accurate modeling and specific waste material mixing criteria for implementing bi-material concrete sections at various polypropylene fiber percentage levels. This article gives fundamental models and correlations for bi-material concrete, including multiple proportions of polypropylene fiber. Attempts to create logical, solid constitutive models.

1. Generally, in this study, the mechanical traits of bi-material concrete are taken into account, and mechanical properties improve as the polypropylene fiber content increases up to 0.5 %, corresponding to PC00.
2. As the polypropylene fiber fraction of the mix raised to 0.5 %, the CS of the bi-material concrete increased by 10.23 %, corresponding to PC00.
3. As the polypropylene fiber fraction in the mix boosted up to 0.5 %, the STS of bi-material concrete boosted by 4.53 %, corresponding to PC00.
4. As the polypropylene fiber fraction in the mix raised to 0.5 %, the FS of bi-material concrete was enhanced by 3.23 %, corresponding to PC00.

The experimental study has concluded that the maximum amount of polypropylene fiber that can be incorporated into concrete without reducing its mechanical traits is 0.5 %. Additional research on various polypropylene fiber sizes and categories is needed. Another thing to consider in the future is how adding more ingredients to polypropylene fiber bi-material concrete can enhance its mechanical properties. Additional empirical analyses should be conducted to determine the durability characteristics of bi-material concrete, including polypropylene fiber.

Disclosures

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References

1. Shah, S. G., & Kishen, J. C. (2010). Nonlinear fracture properties of concrete–concrete interfaces. Mechanics of Materials, 42(10), 916-931.
2. Kanellopoulos, A., Farhat, F. A., Nicolaides, D., & Karihaloo, B. L. (2009). Mechanical and fracture properties of cement-based bi-materials after thermal cycling. Cement and concrete research, 39(11), 1087-1094.
3. Sih, G. C., & Rice, J. R. (1964). The bending of plates of dissimilar materials with cracks.
4. E. Ganesh, P.V. Ramana, and M.K. Shrimali(2022) Solved structural dynamic mathematical models via novel technique approach, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2022.03.419.
5. B K Raghu Prasad, P.V. Ramana(2012)," Modified Adomian decomposition method for fracture of laminated uni-directional composites," Sadhana Vol. 37, Part-1, pp.33-57.
6. Ayush Meena, P.V. Ramana (2021), Mathematical Model for Recycled PolyEthylene Terephthalate Material Mechanical Strengths, Materials Today: Proceedings, 38, Part 5.
7. Arigela Surendranath, P.V. Ramana (2021), Mathematical Approach on Recycled Material Strength Performance Via Statistical Mode, Materials Today: Proceedings, 38, Part 5.
8. Ayush Meena, P.V. Ramana(2021), High-Rise Structural Stalling and Drift Effect Owe to Lateral Loading, Materials Today: Proceedings, 38, Part 5.
9. P.V. Ramana (2021), Statistical concert of solid effect on fiber concrete, Materials Today: Proceedings, 38, Part 5.
10. E. Ganesh, P.V. Ramana, and M.K. Shrimali (2022), Unsolved structural dynamic mathematical models via Novel technique approach, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2022.03.636.
11. Arigela Surendranath, P.V. Ramana (2021), Interpretation of bi-material interface through the mechanical and

microstructural possessions Materials Today: Proceedings,17, Part 3.

12. Anamika Agnihotri, P.V. Ramana(2021), GGBS: fly-Ash Evaluation and Mechanical properties within high strength concrete, Materials Today: Proceedings, 38, Part 5.
13. Ayush Meena, P.V. Ramana(2021), Assessment of endurance and microstructural properties affect polypropylene concrete, Materials Today: Proceedings, 38, Part 5.
14. P.V. Ramana (2020), Functioning of bi-material interface intended for polypropylene fiber concrete, Materials Today: Proceedings,14, Part 2.
15. Ayush Meena, PV Ramana (2021), "Assessment of structural wall stiffness impact due to blast load," Elsevier: Materials Today. https://doi.org/10.1016/j.matpr.2021.03.093.
16. Anamika Agnihotri, Ajay Singh Jethoo, P.V. Ramana (2021), "Mechanical and Durability Analysis of Recycled Materials", Key Engineering Materials (Vol. 882, pp. 228-236). Trans Tech Publications Ltd.
17. Anamika Agnihotri, Ajay Singh Jethoo, P.V. Ramana, Mechanical properties of unprotected recycled concrete to fiery-hot, Materials Today: Proceedings (2021), ISSN 2214-7853.https://doi.org/10.1016/j.matpr.2020.11.702
18. Ajay Singh Jethoo, Anamika Agnihotri, P.V. Ramana "Reprocessed Materials Evaluation on Perfunctory and Flame Endurance of Structures", International Conference on Management, Science & Technology (ICMST- 2021) – ONLINE, 29-30 May, 2021
19. Pul, Selin. (2008). Experimental investigation of tensile behaviour of high-strength concrete, Materials, and Structures, 49(6), 755-764.
20. Arıoglu, N., Girgin, Z. C., & Arıoglu, E. (2006). Evaluation of ratio between splitting tensile strength and compressive strength for concretes up to 120 MPa and its application in strength criterion. ACI materials journal, 103(1), 18-24.
21. Ismeik, M. (2009). Effect of mineral admixtures on mechanical properties of high-strength concrete made with locally available materials. Jordan Journal of Civil Engineering, 3(1), 78-90.
22. Kothai, L., & Malathy, R. (2012). Strength studies on self compacting concrete with manufactured sand partially replace natural sand. European Journal of Scientific Research, 89(3), 490-496.
23. Lavanya, G., & Jegan, J. (2015). Evaluation of the relationship between split tensile and compressive strength for geopolymer concrete of varying grades and molarity. Int. J. Appl. Eng. Res, 10(15), 35523-35527.
24. Suda, V. R., & Paul, S. P. (2022). Relationship between ternary blended concrete's compressive, split tensile, and flexural strengths. Materials Today: Proceedings.
25. ACI-363-R. State of the art report on high-strength concrete. American Concrete Institute, 1992, Farmington Hills (Michigan)
26. IS-456-2000. Plain and reinforced concrete code of practice. Indian Standard, 2000, India
27. Mindess, S., Young, F., & Darwin, D. (2003). Concrete 2nd edition. Technical Documents, 585.
28. Legeron, F., & Paultre, P. (2000). prediction of modulus of rupture of concrete. Materials Journal, 97(2), 193-200.