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INVESTIGATING THE COMPRESSIVE AND TENSILE PERFORMANCE OF CONCRETE INCORPORATING RECYCLED AGGREGATES, PLASTIC, AND RUBBER WASTE

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Abstract
Concrete production's heavy reliance on natural resources and the pressing issue of plastic and rubber waste disposal necessitates sustainable alternatives. This study uniquely addresses this by investigating the combined and varying proportions of plastic and rubber powder as partial replacements for fine aggregate in M15 concrete, systematically analyzing both compressive and split tensile strengths across ten distinct mix designs. Utilizing eighty cylindrical specimens cured for 7 and 28 days, the research revealed a wide performance range with compressive and tensile strengths. The findings indicate that the specific proportions of waste materials significantly influence concrete's mechanical properties, underscoring the critical need for careful mix design. The research confirms that while some combinations of plastic and rubber can enhance concrete properties, others may reduce strength; nevertheless, these additions offer valuable benefits like improved flexibility, impact resistance, and soundproofing, paving the way for specialized, eco-friendly concrete solutions and a more sustainable construction industry.

INTRODUCTION

Concrete is a widely used material that is shaping our societies, it's the backbone of our cities and infrastructure. but making all that concrete requires a huge amount of natural resources, and those aren't infinite and also we're constantly struggling with proper disposing of plastic and rubber waste. There are 3 main ingredients in a concrete mix, namely cement, aggregate and water. Where aggregate is further classified on the basis of size namely sand (fine aggregate) and gravel (coarse aggregate). Each material plays a crucial role. Cement acts like an adhesive that holds everything together, sand and gravel gives its size and strength, while water reacts with cement and though hydration it hardens. The way these ingredients interact defines the concrete performance, i.e. compressive strength, tensile strength, flexural strength, density or durability.

Plastic powder, which comes from all sorts of recycled plastics (like water bottles, plastic packages and milk jugs), is usually lighter than natural sand. This means we can make lighter concrete, which can be a huge advantage for certain structures 0. Since plastic doesn't absorb the need of water decreases. Then there's rubber powder, sourced from old tires. It properties include elasticity and sound absorption. The additives make concrete that's tougher, more flexible, and even sound proof 0. However, problems arise like making sure the rubber sticks well to the cement and dealing with a potential dip in strength. This research dives deep into these challenges and opportunities, exploring how using plastic and rubber powder as substitutes for fine aggregate impacts concrete's mechanical properties. This study focuses on using plastic powder and rubber powder to replace some of the traditional materials in concrete. It's an opportunity in helping our planet by using up waste and potentially making concrete even better.

Integrating plastic and rubber waste into concrete presents a fascinating balance of benefits and challenges. Research shows that the density of plastic significantly impacts concrete strength, with lighter plastics affecting its overall integrity 0. While using plastic can reduce carbon emissions, adding too much might decrease compressive strength 0. Similarly, incorporating treated rubber can improve concrete's performance 00, making it lighter and more resistant to wear and tear 0. The distribution and connection of rubber particles within the cement are vital for strength 0, and while rubber can reduce strength, silica fume can help mitigate this effect **Error! Reference source not found.**.

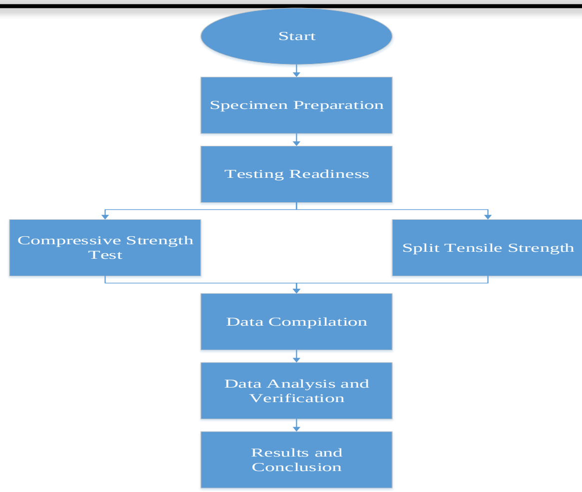
A comprehensive study suggests that replacing 10-20% of aggregate with plastic is often optimal, influencing density, strength, and insulation 0. Different recycled plastics can even boost impact energy and strength. Although adding rubber often lowers compressive strength, combining it with human hair fiber in specific ratios can surprisingly improve both compressive and splitting tensile strengths 0. Despite potential strength reductions from high rubber content, rubberized concrete offers significant advantages like wear resistance and toughness 0. Some studies even indicate that a small amount of plastic powder can increase compressive strength 0.

Other studies shows that replacing coarse aggregate with PET bottle waste leads to lighter concrete with reduced water absorption and heat conductivity 0. Studies also explore how untreated tire rubber affects concrete properties, and interestingly, adding rubber can even boost compressive strength and compactness in chloride-exposed environments **Error! Reference source not found.**. Ultimately, using plastic and rubber in concrete causes changes, depending on type, size, and quantity. While there might be a slight dip in overall strength, these additions bring valuable benefits like improved flexibility, impact resistance, and soundproofing, opening doors for specialized, eco-friendly concrete solutions.

Methodology

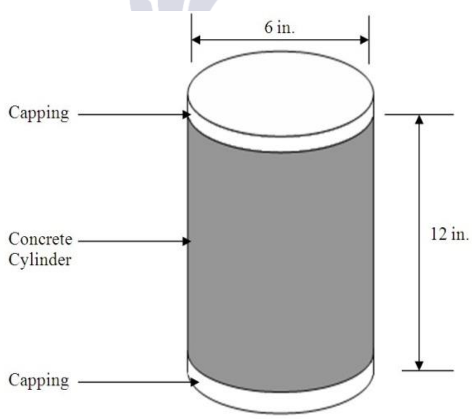
The experimental studies focused to investigate the mechanical properties of concrete incorporated with rubber and plastic waste. A total of 10 mix design were used of grade M15 as per code ACI 211.1, i.e. ratio of 1:2:4 and a water/cement ratio of 0.6. All experimental activities were conducted under controlled environment to adhere proper safety. Steps of methodology are as follow in figure 1.1:

Figure 1.1 Steps of Methodology



For both conventional and plastic rubber concrete (PRC), the primary materials included Ordinary Portland Cement (OPC) as the binding agent, designed for an M15 concrete grade with a 1:2:4 ratios. Recycled coarse aggregate, constituting 60-80% of the concrete's volume and 70-85% of its mass, and fine aggregate, used as a filler, were both sourced from the lab inventory. Potable water was utilized with a water-cement ratio of 0.6, a crucial factor for achieving the desired concrete quality. Additionally, rubber powder, derived from tire waste, and Class 2 HDPE plastic powder were both incorporated as replacement materials for fine aggregate.

Figure 1.2 Specimen Size



The concrete specimens were prepared using cylindrical molds with a height of 12 inches and a diameter of 6 inches as shown in Figure 1.2. A total of 80 samples were casted. Manual batching of materials was performed in the lab using a weighing machine, maintaining a water-cement ratio of 0.6. Before casting, oil was applied to the molds. The concrete materials were mixed until a smooth consistency was achieved. The concrete mixture was then poured and casted. After 24 hours, the specimens were demolded and subsequently cured for 7 to 28 days to achieve the desired concrete properties. The specimens were tested in both compressive strength and split tensile strength using a computerized compressive testing machine (CTM) with proper capping.

Table 1.1 Mix Design

	CEMENT	SAND				

MIX DESIGN					PLASTIC POWDER		RUBBER POWDER		RECYCLE COARSE AGGREGATE		COARES AGGREGATE	
Unit	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg
PRC 1	100	2.014	50	2.014	25	1.007	25	1.007	100	8.056	0	0.000
PRC 2	100	2.014	0	0	50	2.014	50	2.014	100	8.056	0	0.000
PRC 3	100	2.014	25	1.007	25	1.007	50	2.014	100	8.056	0	0.000
PRC 4	100	2.014	75	3.021	0	0	25	1.007	100	8.056	0	0.000
PRC 5	100	2.014	50	2.014	0	0	50	2.014	100	8.056	0	0.000
PRC 6	100	2.014	75	3.021	25	1.007	0	0	100	8.056	0	0.000
PRC 7	100	2.014	50	2.014	50	2.014	0	0	100	8.056	0	0.000
PRC 8	100	2.014	25	1.007	50	2.014	25	1.007	100	8.056	0	0.000
PRC 9	100	2.014	100	4.028	0	0	0	0	100	8.056	0	0.000
PCC10	100	2.014	100	4.028	0	0	0	0	0	0.000	100	8.056

The data shows that a total of ten distinct concrete mix designs (PRC1-9, PCC10), varying proportions of cement, sand, plastic powder, rubber powder, recycled coarse aggregate and coarse aggregate, while maintaining a constant water/cement ratio of 0.6. The percentages used varied from 0%, 25%, 50% and 100% replacement of fine aggregate as shown in table 1.1.

Results and Discussion:

A meticulous examination of the compressive strength data reveals a wide range of performance. For instance, PRC 6 consistently achieves the highest compressive strengths, recording an impressive 2086.83 psi at 7 days as shown in figure 2.1 and 3210.90 psi at 28 days as shown in figure 2.2. This mix's composition, characterized by 75% sand, 25% plastic powder, and a lack of rubber powder, suggests a favorable blend for compressive load resistance. In stark contrast, PRC 2 exhibits the lowest compressive strengths at both intervals, with values of 156.62 psi at 7 days and 244.55 psi at 28 days, likely attributable to its complete absence of sand coupled with the presence of both plastic and rubber powders. PCC10 also demonstrates robust compressive strength, reaching 1894.46 psi at 7 days and 2912.77 psi at 28 days, highlighting the significant contribution of coarse aggregate, as shown in table 2.1

Table 2.1 Compressive Strength in 7 and 28 Days

MIX DESIGN	COMPRESSIVE (Cylinder) 7 DAYS Test 01	COMPRESSIVE (Cylinder) 7 DAYS Test 02	COMPRESSIVE (Cylinder) 7 DAYS Average	COMPRESSIVE (Cylinder) 28 DAYS Test 01	COMPRESSIVE (Cylinder) 28 DAYS Test 02	COMPRESSIVE (Cylinder) 28 DAYS Average
Unit	psi	psi	psi	psi	psi	psi
PRC 1	233.97	232.56	233.27	359.96	361.36	360.66
PRC 2	158.24	154.99	156.62	243.45	245.66	244.55
PRC 3	465.40	462.00	463.70	716.00	720.25	718.13
PRC 4	1300.90	1295.30	1298.10	2001.38	1998.60	1999.99
PRC 5	627.56	632.25	629.91	965.48	977.30	971.39
PRC 6	2086.30	2087.35	2086.83	3209.70	3212.11	3210.90
PRC 7	1560.28	1559.36	1559.82	2400.42	2405.66	2403.04
PRC 8	971.82	972.39	972.11	1495.11	1500.69	1497.90
PRC 9	1027.35	1027.22	1027.28	1580.54	1569.69	1575.11
PCC10	1893.38	1895.55	1894.46	2912.89	2912.66	2912.77

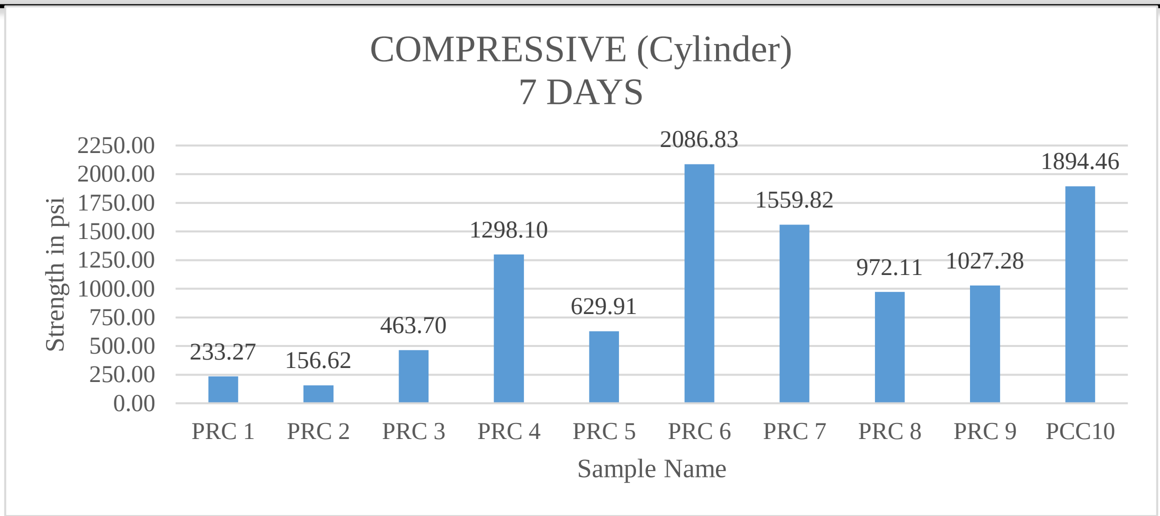


Figure 2.1 Compressive Strength at 28 Days

Beyond compressive strength, split tensile data reveals PRC 6's superior tensile performance 281.57 psi at 7 days, 428.71 psi at 28 days, while PRC 2 consistently shows the lowest 142.32 psi at 7 days as shown in figure 2.3, 220.80 psi at 28 days as shown in figure 2.4. Notably, PRC 2's tensile strength reduction is not proportional to its compressive decline, suggesting a nuanced impact of plastic/rubber powders on tensile properties. PCC10's robust 28-day tensile strength (313.98 psi) highlights the critical role of coarse aggregate. This systematic material variation provides a basis for understanding and optimizing concrete's mechanical performance.

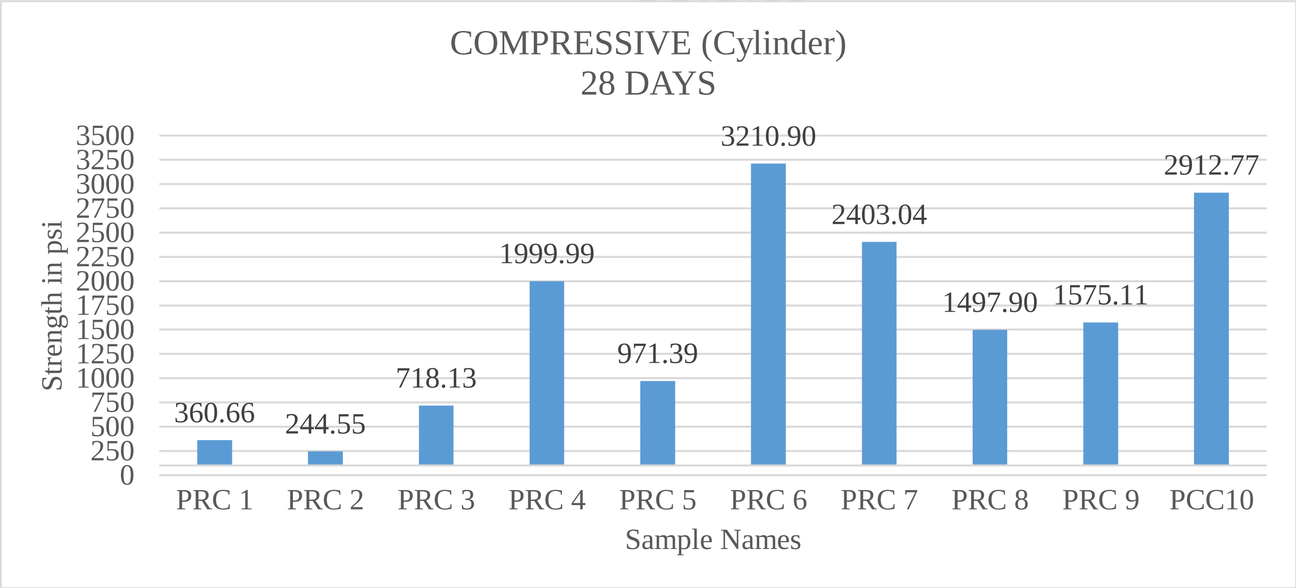


Figure 2.2 Compressive Strength at 7 Days

Table 2.2 Split Tensile Strength in 7 and 28

MIX DESIGN	SPLIT TENSILE (Cylinder) 7 DAYS Test 01	SPLIT TENSILE (Cylinder) 7 DAYS Test 02	SPLIT TENSILE (Cylinder) 7 DAYS Average	SPLIT TENSILE (Cylinder) 28 DAYS Test 01	SPLIT TENSILE (Cylinder) 28 DAYS Test 02	SPLIT TENSILE (Cylinder) 28 DAYS Average
Unit	psi	psi	psi	psi	psi	psi
PRC 1	44.68	44.02	44.35	68.28	69.20	68.74
PRC 2	143.52	141.12	142.32	221.30	220.30	220.80
PRC 3	75.43	78.60	77.02	116.55	115.55	116.05
PRC 4	172.22	169.69	170.96	264.42	265.50	264.96
PRC 5	88.99	89.66	89.32	135.40	138.40	136.90
PRC 6	278.66	284.48	281.57	426.72	430.69	428.71
PRC 7	71.90	75.82	73.86	111.20	110.02	110.61
PRC 8	91.43	92.20	91.82	141.13	140.20	140.67
PRC 9	242.56	251.98	247.27	370.75	375.60	373.18
PCC10	315.36	312.60	313.98	484.00	486.33	485.17

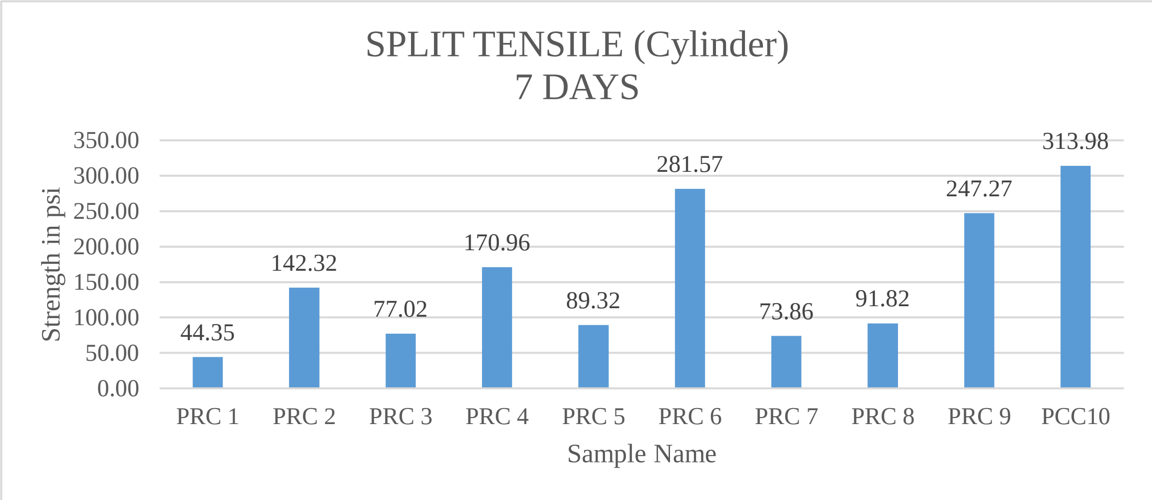


Figure 2.3 Split Tensile Strength at 7 Days

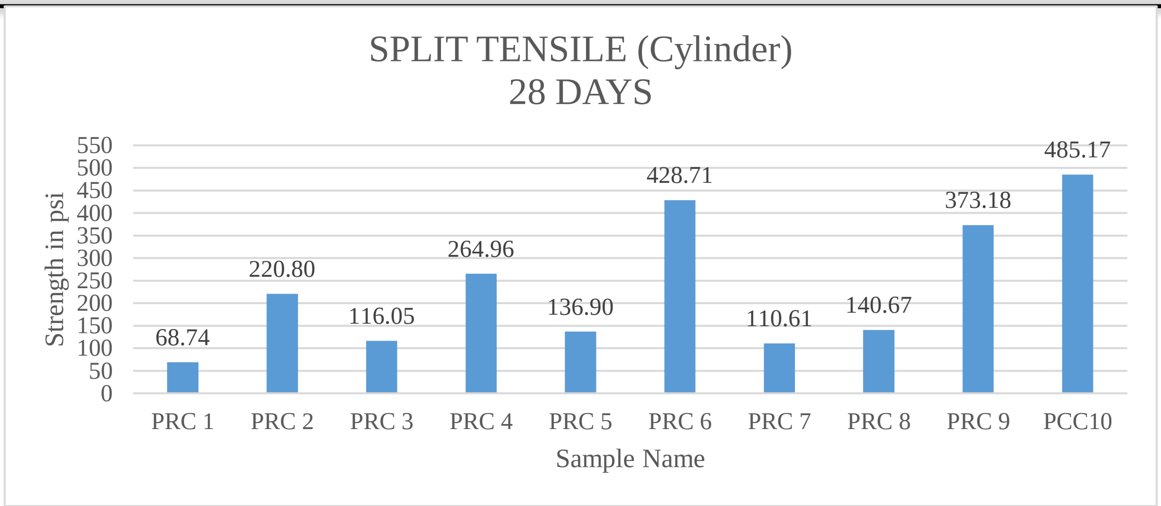


Figure 2.4 Split Tensile Strength at 28 Days

Conclusion:

This research investigated the mechanical properties of concrete incorporating recycled plastic and rubber waste as partial replacements for fine aggregate, utilizing 10-M15 concrete mix designs with a constant water/cement ratio of 0.6. The study found a wide range of performance based on mix composition. PRC 6, with 75% sand and 25% plastic powder, consistently showed the highest compressive and tensile strengths, suggesting an optimal blend for load resistance. In contrast, PRC 2, lacking sand and containing both plastic and rubber powders, exhibited the lowest strengths, indicating a detrimental effect. The inclusion of coarse aggregate in PCC10 significantly contributed to robust compressive and tensile strengths. While some combinations of plastic and rubber can enhance concrete properties, others may reduce strength; however, these additions can offer benefits like improved flexibility, impact resistance, and soundproofing, leading to specialized, eco-friendly concrete solutions.

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