An Experimental Investigation on Concrete Using Recycled Plastic as a Partial Replacement for Fine Aggregate and Nanosilica as a Partial Replacement for Cement

U BARATH , KOMALI[2]

[1]PG Student, Dept. of Civil (structural engineering and Construction Management), Golden ValleyIntegratedCampus, Madanapalli, Chittoor,Andhra Pradesh, India.

[2]AssistantProfessor,Dept.ofCivilEngineering,GoldenValleyIntegratedCampus,Madanapalle,Chittoor, AndhraPradesh

ABSTRACT

Concrete has been used as a construction material in the building industry for approximately two centuries. Each year, more than one ton of concrete is used per person globally. Therefore, conducting research on the use of modern technologies in concrete production is of great importance. One of the most critical global challenges is managing waste and promoting its reuse. Reducing the required amount of Portland cement without compromising concrete performance is especially significant for large-scale projects that demand vast quantities of cement.Moreover, the production of Portland cement clinker consumes large amounts of energy and has a considerable environmental impact, including extensive quarrying for raw materials. Recycling waste materials in concrete manufacturing not only provides a promising resource for high-quality concrete production but also contributes to resolving waste disposal issues.A large volume of ceramic tiles becomes waste due to their physical and chemical properties, making them non-reusable and non-recyclable through conventional methods. Given the substantial volume of concrete production and the potential to incorporate waste materials, using ceramic waste in concrete could be an effective strategy for environmental protection and improving concrete properties.This experimental study investigates the feasibility of using plastic waste as a partial replacement for fine aggregate in concrete, up to 25%, with a fixed proportion of 5%. Additionally, nano-silica is used to replace cement at levels of 0%, 4%, and 8% in M20 and M30 grade concrete. All other mix parameters are kept constant. The slump value and compressive strength of the concrete samples were then measured and analyzed.

I. INTRODUCTION

Portland cement clinker production is highly energy-intensive and has a significant environmental impact. It involves massive quarrying for raw materials, as approximately **1.7 tons of raw material** are needed to produce **1 ton of clinker**, emitting about **850 kg of CO_2** per ton of clinker produced. Therefore, using **pozzolanic and cementitious materials** as alternatives has become increasingly important in concrete production.

In recent years, the **disposal of industrial waste materials** has become a critical global challenge. Many industries are now seeking methods to **reuse waste** effectively. The **replacement of cement in concrete with waste materials** not only saves energy but also has a positive environmental impact. Since the cost of cement accounts for more than **45% of concrete costs**, such replacements can also lead to substantial cost reductions.

Several studies have identified the potential of using **ceramic waste** in concrete. Ceramic waste is known for its durability, hardness, and resistance to biological, chemical, and physical degradation. However, it cannot be recycled by conventional processes. Utilizing **inorganic industrial residuals** like ceramic waste in concrete helps achieve **sustainable concrete design** and a **greener environment**. The waste generated during various ceramic production stages can range from **3% to 7%** of daily production.

Literature Review

Several studies have explored ceramic and plastic waste in concrete:

- **Lavat et al.** reported a decline in early strength with ceramic waste.
- **Ay and Ünal** confirmed the pozzolanic reactivity of ceramic powder.
- **Toledo Filho et al.** observed a slight increase in compressive strength with 10–20% brick powder cement replacement.
- **Torgal and Jalali** found a slight decrease in compressive strength and water permeability using 20% ground ceramics.
- **Ferdinand Brandl and Nicolas Bertrand** used nanoparticles and UV light to isolate contaminants from soil and water.
- **Nano Zero Valent Iron (nZVI)**, carbon nanotubes, and nanofibers are being used to remediate heavy metals and chlorinated compounds.

Regarding **plastic waste**:

- **Sreenath & Harishankar (2017)**: 10% LDPE replacement increased compressive strength from 34.96 MPa to 38.95 MPa.
- **Ramadevi & Manju (2012)**: PET fiber at 2% increased strength, but higher amounts decreased it.

- **Aravind & John (2015)**: Fine aggregate replacement with plastic fines generally reduced strength.
- **Arivalagan (2016)**: 10% PET waste increased compressive strength by 26%, but more than 15% lowered it.
- **Guendouz et al. (2016)**: 20% LDPE replacement increased strength by 30%, 40% replacement decreased bulk density.
- **Suganthy et al. (2013)**: Replacing sand with plastic reduced concrete weight linearly.

Objectives of the Study

This experimental study aims to:

1. Evaluate the strength development of nano-silica concrete over time compared to control concrete.
2. Compare the strength of nano-silica concrete with ceramic tile coarse aggregate replacement.
3. Promote the positive use of industrial waste.
4. Conduct compressive tests on nano-silica and ceramic waste concrete as per IS standard specimens.
5. Protect the environment through proper waste utilization.
6. Achieve strength improvement with reduced material costs.

Experimental Program

The experimental framework includes:

- Partial **replacement of cement with nano-silica** (0%, 2%, 4%, 6%, 8%) in **M20 and M30** grade concrete.
- Replacement of **fine aggregate with plastic waste** up to **25%** with a fixed value of 5%.
- Replacement of **coarse aggregate with ceramic waste**.
- **Curing** and testing at **7, 28, and 56 days** for:
  - **Compressive Strength**
  - **Split Tensile Strength**

Materials Used

- **Cement**: OPC 53 Grade conforming to IS: 8112-1989.
- **Fine Aggregate**: Clean river sand with rounded particles, conforming to standards.
- **Coarse Aggregate**: Crushed granite stones ranging between 9.5 mm to 37.5 mm.
- **Water**: Clean potable water for mixing and curing.
- **Nano-Silica**: Used as a cement replacement due to its high pozzolanic activity.
- **Recycled Plastic Waste**: PET plastic bottles shredded to 4–0.075 mm using a blade mill.
- **Ceramic Tile Waste**: Used as partial coarse aggregate replacement.
- **Rice Husk Ash (optional)**: Potential pozzolanic material, though not emphasized in current tests.natural sand was used in this study. Properties ofsand aslongascoarseaggregate andPET.

NanoSiO2

The average size of nano silica was found to be 236nmfromParticleSizeAnalyzer,thereportofwhichhasbeenpresentedintheAppendix.Theproperties of the material, the nano silicausedinthe experiment. Nanotechnology is widely regardedasoneofthetwenty-firstcentury'skeytechnologies,anditseconomicimportanceissharply on the rise. In the construction industry,nanomaterials has potentials that are already usabletoday, especially the functional characteristics suchas increased tensile strength, self-cleaning capacity,fireresistance,andadditivesbasedonnanomaterialsmakecommonmaterialslighter,morepermeable,andmoreresistant towear

Quantity of materials in kg / m^3 of concrete @M20

Mix	Nano Silica % of cement	Replacement of Recycled plastic Waste Replacement		Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	Water (lit/m^3)
CC	0%	0%	0	360	584	1223.8	180.42
		5%	29.2	360	554.6	1223.8	180.42
		10%	58.4	360	525.6	1223.8	180.42
		15%	87.6	360	496.4	1223.8	180.42
		20%	116.8	360	467.2	1223.8	180.42
		25%	146	360	438	1223.8	180.42
Mix-1	4%	0%	0	360	584	1223.8	180.42
		5%	29.2	360	554.6	1223.8	180.42
		10%	58.4	360	525.6	1223.8	180.42
		15%	87.6	360	496.4	1223.8	180.42
		20%	116.8	360	467.2	1223.8	180.42
		25%	146	360	438	1223.8	180.42
Mix-2	8%	0%	0	360	584	1223.8	180.42
		5%	29.2	360	554.6	1223.8	180.42
		10%	58.4	360	525.6	1223.8	180.42
		15%	87.6	360	496.4	1223.8	180.42
		20%	116.8	360	467.2	1223.8	180.42
		25%	146	360	438	1223.8	180.42

Quantityofmaterialsinkg/m^{3}ofconcrete@M30

Mix	Nano Silica % of cement	Replacement of Recycled plastic Waste Replacement		Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	Water (lit/m^3)
CC	0%	0%	0	394	732	1139	197
		5%	36.6	394	695.4	1139	197
		10%	73.2	394	658.8	1139	197
		15%	109.8	394	622.2	1139	197
		20%	146.4	394	585.6	1139	197
		25%	183	394	549	1139	197
Mix-1	4%	0%	0	394	732	1139	197
		5%	36.6	394	695.4	1139	197
		10%	73.2	394	658.8	1139	197
		15%	109.8	394	622.2	1139	197
		20%	146.4	394	585.6	1139	197
		25%	183	394	549	1139	197
Mix-2	8%	0%	0	394	732	1139	197
		5%	36.6	394	695.4	1139	197
		10%	73.2	394	658.8	1139	197
		15%	109.8	394	622.2	1139	197
		20%	146.4	394	585.6	1139	197
		25%	183	394	549	1139	197

VIEXPERIMENTALINVESTIGATION

Thefollowingarethestrengthtestswhichwasconductedinthe project:

- Compressivestrengthtest
- Splittensilestrengthtest

VRESULTS

The results completed in the present investigationare reported in the form of Tables and Graphs forvariouspercentageofRecycledplasticwasteasfineaggregate and nano silicawithcement

SlumptestforConcrete

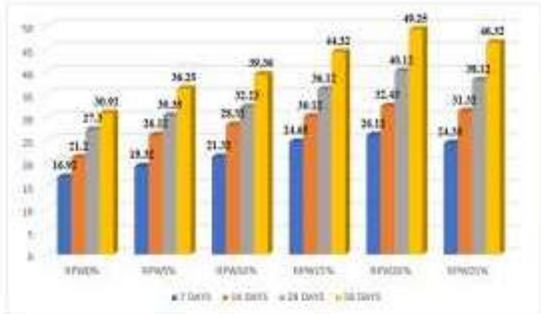
S.No.	RPW (Recycled Plastic Waste)	M20	M30
1	0%	65	50
2	5%	93	80
3	10%	108	86
4	15%	116	95
5	20%	135	150
6	25%	112	125

Compressive strength of concrete with mixdesignof M20 @0% NanoSilica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	16.92	21.2	27.3	30.92
RPW5%	18.99	23.62	29.32	34.35
RPW10%	20.12	24.98	30.64	38.32
RPW15%	22.35	27.32	34.25	42.12
RPW20%	24.38	29.12	39.12	46.58
RPW25%	23.12	27.32	36.02	40.12

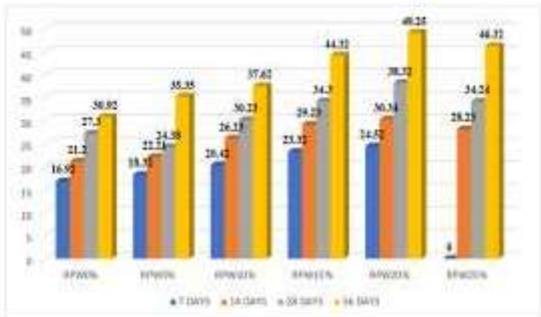
Compressive strength of concrete with mixdesignofM20@4%Nano Silica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	16.92	21.2	27.3	30.92
RPW5%	19.32	26.12	30.35	36.25
RPW10%	21.32	28.32	32.23	39.36
RPW15%	24.65	30.12	36.12	44.32
RPW20%	26.12	32.43	40.12	49.25
RPW25%	24.35	31.32	38.12	46.32



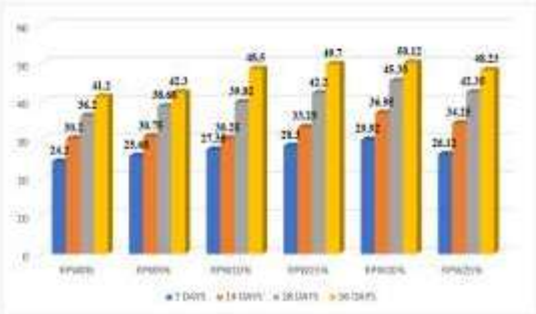
Compressive strength of concrete with mixdesignofM20@8%Nano Silica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	16.92	21.2	27.3	30.92
RPW5%	18.32	22.21	24.58	35.35
RPW10%	20.42	26.23	30.23	37.62
RPW15%	23.32	29.23	34.3	44.32
RPW20%	24.52	30.34	38.32	49.25
RPW25%	21.33	28.23	34.24	46.32



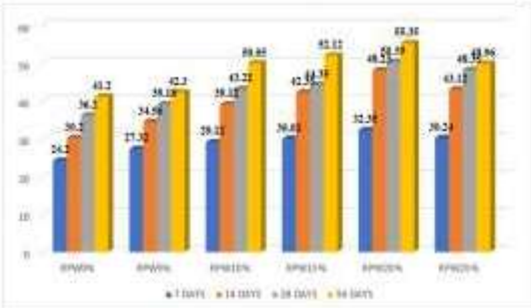
Compressive strength of concrete with mixdesignofM30@0%Nano Silica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	24.2	30.2	36.2	41.2
RPW5%	25.68	30.75	38.68	42.3
RPW10%	27.35	30.25	39.82	48.5
RPW15%	28.3	33.25	42.2	49.7
RPW20%	29.92	36.95	45.35	50.12
RPW25%	26.12	34.25	42.35	48.23



Compressivestrengthofconcretewithmixdesignof M30@4%Nano Silica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	24.2	30.2	36.2	41.2
RPW5%	27.32	34.56	39.18	42.3
RPW10%	29.12	39.12	43.22	50.05
RPW15%	30.02	42.35	44.35	52.12
RPW20%	32.35	48.23	50.39	55.35
RPW25%	30.24	43.12	48.35	49.96

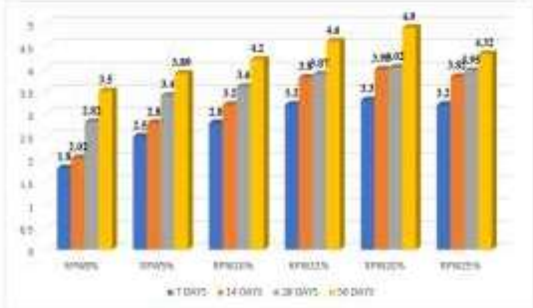


Compressivestrengthofconcretewithmixdesignof M30@8%Nano Silica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	24.2	30.2	36.2	41.2
RPW5%	26.23	32.56	36.23	40.12
RPW10%	28.32	38.01	40.23	49.12
RPW15%	29.21	40.12	42.3	50.12
RPW20%	30.12	42.32	49.23	52.12
RPW25%	29.12	39.12	46.12	48.23

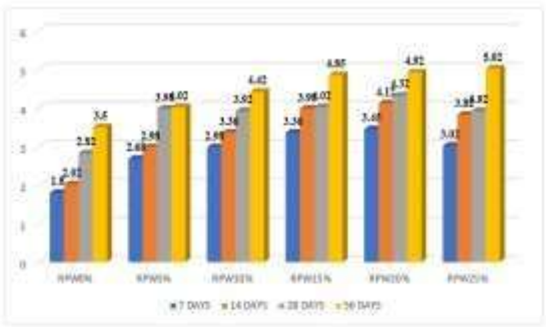
Split tensile strength of concrete with mix designofM20@0%NanoSilica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	1.8	2.02	2.82	3.5
RPW5%	2.5	2.8	3.4	3.89
RPW10%	2.8	3.2	3.6	4.2
RPW15%	3.2	3.8	3.87	4.6
RPW20%	3.3	3.98	4.02	4.9
RPW25%	3.2	3.82	3.95	4.32



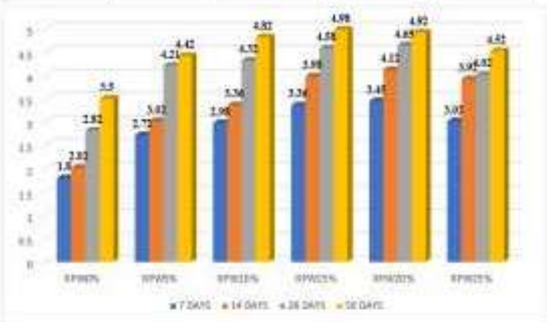
Split tensile strength of concrete with mix designofM20@4% NanoSilica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	1.8	2.02	2.82	3.5
RPW5%	2.68	2.98	3.98	4.02
RPW10%	2.98	3.36	3.92	4.42
RPW15%	3.36	3.98	4.02	4.85
RPW20%	3.45	4.12	4.32	4.92
RPW25%	3.02	3.82	3.92	5.02



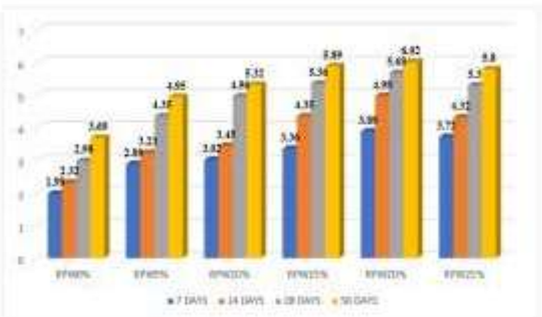
Splittensile strengthofconcretewithmixdesignofM20@8% NanoSilica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	1.8	2.02	2.82	3.5
RPW5%	2.72	3.02	4.21	4.42
RPW10%	2.98	3.36	4.32	4.82
RPW15%	3.36	3.98	4.58	4.98
RPW20%	3.45	4.12	4.65	4.92
RPW25%	3.02	3.92	4.02	4.52



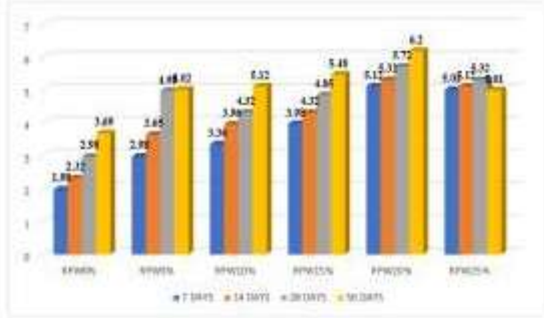
Splittensile strengthofconcretewithmixdesignofM30@0% NanoSilica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	1.98	2.32	2.98	3.69
RPW5%	2.89	3.23	4.35	4.95
RPW10%	3.02	3.45	4.96	5.32
RPW15%	3.36	4.35	5.36	5.89
RPW20%	3.89	4.98	5.68	6.02
RPW25%	3.72	4.32	5.3	5.8



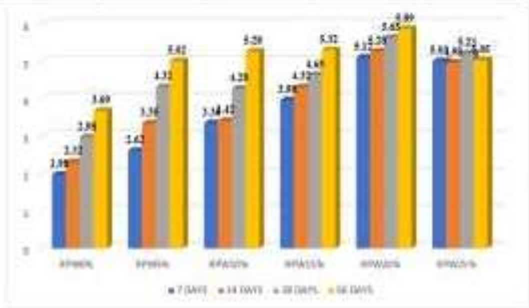
Split tensile strength of concrete with mix designofM30@4% NanoSilica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	1.98	2.32	2.98	3.69
RPW5%	2.98	3.65	4.98	5.02
RPW10%	3.360	3.96	4.32	5.12
RPW15%	3.98	4.32	4.85	5.48
RPW20%	5.12	5.32	5.72	6.2
RPW25%	5.02	5.12	5.32	5.03



Split tensile strength of concrete with mix designofM30@8% NanoSilica

RPW (Recycled Plastic Waste)	7 DAYS	14 DAYS	28 DAYS	56 DAYS
RPW0%	1.98	2.32	2.98	3.69
RPW5%	2.62	3.35	4.32	5.02
RPW10%	3.360	3.42	4.28	5.28
RPW15%	3.98	4.32	4.65	5.32
RPW20%	5.12	5.28	5.65	5.89
RPW25%	5.02	4.98	5.23	5.05



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VI. CONCLUSIONS

Based on the study on the effect of nanomaterials as cement replacement in concrete incorporating ceramic tiles as coarse aggregate replacement, the following conclusions were drawn:

1. **Workability**: Replacing fine aggregate with recycled plastic waste significantly affects the workability of concrete.

2. **Compressive Strength (Plastic Replacement)**: Concrete mixes with up to **20% recycled plastic waste** as fine aggregate replacement show **higher compressive strength** than conventional concrete.
3. **Strength Over Time**: For **7, 14, 28, and 56 days of curing**, compressive strength with **20% recycled plastic waste** replacement remains **higher than that of conventional concrete**.
4. **Effect of Nano Silica on Compressive Strength**: Adding **4% Nano Silica** (by weight of cement) to concrete with recycled plastic waste as fine aggregate **increases compressive strength by up to 20%** compared to normal concrete.
5. **Split Tensile Strength**: For 7, 14, 28, and 56 days of curing, **split tensile strength** of concrete with **20% recycled plastic waste** is **higher than conventional concrete**.
6. **Effect of Nano Silica on Split Tensile Strength**: Incorporating **4% Nano Silica** significantly increases **split tensile strength by up to 20%** compared to conventional concrete.
7. **Aggregate Replacement**: Based on M20 and M30 grades, the **replacement of coarse aggregate with ceramic waste** and **fine aggregate with recycled plastic waste** yields favorable results.
8. **Optimum Mix Recommendation**: The **optimum mix** is identified as **20% recycled plastic waste (as fine aggregate replacement)** along with **4% Nano Silica** (by weight of cement), which is recommended for enhanced mechanical properties.

Compressive Strength Test Results (N/mm²)

M20 (20% Replacement of Fine Aggregate)

Nano Silica	7 Days	14 Days	28 Days	56 Days
0%	24.38	29.12	39.12	46.58
4%	26.12	32.43	40.12	49.25
8%	24.52	30.34	38.32	49.25

M30 (20% Replacement of Fine Aggregate)

Nano Silica	7 Days	14 Days	28 Days	56 Days
0%	29.92	36.95	45.35	50.12
4%	32.35	48.23	50.39	55.35
8%	30.12	42.32	49.23	52.12

Split Tensile Strength Test Results (N/mm²)

M20 (20% Replacement of Fine Aggregate)

Nano Silica	7 Days	14 Days	28 Days	56 Days
0%	3.30	3.98	4.02	4.90
4%	3.45	4.12	4.32	4.92
8%	3.28	4.02	4.15	4.62

M30 (20% Replacement of Fine Aggregate)

Nano Silica	7 Days	14 Days	28 Days	56 Days
0%	3.89	4.98	5.68	6.02
4%	5.12	5.32	5.72	6.20
8%	5.12	5.28	5.65	5.89

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