EFFECT OF POLYPROPYLENE FIBRE ON THE STRENGTH OF CONCRETE INCORPORATING RICE HUSK ASH

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ABSTRACT:

The increase in Carbon Dioxide (CO_2) gas emissions during the production of cement have increased the necessity for the development of eco-friendly sustainable concrete using alternative binders. This research was conducted to study the strength behaviour in terms of compressive and flexural strength of concrete incorporating rice husk ash (RHA) as a supplementary cementitious material. RHA is a potential alternative binder due to its pozzolanic nature but it can partially replace cement to a certain amount, beyond it, the strength decreases making the concrete less viable. Therefore, to strengthen RHA-based eco-friendly concrete, Polypropylene (PP) fibres were used to reinforce concrete. Based on the results, it was observed that 5% RHA achieved higher strength than the control sample, however, a further increase in RHA content resulted in a significant decrease in strength. Concrete with 10% RHA which showed reduced strength was reinforced with PP fibres which resulted in a gain in strength.

1. INTRODUCTION

The construction industry is among the most rapidly growing industries around the globe which contributes significantly to the growth of a country's socioeconomics (Sohu et al., 2018). Concrete, the most widely used building material by the construction industry, is an artificial component consisting of cement, aggregates and water. Cement is the most important ingredient in concrete as it acts as a binder, glueing all other ingredients together to form a hard solid component, which can be used for a variety of civil engineering applications, ranging from small residential houses to tall skyscrapers (Sandhu et al., 2019). However, the increase in construction of buildings and infrastructures across the world has increased the demand for concrete, thus also increasing the production of cement. According to (Suhendro 2014), it has been estimated that approximately 10% of Carbon Dioxide (CO_2) gas is released by the cement industry, directly and indirectly, during the production of cement.

The increase in production of cement means an increase in CO_2 gas emissions, which are harmful to the ozone layer and contribute to global warming.

Another disadvantage of cement is that it utilizes natural resources such as clay and limestone, and with the never-ending demand of cement in the construction industry as the main binder material, the natural resources are being depleted at an alarming rate.

With the urbanization (Abdel-Shafy et al., 2018) and industrialization, waste generation has increased exponentially, which are generally thrown into landfills without undergoing proper treatment, and thus causes significant health as well as environmental issues. Over the years, researchers have tried to reduce the negative impact being caused by the production of cement and the generation of waste materials on the environment, by substituting partially cement content in the manufacturing of concrete. This partial replacement allows the reduction in cement content while simultaneously reusing the waste materials. Utilization of waste materials as supplementary cementitious materials (SCMs) in concrete is not a relatively new concept, research has been ongoing for decades to develop sustainable concrete with various SCMs (Ramadhansyah et al., 2020; Ashish 2019; Gettu et al., 2019; Jhatial et al., 2019a; Juenger et al., 2019; Martirena & Monzó, 2018).

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For this study, agro-industrial waste material known as Rice Husk Ash (RHA) is utilized to replace cement partially. RHA is a by-product of rice which is being consumed by half of the world's population, while approximately 10% of world's arable land is utilized for growing rice alone (Koushkbaghi et al., 2019).

According to (Krishna et al., 2016), it has been estimated that 600 million tons of rice paddy are produced annually, average rice paddy consists of 25% husk, 10% barn and germ while remaining is rice. The husks are utilized in the boiler as fuel by the rice mills to generate electricity, which in turn produces solid waste known as RHA, shown in Figure 1. This solid waste is of no commercial use to the rice mills and therefore dumped in the open air, due to it being a powder, causes significant health issues to the people living nearby.

Figure 1. Sample of Rice Husk and Rice Husk Ash (Jhatial et al., 2019b)

RHA is an effective pozzolanic-based SCM due to highest concentration of silica amongst the plant residues. Being pozzolanic, allows the material to be utilized as cementitious material when properly but finely ground. The potential utilization of RHA in the production of concrete could help reduce the dependency of cement, as well as reduce the cost of construction and achieve sustainability. Furthermore, the utilization of waste materials in the construction industry means that these waste materials could be potentially used thus reducing the landfill developments.

Previous studies (Hussain et al., 2019; Kachwala et al., 2015; Rahim et al., 2014; Chao-Lung et al., 2011; Kishore et al., 2011) have suggested that RHA could be used to replace cement content up to a certain limit without compromising on the strength of concrete. Beyond this limit, the increase in RHA content tends to reduce the strength. Concrete is well known as a brittle material, which is strong under compression but weak under tension. With the partial replacement of cement, this increases its brittleness, and thus losses strength when higher content of RHA is used. Concrete tends to fail without prior warnings, and due to this it relatively achieves low flexural strength.

Fibre reinforcement in concrete can compensate this brittle behaviour and turn the concrete into ductile as shown in Figure 2. Such a change in behaviour allows the concrete to develop some resistance to cracking, thus increase the flexural strength of concrete. The benefits of adding fibres in concrete are not just the enhancement in strength (Nair et al., 2018) but also durability.

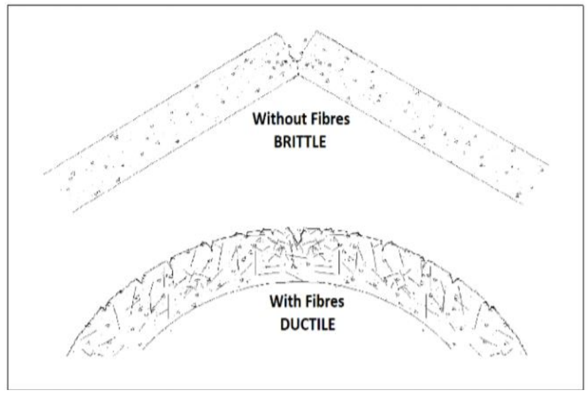

Figure 2. Behaviour change of concrete due to fibres (Jhatial et al., 2018a)

Polypropylene (PP) fibres are a by-product of petroleum refining through polymerization of propylene (Jhatial et al., 2018b). Concrete develops cracks when the load is applied, the cracks propagate rapidly, ultimately causing the structure to fail. PP fibres are utilized in concrete develop a bridging mechanism in the matrix which improves the strength of concrete along with toughness and deformation characteristics, allowing it to resist the failure.

The utilization of PP fibres as a reinforcement in concrete has been done over the years. It has been reported that PP fibres although decrease the workability of concrete, it significantly improve the strength (Memon et al., 2018; Ibrahm and Abbas, 2017; Jhatial et al., 2018c; Mohod, 2015; Singh, 2014; Bagherzadeh et al., 2012), while recent studies have suggested that PP fibres tend to reduce thermal conductivity value of concrete (Jhatial et al., 2020).

Therefore, the objective of this research is to determine the strength of concrete incorporating RHA while reinforcing it with PP fibres.

2. RESEARCH METHODOLOGY

This study was conducted to investigate the effect on the strength of PP fibres utilized (0%, 0.10%, 0.20% and 0.30%) to reinforce the concrete incorporating RHA as partial cement replacement.

2.1 Materials and Mixes

In this experimental work, the ordinary Portland cement (OPC) of a single batch of 53 Grade is used. Precautionary measures were taken to protect and store cement bags in airtight containers to prevent them from weathering agencies and adverse atmospheric effects. The local fine aggregates and coarse aggregates were acquired for this experimental work, the properties of the aggregates are tabulated in Table 1. M30 grade concrete was prepared, the mix proportions are mentioned in Table 2.

Table 1. Properties of Aggregates

Property	Coarse Aggregates	Fine Aggregates
Water Absorption	1 %	2.2 %
Bulking Density	1.610 gm/cc	1.542 gm/cc
Specific Gravity	2.74 (for 20 mm aggregates)	2.62
Fineness Modulus	7.17	2.74

Table 2. Mix proportions of Concrete

Mix Designation	Cement (%)	RHA (%)	PP Fibres (%)
M0	100%	0%	---
M1	95%	5%	---
M2	90%	10%	---
M3	85%	15%	---
M4	90%	10%	0.10%
M5	90%	10%	0.20%
M6	90%	10%	0.30%

2.2 Experimental Work

The experimental work consisted of two stages. The initial stage consists of the preparation of concrete specimens incorporating RHA as partial cement replacement (5%, 10% and 15% by weight of cement). The specimen comprising of cubes and beams were then tested against compression and flexural tensile bending strength.

The results obtained from the first stage were analyzed and an optimum RHA content was nominated contributing to considerable strength of concrete. The concrete mix which contained a slightly higher content of RHA than the optimum mix was chosen to be reinforced with 0.1%. 0.20% and 0.30% PP fibres to determine whether PP fibres on concrete incorporating RHA beyond optimum content could yield better results.

The materials for each mix were weighed before mixing of the materials. Initially, sand, coarse aggregates and binders (OPC and RHA) were mixed thoroughly for about 3-5 minutes to ensure uniform dispersion of RHA in the mix, afterwards, respective PP fibres were added to the mix.

The water was added gradually into the concrete mixer such that water can be distributed uniformly on the dry mix and mixing continued for about 3 minutes to achieve the uniform mix. The specific specimens of standard size were cast. After 24 hours, the specimens were demoulded and cured for 7 and 28 days.

The specific specimens were tested in the universal testing machine (UTM) for compressive strength per BS EN 12390-3:2019 and flexural strength per BS EN 12390-5:2019. A total of 3 cubic specimens for each mix were prepared for 7 days and 28 days compressive strength testing while 3 beams were prepared for each mix for 28 days flexural strength testing.

3. RESULTS AND DISCUSSION

3.1 Workability

Workability of concrete mixes was determined by the slump test per BS EN 12350-2:2019. The determined slump values of each mix are illustrated in Figure 3. It can be observed that concrete with no RHA or PP fibres (M0) exhibited good slump of 55 mm, however, the addition of RHA reduced the slump of the concrete mix, which can be attributed to the water absorption property of RHA. Furthermore, the mixes in which PP fibres were added also exhibited reduced slump which may be due to the number of fibres increases with the increase in % thus causing difficulty in the movement for other ingredients of concrete, thus the workability is reduced.

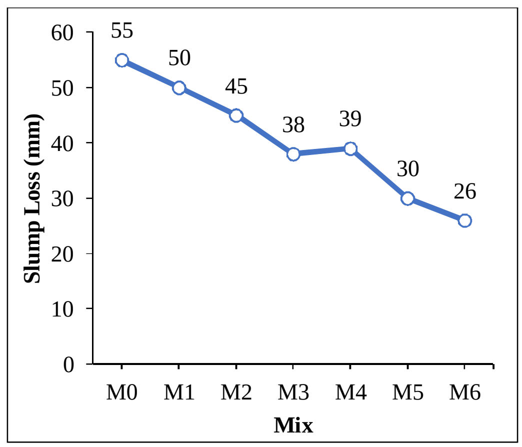

Figure 3. Slump Loss of Concrete

3.2 Compressive Strength

The compressive strength of concrete incorporating RHA is tabulated in Table 2. From the table, it can be observed that M1 in which 5% RHA content was used to replace cement, achieved 6.34% and 12% increase in strength compared to control M0 samples for 7 and 28 days respectively. However, a further increase in RHA content resulted in a significant loss in strength compared to the control sample.

This loss can be attributed to the pozzolanic reaction. RHA, as mentioned earlier, consists of the highest silica content and during the pozzolanic reaction, it consumes the freely available $Ca(OH)_2$.

From the results, it can be said that 5% RHA content consumes the available $Ca(OH)_2$ and develops additional C-S-H gel which increases the strength. However, the increase in RHA reduces the available $Ca(OH)_2$ content, thus adversely affecting the strength.

Table 3. Average Compressive Strength of Concrete Incorporating RHA

Testing	Mix	Compressive Strength (MPa)	The difference in Strength w.r.t M0 (%)
7 Days	M0	35.32	---
	M1	37.56	+ 6.34 %
	M2	32.37	- 8.35 %
	M3	31.13	- 11.86 %
28 Days	M0	37.68	---
	M1	42.2	+ 12.00 %
	M2	37.2	- 1.27 %
	M3	35.20	- 6.58 %

Furthermore, the average compressive strength of concrete incorporating 10% RHA reinforced with PP fibres is tabulated in Table 3. The addition of PP fibres to concrete incorporating 10% RHA exhibited positive results, as 0.10% and 0.20% PP fibres increased the flexural strength of concrete.

This may be due to the ability of PP fibres to enhance the bonding and act as a reinforcement bridge, which could reduce the cracks from propagating further. However, a further increase in PP fibre content resulted in a decrease in flexural strength. This decrease may be due to higher fibre content may cause congestion of fibres, thus resulting in balling effect and improper bonding with concrete.

Table 4. Average Compressive Strength of Concrete Incorporating RHA reinforced with PP Fibres

Testing	Mix	Compressive Strength (MPa)	Difference in Strength w.r.t M2 (%)
7 Days	M2	32.37	---
	M4	32.42	+ 0.15 %
	M5	35.53	+ 9.76 %
	M6	31.08	- 3.99 %
28 Days	M2	37.20	---
	M4	37.83	+ 1.69 %
	M5	40.75	+ 9.54 %
	M6	37.07	- 0.35 %

3.3 Flexural Strength

The flexural strength of concrete incorporating RHA is tabulated in Table 4. It was observed that the increase in RHA content significantly decreased the flexural strength of concrete such that 5% RHA content showed 8.03% loss while 15% RHA content showed 30.57% loss in strength compared with the control sample M0. The loss in flexural strength can be attributed to a reduction in available $Ca(OH)_2$ which resists the pozzolanic reaction and ultimately the development of C-S-H gels which contribute to the strength gain.

Table 5. Average Flexural Strength of Concrete Incorporating RHA

Mix	Flexural Strength (MPa)	Difference in Strength w.r.t M0 (%)
M0	3.86	---
M1	3.55	- 8.03 %
M2	2.84	- 26.42 %
M3	2.68	- 30.57 %

Furthermore, the average flexural strength of concrete incorporating 10% RHA reinforced with PP fibres is tabulated in Table 5. The addition of PP fibres to concrete incorporating 10% RHA exhibited positive results, as 0.10% and 0.20% PP fibres increased the flexural strength of concrete. This increase can be attributed to the bridging mechanism of the fibres which convert the brittle concrete into ductile. With the gradual increase in fibre content, the fibres resist the formation, propagation and widening of cracks more effectively.

Table 6. Average Flexural Strength of Concrete Incorporating RHA reinforced with PP Fibres

Mix	Flexural Strength (MPa)	Difference in Strength w.r.t M2 (%)
M2	2.84	---
M4	2.88	+ 1.41 %
M5	2.92	+ 2.82 %
M6	2.78	- 2.11 %

4. CONCLUSION

A positive contribution to the sustainable growth of concrete technology can be achieved using rice husk ash and polypropylene fibres by reducing, rescuing and recycling the solid agricultural and industrial waste and reduction of CO_2 emission from various cement reactions. Following are the results and observations made by the experiential work conducted:

1. Due to its high surface area, the RHA absorbed more water during mixing and thus ultimately adversely impacting the workability of concrete, as higher RHA content was added into the mix, the lower slump value was recorded.

2. The optimum replacement was determined to be 5% RHA, where higher strength was recorded. However, for long term construction, the optimum value of 10% RHA replacement is suggested.

3. Inclusion of PP fibres had a negative impact on the workability, but at the same time, it enhanced the compressive and flexural strength of concrete. It was determined that 0.20% PP fibres was optimum when used to reinforce concrete incorporating 10% RHA.

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