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EFFECT OF USING WASTE FIBERS ON THE STRENGTH PROPERTIES OF SUSTAINABLE REACTIVE POWDER CONCRETE

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ABSTRACT

A bulk volume of waste tires, an underrated global resource, is disposed of in landfills worldwide. Extracting recycled steel fibers from these tires is an evolving trend nowadays. Reactive-Powder Concrete (RPC), the most recent generation of concrete produced in the early 1990s and possessing extremely high mechanical strength criteria, is a modified form of high-performance concrete. This study looked into how the volume proportion of new and waste steel fibers affected the compressive, flexural, and impact strengths of RPC when it was curried at high temperatures. Steel fibers (new and waste tire fibers) with volume fractions of 1%, 1.5%, and 2% were used to reinforce RPC. It was clear that increasing the amount of steel fiber had a beneficial effect on compressive, flexural, and impact strengths. Also, the results showed that the outcomes of RPC having steel fibers sourced from end-of-life tires are similar to those of industrial steel fibers.

KEYWORDS

Discarded tire, Compressive, Flexural, Metakaolin, New fibers, Impact.

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1. INTRODUCTION

RPC, or reactive powder concrete, is a form of concrete that lacks coarse aggregate but still contains steel fiber, cement, mineral admixture, sand, and quartz powder, as well as very little water to act as a binding agent (Cai et al., 2023; Richard and Cheyrezy, 1995; Hasan and Nayyef, 2020). By eliminating the coarse particles and using a very low water-to-binder ratio, Richard and Cheyrezy created RPC in 1995 (Richard and Cheyrezy, 1995). Richard and Cheyrezy created RPC in 1995 by removing coarse particles and utilizing a very low water-to-binder ratio. RPC has incredibly high compressive strength and imperviousness compared to normal high-strength concrete (Richard and Cheyrezy,1994; Richard and Cheyrezy, 1995). RPC may or may not be fibered; however, adding steel fibers increases the material's ductility, flexibility, tensile strength, and impact resistance (Raza et al., 2022). According to studies, fibers can be used to boost the ductility of plain RPC. Fibers increase the tensile strength and fracture toughness of concrete (Wu et al., 2016; Raza et al., 2022). Due to the extremely low water-to-cement ratio, it has a dense matrix, which makes it more brittle. To provide ductility and impact resistance, RPC is made with a large amount of fiber reinforcing (Richard and Cheyrezy, 1994; Richard and Cheyrezy, 1995).

The appropriate disposal of used tires has garnered a lot of attention in recent years due to the environmental damage they pose (Papakonstantinou and Tobolski, 2006; Zhang and Gao, 2020). Despite the growth of the vehicle sector, several countries have not given scrap tire recycling more attention. The three basic components of waste tires are rubber, carbon, and metals. In many nations, the human population has very major issues with the disposal of used tires (Siddique and Naik 2004; Papakonstantinou and Tobolski, 2006; Zhang and Gao, 2020). Waste tires are currently used around the world mostly for retreading tires and producing rubber powder, but the metal wires are not effectively utilized. Numerous studies have examined the characteristics of concrete reinforced with recycled tires' rubber, but few have examined the characteristics of concrete reinforced with recycled tires' steel (Siddique and Naik 2004; Papakonstantinou and Tobolski, 2006; Zhang and Gao, 2020).

2. RESEARCH SIGNIFICANCE

The mechanical characteristics and impact strength of RPC reinforced with waste steel fibers from discarded tire fibers (DTFs) have received very little attention up to this point in the study. Additionally, the information currently provided is insufficient to make decisions regarding the dosage of DTFs for the best mechanical performance. At the various fiber quantities, reliable data on the comparison of the new steel fiber NFs and DTFs-reinforced RPC's qualities is required. Therefore, the purpose of this experimental investigation is to compare the compressive strength (CS), flexural strength (FS), and impact strength (IS) of DTFs and NFs fibers with three different fiber volumes (1, 1.5, and 2%). The findings will provide important information about the advantages and recommended dosage of recycled fibers. The growing need for sustainability forces RPC to investigate potential eco-friendly concrete used to repair highway streets, airport streets, and bridges that need ultra-high strength (strength, flexibility, and impact strength).

3. MATERIALS AND METHODS

3.1. Components of RPC Mixes

The following components were employed in this study to create RPC mixes: cement, high-reactivity metakaolin (HMK) **(ASTM C618-Type N)**, fine aggregate, water, and steel fiber. The results showed that the adopted cement satisfied Iraqi specification No. 5/1984. In situations where the surface was dry yet saturated, Al-Ekhaider natural sand was used as the fine aggregate. To ascertain the grading and other physical and chemical characteristics, it was investigated. The Findings demonstrate that the sand quality and sulfate concentration complied with Iraqi Standard No. 45/1984. Table 1 contains technical information regarding the used HMK. In this study, tab water was utilized. It is impossible to achieve workability with a low W/C percentage without excellent, high-range plasticizers. Therefore, the workability of both plain and fiber-reinforced RPCs was controlled by the use of Selenium-6100, an excellent plasticizing additive based on polycarboxylate (density 1.07+0.01, P.H. level >6, and content of chloride ion <0.2%).

Table 1. Properties of HMK.

Strength Activity index%	Specific Gravity	Specific Surface(blain method),cm^2/gm	LOI
164	3.11	5741	7.97

To study the compressive, tensile, and impact strengths of RPC, mixes were produced with two types of steel fibers. Ordinary steel fibers (new steel fiber) of length 20mm and diameter 0.9 mm with a tensile strength greater than 1100 MPa can be employed as fiber reinforcement. Steel wires that were recovered from tire scrapes were chopped into 15–20 mm-long pieces and used as waste fibers.

3.2. Mix Proportion

Two sets of RPCs with a combined total of seven combinations were explored to carry out the objectives of this study, as shown in Table 2. The first group (RPC2, RPC3, and RPC4) contains new steel fiber NFs, while the second group (RPC5, RPC6, and RPC7) contains DTFs (discarded tire fibers). The RPC1 represents the reference mix. The proportions of cement, HMK, fine aggregate, water, and superplasticizer were, respectively, 1:0.21:1.02:0.25. After 14 days of curing in 90°C hot water, this mix design ratio for the simple batch produced cubes with compressive strengths of 145 MPa and a flow table of 80±5mm.The workability was carried out according to ASTM C-1437-15, as shown in picture 1.

Table 2. Composition of all reactive powder mixes.

Mix No.	RPC1	SRPC2	SRPC3	SRPC4	SRPC5	SRPC6	SRPC7
description	reference	With new steel fibers			With discarded tire fibers		
C:(kg/m^3)	935	935	935	935	935	935	935
HMK:(kg/m^3)	195	195	195	195	195	195	195
FA:(kg/m^3)	950	950	950	950	950	950	950
CA:(kg/m^3)	7.5% by weight of cement						
S_f:(by volume)	0%	1%	1.5%	2%	1%	1.5%	2%
W:(kg/m^3)	235	235	235	235	235	235	235
(W/C)%	0.25	0.25	0.25	0.25	0.2	0.25	0.25
Flow table%	82	81	78	77	80	77	76

Notation: C: Cement. HMK: High reactivity metakaolin. FA: Fine Aggregate.
CA: Chemical Admixture(Superplasticizers). W :Water. S_f: Steel fibers

4. RESULTS AND DISCUSSION

4.1. Compressive Strength

The compressive strength test of plain and reinforced RPC was carried out in accordance with ASTM C109/C 109M- 16. All combinations compressive strengths were measured using 50-mm cube samples, as shown in picture 2. The results of compression strength testing for all RPC combinations in comparison to plain RPC (reference or RPC1) are displayed in Table 3 and Fig. 1. RPC's compressive strength was measured at 14, 28, 60, and 90 days after 90°C hot water curing. The specimens in Fig. 1 exhibit considerable compressive strength (93–104 MP) after 14 days, according to the results. This is because the quality of the microstructures and mechanical characteristics can be further improved by heat treatment (Zhang et al., 2020).

The RPC1 mixture in Table 2 and Fig. 2 has the same proportions as the other mixtures but does not contain steel fibers. The results are shown in this figure, which indicates that using steel fiber resulted in a slight improvement in compressive strength. This results from the fact that the addition of fibers to the mixture boosts both compressive and flexural strength

(Graybeal and Baby, 2013). Because the addition of fibers prevents cracks induced by loadings or forces from propagating, the RPC mixture's compressive strength can be increased (Zhang, et al., 2020).

Comparing the RPC with the NFs and DTFs to the reference concrete RPC1, however, revealed a little improvement in 28-day compressive strength. At the age of 28 days, group 1 (RPC2, RPC3, and RPC4) and group 2 (RPC5, RPC6, and RPC7), respectively, had an increase in compressive strength of (6.3, 9.8, 14.3)% and (3.6, 8, 12.5)%, respectively. The crack arrest theory of the fibers, which explains the rise in compressive strength, may be linked to such an increase **(**Siddique and Naik 2004**;** Graybeal and Baby, 2013).

Compressive strength measurements revealed that the strength of RPC containing NFs and DTFs was only marginally higher than that of the reference mix (RPC1). As demonstrated in Fig. 2 and 3, the compressive strengths of the mixes in series 1 that were reinforced with NFs were higher than those of the mixes in series 2 that were reinforced with DTFs.

Picture 1. Flow table test

Picture 2. Compressive strength samples

Table 3. Compressive strength of sustainable RPC mixes with different ages.

Mixes	Compressive Strength (MPa) 14 days	28 days	60 days	90 days
RPC1	93	112	115	117
RPC2	98	119	122	121
RPC3	102	123	126	129
RPC4	104	128	132	133
RPC5	96	116	118	121
RPC6	99	121	124	126
RPC7	104	126	129	132

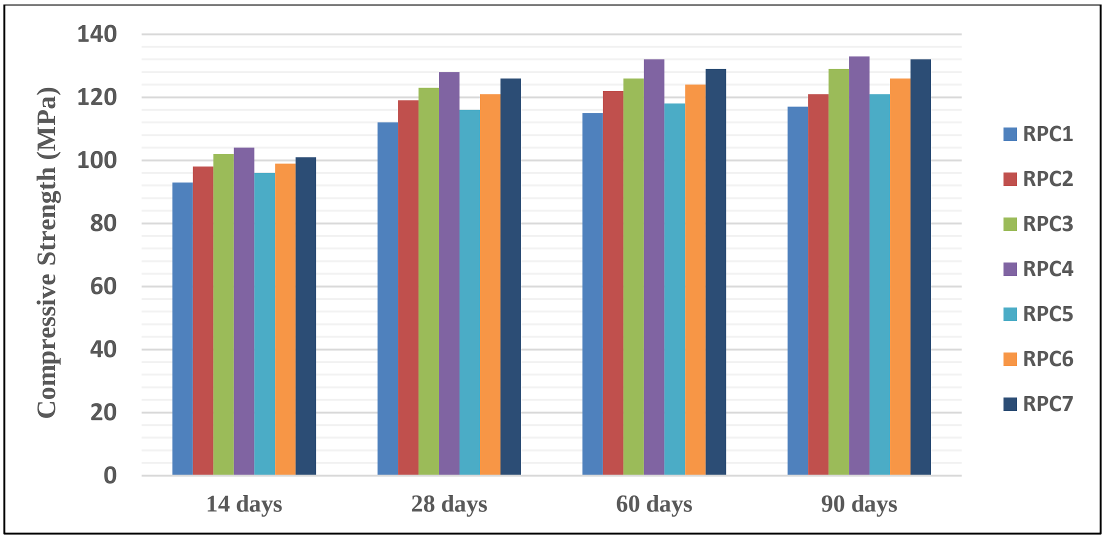

Fig. 1. Compressive strength of all mixes with different ages.

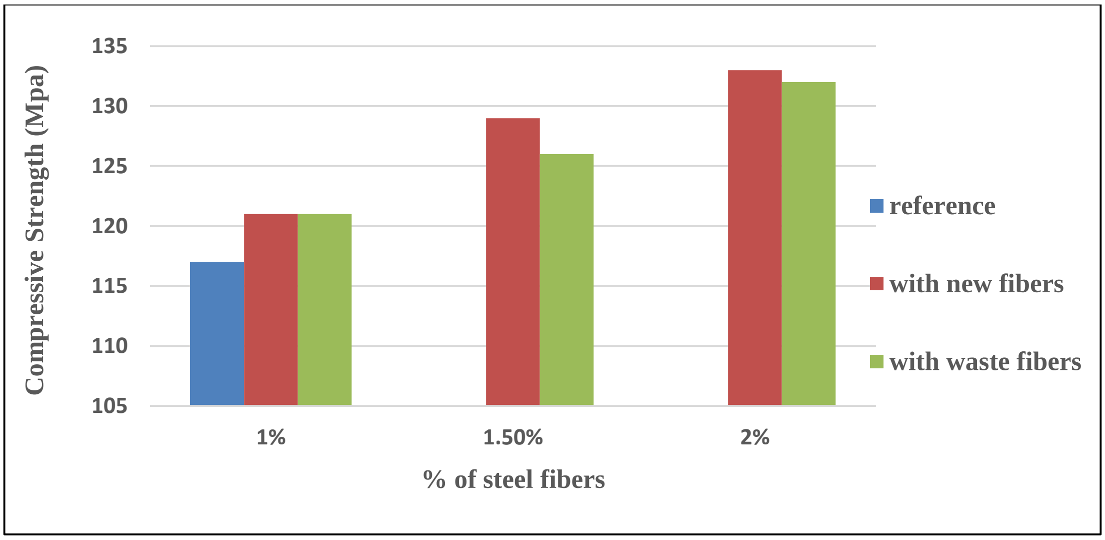

Fig. 2. Compressive strength of RPC with new and waste fibers at different percentagefor 90 days.

4.2. Flexural Strength

On specimens of a 40*40*160 mm prism, plain-RPC and reinforced-RPC flexural strength tests are conducted. This test is carried out using an **ASTM C-293- 16** basic beam with a central point loading as shown in picture 3. Table 4 and Fig. 3 both display the specimens' flexural strengths. Flexural strength was assessed at 14, 28, 60, and 90 days after 90°C hot water curing. Fig. 3 shows the test results for flexural strength and shows how RPC with and without steel fibers behaves in terms of flexural strength. Due to the influence of the steel fibers and heat treatment, flexural strength has significantly increased. The findings showed that, on average, all concrete specimen mixes continuously increased in flexural strength as curing ages increased. Flexural strength in 28 days was enhanced by 47.3%, 84.6%, and 112.1% respectively, by adding NFs at ,1%, 1.5%, and 2%. By adding DTFs, RPC's flexural strength increased by 45.1%, 76.9%, and 107.7%. This behavior is brought on by pore size and grain size refinement techniques, which enhance the transition zone and lessen interface microcracking (Soutsos et al., 2005; Hasan and Nayyef, 2020).

Previous research on fibrous concrete came to the conclusion that adding fibers to reactive powder concrete increases its flexural strength of the RPC are apparent (Kushartomo and Ivan, 2017; Pilakoutas et al., 2004; Wang et al., 2021). DTFs demonstrated less improvement in flexural strength compared to NFs.

Picture 3. Flexural strength samples

Table 4. Flexural strength of all mixes with different ages.

	Flexural strength(MPa)			
Mixes	**14 days**	**28 days**	**60 days**	**90 days**
RPC1	8.8	9.1	9.2	9.2
SRPC2	13.1	13.4	13.6	13.7
RPC3	16.6	16.8	16.9	17.1
RPC4	19.2	19.3	19.5	19.4
RPC5	12.9	13.2	13.2	13.3
RPC6	15.9	16.1	16.3	16.4
RPC7	18.8	18.9	19.0	19.2

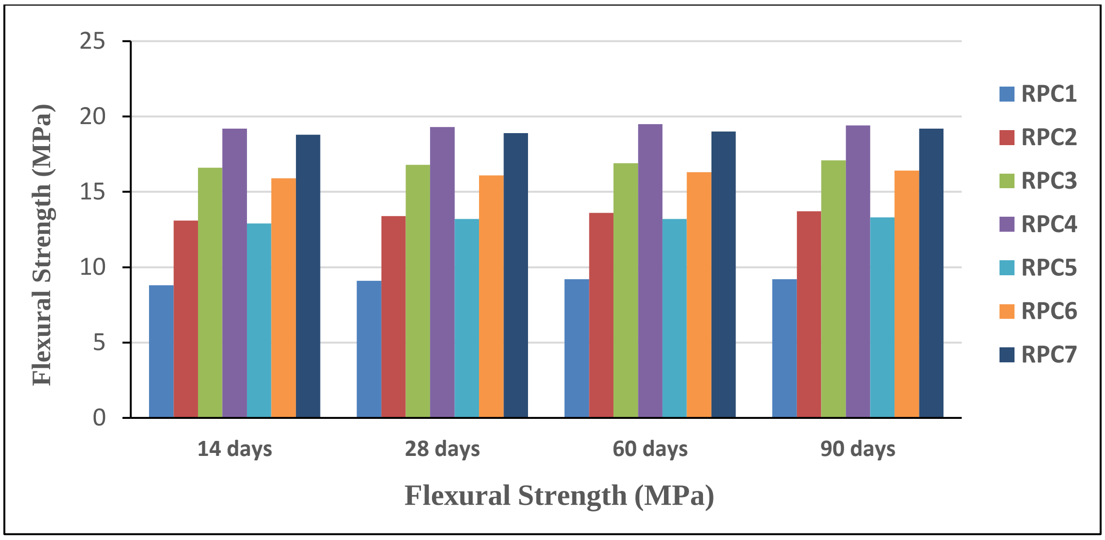

Fig. 3. Flexural strength of all mixes with different ages.

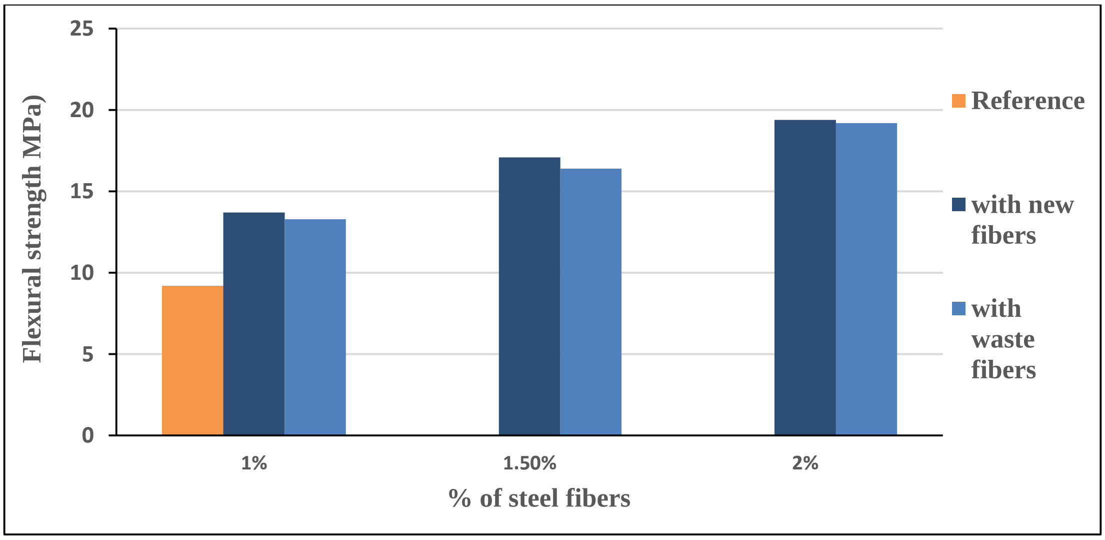

Fig. 4. Flexural strength of RPC with new and waste fibers at different percentage for 90 days.

4.3. Impact Strength

The impact resistance of reinforced concrete can be assessed using the test method suggested by **ACI Committee 544**, as shown in picture 4. The impact resistance property might be assessed using the drop-mass test (repeated impact), according to the committee report of **ACI Committee 544**. In this study, a simple apparatus for calculating the minimal number of drop-mass impacts required to cause failure is developed, allowing for the measurement of concrete slab impact resistance. The model has dimensions of 500 * 500* 40 mm and 500 * 500 * 20 mm. A hole in a cylindrical tube with an inner diameter of 10.5 cm is used to launch a solid steel ball measuring 6.35 cm in diameter and weighing 3.75 kg. The tube, which is secured with brackets to keep it in place throughout the test, is then filled with the spherical mass. To build shock resistance, throw the thing frequently. When the iron block is thrown into the model from the specified height of 1 m, count how many blows result in failure. In this experiment, mixes made with DTFs and NFs as well as the reference combination were examined. The impact resistance results for the various types of concrete at 28, 60, and 90 days are displayed in Tables 5 and 6 and Fig. 5 and 6 in terms of the number of blows required to initiate the first crack and failure. The impacts of an RPC with NFs and an RPC with DTFs were compared by researchers **(**Papakonstantinou and Tobolski, 2006; Nasaif and Hasan 2022)**.** RPC with NFs displayed better impact resistance in terms of the quantity of blows required to cause a first crack and failure as compared to RPC with DTFs. Also The impact of an RPC slab measuring 500x500x40mm with and without steel fibers (NFs or DTFs) was investigated in relation to that of a slab measuring 500x500x20mm with or without steel fibers. In terms of the number of blows needed to initiate the first crack and failure, RPC with a slab dimension of 500* 500* 40 mm demonstrated stronger impact resistance than RPC with a slab dimension of 50* 50* 2 mm. This tendency is typically caused by substantially higher stiffness in thicker slabs (Adeline et al., 1998; Nasaif and Hasan 2022) as shown in Fig. 7. For instance, RPC4's slab of mix failed at 323 blows for a slab 20 mm thick and at 453 blows for a slab 40 mm thick and at 28 days.

Picture 4. impact test

Table 5. Impact resistance results of all RPC mixes when dimensions of slab is (500*500*20) mm.

Impact resistance (Number of Blow)						
Age	**28 days**		**60 days**		**90 days**	
Mixes	**First Crack**	**Failure**	**First Crack**	**Failure**	**First Crack**	**Failure**
RPC1	17	82	20	91	25	96
RPC2	35	176	45	196	53	204
RPC3	58	251	73	285	80	298
RPC4	66	323	85	392	94	401
RPC5	24	165	38	191	46	199
RPC6	42	232	65	276	75	286
RPC7	61	310	74	383	88	393

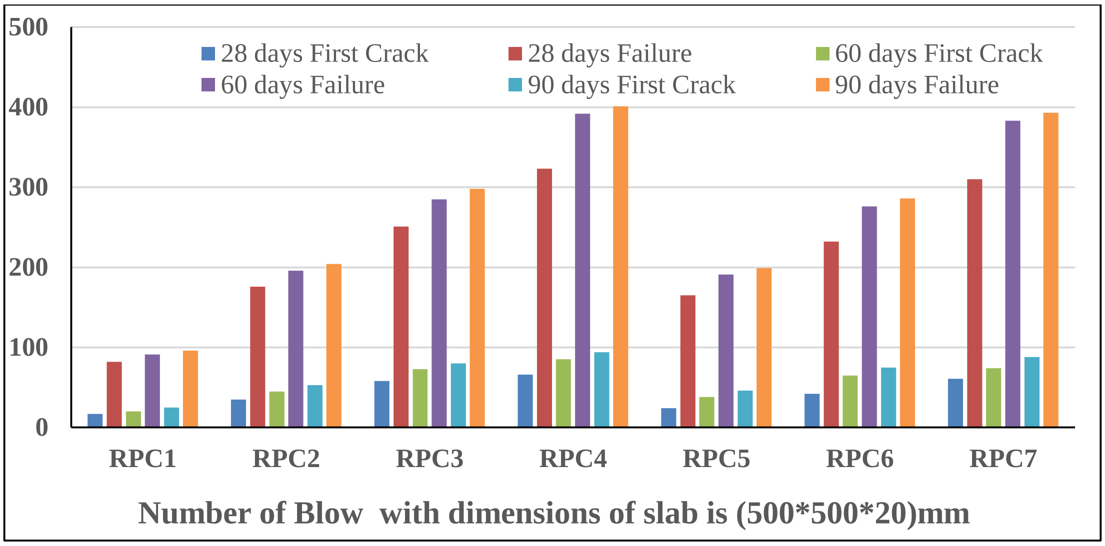

Fig. 5. Impact resistance of all mixes for different ages with slab of (500*500*20) mm.

Table 6. Impact resistance results of all mixes of RPC when dimensions of slab (500*500*40)mm

Impact resistance (Number of Blow)						
Age	**28 days**		**60 days**		**90 days**	
Mixes	**First Crack**	**Failure**	**First Crack**	**Failure**	**First Crack**	**Failure**
RPC1	33	152	45	166	53	174
RPC2	57	257	74	276	79	285
RPC3	79	379	99	396	105	402
RPC4	94	453	112	475	120	487
RPC5	43	225	70	268	79	278
RPC6	66	352	87	382	93	394
RPC7	85	428	104	469	111	479

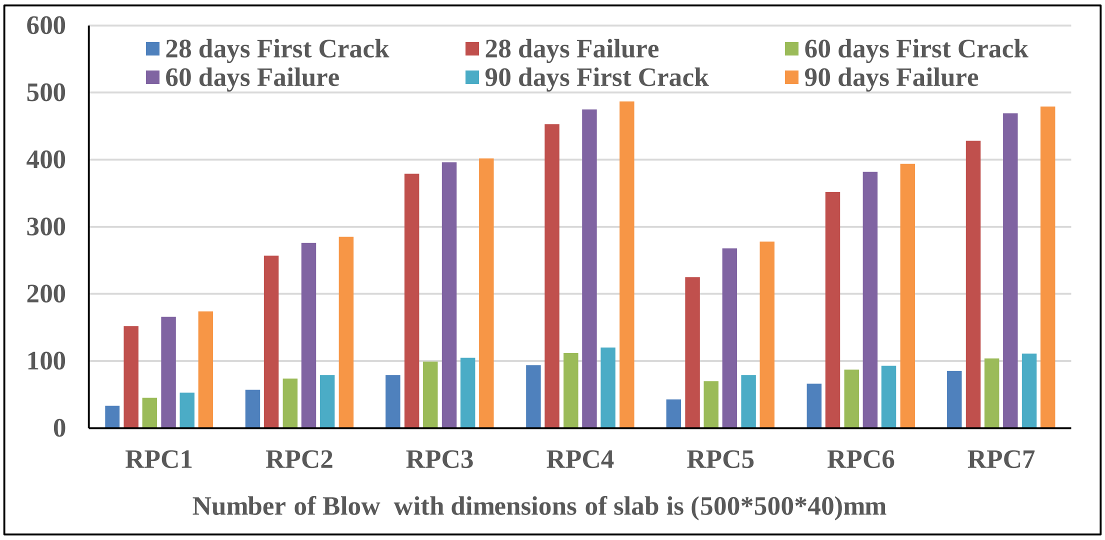

Fig. 6. Impact resistance of all mixes for different ages with slab of (500*500*40) mm.

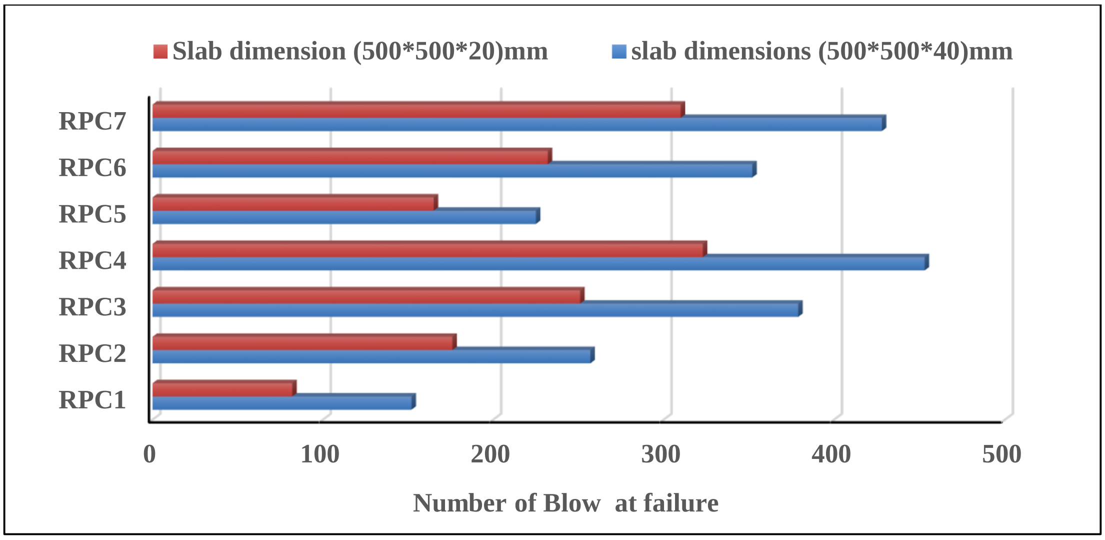

Fig. 7. Impact resistance of all mixes for 28 days at failure with different slab dimensions

5. CONCLUSIONS

This study looked into the characteristics of RPCs with varying NF and DTF contents (0, 1, 1.5, and 2%). The primary conclusions of this investigation are as follows:

- The impact strength of an RPC with DTFs is less than that of an identical RPC with NFs.
- At a 2% addition of DTFs, RPC's compressive strength improved by 9%. Compared to RPC with NFs at the same volume of fibers, RPC with DTFs was approximately 95% more efficient.
- The inclusion of NFs or DTFs increased the flexural strength more than the compressive strength. At 2% fiber volume, the maximum flexural strength with NFs was attained.
- RPC samples with a 2 percent fiber content outperformed ones with 0, 1, and 1.5% fiber volumes in terms of impact strength.
- In terms of compressive, flexural, and impact strength, RPC with DTFs generally exhibits equivalent findings as RPC with NFs; however, more research is needed to determine the bond strength, splitting tensile strength, and other mechanical properties of RPC with the two types of steel fibers (NFs and DTFs).

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