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Investigation on the use of waste tyre crumb rubber in concrete paving blocks

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Abstract. This paper investigates the utilization of waste tyre crumb rubber as the fine aggregate in precast concrete Paving block (PCPB). PCPB's are generally preferred for city roads, pedestrian crosswalk, parking lots and bus terminals. The main aim of this paper is to evaluate the mechanical properties of wet cast PCPB containing waste tyre crumb rubber. The mechanical properties were investigated using a density, compressive strength, split tensile strength and flexural strength tests at 7, 28 56 days according to the IS 15688:2006 and EN1338. The wet cast method was followed for producing PCPB samples. The fine aggregate (river sand) was replaced with waste tyre crumb in percentage of 5%, 10%, 15%, 20% and 25% by volume. All the test results were compared with the conventional PCPB (Without rubber). The test results indicate its feasibility for incorporating waste tyre crumb rubber in the production of PCPB by the wet cast method.

Keywords: paving block; wet casting; crumb rubber; compressive strength; split tensile strength; flexural strength

1. Introduction

Discarded automobile tyres represent a major environmental issue of increasing relevance. The quantity of waste tyre disposal is increasing year by year. In 2009 the quantity of waste tyre was 3000 million in EU and 1000 million in the US. By 2030 the waste tyre disposal quantity is expected to reach 1200 million, representing almost 5000 million tyres to discard on a regular basis (Oikonomou and Mavridou 2009, Pacheco *et al.* 2012).

At present large quantities of waste tyres are dumped in the open air or subject to burning or landfill. Waste tyre landfilling leads to ecological threat and contributes to the reduction of biodiversity. Waste tyres also hold toxic and soluble components. Burning of waste tyres needs high temperature, which results in the melting of tyres and toxic fumes and production of oil that contaminates soil and ground water. Methods are being evolved for preventing environmental pollution that may result due to this and for finding satisfactory methods for waste tyre disposal (Cairns *et al.* 2004, Chen *et al.* 2007).

Many researchers agree on the waste tyres are good material for construction purpose. Some studies recommend the use of the waste tyres as a fine or coarse aggregate in concrete preparation. Waste tyre can be managed as a whole tyre, shredded tyre, chopped tyre, ground rubber or crumb rubber.

This paper investigates the feasibility of using crumb rubber as a fine aggregate in the production of PCPB and the mechanical properties of the PCPB with crumb rubber. Crumb rubber consists of particles ranging from 0.075 mm to 4.75 mm. It is obtained from waste tyres by using the following two methods: (i) cracker mill process and (ii) granular process.

The first method generates irregularly shaped particles having a larger surface area. The size of these particles varies from 0.5 mm to 5 mm and the material is commonly known as crumb rubber. The second method usually produces granulated crumb rubber, ranging from 0.5 mm to 9.5 mm (Eldin Neil and Senouci 1993, Fedroff 1996, Guneyisi *et al.* 2004, Batayneh *et al.* 2008, Mohammed *et al.* 2011, Issa and Salem 2013).

Many studies have been conducted for finding the physical and mechanical properties of concrete containing crumb rubber. The density of concrete mixture containing crumb rubber decreases as the percentage of crumb rubber replacement increases due to the low specific gravity of crumb rubber. The higher air content of concrete containing crumb rubber may be due to the nonpolar nature of crumb rubber particles. When crumb rubber is added to the concrete mixture, it may attract air as it repels water due to its nonpolar nature. This increase in air voids in the concrete mixture leads to strength reduction (Ali *et al.* 1993, Fattuhi and Clark 1996, Segre and Joekes 2000, Guneyisi *et al.* 2004, El-Gammal *et al.* 2010, Wang *et al.* 2012).

The compressive strength of the concrete decreased as the percentage of crumb rubber increased. A Few studies have been done to for incorporating the compressive strength of concrete by using some pre-treatment methods. The main reason for the strength reduction is the lack of adhesion between crumb rubber particles and other concrete materials, as the rubber particles having more air content may increase the voids in the concrete. The main aim of this pre-treatment is to improve the bonding between crumb rubber and other concrete materials which may help higher compressive strength (Khatib and Bayomy 1999, Zhu *et al.* 2002, Kaloush *et al.* 2005, Najim and Hall 2013).

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Table 1 Physical properties of cement

Property	Value
Specific gravity	3.14
Initial setting time	65 min
Final setting time	280 min
Normal consistency	31%
Fineness	320 m^2/kg
28 days compressive strength	56.96 MPa

Washing the rubber particles with water to acid etching, plasma pre-treatment and various coupling agents in acid pre-treatment, rubber particles are soaked in NaOH for 5 minutes and then cleaned with water. This treatment improves the strength of concrete containing crumb rubber, which in turns, increases the surface roughness of the rubber particles (Li *et al*. 2004).

Lee *et al.* (1998) have investigated the flexure and impact strength of tyre added latex concrete (TALC). In TALC, Styrene Butadiene Rubber (SBR) latex is used for modifying the crumb rubber filled with the concrete. They found TALC showed higher flexure and impact strength than with conventional Portland cement and latex modified concrete. For the SEM pictures, SBR latex formed a thin film at the interface of cement mortar and aggregates, increasing the interfacial bonding between crumb rubber and cement paste.

Huang *et al.* (2004) suggest the following ways to ensure an effective increase in the strength of rubber filled concrete: (i) reducing the maximum rubber chip size; (ii) using a stiffer coarse aggregate; (3) employing uniform coarse aggregate size distribution using harder cement mortar it has a high strength as using softer cement mortar if it is good as the ductility rubber content should be limited to a certain percentage for practical purposes.

Dong *et al.* (2013) found compressive strength, split tensile strength and flexural strength of concrete incorporating coated rubber (cementitious coating around rubber particles with silane coupling agent) improved 10% to 20% compared to uncoated rubber. The coated rubber chloride ion resistance is similar to the conventional concrete (without rubber) and the energy absorption capacity also improved through the coating agent.

Silane coupling agent was effective in developing the bond between rubber particles and cement paste matrix. The rubber can still be used in the concrete in a mild environmental condition and the concrete containing crumb rubber will not substantially affect the durability of concrete.

Anyway, crumb rubber is used as a construction material in view of its specific gravity, elasticity, sound absorption, high crack resistance and impact resistance (Tountanji 1996, Siddique and Naik 2004, Azmi *et al.* 2008, Al-Tayeb *et al.* 2013, Shu and Huang 2014, Emiroglu *et al.* 2015). But in view of strength reduction, the concrete containing crumb rubber is suitable for non-structural application and not for structural applications without pre-treatment of crumb rubber. A very limited number of studies have been published on the subject of utilization of crumb rubber in

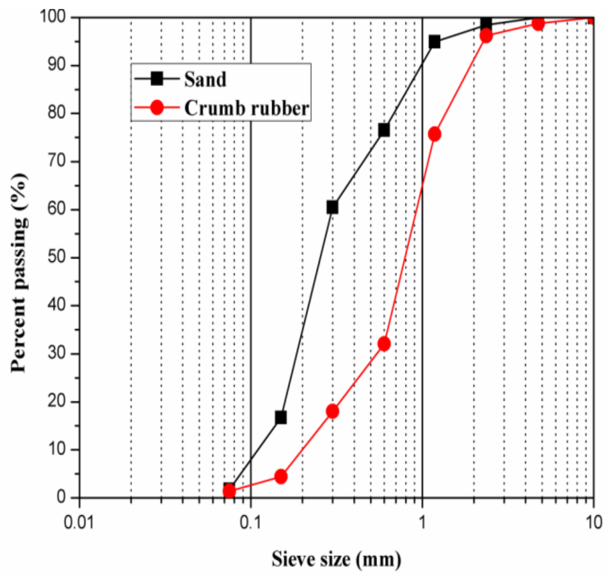


Fig. 1 Gradation of sand and crumb rubber

non-structural elements (Ling *et al.* 2009, Ling 2011, Ling 2012). This paper focuses on the utilization of crumb rubber in non-structural elements like paving block. The crumb rubber is mainly produced from discarded automobile tyres. The size of the crumb rubber is equal to fine aggregate. Solid, unreinforced pre-cast cement concrete paving units are used in the surface course of pavements, with a minimum horizontal cross-section of 50mm from any edge in any direction, have an aspect ratio of not more than four. The PCPB is a very good alternative for both flexible and rigid pavements. PCPB pavements were found to have applications in several situations, such as footpaths, residential streets, car stations, fuel stations, rural roads, highway rest areas, toll plazas, bus depots, city roads, embankment stabilization and industrial flooring. The main objective of the paper is to investigate the mechanical properties of PCPB with waste tyre crumb rubber as the partial replacement of fine aggregate in the concrete mix.

2. Experimental investigation

2.1 Materials

Ordinary Portland cement of 53 grades conforming to IS 12269 was used. The physical properties are tabulated as shown in Table 1.

River sand with a maximum size of 4.75 mm, specific gravity of 2.65 and fineness modulus of 2.45 has been taken as a fine aggregate. Broken granite stone with a maximum size of 12 mm, specific gravity of 2.63 and fineness modulus of 7.2 has been taken as a coarse aggregate. Crumb rubber produced from waste tyres has been used as a partial substitute for fine aggregate in the production of concrete paving block. Crumb rubber with a size varying from 4.75 mm to 0.15 mm, Specific gravity of 0.689 and fineness modulus of 2.68 has been used. Fine aggregate and crumb rubber sieve analysis were carried out in accordance with the requirement of IS 383. Crumb rubber is a fine material with gradation not close to that of river sand due to the non-

Table 2 Mix proportions

Mix ID	Details of mix ID	C	FA	CA	CR	w/c	SP
R0	Control mix	1	2.27	2.65	0	0.4	0.04
R5	5% FA replaced by CR	1	2.08	2.65	0.19	0.4	0.04
R10	10% FA replaced by CR	1	1.97	2.65	0.30	0.4	0.04
R15	15% FA replaced by CR	1	1.86	2.65	0.41	0.4	0.04
R20	20% FA replaced by CR	1	1.75	2.65	0.52	0.4	0.04
R25	25% FA replaced by CR	1	1.64	2.65	0.63	0.4	0.04

Note: C-Cement, FA- Fine Aggregate, CA-Coarse Aggregate, CR-Crumb Rubber, W/C-Water cement ratio, SP-Superplaticiser

polar nature. The crumb rubber and river sand gradation curve as shown in Fig. 1. Light brown colour Sikaviscocrete 20 HE was used as a superplasticiser for improving the workability of the concrete with a specific gravity of 1.08.

2.2 Mix proportions

M40 grade concrete with cement, fine aggregate and coarse aggregate in the ratio of 1:2.27:2.65 with 0.4 water-cement ratio without crumb rubber is called control concrete mix. The target strength of 46.60 MPa was arrived at from the mix design according to IS 10262. In this study, five varieties of crumb rubber content with 5%, 10%, 15%, 20% and 25% replacement by volume of sand were used. The mix proportions of concretes with and without crumb rubber are given in Table 2.

2.3 Preparation of paving blocks

Paving block manufacturers follow two methods of specimen preparation which are:

(i) Dry casting method and

(ii) Wet casting method.

The main differences between these two methods are in the water-cement ratio and the compaction techniques. In the dry casting method, a low water–cement ratio was used and the specimens were compacted by hydraulic pressure. In wet casting, a high water-cement ratio was used, compared to dry casting and the specimen was compacted by continuous vibration. In this study, the wet casting method was followed for the specimen preparation.

In this method, two layers are provided using the bottom layer 12mm down size coarse aggregate and the top layer 6mm down size coarse aggregate. High frequency vibration was applied in the specimen of wet casting. Rubber moulds were used considering the ease of handling.

Fig. 2 shows the wet casting PCPB manufacturing unit. After placing the concrete, the moulds were kept on a wooden plate and covered for curing of concrete by using plastic covers. There is no need for the water curing in this method. The curing process was done in the mould itself considering the high water cement ratio and heavy vibration more volume of water present in the mould. This water would take care of heat of hydration, and so all the moulds are covered. The plastic cover was removed after 24 hours and the specimens were demoulded and kept in a steel rack

(a) Pan mixture

(b) Placing of concrete in PCPB mould

(c) Specimens are arranged for curing

(d) Curing

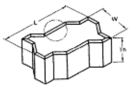
Fig. 2 Typical view of wet casting PCPB manufacturing unit

for 3 day air cuing after which the PCPB was used. The size and shape of the specimens are presented in Table 3.

2.4 Test method

The scope of the tests carried out was to determine the density, compressive strength, split tensile strength and flexural strength at 7, 28 and 56 days of the PCPB

Table 3 Size and Shape of the specimens

Size			Aspect ratio	Plan Area (mm^2)	Shape
Length (mm)	Width (mm)	Thickness (mm)			
240	125	80	3	30868	

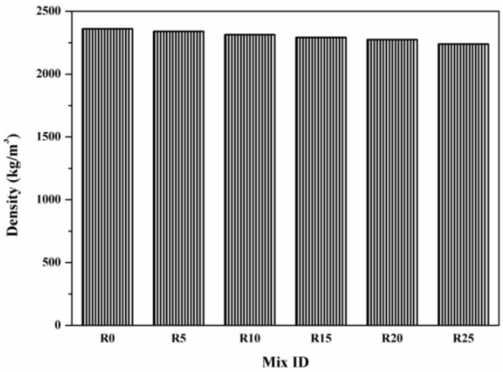


Fig. 3 Density of wet cast PCPB for different crumb rubber content

specimens. Each test value represents the average of five samples.

The density of paving blocks was determined using the water displacement method as per BS 1881 Part 114 for hardened concrete. The compressive strength, split tensile strength and flexural strength of Paving blocks were determined based on the EN 1338 and IS 15658 recommendations.

The compressive strength of paving blocks was determined by using compression testing machine with a maximum capacity of 3000 kN. The compressive load was applied at a rate of 15±3 N/ mm^2/min to the plan area of CPB. The apparent compressive strength of individual specimen shall be calculated by dividing the failure load (N) by the plan area (mm^2).

Split tensile strength tests were carried out along the longest splitting section of the block specimen. Prior to testing, each block specimen was concentrically packed with two steel packing pieces on the top and bottom faces in contact with the platens of the loading machine. The load was applied gradually and the test was terminated when the specimen split into halves. The failure load was recorded and the split tensile strength was calculated based on the failure load.

For the flexural strength test, the load should be applied from the top of the specimen in the form of a simple beam loading through a roller placed midway between the supporting rollers. The load should be applied without shock and increased continuously at a uniform rate of 6 kN/min. The load shall be increased until the specimen fails, and the failure load applied should be recorded and the flexural strength was calculated based on the failure load.

3. Result and discussion

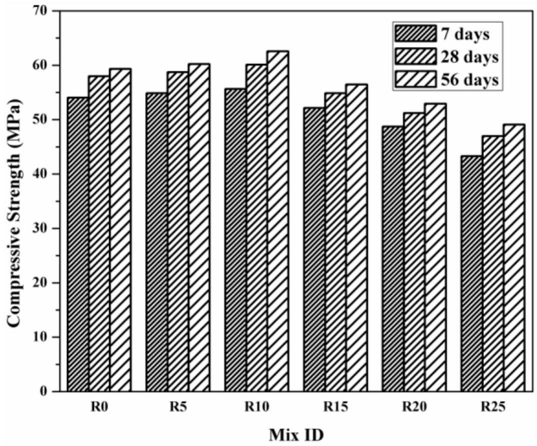


Fig. 4 Compressive strength of wet cast PCPB for different crumb rubber content

3.1 Density

Fig. 3 shows the variation between the density of wet cast PCPB and percentage of crumb rubber replacement. Fig. 3 clearly shows an increase in the crumb rubber replacement while the density of wet cast PCPB decreased. The density was reduced by about 1% to 5.08% when 5% to 25% of the sand was replaced by crumb rubber. This is mainly due to the low specific gravity of crumb rubber as compared to natural river sand.

3.2 Compressive strength

The compressive strength of wet cast PCPB of M40 grade made with and without crumb rubber was determined at the age of 7, 28, 56 days. The test results of wet cast PCPB are shown in Fig. 4.

From the test results, the increase in the compressive strength of the wet cast PCPB with the addition of 5% and 10% crumb rubber content was observed. The increase in the compressive strength was seen as 1.48% and 2.97% at 7 days and 1.65% and 3.62% at 28 days and 1.68% and 3.84% at 56 days respectively as compared to control wet cast PCPB. The decrease in the compressive strength of the wet cast PCPB with an addition of 15%, 20% and 25% crumb rubber content was also observed. Reduction in the compressive strength was seen as 4.51%, 10.84% and 16.62% at 7 days and 5.32%, 11.72% and 18.40% at 28 days 5.92%, 12.16% and 20.01% at 56 days respectively as compared to control wet cast PCPB.

Many researchers report decreased in the compressive strength of concrete following increased in the crumb rubber content (Ling *et al.* 2009, Ling 2011, Ling 2012). But in this study, the compressive strength of PCPB was increased up to 10% of crumb rubber replacement. The main reason for this strength gain is the casting method of the PCPB. The wet casting method was followed in this study. A higher amount of water-cement ratio used in the wet casting method and a higher level of vibration was applied during the specimen compaction considering this the crumb rubber helps to fill the pores in the concrete mixture. During the compaction of PCPB, the bubbles of

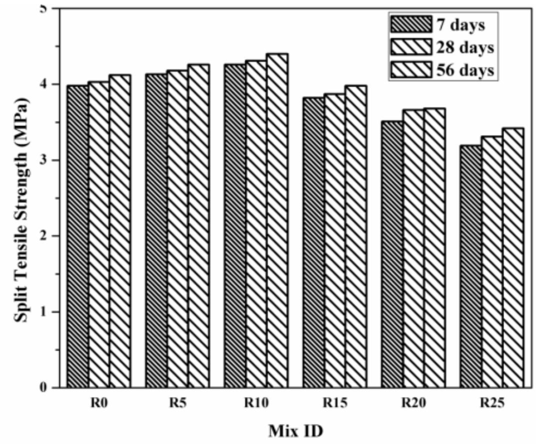


Fig. 5 Split tensile strength of wet cast PCPB for different crumb rubber content

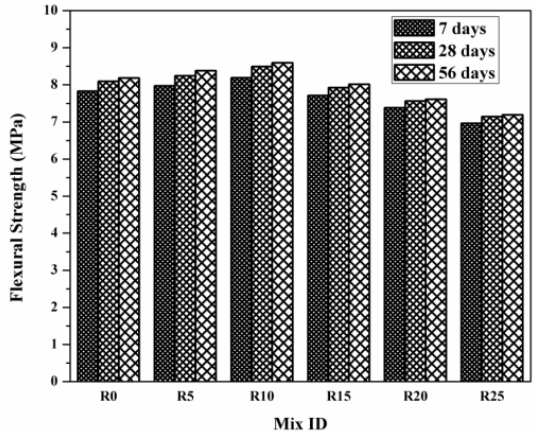


Fig. 6 Flexural strength of wet cast PCPB for different crumb rubber content

entrapped air moved upwards to the surface of the PCPB and crumb rubber act as the filler of the pores which also makes it stronger. Hence the compressive strength of the wet cast, PCPB increased up to 10% of crumb rubber replacements. However, further increase of crumb rubber content in the concrete mixture significantly affected the adhesion between crumb rubber and other concrete materials. Poor adhesion between the crumb rubber and cement paste developed the weakest phase and interfacial transition zone. The strength reduction is also attributed to the reduction of load carrying material (sand) with an increase in crumb rubber content (Ling *et al.* 2009, Ling 2011, Ling 2012).

3.3 Split tensile strength

The split tensile strength, as well as the compressive strength, increased and decreased depending upon the percentage of crumb rubber replacement. Fig. 5 shows the test results of split tensile strength for the PCPB without rubber and PCPB containing replacement of river sand by crumb rubber by volume.

The test results showed that the 5% and 10% of crumb rubber containing PCPB split tensile strength increased 3.76% and 7.05% at 7 days and 3.72% and 6.94% at 28

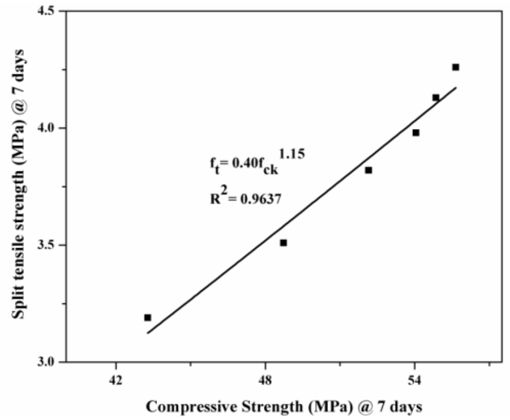


Fig. 7 The relationship between compressive strength with split tensile strength for wet cast PCPB containing crumb rubber at 7 days

days and 3.39% and 6.79% at 56 days respectively. At the same time, 15%, 20% and 25% of crumb rubber containing PCPB split tensile strength decreased 4.02%, 11.80% and 19.84% at 7 days and 3.97%, 9.18% and 17.86% at 28 days and 3.39%, 6.79% and 16.99% at 56 days respectively.

3.4 Flexural strength

Flexural strength of PCPB with and without crumb rubber is graphically represented in Fig. 6.

It limited improvement of flexural strength to relatively small rubber contents as well as the compressive and split tensile strength was seen. Increasing crumb rubber content 5% and 10% of the fine aggregate volume the flexural strength increased 2.44% and 5.01% at 7 days and 1.85% and 4.94% at 28 days and 1.78% and 4.59% at 56 days respectively. The flexural strength was decreased by 2.07%, 6.96% and 12.10% at 7 days, 2.10%, 6.55% and 11.74% at 28 days and 1.53%, 5.74% and 11.11% at 56 days as a percentage of crumb rubber content increased by 15%, 20% and 25% respectively.

Generally, normal concrete is brittle by nature, but, when the rubber content is increased, the concrete is more ductile or flexible. Accordingly, in this study the flexural strength was increased with low volume of crumb rubber (5% and 10%). But when the crumb rubber increased to higher amounts (15%, 20% and 25%), flexural strength decreased. During the specimen preparation, heavy vibration was used for compacting the PCPB. The crumb rubber fills the voids due to the heavy vibration, but the crumb rubber content increased smaller amount of rubber particles filling the voids and the remaining amount of rubber particles was mixed with cement paste and thus would affect the rubber cement matrix as the particles are much softer than other concrete materials, on loading the crack propagation are very fast around rubber particles which leads to the failure of the PCPB (Ling *et al.* 2009, Ling 2011, Ling 2012).

3.5 The correlation between compressive strength with split tensile strength and flexural strength for PCPB containing crumb rubber

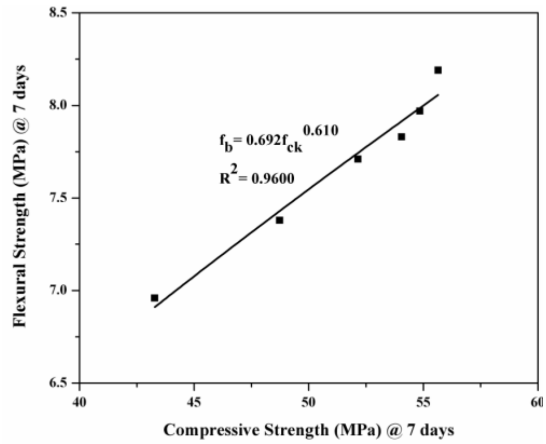


Fig. 8 The Relationship between compressive strength with flexural strength for wet cast PCPB containing crumb rubber at 7 days

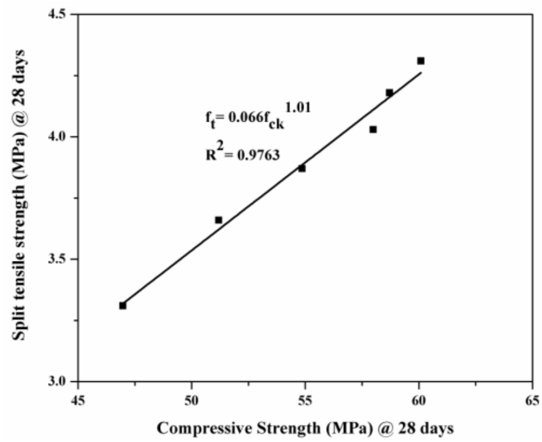


Fig. 9 Relationship between compressive strength with split tensile strength for wet cast PCPB containing crumb rubber at 28 days

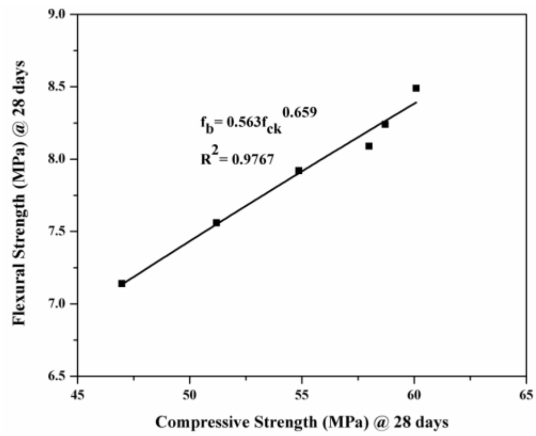


Fig. 10 The Relationship between compressive strength with flexural strength for wet cast PCPB containing crumb rubber at 28 days

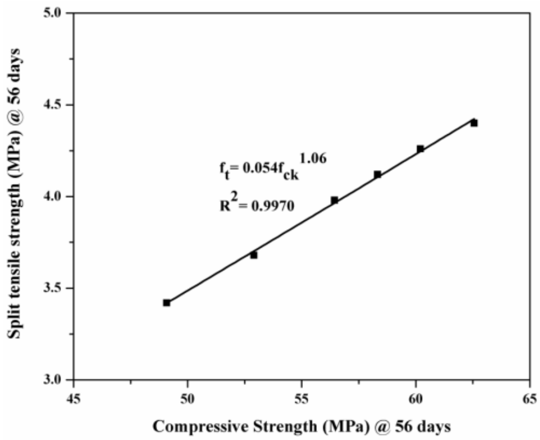


Fig. 11 The Relationship between compressive strength with split tensile strength for wet cast PCPB containing crumb rubber at 56 days

The correlation was done for finding the relationship between compressive strength with split tensile strength and flexural strength at 7, 28 and 56 days. The correlation curve was drawn on the basis of the compressive strength, split tensile strength and flexural strength test results of PCPB as shown in Fig. 7. An increase in the compressive strength of PCPB could be seen as the split tensile strength and flexural strength increased. When the compressive strength of PCPB decreased, the split tensile strength and flexural strength also decreased, depending upon the percentage of crumb rubber replacements. The test results also specify increase in the compressive strength, split tensile strength and flexural strength of crumb rubber PCPB increased as the age increased from 7 to 56 days.

The analysis in Fig. 7 shows the best fit lines representing the relationship between compressive strength and split tensile strength at an age of 7 days are given as

$$f_t = 0.40\, f_{ck}^{\;1.15} \qquad (1)$$

Where f_t and f_{ck} are the split tensile strength and compressive strength respectively at 7 days. The R^2 value was found to be 0.9637.

The analysis in Fig. 8 also shows the best fit lines representing the relationship between compressive strength with flexural strength at an age of 7 days given as

$$f_b = 0.692\, f_{ck}^{\;0.61} \qquad (2)$$

Where f_b and f_{ck} are the flexural strength and compressive strength respectively at 7 days. The R^2 value was found to be 0.9600.

Fig. 9 shows the proposed equation for the relationship between compressive strength and split tensile strength at an age of 28 days. The equation is given as

$$f_t = 0.066\, f_{ck}^{\;1.01} \qquad (3)$$

Where f_t and f_{ck} are the split tensile strength and compressive strength respectively at 28 days. The value R^2 was found to be 0.9763.

Fig. 10 also shows the proposed equation for the relationship between compressive strength and flexural strength at an age of 28 days. The equation is given as

$$f_b = 0.563\, f_{ck}^{\;0.659} \qquad (4)$$

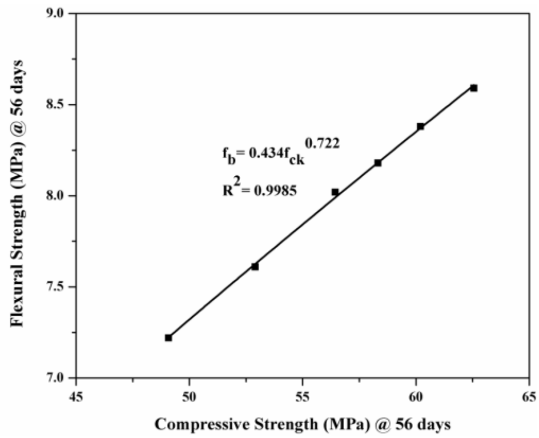


Fig. 12 The Relationship between compressive strength with flexural strength for wet cast PCPB containing crumb rubber at 56 days

Where f_b and f_{ck} are the flexural strength and compressive strength respectively at 28 days. The R^2 value was found to be 0.9767.

The relationship between the compressive strength and the split tensile strength at 56 days is shown in Fig. 11. The best fit line is given as

$$f_t = 0.054 f_{ck}^{1.06} \quad (5)$$

Where f_t and f_{ck} are the split tensile strength and compressive strength respectively at 56 days. The R^2 value was found to be 0.9970.

The relationship between the compressive strength with flexural strength at 56 days is shown in Fig. 12. The best fit line is given as

$$f_b = 0.434 f_{ck}^{0.722} \quad (6)$$

Where f_b and f_{ck} are the flexural strength and compressive strength respectively at 56 days. The R^2 value was found to be 0.9985.

The regression analysis shows all the models for split tensile strength and flexural strength at 7, 28, 56 days show high R^2 values being close to 1. This means that the proposed models from the Eqs. (1)-(6) acceptable fit the data.

4. Conclusions

• The performance of wet cast PCPB varies based on the percentage of crumb rubber content. In wet cast PCPB, compressive strength, split tensile strength and flexural strength values are found to increase with increasing crumb rubber content up to 10% and decreases with increasing crumb rubber content of 15% to 25% as compared to the controlled PCPB (without Crumb rubber).

• The strength gain is mainly determined by the method of casting. In the wet casting method, higher amount of water cement ratio is used and higher level of vibration applied during the specimen compaction for that the bubbles of entrapped air move upwards to the surface of the PCPB and the rubber act as the filler of the pores and it also make stronger.

• However, on further increase of the rubber content, a smaller amount of rubber only fills the voids and the remaining amounts of rubber particles mix with cement paste and thus affecting the rubber cement matrix because the particles is much softer than other concrete materials. So, on loading the crack propagation is very fast around rubber particles which lead to the failure of the PCPB.

• The target compressive strength can be achieved by the wet cat PCPB having 5%, 10%, 15%, 20% and 25% crumb rubber content. Therefore, there is no need in the wet casting method for any pre-treatment techniques for improving the performance of the PCPB containing waste tyre crumb rubber.

• As the testing age increases, the compressive strength, split tensile strength and flexural strength increase in all types of the mixture due to the increase in filling of the voids inside the mixture with calcium silicate hydrate (C–S–H).

• Equations (1)-(6) are proposed for predicting the relationship between compressive strength with split tensile strength and flexural strength for PCPB with waste tyre crumb rubber at 7, 28 and 56 days of age with waste tyre crumb rubber replacement in the range of 0–25% with the cement content of 380 kg/m^3 and the water cement ratio of 0.4. Fine aggregate is in the range of 626–865 kg/m^3 and the coarse aggregate of 1010 kg/m^3.

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