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Research Article

Development of Pervious Concrete with Enhanced Skid Resistance using Waste Tires Particles

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Abstract: Rubber tires are excessively increasing with the advancement in transportation technologies. It is difficult to dispose off the tires and as such they cause environmental threats to the on-land and aquatic lives. In this work crumb rubber is used as a fractional replacement of sand in concrete at 5%, 10% and 15% by mass. The aim is to produce a porous concrete with acceptable mechanical strength and high skid resistance. The workability and fresh density of the concrete decreased with the crumb rubber. Similar reduction in mechanical strength was also noticed, however, 5% replacement showed mechanical properties similar to those of the control units. The crumb rubber enhanced the porosity of the material. The study as a whole suggests that a lightweight concrete with enhanced porosity and skid resistance can be produced by recycling crumb rubber as a partial replacement of sand. The porous concrete with good skid resistance is a useful pavement material as it allows the infiltration of rainwater through it and thus has the capacity to reduce runoff during heavy rainfalls. It can additionally help reduce the accidents due to higher skid resistance in wet conditions.

Keywords: Concrete, Crumb Rubber, Skid Resistance, Mechanical Properties, Rigid Pavement.

1. INTRODUCTION

The recycling of waste materials as a replacement of the ingredients of concrete is being practiced all around the globe. This replacement is in accordance with the sustainable development goals of the United Nations and serves a dual purpose; it reduces the environmental hazards posed by the waste, and it provides a hybrid type of concrete that incorporates a lesser quantity of natural resouces (cement, sand or coarse aggregates). Sand is an important ingrdient of concrete; it is not only used in construction but also in electronic appliances. It is a source of silicon, an important ingrdient of electronic appliances. Its huge utilization will lead to the scarcity in future and many intellectuals are of the view that the world will face a shortage of this natural source [1]. Several studies are available on partial replacement of sand by rubber and other waste materials. In all these studies, rubber particles were either directly incorporated in cementitious mixes or pre-treated/soaked in water/alkaline solutions before their incorporation in the cementitious mixes. Some important studies are described here:

Safan *et al.* [2] studied the effect of crumb rubber on properties on concrete. The authors have reported a 37% decrease in compressive strength with 15% substitution of sand by untreated crumb rubber. When crumb rubber was pre-treated with NaOH, the concrete recovered the strength by 13%. Choudhary *et al.* [3] have reported a decrease in workability of mortar with crumb rubber; the authors attributed the decrease to water retention capability of rubber particles. Sharma *et al.* [4] used crumb rubber as additive to bitumenous mixes. The authors claimed that the modified bitumen possessed lesser flexibility but higher resistance against rutting. Saifuddin *et al.* [5] examined the effect of crumb rubber on concrete performance. The authors have reported that the concrete containing rubber had a smoother surface and higher flexibility. The rubber particles enhanced the resistance to water (impermeability) and the compressive strength increased up to 5% partial replacement. Eltayeb *et al.* [6] used crumb rubber in place of fine aggregates in the range of 0-50% in concrete. The authors evaluated the modified concrete in terms of resistance to bullets, blast, impact and collision loads. The concrete outperfomed the conventional

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concrete in the dynamic parameters as mentioned above. Deshpande *et al.* [7] used treated and untreated rubber particles as fractional substitute of sand in concrete. The authors have reported that the concrete containing treated rubber particles had higher strength than that of the concrete containing untreated particles. Kashani *et al.* [8] studied the performance of lightweight cellular concrete (LCC) employing waste crumb rubber as a filler. Crumb rubber was soaked in NaOH solution prior to the mixing in concrete matrix. The acoustic and thermal insulation, as well as the water absorption capacities of LCC got improved with crumb rubber addition. The treatment also improved the ITZ (Intersticial Transition Zone) of the mix. Khan *et al.* [9] utilized crumb rubber particles as partial substitute of sand for making sustainable concrete mixes.The performance of the specimens was evaluated in terms of physical, mechanical and durability properties using standard destructive and non-destructive techniques. They have mentioned that the rubber particles reduce the weight and strength but enhance the thermal insulation of the material.

Automotive industry is growing in Pakistan. With the growth of the industry, the number of waste tyres are also growing. In each city of Pakistan, the discarded waste tyres are stored and dumped in improper way as shown in Figure 1. Most unformtunate part of this story is that these waste tyres are also used as fuel, which emits toxic gases into the atmosphere. Present study focusses on the use of grinded waste local tyres as partial substitute of fine aggregates in normal concrete and concrete pavements. The emphasis is not only to promote the recycling of local waste tyre rubber in building and pavement materials but also to produce a concrete with enhanced porosity and skid resistance; both these charateristics are helpful in rainfall or moonson season as they not only allow the infiltration of water and thus decrease the surface runoff and flooding but also provide enhanced skid resistnace to the moving tyres. This study was formulated in accordance with the sustainable development goals of the United Nations, which stress for sustainable cities and responsible consumption and production.

2. MATERIALS AND METHODS

Concrete was designed, mixed, prepared and cured as per ASTM (American Society for Testing and Materials) standards in the controlled laboratory environment. The machine mixing was carried out with the help of the concrete mixer.

Fig. 1. Waste rubber tyres store.

The materials used for the reasearch work are shown in Table 1. The properties of coarse aggregates, fine aggregates and crumb rubber are given in the Table 2, Table 3 and Table 4, respectively. These properties were determined by using the ASTM standards.

The concrete's composition is shown in the Table 5. Crumb rubber was used as fractional replacement of sand by mass; the percentages were fixed as 5%, 10%, and 15% on the basis of previous studies. All the ingredients were mixed in accordance with ASTM C 685/C685M–17 [10].

The mixing was carried out in a tilting drum concrete mixer. The fresh concrete mix was cast in cylindrical and beam moulds. Workability of the fresh concrete was determined according to the ASTM C 143 method [11]. Similarly the fresh density of concrete was found out by ASTM C 138 [12]. The compressive strength and flexural strength of the specimens were evaluated as per standard ASTM C 39/C 39M [13] and ASTM C 78 [14] methods, respectively. Skid resistance test was carried on the slabs after the slabs were cured for 28 days; the test was carried out by following the standard ASTM E2340/E2340M method [15]. Thermal conductivity of the concrete was measured by employing ASTM C1045–07 and ASTM C177-13 standard methods [16, 17]. Fourier's law was applied for calculating the thermal conductivity of the cores. Finally, the porosity in concrete was measured through standard ASTM water absorption test in the hardened state [18].

Table 1. Description of the materials used.

Sr. No.	Material	Description
1	Coarse aggregates	Obtained from Margalla crush plant near Islamabad
2	Fine aggregates	Lawrencepur Sand (Well-documented river sand)
3	Cement	Bestway Cement (A well-known Pakistani Brand)
4	Crumb rubber	Obtained by grinding the waste tires of vehicles in district Mirpur Azad Kashmir, Pakistan

Table 2. Properties of coarse aggregates.

Sr. No.	Properties	Value Obtained
1	Water absorption (%)	0.46
2	Fineness Modulus (FM)	7.71
3	Specific Gravity	2.64
4	Bulk Density (kg/m^3)	1598
5	Flakiness Index (%)	26.616
6	Elongation Index (%)	11.838

Table 3. Properties of fine aggregates.

Sr. No.	Properties	Value Obtained
1	Specific Gravity	2.69
2	Bulk Density (kg/m^3)	1500
3	Dry Density (kg/m^3)	1850
4	Fineness Modulus	3
5	Water Absorption (%)	3.88
6	Moisture Content (%)	2.01

Table 4. Properties of crumb rubber.

Sr. No.	Properties	Value Obtained
1	Specific Gravity	1.62
2	Fineness Modulus	3.5
3	Color	Black color due to carbon content
4	Surface	Moderately Rough surface

Table 5. Concrete's composition.

Sr. No.	Mix design	Mix criteria	Cement (Kg)	w / c ratio	Water (Kg)	Sand (Kg)	CR (Kg)	Crush (kg)	No of specimens	No of slabs
1	1:2:4	CR0	36	0.55	19.8	72	0	144	9	1
2	1:2:4	CR5	36	0.55	19.8	68.4	3.6	136.8	12	1
3	1:2:4	CR10	36	0.55	19.8	64.8	7.2	129.6	9	1
4	1:2:4	CR15	36	0.55	19.8	61.2	10.8	122.4	9	1

3. RESULTS AND DISCUSSION

3.1 Workability

The slump values of the specimens are presented in Figure 2. In all the cases, a true slump was observed; the slump cone shape of rubberized concrete (10%) is shown in Figure 3. From Figure 2, it can be observed that the workability decreased with the quantity of crumb rubber. There are two reasons for the reduction. Firstly, the rubber particles have good shock absorbing characteristics; the compaction efforts are not effective in expelling air, which reduces the slump [19, 20]. Secondly, the rubber particles act as fibres and keep the concrete matrix intact; this makes the mix more cohesive [9]. The workability was reduced but a cohesive true slump took place. The least value of slump (22.5 mm) was recorded with 15% fractional replacement. It is expected that further increment in the crumb rubber content will make the concrete mix less workable.

Concrete with a low slump is preferred in rigid pavements. The low slump allows the pavement not to deform, once the machinery is removed. This deformation also affects the concrete surface. A higher workability may also allow the segregation of the cement paste from the aggregates. For these reasons, the workability of the rigid pavements is purposely kept low (0-75 mm) [21]. The slump values as obtained during this study lie within the range of 0-75 mm; moreover, the true slump as shown in Figure 3 depicts that the concrete is cohesive and is free from segregation.

3.2 Fresh Density

The variation of fresh density with rubber content is shown in Figure 4. Crumbed rubber particles are lighter in weight than the sand particles. The specific gravity of crumb rubber is 1.62 against that of 2.69 for sand. Therefore, with the increase in crumbed rubber proportion the mass of concrete samples is reduced; hence, the density of fresh concrete decreases with the increase in rubber content. Secondly, after the incorporation of crumb rubber, voids are generated in concrete, which causes loss of weight of the sample per unit volume.

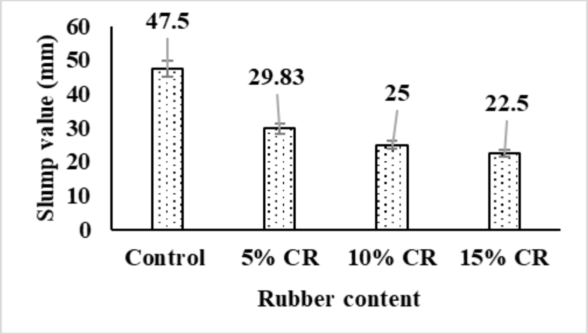

Fig. 2. Variation of slump with rubber content.

Fig. 3. True slump in rubberized concrete containing 10% crumb rubber.

The crumb rubber particles hinder the compaction efforts due to shock absorbing characteristics of the rubber particles; the air gets trapped within the matrix. Therefore, the results are closely linked to the slump test results. The basic principle that lies behind the making of a light-weight concrete is the induction of air [19]. For this purpose, various admixtures are added. Thus, the rubber particles act as admixtures and reduce the weight of the concrete. Light weight concrete pavements are advantageous in the situations, where roads are constructed over a weak soil. The heavyweight pavements tend to settle down in such situations, whereas, a lightweight pavements perform relatively better [22].

3.3 Compressive Strength

The variation of compressive strength with rubber content is shown in Figure 5. The control unit showed the maximum compressive strength. As the sand was fractionally replaced with the crumb rubber, the bonding between concrete mix got disturbed and this made the loss of strength in compression. The crumb rubber decreased the compressive strength of the concrete because it entrapped the air and generated free spaces that resulted in the air void production in the concrete mix. The compressive

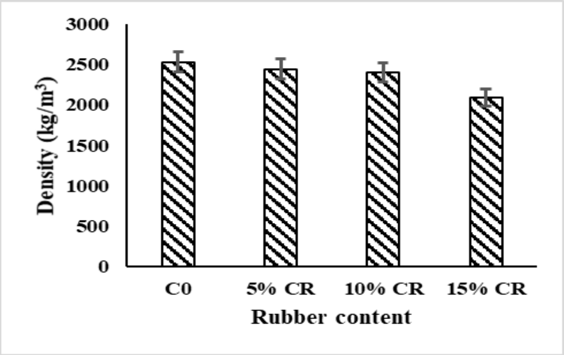

Fig. 4. Variation of fresh density with rubber content.

strength is directly related to the density of the material [23]. This also shows that the stiffness of the crumb rubber is lesser to sustain the same loads as the control unit does. The incorporation of the rubber particles as a partial replacement of sand, introduces air voids. These voids/pores decrease the strength, increase the porosity and therefore decrease the density. The results are consistent and are inter-linked. The microstructure and concrete specimen texture are shown in Figure 6 [9] and Figure 7, respectively. The compressive strength although is specified for concrete pavements, but is not usually considered a critical parameter for road performance. However, it is determined because the test is simple and commonly available and the result values are closely related to flexural strength, tensile strength, density and permeability [24]. Typical compressive strength for road pavements range from 20 MPa to 40 MPa [21]; whereas, higher compressive strengths lead to shrinkage cracks.

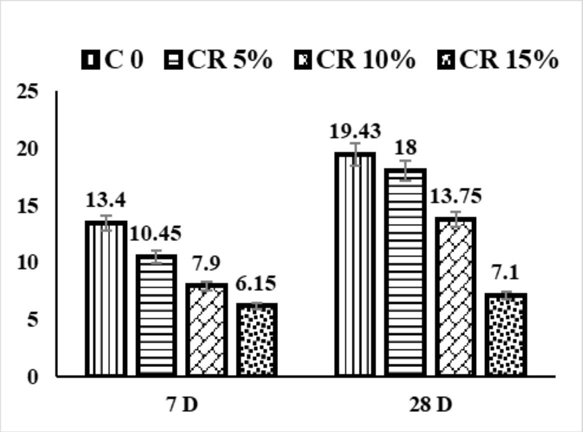

Fig. 5. Variation of compressive strength with crumb rubber.

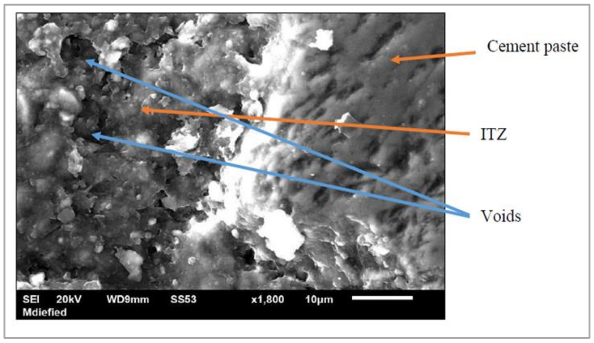

Fig. 6. Microscopic view showing the formation of higher number of voids at 15% replacement level.

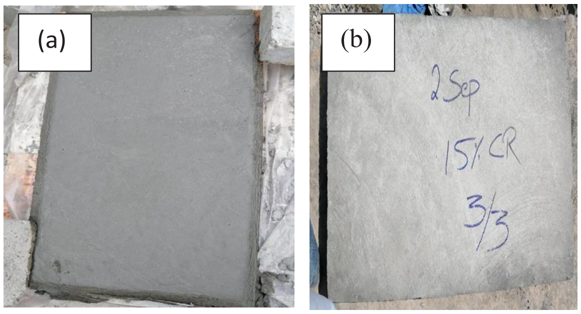

Fig. 7. Smooth surface of CR 15 sample (a) fresh form, (b) cured form.

3.4 Flexural Strength

The flexural strength is an important indicator of the performance of the concrete pavement. The variation of flexural strength with rubber content is shown in Figure 8. The control unit showed the maximum strength of all the specimens. The specimens containing the crumb rubber showed a linear decrease. The control unit shows a strength of 6.3 MPa and 9.1 MPa at 7 and 28 days, respectively. These values are suitable for concrete pavements as per international standards [21].

For ordinary concrete, the flexural strength varies as 10-20% of the compressive strength [25, 26]. The flexural strength is more than 20% of the compressive strength in the present case. Although, flexural strength is usually considered to be directly linked to the compressive strength; as a matter of fact, the two parameters depend on different variables. While, compressive strength is dependent on the density of the material, the flexural strength is more dependent on the cohesion of the material. Since, rubber particles may act as fibres,

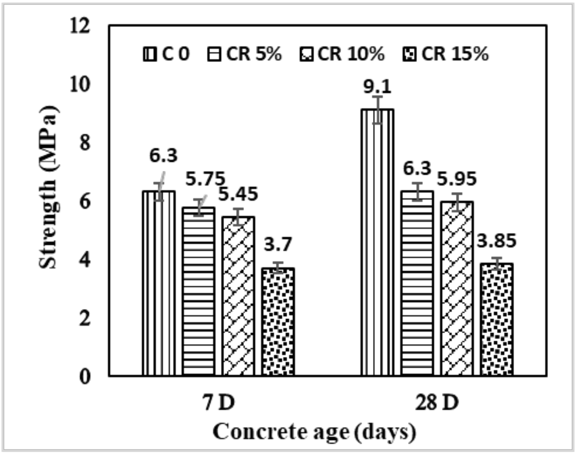

Fig. 8. Flexural strength of concrete as a function of %age replacement of CR.

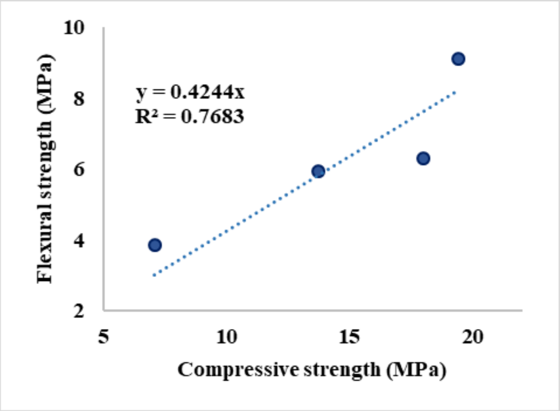

Fig. 9. Relationship between flexural and compressive strengths.

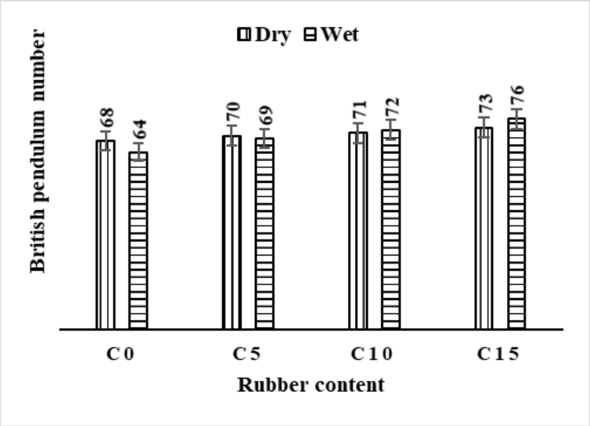

Fig. 10. British pendulum number of concrete as a function

interconnecting the concrete particles, they have the capacity to enhance the flexural strength [19, 27]. The minimum flexural strength requirement for a concrete pavement is mostly designated as 4 – 4.5 MPa at 28 days of age in various codes [21, 28] pavement aggregates, applied load characteristics, and climate. Various sub-grade condition and concrete slab flexural strength values results on the pavement design thickness that have a direct impact on the cost construction. In this study, the rigid pavement design of an apron with various sub-grade condition and concrete flexural strength values are presented. As a reference, the Federal Aviation and Administration (FAA; thus the rubber concrete while having low compressive strength, exhibits comparatively good flexural strength. The relationship between the compressive strength and the flexural strength is given in the form of the equation (1) and diagrammatically shown in Figure 9. The curve shows that flexural strength is directly proportional to the compressive strength:

$$f_f = 0.42. f_c' \quad (1)$$

Where, f_f is the flexural strength and f_c' is the compressive strength (both in MPa).

3.5 Skid Resistant Test

Figure 10 shows a comparison of skid resistances of dry and wet surfaces of control units and rubberized slabs. The skid resistance of the control unit is greater on dry surface than on wet surface of the pavement.

Higher value of the British Pendulum Number shows a good surface of the concrete pavement. It indicates the strong resistance for fast traffic flows. For concrete pavements with 5% rubber content, the value of skid resistance on dry and wet surfaces is almost same, however, the rubber improves the resistance of the concrete. The slab with 10% replacement of sand with crumb rubber shows different behaviour than control sample and 5% CR slab; its skid resistance on wet surface is greater than that on the dry surfaces. This behaviour exhibits an improved adhesive nature of crumb rubber after contacting with water. The skid resistance of the concrete with 15% rubber content is higher on wet surface than on the dry one. This is because of the rough texture of the crumb rubber that improves the resistance when in contact with the water.

3.6 Thermal Conductivity

Figure 11 shows the variation of thermal conductivity with the rubber content. Thermal conductivity decreases as the rubber content of the concrete increases. The results are analogous to those of compressive strength and density. The results demonstrates that the concrete has air voids, which reduce the thermal conductivity.

According to US Department of Transportation, the thermal conductivity of the pavement materials normally varies from 0.8 Watts/m-K to 2.0 Watts/m-K [29]. In the present study, the thermal conductivity of the control material lies within the range. The low thermal conductivities are advantageous in normal as well as in pavement concretes. The lower thermal conductivities keep the temperature low within the pavements and ensure high-temperature stability of the pavements [30].

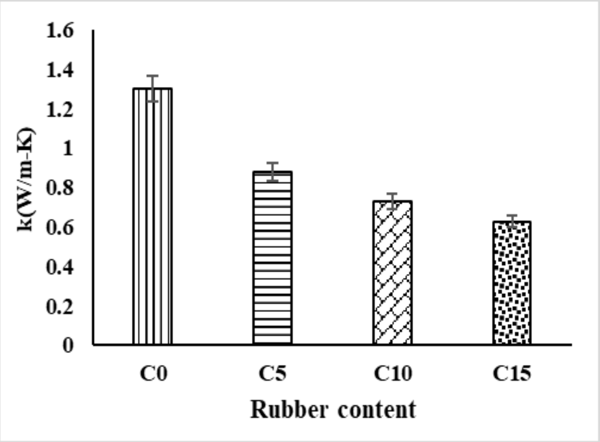

Fig. 11. Variation of thermal conductivity with rubber

3.7. Porosity (Water Absorption Test)

The effect of rubber content on porosity was confirmed through water absorption test [18]. Figure 12 shows the variation of the water absorption of control unit and the others incorporated with crumb rubber at 5%, 10% and 15% levels. Porosity of the concrete was evaluated by dipping the cores of the specimens into the water and by recording the dry and wet masses before and after dipping the cores in water. As the rubber content increases in the concrete, the voids also increase. The increase in voids leads to higher water absorption; this is an indicator of higher porosity with rubber content. Higher porosities make the concrete pervious. The pervious concrete in pavements is advantageous in today's life, especially, during the Monson season as it has higher capacity to absorb water. It also allows rain water to infiltrate through it. Pakistan is frequently facing surface runoff during these days and the rubber content helps enhance the water absorption capacity of the rigid pavements.

The relationship between the porosity and thermal conductivity is given by the equation (2) and graphically shown in Figure 13.

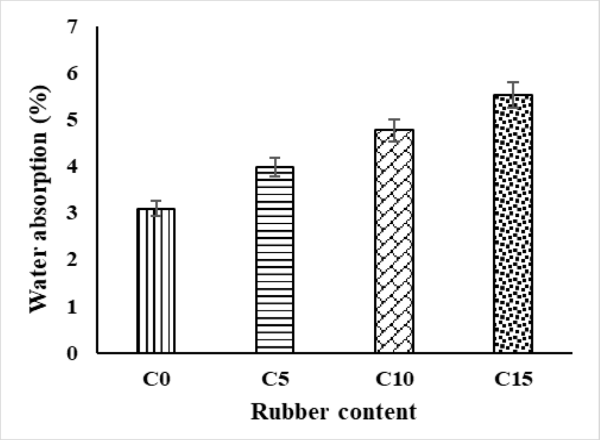

Fig. 12. Enhancement of water absorption with rubber content.

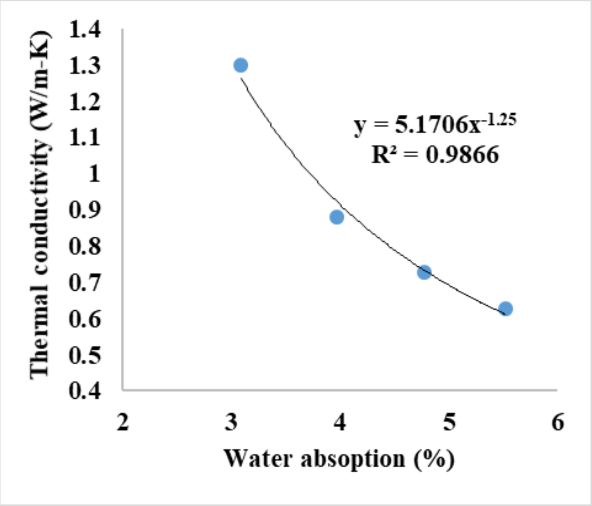

Fig. 13. Variation in thermal conductivity with porosity.

$$k = 5.17.w^{-1.25} \qquad (2)$$

Where k is the thermal conductivity in W/m-K and w is the water absorption in percentage.

4. CONCLUSIONS

This work describes the benefits and drawbacks of using rubberized concrete for road pavements. The material was evaluated through some physical, mechanical and durability parameters. Based on the experimental work, following conclusions are drawn:

1. Rubber content reduces the workability. The compaction efforts are not effective in expelling air due to shock absorbing characteristics of the rubber particles. This in turn also reduces density, mechanical strength, and enhances porosity and thermal insulation.
2. The reduced workability and true slump indicate that the concrete containing rubber particles is suited for rigid pavements.
3. The lightweight pavements are suited if the pavements are to be laid over weak soils.
4. Rubber particles enhance the skid resistance of concrete both in wet and dry conditions. This shows that the rubber particles enhance the surface roughness of the pavement.
5. Present day urbanization is resulting in floods/

surface runoff in cities. Rubber particles enhance the perviousness of concrete and thus allow the passage of water through it. The use of rubberized concrete for low-to-average-volume traffic roads/streets can be a viable solution in flood-affected areas.
6. Rubber content reduces thermal conductivity. This will maintain stable temperature levels within the pavement.
7. The enhancement of the skid resistance in wet conditions demonstrate that the rubberized concrete pavements can increase the friction between the tyres and the pavement and thus add to the safety of the vehicles in rainy seasons.

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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