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Effect of Mineral Filler type on Strength of Roller Compacted Rubbercrete for Pavement Applications

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Abstract. This paper investigated the possibility of using crumb rubber as partial replacement to fine aggregate in roller compacted concrete for pavement applications where fine aggregate was replaced with crumb rubber at 0%, 10%, 20% and 30% to produce roller compacted rubbercrete (RCR). In order to achieve a combined aggregate gradation similar to the one recommended by ACI 211.3R and US Army Corps of Engineers method, fly ash was used as mineral filler. Several trials were done to achieve the combined grading, and finally a combination of 55% fine aggregate, 40% coarse aggregate and 5% fly ash as mineral filler was used. Silica fume was then used as mineral filler instead of fly ash and the fresh density and compressive strength were compared. A target flexural strength of 4.5 MPa and the mix design was developed using the geotechnical concept according to ACI 211.3R/CRD-C161-92. The Results showed that fresh density and compressive strength decreases with increase in partial replacement of fine aggregate with crumb rubber. RCR containing silica fume showed lower fresh density and higher compressive strengths than that with fly ash. However, all the mixes achieved a strength higher than the design target strength at 28 days except for 30% crumb rubber containing fly ash mineral filler, while 10% crumb rubber achieved target strength even at 3 and 7 days for silica fume and fly ash.

1. Introduction

As the world population keeps increasing, likewise the number of vehicle usage due to the rapid demand in transportation which is a basic necessity of life. This leads to increase in waste tire generation [1]. Disposal of waste tires is becoming a serious issue to most countries as the world is now focusing towards sustainability of environment. In most highly technological advanced countries it was estimated that every one person generate one waste tire annually and the total number generated annually stands to about 1 billion, with future estimation to reach 1.2 billion by 2030. Globally approximately 4 billion numbers of waste tires are discarded as landfills yearly where more than half of it is dumped without any pre-treating [2-5]. In the US, the waste tire generation increased rapidly from 3.8 million tons in 2013 to more than 4.1 million tons in 2015 where only about 7% are used for civil engineering applications [6, 7]. These waste tires constitute parts of solid waste where its management is becoming a major concern globally as it is non-biodegradable, it will only be stockpiled when disposed as landfills causing aesthetic and health hazards to the environment by providing shelter and breeding grounds for rodents, mosquitoes, snake etc. [8]. Several attempts of waste tire management are been practiced worldwide, some methods of recycling or reusing waste tires include; production of fuel for cement kiln, in asphaltic pavement, production of carbon black, in marine as artificial reef, in pyrolysis i.e. production of tire derived fuel [4, 9, 10]. The construction industry keeps expanding due to rapid development in technology with concrete been the most used construction material and the most used substance in the world after air and water, one of the major challenges facing the world of construction is the sustainability of the natural materials mostly aggregate as their production involves pollution to the environment [2, 4, 11]. One of the possible ways to reduce the effect of shortage in construction materials, sustainability of environment and waste tire disposal issues is by utilizing the waste tire as partial replacement to natural aggregate in concrete to produce rubberized concrete [12], and can be used in roller compacted concrete to produce roller compacted rubbercrete (RCR) [13]. This will also reduce the cost of concrete by reducing the amount of costly aggregate used [4, 9, 14, 15]. Waste tires are grounded into smaller particles ranging from 75μm to 4.75mm with the steel, fiber, dust and any contaminant removed, and used as crumb rubber to partially replaced fine aggregate in concrete [9].

In this paper the effect of partial replacement of fine aggregate with crumb rubber on roller compacted rubbercrete (RCR) for pavement applications was studied and the effect of replacing fly ash with silica fume as mineral filler was also studied. Crumb rubber (CR) was used from 0% to 30% in multiples of 10%, where fly ash and silica fume were used as mineral fillers at 5%.

2. Materials and Methods

This section describe the materials used and the experimental procedures adopted to obtain the results of the study

2.1. Materials

In this study, Portland cement of grade 43 with specific gravity of 3.15 is used, natural river sand was used as fine aggregate with specific gravity of 2.65, fineness modulus 2.86 and water absorption 1.24%. Two sizes of coarse aggregate of NMSA 19 mm and 10 mm were used as coarse aggregate with specific gravities 2.66 and 2.55 respectively. Three sizes of crumb rubber mesh 30, 1-3 mm and 3-5 mm with specific gravities 0.95, 0.9 and 0.94 respectively were used in proportions 40%, 40% and 20% respectively. Figure 1 shows the grading of fine aggregate and crumb rubber. While the properties of fly ash and silica fume used are shown in Table 1.

Table 1: Properties of fly ash and silica fume

Oxides (%)	SiO_2	Fe_2O_3	CaO	Al_2O_3	MgO	K_2O	SO_3	TiO_2	P_2O_5	LOI	S.G
Fly ash	34.5	23.6	19.0	12.8	2.27	2.08	1.49	1.46	1.27	-	2.3
Silica Fume	91.6	1.68	0.91	1.69	-	1.19	0.33	-	-	2.75	2.26

2.2 Methods

In order to evaluate the performance of roller compacted rubbercrete (RCR) pavement with partial replacement of fine aggregate with crumb rubber, 8 mixes were prepared by varying the percentage of CR content at 0%, 10%, 20% and 30% by volume of fine aggregate for 5% fly ash and 5% silica fume as mineral fillers. The mixes with 0% CR for 5% fly ash were taken as the control. The combined aggregate grading curve as shown in Fig 2 was obtained by combing 55% fine aggregate, 20% 19 mm NMSA, 20% 10 mm NMSA, and 5% mineral filler

A target flexural strength of 4.5 MPa which is equivalent to strength C30/37, 37MPa cube strength (BS EN 1992-2-1) was selected, and the mix design was developed using the geotechnical concept according to ACI 211.3R/CRD-C161-92, the water and cement contents were obtained using the moisture content-dry density relationship according to ASTM D1557. The cement content used was 13% by weight of dry aggregate. The fresh density was determined according to ASTM C1170; while compressive strengths were obtained for 3, 7 and 28 days of curing according to ASTM C 1435, and the compaction was done using a vibrating hammer.

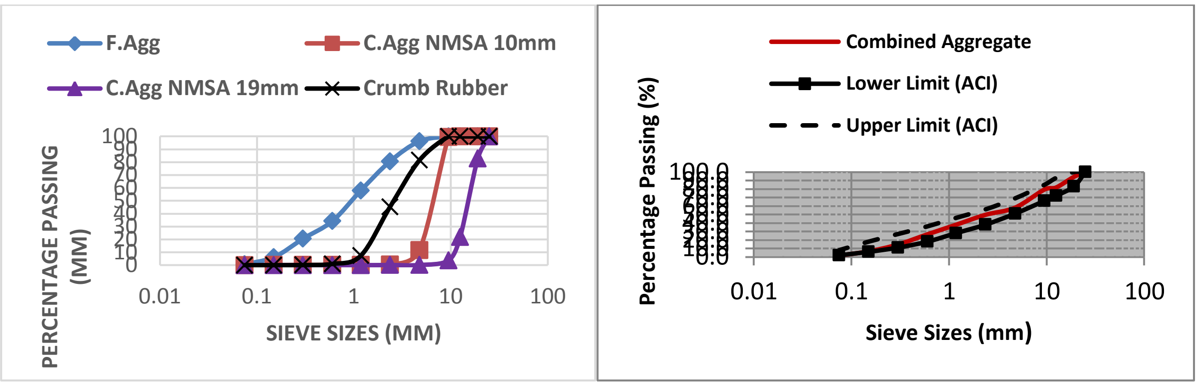


Figure 1 Sieve Analysis (a) Aggregates (b) Combined aggregate gradation

3. Results and Discussions

3.1 Effect of Crumb Rubber on Fresh Density of Roller Compacted Rubbercrete

The fresh density of RCR mix decreases with increase in partial replacement of fine aggregate with CR as shown in Fig 3. However, as shown in Fig 4 the reduction in was more pronounced when silica fume was used as mineral filler compared to fly ash. This is due to lower specific gravity of silica fume compared to fine aggregate with silica fume having more water absorption capacity. The reduction in fresh density due to crumb rubber addition can mainly be attributed to lower specific gravity and density of the crumb rubber compared to fine aggregate it replaced, and due to hydrophobic and non-polar nature of crumb rubber making it to entrap air on its surface thus reducing its fresh density

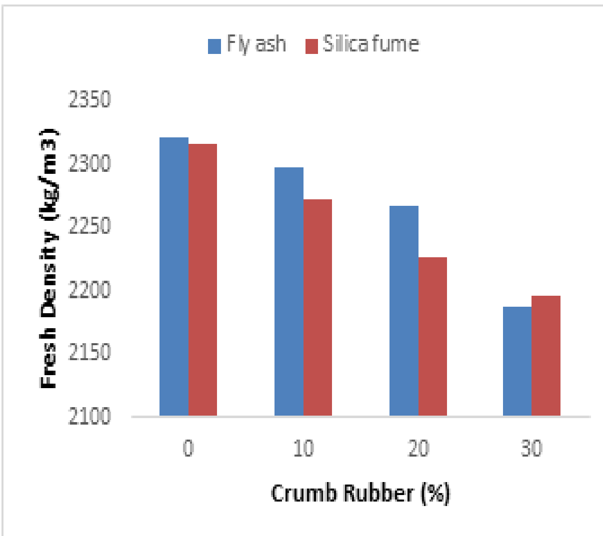


Figure 3: Fresh density of RCR

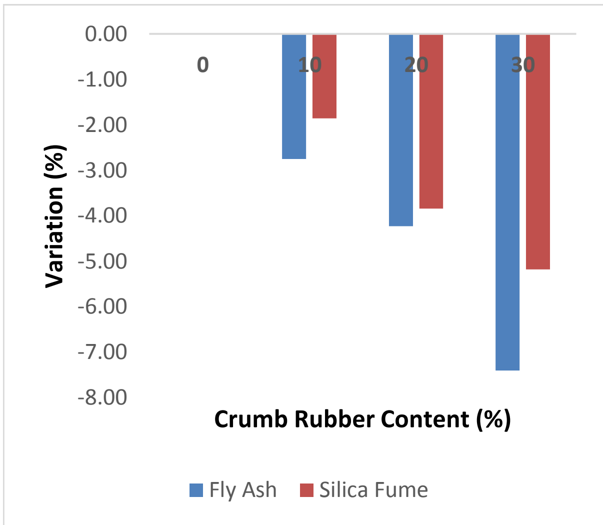
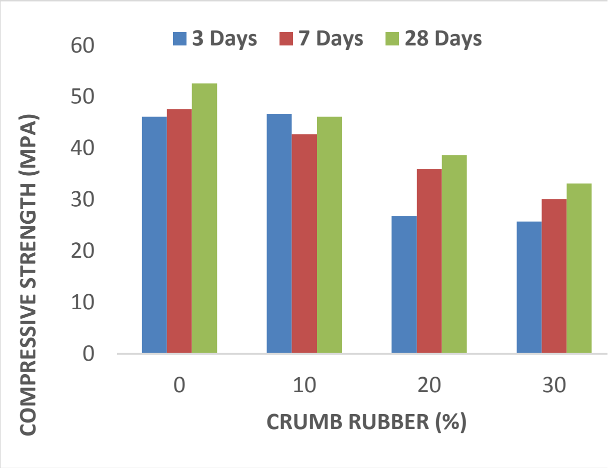


Figure 4: Variation of fresh density with reference to the control mix.

3.2 Compressive Strength

The compressive strength of RCR with either silica fume or fly ash as mineral filler decreases with increase in partial replacement of fine aggregate with crumb rubber as shown in Figs 5 and 6. This reduction in strength can be due to the following reasons; poor bonding between crumb rubber particles and cement paste, lower specific gravity, density and stiffness of crumb rubber in relation to fine aggregate, high porosity in the hardened RCR mix due to entrapped air on the fresh mix. However, all the mixes achieved a strength higher than the target strength at 28 days expect 30% crumb rubber containing 5% fly ash mineral filler, and 10% crumb rubber achieved a strength more than the target strength even at 3 and 7 days. This is due to the ability of the mineral fillers to contribute to strength development through their pozzolanic reactions. Though, the reduction in strength was lower when silica fume was used as mineral filler compared to fly ash as seen in Fig 6. This is due to the higher pozzolanic reactivity of silica fume compared to fly ash making it to consume more $Ca(OH)_2$ and producing more C-S-H gel which is responsible for strength development, with fly ash having a very low pozzolanic reactivity at early ages of curing.



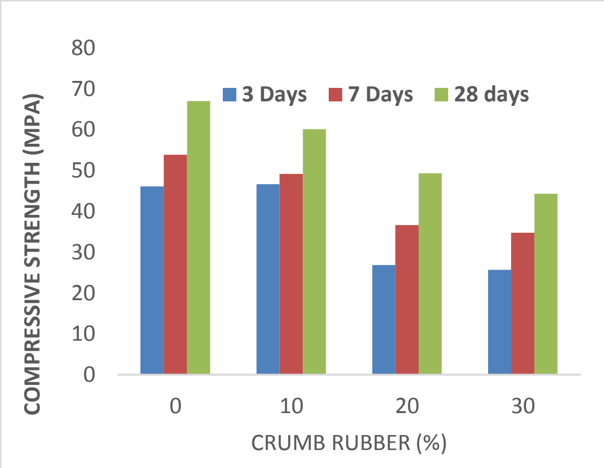


Figure 5: Compressive strength of (a) Fly ash mineral filler (b) Silica fume mineral filler

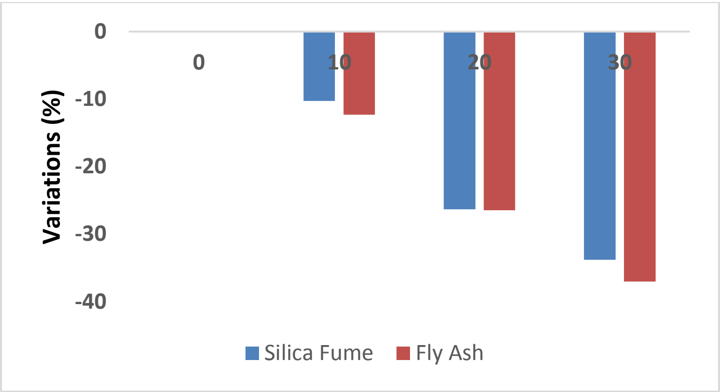


Figure 6: Variation of compressive strength with reference to the control mix

4. Conclusions

This paper investigated the possibility of using crumb rubber as partial replacement to fine aggregate in roller compacted concrete for pavement applications, and compares the use of fly ash and silica fume as mineral filler. The results obtained showed that crumb rubber addition decreases the fresh density and compressive strength. However, all the mixes achieved strength higher than the design target strength at 28 days except for 30% crumb rubber containing fly ash mineral filler. Conversely, when silica fume was used as mineral filler the reduction in fresh density was higher compared to that of fly ash. However the reduction in compressive strength was higher for fly ash mineral filler than silica fume which was mainly due to the slower pozzolanic reaction of fly ash. Replacing fly ash with silica as a mineral filler was successful in mitigating loss in compressive strength for up to 20% CR.

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