DURABILITY AND LEACHATE ANALYSIS OF FLY ASH-LIME-GYPSUM COMPOSITE MIXED WITH TREATED TIRE CHIPS

S. P. Guleria [1] and R. K. Dutta [2]

ABSTRACT

The objective of the present study is to investigate the effect of randomly distributed tire chips, derived from waste tires on the durability of reference mix containing fly ash, lime and gypsum. The dry, water, sodium hydroxide and carbon tetra chloride treated tire chips were used in the study. The tire chip content was varied from 5% to 15% and specimen were cured for 7, 28, 90, and 180 days with two different curing methods (in a dessicator and water filled container). The results of the study revealed that the weight loss of reference mix mixed with dry tire chips can be decreased with treatment with water, sodium hydroxide and carbon tetra chloride. Decrease in weight loss was highest with carbon tetra chloride followed by sodium hydroxide and water. Further, the weight loss of reference mix with dry/treated tire chip decreased with the increase in curing period and the decrease was highest when specimens were cured in water filled container. The weight loss of the reference mix mixed with dry/treated tire chips increased with the increase in tire chip content. Leachate analysis have shown that reference mix mixed with dry/treated tire chips does not cause leaching of any harmful metals. Potential use of this material can be in road subbases having light traffic.

Key words: Tire chip, treatment, durability, leaching.

1. INTRODUCTION

The recycling of rubber tire waste and fly ash, can conserve valuable natural resources and reduce the amount of waste which otherwise requires disposal in landfills. Therefore, there is dire need to look for their uses in civil engineering. Further, before their actual use at the site, it becomes immensely important to look into its environmental aspect so that these waste materials may not have any adverse impact on the environment. With globalization of Indian economy and emphasis on development of infrastructure, the number of vehicles on road is on the increase. The total number of discarded tires in India was of the order of 112 million per year (Rao and Dutta 2006). Further, with the cumulative growth rate of 8% of vehicles in India (Automan 1999) the total number of waste tires will be in the order of 172 million per year at present. On the other hand, the production of fly ash in India is on increase day by day with the coming up of new thermal plants for power generation. India has registered only 13% use of fly ash compared to more than 40% use by the developed countries like Japan, United States and United Kingdom (Das and Yudhbir 2005). Fly ash is a fine-grained material of mostly silt size particles. It is non plastic and can therefore be handled easily. Further, because of its pozzolanic properties, it can be stabilized with cement/lime/gypsum or in combination to achieve the required durability. Further, for safe and effective utilization of stabilized fly ash, environmental safety (Ghosh 1996) aspects need to be considered. Keeping the above in view, tests were carried out to examine the effect of treated tire chips on the durability of fly ash-lime-gypsum composite by varying the treated tire chip content, curing period and curing method. Leachate analysis was also carried out at 90 days to ascertain that new composite material should not have adverse impact on the environment. The results obtained from these tests have been presented and discussed in this paper.

2. BACKGROUND

The road constructed with tire chips was monitored by Eldin and Senouci (1992) and the chemical analysis of leachate generated as derived from tire chips has shown little or no likelihood of detrimental effects on ground water. Studies reported by Downs *et al.* (1997) have indicated that leaching from the tire chips take place at low pH level. The concentration of contaminants that leached out depends on the pH of the environment (Sengupta and Miller 1999). Leaching tests conducted on tire chips and soil mixtures by O'Shaughnessy and Garga (2000) in column tests under acidic (pH 3.5), neutral (pH 6.5) and alkaline conditions (pH 9.5) reported the leaching of aluminum, iron, zinc and manganese metal. Further literature on tire chips indicates that they are highly durable when submerged in 25 m deep sea water for 42 years and do not show any adverse effect on strength properties (Ab-Malek and Stevenson 1995). Similar observations were made by Ready and Saichek (1998) when tire chips were placed in landfill under extreme acidic conditions. Many investigators (Ghosh and Subbarao 1998; Webster and Loehr 1996; Goh and Tay 1993) highlighted the environmental aspect of fly ash utilization. The class *F* fly ash when stabilized with lime alone or in combination with small percentages of gypsum yields a strong

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impermeable matrix (Ghosh 1996). The stabilization of fly ash with lime and gypsum in comparison to unstabilized fly ash shows the reduction in the leaching of metals (Ghosh and Subbarao 1998). The effectiveness of gypsum to reduce the leaching of lime from stabilized matrix was reported by Ghosh and Subbarao (2006). Further, lime stabilization improves the durability of fly ash (Ghosh and Subbarao 2001). The dissociation of fly ash and maximum leaching of metals take place at lower pH value from fly ash (Prasad and Mondal 2008). The authors further emphasized the importance of conducting the leachability test on fly ash as the trace elements present in fly ash have the tendency to leach out and contaminate the surface and ground water. The literature as presented above clearly indicate that there are number of studies relating to the use of fly ash or tire chips alone or mixed with cement/lime, gypsum or in combination. However no study relating to effect of treated tire chips on durability of fly ash-lime-gypsum composite has been reported so far. The present study is thus an attempt to study the effect of treated tire chip content, curing periods and curing methods on the durability. Further, leachability tests were also conducted on tire chips, fly ash-lime-gypsum composite and fly ash-lime-gypsum composite mixed with treated tire chips to study leaching of harmful metals.

3. MATERIALS USED AND EXPERIMENTAL PROCEDURE

3.1 Fly Ash

The fly ash (Class *F*) used in the study was procured from Ropar Thermal Power Plant, Punjab, India. The fly ash had a specific gravity, dry unit weight and optimum moisture content of 2.07, 9.54 kN/m^3, and 20%, respectively. The chemical composition of fly ash was: SiO_2 = 56.32%; Al_2O_3 = 30.87%; Fe_2O_3 = 4.94%; CaO = 1.58%; MgO = 0.70; loss on ignition = 4.52.

3.2 Lime and Gypsum

Commercially available lime and gypsum were used in the study. The chemical composition of lime was SiO_2 = 0.98%; Al_2O_3 = 5.38%; Fe_2O_3 = 0.69%; CaO = 69.50%; MgO = 0.30%; loss on ignition = 22.80%; and others = 0.71%. The gypsum used in this study was procured from the local market and was having the chemical composition as CaO = 28.34%; SiO_2 = 5.47%; Al_2O_3 = 2.45%; Fe_2O_3 = 1.93%; MgO = 2.06%; SO_3 = 40.43%.

3.3 Tire Chips

The tire chips were derived from the waste tires of passenger car. The tread rubber was first removed from waste tire and was cut into strip of 10 mm size. Further, chips of approximately 5 mm irregular size were derived as per the technique reported by Rao and Dutta (2006). The tire chips were found to have specific gravity of 1.12 and the average thickness of 2.7 mm. Since in the present study, the ratio of the maximum chip size to the diameter of the specimen is around 7, hence, the results obtained are likely to be indicative of the overall behaviour for the purposes of comparison.

3.4 Fly Ash-Lime-Gypsum Composite

Guleria and Dutta (2012) reported that the dry unit weight and optimum moisture content of the flyash + 8% lime + (0.4 to 0.9%) gypsum varied from 10.10 to 10.38 kN/m^3, and 26.15% to 26.20%, respectively, when the content of gypsum was increased from 0.4 to 0.9% in the fly ash + 8% lime mix. However, the change in the dry unit weight and optimum moisture content is within the experimental error, hence for all practical purposes they concluded that addition of small percentages of gypsum (less than 1%) to the fly ash + 8% lime mix has no effect on the dry unit weight and optimum moisture content. Based upon the above study, a reference mix of fly ash + 8% lime + 0.9% gypsum was selected for further experimental work.

3.5 Sample Preparation

The fly ash was ground lightly by hand with a pestle to separate the individual particles. A metallic mould having size 38 mm inner diameter and 76 mm long, with additional detachable collars at both ends were used to prepare cylindrical specimens. In order to keep the total volume of the cylindrical specimen as constant, fly ash equivalent to the weight of tire chips was removed and replaced with dry tire chips (designated as C1 tire chips) corresponding to 5%, 10%, and 15% of dry weight of fly ash. The quantity of 8% lime and 0.9% gypsum corresponding to reduced dry weight of fly ash was then mixed thoroughly and the required quantity of water (corresponding to optimum moisture content (OMC)) was added to the mix. Further, the dry tire chips will absorb the water when mixed with the wet reference mix and thus decreasing the optimum moisture content and affecting the dry unit weight. Also the dry tire chips contain dust particles on its surface. These dust particles may cause hindrance in bonding of tire chips with fly ash-lime-gypsum matrix. Various researchers (Raghavan *et al*. 1998; Lee *et al*. 1998; Chung and Hong 1999; Segre and Joekes 2000; Biel and Lee 1996) have reported that the lower bond strength between dry tire chips with cement/concrete matrix results the decrease in the compressive strength of the composite. Thus in order to keep the OMC constant and make the surface of the tire chips free from dust, tire chips in the subsequent series of experiments were dipped in water (designated as C2 tire chips), sodium hydroxide solution (designated as C3 tire chips) and carbon tetra chloride solution (designated as C4 tire chips) for 20 minutes before adding them to the reference mix. Further, to facilitate compaction, the quantity of water/solution equivalent to the weight of the absorbed water/solution by the tire chips was deducted from the quantity of water corresponding to the optimum moisture content. To ensure uniform compaction, specimen was compressed statically from both ends till the specimen just reached the dimensions of the mould so as avoid the elastic rebound of tire chips. Then the specimen was extracted with the hydraulic jack and was allowed to dry at room temperature.

3.6 Curing

For curing the specimens with the help of first method (designated as M1), the specimens were extruded from the mould and were closely wrapped individually in polyethylene bags to prevent moisture loss. Thereafter specimens were placed in a dessicator and the dessicator was closed with a lid and kept at room temperature. For the second method of curing (designated as M2), the dried specimens were placed in water tank filled with water and having the provision of inflow and out flow for curing. The tap water was kept running slowly and continuously so that the contaminated water in the tank due to leaching action, if any, was continuously displaced. This method would simulate the conditions where low volume roads are subjected to prolonged flooding and submergence soon after their construction.

3.7 Tests Conducted

For conducting the leachate analysis, leachate solution was prepared by mixing 500 ml of distilled water with 5.7 ml of acetic acid. Further, 1N NaOH was added in the leachate solution and final leachate solution was made to one litre by adding additional distilled water. By adopting the above procedure a pH value of 4.93 was maintained. Rodriguez and Estaire (2010) have also fixed pH of leachate solution to 4.5 by adopting the similar procedure. Separate leachate solutions were prepared for 15% C1 tire chips, reference mix with/without 15% C1, C2, C3, and C4 tire chips. A tire chip content of 15% C1, C2, C3, and C4 to be mixed in reference mix was selected so as to check the maximum adverse leaching of metals that could take place from tire chips when mixed with reference mix. The prepared leachate solutions were preserved in a closed container and were kept in a dessicator at room temperature for three month duration. Daily shaking of the leachate solutions at a rate of 30 ± 2 rpm was done so as to aggravate the reaction between the failed specimens and leachate solution. The superannuated leachate solution after 90 days was filtered through Whatman 40 filter for analyzing calcium, sodium, sulfate, Iron, Zinc, Manganese, copper, lead, chromium, cadmium and Nickel. The atomic absorption spectrophotometer (Fig. 1) and flame photometry (Fig. 2) apparatus were used for carrying out metal analysis. The durability tests were conducted were as per IS 4332 (Part IV)-1968 Re-affirmed 2006. The specimens were immersed in water for 5 hours followed by drying cycle which was carried out for another 42 hours at 70°C. This will constitute one wet-dry cycle. After each cycle, the specimens were brushed with a steel wire brush and the loss in the material is recorded as weight loss in percentage. 12 such cycles were repeated.

4. RESULT AND DISCUSSION

4.1 Leachate Analysis

The results of leaching of sodium, zinc, calcium, iron, sulfate, manganese, copper, lead, chromium, cadmium and nickel carried out on pure tire chips, reference mix and reference mix with 15% C1, C2, C3, and C4 tire chips for 90 days duration are shown in Table 1. A study of this table reveals that the leachability of sodium from pure tire chips was 1900 mg/l. The study was found in agreement with Westerberg and Macsik (2000), where similar leaching of sodium was reported from the tire chips of size 13.6 mm. The leachability of sodium for the reference mix was 1407 mg/l. The leachability of sodium increased to 1502, 1602, 1789, and 1700 mg/l respectively for the reference mix with 15% C1, C2, C3, and C4 tire chips. The increase in leachability of sodium for the reference mix mixed with 15% C1, C2, C3, and C4 tire chips was perhaps due to possible reaction of sodium hydroxide and carbon tetra chloride with the fly ash, lime and gypsum that lead to the increase in leachability of sodium. The leachability of zinc from pure tire chips was 4.22 mg/l. The study was found in agreement with Aydilek *et al*. (2006) and Westerberg and Macsik (2000), where similar leachability of zinc

Fig. 1 Atomic absorption spectrophotometer

Fig. 2 Flame photometry

Table 1 Leachate analyses of the reference mix, tire chips and reference mix mixed with C1 and C2, C3, C4 treated tire chips for 90 days of duration

Parameter	C1M2 (mg/l)	C2M2 (mg/l)	C3M2 (mg/l)	C4M2 (mg/l)	Tire chip (mg/l)	RM2 (mg/l)	Standards*(Land disposal) (as per mode of disposal)	
							Surface water	Public sewer
Calcium	850.5	901.3	1002.2	1200	40	1200	NR	NR
Sodium	1502	1602	1789	1700	1900	1407	NR	NR
Sulfate	607	823	567	912	100.2	711	NR	NR
Iron	25.1	26.9	20.1	18.3	3.12	30.4	NR	NR
Zinc	1.52	1.92	1.23	1.96	4.22	3.56	5	15
Manganese	0.69	0.89	1.11	0.92	0.2	0.50	NR	NR
Copper	ND	ND	ND	ND	ND	ND	3.0	3.0
Lead	ND	ND	ND	ND	ND	ND	0.1	1.0
Chromium	ND	ND	ND	ND	ND	ND	2.0	2.0
Cadmium	ND	ND	ND	ND	ND	ND	2.0	1.0
Nickel	ND	ND	ND	ND	ND	ND	3.0	3.0

Standards as given in (Land disposal) as per Govt. of India MoEF Notification, 25th September 2000, ND = Not detected, NR = Not reported.

from the tire chips was reported. The leachability of zinc from the reference mix was 3.56 mg/l. The leachability of zinc decreased to 1.52, 1.92, 1.23, and 1.96 mg/l respectively when the reference mix was mixed with 15% C1, C2, C3, and C4 tire chips. The reduction in the leachability of zinc from the reference mix mixed with 15% C1, C2, C3, and C4 tire chips in comparison to reference mix was perhaps due to trapping of zinc leached out of pure tire chips in the reference mix material due to hardening of fly ash, lime and gypsum due to pozzolanic reaction. The leaching of calcium, iron and sulfate from pure tire chips was 40 mg/l, 3.12 mg/l, and 100.2 mg/l respectively. These values increased to 1200 mg/l, 30.4 mg/l, and 711 mg/l for the reference mix respectively. This increase in leaching of calcium was due to the presence of calcium oxide in fly ash, lime and gypsum. Ghosh and Subarao (2006) also reported leaching of calcium of 550 ppm from fly ash + 10% lime + 1% gypsum composite cured at 28 days. The increase in leaching of iron was due to the presence of Fe_2O_3 (4.94%) in fly ash. Increase in leachability of iron from the flyash-lime-gypsum composite was found in agreement with the results reported for Ramagundam fly ash by Prasad and Mondal (2008). Increase in leachability of sulfate was due to the presence of sulfate in the gypsum and the fly ash. The leaching of calcium, iron and sulfate from the reference mix with 15% C1, C2, C3, and C4 tire chips was 850.5 mg/l, 901.3 mg/l, 1002.2 mg/l, 1200 mg/l 25.1 mg/l, 26.9 mg/l, 20.1 mg/l, 18.3 mg/l, 607 mg/l, 823 mg/l, 567 mg/l, and 912 mg/l respectively. It was further observed from the results shown above that the leaching of calcium and iron was less in the reference mix with 15% C1, C2, C3, and C4 tire chips in comparison to the reference mix. The reduction in the leachability of calcium and iron from the reference mix mixed with 15% C1, C2, C3, and C4 tire chips in comparison to reference mix was perhaps due to trapping of calcium and iron leached out in the reference mix material due to hardening of fly ash, lime and gypsum due to pozzolanic reaction. Further, the leaching of manganese from pure tire chips was 0.20 mg/l. A low level leaching of manganese from tire chips was reported by Aydilek *et al*. (2006). The leaching of manganese from the reference mix was 0.50 mg/l. A leaching of manganese of the order of 127 mg/kg was observed from the Ramagundam fly ash as reported by Prasad and Mondal (2008) in acidic environment. The leaching of manganese from the reference mix with 15% C1, C2, C3, and C4 tire chips was 0.69 mg/l, 0.89 mg/l, 1.11 mg/l, and 0.92 mg/l respectively. The increase in the leaching of manganese for the reference mix with 15% C1, C2, C3, and C4 tire chips in comparison to the reference mix was due to the fact acidic environment causes more dissociation that lead to the increase in the leachability of manganese. Study of Table 1 further reveals that tire chips, reference mix and reference mix mixed with 15% C1, C2, C3, and C4 tire chips do not leach out any harmful metals like copper, lead, chromium, cadmium and nickel. Tire chips leach very low level leaching of aluminum, zinc, iron, copper, lead, chromium, cadmium and nickel (Rowe and McIsaac 2005; Aydilek *et al*. 2006; Shalaby and Khan 2002). Past studies (Rowe and McIsaac 2005; Kaushik *et al*. 2010) have suggested that the leaching of small traces of metals will be quickly captured in the clog material and will not cause any harmful effect. Hence from the above, it can be concluded that the composite made from reference mix mixed with 15% C1, C2, C3, and C4 tire chips has shown a reduction in the leaching of sodium and zinc in comparison to pure tire chips and the reference mix respectively. The leachability of calcium, sulfate and manganese in comparison to pure tire chips was higher. Further, the composite made from reference mix mixed with 15% C1, C2, C3, and C4 tire chips has shown a reduction in the leaching of iron in comparison to the reference mix. However the values were found within permissible limit as prescribed by the Ministry of Environment and Forest, Govt. of India. Further, no evidence regarding the presence of harmful metals like copper, lead, chromium, cadmium and nickel were found in the composite. Its use as constructional material at the actual construction site will not cause any adverse impact on the environment.

4.2 Durability Test

One of the most important properties that the stabilized soils should have is the ability to retain its strength over the year when exposed to the destructive forces of weather. One of the most commonly used durability tests on stabilized soils in a non-frost area is wetting and drying test. Figures 3 and 4 shows the results of variation of weight loss of specimens of reference mix with/without 5% C1, C2, C3, and C4 tire chips with curing period and cured with method M1 and M2 respectively. The results of weight loss for the cases of reference mix mixed with 10% and 15% C1, C2, C3, and C4 tire chips cured for 7, 28, 90, and 180 days with curing methods M1 and M2 are shown in Table 2. A study of Fig. 3 reveals that weight loss of reference mix mixed with C1 tire chips decreased when C1 tire chips were replaced with C2, C3, and C4 tire chips. For example, a weight loss of 16.11% for specimen 05C1M1 cured for 90 days decreased to 15.11%, 14.21%, and 14.17% respectively when C1 tire chips were replaced with C2, C3, and C4 tire chips. A similar trend of decrease in weight loss was observed when specimens were cured with M2 method of curing as evident from Fig. 4. Figure 5 shows the photographs of the specimens of reference mix mixed with 5% C1, C2, C3, and C4 tire chips after completion of 12 cycles of wet-dry tests. A study of Fig. 5 reveals that weight loss was least for C4 tyre chips and was highest for C1 tire chips in reference mix, *i.e.,* C4 < C3 < C2 < C1. The decrease in weight loss with the inclusion of C2, C3, and C4 treated tire chips is attributed to the fact that treatment with water, sodium hydroxide and carbon tetra chloride solution causes an improvement in bonding with reference mix due to removal of acidic and carboxyl groups present on the C1 tire chips. A close examination of Figs. 5, 6, and Table 2 reveals that weight loss of reference mix mixed with C1, C2, C3, and C4 tire chip decreases with the change in curing method from M1 to M2. For example, a weight loss of 14.45% for the specimen of reference mix mixed with 5% C4 tire chips at 90 days with M1 curing method decreased to 12.58% with the change in curing method to M2 as evident from Figs. 5, 6, and Table 2. Similar decrease in weight loss was observed at other curing periods. The decrease in weight loss is attributed to the fact that continuous supply of water in curing method M2 makes the specimen harder and improves the bonding of tire chips with reference mix and thus decreases the weight loss of the specimens. Figure 6 shows the variation of weight loss with tire chip content (5% to 15%) of specimen of reference mix cured for 180 days of curing with curing method M2. A close examination of Fig. 6 reveals that weight loss of reference mix increases with the increase in the tire chip content. For example, from Fig. 6, a value of weight loss of 14.31% of reference mix

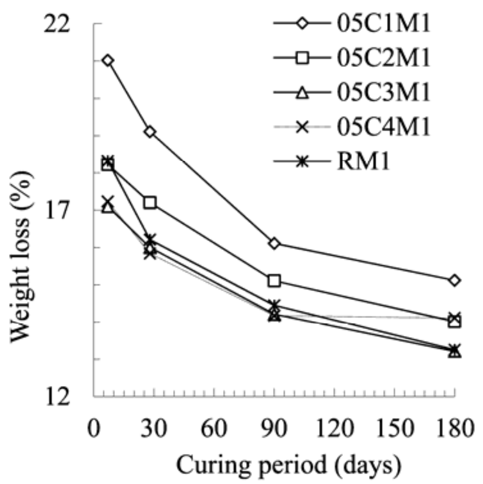


Fig. 3 Weight loss of the reference mix with/without 5% C1, C2, C3, and C4 tire chips cured at 7, 28, 90, and 180 days of curing with M1 curing method

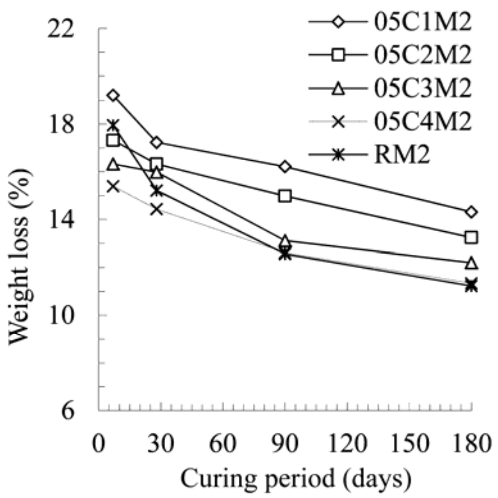


Fig. 4 Weight loss of the reference mix with/without 5% C1, C2, C3, and C4 tire chips cured at 7, 28, 90, and 180 days of curing with M2 curing method

(a) (b) (c) (d)

Fig. 5 Photographs after the completion of 12 cycles of wetting and drying of reference mix mixed with 5% (a) C1; (b) C2; (c) C3; and (d) C4 tire chips cured for 90 days with curing method M1

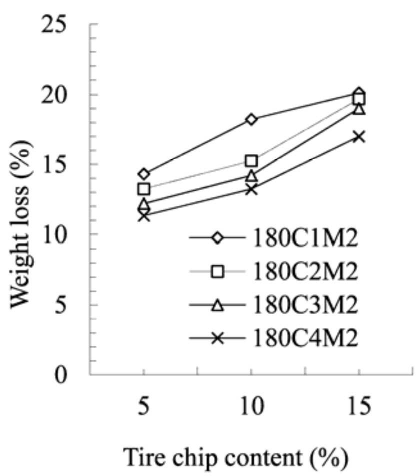


Fig. 6 Variation of weight loss with tire chip content of the reference mix mixed with C1, C2, C3, and C4 tire chip and cured for 180 days with curing method M2

Table 2 Weight losses for the reference mix mixed with 5%, 10%, and 15% C1, C2, C3, C4 tire chips

Tire chips (%)	Curing period (days)	M1					M2				
		R	C1	C2	C3	C4	R	C1	C2	C3	C4
0	7	18.32					17.95				
	28	16.21					15.21				
	90	14.45					12.56				
	180	13.25					11.23				
5	7		21.02	18.22	17.1	17.23		19.21	17.32	16.32	15.39
	28		19.11	17.2	16	15.84		17.23	16.32	15.98	14.43
	90		16.11	15.11	14.21	14.26		16.21	14.98	13.11	12.62
	180		15.12	14.01	13.21	14.11		14.31	13.24	12.2	11.34
10	7		23.42	22.9	20.32	19.21		20.01	19.11	18.42	16.32
	28		21.23	19.11	18.21	17.77		19.23	18.25	17.33	16.68
	90		19.04	18.99	17.91	16.23		18.99	17.22	16.46	15.39
	180		18.40	18.22	17.32	15.23		18.23	15.25	14.21	13.24
15	7		24.86	23.11	22.39	21.33		22.36	21.54	20.88	19.43
	28		23.11	22.01	21.27	21.02		22.21	21.67	20.88	19.69
	90		23.07	21.37	20.99	20.55		21.47	20.99	20.21	18.96
	180		22.32	21	20.22	19.11		20.12	19.69	19.01	17.2

mixed with 5% C1 tire chips cured for 180 days with curing method M2 increased to 18.23% with the increase in the tire chip content to 10%. The value of weight loss for the same specimen further increased to 20.12% with the increase in tire chip content to 15%. A similar trend of increase in weight loss with the increase in the tire chip content was observed with the use of other treated tire chips, curing method and curing periods as evident from Figs. 6, 7, and Table 2. The photograph of reference mix mixed with 5%, 10%, and 15% C4 tire chips after completion of 12 cycles of wetting and drying and cured for 90 days with curing method M2 are shown in Fig. 8. A study of Fig. 8 reveals that weight loss was highest with the use of 15% C4 tire chips followed by 10% and 5% respectively. This decrease in the weight

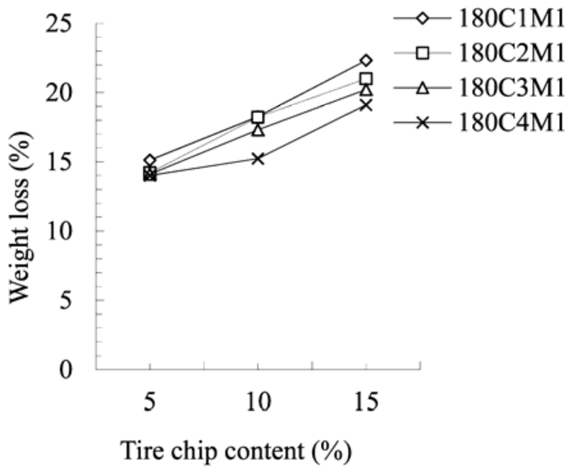
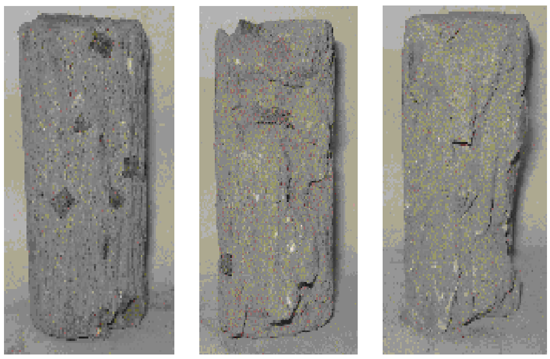


Fig. 7 Variation of weight loss with tire chip content of the reference mix mixed with C1, C2, C3, and C4 tire chip and cured for 180 days with curing method M1



(a) (b) (c)

Fig. 8 Photographs of specimens of reference mix mixed with (a) 5%; (b) 10%; and (c) 15% C4 tire chips after completion of 12 cycles of wetting and drying at 90 days of curing with M2 curing method

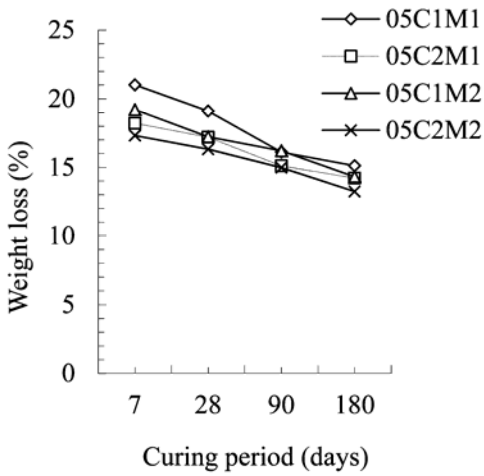


Fig. 9 Variation of weight loss with curing period for the reference mix mixed with 5% C1 and C2 treated tire chips and cured with M1 and M2 curing methods

loss of reference mix with the increase in tire chip content is attributed to the fact that heating of reference mix mixed with tire chips in oven during the drying cycle causes' dissimilar thermal expansion between reference mix and tire chips. This dissimilar expansion and melting of tire chips during the drying cycles causes a reduction in the bond between the tire chip and reference mix. Application of wire brush after the drying cycle further induces abrasive action which leads to removal of tire chips leading to increase in weight loss and formation of voids. Figure 9 shows the results of weight loss for the reference mix mixed with 5% C1 and C2 tire chips cured for 7, 28, 90, and 180 days with curing method M1 and M2. A study of Fig. 9 reveals that the weight loss specimen of reference mix mixed with tire chips decreases with the increase in the curing period. For example, a weight loss of 17.32% for specimen 05C2M2 cured for 7 days decreased to 16.32% and 14.98% respectively with the increase in the curing period to 28 and 90 days. The weight loss of same specimen further decreased to 13.24% with the increase in the curing period to 180 days. The similar decrease in weight loss with the increase in the curing period was observed with the use of other treated tire chips, curing method and curing periods as evident from Figs. 9, 10, and Table 2. A close examination of Figs. 9, 10, and Table 2 further reveals that decrease in weight loss was more significant upto 90 days of curing, whereas beyond 90 days of curing a nominal decrease in the weight loss was observed. From above it can be concluded that the weight loss of the reference mix mixed with C1 tire chips decreases when C1 tire chips were replaced with C2, C3, and C4 in the reference mix. The weight loss of reference mix was highest with the inclusion of C1 tire chips and least with the C4 tire chips, *i.e.*, C4 < C3 < C2 < C1. Weight loss of reference mix mixed with C1, C2, C3, and C4 tire chips decreases with the increase in the curing period and change in curing method from M1 to M2. The soil-cement losses for 12 cycles of wet dry tests as allowed by Association of American State Highway and Transportation Officials (AASHTO) for sandy and gravelly soils are 14%. For the specimen of reference mix mixed with tire chips, the weight loss was below 14% for the reference mix mixed with 5% C3 and C4 tire chips cured for 90 days with curing method M2. Specimen cured for 180 days with curing method M1, the weight loss was observed closer to 14% for the reference mix mixed with 5% C3, C4 tire chips. However, with the change in curing method from M1 to M2, the reference mix mixed with 5% C2, C3, and C4 tire chips has shown weight loss values less than 14%. Hence, it can be concluded that reference mix mixed 5% C2, C3, C4 tire chips can have application for subbase courses in road having light traffic. The fly ash-lime-gypsum composite mixed with treated tire chip satisfy the requirement of unconfined compressive strength as reported by Guleria and Dutta (2011, 2012) for application in subbase courses in road having light traffic. However, other parameters like CBR, permeability need to be studied before the materials are used for the actual field situation. Authors are of the view that as the new composite material contains different waste materials; their use in civil engineering will solve the disposal problems. However, the cost economics needs to be worked out which is beyond the scope of the present study.

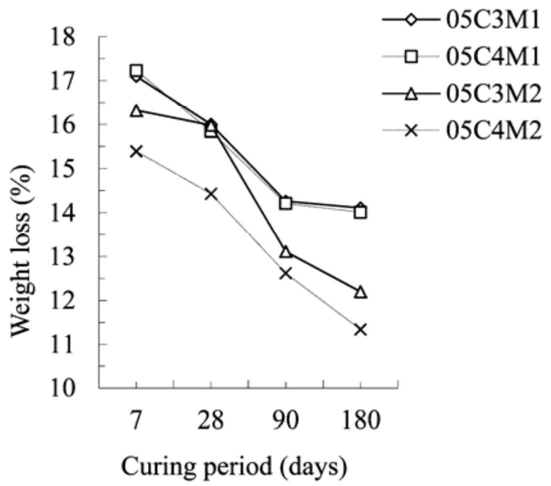


Fig. 10 Variation of weight loss with curing period for the reference mix mixed with 5% C3 and C4 treated tire chips and cured with M1 and M2 curing methods

5. CONCLUSIONS

In the present paper, reference mix containing fly ash + 8% lime + 0.9% gypsum was mixed with the C1, C2, C3, and C4 tire chips. The tire chip content was varied from 5% to 15% and the specimens were cured for 7 to 180 days by two different curing methods (in a dessicator at room temperature and in water filled container having a provision of inflow and out flow). Further, on the basis of results presented, the following conclusions can be drawn.

1. The weight loss of the reference mix mixed with C1 tire chips can be decreased with the carbon tetra chloride, sodium hydroxide and water treatment provided on C1 tire chips. The decrease in weight loss was highest with the carbon tetra chloride followed by sodium hydroxide and water.
2. A decrease in weight loss was observed when specimens were cured in water filled container in comparison to curing in dessicator.
3. The weight loss of reference mix mixed with C1, C2, C3, and C4 tire chips decreases with the increase in curing period and the decrease was significant up to 90 days of curing period.
4. The weight loss increased with the increase in C1, C2, C3, and C4 tire chip content (5% to 15%) in the reference mix.
5. Leachate analysis of reference mix with/without dry/treated tire chips has shown a decrease in the leachability of zinc and an increase of calcium, sulfate and iron concentration in comparison to tire chips. Further, no leachability of harmful metals like copper, lead, chromium, cadmium and nickel metals were observed from the leachate solution of tire chips, reference mix with/ without C1, C2, C3, and C4 tire chips.

On the whole, this study has attempted to provide the insight of the effect of C1, C2, C3, and C4 tire chips, curing period and curing methods on the durability of the reference mix containing fly ash + 8% lime + 0.9% gypsum. The results reveal that the durability of the reference mix mixed with C1 tire chips can be significantly improved by providing surface treatment with the carbon tetra chloride, sodium hydroxide and water. The reference mix mixed with treated tire chips can be a good material for use in subbases in road having light traffic. Utilizing some portion of these waste materials in this way will reduce the quantity of the waste that needs to be disposed of. More so the use in this way will be in an environmental friendly manner.

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