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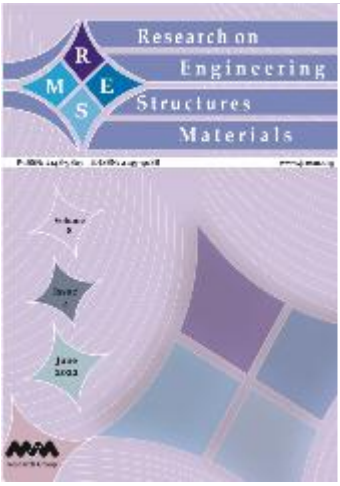

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Research Article

Utilization of textile and tannery sludges in cement mortar

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Abstract

The aim of this study is to investigate the characteristics of Textile ETP and Tannery sludges and strength characteristics of cement-sludge mortar. The textile Effluent Treatment Plant (ETP) and tannery sludges have the potential to become a serious environmental burden for Bangladesh in the future because of their high rate of generation, with a very limited safe disposal option. On the other hand, day by day the demand and price of cement are increasing. This study was devoted to evaluate the technical feasibility of utilizing textile ETP and tannery sludges in cement mortar both as separate and mixed modes. An attempt was taken to replace 5%, 10%, 15% and 20% by weight of cement in mortar with textile ETP and tannery sludges both as a separate and mixed modes. To evaluate the characteristics of the textile ETP and tannery sludges, the pH, moisture content, organic matter content, chemical composition (XRF), TCLP (Heavy Metal) tests were studied. The initial and final setting time, compressive strength, tensile strength, and water absorption of mortar by partial replacement of cement by textile ETP and tannery sludges both as separate and mixed modes were studied to evaluate the properties of cement-sludge mortar. It was found that the textile ETP and tannery sludges both as separate and mixed modes can be a replacement of cement up to 10% in cement mortar and can be used for the purposes of S-type of mortar. The textile ETP sludge as a separate and mixed modes of the sludges can be a replacement of cement up to 20% and can be used for the purposes of N-type of mortar.

1. Introduction

Cement mortar is a hardening material used to bind building blocks such as stones, bricks, and concrete masonry units together which is developed by mixing cement, sand, and water. Mainly sand and binding materials are responsible for the strength and durability of the mortar. Cement mortars are used for plastering the exposed surface of masonry and one of the largest used materials in the construction industry of Bangladesh. The consumption rate of cement mortar in Bangladesh is rapidly increasing due to the construction boom. As the cost of construction materials, especially cement is gradually increasing day by day, therefore, a cheaper solution for cement mortar is required. The Textile and clothing industry have a large contribution to Bangladesh's economy. In 2002, the total commodities exported by Bangladesh out of which 77% was textile clothing and ready-made garments (RMG) [1]. Everyday textile industries in Bangladesh generate around 2.82 million m^3 wastewater, which generates 1.14 kg of solid sludge per m^3 of wastewater [2].

Similar to the textile, the leather industry also produces a huge amount of wastewater and solid waste, which is known as tannery waste [3]. Normally 100-150 kg of sludge is created

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after processing per ton of hides/skins [4]. The government of Bangladesh established a large Common Effluent Treatment Plant (CETP), to treat the wastewater generated from this industry which is situated in BSCIC Tannery Industrial Estate, Hemayetpur. BSCIC Tannery Industrial Estate's CETP also generates approximately 20,000 m^3 of tannery effluent and 232 tons of solid waste per day [5].

Based on the discussion above, this is evident that both industries have a very high sludge generation rate. Several options are available to manage these sludges. In Bangladesh, landfill is the only option to manage these sludges, however, landfill has serious adverse environmental effect and there is also scarcity of land. Therefore, it is required to find an alternate path to consume these sludges to save the environment from pollution and recycling could be a promising way. Both sludges can be used in making concrete block, preparing brick, generating biogas, and can also be used for composting [6 ,7]. Balasubramania et al. [8] explored the possibility of using textile ETP in different non-structural building materials such as flooring titles, hollow bricks, solid bricks etc. It was concluded that cement in these building materials can be replaced up to a quantity of 30% by the textile ETP. The chemical sludge generated from the treatment of textile dyeing wastewater was reused in cement blocks as a partial replacement of cement by Patel and Pandey [9]. It was shown that the compressive strength of the cement decreases as the proportion of the sludge increases. The structural and non-structural application by partial substitution of concrete by fly ash up to 30%, and ETP sludge was replaced by fine aggregate up to 20% by Mariappan et al. [10]. The research found that ETP sludge-based concrete performs and fulfills the basic properties of conventional concrete and addition of textile sludge more than 20% reduces the strength of the block noticeably. Goyal et al. [11] investigated the effect of replacement of cement by textile sludge on the properties of mortar and paste. Cement was replaced by textile sludge up to 20% by weight. Results indicated no adverse effect of introducing textile sludge in place of cement up to 5% replacement level. However, there was a considerable loss in strength for higher replacement levels. Jeevanandam et al. [12] reused textile effluent treatment plant (ETP) sludge in substituting cement in conventional cement mortar. Cement in the mortar was replaced by sludge from 0% to 60% with an interval of 10%. They concluded that textile ETP sludge has a potential to be reused up to 20% replacement of cement in cement mortar and can be used as construction materials of different applications. An attempt was taken to investigate the behavior of concrete and its mechanical properties with replacement of cement with textile sludge by Arul et al. [13]. From their experimental investigations, it was found that there is a possibility of utilization of textile industry sludge up to 15% without adding any admixtures.

Similar to the aforementioned works, a group of other researchers focused on tannery sludge to replace cement in various civil engineering applications. Juel et al. [14] prepared clay bricks with different proportions of sludge varying between 10% to 40% by dry weight in both laboratory-controlled and field conditions. The applicability of sludge brick was assessed based on their mechanical and physical properties. Results from that study indicated that it is possible to produce good quality bricks by incorporating tannery sludge that can satisfy all the required mechanical and physical properties as per ASTM and BDS standards. The utilization of tannery sludge by producing a ceramic product was explored by Basegio et al. [15]. The tannery sludge and clay were mixed together in different proportions, and the quality of the ceramic product was characterized in terms of water absorption, porosity, linear shrinkage and transverse rupture strength. Their experimental investigation concluded that in a ceramic product, 10% tannery sludge can be used safely. Malaiskiene et al. [16] recycled tannery sludge in cement mortar for partial replacement of cement by weight. The percentage of cement replacement by the tannery sludge was gradually varied from 3–12%. Results of their study indicated that it is feasible to use tannery sludge in construction mortars by replacing 6% of cement. In addition to the tannery and textile sludges, other researchers devoted their studies to other types of sludges as well. For example, Brotons et al. [17] and Mandlik and Karale [18] utilized sewage sludge; Ching et al. [19] and Kaish et al. [20] explored the possibility of using alum sludge; Allam et al. [21] used granite sludge, Lima and Zulanas [22] utilized hazardous sludge and Ahmad et al. [23] utilized wastepaper sludge in various cementitious products.

From the above works, it is evident that both the textile ETP and tannery sludges have potential to utilize in civil construction, however, a very limited studies were carried out for partial replacement of cement in mortar. Further, from above studies this is not possible to recommend an optimum value for the sludges available in Bangladesh to replacement cement in mortar as the properties of Bangladeshi sludges could be different from other countries. Therefore, further studies are required based on the textile and tannery sludges available in Bangladesh as a partial replacement of cement in mortar to find an optimum percentage of cement replacement in mortar. Furthermore, this is also necessary to know when the textile and tannery sludges are used in combine mode to partially replace the cement in mortar, how the results differ from the separate mode (only textile or tannery sludge). This kind of mixed mode usage of sludges to replace cement in mortar is also absent in past investigations. Knowing their effect on cement mortar performance will give great flexibility to the users i.e., where there is scarcity of one type of sludge, they can combine the textile and tannery sludges to replace the cement partially in mortar. Therefore, the aim of this study is to utilize the textile ETP and tannery sludges in cement mortar to replace cement partially both as a separate and mixed modes.

2. Working Procedure

The textile ETP sludge was collected from an effluent treatment plant known as Integrated Textile Resources Ltd. (Network Group) and the tannery sludge sample was collected from the Common Effluent Treatment Plant (CETP) of BSCIC Tannery Industrial Estate (Fig. 1). Portland composite cement (PCC) (Type II) and river sand were used in the experimental tests. The textile ETP and tannery sludges were oven dried for 24 hours at 105° C. After 24-hours heating, the color of the textile ETP sludge remained the same, yet the color of the tannery sludge changed to ash color from the black (Fig. 2). Then the oven dried sludges were hammered and turned into powder so that it can be mixed with the mortar (Fig. 3). The characteristics of textile and tannery sludges were evaluated using several experimental tests, it includes the moisture content and pH of the sludges (both as separate and mixed modes) (Fig. 4). The Organic Matter Content, Chemical Composition, and TCLP (Heavy Metal) tests were also carried out for the textile ETP and tannery sludges in combine mode.

(a) Textile sludge dumping zone

(b) Tannery sludge dumping zone

Fig. 1 Dumping zones of textile and tannery sludges

(a) Colour of textile ETP sludge before oven dry

(b) Colour of textile ETP sludge after oven dry

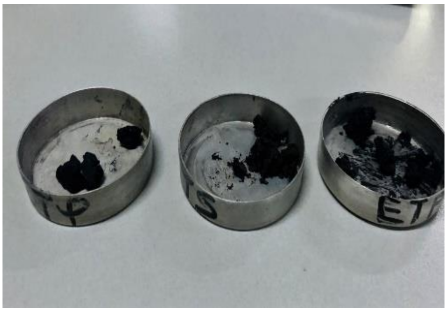
(c) Colour of tannery sludge before oven dry

(d) Colour of tannery sludge after oven dry

Fig. 2 Colour of textile ETP and tannery sample before and after the oven dry process

Fig. 3 Hammering of oven dry sludge to make it powder

The cement and sand that were used to prepare the mortar, all the basic tests such normal consistency of cement and sieve analysis of sand were carried out. Three different types of cement mortar with sludges were prepared as summarized in Table 1. The basic ratio for cement and sand were set to 1:2.75 and a water-cement ratio was set to 0.485 by following the guideline of ASTM C109 and C307. The portion of the cement was gradually replaced by the sludges by weight. For all three types of mortar, the cement was replaced by weight of sludge for 5%, 10%, 15% and 20%. Around 72 cement mortar cubes and 36 briquet samples of sludge-cement-sand mixture of varying proportion (5%, 10%, 15%, 20%, replacement by weight) was prepared (Fig. 4). To quantify the quality of the cement-sludge mortar, the initial and final setting time, compressive strength, tensile strength and water absorption tests were carried out by following appropriate codes and standards (Fig. 4).



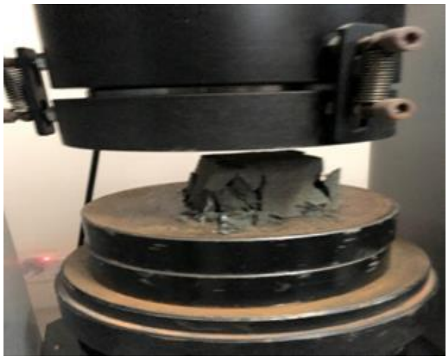
(a) Moisture content test

(b) pH determination

(c) Cement-sludge mortar preparation

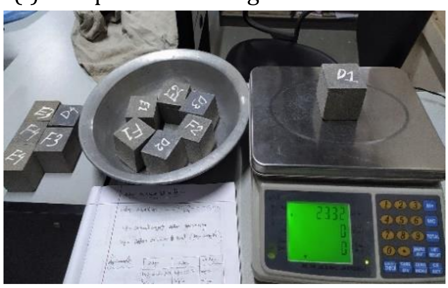
(d) Mortar cubes and briquet under water curing

(e) Initial and final setting time test



(f) Compressive strength test of mortar

(g) Tensile strength test of mortar



(h) Water absorption test

Fig. 4 Testing of Cement-Sludge mortar

3. Results and Discussion

3.1. Characteristics of Textile ETP and Tannery Sludges

3.1.1 Moisture Content and pH

The moisture content and pH for textile ETP and tannery sludges were determined both as separate and mixed modes. The moisture content test was conducted based on ASTM

Table 1. Composition of Cement Mortar

Sludge Used	Materials Used	0% Replacement by Weight (kg/m³)	5% Replacement by Weight (kg/m³)	10% Replacement by Weight (kg/m³)	15% Replacement by Weight (kg/m³)	20% Replacement by Weight (kg/m³)
Textile ETP Sludge (TETPS)	Cement	384.00	365.00	345.50	326.00	307.00
	Sand	1170.00	1170.00	1170.00	1170.00	1170.00
	Water	187.00	187.00	187.00	187.00	187.00
	TETPS	0.00	19.00	38.50	58.00	77.00
Tannery Sludge (TS)	Cement	384.00	365.00	345.50	326.00	307.00
	Sand	1170.00	1170.00	1170.00	1170.00	1170.00
	Water	187.00	187.00	187.00	187.00	187.00
	TS	0.00	19.00	38.50	58.00	77.00
Textile ETP Sludge (TETPS) + Tannery Sludge (TS)	Cement	384.00	365.00	345.50	326.00	307.00
	Sand	1170.00	1170.00	1170.00	1170.00	1170.00
	Water	187.00	187.00	187.00	187.00	187.00
	TETPS	0.00	9.50	19.25	29.00	38.50
	TS	0.00	9.50	19.25	29.00	38.50

D2216 standard and the electrometric method was used to carry out pH test. For moisture content test, 2.5 gm sample was taken for separate and mixed modes (for mixed mode 50% of each sludge was mixed). The moisture contents of raw textile ETP and tannery sludges in separate mode were 59% and 67%, respectively, whereas in mixed mode it was 64%. The pH of dry textile ETP sludge was 6.07 at a temperature 27.7° C. Therefore, it can be classified as acidic. The dry tannery sludge had a pH value of 8.10 at 28° C, which seems that the dry tannery sludge is basic. The pH in mixed mode of textile ETP and tannery sludges was 6.98 at a temperature of 27.1° C. Therefore, the sludges in the mixed mode can be classified as neutral.

Table 2. Chemical Composition of a Mixed Mode of Textile ETP and Tannery Sludge

Analyte	Sludge Sample Result (%)	Expected concentration for Portland Composite Cement (PCC) According to (Md. Alhaz Uddin, et al., 2013)
CaO	33.0355	64.82
SiO_2	13.6849	20.60
Cr_2O_3	10.7118	-
Al_2O_3	10.2913	4.74
TiO_2	8.4906	-
MgO	7.0763	1.84
SO_3	5.8915	2.4
Fe_2O_3	4.7440	3.28
Na_2O	2.1392	0.21
P_2O_5	1.4806	-
Cl	0.9586	-
ZnO	0.7905	-
K_2O	0.5052	0.38
ZrO_2	0.1189	-
SrO	0.0811	-
LOI	-	1.73

3.1.2. Organic Matter Content and Chemical Composition

The organic matter content in the mixed mode of textile ETP and tannery sludge was found 53.76% based on the dry combustion method. The chemical composition of mixed mode of textile ETP and tannery sludges was determined using X-Ray Fluorescence (XRF-1800, Shimadzu) method. The chemical composition results of the combined textile ETP and tannery sludges were summarized as percentage of major oxides as shown in Table 2. The expected concentration [24] of oxide components for Portland Composite Cement (PCC) was also compared in Table 2. It was found that the slurry in mixed mode has similar chemical components as the Portland composite cement (PCC) yet the proportion is different.

3.1.3. TCLP Test (Heavy Metal Determination)

Toxicity Characteristics Leaching Procedure (TCLP) test results of the combined textile ETP and tannery sludges are shown in Table 3. As can be seen the concentration of all the metals in the sludge is lower than the USEPA guideline values which indicates the lower risk of surface and ground water pollution and less hazardous.

Table 3. Heavy Metals of a Mixed Mode of Textile ETP and Tannery Sludge

	Heavy Metal Concentration (mg/L)							
	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Sludge Sample	0	0	0.726	0	0	3.86	0.039	2.33
USEPA Guideline Values	5	1	5	-	0.2	-	5	150

From the above TCLP test results, it can be concluded that the textile ETP and tannery sludges both as separate and mixed modes can be incorporated in cement mortar and at the end-of-life cycle, this mortar waste will not cause any environmental hazard.

3.2. Characteristics of Cement-Sludge Mortar

3.2.1. Initial and Final Setting Time

The initial and final setting time of sludge-cement mortar where cement was replaced by 5%, 10%, 15%, and 20% textile ETP and tannery sludges as separate and mixed modes. The normal consistency of cement was 30% which is within the recommended value of 22 to 30 percent by weight of dry cement according to ASTM C187 for 10 mm penetration. According to ASTM C150, the minimum initial setting time for Portland composite cement has to be 45 minutes and the final setting time should be lower than 375 minutes.

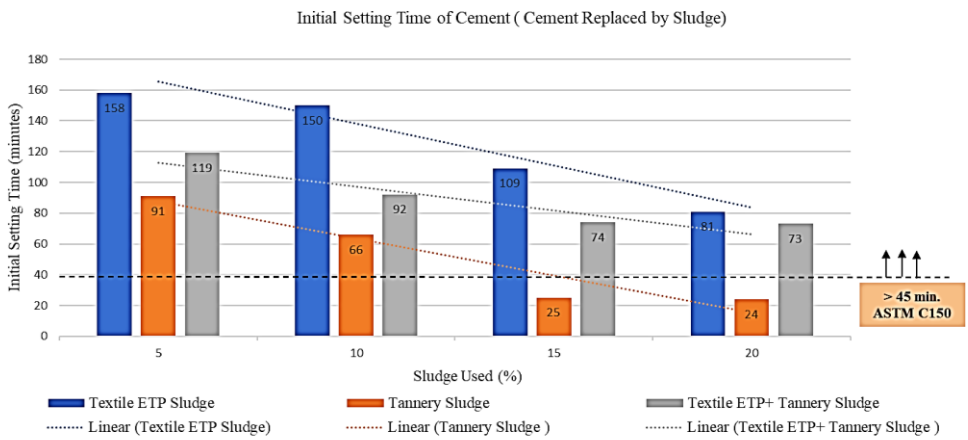


Fig. 5 Initial setting time of cement-sludge mortar

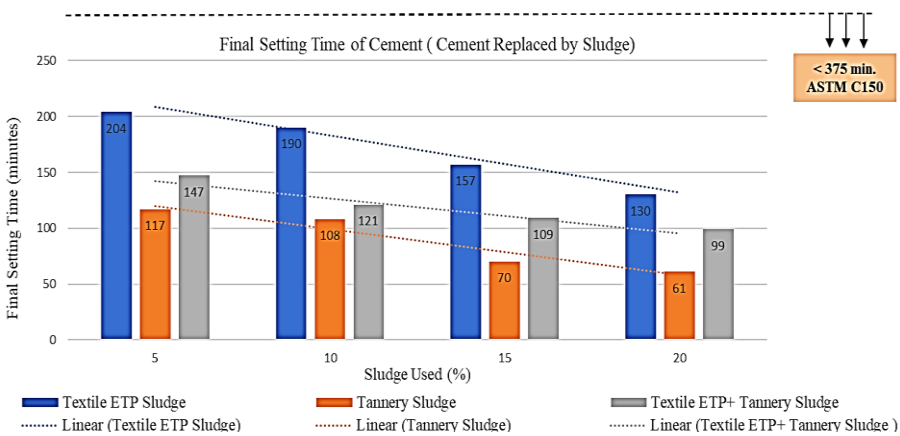


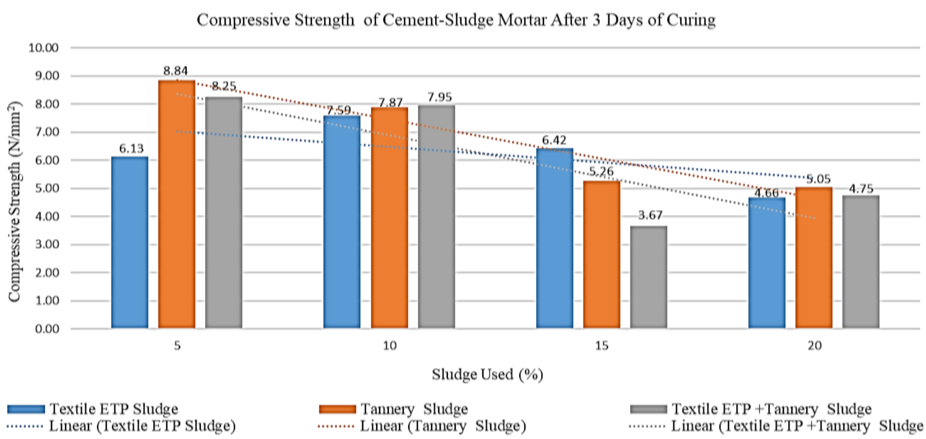
Fig. 6 Final setting time of cement-sludge mortar

The initial setting time results of cement-sludge mortars are plotted in Fig. 5. It was found that the initial setting time of cement-sludge mortars decreases when the amount of sludge inclusion increases. Similar findings were also reported by Goyal et a. [11] and Jeevandam et al. [12]. The initial setting time of cement-sludge mortars with 15% and 20% replacement of cement by tannery sludge are settling earlier than the ASTM standard recommended value. However, for other cases, the cement-sludge mortar's initial setting time is more than the ASTM standard recommended value. In the case of final setting time, it can be seen that the final setting times of cement-sludge mortars are also decreasing with the increase in sludge inclusion as shown in Fig. 6. As can be seen, all the sludge mortar has a final setting time less than 375 minutes and following the ASTM standard.

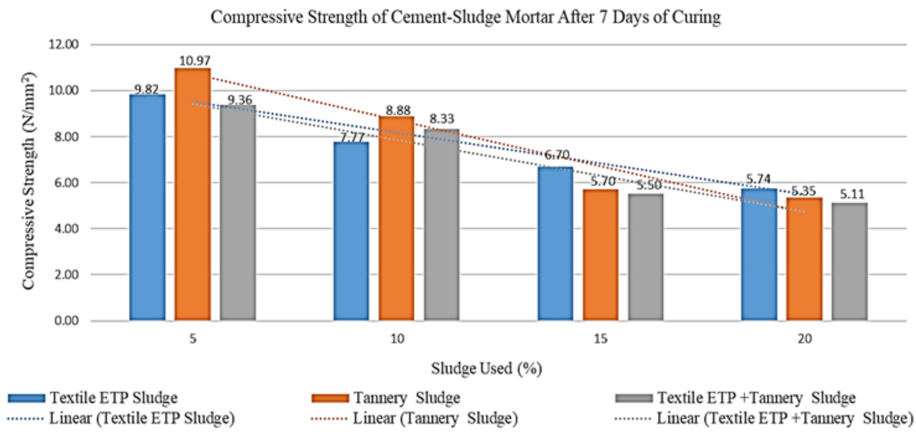
3.2.2. Compressive and Tensile Strength of Cement-Sludge Mortar

The 3 days, 7 days and 28 days compressive strengths of cement-sludge mortars are summarized in Fig. 7. From the plot, it is evident that the compressive strength of the cement-sludge mortar decreases with the increase in sludge amount in the mortar which has good agreement with earlier findings [13,16]. According to ASTM C270-14a, the S-type and N-type of mortar should have a minimum compressive strength of 1800 Psi or 12.4 N/mm^2 and 750 Psi or 5.2 N/mm^2 at 28 days, respectively. The 5% and 10% replacement of cement with the textile ETP and tannery sludges both as separate and mixed modes have more than 1800 Psi or 12.4 N/mm^2 compressive strength at 28 days which fulfils the requirement of S-type of cement mortar. For higher percentage of replacement (15% and 20% cases), the cement-sludge mortar fulfils the requirement of N-type mortar. Therefore, the textile ETP and tannery sludges can be utilized in cement-sludge mortar by replacing 5% and 10% of cement in mortar by its weight to produce code recommended S-type of mortar. However, with a higher percentage, the cement-sludge mortar can be used to produce N-type of mortar.

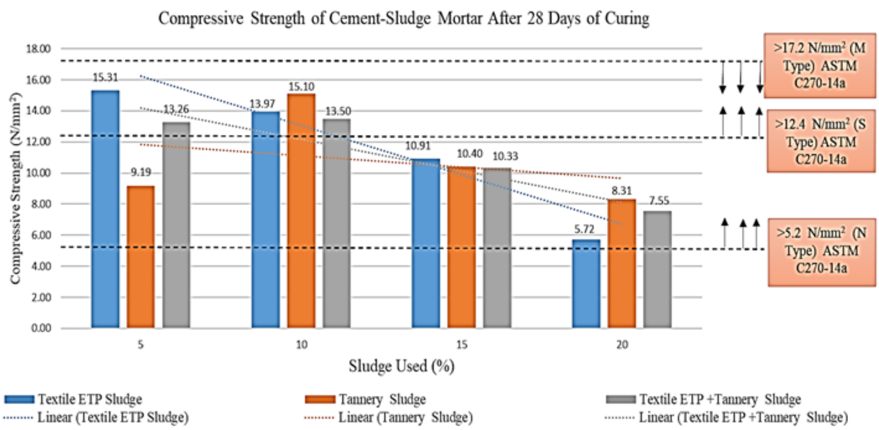
According to ASTM 307-03, usually cement mortar doesn't experience any tension during its service life and tension test is not recommended for mortar, therefore, lower or higher tension will not produce any impact on mortar during its service life. The tensile strength of cement mortar is tested only for research purposes and further information by following the ASTM C307-03 standard. The 3 days, 7days, and 28 days tensile strengths of cement-sludge mortar are plotted in Fig. 8. The tensile strength of cement-sludge mortar decreases with the increase in sludge amount in the mortar. As compared to the textile ETP sludge, the tannery sludge mortar has comparatively lower tensile strength.



(a) Compressive strength of prepared samples after 3 days of curing

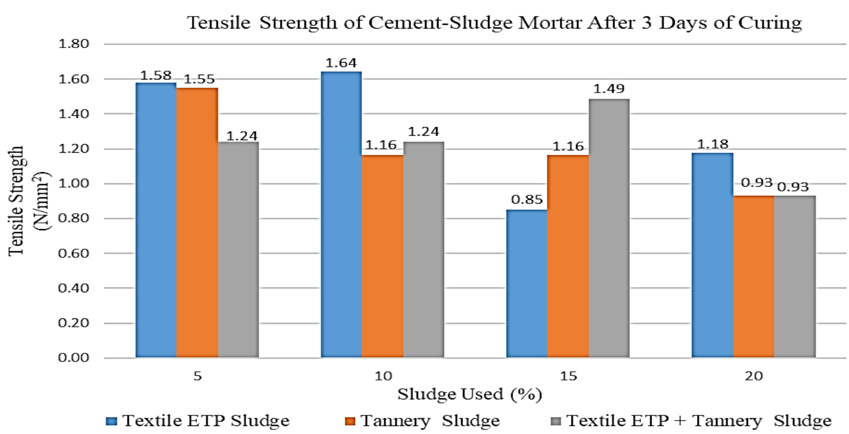


(b) Compressive strength of prepared samples after 7 days of curing

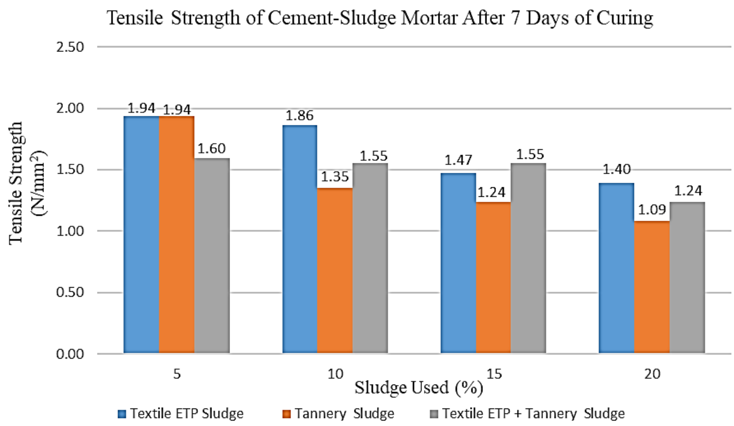


(c) Compressive strength of prepared samples after 28 days of curing

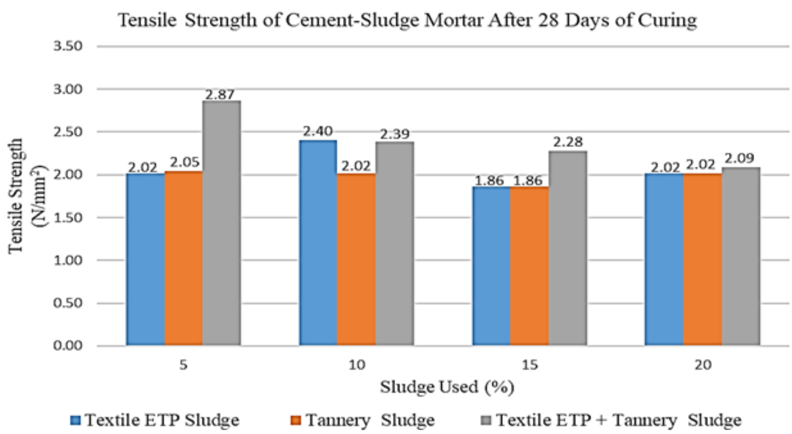
Fig. 7 Compressive Strength test of Cement-Sludge Mortar



(a) Tensile strength of prepared samples after 3 days of curing



(b) Tensile strength of prepared samples after 7 days of curing



(c) Tensile strength of prepared samples after 28 days of curing

Fig. 8 Tensile Strength test of Cement-Sludge Mortar

3.2.3. Water Absorption Capacity of Cement-Sludge Mortar

The water absorption test of cement-sludge mortar was carried out only for 28 days cured mortar. The water absorption values of cement-sludge mortar are shown in Fig. 9. In general, the water absorption quantity gradually decreases with the increase in sludge quantity in the mortar. In addition to that, textile sludge mortar absorbs more water than the tannery sludge-mortar. Though there is no recommended value for water absorption quantity of cement mortar, however, a good mortar should have a water absorption capacity less than 10%. In the present study, all the cement-sludge mortars have a water absorption capacity less than or very close to the desired value of 10%.

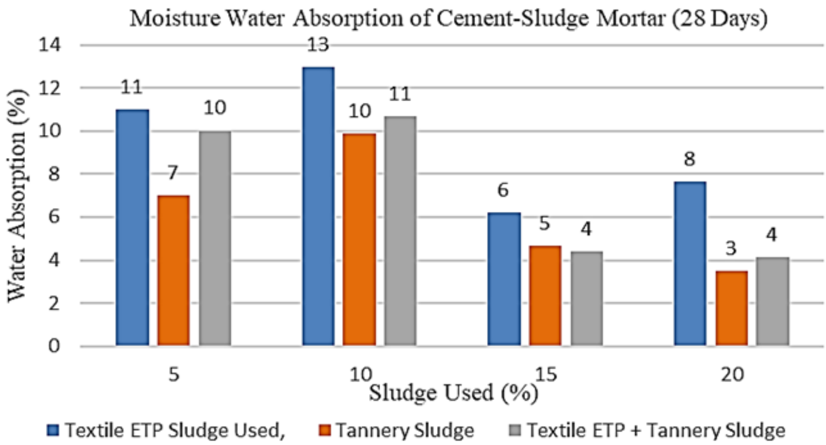


Fig. 9 Water absorption of cement-sludge mortar

4. Conclusions

In this study, textile ETP and tannery sludges are utilized in cement mortar as a partial replacement of cement. Important physical and chemical tests of sludges were carried out. The cement mortars were prepared by replacing 5%, 10%, 15% and 20% (by dry weight) of cement by textile and tannery sludges both as separate and mixed modes and the performance of sludge-cement mortars were evaluated.

The major findings of this study are follows:

- Based on the pH value, the dry textile ETP and tannery sludges can be classified as acidic and basic, respectively. However, in mixed mode, the sludge becomes neutral. The organic matter content percentage in the mixed mode of textile ETP and tannery sludges is 53.76%. The combined mode of textile ETP and tannery sludges has a chemical composition, similar to the Portland Composite Cement (PCC) with different quantities. The heavy metals concentration like As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn in the combined mode of sludges are also within the allowable limit as per the guideline of USEPA. Therefore, the textile ETP and tannery sludges can be utilized safely in cement mortar for partial replacement of cement due to its less hazardous behavior.
- The addition of sludge, in general decreases both the initial and final setting time of cement-sludge mortar and the tannery sludge-cement mortar has comparatively lesser initial and final setting time. The initial setting times for all the cement-sludge mortars both as separate and mixed modes were more than 45 minutes, except for 15% and 20% replacement of cement by tannery sludge cases. In case of final setting time, for any value of cement replacement, the cement-sludge mortar had final setting time less than the codal recommendation.
- Textile ETP and tannery sludges both as separate and mixed modes, up to 10% replacement of cement, fulfilled the compressive strength requirement at 28 days for S type of mortar which can be used for masonry structures with normal to moderate loading such as foundation walls, manholes, sewers, and pavements walks etc. Up to 20% partial replacement of cement by the textile ETP and tannery sludges both as separate and mixed modes fulfilled the compressive strength requirement at 28 days for N-type of mortar which can be utilized for unimportant masonry structures such as partition and parapet walls. For all the cement-sludge mortars, both as separate and mixed modes, the water absorption capacity was near about or less than 10%.

Finally, it can be said that textile ETP and tannery sludges are safe to use in cement mortar and a combination of textile ETP and tannery sludges has better performances as compared to the separate cases in all aspects.

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