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# Utilization of Textile Effluent Treatment Plant Sludge as Supplementary Cementitious Material in Concrete

**M. Mottakin[1], M. M. Hossain[2], S. D. Datta[3]**

[1]Department of Building Engineering and Construction Management, Khulna University of Engineering and Technology, Bangladesh (shahriarmottakin5441@gmail.com)
[2]Department of Building Engineering and Construction Management, Khulna University of Engineering and Technology, Bangladesh (mehrabhossain@becm.kuet.ac.bd)
[3]Department of Building Engineering and Construction Management, Khulna University of Engineering and Technology, Bangladesh (sd.datta@becm.kuet.ac.bd)

## Abstract

With a growing interest in recycling and reusing waste, research is needed to explore ways to transform industrial waste into construction materials. This study explores the potential utilization of textile effluent treatment plant (ETP) sludge as a supplementary cementitious material (SCM) in concrete. The goal of this study was to evaluate the fresh and hardened properties of concrete to find the optimal percentage of textile ETP sludge (TES) in concrete. In this investigation, five concrete mixtures were prepared by substituting up to 20% of the cement with TES by weight. The effect of TES in fresh concrete was investigated by the slump test. In addition, hardened properties were assessed through the compressive and splitting tensile strength tests. The test findings showed that as the amount of TES increased, the workability and hardened properties decreased compared to the control mix. Furthermore, up to 10% ETP sludge substitution showed nearly the same strength as the control mix, but after 10%, the strength started to decline at a faster rate. After assessing all of the results, it was found that supplementing 5% ETP sludge with cement yields the most favorable results and can be utilized in concrete to reduce adverse environmental impacts.

***Keywords:*** *ETP sludge; Supplementary cementitious material; Concrete; Textile industry; Compressive strength*.

## 1 Introduction

Concrete has long been acknowledged as the most widely used material in the construction sector. The production of concrete involves the use of large amounts of raw materials, resulting in substantial energy consumption and environmental contamination. Cement is a vital ingredient required for the production of concrete; however, its manufacturing process generates substantial carbon dioxide ($CO_2$) emissions that contaminate the environment. It has been estimated that the manufacturing of one ton of ordinary Portland cement (OPC) contributes to the discharge of around one ton of $CO_2$, contributing to 5-7% of global carbon emissions and causing environmental degradation (Hasan et al., 2022). Researchers are exploring alternatives or partial replacements for OPC due to the growing environmental concerns associated with its production (Ahmad et al., 2022; Goyal et al., 2019; Hasan et al., 2022).

On the other hand, Bangladesh's textile industry has been a driving force in the country's rapid industrialization over the last two decades. Anwar et al. predicted that textile ETPs produced 36,000 metric tons of sludge in 2012 (Anwar et al., 2018). In 2016, sludge deposits from total suspended solids amounted to 49,442 metric tons and were anticipated to nearly reach 80,000 metric tons by 2021 solely from the textile industries (Hossain et al., 2018). This sludge is extremely harmful to the environment. The majority of textile industries now dump their sludge in landfills; therefore, reusing it as SCM would be a unique and novel approach. The goal of this study was to optimize the use of TES in order to address environmental concerns and create a sustainable alternative to cement.

## 2 Experimental Design

Figure 1 depicts the sequence of activities followed in this investigation. In this study, the concrete specimens were produced using Type 1 cement, also known as OPC, in accordance with the specifications specified in BDS-EN-197-1 (CEN, 2011). In addition, powdered TES was used as a supplementary binding material in this study. TES was obtained from Zaber & Zubair Fabrics Ltd. in Tongi, Gazipur, Bangladesh. The TES sample preparation involved several steps. Initially, it was manually ground and air-dried for 3 to 4 days. Then, the TES sample was dried in an oven for one day at 105°C. After that, it cooled to room temperature. Next, the sample was subjected to the Los Angeles Abrasion Test machine, where it was crushed. After crushing, the resulting powdery material was passed through the No. 200 sieve, and the portion of the material that was successful in getting through the sieve was chosen for use as SCM, as shown in Figure 2. The X-ray fluorescence (XRF) analysis of TES reveals that it contains approximately 33.33% CaO, whereas OPC contains 66.89% CaO, which serves as the primary binding component of cement. Furthermore, XRF analysis determined that TES exhibits a 37.4% loss on ignition (LOI). In this study, crushed stone chips collected from local sources were used for the coarse aggregate. The maximum size of the stone chips used was 19 mm. The fine aggregate employed in this investigation was naturally washed river sand taken from Sylhet, Bangladesh, with particle sizes not larger than 4.75 mm. All concrete mixes were prepared using fresh water with a pH of 7.34.

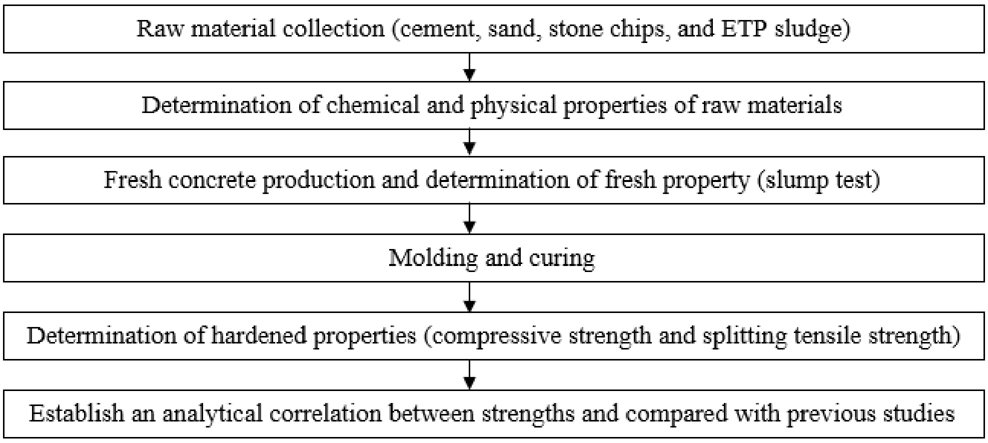

Figure 1. Sequence of activities followed in this investigation.

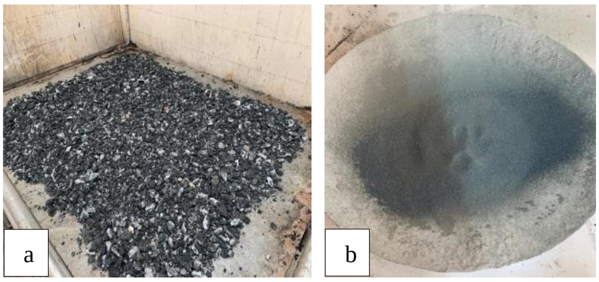

Figure 2. (a) TES at drying sludge bed; (b) TES powder after sieve.

The mix design was carried out in accordance with ACI 211.1 (ACI, 1991). The ratios of binder, fine, and coarse aggregate in the mixes were 1:1.66:2.10, and the ratio of water to binder was 0.32. In order to conduct this research, five different concrete mixtures were prepared in the laboratory. The initial mix, referred to as the control mix, was prepared using a traditional mix design and did not contain any TES. This mixture is denoted as TES00 for the purpose of this investigation. The other four mixtures, labeled TES05, TES10, TES15, and TES20, respectively, replaced 5%, 10%, 15%, and 20% of the cement with TES. All concrete mixtures in this study were made as 100 mm dia. × 200 mm height cylindrical samples. The slump test was carried out following ASTM C143 (ASTM, 2015) to evaluate the workability of fresh concrete. Then, the specimens were water-cured for 7 and 28 days. A curing environment with 25 ± 3°C and 78 ± 5% relative humidity was presented in the lab. At 7 and 28 days, uniaxial compressive strength and splitting tensile strength tests were evaluated on the cured specimens to find out the hardened properties of TES concrete in accordance with ASTM C39 (ASTM, 2011) and ASTM C496 (ASTM, 2007), respectively. Figure 3 shows the instrument set-up for the slump, compressive, and tensile strength tests.

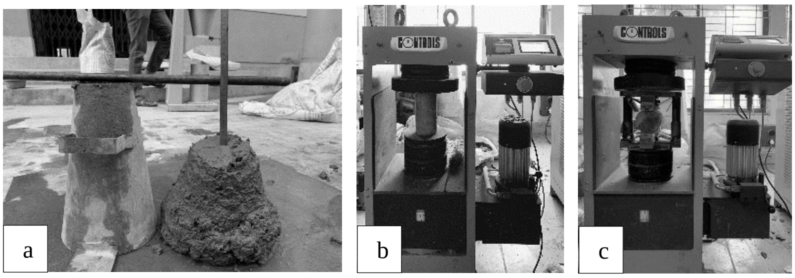

Figure 3. (a) Slump test; (b) compressive strength test; and (c) splitting tensile strength test.

## 3 Results and Discussion

### 3.1 Slump

Figure 4 illustrates the slump values of all concrete mixes. It is observed from the test results that as the TES concentration increased, the slump value decreased. The slump value of the control mix was measured to be 110 mm, while the slump of TES05 was measured to be around 101 mm, which is 9 mm less than the control mix. In addition, the slump values for concrete containing 10%, 15%, and 20% TES were also lower than the control mix, with values of 92 mm, 72 mm, and 67.67 mm, respectively. Other investigations have also observed a similar tendency to reduce the slump by incorporating TES (Jahagirdar et al., 2023; Kaur et al., 2017; Kulkarni et al., 2012). Kaur et al. (2017) observed that the slump value decreased from 95 mm in the control mix to 70 mm when replacing cement with 35% textile sludge, leading to the conclusion that beyond a 35% replacement, there is no proper bonding between the materials (Kaur et al., 2017). In this investigation, slump test results indicate that TES has the potential to be employed as SCM in concrete, with up to 10% cement replacement, without significantly affecting the mixture's workability.

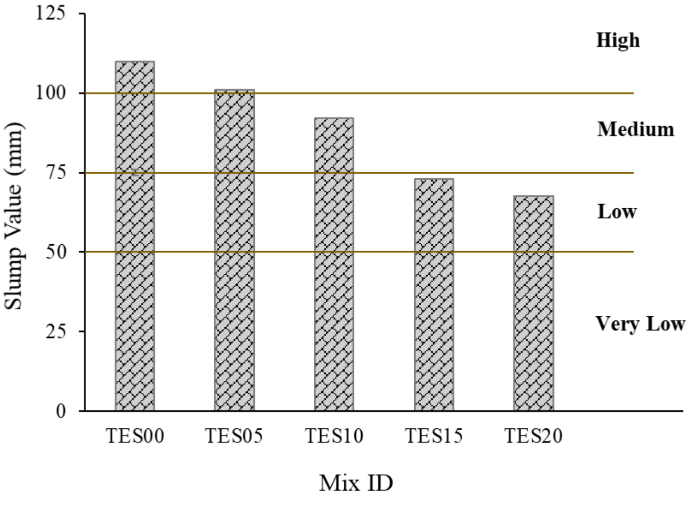

Figure 4. Effects of TES on slump values.

### 3.2 Compressive Strength

Figure 5 depicts the compressive strength and the normalized compressive strength of concrete specimens incorporating different concentrations of TES. The compressive strength of TES20 was observed to be a minimum of 17.28 MPa at 7 days, while TES00 showed a maximum strength of 25.44 MPa. Similarly, at 28 days, TES20 exhibited the lowest compressive strength of 23.12 MPa, whereas TES00 showed the highest strength of 33.92 MPa. The compressive strength exhibited a decrease as the proportion of TES increased up to 10%. After that point, the inclusion of TES resulted in a significant decrease. Among all the substituted concrete mixes, the TES05 mix exhibited the highest compressive strength, reaching 23.28 MPa at 7 days and 31.33 MPa at 28 days. It is consistent with previous investigations that the addition of TES reduces compressive strength (Goyal et al., 2019; Sandesh et al., 2014). A study found that at 28 days, the compressive strengths of mixes with 5%, 10%, 15%, and 20% TES were equivalent to 97%, 90.033%, 83.58%, and 66.19% of the control mix, respectively (Goyal et al., 2019). As the replacement levels of TES increase, the amount of calcium silicate hydrate (C-S-H) formed decreases, which results in a lower development of concrete strength. The excessive LOI of TES can be identified as another contributing factor in the deterioration of the compressive strength of specimens that contain a high percentage of TES in their composition. A significant LOI value signifies the existence of organic substances that degrade while mixing or later during hydration, resulting in a decline in the strength of the concrete.

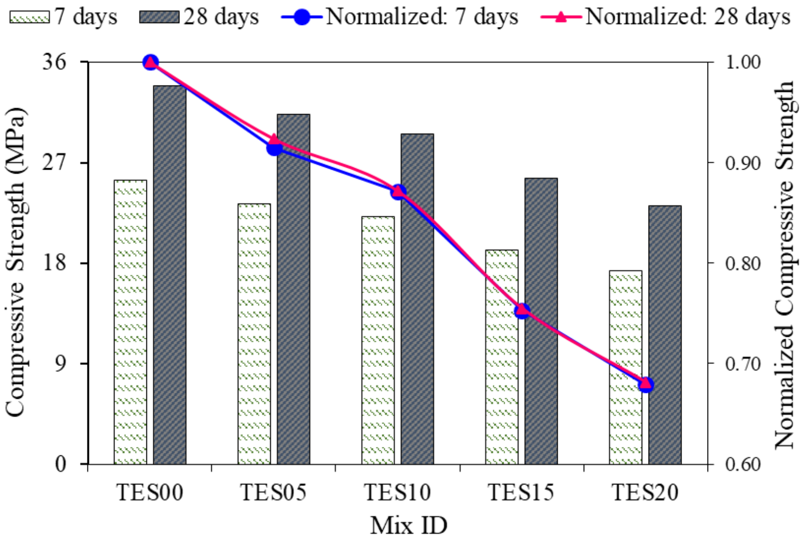

Figure 5. Compressive strength and normalized compressive strength of TES-incorporated concrete mixes.

### 3.3 Splitting Tensile Strength

Similarly, Figure 6 depicts the splitting tensile strength and the normalized splitting tensile strength of test specimens with varying percentages of TES, demonstrating a decline in tensile strength as the proportion of TES increased up to 10%. After that point, the inclusion of TES resulted in a significant decrease. It seemed that the tensile strength of concrete specimens varied between 2.06 MPa and 3.99 MPa at all curing ages. Among all the substituted concrete mixes, the TES05 mix exhibited the highest tensile strength, reaching 2.99 MPa at 7 days and 3.81 MPa at 28 days. It is consistent with the previous investigations that the addition of TES reduces the tensile strength (Arul et al., 2015; Goyal et al., 2019; Sandesh et al., 2014). An investigation observed that the splitting tensile strength of mixes containing 5%, 7%, and 9% TES decreased by 27.6%, 35.1%, and 39.6%, respectively, relative to the reference mix at 28 days (Sandesh et al., 2014). This decrease in splitting tensile strength is related to the increased water absorption and smaller particle size of TES sludge, which may result in weakened interfacial bonds within the concrete matrix as the replacement level increases.

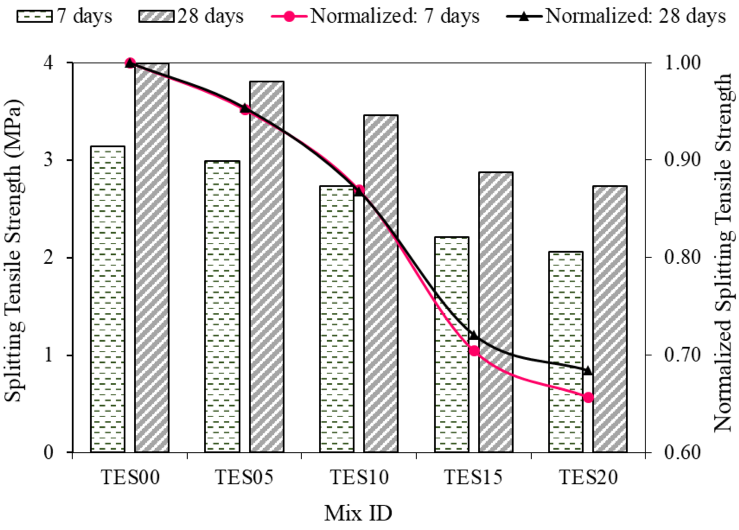

Figure 6. Splitting tensile strength and normalized splitting tensile strength of TES-incorporated concrete mixes.

### 3.4 Analytical Relationship of Strengths

The relationship between the splitting tensile strength and compressive strength of the TES-incorporated concrete specimens is illustrated in Figure 7. In order to conduct a comparative analysis of outcomes, a variety of commonly employed equations derived from multiple standards are utilized. By employing these analytical equations, it is possible to reduce the extensive quantity of laboratory testing. In this study, the anticipated data are computed based on a set of four established standards. ACI 318-11 (ACI, 2011), JSCE-07 (JSCE, 2007), EC-04-Eurocode 2 (Eurocode, 2004), and JCI-08 (JCI, 2008) recommend formulas 1 to 4, respectively, for forecasting the splitting tensile strength based on the compressive strength of concrete mixes.

$$f_{sp} = 0.53\sqrt{f'_c} \tag{1}$$

$$f_{sp} = 0.44\sqrt{f'_c} \tag{2}$$

$$f_{sp} = 0.03\,(f'_c)^{2/3} \tag{3}$$

$$f_{sp} = 0.13\,(f'_c)^{0.85} \tag{4}$$

where $f_{sp}$ = splitting tensile strength and $f'_c$ = compressive strength.

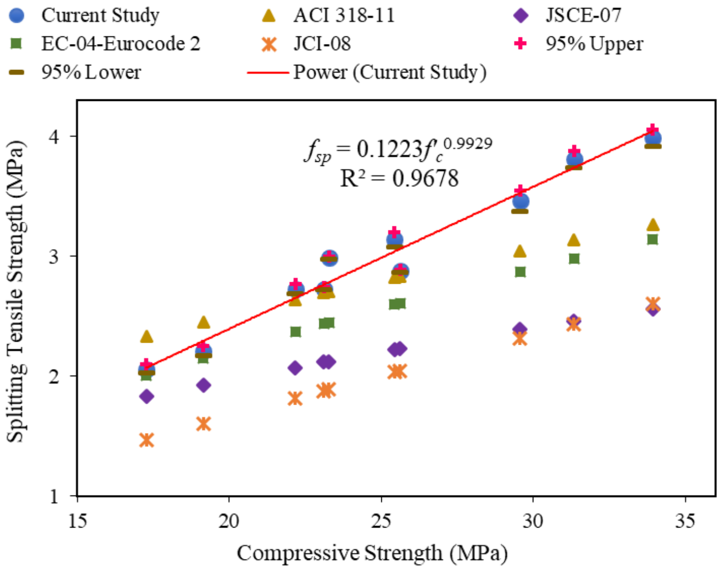

Figure 7. Relationship between the splitting tensile ($f_{sp}$) and compressive strength ($f'_c$) of TES concrete.

According to the data presented in Figure 7, the actual splitting tensile strengths in the experiment are notably higher than the estimated values derived from all applicable standards. It can be noticed that the projected values of ACI 318-11 were the closest to the experimental values, whereas JCI-08 exhibited the greatest significant deviation within the experimental data. The splitting tensile and compressive strength were found to have a significant correlation, with the coefficient of determination ($R^2$) equaling 0.9678. This indicates that linear correlation may explain 96.78% of the mean tensile strength, while the remaining 3.22% is still unexplained. For describing the relationship between splitting tensile ($f_{sp}$) and compressive strength ($f'_c$) of TES-incorporated concrete in this experiment, the following formula is suggested:

$$f_{sp} = 0.1223 \times (f'_c)^{0.9929} \tag{5}$$

### 4 Conclusion

After assessing the results obtained from the slump, compressive, and splitting tensile strength tests conducted on concrete specimens with different proportions of TES, the following conclusions can be made:

- The slump value decreased as the TES concentration increased in the concrete mixture. This suggests that the incorporation of TES lowers the workability of the concrete. Up to 10% substitution of TES for cement had no noteworthy impact on the workability of the composition.
- The concrete specimens with 5% TES achieved the highest compressive strength. At 7 days, the TES05 mix had a compressive strength of 23.28 MPa, which increased to 31.33 MPa at 28 days.
- Likewise, the concrete mixes containing 5% TES exhibited the highest splitting tensile strength. The TES05 mix had splitting tensile strengths of 2.99 MPa and 3.81 MPa at 7 and 28 days, respectively.
- The prediction of the splitting tensile strength on the basis of the compressive strength data demonstrated a satisfactory evaluation, as indicated by the decent regression coefficient observed in the experimental outcomes.

These results suggest that incorporating 5% TES into the concrete mix could provide an optimal balance of strength and workability. It also indicates that TES can be used as a SCM in concrete without substantially degrading the hardened properties of the mixture. However, further research and testing are needed to determine other aspects of TES-based concrete performance, like durability and long-term behavior.

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