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# Effect of Tyre Waste Addition on UCS of Bentonite-Sand and Bentonite-Rock Quarry Dust Mixes

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**Abstract.** The bentonite-sand (B:S) mixes are mostly used as liner/barrier material in the construction of landfills. The sand is mainly obtained from the river banks. The consumption of natural sand is quite high due to its excessive usage in the construction works that leads to its scarcity. To overcome this crisis, the partial or full replacement of sand by the promising geo-material rock quarry dust (Q) can be an economic and effective solution. In this paper, the effect of the full replacement of sand by the waste material rock quarry dust on the unconfined compressive strength (UCS) of B:S mixes at different curing period was studied. Here, the B:S and B:Q mixes were prepared at their corresponding maximum dry density (MDD) and optimum moisture content (OMC). The UCS of all the mixes was evaluated at a curing period of 0, 3, 7 and 14 days. The result indicates that the UCS of B:Q mixes is higher than the UCS of B:S mixes for different curing periods. This study investigates whether the addition of the waste tyre dust (TD) can enhance the UCS of B:S and B:Q mixes at different curing periods. The TD content ranging from 2 to 16% by weight was used as an additive in various B:S and B:Q mixes. The highest UCS value was observed at TD = 14% for both the B:S and B:Q mixes. The UCS of the mixes increased with the increase in the curing period. The failure strain was found to increase with the increase in the tyre dust content in the mixes.

**Keywords**: Bentonite-Sand Mix, Unconfined Compressive Strength, Additives, Curing Period, Effect.

## 1 Introduction

Disposal of hazardous waste is one of the greatest challenges to mankind for all times. With expanded natural contamination and its acknowledgement has prompted the requirement for designed engineered waste management facilities. The B:S mixes are mostly used as a liner/barrier material at the municipal solid waste disposal site and also in the nuclear waste repository. The compacted B:S mixes are mostly used as a liner in a landfill and in vertical cut-off walls because of their less vulnerability to desiccation cracking and frost action [1]. The bentonite has a high content of montmorillonite and is mostly used to achieve low permeability in B:S mixes. It has high swelling capacity which can fill up the voids between sand particles. Moreover, bentonite has high compressibility which is undesirable in most practical purposes. The

B:S mixes provide low compressibility which is offered by sand in the matrix [2]. Apart from permeability, the strength is the important criteria of B:S mixes and is required to evaluate for the design of the liner in the landfill. The UCS test is one of the quickest, cost-effective and simplest tests for determining the compressive strength. The UCS is useful for determining the shear strength of undisturbed and remoulded samples as well as the bearing capacity of the soil [3]. There are many practical situations like in embankments, shallow footings and retaining walls where the UCS test is most appropriate to use. Kolawole et al. (2006) [4] reported that the UCS larger than 200 kPa is most suitable for liner material. It is commonly observed that locally available sand is mixed with bentonite to improve its specific designing qualities like maximum dry density (MDD) [1], shrinkage, shear strength, and thermal conductivity. Sridharan et al. (1986) [5] proposed that 20% of bentonite is adequate to fill the voids made by the sand framework. Hoeks et al. (1987) [6] highlighted that an addition of 12% bentonite can achieve the required hydraulic conductivity of $10^{-9}$ m/s. Mollins et al. (1996) [7] suggested that the bentonite content of 20% is sufficient to fill up the voids in S:B matrix. A decrease in the hydraulic conductivity was observed with increase in the bentonite content, but after 20% bentonite content the decrease in the hydraulic conductivity was marginal [2]. Sand, the mostly used fine aggregate is commonly derived from the river banks. The consumption of natural sand is not only limited to geotechnical and geoenvironmental applications, but also in construction industries. So, there is need of an alternative material in the near future to overcome the scarcity of sand. The rock quarry dust (Q) is a by-product from the rock crushing process. In quarrying process, the parent rock has been crushed into coarse aggregates, during the quarrying process; the fine residue generated is called quarry dust and is mostly found as waste. The disposal of such wastes has become a big topic amongst the researchers. Over the last two decades, there is a rapid rise in the number of motor vehicles across the globe. It is estimated that 0.6 million tonnes of tyre scraps are generated annually across India. Nearly 70% of these waste tyres are thrown in landfill or were illegally dumped [8]. So, the scientific utilization of such waste will be beneficial. Ghazavi and Sakhi (2005) [9] reported an increase in the angle of shearing resistance from 10 to 94% after addition of tyre chip of 15, 30 and 50% by volume to sand. The maximum improvement was obtained for 50% shreds content of size 4×8 cm. Gotteland et al. (2005) [10] reported an increase in the shear strength of soil-tyre crumb for tyre crumb content up to 34% by mass. Marto et al. (2013) [11] found that shear resistance of sand-tyre chips mixture is greater than the sand alone and for optimum tyre mix of 20% the increases in internal friction angle was from 32.8° to 34.2°. Reddy et al. (2016) [12] suggested an optimum of 30-40% tyre chips for a sand-tyre mixes is effective for the backfill material. However, there is not much research work available in the literature related to the effect of tyre dust addition on the UCS of B:S and B:Q mixes. The tyre dust consists of the tyre waste having a range of small particle sizes. As the bentonite shows high swelling and shrinkage behaviour, it is expected that the tyre dust can reduce the amount of desiccation cracks and increase the UCS of the mixes. It can also improve the ductility of the mixes. Therefore, this study investigates the effect of tyre dust addition on the UCS of B:S and B:Q mixes. In the first phase of experiments, the effect of full replacement of sand in B:S mix with rock quarry dust on the UCS and failure strain was studied. In the next phase, the UCS and failure strain of B:S:TD and B:Q:TD mixes were determined and compared to find out the optimum tyre dust content and mix. The study was also done to understand the effect of curing period on the UCS of B:S, B:Q, B:S:TD and B:Q:TD mixes.

## 2 Materials and Methods

Locally available sand (S), rock quarry dust (Q), tyre dust (TD) and commercially available bentonite clay (B) of high compressibility were selected for the study. The sand samples were collected from Kulshi riverbank and rock quarry dust was collected from Patharkuchi crusher unit in Kamrup, Assam, India. The basic tests were conducted as per Indian standard specifications. The Fig. 1 shows the grain size distribution curves of sand, rock quarry dust and tyre dust. It highlights that the percentage of finer particles is greater in rock quarry dust compared to sand. Both the sand and rock quarry dust are poorly graded. Based on the sizes and range, the tyre dust can be classified as tyre crumbs/granulated rubber [13].

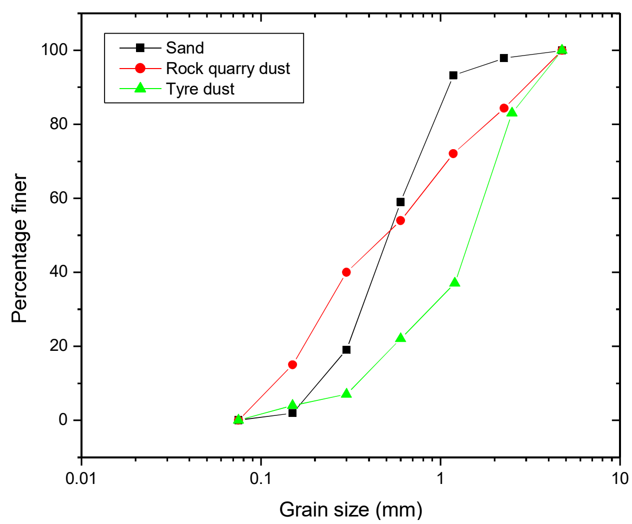


**Fig. 1.** Grain size distribution curves of sand, rock quarry dust and tyre dust.

The IS classification of the samples conforming to IS: 1498-(1970) [14] was done using liquid limit and plasticity index for cohesive samples and based on particle size fractions for cohesion less samples. The Table 1 shows the physical properties and classification of sand, rock quarry dust and bentonite. All the properties were determined using the guidelines of the respective IS codes.

**Table 1.** Physical properties and classification of sand, rock quarry dust and bentonite.

| Property | Sand | Rock quarry dust | Bentonite |
|---|---|---|---|
| Specific gravity, G | 2.67 | 2.72 | 2.65 |
| $D_{10}$ (mm) | 0.22 | 0.095 | - |
| $D_{30}$ (mm) | 0.38 | 0.23 | - |
| $D_{60}$ (mm) | 0.64 | 0.85 | - |
| Coefficient of uniformity, $C_u$ | 2.91 | 8.95 | - |
| Coefficient of curvature, $C_c$ | 1.02 | 0.655 | - |
| Liquid limit, $w_L$ (%) | - | - | 207 |
| Plastic limit, $w_P$ (%) | - | - | 62.5 |
| Plasticity index, PI (%) | NP | NP | 144.5 |
| Swelling index (%) | - | - | 883.3 |
| Classification | SP | SP | CH |

The mineralogical classification of sand and rock quarry dust was done using electron microscope. The shape and mineral characterization of sand and rock quarry dust are listed in Table 2.

**Table 2.** Shape and mineralogical characterization of sand and rock quarry dust minerals.

| Minerals | Sand, S | | Rock quarry dust, Q | |
|---|---|---|---|---|
| | Amount (%) | Shape | Amount (%) | Shape |
| Quartz | >95 | Rounded to subrounded | >65 | Angular to subangular |
| Biotite | 2-3 | Flaky | 3-4 | Flaky |
| Muscovite | 1-2 | Flaky | 1-2 | Rounded, flakey |
| Feldsper | - | - | >25 | Elongated, subangular to angular |
| Hornblende | - | - | >1 | Elongated |
| Rock fragments | <1 | Subangular | >1 | Elongated, subangular |
| Others | <1 | Subrounded | - | - |

The major mineral present in the sand is quartz with rounded to subrounded shape, whereas in rock quarry dust the major mineral is quartz and substantial amount of feldspar is also present and the shape of minerals are angular to subangular.

The experimental investigation was conducted in three phases. In the first phase, the effect of replacement of sand completely by the rock quarry dust on the UCS of the B:S mix was studied. The bentonite content was kept as 30% and sand content as 70% in the mix of B:S and the mix was designated as B30:S70. In the second phase, the effect of tyre dust content on the UCS of B:S and B:Q mixes were investigated to find out the optimum tyre dust content for a particular curing period of the sample. In the third phase, the effect of the curing period on the UCS of the B:S and B:Q mixes was evaluated. The required samples were prepared by adding air-dried bentonite to the air-dried sand or rock quarry dust in different proportions of the total weight of the mix. The TD was added as a proportion of total weight after the addition of sand or rock quarry dust. The TD proportion ranging from 2 to 16% was added. After thorough mixing, each sample was sealed in an airtight polythene bag and kept inside a desiccator for 24 hours for uniform distribution of moisture before the UCS samples were prepared and test was performed. The UCS samples of the mixes were prepared at their corresponding MDD and OMC. The UCS of the samples was determined as per IS guidelines. The test samples prepared were sealed with an airtight polythene bag and kept in desiccator for 3, 7 and 14 days and then the tests were performed. The Fig. 2 shows the UCS test setup and Fig. 3 shows the failure pattern of the B30:Q70 mix sample while performing the UCS test.

The compaction of the mixes was done by the Proctor's light compaction method as per IS: 2720-7 (1974) [15]. The OMC and MDD values are shown in the Table 3 for all the samples.

**Table 3.** MDD and OMC values for different mixes.

| Mix | OMC (%) | MDD (gm/cc) | Mix | OMC (%) | MDD (gm/cc) |
|---|---|---|---|---|---|
| B30:S70 | 15.10 | 1.82 | B30:Q70 | 12.60 | 2.02 |
| B30:S70 + 2%TD | 16.20 | 1.79 | B30:Q70+2%TD | 15.80 | 1.98 |
| B30:S70 + 4%TD | 17.00 | 1.75 | B30:Q70+4%TD | 16.01 | 1.87 |
| B30:S70 + 6%TD | 17.30 | 1.71 | B30:Q70 +6%TD | 16.40 | 1.80 |
| B30:S70 + 8%TD | 17.50 | 1.68 | B30:Q70 +8%TD | 16.82 | 1.76 |
| B30:S70 + 10%TD | 17.61 | 1.67 | B30:Q70 +10%TD | 17.03 | 1.70 |
| B30:S70 + 12%TD | 17.72 | 1.65 | B30:Q70 +12%TD | 17.40 | 1.68 |
| B30:S70 + 14%TD | 18.01 | 1.64 | B30:Q70 +14%TD | 17.90 | 1.65 |
| B30:S70 + 15%TD | 18.05 | 1.63 | B30:Q70 +15%TD | 18.00 | 1.64 |
| B30:S70 + 16%TD | 18.10 | 1.63 | B30:Q70 +16%TD | 18.20 | 1.64 |

**Fig. 2.** UCS test setup.

**Fig. 3.** Failure pattern of B30:Q70 sample

## 3 Results and Discussion

### 3.1 Stress versus Strain characteristics of B:S and B:Q mixes

The B30:S70 and B30:Q70 mixes were prepared at their corresponding MDD and OMC. The UCS sample was prepared and the UCS test was performed just after the sample was made (curing period is equal to 0). The stress versus strain plots are compared in the Fig. 4.

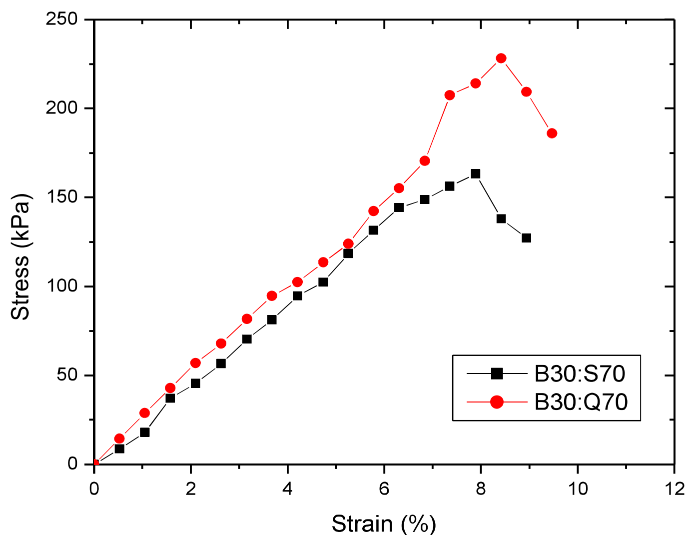


**Fig. 4.** Stress versus strain plots of B30:S70 and B30:Q70 mixes for a curing period of 0 day.

It is evident from the Fig. 5 that the UCS of B30:Q70 mix is comparatively much higher than that of B30:S70 mix which is 228.13 kPa. The UCS of B30:S70 mix is 163.26 kPa. The UCS of B30:Q70 mix is 39.7% more than that of B30:S70 mix. The failure strain is found to be more in case of B:Q mix than that of the B:S mix.

### 3.2 Stress versus Strain characteristics of B:S:TD and B:Q:TD mixes

The tyre dust proportion ranging from 2 to 16% was added and the strength behaviour was studied. The variations of stress with strain were evaluated for B30:S70 and B30:Q70 mix with added tyre dust proportions. The stress versus strain variation of B30:S70 and B30:Q70 mixes for different TD content are shown in the Figs 5(a) and (b) respectively.

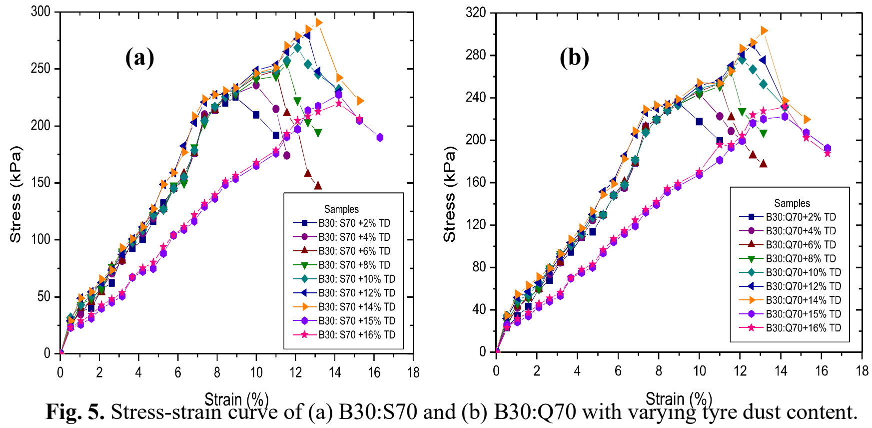


**Fig. 5.** Stress-strain curve of (a) B30:S70 and (b) B30:Q70 with varying tyre dust content.

The variation of the UCS of the mixes with the TD content is shown in the Fig. 7(a). From the Fig. 7(a), it is evident that the UCS of both the mixes increases upto TD = 14% and the further increase in the TD content, the UCS of the mixes reduces abruptly. So, the TD = 14% can be considered as the optimum TD content for both the mixes. But, the UCS of the B:Q mix is higher than that of the B:S mix for TD = 14%. The Fig. 7(b) depicts a significant increase in the failure strain after the addition of tyre dust ranging from 2 to 16 % by weight. This may be due to higher strain mobilized within tyre fibres. The failure strain was found to be same for both the mixes after the addition of tyre dust. The Fig. 6 compares the stress versus strain variations of the optimum mixes. It highlights that the mix B30:S70+14%TD can be replaced by the mix B30:Q70+14%TD in the geotechnical or geoenvironmental applications where the UCS is important. Therefore, it can be concluded that the sand can be completely replaced by the rock quarry dust in that optimum mix.

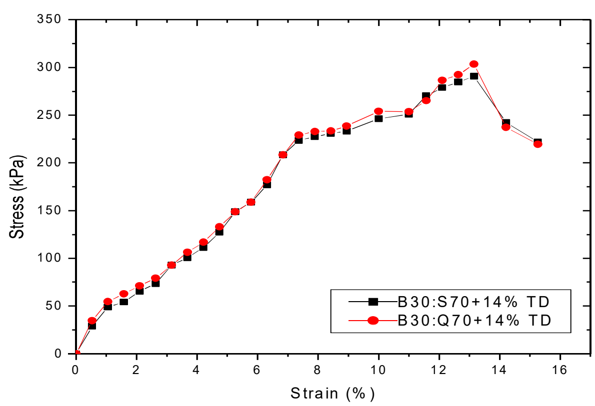


**Fig. 6.** Stress versus strain plots of mixes with optimum tyre dust content.

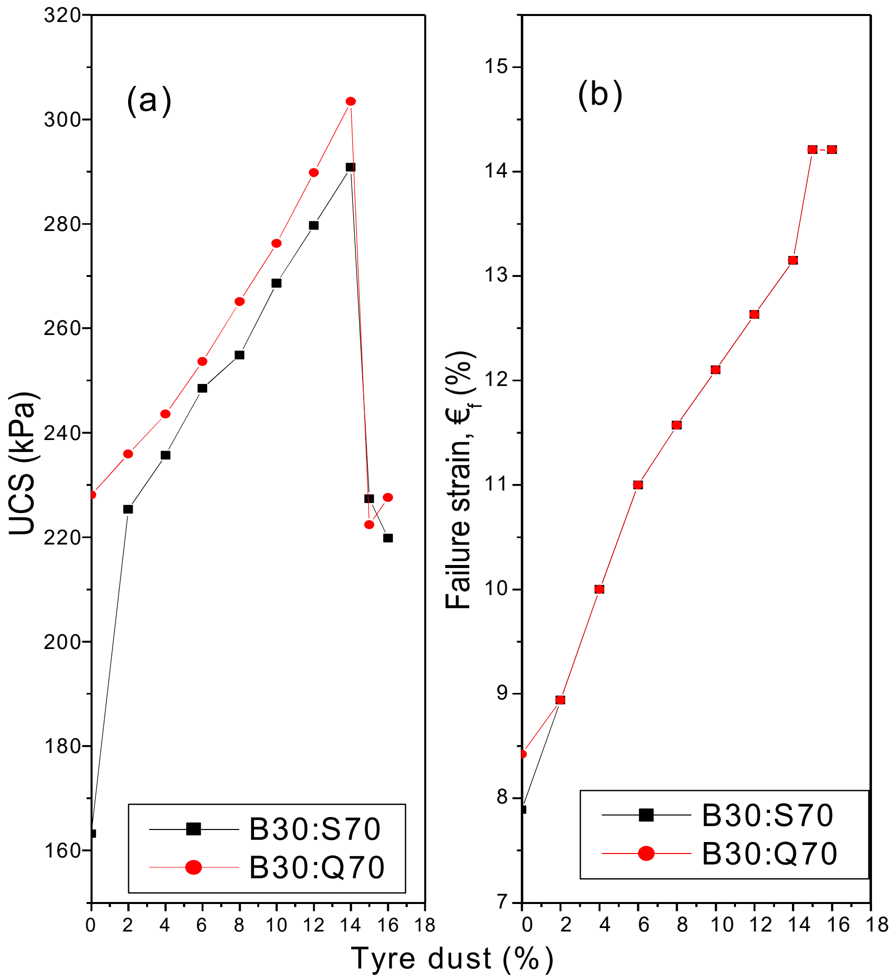


**Fig. 7.** Effect of tyre dust content on (a) UCS and (b) failure strain of B30:S70 and B30:Q70 mixes.

It has been found that the combination of B30:S70 or B30:Q70 mix with the addition of tyre dust exhibits ductile behaviour. The failure was observed by the increasing bulging of the specimen with the increase in the TD content in the mix as evident from the Fig. 8. The vertical failure pattern of the specimen can be clearly noticed. This may be due to the enhanced frictional resistance between the rough textures of the tyre dust and the sand or rock quarry dust particles. Also, the stress versus strain curve highlights that the reinforced mix has the potential to sustain up to a higher strain value as compared to the unreinforced or less reinforced mixes.

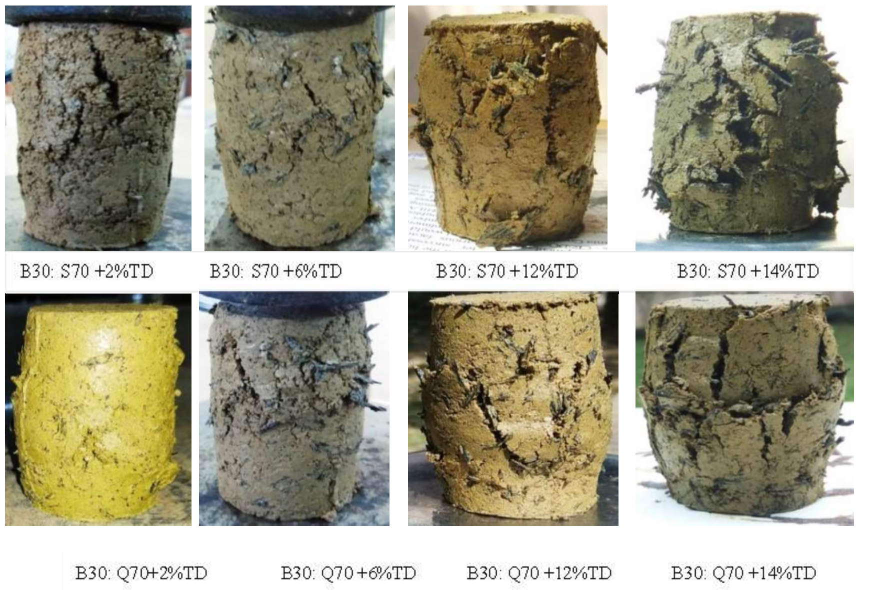


**Fig. 8.** Failure patterns of B30:S70 and B30:Q70 mix samples with TD content.

### 3.3 Effect of curing period on UCS of B:S and B:Q Mixes

The stress-strain variations of the B30:S70 and B30:Q70 mixes at a curing period of 0, 3, 7 and 14 days are presented in the Figs 9 (a) and (b) respectively. The stress versus strain curve shows an increase in the peak stress value with increase in the curing period for all the test samples. This may be due to the thixotropy or time-dependent hardening. It is mainly due to the tendency of cohesive soil to regain their chemical equilibrium by reorienting the water molecules in the adsorbed water layer. Similar phenomenon was described as isothermal, reversible and time dependent process of hardening which occurs at constant volume and at rest condition [16, 17]. Subba Rao (2003) [18] concluded that the increase in shear strength with curing period was due to the rearrangement of particles and formation of strong bonds during the aging process. The Fig. 10 shows a significant increase in the UCS value of the B30:S70 and B30:Q70 mixes from 0 to 14 days of curing period. The increase in the UCS for 14 days of curing period was 26.22% for B30:S70 and 20.93% for B30:Q70 mix from 0 day of curing period.

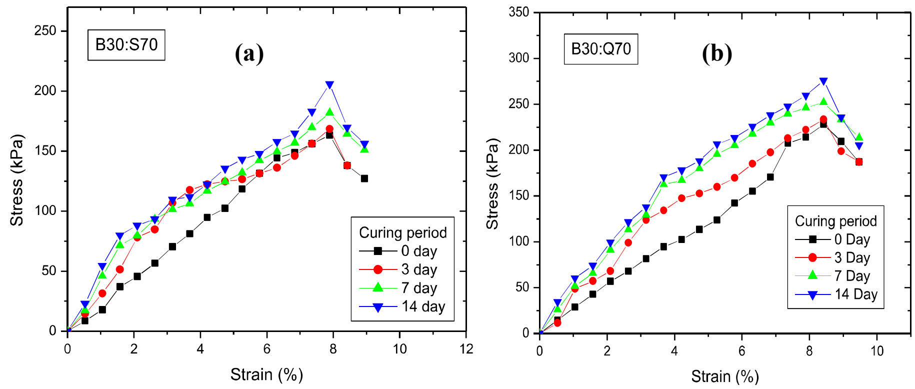


**Fig. 9.** Stress versus strain plots of (a) B30:S70 and (b) B30:Q70 mixes at different curing period.

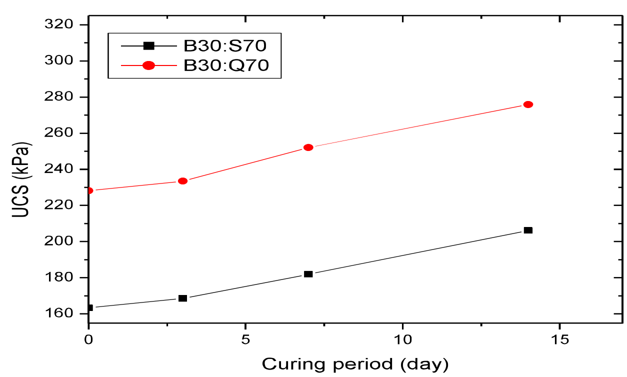


**Fig. 10.** Variation of UCS of B30: S70 and B30: Q70 mixes with curing period.

### 3.4 Effect of curing period on UCS of B:S:TD and B:Q:TD mixes

The Figs 11 (a) and (b) show the effect of the curing period on the stress versus strain characteristics of the optimum mixes B30:S70+14%TD and B30:Q70+14%TD. The Fig. 12 highlights that the UCS increases linearly for both B30:S70+14%TD and B30:Q70+14%TD mixes up to 14 days of curing period. The increase in the UCS for 14 days of curing period was 13.05% for the B30:S70+14%TD mix and 10.83% for the B30:Q70+14%TD mix which is approximately 50% of the increase in the UCS of their corresponding mixes without the addition of the tyre dust. The effect of the curing period on failure strain was found to be insignificant for these mixes.

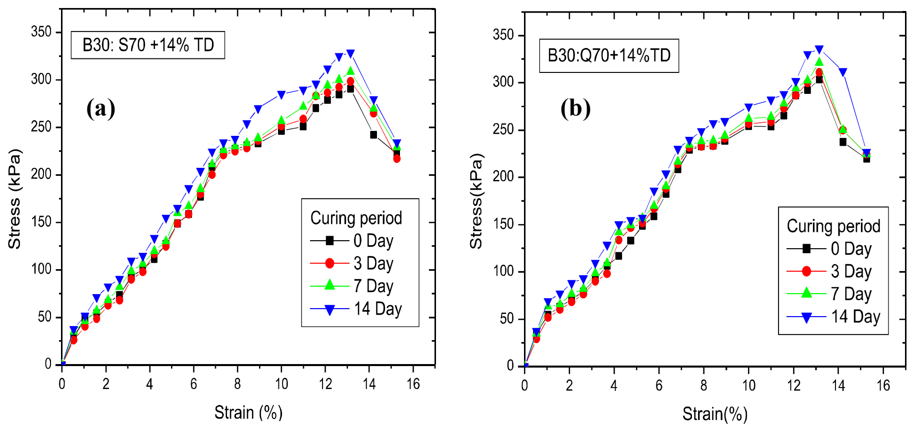


**Fig. 11.** Stress versus strain curve of (a) B30:S70+14%TD and (b) B30:Q70+14%TD mixes of different curing period.

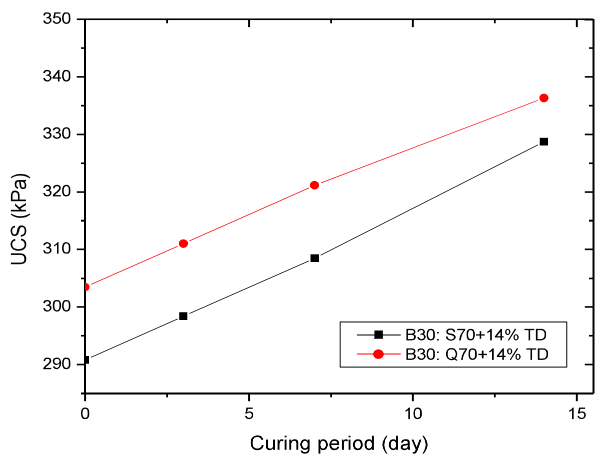


**Fig. 12.** Variation of UCS with curing period of B30:S70+14%TD and B30:Q70+14%TD mixes.

## 4 Conclusions

The following conclusions can be made from this study:

1. The UCS of B30:Q70 mix is comparatively higher than that of the B30:S70 mix and the value is greater than 200 kPa. Therefore, the rock quarry dust can completely replace the sand in the B:S mix and the B:Q mix can be a suitable liner material in a landfill.

2. The tyre dust content influences the UCS of the B:S and B:Q mixes significantly. For both the mixes, the improvement in the UCS was obtained up to a TD content of 14%. After that, a sharp reduction in the UCS was found. The optimum mix was found to be the B30:Q70+14%TD mix.
3. The failure patterns of the B:S and B:Q specimen are brittle, and the mixes containing the tyre dust are ductile which can sustain a higher strain as compared to the specimens without the tyre dust.
4. The UCS of all the mixes increases with the increase in the curing period. The curing period does not have significant influence on the failure strain of the mixes.
5. All the B30:S70:TD and B30:Q70:TD mixes where, TD = 2 to 16%, have the UCS greater than 200 kPa. Moreover, for a particular TD content, the UCS of a B30:Q70:TD mix is greater than that of a B30:S70:TD mix and hence, the mix B30:Q70:TD can easily replace the mix B30:S70:TD. Therefore, these mixes can be used as liner material though other important properties like sorption capacity, permeability of those mixes etc. should be investigated.

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