Influence of lime on the unconfined compressive strength of coal gangue

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Abstract. Coal gangue is one of the largest industrial residues generated during the coal mining process. The surge in demand for coal has led to further increase in coal gangue production and its safe disposal is an arduous effort in terms of costs involved and the associated environmental impacts. To address these issues, innovative methods are explored for coal gangue utilisation in different fields. The bulk and effective utilisation of coal gangue can be attained by using it for various geotechnical applications. Unconfined compressive strength (UCS) of any material plays a major role in its utilisation for various geotechnical applications like reclamation fill, fill behind retaining wall, base and sub base layer. In the present study, the UCS of coal gangue and its variation on addition of lime at different curing periods has been studied. The effect of lime content and curing period clearly manifested with a significant increase in UCS of stabilised coal gangue. The improvement in strength is attributed to the formation of pozzolanic compounds with the curing period.

Keywords: coal gangue; unconfined compression strength; pozzolanic compounds; backfill; reclaimed fill

1 Introduction

Coal-based thermal power stations generate many residues during the combustion process and collectively they are referred as coal combustion residues (CCR's). CCR's include fly ash, pond ash, bottom ash etc. which create severe problems while handling and disposing them [1]. In India, the majority of coal produced is of inferior grade with a poor calorific value which has contributed to the increased level of CCR's generation of about hundred million tons per year [2]. Disposal of these residues consume large volumes of land contaminating the ground and surface water bodies, thereby leading to severe environmental and ecological impacts [3-6]. In a vast and developing country like India, due to the scarcity of quality construction materials with desired durability and strength properties. However, with the increase in costs of conveyance, there is a substantially increase in demand to for alternate materials [7]. Hence, attempts are made to identify alternate avenues for the bulk utilization of these residues. Over the past few decades, the development of green construction materials has been promoted significantly by the higher sustainability standards of the construction industry [8-11]. The usage of such alternate materials can bring down energy consumption, greenhouse emissions and usage of raw materials [12-13]. Eventually, contributes to the reduction in overall project costs and to

address environmental issues associated with its disposal. Hence bulk utilization of the recycled materials can resolve all the above mentioned issues to a large extent.

In this context, the present work intends to study the feasibility of utilizing coal mine waste i.e. coal gangue as a fill material. The strength of the material is considered one of the primary criteria for backfill applications. In the present study, an attempt has been made to study the unconfined compressive strength (UCS) of coal gangue. An attempt has been made to study the effect of lime addition on UCS of coal gangue. Moreover, the role of curing period on the UCS of lime treated coal gangue has also been studied.

2 Materials and methodology

Coal gangue was procured from Kakatiya Coal mines, Bhupalpally, Telangana. These samples were air-dried and crushed prior to passing through a 0.425mm mesh sieve to homogenize them for the subsequent analysis. The powdered coal gangue samples were dried in a temperature-controlled oven at 100°C for 24 h to remove moisture. Analytical grade hydrated lime has been used in the present study. Varying lime (2% 4% and 6%) percentages was added to the coal gangue on weight basis. To understand the influence of lime, moisture content was fixed at OMC of untreated coal gangue. The samples were cured for a period of 7, 14, 21, 28 days in a desiccator. The UCS testing was done in accordance with ASTM D2166 [14]. The physical properties of coal gangue are presented in Table 1.

Table 1. Physical properties of coal gangue

Properties	**Values**
Specific gravity	2.57
Grain Size Distribution	
Coarse fraction (%)	11
Fine fraction (%)	89
Atterberg limits	
Liquid limit (%)	28
Plastic limit (%)	NP
Plasticity Index (%)	NP
Compaction Characteristics	
Optimum moisture content (%)	17.6

Maximum dry density (kN/m^3)	21
pH	7.24
Carbon content (%)	3.5

3 Results and Discussion

The Unconfined Compressive Strength (UCS) of untreated coal gangue and its increment with lime addition at 28 days curing period is presented in Table 2.

Table 2. Increment in UCS of lime stabilised coal gangue

Combinations	**Unconfined Compressive Strength (kPa)**
Coal Gangue + 0% Lime	118 (x)
Coal Gangue+2% Lime	770 (6.54x)
Coal Gangue+4% Lime	1041 (8.83x)
Coal Gangue+6% Lime	1300 (11.02x)

3.1 Effect of lime content

The UCS of the lime stabilised coal gangue is shown in figure 1. From the figure, it can be noted that with the addition of lime, there is a substantial increase in UCS of coal gangue. The maximum increase in UCS was observed for 6 % lime addition with an increment of 1100 %. The initial increase in UCS at lower curing period can be attributed to the onset of pozzolanic reaction. Addition of lime triggers the breaking of Si-O bonds in the silica rich coal gangue. Coal gangue with reactive silica can produce more cementitious compounds on reaction with lime addition as it increases the hydroxyl ion supply for the hydration of Coal gangue [15-17]. Moreover, the rate of gain in UCS value with curing period for lime stabilized coal gangue is low at the beginning but it increases with increase in curing period. Low UCS value at less curing period may be due to low pH values of the pore fluid.

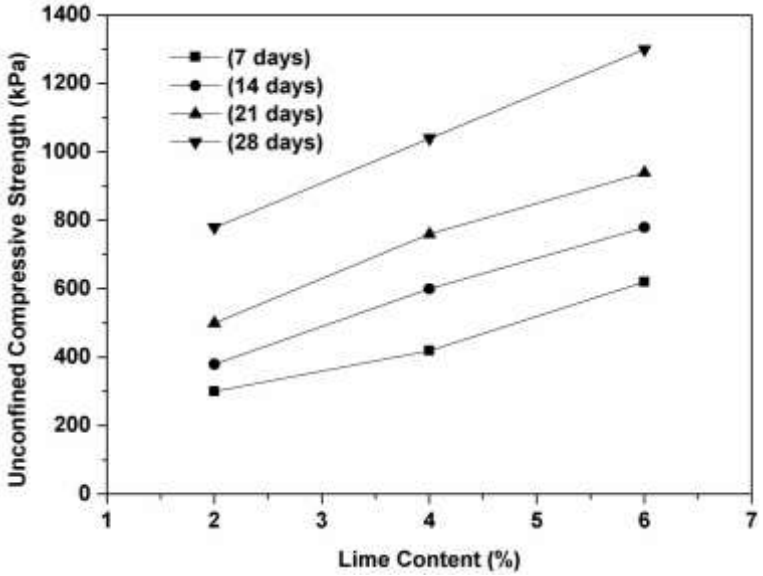

Fig 1. Variation in UCS of Coal Gangue with lime content

3.2 Effect of curing period

Effect of curing over a period of 28 days for lime stabilized coal gangue is presented in Figure 2. It is evident from the figure that curing has a pronounced effect on unconfined compressive strength of coal gangue samples. There is a linear increase in UCS value with curing period. This behaviour is due to the fact that addition of lime initiates the reaction between the silica and some alumina of the lattices of coal gangue. Further, highly alkaline environment produced due to lime addition helps in dissolution of alumina-silicates which are eventually precipitated as hydrated cementitious reaction products [18-20]. Furthermore, lime addition results in increased number of hydration products to fill the pore structures. The gain in strength due to lime is mainly believed due to substitution of other cations by calcium.

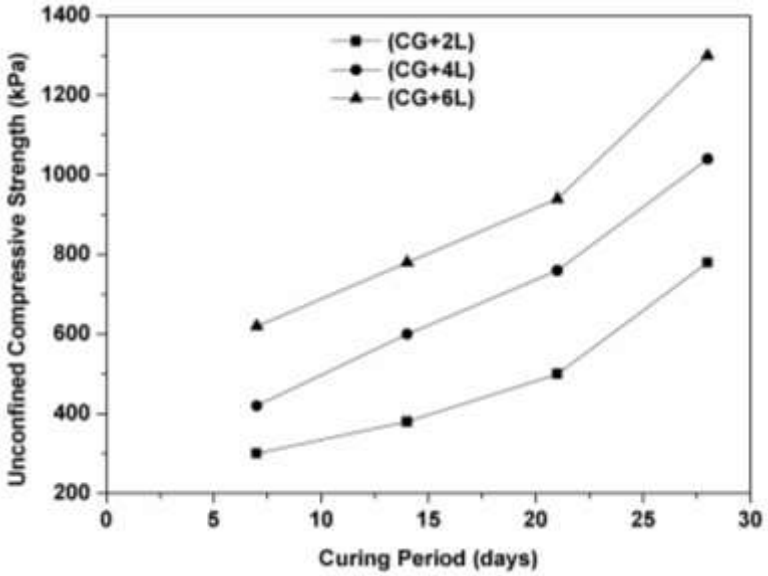

Fig 2. Variation in UCS of Coal Gangue with Curing Period.

The stress-strain behaviour of coal gangue at varying lime contents is presented in Figure 3. It was observed that the addition of lime has a profound effect on the stress-strain behaviour of coal gangue. A relatively linear behaviour of stress increase was noted for the corresponding strains. However, irrespective of stabilization, the failure point (at 4.3 % strain) of coal gangue has remained constant for all the combinations considered. It was noticed that the application of load in excess of 3.5 % strain has no significant impact on the stress-behaviour. Further, the effect of lime addition was noticeable from 2 % strain, which may be due to the realignment of minerals of coal gangue [21].

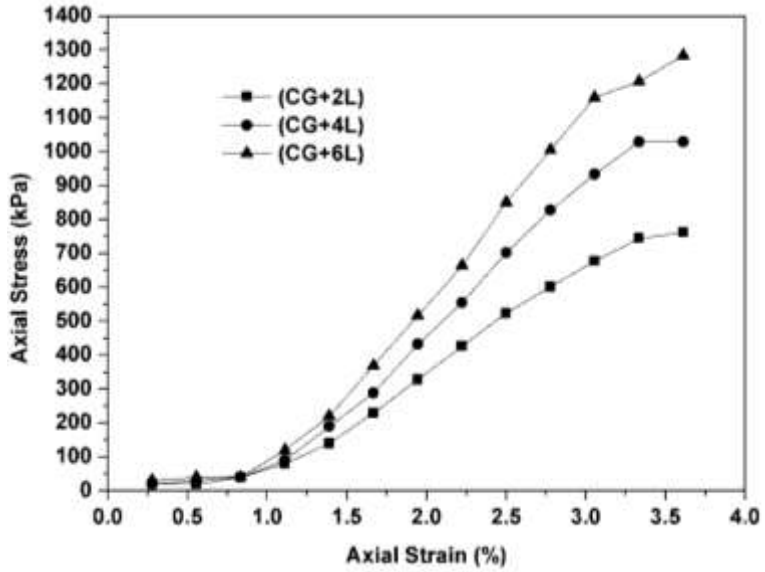

Fig 3. Stress-strain behaviour of lime stabilized coal gangue

Fig 4. UCS samples of coal gangue and lime mixtures.

4 Conclusions

In the present study, the strength behaviour of coal gangue was evaluated to assess its feasibility as a backfill material. The effect of lime (2%, 4% and 6 %) on UCS of coal gangue was also investigated. The following conclusions are drawn from the study:

- The addition of lime has a led to a substantial increase in UCS of coal gangue. With an increment of 1100 %, the maximum increase in UCS was observed for 6 % lime addition.
- There is a linear increase in UCS value with the curing period. An enhancement in UCS of 400 % was observed with the curing period.
- It was observed that the addition of lime has a profound effect on the stress-strain behaviour of coal gangue.
- . It was noticed that the application of load in excess of 3.5 % strain has no significant impact on the stress-behaviour.

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