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# Soil Stabilization of Forest Roads Sub-base Using Lime Mud Waste from the Chemical Recovery Process in Alkaline Pulp Mill

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**Abstract:** In this study, lime mud waste obtained from kraft pulp mill recovery unit was investigated on soil stabilization of forest road which is the one of the most important structure for forestry operations. Some chemical and physical characteristics of lime mud waste and soils collected from three different regions around Blaksea territory, in Turkey were initially analysed and then treated with lime mud waste with various ratio. Mechanical properties of treated soils were determined according to standards by realizing atterberg limits, specific weight, triaxial compression and compaction tests. Atterberg limits results indicated that it was possible to increase liquid and plastic limit values of soils with increasing the addition of lime mud in the mixture. Depending on lime mud content, cohesion values of soils were changed depending on the soil types. Addition of lime mud was affected positively to slip strength of soils. In order to obtain maximum dry density, more water content was required on mixtures. As a result, forest roads deformed depending on environmental effects and exceed loading could be stabilised and maintained by using lime mud waste.

**Key words:** Atterberg limits, forest road, lime mud, paper industry, waste utilization

## INTRODUCTION

The pulp and paper industry is the sixth largest pollution source discharging a variety of gaseous, liquid and solid wastes into the environment (Joung *et al.*, 2003). Waste handling is a concern in pulp and paper mills as well as in all industrial plants. Best available techniques for reducing waste is to minimize the generation of solid waste and/or reuse these materials, wherever practicable. Lime mud, is the by-product or industrial waste of the kraft pulp mill recovery unit and is principally composed of the calcium carbonate, small amount of magnesium carbonate and other trace minerals (Gaskin, 2004). Increase in the amount of pulp production in the last decades has also increased the amount of material that needs to be disposed of and this waste is commonly sent to landfills. Recently, concern has risen over the amount and quality of future landfill space. Landfills are becoming difficult to site and costly to construct and operate because of more stringent regulations, diminishing land availability and public opposition (Thacker, 1998).

Although alternatives, such as land application (Rabas, 1988), seem to be working, many mills worry about future problems. With the detectable limits of toxins decreasing, some mills fear that current sites will have to be cleaned up at high cost due to water contamination. Traditional burning shifts some of the residue back to the air discharge stream with its resulting costs and problems. Some alternative processes, such as fluidized bed systems, seem to be more environmentally friendly. Microbiological treatment is still relatively new and is yet to be used on a large scale. Alternative uses for lime mud, such as bricks and cement, are an excellent option if a user can be found near the mill and if long term contracts can be acquired. New products developed from pulp mill waste, however, need to have a market to make them economically feasible. It does not make sense to develop and create products for which there is no market.

In recent years, researchers from many fields have attempted to solve the problems posed by industrial wastes. Recent projects illustrated that successful waste utilization could result in considerable saving in construction costs (Çokça, 1999). In the world, a large quantity of industrial wastes are stabilized with cement or used as an additive material in cement manufacturing sector. These materials are fly ash collected from power plant, municipal solid waste fly ash and the other industrial wastes (Eroğlu, 2003).

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Effects of two types of lime on unstable (CBR<6) sub-grade soil were investigated by Hieckel (1997) and it was found that dried lime kiln sludge and hydrated lime by-product reduced the maximum dry density and plasticity index. Limes also increased optimum moisture contents, compressive strengths and immediate bearing values of sub-grade soils. The effectiveness of cement kiln dust as a soil stabilizer was investigated and it was found that the addition of cement kiln dust increased the unconfined compressive strength of soil. Increases in unconfined compressive strength were inversely proportional to the plasticity index of untreated soil. Significant plasticity index reductions occurred with cement kiln dust treatment, particularly for high plasticity index soils (Miller and Azad, 2000).

Lime piles, which essentially consist of holes in the ground filled with lime, have been used for two distinct purposes for the treatment of clay soils *in situ*. The first concerns the treatment of soft soils to improve their bearing capacity and in this case uses relatively large diameter quicklime piles at close spacing. The result is a significant reduction in the water content of soil, causing densification and concomitant increases in its strength and stiffness. The second application is in the stabilization of failing slopes, for which both quicklime and lime slurry piles have been used with the intention of causing ion migration and subsequent lime-clay reactions in the surrounding soil (Rogers and Glendinning, 1999).

Substantial improvements in resilient modulus of four soils including a gravel-sand mixture, a sandy silt, a silty sand and highly plastic lay, indicate that fly ash from the power plants have exceptionally high potential for soil stabilization. Moderate increases were observed in the unconfined compressive strength of the same four soils plus additional silty sand and sandy silt when treated with fly ashes from power plants (Turner, 1997).

Maintaining and/or stabilization of the forest roads which are one of the most important structures for forestry operations could be a novel alternative way of lime mud disposal. Due to wood transportation by truck, tire pressure, drainage problems, frost, negative weather conditions and unsuitable construction techniques the untreated forest roads are easily deformed. In this reason maintenance cost of forest roads is being increased and various techniques and materials are used for an improvement of the road ground.

## MATERIALS AND METHODS

Lime mud which is typically a industrial solid waste was obtained from the recausticizing process, inserted in the energy and chemical recovery circuit, of the SEKA Pulp Mill, Turkey that utilizes wheat straw (*Triticum sativum* L.) (65%) and common reed (*Phragmites australis*) (35%) as the principal raw material. Main physical and chemical characterization of lime mud was performed in ACME laboratory, Canada according to standard tests methods and data are presented in Table 1.

Due to the high water content of this waste, initially it was dried to environment temperature and subsequently screened before being mixed with the upper layer of the various kinds of forest road soils.

Three typical soils (from upper layer of forest road) collected from Artvin (sandy clay; S1), Borcka (loamy clay; S2) and Trabzon (clay; S3) regions in Turkey, were used. Some physical and chemical properties of the untreated soils were analysed and exhibited in Table 2.

In order to investigate the effects of lime mud on soils engineering properties, the collected soils (S1, S2 and S3) were treated with the percentage of 0, 5, 10 and 15% lime mud based on the dry weight and then standard samples were prepared for physical testing. Atterberg limits, specific weight, trivial soil strength and compaction tests were carried out on the samples in the laboratory of Regional Directorate of State Hydraulic Works (DSI), Trabzon, Turkey in 2003.

Table 1: Some physical and chemical properties of lime mud

| Physical properties | Lime mud | Chemical properties (%) | Lime mud |
|---|---|---|---|
| Blain fineness ($cm^2 g^{-1}$) | 4664 | CaO | 40.09 |
| Water content (%) | 28.00 | $SiO_2$ | 9.19 |
| Loss on ignition (%) | 47.00 | $Na_2O$ | 3.01 |
| Specific weight ($g cm^{-3}$) | 2.43 | $Al_2O_3$ | 0.10 |
| Fineness (90/200 μm) (%) | 40/80 | MgO | 0.15 |

Table 2: Some chemical and physical properties of untreated soils

| Physical properties | S1 | S2 | S3 | Chemical properties | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|
| Atterberg limits | | | | | | | |
| Liquid limit (%) | 34.5 | 53.6 | 33.9 | pH | 4.81 | 6.30 | 7.03 |
| Plastic limit (%) | 21.8 | 28.4 | 19.2 | $CaCO_3$ (%) | 1.60 | 1.60 | 0.80 |
| Plasticity index (%) | 12.7 | 25.2 | 14.7 | P (%) | 0.16 | 0.02 | 0.02 |
| Conductivity ($mS cm^{-3}$) | 0.033 | 0.192 | 0.144 | Ca (%) | 0.76 | 0.33 | 0.52 |
| Sand (%) | 60.76 | 50.76 | 33.76 | Mg (%) | 0.04 | 0.04 | 0.04 |
| Clay (%) | 28.24 | 40.24 | 56.24 | K (%) | 0.017 | 0.007 | 0.009 |
| Silt (%) | 11.00 | 9.00 | 10.00 | Na (%) | 0.013 | 0.006 | 0.009 |
| Organic matter (%) | 0.39 | 0.81 | 1.13 | Cu (ppm) | 0.404 | 0.175 | 0.019 |

## RESULTS AND DISCUSSION

The results of particle size analysis of soils were shown at Fig. 1. According to the result of these analyses, it can be easily said that S2 has thinner grain than S1 and S3, on the other hand S1 has the roughest structure.

Figures 2-4 exposure effects of lime mud addition on Atterberg limits of collected soils. Liquid and plastic limit values of S1, S2 and S3 increased as the lime mud addition increased. Plasticity index values of S1 and S3 increased as the lime mud content increased but plasticity index values of S2 decreased as lime mud content increased.

Figure 5 plots the specific weight value vs. the addition of lime mud to the collected soil samples. As can be seen from the figure specific weight values of S1 and S2 decreased as the lime mud addition increased. Specific weight values of S3 increases as the lime mud content increased. Variation of specific weight according to the soil types can be explained by specific mineralogical structure of soils that include various amount of clay, sand and silt content of soils.

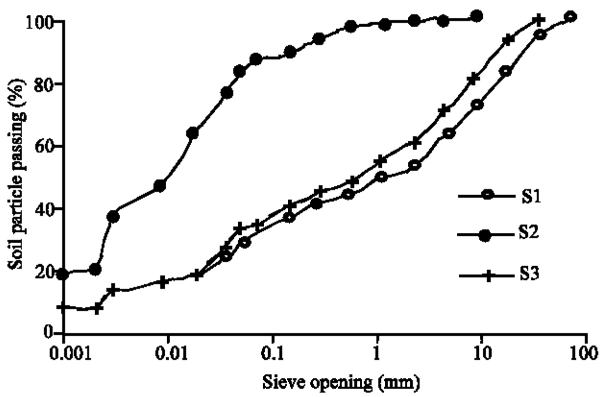


Fig. 1: Particle size analysis of collected soils

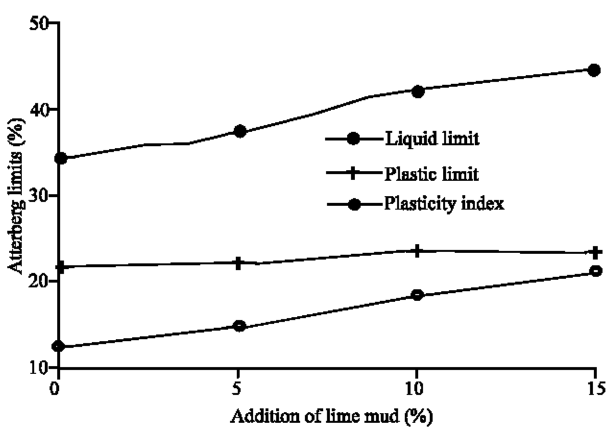


Fig. 2: Variation of atterberg limits depending on lime mud addition for S1

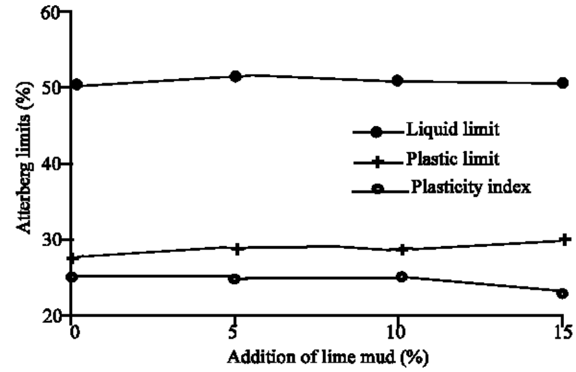


Fig. 3: Variation of atterberg limits depending on lime mud addition for S2

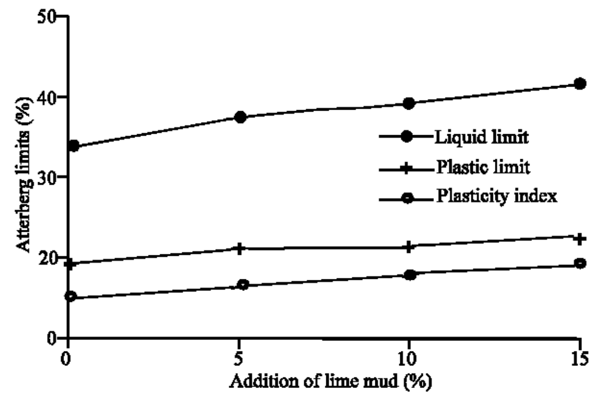


Fig. 4: Variation of atterberg limits depending on lime mud addition for S3

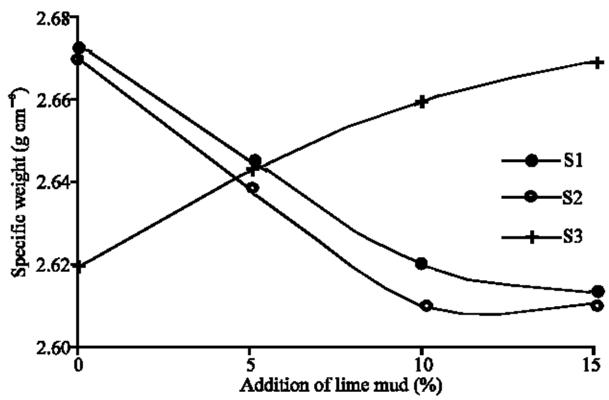


Fig. 5: Effect of lime mud addition on specific weight of mixture

Soil cohesion tests were conducted with collected soils treated with lime mud at different percentage. Cohesion test values of S1 were decreased depending on lime mud content but on the other hand cohesion test values of S2 were gradually increased. Cohesion values of S3 were increased up to some point (10% lime mud

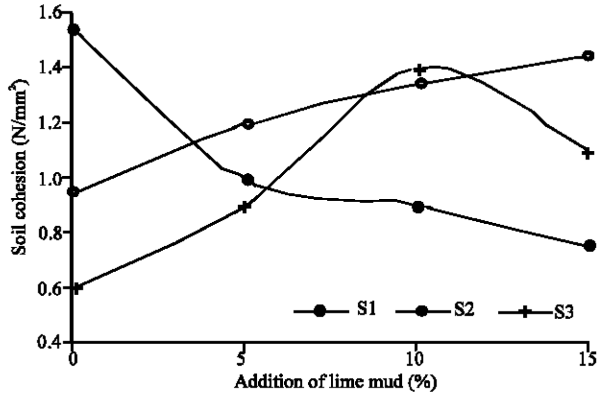


Fig. 6: Variation of soil cohesion depending on lime mud content

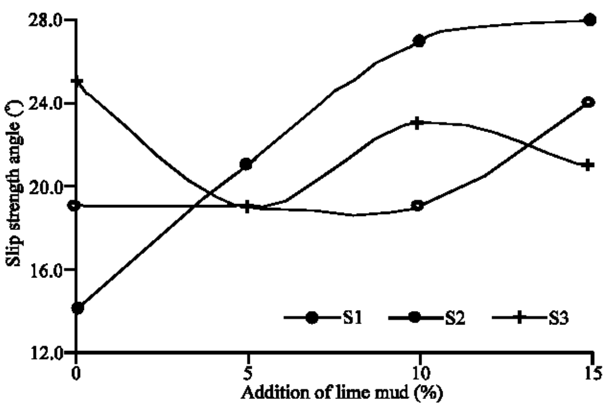


Fig. 7: Variation of slip strength angle depending on lime mud content

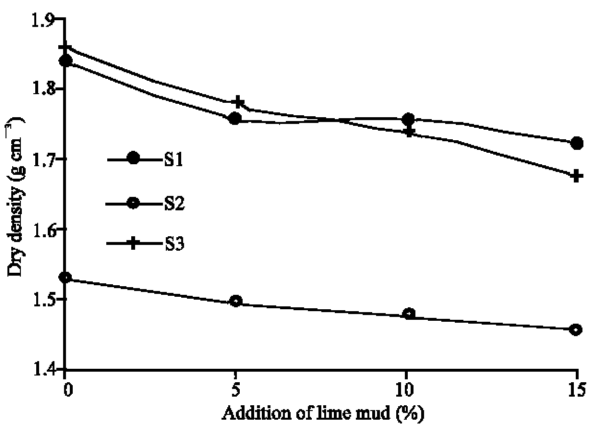


Fig. 8: Relation between dry density and lime mud content

content), after that, it was decreased as lime mud content increase (Fig. 6).

The results given in Fig. 7, indicated that slip strength behaviour of treated soils depended on both addition of lime content and properties of soil. With the increasing addition of lime mud in soil, the slip strength S1 was increased. Slip strength of S2 remained stable from 0 to 10% lime mud content and then was increased up to 15% lime mud addition. Slip strength of S3 was decreased by 5% lime mud addition but hereafter it was increased up to 10% lime mud content then again it was decreased gradually.

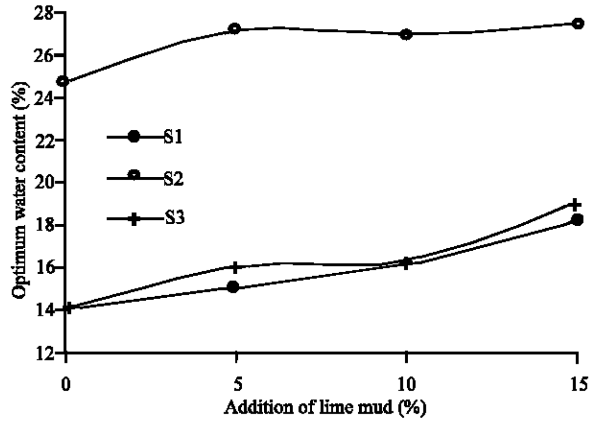


Fig. 9: Relation between optimum water content and lime mud content

Compaction experiments have demonstrated how the dry density and water content values were dependent on the degree of lime mud addition and soil types. Dry density values of S1, S2 and S3 were decreased depending on lime mud content (Fig. 8). According to result of compaction test; optimum water content of soils were increased depending on lime mud content (Fig. 9). This situation indicated that maximum dry density of mixtures was obtained from more water content

## CONCLUSIONS

From this experimental study on the influence of lime mud obtained from the pulp mill recovery unit on the stabilization of forest road soil, some conclusions were found. Liquid limit and plastic limit values were increased for collected three types of soils with increasing the addition of lime mud in the mixture. On the other hand plasticity index value was increased only for S1 and S3 soils. It was meant that physical properties of soils were crucial for treatment. Specific gravity values of S1, S2 and S3 were decreased as increasing lime mud content. Depending on lime mud content, cohesion values of soils were changed depending on the soil types. Slip strength angles of S1 were decreased depending on lime mud content. For S2 slip strength angle remained stable between 5-10% lime mud content, on 15% lime mud content it was increased. Increasing the lime mud content, slip strength coefficients were increased for tree soils. Namely, addition of lime mud was affected positively to slip strength of soils. Dry density values of three soils were decreased and optimum water content of soils was increased with increasing the lime mud addition. In order to obtain maximum dry density, more water content was required on mixtures. Decreasing of dry density values depending on lime mud content means that addition of lime mud was affected negatively compressing ability of soils. As a consequence forest roads are deformed depending on environmental effects and exceed loading.

In order to prevent this situation, forest roads superstructures should be built immediately by alternative techniques and materials. From this laboratory study lime mud can be suggested as an alternative material for stabilization of forest road superstructures. In fact, this study has essentially been conducted in the laboratory and no *in situ* testing has been performed yet to verify the potential of the purposed technique for *in situ* condition.

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