EVALUATION OF LIME-TREATED ARIAKE CLAY WITH FLY ASH AS ROAD MATERIALS

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The paper presents mainly the physical-mechanical properties of the lime-treated Ariake clay with fly ash (LAF), and the utilization as road materials. The effects of quicklime and fly ash on the improvement of the strength of Ariake clay were investigated. Considerable changes in strength of the mixture due to the addition of fly ash were observed which were explained based on the strength mechanism of the LAF mixture. The engineering properties of the LAF mixture were improved due to a certain amount of replacement of lime with fly ash. Results from pavement structure analysis show the mixture can be used as either subgrade or subbase.

Keywords: *pavement material, lime, soft clay, fly ash, unconfined compressive strength*

1. INTROCDUION

Ariake clay is a special kind of soft clay deposited around the shore of the Ariake sea in northern Kyushu, Japan. The geotechnical properties are listed in Table 1. The natural water content in Ariake clay may be near as high as 200% at most. Its unconfined compressive strength is far less than 0.1MPa, even its water content is less than 100% [1]. Therefore, most of Ariake clay could not be used as subgrade directly in pavement engineering. Researches on improvement of Ariake clay has been documented[2), 3)] and focused on the treatment with lime and cement. Although researches have shown that the strength of the lime-treated Ariake clay (LA) can reach 0.7 MPa or more, a value that is the minimum requirement used as a pavement material[4)], the amount of such admixtures needed will be so high that problems of high lime-contained clay are raised not only economically but also technically.

On the other hand, fly ash generated from the combustion of coal in power plants and from the burning of municipal solid waste is increasing worldwide. Problems raised from fly ash in terms of land use, pollution of air and water are quite serious, in addition to the enormous cost involved. Research on the utilization of fly ash in civil engineering has been available for some years. By being mixed with proper proportion lime, fly ash can be used as a pavement material.[5)-7)]

Table 1 Engineering properties of Ariake clay

Soil properties	Value
Density of soil particle (g/cm^3)	2.26-2.82
Liquid limit (%)	32-150
Natural water content (%)	12-173
Density (g/cm^3)	1.18-2.07
Unconfined compressive strength (MPa)	0.004-0.02
Standard penetration value N	0-5

In order to examine the feasibility of partial replacement of lime with fly ash in LA, a laboratory investigation of the engineering properties of the mixture of lime-treated Ariake clay with fly ash (LAF) was undertaken at Saga University. The possibility of the replacement of quicklime with fly ash in the LAF mixture was discussed by a comparison and evaluation of the physical-mechanical properties of the LA and LAF mixtures. Finally, CRISP, a FEM Program, was employed to study the behaviors of pavement structure assuming the LAF mixture to be used as either a subbase or a subgrade layer.

2. EXPERIMENT DETAILS

(1) Materials used

a) Ariake clay

Ariake clay has a certain variation in physical and mechanical properties. Ariake clay used in the study was dug from 0.5 –2.0 m deep in the ground, in Ogiogi Gun, Ashikari Machi, Saga prefecture. The physical properties were listed in Table 2. Here, it is necessary to note that the sand content in the Ariake clay is a little higher than in average Ariake clay, on the contrary, the content of clay is less than in average Ariake clay.

Table 2 Physical properties of Ariake clay[10)]

Natural water content (%)		105-115
Density of soil particle (g/cm^3)		2.54
Grade (%)	Gravel	0.0
	Sand	37.0
	Silt	44.0
	Clay	19.0
Liquid limit	(%)	89.5
Plasticity limit	(%)	39.6
Plastic index		49.9
Ig. loss	(%)	7.4

b) Fly ash

Both of the fly ash from the combustion in power plants and from the burning of municipal solid waste have been found applications in civil engineering. Fly ash used in the study is coal fly ash. This is a normal kind of fly ash. The physical properties were listed in Table 3 and chemical properties listed in Table 4.

(2) Test program

A series of laboratory tests was carried out on Ariake clay to examine the feasibility of using fly ash as alternative admixture for the lime and understand the influence of lime and fly ash on the strength formation in the LA and the LAF mixture as well. Parallel tests with three samples were conducted to gain data on the relative effect of the two additive materials. A comparative evaluation was conducted mainly on the basis of the following criteria, namely (1) Unconfined compressive strength q_u, (2) Deformation Modulus E_{50} and ratio of E_{50} to q_u, (3) Water reduction, (4) Failure strain, (5) Density.

Table 3 Physical properties of fly ash[10)]

Natural water content (%)		0.13
Density of the particle (g/cm^3)		2.38
Grade	Gravel (%)	0.0
	Sand (%)	11.1
	Silt (%)	54.9
	Clay (%)	34.0
Liquid limit	(%)	NP
Plastic limit	(%)	NP

Table 4 Chemical properties of fly ash[10)]

Ig. loss (%)		3.02
Chemical Compositions (%)	Si_2O_3	61.21
	Al_2O_3	21.85
	Fe_2O_3	5.15
	TiO_2	1.06
	CaO	4.65
	MgO	1.32
	Na_2O	0.70
	K_2O	0.93

Table 5 Experimental program

Fly ash (%)	Lime (%)	Test items	Curing cases
0, 5, 10,15, 20,25, 30	10 20 30	q_u, E_{50}, Max. strain, Density, Water content	7 days (in air), 28 days (in air), 6 days (in air)+ 1 day (in water)

To ascertain the strength of the mixture, the following laboratory testing was carried out:

(1) The influence of lime content on the strength of the LA.

(2) The influence of fly ash content on the strength of the LAF mixture.

The test combinations were referred in Table 5. All of the mixtures were blended by a mixing machine for 10 minutes uniformly. Samples of both LA and LAF were molded in cylindrical molds with 5 cm in diameter and 10 cm in length by vibrating. The standard of vibrating is to dispel, as much as possible, the air out of the sample. The additive content was defined by the ratio of the mass of the additive to the dry mass of the natural clay, expressed as a percentage.

3. TEST RESULTS AND DISCUSSIONS

(1) Water content

Reduction of water content in the mixture is one of the aims for treatment of soft soil. Not only strength but also dry shrinkage property, a durability index, of a cement or lime-treated pavement material is dominantly affected by the water content in the mixtures[13].

The water content in the LAF mixture comes from mainly Ariake clay. The reduction of water content in the LAF mixture is caused by the hydration and pozzolanic reaction. Besides, for a fixed lime content, increasing the proportion of fly ash in the LAF mixture will decrease Ariake clay and increase pozzolanic reaction. Therefore, water content in the mixture will be decreased with the increase of fly ash, as shown in Fig.1. It showed that about 10-20% water content reductions were occurred for an addition of fly ash 30 % for lime content cases 10 to 30 % in the mixture. Results from 28 days curing are similar to those.

(2) Density

Density of a mixture depends on its structure compositions of void, water and solid material. Mixture with a bigger density indicates the mixture has a denser structure. A denser mixture is desirable as pavement materials with respects to less deformation

Results shows that the density of the mixture increases up to 10-15% with the addition of fly ash, but decreases with a further addition of fly ash, see Fig.2. The decrease of density when content of fly ash is added excessively is possibly caused from the difficult of compaction by vibrating due to the reduction of water content.

(3) Unconfined compressive strength mechanism q_u of the LAF mixture

Failure of samples made of the LAF mixture under test loading will happen in the weakest part among the Ariake clay, fly ash and lime in the mixture. To a larger extent, the strength q_u of the three parts depends on reactions occurred in the mixture after mixing Ariake clay, fly ash with lime together. To understand the strength of LAF mixture, the strength of LA and the influence of fly ash on the LAF mixture were investigated in the following sections.

a) q_u of the LA mixture

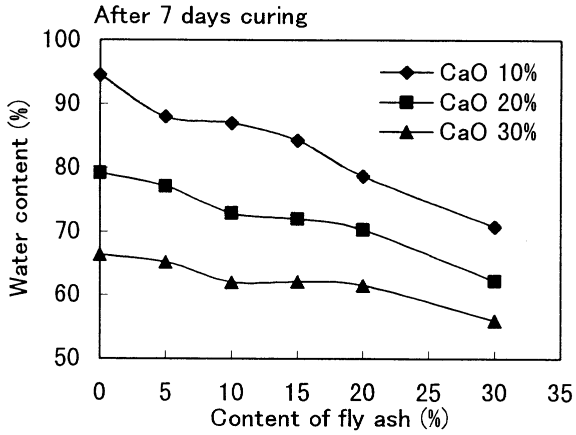


Fig. 1 Water content of the LAF mixture

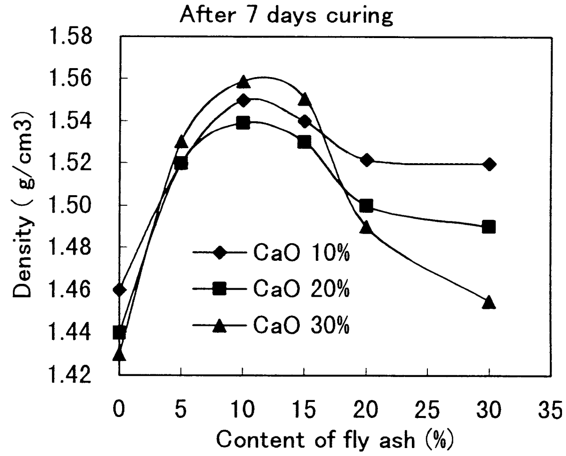


Fig. 2 Density of the LAF mixture

Addition of quick lime in the Ariake clay changes the compositions in the Ariake clay due to a series of reactions and then increases the strength of the LA. These reactions include hydration, cation and pozzolanic reaction.

The mechanism of the strength improvement of the treatment for Ariake clay by lime is the same as that for average soft soil. But a sharp elimination of water content in the Ariake clay is the main purpose of the improvement using quicklime. Studies on water reduction analysis of the treatment of Ariake clay by quicklime showed that almost 30% of the water in the Ariake clay was reduced by hydration, while only 10% of the reduced water is due to pozzolanic reaction. Without the great reduction of water from hydration it is difficult to get 80% increasing in strength from pozzolanic[2].

Fig.3 shows the result of the variation of the strength of the LA with the content of the lime. A

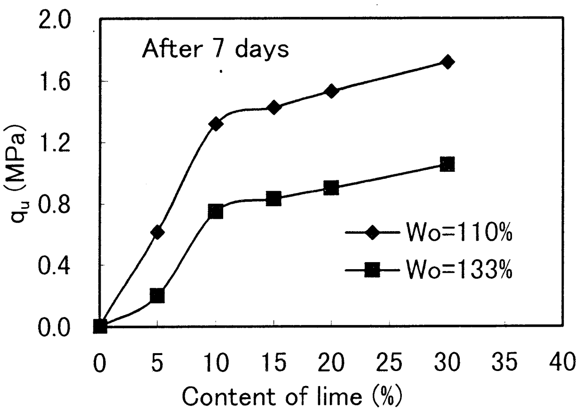


Fig. 3 Unconfined compressive strength q_u of LA

higher initial water content w_0 in the Ariake clay needs a relative higher content of lime to reduce the water content by hydration reaction and to achieve a required strength.

b) Effect of fly ash on the LAF mixture

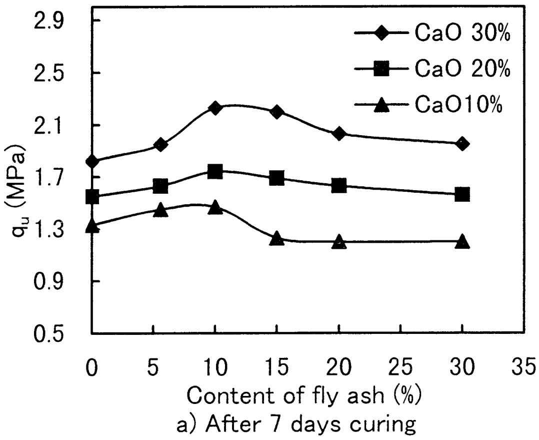
With the addition of fly ash in the lime-treated clay, the following factors alter the strength of the LA. (1) The effect of lime content in fly ash will be the same that of added lime, (2) The effect of the finer or coarser size fraction of the fly ash, (3) Hydration and pozzolanic reaction of the fly ash.

It has been proved that a coarser size fraction from the fly ash will decrease the liquid limit, increase plastic limit and decrease the plastic index of the clay[11]. That is to say, increasing coarser size in the clay will increase the strength of the clay and vice versa. The reactivity of the fly ash depends on lime content. There is however an optimum lime content for any type of fly ash to reach its maximum reactivity, which has the maximum unconfined compressive strength[14]. If lime available in the mixture is less than the optimum content, extra fly ash will became free fly ash. On the contrast, if lime available in the mixture is more than needed, free lime is available.

Samples made only from fly ash showed a very limited unconfined compressive strength after 7 days curing in the air, and even less than 1.0 MPa at 28 days[9]. It has been proved that only when fly ash mixed with a certain amount lime will the mixture show a higher strength[8]. Both free lime and fly ash particle are also weak in strength.

(4) q_u of the LAF mixture

Results presented in Fig. 4 show that the strengths of the LA (case of fly ash 0%) and LAF mixture were affected by the addition of the lime and fly ash.



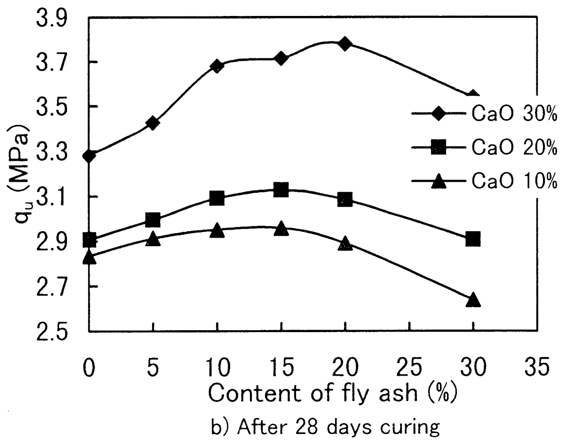


Fig. 4 Unconfined compressive strength q_u of the LAF mixture: a) after7 days curing, b) after 28 days curing

In this case, the fly ash has finer size fraction than the Ariake clay as shown in Table1 and 2. When the content of fly ash is increasing, both contents of CaO and finer particles will increase. These two factors have opposite influence on the strength of the mixture in the study. Usually, the later factor is dominant because CaO content available in fly ash is limited. CaO content will increase only 0.23, 0.46, 0.69, 0.92, 1.15%, while the clay particle content will increase 1.7, 3.4, 5.1, 6.8, 8.5, 10.2%, for an addition of fly ash 5, 10, 15, 20, 25, 30% respectively.

On the other hand, fly ash itself causes hydration and pozzolanic reactions, which increase the strength of the LAF mixture. These reactions depend on lime content. Because the lime content is lower than the optimum content, lime available in the mixture to react with fly ash is limited. Fly ash will become extra with the increase of fly ash. There is an optimum content of fly ash at which the mixture reaches a highest value of the strength for the three cases with a lime content 10, 20 to 30%. For higher lime content mixture, it can provide with more lime to react with fly ash. This is why the optimum contents are bigger for the cases with higher content of lime mixtures. Compared with cases at 7 days curing, cases at 28 days curing have similar results.

It can be found that the strengths of the LA after 7 days curing increased 35% for an addition of quick lime from 10% to 30%. The strength increased for an additional increase of lime 10% after 7 days curing is about 15%. This increasing ratio can be achieved by a proper addition of fly ash.

The optimum content of fly ash in the LAF mixture is from 10 to 15% corresponding to cases for 7 days curing and 10 to 20 % for 28 days curing.

(5) Modulus of the LAF mixture, E_{50}

A common index to evaluate the deformation resistant ability of pavement materials is resilient modulus. E_{50}, deformation modulus that can be obtained from unconfined compressive test, is also used in geotechnical engineering in Japan. It is defined as the ratio of the half maximum strength to the strain at the strength. It also indicates the average state of the relationship of stress and strain in the mixture.

Fig. 5 shows the corresponding modulus E_{50} after 7 days and 28 days curing. Compared with the cases of the LA in which no fly ash was added, E_{50} of the LAF mixture for cases after 7 days curing change with the addition of fly ash. It will increase as much as 10-20% when the fly ash is properly increased. The increase of the modulus, E_{50}, in the early age 7 days is meaningful for construction, because a stronger material can provide engineers with a better workability site.

However, E_{50}, for cases after 28 days curing, decrease when fly ash was added. The maximum decreasing rate was observed for cases when a high lime content is used. It can be as much as 30%.

E_{50} of a material is important to the behavior of a pavement structure. The stress distribution in a pavement structure is, determined by not only the modulus of every layer but also the ratios of the modulus. The larger the deformation modulus E_{50} of the material is, the bigger the load induced stress of the material will be[12]. Therefore, the ratio of E_{50}/q_u of pavement materials should be restricted within a range. Otherwise the material will be easy to produce plastic deformation and even cracking[15].

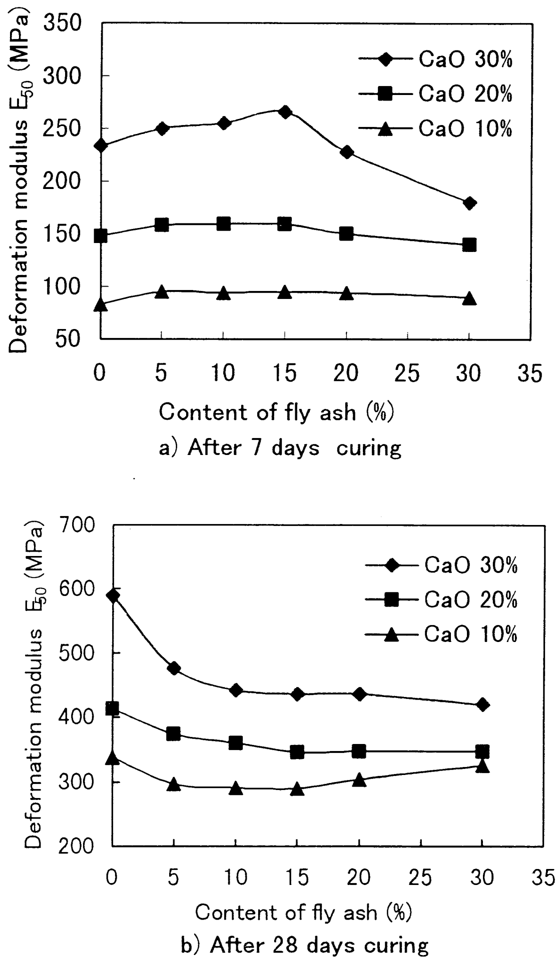


Fig. 5 Deformation modulus E_{50} of the LAF mixture: a) after 7 days curing, b) after 28 days curing

Analysis of the rate of E_{50}/q_u shows it decreases when fly ash is added. Therefore, a rate E_{50}/q_u of LA can be reduced by mixing a proper amount of fly ash.

(6) Failure strain

Materials with high crack resistance are desirable as pavement materials. Pavement materials must have to withstand the strain induced by traffic loads and dry contract. Besides, pavements built on the soft foundation will cause more strain on subbase and subgrade [12]. The capacity of cracking resistance can be evaluated by the failure strain, which is measured when the strength reaches the maximum value.

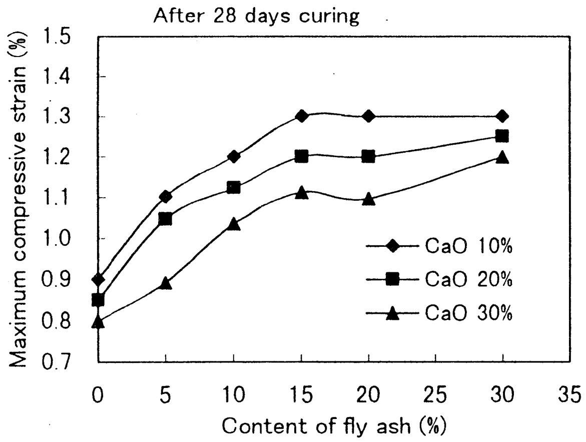


Fig. 6 Maximum failure compressive strain

A comparison was made between the samples of the LA and LAF mixture. It was found that the maximum failure compressive strains for cases at 7 days curing changed slightly, however the strains at 28 days curing showed a significant variation as shown in Fig.6. An increasing rate of 30% of the failure strain, for cases with lime content of 10% and 20%, were observed, and 40% for case with lime content 30% in the study.

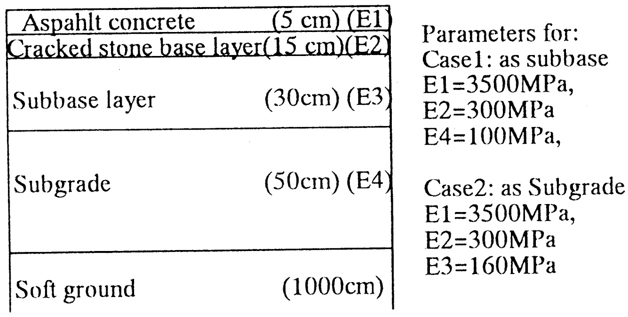
4. UTILIZATION OF THE MIXTURE AS ROAD MATERIALS

(1) Outline of the analysis

This section discussed the behavior of the LAF mixture as either subbase or subgrade respectively in a typical asphalt concrete pavement structure[16] commonly built on soft grounds in Saga, see Fig.7. It is for Japanese traffic classification of “A” volume. It consists of an asphalt concrete layer (5cm), base layer (15cm), subbase layer (30cm) and treated sugbrade (50cm) supported by a soft ground (1000cm). The possibility of the utilization in road engineering was evaluated by pavement structure analysis using CRISP, a FEM program.

Elastic properties (E, μ) were assumed for the top four layers and Cam-clay model (λ, κ, M) for the soft ground. Parameters are showed also in Fig. 7. More details on the structure and analysis model can be found in our other paper[12].

Deformation modulus E_{50} obtained form the tests of the LAF mixture were used as the modulus of elasticity of either a subbase (E3) or subgrade (E4).



Note: λ= 0.61, virgin loading slope in e-ln(p') plot

κ=0.06, reloading /unloading slope in e-ln(p') plot

M=1.3, slope of failure line in p'-q plot

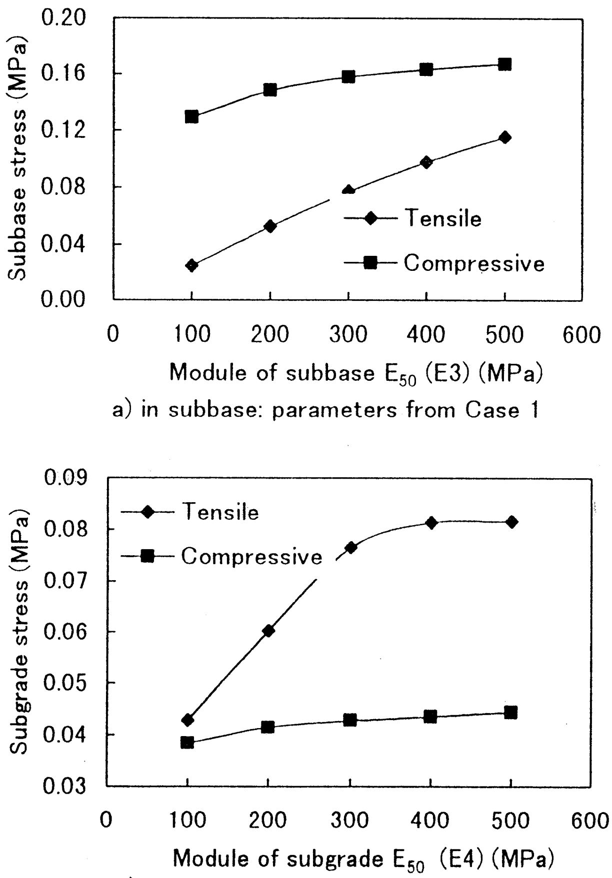
p': effective mean stress, q: deviator stress

μ = Poisson's ratio, 0.25 for pavement layers, 0.35 for foundation

Fig.7 A typical asphalt concrete pavement structure

The traffic load was a dual wheels traffic load with a weight of 50 kN. This is one side of a single axle for a standard traffic load with 100 kN.

(2) Numerical results



a) in subbase: parameters from Case 1

b) in subgrade: parameters from Case 2

Fig. 8 Stresses in the pavement structure: a) in subbase, b) in subgrade

Fig. 8 (a) shows the calculating vertical compressive stresses (σ_c) on the top of the subbase and the horizontal tensile stresses (σ_t) at the bottom of the subbase with different deformation modulus E_{50} for the subbase layer.

Fig. 8 (b) shows the calculating vertical compressive stresses (σ_c) on the top of the subgrade and the horizontal tensile stresses (σ_t) at the bottom of the subgrade with different deformation modulus E_{50} for the subgrade layer.

Both of the vertical compressive stresses (σ_c) are far less than the unconfined compressive strength of the LAF mixture q_u for deformation modulus E_{50} after both 7 days and 28 days curing. The values of the compressive stresses in the two layers are not very sensitive to the deformation modulus E_{50}.

As for the horizontal tensile stresses are concerned, it should be noted that tensile strength of a pavement material is far less than the compressive strength. In addition, fatigue influence on the strength will reduce a lot the static strength. The tensile strength of the LAF mixture has not yet measured for all the cases in the study. From the results of very limited samples of the LAF mixture, it was showed the tensile strength was only about 1/6-1/10 of the compressive strength. The tensile strength of the LAF mixtures, therefore, will be 0.1 MPa to 0.2 MPa after 7 days curing and 0.25 MPa to 0.38 MPa after 28 days. The tensile strength of the LAF mixture after taking into consideration of fatigue influence will be around 0.13 to 0.19 MPa after 28 days curing if a reduction of 50 % due to fatigue Is assumed.

Deformation modulus, E_{50}, ranges from 80 to 275 MPa after 7 days curing, from which the tensile stresses will be generated about 0.02 to 0.08 MPa for subbase and about 0.04 to 0.08 MPa for subgrade. The tensile stresses will be around 0.08 to 0.13 MPa for the subbase and around 0.08 MPa for the subgrade corresponding E_{50} from 280 to 600 MPa after 28 days curing.

It is clear that both vertical compressive and horizontal tensile stresses are less than the strengths of the LAF mixture, but the compressive strength will have a bigger margin. The decrease in deformation modulus, E_{50}, at 28 days when fly ash was added is helpful to reduce the tensile stress, especially, when the mixture was used as a subbase.

5. SUMMARY AND CONCLUSIONS

Ariake clay can not be used as road materials without treatment. Lime treated Ariake clay can reach the strength requirements as road materials, but has problems regarding economy and technology. Replacement of lime with fly ash is aimed at making use of fly ash. A study on investigation of using fly ash in the LA was carried out by means of laboratory tests. The physical–mechanical properties of the LAF mixture concerned by pavement engineering were compared with that without fly ash. Among those, the variation of unconfined compressive strength with the addition of fly ash was explained by means of strength formation of LAF mixture. The behavior of the mixture as a pavement material either subgrade or subbase was evaluated by pavement structure analysis. Based on the results obtained in this study, following conclusions can be drawn:

1) The physical- mechanical properties of the LAF mixture are significantly altered by the addition of fly ash. The extent of variation depends on the content of lime and fly ash added, the particle size fraction and the pozzolanic reactivity of the fly ash. Replacement of partial lime with fly ash is possible. The LAF mixture can not only improve the unconfined compressive strength q_u but also the deformation modulus E_{50}, maximum failure strain, density and water content in case that fly ash is properly added.
2) The pozzolanic reactivity of fly ash influences the properties of the LAF mixture by formation of cementitious compounds. With changing in lime content the pozzolanic reactivity of fly ash changes and hence the effect of fly ash is dependent upon the lime content. The optimum content of fly ash, when the mixture has a maximum strength is changed with the lime content in the Ariake clay and the particle size fraction of the fly ash and clay. Extra addition of fly ash will make it become free fly ash and decrease the strength of the mixture.
3) The stress analysis of the pavement structure with the LAF mixture as a pavement layer indicated that the mixture can be used as a subbase or a subgrade layer. The compressive strength has a bigger margin. So the tensile strength of the LAF mixture will be relatively

crucial to the structure if a high lime content is used. A decreasing of the deformation modulus when fly ash was added will reduce the tensile stress of the layer significantly, therefore prolong the life of the pavement structure.

4) Properties of the LAF mixture such as the tensile strength, fatigue and durability should be further studied.

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フライアッシュと石灰を混入した有明粘土の道路舗装材としての評価

鬼塚　克忠　　　沈　菊男

この論文は、主にフライアッシュ（F）を混入した有明粘土（A）の石灰（L）処理（ＬＡＦ）混合物の性質と、道路舗装材としての評価を述べている。生石灰とフライアッシュによる有明粘土の強度改良の影響について明らかにした。フライアッシュの添加による混合物の強度の著しい変化はＬＡＦ混合物の力的メカニズムに基づいて説明できると考えられる。ＬＡＦ混合物の工学的性質は石灰をある程度フライアッシュで置き換えることによって改良される。舗装構造解析の結果は、この混合物が路床、下層路盤の材料として使用できることを示す。